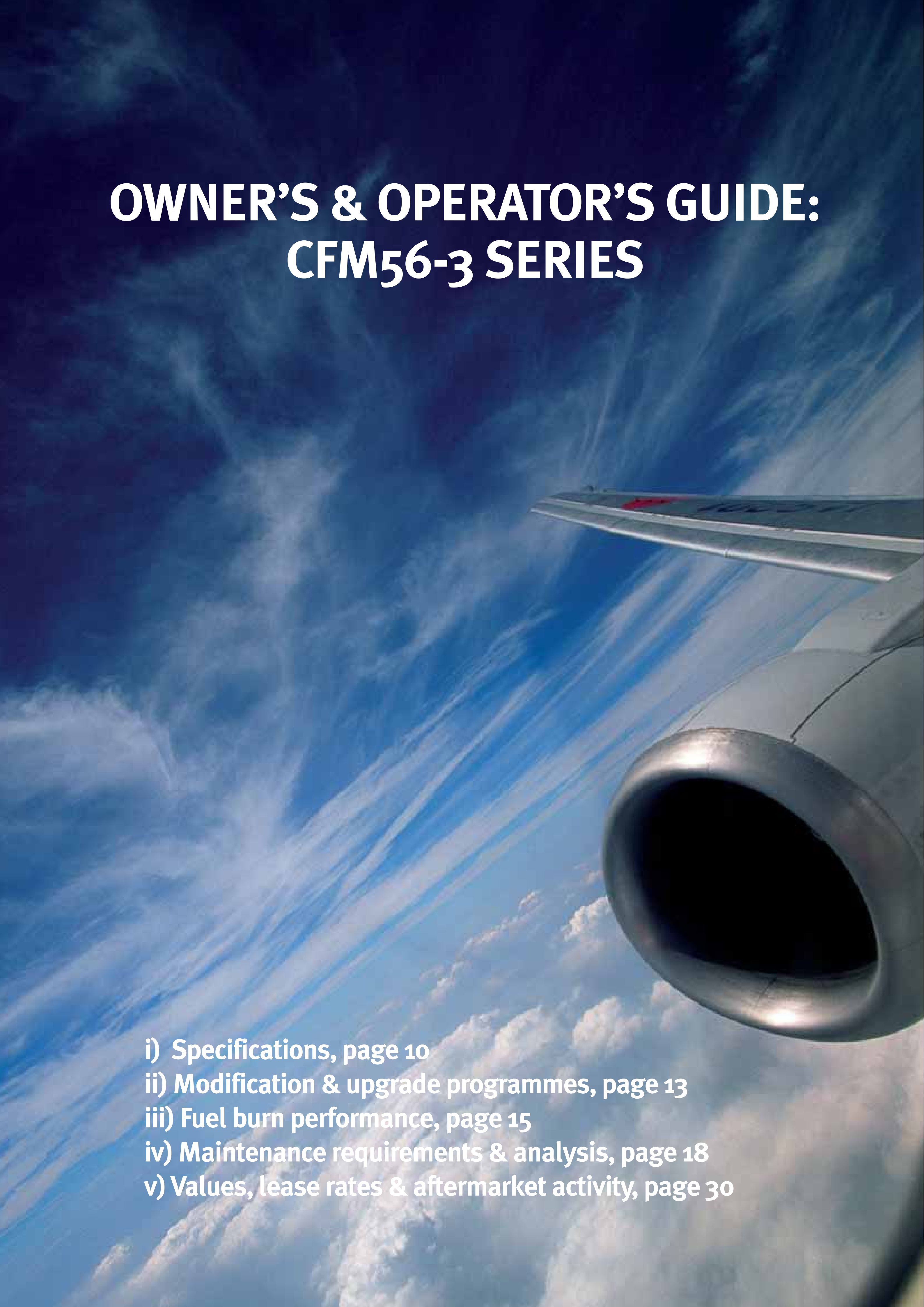
OWNER'S & OPERATOR'S GUIDE: CFM56-3 SERIES



CFM56-3 series specifications

The CFM56-3 series is ratings between 18,500lbs and 23,500lbs thrust. Its specifications & EGT margin performance are examined.

The CFM56-3 is the second of five series of the CFM56 engine model, and was the first to sell several thousand units. Certified in 1984, the CFM56-3 ceased production in 1999, after some 4,500 units had been built. As the sole powerplant for the 737-300/-400/-500, the CFM56-3 will continue operating in large numbers for another 20 years on account of the aircraft's popularity.

Configuration

The CFM56 family has a two-shaft design and provides a range of engines rated between 18,000lbs and 34,000lbs thrust across five series. The -3 series was derived from the initial -2 series utilised to re-engine the DC-8-60 series.

The CFM56-3 has a 60-inch fan diameter, and the three variants have bypass ratios between 4.8:1 and 5.1:1. The engine's high-pressure (HP) system has a nine-stage high-pressure compressor (HPC) and single-stage high-pressure turbine (HPT). The low-pressure (LP) system has a three-stage low-pressure compressor (LPC) and four-stage low-pressure turbine (LPT).

There are three main variants: the -3B1 rated at 18,500lbs and 20,000lbs thrust; the -3B2 rated up to 22,000lbs thrust; and the -3C1 rated up to 23,500lbs thrust (introduced in 1988, it is the only variant available at all four thrust ratings).

