The CFM56-5C series is at the highest thrust limit of the CFM56 family. Despite being noted for high EGT margin erosion, the engine still manages to achieve respectable on-wing intervals, and has few other removal drivers. Modifications should improve EGT margin retention and so reduce maintenance reserves.

CFM56-5C maintenance cost analysis

There are three variants of the CFM56-5C series powering the A340-200/-300. These are rated at 31,200lbs (-5C2), 32,500lbs (-5C3) and 34,000lbs (-5C4). The CFM56-5C entered service 10 years ago, and the oldest powerplants have reached maturity. This allows maintenance costs to be assessed.

CFM56-5C configuration

The higher rated variants have higher exhaust gas temperature (EGT) margins *(see table, this page)*. The basic -5C2 has an EGT red line limit of 950 degrees centigrade, the -5C3 965 degrees and -5C4 975 degrees.

Modification packages have been introduced since initial service entry to allow the -5C2 to have sub-variants with the same EGT red line limit as the -5C3 and -5C4, and to allow the -5C3 to have the same EGT red line limit as the -5C4 *(see table, this page)*. These sub-variants are a result of modifications to turbomachinery hardware. The increased EGT red line limit increases EGT margin and so allows longer on-wing time between removals for shop visits.

The -5C2/-5C3/-5C4 all power the A340-200 and 257 tonne maximum take-off weight variant of the A340-300. The CFM56-5C4/1 is a thrust bump option which powers the 271 tonne variant of the A340-300, sometimes referred to as the -300E.

CFM56-5C in operation

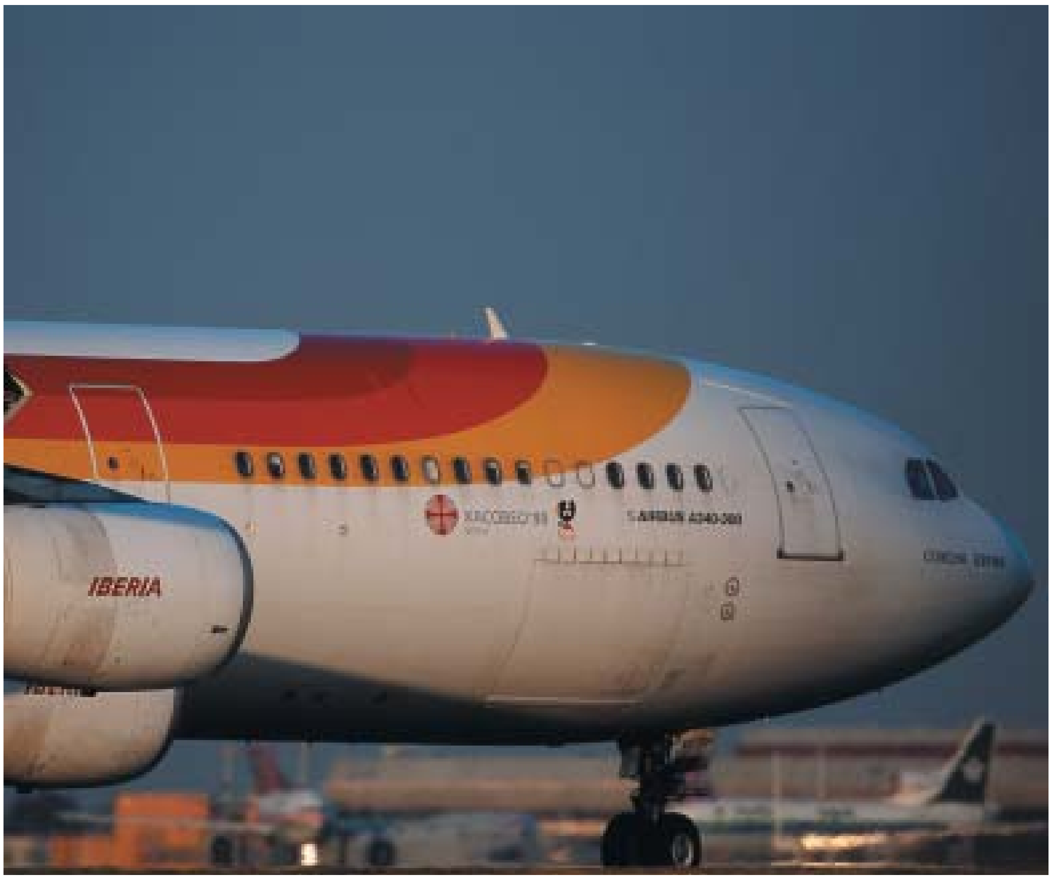
The A340-200/-300 is used almost exclusively as a long-haul aircraft by its operators. The -200 and -300 both have the range performance to operate on routes with flight times in excess of 12 hours. The majority of A340 operators are based in Europe and the Asia Pacific, but there are also some in North America, Central and South America, Africa and the Middle East. While airlines operate the A340 on long sectors, they also use the aircraft on short- and medium-haul routes as a consequence of route networks. The A340 in many cases achieves 4,500-5,000 flight hours (FH) per year.

