

CFM56-3 maintenance analysis & budget

The CFM56-3 can be operated at four different thrust ratings, and is operated in a variety of operating temperatures at conditions. The variation in removal intervals and the effect on maintenance reserves is examined.

The CFM56-3 is operated in large numbers, and will remain an important engine in the global repair and overhaul market for at least another 15 years.

The engine is operated worldwide and utilised in a wide variety of operations. Many factors influence the CFM56-3's maintenance costs and its wide-ranging maintenance reserves per engine flight hour (EFH).

The first group of factors comprises the engine's operating parameters: outside air temperature (OAT); EFH in engine flight cycle (EFC) ratio; level of take-off thrust de-rate; and the type of environment in which it is utilised.

The second group of factors includes: the engine's thrust rating; on-wing interval achieved prior to each shop visit; and the degree of hardware deterioration. The engine's life limited parts (LLPs) and their remaining life influence the timing of engine removals and removal intervals.

The third group of factors that affect the CFM56-3's maintenance reserves per EFH are the maintenance status of the engine at removal and the workscope of its previous shop visit.

Engine in operation

About 4,500 CFM56-3s operate globally with 195 different airlines. The -3 fleet has accumulated more than 150 million EFH and 108 million EFC; and has an average EFC time of 1.4EFH.

About 1,300 of the 1,900 operators are based in the moderate climates of North America and Europe.

About 700 aircraft are operated in North America. Of these, 380 aircraft are powered by the lowest thrust-rated -3B1, 135 by the -3B2 and 185 by the highest thrust-rated -3C1 (see *CFM56-3 series specifications, page 10*). The largest fleets are operated by Southwest, United, Continental, USAirways/America West, Delta, and Alaska Airlines. Southwest's fleet operates at an average EFC time of 1.22EFH, while United's operates at an average EFC time of 1.7EFH.

Many aircraft are operated in temperate climates, but are also utilised in parts of the US with high ambient temperatures. This includes operations by Delta at Salt Lake City, and America West and Southwest Airlines at Phoenix. Midday ambient temperatures often exceed 45 degrees centigrade in July and August.

There is a wide variety of operators in Europe. Out of 600 aircraft, about 185 are equipped with the -3B1, 85 with the -3B2 and 330 with the -3C1. About 180 737-400s in Europe are equipped with the -3C1 that can be rated at 23,500lbs thrust.

It is these engines that have the lowest EGT margins and are most sensitive to high OATs. Peak daily ambient temperatures reach about 35-38 degrees Centigrade (95-100 degrees Fahrenheit) at airports in southern Europe and in the Mediterranean in the summer months. Airlines operating in northern Europe often experience cool ambient temperatures.

European operators include many flag carriers, which operate their aircraft on routes where average EFC times are close to 1.4EFH.

The 737-300/-400/-500 has also been popular with several inclusive-tour carriers, which typically utilise the aircraft on cycles of 2.0-3.0EFH. Many are flown to and from the Mediterranean and Southern Europe.

Most of the remaining 590 aircraft in service are operated in regions that experience high ambient temperatures for most of the year. More than 310 of these aircraft are the -300 variant, and another 190 are the -400, most of which are powered by the -3C1. These aircraft are the most sensitive to high OATs because of their relatively low EGT margins.

EGT margin

The last CFM56-3s were manufactured in 1999, and so most of these engines have been through their first shop visit and have reached maturity.

Most CFM56-3s recover about 70% of the original exhaust gas temperature (EGT) margin after the first shop visit. The subsequent removals of most engines will therefore be forced by erosion of EGT margin, if the remaining life cycles on life limited parts (LLPs) are not limiting.

Dave Carr, team leader at Total Engine Support (TES), explains that the installed EGT margins of new CFM56-3 series engines are corrected and expressed for a standard OAT of 30 degrees centigrade. These are: 115-120 degrees centigrade for the -3B1 rated at 18,500lbs thrust; 90-100 degrees centigrade for an engine rated at 20,000lbs thrust; 60-70 degrees centigrade for the -3B2 or -3C1 rated at 22,000lbs thrust; and 40-50 degrees centigrade for the -3C1 rated at 23,500lbs thrust.

These EGT margins are only for new engines, and restored EGT margins following an engine's first shop visit are about 70% of the new margin. "The rate of EGT margin recovery and subsequent erosion also depends on the shop visit workscope," says Joao Baleizao, CFM56 powerplant engineer at TAP Maintenance & Engineering. "Most parts in the core should be refurbished. Seals are one example, and blades should be ground to the closest clearance within limits. This minimises the gap between the blade tips and the inner wall of the engine casing, and so minimises leaks around the end of the blades.