The 737-300 can be configured with the -3C1 or -3B1 variant rated at 20,000lbs and 22,000lbs, while the largest 737-400 can be equipped with the -3C1 rated at 22,000lbs and 23,500lbs, or powered by the -3B2 rated at 22,000lbs. The smallest -500 can be configured with the -3C1 rated at 18,500lbs or 20,000lbs, or with the -3B1 rated at 18,500lbs *(see table, page 11)*.

Because each aircraft model uses at least two thrust ratings, and all four ratings are applied across the three aircraft variants, the CFM56-3C1 can be re-rated to different thrust ratings to satisfy airlines' operational requirements. The ability to re-rate is also useful when an engine has used its exhaust gas temperature (EGT) margin at a high rating, and can regain some margin by being de-rated to a lower thrust. This process gains additional on-wing time.

Life limited parts

The CFM56-3 comprises five main modules: the fan, booster, HPC, HPT and LPT. The CFM56-3 has 19 LLPs.

These LLPs include three in the fan and booster module of the LP system: the fan disk, booster spool and and fan shaft. CFMI's intention is for all these LLPs to have lives of 30,000EFC. These have a list price of $305,000.

There are another seven LLPs in the turbine module of the LP system: the four disks for the four LPT stages; the stub shaft; the main LPT shaft; and the conical support. CFMI is aiming for all these LLPs to have lives of 25,000EFC. These have a list price of 485,000.

There are just nine LLPs in the HP system: the HPC front shaft; 1-2 HPC spool; 3 HPC disk; 4-9 HPC spool; CDP seal; HPT forward shaft; front air seal; HPT disk; and HPT rear shaft. CFMI's long-term intention is for these parts to have uniform lives of 20,000EFC, but some parts have shorter limited lives. These have a list price of $755,000.

EGT margin

The maximum EGT permitted on the CFM56-3 series is 930 degrees centigrade. The number of times that this 'red-line' temperature can be exceeded, before removal for a shop visit is required, depends on several factors.

At maximum thrust, the EGT increases at a constant rate as outside air temperature (OAT) increases *(see chart, page 11)*. This is because the power management schedule on the aircraft is programmed to provide a constant take-off thrust with rising OAT. Air becomes thinner as OAT rises, so constant thrust is maintained by increasing throttle, resulting in an increase in EGT. The gradient of this increase is 3.2 degrees of EGT for every 1 degree of OAT. Thus, at maximum power, the engine's EGT is 32 degrees higher at an OAT of 20 degrees compared to an OAT of 10 degrees.

In the case of the CFM56-3, constant maximum engine thrust is maintained up to an OAT of 30 degrees centigrade. The power management schedule is then programmed to keep the EGT constant for OATs higher than this 30-degree 'corner point' *(see chart, page 11)*. The EGT is kept constant by reducing engine thrust as OAT rises beyond this point. This process of flat rating provides the engine with some EGT margin at high OATs. EGT margin is the difference between the maximum permitted EGT and the actual EGT of an engine at maximum thrust at the corner-point OAT at sea level conditions *(see chart, page 11)*. In the case of the CFM56-3, the EGT margin is quoted for a standard OAT of 30 degrees centigrade and sea level atmosphere conditions. EGT margin is obviously larger for lower OATs.

The EGT is also lower for lower thrusts, and so lower-rated engines have higher EGT margins. A new CFM56-3 rated at 18,000lbs thrust has an EGT margin of about 116 degrees centigrade at the standard OAT of 30 degrees centigrade. The -3 rated at 20,000lbs thrust has an EGT margin of 92 degrees centigrade, while an engine rated at 22,000lbs thrust has an EGT margin of 65 degrees, and an engine at the highest rating of 23,500lbs thrust has an EGT margin of 45 degrees. The EGT lines of engines with different thrust ratings are parallel *(see chart, page 11)*.

SLOATL

While flat rating keeps EGT constant above an OAT of 30 degrees centigrade, EGT would continue to increase at a constant rate as OAT rises if maximum power were maintained *(see dotted line, chart, page 11)*. The OAT at which EGT reaches the maximum allowed level of 930 degrees centigrade is referred to as the sea level outside air temperature limit (SLOATL), which is the highest sea level OAT at which EGT margin becomes zero at maximum thrust.

SLOATL is calculated by adding the corner-point temperature of 30 degrees centigrade to the engine's EGT margin at standard temperature, divided by the gradient constant of 3.2. A CFM56-3 rated at 23,500lbs thrust with an initial EGT margin of 45 degrees therefore has a SLOATL of 44.06 degrees *(see table, page 11)*. An engine rated at 22,000lbs thrust with an EGT margin of 65 degrees has a SLOATL of 50.3 degrees, an engine rated at 20,000lbs thrust with an EGT margin of 92 degrees has a SLOATL of 58.9 degrees, and an engine rated at 18,500lbs thrust with an EGT margin of 116 degrees has a SLOATL of 66.2 degrees. Engines rated at 22,000lbs and 23,500lbs thrust are clearly more sensitive to high OATs.