Air France uses the A340 for routes from France to Africa, the US and Canada, and the Asia Pacific. "We generate about 4,800FH annually with the aircraft and our FH: flight cycle (FC) ratio is about 7.3:1," explains Michel Laudy, CFM56 product engineering manager at Air France Industries. "We have a mixed fleet of six -5C2/F-powered aircraft and 16 -5C4-powered aircraft. The 950 degrees red line EGT limit on the -5C2 led us to an upgrade, and the -5C2/F has a higher limit of 965 degrees."

Iberia, another major A340 operator, uses its -5C4-powered fleet, among others, on routes from Madrid to Johannesburg, Bogota, Lima, Buenos Aires and Mexico. It also flies the A340 on shorter routes to New York or Chicago, as well as the Canary Islands. "Our annual operation is about 4,500FH per year, and FH:FC ratio is 7:1. Our level of thrust derate is about 5%," says Jose Quiros, powerplant overhaul director, maintenance & engineering division at Iberia. "Some of these Central and South American airports are hot and high, and there is a high risk of EGT exceedences at them, as in Bogota and others, during take-off. If an engine has already experienced an EGT red line exceedence there is a higher chance of re-occurrence on a later flight. If two engines exceed EGT limits the take-off has to be rejected. Aircraft which have engines that have experienced these exceedences are then put on shorter routes such as New

CFM56-5C SERIES CONFIGURATION DATA

Engine variant	Thrust rating (lbs)	EGT red line limit (Degrees centigrade)	Application
CFM56-5C2	31,200	950	A340-200/-300
CFM56-5C2F/-5C2F4	31,200	965	A340-200/-300
CFM56-5C2G/-5C2G4	31,200	975	A340-200/-300
CFM56-5C3	32,500	965	A340-200/-300
CFM56-5C3F/-5C3F4	32,500	965	A340-200/-300
CFM56-5C3G/-5C3G4	32,500	975	A340-200/-300
CFM56-5C4	34,000	975	A340-200/-300
CFM56-5C4/1	34,000	975	A340-300E



Iberia uses its -5C4 fleet on long routes from Spain to South & Central America, South Africa, North America and the Canary Islands. Part of its operation is from hot and high airports, which risks exceeding EGT red line limit. Iberia's first removal intervals have been in the region of 13,000EFH after EGT margin erosion of six degrees centigrade for the first 1,000EFH and 2.5 degrees centigrade per 1,000EFH thereafter.

York, where ambient temperatures are lower and less take-off thrust is required. This causes certain operational restrictions. The CFM56-5C is capable of 10 EGT exceedences within certain limits before maintenance action is required, according to aircraft maintenance manual."

TAP Air Portugal has a fleet of four aircraft with -5C3 engines. TAP operates the aircraft from Lisbon to Brazil, the Caribbean, the US and South Africa. "Annual utilisation is about 5,000FH and EFH:EFC 7.6 EFH," says Jorge Leite, engine maintenance commercial manager at Air Portugal Maintenance & Engineering. "The average EFC time has increased since we first introduced the aircraft in late 1994 and early 1995 when we operated it to London and Paris as well as on our long-haul routes. Derate levels are 0-4%."