"One mil of clearance is one thousandth (1/1,000th) of an inch, and in some cases reducing the gap between the blade tip and casing wall by one mil can add about 0.1 degree of EGT margin," continues Baleizao. "One example is the clearance of the high-pressure compressor (HPC) blades. The standard clearance is 80 mil, but the minimum is 54 mil, so reducing the clearance by 26 mil adds about three degrees of EGT margin. Another example is high-pressure turbine (HPT) blade clearance, where each mil of clearance reduction adds about 1.04 degrees of EGT margin. Tighter margins on blade-tip clearances mean that rates of EGT margin loss are initially high, but the mature erosion rates are lower, which prolongs on-wing interval overall. It is particularly important to get a high rate of recovery on engines with higher thrust ratings."

"An engine rated at 23,500lbs thrust will have an installed EGT margin of about 30 degrees Centigrade after a performance restoration," says Carr. "A -3B2 or -3C1 rated at 22,000lbs will have a restored margin of about 40 degrees Centigrade, an engine rated at 20,000lbs will have a restored margin of about 80 degrees, and an engine rated at 18,500lbs thrust will have a restored margin of about 90 degrees (see *table, page 19*)."

Available EGT margin

The first issue to consider is that EGT margins for the CFM56-3 are expressed for a standard OAT of 30 degrees Centigrade and with the engine at maximum thrust and sea level. Available EGT margin is higher when OATs are lower than 30 degrees Centigrade (see table, this page). EGT reduces by 3.2 degrees for every one-degree reduction in OAT, and so EGT margin increases by the same amount.

The implications of this are that an engine rated at 23,500lbs will have an available EGT margin of 62 degrees Centigrade, fresh after a shop visit, when OAT is 20 degrees, rather than a lower EGT margin at the standard OAT of 30 degrees. Operating with this additional 32 degrees will naturally increase the engine's on-wing life. The same engine operating in a cooler environment with an OAT of 10 degrees will have an available EGT margin of 94 degrees.

Similarly, an engine rated at 22,000lbs will have an available EGT margin of 72 degrees fresh after its first shop visit when operating in an OAT of 20 degrees Centigrade. The available margin will increase to 104 degrees in an OAT of 10 degrees (see table, this page).

The opposite of this is that when operating in hot environments of up to 45 degrees, the highest-rated engines cannot be used at full thrust rating and have to be automatically de-rated to maintain constant EGT (the higher the OAT the higher the de-rate). The level of de-rate has to increase as the engine deteriorates and EGT margin is eroded. High-rated engines that are used in hot environments are often removed for a performance restoration when they still have up to 40 degrees of EGT margin (at a standard OAT of 30 degrees) remaining. An engine with an EGT margin of 40 degrees effectively has zero margin at an OAT of about 42 degrees, which is typical of operating temperatures during the height of summer in desert regions and areas with hot climates.

"The actual annual variation in OATs for airlines throughout the year and across their route network can be wide," explains Dave Beale, CFM56 customer programme manager at MTU Maintenance. "In Europe most airlines experience a range of OATs from minus 5 to plus 30 degrees, while the range is more extreme in the US, Asia Pacific and the Middle East. For some airlines it is as wide as minus 20 degrees Centigrade and plus 40 degrees, while at Phoenix, Delhi or Dubai it can be as high as 45 degrees."

The variation of EGT margin deterioration with OAT has to be considered when assessing an engine's probable on-wing life.

VARIATION OF AVAILABLE EGT MARGIN WITH OAT FOR MATURE CFM56-3 SERIES ENGINES

CFM56-3 rated at 23,500lbs
Standard EGT margin = 30 degrees

OAT deg C	0	10	20	30	35	40
Available EGT margin	126	94	62	30	14	0

CFM56-3 rated at 22,000lbs
Standard EGT margin = 40 degrees

OAT deg C	0	10	20	30	35	40
Available EGT margin	136	104	72	40	24	8

CFM56-3 rated at 20,000lbs
Standard EGT margin = 80 degrees

OAT deg C	0	10	20	30	35	40
Available EGT margin	176	144	112	80	64	48

CFM56-3 rated at 18,500lbs
Standard EGT margin = 90 degrees

OAT deg C	0	10	20	30	35	40
Available EGT margin	186	154	122	90	74	58

Take-off de-rate

Another operational and performance issue to consider is reduced take-off thrust procedures (often referred to as 'take-off de-rate'). A 10% thrust reduction effectively reduces take-off thrust in the order of 2,000lbs, with the benefit of lowering peak EGT. Although the highest thrust-rated engines have low EGT margins that also reduce with time spent on-wing, use of reduced thrust at take-off will increase the effective EGT margin available and so prolong on-wing life.