An engine's SLOATL is higher than

the corner-point temperature for an engine with positive EGT margin *(see chart, this page)*. Since EGT is actually kept constant above the corner-point temperature by reducing engine thrust, take-offs can be conducted for any OAT above this point while the engine still has EGT margin. By calculating SLOATL, the actual highest permitted thrust setting for a given OAT can be determined.

An engine's EGT margin increases at OATs lower than the corner-point temperature of 30 degrees. The increase in EGT margin is 3.2 degrees for every drop of one degree centigrade in OAT below 30 degrees. An engine will thus have an additional 32 degrees of EGT margin when operating at an OAT of 20 degrees at sea level.

Take-off de-rate

Engines are rarely used at full thrust rating, and usually have a level of de-rate for take-off power, which reduces EGT, and consequently increases EGT margin. EGT reduces by about 3.6 degrees for each 1% de-rate on the CFM56-3. De-rates of 5% and 10% will reduce EGT, and increase EGT margin by about 18 degrees and 36 degrees respectively. De-rating can be used if aircraft take-off weights are less than the permitted maximum take-off weight (MTOW), a long runway is available, or OATs are relatively low. Take-off de-rating prolongs on-wing engine life because of reduced EGT. EGT margin reduces at a rate of about 3.5-4.0 degrees per 1,000EFC, and so an average 5% de-rate during operation can add several thousand EFCs to on-wing intervals.

Engine degradation

Engine turbomachinery deteriorates during operation, as a result of which clearances around the blade tips increase, therefore leading to a rise in EGT, and decrease in EGT margin.

Engines only recover about 70% of their original EGT margin after the first shop visit. The restored EGT margin for an engine rated at 23,500lbs thrust is about 30 degrees, about 40 degrees for a 22,000lbs thrust-rated engine, about 80 degrees for an engine rated at 20,000lbs, and about 90 degrees for an engine rated at 18,500lbs.

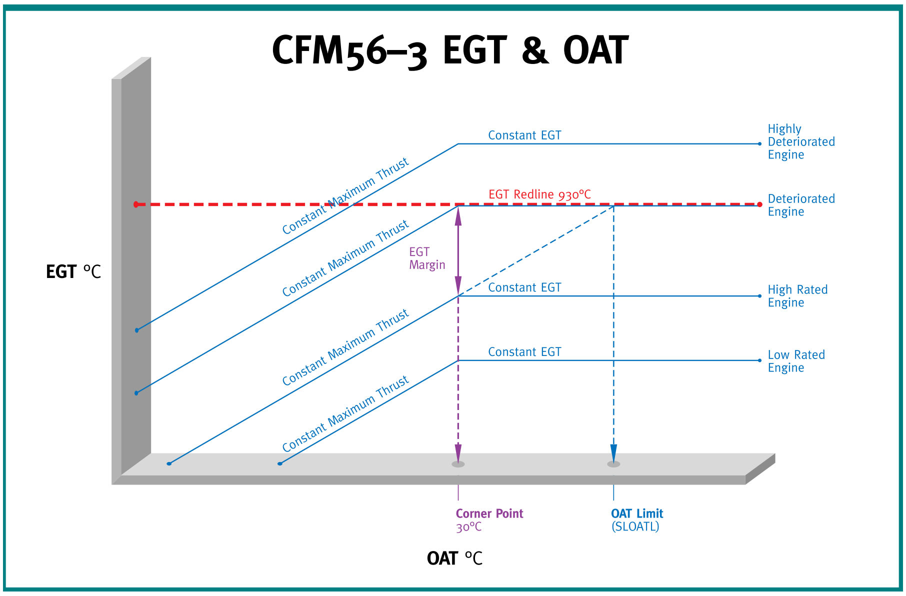
After the first shop visit, engines rated at 23,500lbs and 22,000lbs lose about 15 degrees of EGT margin in the first 2,000EFC on-wing, with EGT margin deteriorating at about four degrees per 1,000EFC. EGT margin will therefore be reduced to about 15 degrees, and SLOATL will fall to 34.7 degrees for the highest-rated engine after 2,000EFC. This engine may only be expected to have an on-wing interval of 5,000-6,000EFC before all EGT margin is used.

An engine rated at 20,000lbs will have an EGT margin of about 25 degrees and SLOATL of 37.8 degrees after the first 2,000EFC following a shop visit. The total interval can be expected to be about 9,000EFC.

The low EGT margins and SLOATLs

CFM56-3 SERIES VARIATION OF AVAILABLE EGT MARGIN & OAT

Engine with EGT margin of 15 degrees centigrade							
SLOATL = 34.69 deg C							
OAT deg C	0	10	20	30	35	40	45
EGT margin deg C	111	79	47	15	N/A		
EGT margin with 5% de-rate							
Engine with EGT margin of 35 degrees centigrade							
SLOATL = 40.94 deg C							
OAT deg C	0	10	20	30	35	40	45
EGT margin deg C	131	99	67	35	19	3	
EGT margin with 5% de-rate							
Engine with EGT margin of 45 degrees centigrade							
SLOATL = 44.06 deg C							
OAT deg C	0	10	20	30	35	40	45
EGT margin deg C	141	109	77	45	29	13	0
EGT margin with 5% de-rate							
Engine with EGT margin of 60 degrees centigrade							
SLOATL = 48.75 deg C							
OAT deg C	0	10	20	30	35	40	45
EGT margin deg C	156	124	92	60	44	28	12
EGT margin with 5% de-rate							