Lufthansa is one of the world's largest A340 operators, and has a mixed fleet of -5C2-powered and -5C4-powered aircraft. "We have six -200s and eight -300s with the -5C2 engine and 20 younger -300s powered by the -5C4. We have upgraded our -5C2 engines to -52/G standard, but operate them as the -52/F," says Lothar Hartel, propulsion systems engineering CFM56-5C at Lufthansa Technik. "We operate the A340-200/-300 all over our long-haul network and achieve about 4,900FH per year. The average EFH:EFC ratio is 7.1. Our average derate level is 14%, with the highest derate of 15% achieved for the -5C4/F on the A340-300 and 10% derate for the -5C2/F on the A340-300."

Despite being a long-haul aircraft, the A340 is also used on medium-haul sectors by airlines such as Cathay Pacific and China Airlines. "Annual utilisation for the whole fleet is about 3,600FH and average EFH:EFC ratio in the region of 6.4," explains Pierre Gires, vice president of customer operations at Snecma Services. "The level of derate for the whole fleet is generally high, with about 70% of take-offs having a derate level of 2-10%."

On-wing performance

Installed EGT margin for the -5C fleet is 60-100 degrees centigrade for new engines. The highest rated -5C4 has an initial production margin of 65-73 degrees, the -5C3 about 80-88 degrees and -5C2 about 90-100 degrees.

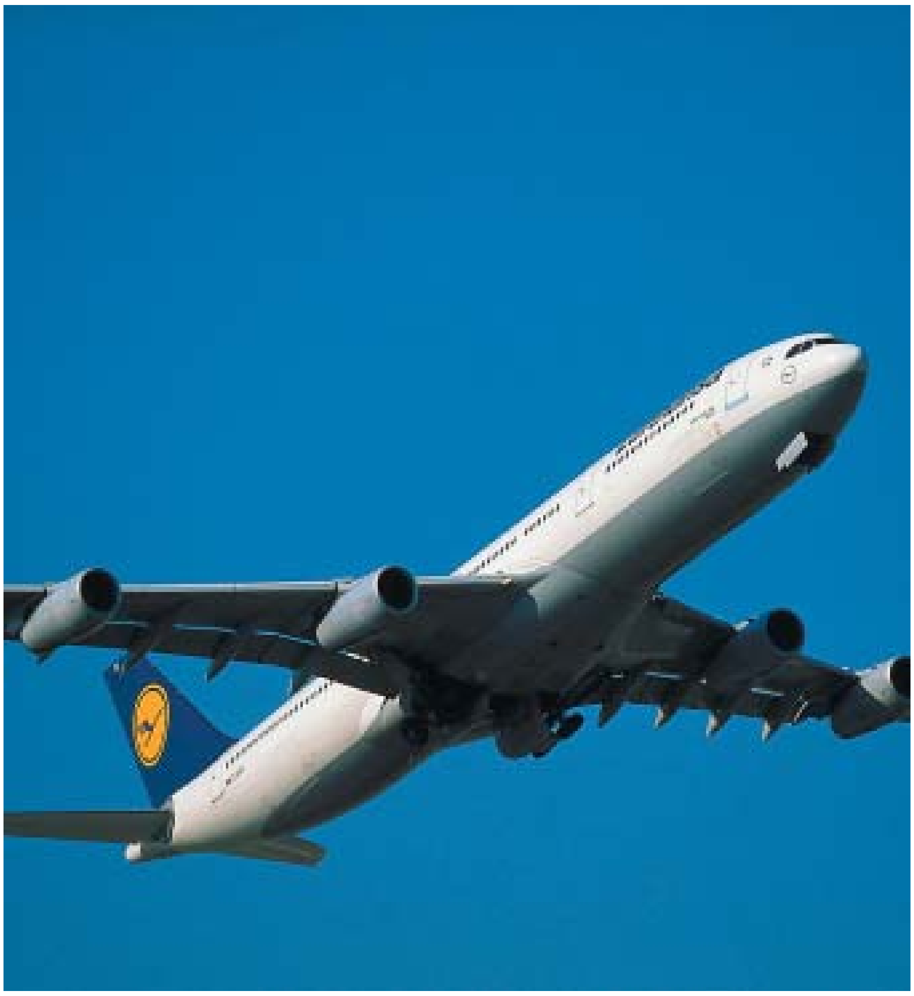
Initial rates of EGT margin erosion tend to be high for the first 1,000-2,000EFH on-wing. "A new -5C4 has an EGT margin of about 65 degrees," says Laudy. "EGT margin loss is about 17 degrees in the first 1,500-2,000EFH, and then about 3 degrees per subsequent 1,000EFH. This allows a first on-wing run of 16,000-17,000EFH. The problem has been poor EGT margin recovery after the first shop visit for the -5C4, which is only about 35 degrees. To counter this we introduced a modification and new "G" hardware to the -5C2/F engines at the first shop visit to allow the same EGT red line as the -5C4 of 975 degrees. This is the -5C2/F with "G" hardware. We manage our engines by derating the -5C4 when EGT margin is eroded, by lowering thrust using the full authority digital engine control (FADEC), to the -5C2/F or -5C2/F4. This increases EGT margin by 20-25 degrees and prolongs on-wing time.