"A take-off de-rate that averages 5% will add 400-500EFC to on-wing life, a 10% de-rate will add 800-900EFC, and a 15% de-rate will add about 1,100EFC," says Carr. "Most European operators achieve de-rates of 5-10%. The problem of having little or zero available EGT margin at high OATs, even when the standard EGT margin is 45-55 degrees, is exacerbated by the fact that airlines operating in hotter temperatures require higher levels of take-off thrust because of the aircraft performance limitations imposed by high temperatures."

Take-off de-rate is affected by several operational factors. "The longer the flight and higher the payload, the higher the take-off gross weight, and so the lower

the level of de-rate," explains Baleizao. "Some inclusive-tour operators fly two- or three-hour sectors, and so have heavy loads. This can be a problem in hot environments, especially with -3C1 engines that have had some of their EGT margin eroded. Temperature problems are experienced in areas of southern Europe, such as Italy, Greece and Portugal. For example, the daily temperature in Lisbon reaches 28-30 degrees Centigrade in July and August."

EGT margin deterioration

The intervals between removals are determined by several factors, with one main issue being performance deterioration and EGT margin erosion. EGT margin deteriorates faster for engines operated at higher thrust ratings. Initial rates after re-installation following a shop visit are also high.

"A mature -3C1 rated at 23,500lbs operating in the typical European or North American theatres where the average OAT is about 20 degrees Centigrade has an initial EGT margin erosion rate of 12 degrees in the first 1,000EFC. It then loses about 6 degrees in the second 1,000EFC, and 4 degrees per 1,000EFC thereafter," says Carr.

On this basis, the engine will be left



with a margin of about 12 degrees after 2,000EFC for a standard OAT of 30 degrees. At an erosion rate of 4 degrees per 1,000EFC, it can expect to have a total on-wing performance interval of about 5,000EFC if operated at an OAT of 30 degrees.

For engines operated in hot and dusty environments where take-off de-rate is not operationally possible, erosion rates are likely to be much greater. Initial erosion rates for the first 2,000EFC for 20-22 degrees and the 5-6 degrees per 1,000EFC or more would not be unusual, and would reduce on-wing performance time to 3,500-4,000EFC.

"An engine rated at 22,000lbs will lose about 16 degrees in the first 2,000EFC," says Carr. This will take EGT margin down to about 24 degrees after 2,000EFC. The rate will then be about 3-4 degrees per 1,000EFC, allowing the engine to remain on-wing for a total time of 8,000EFC. Higher OATs, however, would reduce intervals.

Carr estimates that a -3B2 or -3B1 rated at 20,000lbs will lose 14 degrees in the first 2,000EFC, and then just 2-3 degrees per 1,000EFC thereafter. This erosion rate will, if managed well, allow it to achieve intervals of up to 15,000EFC.

Carr's estimate is that an engine rated at 18,500lbs will lose 9-10 degrees of its EGT margin of 90 degrees in the first 2,000EFC. EGT margin erosion rate will then be 2-3 degrees per 1,000EFC. This will allow long on-wing intervals that are not limited by EGT margin.

The large difference in possible on-wing removal intervals allowed by EGT margins illustrates the value of take-off de-rate, operating at low OATs, and the advanced upgrade modification (see

CFM56-3 modification programmes, page 13) for the higher-rated engines.

Removal causes

Other main factors affecting removal intervals are EFH:EFC ratio and the remaining lives of LLPs.

The EFH:EFC ratio of the CFM56-3 fleet is an average of about 1.4EFH per EFC. Many airlines operate longer average cycles, and average EFC time is another major influence on interval achieved. "The intervals achieved by most -3s are mostly related to the accumulated EFC, rather than EFH, on-wing," explains Beale. "Take-off de-rate and the EFH:EFC have a direct connection. The longer the EFC time, the heavier the take-off weight, the lower the de-rate, and the fewer EFCs achieved as a result. The number of EFHs on-wing are not affected by the rate of de-rate, however. De-rate and EFC removal interval have an inverse relationship. One per cent of de-rate is equal to 3-5% more on-wing time."

"Intervals after the first removal are more or less constant," explains Markus Kleinhans, propulsion systems engineering for the CFM56-3/-7B at Lufthansa Technik. "EFC has more impact on the on-wing interval than EFH for average EFC times of 1.0-1.5 EFH. On longer average sectors, however, where EFC time is 2-3EFH, the accumulated number of EFH on-wing has more of an influence on interval. This is because parts of the engine hardware will begin to deteriorate after a long number of EFH, and this begins to force removals. The number of EFCs achieved on-wing will decline slightly as EFH:EFC increases.