There are large differences in the EGT margin between CFM56-3s rated at 18,500lbs thrust and those rated at 22,000lbs & 23,500lbs thrust. Higher rated engines have EGT margins of 30-40 degrees centigrade. This can severely limit on-wing removal intervals, and so all possible measures should be taken to maximise EGT margin and minimise its rate of deterioration.

of these high-rated engines give a strong incentive for installing CFMI's advanced upgrade kit, which improves EGT margin by 15-20 degrees centigrade *(see CFM56-3 Modification programmes, page 13).*

A deteriorated engine with zero EGT margin at the corner-point OAT of 30 degrees also has zero EGT margin for higher OATs, but still has EGT margin at maximum thrust for lower OATs *(see chart, page 11).* The engine can only be rated at maximum power for OATs up to 30 degrees.

An engine with an even higher level of deterioration can have negative EGT margin at the standard OAT of 30 degrees. In this case the SLOATL is less than 30 degrees *(see chart, page 11).* The engine can still have some EGT margin at maximum power for low OATs, however *(see chart, page 11).*

EGT margin vs OAT

Available EGT margins at maximum thrust for different OATs and SLOATLs for several standard EGT margins can be calculated. Available EGT margins for take-off de-rates of 5% can also be approximated *(see table, page 11).*

A new CFM56-3 rated at 23,500lbs thrust and an EGT margin of about 45 degrees will have zero available margin at a SLOATL of 44 degrees, but will have an available margin of about 77 degrees at an OAT of 20 degrees *(see table, page 11).* It will only have a margin of about 13 degrees at OAT of 40 degrees, one of the highest temperatures an aircraft is likely to experience. EGT margins are increased where a 5% de-rate is possible.

A deteriorated engine with an EGT margin of 35 degrees will have a SLOATL of about 41 degrees, and so will only have an available margin of about 3 degrees at an OAT of 40 degrees. The available margin will increase to about 21 degrees, however, with a 5% de-rate. This point illustrates the need for engines operating in hot environments, with OATs of about 40 degrees, to be removed as a result of performance degradation, even though they have 35-50 degrees of EGT margin remaining.

In the other extreme, an engine with an EGT margin of 45 degrees has an available margin of 77 degrees for an OAT of 20 degrees, the margin also increasing with take-off de-rate. An engine operating in a cool environment of about 10 degrees will have an EGT margin of more than 100 degrees at maximum power.

Lower-rated engines with an EGT margin of 60 degrees will have an available margin of about 90 degrees when operating at an OAT of about 20 degrees.

The variation of available EGT margin with OAT, take-off de-rate and thrust rating means that lower-rated engines have relatively high EGT margins and SLOATLs. This means they will be able to use maximum power, even in hot operating conditions. Low-rated engines also have high EGT margins in moderate climates *(see table, page 11)*, and also still have available margins of 28-45 degrees in the hottest conditions. This means they can achieve relatively long on-wing intervals for most operating temperatures.

Engines with low EGT margins of about 35 degrees will be restricted to maximum power SLOATLs of about 40 degrees. The SLOATL will fall to about 35 degrees and then still further as EGT margins deteriorate in operation *(see table, page 11).* The relatively low EGT margins also mean that their on-wing intervals will be limited by performance degradation.

CFM56-3 production

More than 4,500 CFM56-3s were produced, powering more than 1,900 737-300/-400/-500s still in service and providing spare engine back-up. The -3C1, introduced in 1987, is the most numerous, powering about 900 operational aircraft of all three variants.

The -3C1 fleet is split between all three 737 models, and 390 are used on the 737-400. Only 22 of these aircraft are in North America, while 178 aircraft are based in Europe.

There are 167 aircraft in the Asia Pacific and China, another 14 aircraft in Africa and seven in Latin America. These 188 aircraft are powered by the -3C1, which is capable of a thrust rating of 23,500lbs, and is most sensitive to high OATs and low EGT margins. Only a small number are operated in the Middle East and India, regions that experience some of the highest peak and average ambient temperatures in the world.

The -3B1, the first into service, is the second most numerous variant, powering a total of more than 700 aircraft. Although the engine is rated at 18,500lbs and 20,000lbs thrust for the 737-500 and -300, the -3B1 also powers a small number of -400s for Alaska Airlines. The majority of -3B1s are used on the 737-300, since most -500s are equipped with the -3C1.

The -3B2 is used on only just under 300 aircraft, split between 235 -300s, and 64 737-400s. AC

CFM56-3 modification programmes

The CFM56-3 operates at four different thrust ratings, and in various operating climates and temperatures. Modification programmes are available to increase EGT margin, improve on-wing life and reduce maintenance costs.

There are three major upgrade kits for the CFM56-3: the advanced upgrade kit; and two sub-kits of the advanced upgrade. The first of the sub-kits comprises the enhanced performance upgrade, which is an improvement package for the compressor. The second is the enhanced durability kit for the turbine.

Upgrade package

In 1999 CFMI wanted to introduce the technology that was used in the -7B series to the -3 series. This involved the development of a 3-D aerodynamic package, where airfoils were redesigned for the high-pressure compressor (HPC).