"Restored EGT margin on the reinstalled -5C4 is about 35 degrees. We have a target second on-wing run of about 12,000EFH, and mature on-wing run of about 10,000EFH. Our experience shows, however, that second and mature on-wing runs are in the region of 9,000EFH. We are, however, working to improve our shop visit workscope to get a reinstalled EGT margin of about 40 degrees," continues Laudy.

Iberia experiences similar EGT margin erosion to Air France. "New -5C4 engines have a margin of about 60 degrees, and lose about six degrees for the first 1,000EFH and then about 2.5 degrees per 1,000EFH thereafter," says Quiros. "The first runs we have experienced have been about an average of 13,000EFH. Reinstalled EGT margin after the first shop visit is about 30 degrees, and on-wing runs are about 11,000EFH. Engine EGT margin erosion is also sensitive to EFH:EFC ratio."

TAP's fleet is a mixture of -5C3/F and -5C3/G engines, with different thrust limits. "We have upgraded our -5C3/F engines to partial -5C3/G hardware. The hardware to upgrade the engines is usually installed during the first shop visit, if there is access to the affected area. The differences between the -5C3/F and -5C3/G engines include modifications in the high pressure turbine (HPT) and low pressure turbine (LPT). The full upgrade to a full -5C3/G costs about $1 million, but TAP decided to apply only a partial upgrade," explains Leite.

"HPT hardware is usually upgraded at the first shop visit, and the engines complete the upgrade to partial -5C3/G hardware at the second shop visit when we install upgraded LPT hardware. We consequently have a mixed fleet of three engine variants, each with its own EGT red line limit. EGT margin for new engines has been as high as 48 degrees centigrade," continues Leite. "Restored EGT margin of engines after their first



Lufthansa's -5C2 engines have averaged 17,500EFH and 12,000EFH for their first two removal intervals, while its -5C4s have averaged about 16,000EFH and 10,000EFH.

shop visit is 20-50 degrees centigrade. The lower margin is for poor -5C3/F variants and the higher margins good -5C3/G examples. There is another modification programme, which results in the -5C3/P. This is a better upgrade, and the engine has a higher EGT red line limit."

The global average for the -5C4's restored EGT margin after the first shop visit is 38-40 degrees. It is about 61 degrees for -5C2 engines. Restored EGT margins are about two-thirds of original levels. "We averaged about 40 degrees for our -5C4s and 61 degrees for our -5C2/Fs after their first shop visits," says Hartel. "EGT margin deterioration was initially about 12 degrees for the first 2,000EFH on-wing and then two degrees per 1,000EFH thereafter for both the -5C2 and -5C4. The first run on-wing times we have experienced are averages of about 17,500EFH for the pure -5C2 and 16,000EFH for the -5C4. The upgraded -5C2/Fs then achieved an average second run of about 12,000EFH. The -5C4s are still running their second interval, but we expect this may average 10,000EFH."