The CFM56-3 will have on-wing intervals of 5,000-18,000EFC if not limited by LLPs, depending on thrust rating and operating environment.

Life limited parts

The remaining life of LLPs also has to be considered, since it can actually limit the on-wing intervals of some engines. There are 19 LLPs in the CFM56-3.

The fan and booster module has three LLPs which have a target life of 30,000EFCs, although the lives of certain part numbers are lower than this. LLPs that are limited to less than 30,000EFC have more restricted lives when used on engines rated at 22,000lbs and 23,500lbs than for other engines. These three LLPs have a list price of \$305,000.

The low-pressure turbine (LPT) has seven LLPs, which have a target life of 25,000EFCs. Like the fan and booster module, some part numbers have lives shorter than this and are as short as 5,700EFC. These seven LLPs have a list price of \$485,000.

The HPC and HPT combined have nine LLPs, with a target life of 20,000EFC. Again, some part numbers have lives limited to less than 20,000EFC, and the limits are more stringent for parts used on engines with the highest thrust ratings. These nine LLPs have a list price of \$755,000.

On-wing intervals

Removal intervals are clearly affected by several factors. "The engine's thrust rating, followed by the previous shop visit workscope and the engine's hardware standard, most influence removal interval," says Carr. "The third main influence is the take-off de-rate policy applied, the fourth is the EFH:EFC ratio, while the fifth factor is the operating environment and condition, such as OAT. There are other operational practices, such as warm-up and cool-down time and bleed settings for the engines, which also affect on-wing interval.

"The important issues relating to the standard of the previous shop visit are the hot section, the HPT nozzles and blades, the LPT stage 1 nozzles," continues Carr. "New hardware improves on-wing life significantly, while repaired parts can lose 35-40% of possible interval. The engine should be built in the shop visit so that its performance potential can match its LLP life limits."

Carr estimates that later-build -3C1s

rated at 23,500lbs were capable of first run on-wing intervals in the region of 8,000EFC. This would be about 7,000EFC for engines operating in OATs about 5 degrees higher.

"These engines can achieve second and third intervals of about 6,000EFCs and 5,000EFCs due to performance. This is only if they are operated at average EFC times and levels of take-off de-rate, have the highest hardware standard and are not limited by LLPs," says Carr.

Average OATs that are 5 degrees centigrade higher than those of moderate climates will reduce intervals by about 1,000EFC, and so 23,500lbs engines would be expected to only achieve about 5,000EFC on-wing for their second interval before losing all EGT margin.

Engines rated at 22,000lbs thrust were capable of about 12,000EFC on their first removal interval. Carr estimates that these engines could achieve 9,000EFC and 8,000EFC on their second and third intervals based on EGT margin performance and without any hardware limitations.

These intervals would be 1,000EFC shorter for an engine operating in an environment with an OAT 5 degrees higher.

The -3B2 or -3B1 rated at 20,000lbs would have a first on-wing interval of about 17,000EFC. These can achieve about 13,000EFCs and 11,000EFCs on-wing for their second and third intervals,

if not limited by LLPs or by hardware condition.

Engines rated at 18,500lbs were capable of first intervals of up to 20,000EFC, because of HP system LLP life limits. Based on their EGT margins, engines with this thrust rating are capable of 17,000EFCs and 14,000EFCs on-wing for their second and third intervals.

Operator experience

Air New Zealand operates a fleet of 737-300s for use on domestic and regional services. These aircraft are powered with engines rated at 22,000lbs, and the overall average EFC time is 1.53EFH across the network. The fleet is young, and has not yet experienced second or third removals. The first removal intervals averaged about 14,600EFC. This is high for the thrust rating, although this is aided by the moderate operating temperatures.

Air France operates in a moderate climate. Its fleet of 737-300s and -500s is powered by engines rated at 20,000lbs and 18,500lbs. Its average EFC time is 1.27EFH and it has an annual average OAT of 16 degrees. Its 20,000lbs engines average mature intervals of 9,500EFH and 7,500EFC, while its 18,500lbs engines average mature intervals of 13,500EFH and 10,600EFC. These intervals are both a direct consequence of stub life policy.

United Airlines has a similar operation, and uses 20,000lbs engines for its 737-300s, with an average EFC time of 1.7EFH. Its annual OATs vary widely between minus 29 degrees and plus 49 degrees across its network. "In our experience, first runs have been long, up to the LLP limit of 20,000EFC. The second and third intervals are shorter, at 9,000-10,000EFC, with engines being removed for performance reasons. We have found that we lose 7-8 degrees of EGT margin per 1,000EFC. LLP expiry is also another main removal driver," says John Hoopes, manager of powerplant engineering of CFM56 engines at United Services.