The turbine's durability was improved by increasing the cooling of high-pressure turbine (HPT) blades and enhancing the design of the HPT blade tips.

The effect of the 3-D airfoils in the HPC was to increase exhaust gas temperature (EGT) margin by 20 degrees centigrade, compared to a target improvement of 15 degrees.

A new material, N5, was used in the HPT nozzle. CFMI claims that the effect of this, combined with better HPT blade cooling and an improved tip shelf, was to reduce the scrap rate of HPT blades by about 50%. The scrap and replacement rate for HPT blades is 30-40% at the first shop visit. Another 30% of blades are replaced at the subsequent shop visit. The upgrades to the turbine have therefore increased the life of HPT blades by 50%.

The advanced upgrade comprises the HPC and HPT improvements together as one package. These are known as the 'time on-wing' upgrade. CFMI claims that total maintenance and fuel costs are reduced by 20% when both the HPC and HPT improvements are incorporated in an engine. The effect of the 3-D aerodynamic blades is to improve fuel burn by 1.6-1.8%. A 737-300 operating on a route with a still air distance of about 550nm would burn about 1,400 US Gallons. The improvement in fuel burn would save about 24 US Gallons on the trip, and at an annual utilisation of 1,700 flight cycles per year would result in a total saving of about 41,000 US Gallons. At current full prices this would be equal to about $80,000 per year per aircraft.

Enhanced performance kit

The enhanced performance kit mainly relates to upgrades in the HPC. The 3-D aerodynamic blades deliver most of the increased EGT margin that is provided by the advanced upgrade package. The enhanced package increases EGT margin by 15 degrees centigrade. Given that EGT margin deterioration rates on the CFM56-3 are 3.0-4.0 degrees per 1,000EFC after the first 2,000EFC since shop visit, the additional EGT margin will allow the engine to stay on-wing for another 3,500-4,000EFC. This will be equal to 5,000-6,000EFH at most operators' engine flight cycle times, and so be an element in reducing maintenance costs per engine flight hour.

The increase in EGT margin will be particularly beneficial to airlines operating in hot climates. The EGT margins of engines rated at 23,500lbs thrust are only about 30 degrees after the first shop visit, and so the engines have a sea level outside temperature limit (SLOATL) of about 39.4 degrees *(see CFM56-3 specifications, page 10)*. The EGT margin also reduces by about 15 degrees during the first 2,000EFC on-wing, and the SLOATL goes down to about 34.7 degrees. Similarly, the EGT margin of engines rated at 22,000lbs thrust is only about 40 degrees, and the SLOATL is only 42.5 degrees. The EGT margin is reduced to about 25 degrees after the first 2,000EFC on-wing, and so the SLOATL is reduced to about 37.8 degrees.

This illustrates how engines with high thrust ratings can benefit from the HPC enhancement kit, which increases EGT

CFM56-3s rated at 22,000lbs & 23,500lbs thrust that operate in high temperatures have the most to gain from the performance upgrade modifications. These increase EGT margin and so improve on-wing life.

Southwest was one of the first airlines to install the full upgrade kit for the CFM56-3. It expects on-wing interval to increase by about 2,900EFC as a consequence.

margin by 15 degrees. This would allow these higher-rated engines to operate with fewer take-off power restrictions and achieve longer on-wing intervals.

The catalogue price for the parts for the enhanced performance kit is $485,000, and discounts are provided for volume purchases. The kit is installed during a shop visit, and usually when HPC parts are expected to be scrapped. The net cost is thus less than the list price of $485,000 when the cost of installing the regular HPC airfoils is considered. CFMI claims that the incremental cost of installing the new 3-D aerodynamic blades is about $300,000. Moreover, this cost is only incurred once by the operator, because the catalogue price of the 3-D aerodynamic HPC blades is the same as the price of the 2-D aerodynamic blades. The costs of replacing 2-D and 3-D blades at subsequent shop visits are the same.

Turbine upgrade

The turbine upgrade kit only includes the use of N5 material on the HPT nozzles, unlike the full upgrade kit, which also includes improved HPT blade shrouds, as well as the full upgrades on the HPC.

The catalogue price for the turbine upgrade kit is $370,000. Like the enhanced performance kit, the new turbine nozzles will be installed at a shop visit when the old material is due for replacement and so the kit will have an incremental cost over the replacement of the original nozzle materials. The new materials can extend the on-wing life of the engine, and they have the same catalogue price as the original nozzle materials.

Full upgrade kit

The catalogue price of the full upgrade kit is $1.4 million, which includes the full HPC upgrade, the HPT blade shroud upgrade and new HPT nozzle material.

As with the two smaller upgrade kits, CFMI claims that the full kit has a lower incremental cost than the list price of $1.4 million, since the parts being installed are replacing worn parts. CFMI puts this incremental cost at about $400,000.

The benefit of the upgrade is that on-wing removal intervals are extended. CFMI reports that some operators are achieving increases in the order of 4,000EFC, while others are recording increases of up to 8,000EFC. At average EFC times of about 1.5EFH, the installation of the full kit is increasing intervals by 6,000-12,000EFH.