Auvinash Narayen, engine programme manager at Total Engine Support (TES) explains that although the CFM56-5C is relatively free of problems caused by airworthiness directives (ADs) and service bulletins (SBs) like other engine types, the CFM56-5C is at the top of the engine family's thrust range and suffers high EGT margin erosion as a result. "Average restored EGT margin is 70% of the production margin. EGT margin deterioration rate is an average of 14 degrees centigrade for the first 2,000EFH and then 2-3 degrees centigrade per 1,000EFH thereafter. A low restored margin limits subsequent on-wing runs," says Narayen. "First removal intervals can be 13,000-20,000EFH, depending on the production EGT margin and type of operation. The second removal interval is between 9,000EFH and 14,000EFH."

"Restored EGT margin is slowly increasing," says Gires. "We are doing performance and workscope analysis to define the best shop visit practices to improve restored EGT margin, and it is slowly increasing to the 40-45 degrees range. The workscope planning guide has been changed and clearances between stators and blades have been monitored as part of achieving this. So far, the -5C series loses about 14 degrees EGT margin in the first 2,000EFH, which then reduces to 2-3 degrees per 1,000EFH thereafter."

Modifications

The HPT and LPT upgrade packages for each variant to a higher-specification sub-variant allow a higher EGT margin. The -5C2/F, for example, has an EGT red line limit of 965 degrees. Upgrade to the -5C2/G results in an EGT red line limit of 975 degrees. The price of this package depends on the original configuration of the engine, as well as discussions between operators and CFMI.

"The CFM56-5C has had some EGT margin and HPT blade durability problems," explains Hartel. "CFMI has introduced a new HPT blade (single-crystal material), through an exchange programme under SB 72-469, to overcome this. The -5C4 has had this blade from the beginning, and all engines with a 975 degrees EGT red line limit must have these single-crystal blades. CFMI absorbs part of the cost of retrofitting these new blades. Over time only the single-crystal blades will become available anyway. The -C2/F and -5C3/F, with a red line limit of 965 degrees, would not require the capabilities of the single crystal blade, however, the pre-SB 72-0469 blades are retired from service."

The upgrade to G engines also includes the upgrading of HPT vanes and LPT blades and vanes. Many airlines have modified the LPT blades and vanes to G standard at the second shop visit. The original parts would last longer than two shop visits, and so the upgrade programme increases the cost of the shop visit.

A more advanced modification programme, the -5C/P modification, further increases EGT margin. This programme includes the installation of 3-D aerodynamic HPT blades and nozzle guide vanes, 3-D aerodynamic HPC blades and 3-D aerodynamic first stage LPT nozzle guide vanes. "This package is not available yet, but is expected to increase the EGT margin of engines after a shop visit by at least 13 degrees, that is to 45-50 degrees for -5C4s. It is also expected to reduce fuel burn by 1.1-1.2%. The full package is expected to cost $2.3-2.4 million per engine," explains Laudy.

Removal causes

The CFM56-5C's performance is consistent with most operators. "Performance degradation and low EGT margin are the prime removal driver," says Narayen. "The engine's other main

The CFM56-5C's main removal drivers has been EGT margin erosion and high pressure turbine blade cracking. Modification programmes have been introduced to increase EGT red line limit and to introduce single-crystal turbine blades that have better durability. These should lead to longer removal intervals.

issue relates to it being the high thrust end of the CFM56 family. This results in high deterioration of the engine's turbomachinery hardware. This was particularly true for the 1st stage HPT blades. The original blades on the -5C2 and -5C3 engines suffered cracking. These blades have been replaced with single-crystal blades, and this retrofit has been another removal driver."

"The initial high rate of EGT margin erosion and low restored EGT margin limit the on-wing runs of most engines," says Laudy. "Cracks in the HPT blades are another main removal cause, which should be the driver for the future."

"We removed most of our -5C4s for their first shop visit because of HPT blade cracking at about 20,000EFH," says Hartel. "Because of the HPT blade cracking problems there is an on-going inspection programme for the HPT blades. This has to be performed once every 100EFCs to detect any possible blade failures, so adding to the maintenance burden."

Several operators comment that cracks in the HPT blade are at its trailing edge, causing removals. In some cases it has been the prime driver, ahead of EGT margin erosion. Blades have now been improved, and so account for a smaller portion of removals.