Southwest Airlines has a fleet of more than 170 737-300s/-500s, the youngest of which is nine years old. Its fleet is powered by engines rated at 20,000lbs thrust and operated at 1.22EFH per EFC. Like United, Southwest experiences a wide range of OATs, the highest being 46 degrees centigrade. Its second and third intervals have been about 14,000EFC, and LLP expiry is the main removal driver. Southwest is known to achieve some of the longest removal intervals of all CFM56-3 operators, despite the high temperatures in which it operates. Southwest was also the launch customer for the advanced upgrade programme. It predicts this will extend on-wing intervals by about 3,000EFC. It also predicts no net increase in shop visit costs.



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Unscheduled removals

Unscheduled removals occur at a rate of 0.033 per 1,000EFH, about once every 30,000EFH, or equal to once every 21,500EFC. "These are split between engine- and non-engine-related events," says Kleinhans. "Non-engine related events include birdstrikes and foreign object damage (FOD), and occur at a rate of about 0.005 per 1,000EFH. Engine-related events occur at a rate of 0.028 per 1,000EFH, equal to once every 35,700EFH or 26,000EFC. Of these, 60-70% are light, and the remainder are heavy." The rate of heavy events is about 0.0098 per 1,000EFH, equal to about once every 100,000EFH. Light repairs occur at a rate of 0.018 per 1,000EFH, about once every 60,000EFH.

Heavy unscheduled visits can include the worst scenarios of a bearing failure, which can incur a shop visit cost in the region of \$2 million. These heavy events are grouped together with non-engine-related events, occurring at a rate of about 0.015 per 1,000EFH, equal to every 67,000EFH and 48,000EFC.

These events occur at random and force engines into shop visits, thereby disrupting the scheduled removal intervals and shop visit patterns of which engines are capable according to their EGT performance and LLP lives. The overall effect is to reduce the expected intervals between scheduled removals.

Shop visit pattern

Most CFM56-3s will have been through their first scheduled shop visit, and the probable first interval and shop visit workscope has to be considered when assessing the subsequent interval, shop visit workscope, requirement to replace LLPs and overall shop visit workscope pattern. The rate of unscheduled removals and their effect on reducing average expected scheduled removal intervals has to be considered in the actual intervals achieved by engines (*see table, page 26*). On average, these will be less than the intervals that the engines are capable of due to EGT margin alone.

The general aim is to build an engine with enough EGT margin for the second on-wing interval to match the LLP limits, if they are expected to become limiting.

Engines will have had varying levels of core engine performance restorations at their first visit. Lower-rated engines will have had heavier worksopes that include the replacement of LLPs. They may also have had LLPs replaced in other modules if their remaining lives at the first shop visit could limit the second intervals.

"While engines have a performance restoration at every shop visit, lower thrust-rated engines will have had long intervals, and the workscope level varies," says Kleinhans. "The fan/booster

and LPT modules are assessed on an on-condition basis, and have a low impact on engine performance. The LPT can be worked on every second shop visit, and the fan/booster section every second or third, depending on the intervals. An overhaul of each of these three major sections is required where a higher level of disassembly is required to remove expired LLPs and install new ones."

A possible shop visit workscope pattern, considering performance-limited intervals, the effect of unscheduled removals, and LLP lives, is considered for each thrust rating (*see table, page 26*).

23,500lbs

The relatively short first intervals of 7,000EFC and 6,500EFC for engines rated at 23,500lbs, mean that the LPT can be worked on every fourth shop visit, while the fan and booster can be worked on during the fifth shop visit if hardware condition allows. The engine operating in a moderate OAT can have a core performance restoration for the first and second shop visit, and then an overhaul of the HP system at the third so that LLPs can be replaced (*see table, page 26*). The engine will have accumulated about 17,500EFC at this stage, equal to 8-9 years of operations.

The engine operating in a hot environment may only achieve second and third intervals of about 4,000EFC. In

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this case it is possible to have a core performance every visit up to the fourth visit, when HP system LLPs have expired.

22,000lbs

Engines rated at 22,000lbs will have longer intervals of 9,000-10,000EFC, when engine-related unscheduled removals are considered.

The first shop visit will be just a performance restoration of the HP system. An overhaul of the core will be required at the second shop visit, to replace LLPs after accumulating about 17,500EFC (see table, page 26). An overhaul of the LPT will be required at the third shop visit to replace LLPs after 24,000EFC, equal to 12 years of operations (see table, page 26). The fan and booster modules will need an overhaul to replace LLPs at the fourth shop visit.