This has to be considered against typical shop visit costs and on-wing intervals of unmodified engines. A mature engine rated at 22,000lbs thrust has a relatively low EGT margin of 45 degrees centigrade following a shop visit, and can be expected to have an on-wing life of 6,000-7,500EFC. A typical core performance restoration has a cost of $900,000, while a shop visit that also includes a workscope on the low-pressure turbine (LPT) or fan/booster section will cost in the region of $1.15 million *(see CFM56-3 maintenance analysis & budget, page 18)*. An unmodified engine therefore has a shop visit reserve of $120-176 per EFC, depending on the workscope performed and the interval.

Extending the interval by about 4,000EFC, through increasing EGT margin, would reduce the reserves to $80-110 per EFC on the basis that the costs of the shop visit were unchanged. This does not take into account the initial cost of installing the kit. If the net cost is taken at $400,000 and amortised over the first two shop visits, which is the probable interval that the new parts would require replacement, it would have an amortisation rate of $27-33 per EFC. The net saving would therefore be $13-33 per EFC over these first two shop visit intervals. This would be equal to a six or seven year period. The saving after this would be up to $55 per EFC. Fuel savings should also be considered.

Operator experience

Southwest Airlines was one of the first airlines to install the full upgrade kit in its fleet. All of its aircraft are rated at 20,000lbs thrust, and the unmodified engines achieve a mature interval of 14,000EFC between shop visits. This interval is one of the highest achieved by all CFM56-3 operators, despite the high temperatures in which Southwest operates. The interval is partially attributed to the high level of take-off de-rates used by Southwest's pilots.

Southwest started modifying its first -3C1 engines about two years ago with the full upgrade kit, and has so far modified about half its fleet. "Prior to the kit we were installing the 'new core' kit, which was a previous modification programme being offered by CFMI," explains Johnny Holley, manager of powerplant engineering at Southwest. "The full upgrade kit has increased EGT margins by 12-15 degrees Fahrenheit (about 5-7 degrees centigrade) compared to unmodified 2-D engines.

"Even though we have been achieving about 14,000EFC on-wing with the engines prior to the modification, we have found that the modified 3-D engines have been losing EGT margin at a slightly lower rate," continues Holley. "Combined with the increased EGT margin this means that we are predicting engines will remain on-wing for about 16 months longer than unmodified engines. This is equal to about 2,900EFC at our rates of utilisation."

Holley also explains that Southwest conducted an analysis on the upgrade kit, and found that it predicted no net increase in the cost of engine material and parts between modified and unmodified engines when the annual rise of list prices was considered. AC

CFM56-3 fuel burn performance

Analysis of the fuel burn performance of six MTOW variants of the 737-300, six variants of the 737-400 and five variants of the -500 reveals consistent fuel burn rates per seat.

The CFM56-3's sole application is the 737-300/-400/-500. The -3C1 can be utilised for all three aircraft, and the -3B1 and -3B2 on two *(see CFM56-3 series specifications, page 10)*. There are six maximum take-off weight (MTOW) and fuel-capacity variants of the 737-300 and -400 models, and five variants of the -500 model. The range of different engine types for each main aircraft variant means that there are several airframe-engine combinations.

The fuel-burn performance of the main airframe-engine combinations that dominate the fleet has been analysed. The MTOW, engine variant and actual take-off weight of the aircraft analysed are summarised *(see table, page 16)*.

Aircraft analysed

Five models of the 737-500 have been evaluated. There are three gross weights, all of which have been analysed with the CFM56-3B1 rated at 18,500lbs thrust. Aircraft with the two higher gross weights of 124,500lbs and 133,500lbs have been analysed with the CFM56-3C1 rated at 20,000lbs thrust *(see table, page 16)*.

Six models of the 737-300 have been analysed. Aircraft with the three lower gross weights have been analysed with the CFM56-3B1 rated at 20,000lbs. The aircraft with the intermediate MTOW of 137,000lbs has been analysed with CFM56-3B2 engines rated at 22,000lbs thrust, while aircraft with the two highest gross weights of 138,500lbs and 139,500lbs have been analysed with the CFM56-3C1 engines also rated at 22,000lbs thrust *(see table, page 16)*.

Six MTOW variants of the 737-400 have been examined. The three aircraft with the lowest MTOWs have been analysed with the CFM56-3B2 engine rated at 22,000lbs thrust, while the three with the highest MTOWs of 142,500lbs, 143,500lbs and 150,000lbs have been analysed with the CFM56-3C1 engine rated at 23,500lbs *(see table, page 16)*.

Route analysed

The route used to analyse these different aircraft is London Heathrow (LHR)-Munich, and aircraft performance has been analysed in both directions to illustrate the effects of wind speed and direction on the actual distance flown, also referred to as equivalent still air distance (ESAD). The LHR-Munich route is typical of many 737 operations, since it has a flight time of 85-100 minutes, depending on direction of travel.

Actual flight time depends on wind speed and direction, and 85% annual Boeing winds and temperatures for the month of April have been used in the flight plans performed by Navtech. The flight plans have been made for the aircraft with a long-range cruise speed of Mach 0.74. The aircraft have been assumed to have full passenger payloads of: 108 for the 737-500; 128 for the -300; and 138 for the -400 *(see table, page 16)*. The standard weight for each passenger plus baggage is 220lbs. The payload for each aircraft is therefore: 23,760lbs for the 737-500; 28,160lbs for the -300; and 30,360lbs for the -400.