Another factor accounting for a smaller number of removals is high oil consumption in the LPT. The CFM56-5C is relatively free of removal causes as a result of ADs and SBs.

Engine management

The CFM56-5C series does not conform to any particular shop visit pattern, such as alternating performance restorations and overhauls. "We have shop visit workscopes designed to recover the highest possible EGT margin and consequential on-wing interval," says Laudy. "We therefore have a relatively high shop visit. These include work on all core modules and the low pressure compressor (LPC). We also work on the LPT to improve oil consumption, as well as installing modifications. The fan module has good reliability."

Quiros explains that the shop visit workscope is critical to restored EGT margin and following reliability. "It is hard to recover high EGT margin, and the parts used influence this. The quality of parts repairs is more critical to restored EGT margin compared to other engines," explains Quiros. "The CFM56-5C requires tight tolerances to get good EGT margin. It is possible to get a higher EGT margin, but this requires a high level of parts replacement. This results in a disproportionate increase in shop visit costs compared to the benefit of increased on-wing interval. Repair versus replacement of parts has a large influence on on-wing time. The various improvement programmes for the CFM56-5C are based on the re-design of parts to improve EGT margin and on-wing time. There is a balance between shop visit cost and removal interval. We are currently in-line with CFMI's material cost prediction, but our forecast is to be over it during the next one or two years due to performance deterioration."

Gires explains that there are three main objectives in the shop visit workscope. "These are performance restoration, engine durability and reliability. Performance restoration is linked to optimising flow path clearances. Tight clearances will result in good performance and restored EGT margin, but then durability declines fast," explains Gires. "A balance has to be reached between clearances and resulting durability if on-wing performance is to be maximised.

"The pattern of shop visits, in most cases, is work on the HPT and HPC and combustor section in the first visit," continues Gires. "The second visit is heavier with the HPC, HPT and combustor included again with additional work on the LPT and possibly the LPC. The LPC may, however, be included at the third shop visit instead."

Shop visit inputs

Shop visit inputs for the CFM56-5C are relatively high because of a high degree of parts replacement. Narayen explains that a set of new HPT blades has to be installed in the engine at every shop visit. "Even new single-crystal blades, which have better retention than the older ones, cannot be repaired because CFMI has not released any repairs for these parts. They therefore have to be replaced. The new P improvement modification, using the 3-D aerodynamic blades that are also used in the -5B/P and -7B series, will lead to a better EGT margin recovery and retention," explains Narayen. "This improved EGT margin retention will result in longer on-wing times. This better retention should lead to a lower cost shop visit."

The inputs for shop visits vary with engine model and thrust rating. Higher rated engines tend to have a higher degree of parts replacement than lower rated engines. The split in cost for parts and sub-contract repairs will depend on the engine shop's repair capabilities. Narayen estimates that higher rated engines will have material and parts cost of about

CFM56-5C PERFORMANCE AND MAINTENANCE COSTS

Engine variant	CFM56-5C2/3	CFM56-5C4
EFH:EFC ratio	7.0	7.0
1st on-wing interval-EFH	16,000	13,000
2nd on-wing interval-EFH	12,000	10,000
Total time-EFH	28,000	23,000
1st S-V cost-$	1,400,000	1,600,000
2nd S-V cost-$	1,500,000	1,800,000
Total S-V cost-$	2,900,000	3,400,000
Shop visit cost reserve-$/EFH	104	140
LLP reserves-$/EFH	20	20
Total reserve-$/EFH	124	160

$1.0 million and a sub-contract repairs cost of $0.3 million. A shop visit will consume 3,500-4,000MH. At a labour rate of $70 per MH, labour cost will be $245,000-280,000. Total shop visit cost will be in the region of $1.6 million. "This will be lower at about $1.4 million for lower rated engines that require a lower level of parts replacement," says Narayen.

Hartel makes a similar estimate for shop visit costs for the higher rated -5C4. Lufthansa Technik, however, has a large component repair capability, and consequently low input for sub-contract repairs. While the combined cost of materials and sub-contract repairs is about $1.3 million, materials account for $1.2 million and sub-contract repairs $0.1 million. A similar labour input would generate a total shop visit cost of $1.6 million for labour charged at $70 per MH.