Engines operating in hotter environments will achieve shorter intervals, and so will require a core overhaul at the third shop visit (see table, page 26). The overhaul of the LPT can be left to the fourth shop visit.

20,000lbs

The longer intervals achieved by engines rated at 20,000lbs mean that their HP system LLPs will have to be replaced at the first shop visit. LLPs in the LPT could also be replaced at the first shop visit, so overhauls of these two main sections will be required. A performance restoration will be required on the HP system at the second shop visit, as well as an overhaul of the fan and booster modules so that LLPs can be replaced (see table, page 26). Installation of new HP

LLPs at the first shop visit will limit the third interval to about 8,000EFC, and an overhaul of the HP system will be needed at the third shop visit to replace LLPs after a total time of 20,000EFC. It may also be prudent at this stage to replace LPT LLPs with a stub life of 5,000EFC (see table, page 26). At this point the engine will have accumulated 36,000EFC, equal to 18 years of operations.

18,500lbs

Like engines rated at 20,000lbs thrust, an engine rated at 18,500lbs will require an overhaul of the core and LPT at the first removal to replace all LLPs so that they do not limit the second interval. This will be after 18,000EFC.

At this stage the engine will be capable of a second run of up to 17,000EFC, but will be limited to 10,000-12,000EFC for the second removal by the stub life of fan and booster LLPs. The third interval will be limited to 10,000EFC by HP system stub lives installed at the first shop visit (see table, page 26). At this stage the engine will have accumulated 38,000EFC, equal to about 19 years of operations.

Shop visit inputs

Because of the four different thrust ratings, different operating conditions and engine management considerations, there are several combinations of shop visit workscopes. The four main workscope types are: a core performance restoration; a core overhaul; an LPT overhaul; and a fan/booster overhaul. The largest shop visit will be an overhaul of all three main sections, comprising a

The objective of maintenance management should be to match the probable removal interval allowed by performance and EGT margin with LLP lives. This should result in the lowest possible maintenance reserves.

full engine overhaul.

The inputs for each of the four main workscopes can be analysed, and the cost of each used to assess the probable cost for a particular shop visit workscope.

A core engine performance restoration will use about 1,500 man-hours (MH) of routine labour, but non-routine labour has to be considered. This can be about equal to the routine portion. Total MH can therefore be about 3,000, although they will vary according to condition, the shop's in-house repair capability and scrap rates of parts. A labour rate of \$70 would take this to \$210,000.

There is a trade-off between the cost of materials and sub-contract repairs, depending on the shop's in-house capability. Carr estimates that, excluding LLPs, materials can cost \$550,000, and sub-contract repairs \$100,000. The balance can be different for shops with less in-house capability, with the cost of materials coming to \$450,000 and sub-contract repairs \$250,000. These inputs would take the total cost of a shop visit to \$860,000-910,000.

Beale estimates that a heavier workscope on the core, to achieve a full overhaul, would use about 3,500MH. This would have a cost of \$245,000 if charged at a labour rate of \$70 per MH. The cost of materials and parts for this heavier workscope would be \$550,000, and for sub-contract repairs it would be up to \$300,000, again excluding LLPs. This would take total cost for this workscope to \$1.0-1.05 million.

In most cases, workscopes on the LPT and fan/booster sections are required when LLPs have to be replaced, and so are usually overhauls. Carr estimates that the LPT will use about 325MH for routine work and about another 750MH for non-routine work. This total of 1,075MH will have a cost of \$75,000 when charged at the standard labour rate of \$70 per MH. The cost of materials is relatively light compared to the HP system, and is in the region of \$100,000. Sub-contract repairs incur a further \$50,000, taking the total cost of the LPT overhaul, excluding LLPs, to \$225,000.

The fan/booster section has similarly light requirements. Estimates for routine labour are 250-300MH, and about 150MH for non-routine. The total of 400-450MH incurs a cost of \$28,000-

CFM56-3 SERIES SHOP VISIT MANAGEMENT & MAINTENANCE RESERVES

Removal	First removal	Second removal	Third removal
Engine rated at 23,500lbs			
High OAT			
Removal interval-EFC	6,500	4,000	4,000
Accumulated interval-EFC	6,500	10,500	14,500
Shop visit workscope	Core restore	Core restore	Core restore
Shop visit cost-\$	860,000	860,000	900,000
LLP replacement	-	-	-
LLP cost-\$	-	-	-
Total reserve-\$/EFC	207	290	300
Total reserve-\$/EFH	148	207	214