On the LHR-Munich route the aircraft experience a small headwind of 2 knots *(see table, page 16)*, which increases the distance flown from a tracked distance of 525nm to an ESAD of 528nm *(see table, page 16)*. This route has a flight time of 86 minutes for the -500 and -300, and 85 minutes for the -400. A taxi time of 20 minutes has been added as standard, and this section of the trip has a fuel burn of 2,000lbs. Block time is 103-106 minutes *(see table, page 16)*.

On the Munich-LHR route the aircraft experience a 53-knot headwind, which increases the distance flown to an ESAD of 630nm. In this case the flight time is 100 minutes for the -500, 97 minutes for the -300 and 99 minutes for the -400. Block times are correspondingly about 20 minutes longer.

The 737-300 and -400 have similar fuel burns per passenger. There are six MTOWs for each variant, the rate of fuel burn per seat for each is similar.

FUEL BURN PERFORMANCE OF CFM56-3 SERIES

Aircraft variant	MTOW lbs	Take-off weight lbs	Engine model	Block Fuel USG	Block time mins	Passenger payload	Fuel USG per passenger	ESAD nm	Wind speed
London-Munich									
737-500	115,500	90,842	CFM56-3B1	1,258	106	108	11.65	528	-2
737-500	124,500	97,564	CFM56-3B1	1,306	106	108	12.10	528	-2
737-500	133,500	104,254	CFM56-3B1	1,351	106	108	12.51	528	-2
737-500	124,500	96,850	CFM56-3C1	1,302	107	108	12.05	528	-2
737-500	133,500	102,989	CFM56-3C1	1,348	107	108	12.48	528	-2
737-300	124,500	100,671	CFM56-3B1	1,345	103	128	10.50	528	-2
737-300	130,000	103,730	CFM56-3B1	1,365	103	128	10.66	528	-2
737-300	135,000	106,121	CFM56-3B1	1,381	103	128	10.79	528	-2
737-300	137,000	110,397	CFM56-3B2	1,394	105	128	10.89	528	-2
737-300	138,500	108,451	CFM56-3C1	1,387	104	128	10.84	528	-2
737-300	139,500	109,552	CFM56-3C1	1,397	104	128	10.92	528	-2
737-400	138,500	115,719	CFM56-3B2	1,438	105	138	10.42	528	-2
737-400	142,400	117,141	CFM56-3B2	1,458	105	138	10.57	528	-2
737-400	150,000	122,501	CFM56-3B2	1,512	105	138	10.96	528	-2
737-400	142,500	116,690	CFM56-3C1	1,472	105	138	10.67	528	-2
737-400	143,500	114,149	CFM56-3C1	1,448	105	138	10.49	528	-2
737-400	150,000	121,244	CFM56-3C1	1,506	105	138	10.91	528	-2
Munich-London									
737-500	115,500	91,813	CFM56-3B1	1,414	120	108	13.10	631	-53
737-500	124,500	98,541	CFM56-3B1	1,464	120	108	13.55	631	-53
737-500	133,500	105,209	CFM56-3B1	1,515	120	108	14.03	631	-53
737-500	124,500	97,789	CFM56-3C1	1,456	121	108	13.48	631	-53
737-500	133,500	103,920	CFM56-3C1	1,506	121	108	13.94	631	-53
737-300	124,500	101,599	CFM56-3B1	1,495	117	128	11.68	628	-53
737-300	130,000	104,579	CFM56-3B1	1,513	117	128	11.82	628	-53
737-300	135,000	107,008	CFM56-3B1	1,541	117	128	12.04	628	-53
737-300	137,000	111,325	CFM56-3B2	1,557	119	128	12.16	630	-53
737-300	138,500	109,447	CFM56-3C1	1,551	118	128	12.12	630	-53
737-300	139,500	110,526	CFM56-3C1	1,560	118	128	12.19	630	-53
737-400	138,500	116,555	CFM56-3B2	1,617	119	138	11.72	630	-53
737-400	142,400	117,873	CFM56-3B2	1,631	119	138	11.82	630	-53
737-400	150,000	123,126	CFM56-3B2	1,683	119	138	12.19	630	-53
737-400	142,500	117,380	CFM56-3C1	1,638	119	138	11.87	630	-53
737-400	143,500	114,953	CFM56-3C1	1,622	119	138	11.76	630	-53
737-400	150,000	121,973	CFM56-3C1	1,679	119	138	12.16	630	-53

Source: Navtech

Aircraft fuel burns

The fuel burn for each aircraft, and the consequent burn per passenger, are shown *(see table, this page)*. The data show that for all three aircraft variants the fuel burn per passenger increases for higher gross weight aircraft models and actual take-off weights. Although none of the aircraft under consideration had an actual take-off weight equal to their MTOW, take-off weights were higher for the aircraft with higher certified MTOWs. The higher fuel burns for these aircraft are explained by their higher operating empty weights (OEWs), which contribute to the higher actual take-off weights.

Although the fuel burn per passenger is higher for aircraft with higher take-off weights, the increase in fuel used per passenger for heavier aircraft compared to lighter aircraft is smaller than the increase in take-off weight.