Costs will rise for a second shop visit, since higher workscopes will be needed as more modules require a higher rate of disassembly and more parts are replaced. The cost for low rated engines will increase to about $1.5 million and higher rated engines to about $1.8 million.

Low rated engines will have lower shop visit reserves per EFH than high rated engines, and will have typical first on-wing runs of 16,000EFH and second intervals of 12,000EFH. This total time of about 28,000EFH compares to a total shop visit cost of about $2.9 million for the two shop visits. This would generate a reserve of about $104 per EFH *(see table, this page)*.

High rated engines will have shorter shop visit intervals of 13,000EFH for the first and about 10,000EFH for the second on-wing run. This total of 23,000EFH compares to a cost of about $3.4 million for the two shop visits. This generates a reserve of about $140 per EFH *(see table, this page)*.

LLP management

Like all other engines operating long-haul aircraft, the CFM56-5C has low costs per EFH for life limited parts (LLPs). With aircraft operating 4,500-5,000FH per year and average FC times of 6-7 FH, the aircraft only accumulate 500-600FC annually. The oldest aircraft in operation will have accumulated about 6,000FCs.

There are 19 LLPs in the CFM56-5C. Some LLP lives depend on thrust rating. Most LLPs have lives of 15,000EFCs, and a few have lives of 20,000EFCs. Three LLPs (the HPT front seal, HPT front shaft and first stage HPT disk) had original lives of 7,700-9,100EFCs. There are later variants of these parts with extended lives. CFMI's goal is to increase the lives of all LLPs to 15,000 or 20,000EFCs. The implication of this is that LLPs will not have to be replaced until the aircraft and engines are about 20 years old.

Most airlines operate a stub life policy for LLPs to avoid premature removals due to expired LLP lives. A mature on-wing time of 10,000EFHs is equal to about 1,700EFCs. Most airlines will also have a stub life policy of 2,000-2,500EFCs. That is, parts with lives of less than 2,000 or 2,500EFCs will be replaced at a shop visit.

The implications are that parts with lives of 15,000EFCs will be replaced at about 13,000EFCs; equal to 78,000-90,000EFHs. This equates to at least 17 years of operation.

Parts with lives of 20,000EFCs will be replaced at about 18,000EFCs, or more than 25 years of service. Airlines may therefore not have to consider the cost of replacing some of these parts if the aircraft are sold or retired from service before this age is reached.

LLP reserves will be the cost of replacement parts amortised over the probable used interval of original parts. The HPT front seal, HPT front shaft and first stage HPT have original lives of 7,700-9,100EFCs. These will therefore be replaced at intervals of about 5,500-7,000EFCs. These parts have a combined list price of about $336,000. Reserves for these would be about $55 per EFC. This is equal to $9 per EFH for aircraft operating an average FC of 6.0FH, but $7 per EFH for aircraft operating an average FC of 7.5FH.

All other parts will have their original life of 15,000EFCs, and so be replaced at about 13,000EFCs. These remaining parts have a list price of about $1.24 million, and employing a stub life policy of 2,000EFCs results in a reserve of $97 per EFC. This is equal to $16 per EFH for aircraft operating operating average cycles of 6.0FH, but lower at $13 per EFH for aircraft operating cycles of 7.5FH.

Total reserves for LLPs will be about $152 per EFC, equal to $25 per EFH for aircraft operating an average cycle of 6.0FH and $20 per EFH for aircraft operating an average cycle of 7.5FH *(see table, this page)*.

Summary

Total reserves for a low rated engine will be in the region of $124 per EFH, and $160 per EFH for a high rated engine *(see table, this page)*. While most engines experience a rise in engine reserves as they mature, the CFM56-5C may be able to maintain or even reduce its maintenance reserves. The introduction of the P modification will increase EGT margin and on-wing life by as much as 2,000-3,000EFH. In parallel the engine may also have lower parts replacement and a higher degree of parts repair, thereby reducing shop visit costs. This should then maintain or lower reserves. AC