Moderate OAT			
Removal interval-EFC	7,000	5,000	5,000
Accumulated interval-EFC	7,000	12,000	17,000
Shop visit workscope	Core restore	Core restore	Core overhaul
Shop visit cost-\$	860,000	860,000	900,000
LLP replacement	-	-	HP system
LLP cost-\$	-	-	700,000
Total reserve-\$/EFC	200	249	257
Total reserve-\$/EFH	143	178	184

Engine rated at 22,000lbs

High OAT			
Removal interval-EFC	9,000	6,000	5,000
Accumulated interval-EFC	9,000	15,000	20,000
Shop visit workscope	Core restore	Core restore	Core overhaul
Shop visit cost-\$	860,000	860,000	1,000,000
LLP replacement	-	-	HP system
LLP cost-\$	-	-	777,000
Total reserve-\$/EFC	164	211	268
Total reserve-\$/EFH	117	151	191

Moderate OAT			
Removal interval-EFC	10,000	7,500	6,500
Accumulated interval-EFC	10,000	17,500	24,000
Shop visit workscope	Core restore	Core overhaul	Core restore & LPT overhaul
Shop visit cost-\$	860,000	1,000,000	1,085,000
LLP replacement	-	HP system	LPT
LLP cost-\$	-	755,000	485,000
Total reserve-\$/EFC	159	206	240
Total reserve-\$/EFH	114	147	171

Engine rated at 20,000lbs

Moderate OAT			
Removal interval-EFC	16,000	12,000	8,000
Accumulated interval-EFC	16,000	28,000	36,000
Shop visit workscope	Core & LPT overhaul	Core restore & fan/booster overhaul	Core & LPT overhaul
Shop visit cost-\$	1,225,000	970,000	1,225,000
LLP replacement	HP system & LPT	Fan/booster	HP system & LPT
LLP cost-\$	1,240,000	305,000	1,240,000
Total reserve-\$/EFC	166	154	219
Total reserve-\$/EFH	118	110	157

Engine rated at 18,500lbs

Moderate OAT			
Removal interval-EFC	18,000	10,000	10,000
Accumulated interval-EFC	18,000	28,000	38,000
Shop visit workscope	Core & LPT overhaul	Core restore & fan/booster overhaul	Core & LPT overhaul
Shop visit cost-\$	1,225,000	970,000	1,225,000
LLP replacement	HP system & LPT	Fan/booster	HP system & LPT
LLP cost-\$	1,240,000	305,000	1,240,000
Total reserve-\$/EFC	148	169	198
Total reserve-\$/EFH	106	121	141

32,000 when charged at the standard rate of \$70 per MH.

The cost of materials is \$50,000-60,000, while sub-contract repairs require only about \$20,000. This takes the total cost of a fan/booster overhaul to about \$105,000, excluding LLPs.

The requirement for a full engine overhaul is rare, since LPT and fan/booster modules are likely to require overhauls at different intervals to the engine core. The total labour requirement for such a workscope is 4,500-5,500MH, which costs \$310,000-385,000 at the standard labour rate of \$70 per MH. Materials will cost about \$800,000-850,000, and sub-contract repairs \$250,000-300,000, taking the total cost to \$1.4-1.5 million.

Reducing shop visit costs

As previously described, certain shop visit techniques can be employed to increase subsequent EGT margin and so prolong the following on-wing life.

“Work on the core modules provides the best financial return in terms of recovering EGT margin and on-wing time. Work on the LPT can add another 5 or 6 degrees of EGT margin, and work on the booster can add a further 3 degrees,” says Carr. “Water washing can extend time on-wing, especially in dusty environments where cooling holes in HPT blades can get blocked. A warm-up time of 10-15 minutes after start can also increase EGT margin, or reduce its rate of erosion.

“The best shop visit policy is to match the EGT margin and performance life with remaining LLP lives, which will affect blade repair policy,” continues Carr. “The latest HPT blades with better coating materials can also extend on-wing life.”

One way of reducing shop visit inputs is to use parts manufacturing approval (PMA) components. There are several suppliers of PMA parts for the CFM56-3, and virtually every part on the engine can be PMA, with the exception of cases and shafts.

HEICO is one PMA supplier, offering more than 500 different part numbers for the CFM56-3. “The few parts we do not offer are the 3-D aerodynamic parts that are installed during the advanced upgrade modification, but few operators have done this conversion,” says Rob Baumann, President of HEICO Parts Group.

PMA parts cost 45-75% of the original equipment manufacturers' (OEMs) list prices. “The actual discount depends on the part, but it is still substantial,” says Baumann. “Airlines can make hi-tech repairs on OEM parts, but repaired parts have shorter lives than new ones. The alternative is to have new,



cheaper PMA parts, which have the same on-wing lives of OEM parts. The other main advantage of PMA parts is that the annual increase in our list prices is lower than the OEMs'. We make smaller price increases than the OEMs, only half as often as they increase their prices."

The impact of PMAs on shop visit costs is about \$100,000 per event. An overhaul of the CFM56-3 will cost \$1.2-1.4 million, with parts and materials accounting for 60-70% of this.

Some airlines and lessors have had a policy of not using PMA parts. Lessors, for example, are concerned about the re-marketability of their parts. The number of airlines accepting PMAs is increasing, however. "Airlines' perceptions of PMAs are changing as their concerns about approvals are allayed, they see that there is no difference in the quality of parts, and they realise how much they can save," says Baumann. "HEICO now has a joint venture with American Airlines to develop PMA parts, and Lufthansa Technik has bought 20% of HEICO Aerospace. We currently sell parts to 16 of the world's top 20 airlines, including United, Air Canada and Japan Airlines."

Overall economics

The costs of the shop visit inputs and LLP reserves in accordance with the probable shop visit intervals and workscopes summarised (see table, page 26) can be described in terms of reserves per EFC and EFH.

The shop visit intervals and patterns are based on intervals that can be achieved with the EGT margins each thrust rating will have, taking into account reduction of the average interval due to unscheduled removals and an

average EFC time of 1.4EFH.

The reserves for shop visit inputs increase as intervals reduce or have to be compromised due to LLP stub life and expiry (see table, page 26). The intervals also consider probable timing of LLP replacement at subsequent shop visits. The replacement of LPT LLPs at the second and fifth shop visits means that reserves for these parts have to be accrued during the third, fourth and fifth on-wing intervals.

The lives of the LPT and fan/booster LLPs in relation to annual utilisations of about 1,800-2,000EFC mean that some operators may be tempted to avoid paying their reserves after they have been replaced for the first time, because these parts may not need to be replaced a second time, given the engine's age.

The LLP reserves shown also do not take into consideration the possible resale value of used LLPs that are removed from engines with remaining lives of up to 9,000EFC, which may realise some residual value on the used market.

Reserves for engines rated at 23,500lbs start at \$143-148 per EFH for the first interval, but rise to \$178-207 per EFH for the second interval as time on-wing is shortened. Reserves increase again to \$184-214 per EFH for the third interval as intervals reduce further and shop visit costs increase (see table, page 26). The difference between engines operated in moderate and hot climates is small during the first interval, but rises to \$25-30 per EFH as engines mature.

Reserves for engines rated at 22,000lbs thrust start at \$114-117 per EFH, and increase to \$147-151 per EFH for the second interval as the time on-wing reduces. At this stage the difference between engines operated in hot and

Maintenance reserves increase with age as removal intervals reduce and engine management has to make compromises with LLP lives and expiry.

moderate environments is small. This increases to \$20 per EFH for the third interval, when reserves are \$171 per EFH and \$191 per EFH (see table, page 26).

The longer removal intervals due to high EGT margins, from which engines with lower thrust ratings benefit, are reflected by their lower reserves, and by the fact that their reserves increase at a lower rate than higher-rated engines.

Engines rated at 20,000lbs thrust are compromised, however, by the need to remove LPT LLPs early at the first shop visit at about 16,000EFC to avoid limiting the second on-wing interval to 9,000EFC. This increases the cost of the shop visit because of the need to perform a workscope on the LPT (see table, page 26). Reserves are up to \$110 per EFH up to the second removal, and then increase to \$157 per EFH during the third interval.

Engines rated at 18,500lbs are also forced to compromise the content of their first shop visit, requiring a full workscope on the LPT, as well as replacing LLPs which have stub lives of 7,000EFC. The reserve for the first interval is \$106 per EFH, and reserves up to the third shop visit increase to \$138 per EFH (see table, page 26). This is low relative to engines rated at higher levels of thrust.

These reserves have to be increased to account for the cost of unscheduled removals that require light shop visits. Given that most of these only incur a cost of \$50,000-100,000, and occur on average about every 60,000EFH, they only increase cost per EFH by \$1-2.

The advanced upgrade kit for the CFM56-3 can have the effect of increasing on-wing life by several thousand EFH (see CFM56-3 modification programmes, page 13). This has the net effect of reducing reserves by up to \$30 per EFH on account of increasing EGT margin. The kit, however, is only likely to appeal to airlines operating higher rated engines in hot environments.

Engines that are rated at 18,000lbs and 20,000lbs thrust have sufficient EGT margin to allow long on-wing removal intervals. Higher rated engines, however, have to be managed carefully and are sensitive to OAT, as well as poor shop visit practices. The limited EGT margin on these engines explains why a small number operate in areas of the world with high OATs. **AC**