The fuel used varies from 10.42 to 10.96 USG per passenger for the 737-400. This is equal to about $20-22 per passenger at current fuel prices. The difference in fuel used on the heaviest 737-400 with CFM56-3C1 and lightest -400 model with -3B2 engines *(see table, this page)* is only about 0.5 USG, equal to about $1 in fuel cost.

Unsurprisingly, the 737-500 has the highest fuel burn per passenger compared to the -300 and -400 models. The -500's fuel burn is 11-15% higher than the -300 and -400, which have close fuel burn performance. This puts the 737-500's fuel cost per passenger about $2-3 higher than for the 737-300/-400. This is explained by the -500's high weight per passenger. The 737-300 has almost identical fuel burns per passenger to the -400.

This clearly demonstrates that the CFM56-3 series has consistent fuel burn and consumption for all its three main variants, and four thrust ratings across the various MTOW models of the three aircraft types it powers. The only major variable affecting fuel burn per passenger carried is the actual take-off weight, which is most influenced by the aircraft's OEW. AC

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 to 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 2.0-3.0FH. 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

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.

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.

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.

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 workscopes 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

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.

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 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	485,00
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	1,240,00
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	1,240,00
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

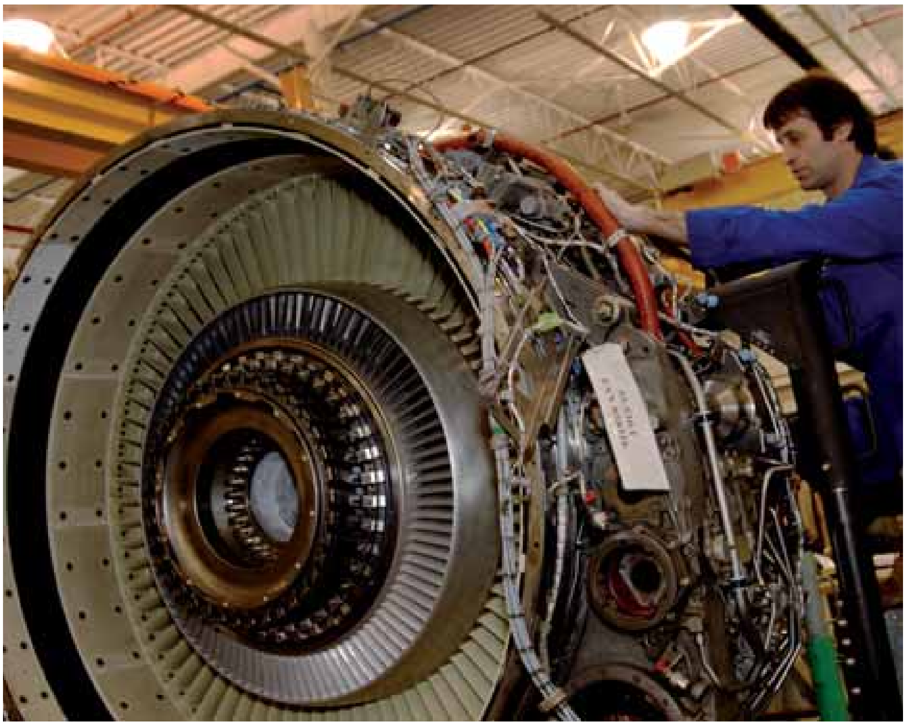
As previously described, certain shop visit techniques can be employed to increase subsequent EGT margin and so prolong the following on-wing life. "Work on the core modules provides the best financial return in terms of recovering EGT margin and on-wing time. Work on the LPT can add another 5 or 6 degrees 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,



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

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 re-sale 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 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

CFM56-3 values & aftermarket activity

CFM56-3 lease rates & values have improved following the re-activation of stored 737 Classics. Factors affecting values & rates are examined.

The aftermarket for the CFM56-3 family of powerplants began rebounding early in 2004, after being depressed in 2002/2003. The supply of engines has shrunk as demand has strengthened, but long-term lease rates are unlikely to see their 2000 highs again.

Chapter 11-driven retirements of large numbers of 737-300s/-400s/-500s by United Airlines and US Airways in 2002 and 2003 made many run-out CFM56-3 engines available. "The CFM56-3B1 variant was particularly favoured then, as it is now, for tear-down," says Austin Willis, president of California-based jet engine parts and trading company JT Power. "Although the -3B1 is cheaper to buy than the 22,500lbs thrust -3B2 and the 23,500lbs thrust -3C1, because it offers less thrust, it also shares many of the same life limited parts (LLPs) as its siblings, and also most of the same non-limited-life components."

The 22,500lb-thrust CFM56-3B2 is also a more attractive target for tear-down specialists than the CFM56-3C1, the highest-thrust member of the family.

"All CFM56-3s built from 1994 until production ceased in 1999 were the -3C1 variant," says Andrew Pearce, director of Dublin-based Macquarie Aviation Capital. "Although the engines sold as -3C1s, rather than -3B1s or -3B2s, they continued to incorporate some key differences such as a reset fan blade angle, turbine-blade cooling holes, a timing kit and a steel compressor case. CFM International relied on operating licences to provide most of the thrust (and price) differentiation among the three variants. As a result of this build policy, later-build -3B1s and -3B2s can act as a particularly valuable source of replacement parts for all three CFM56-3 variants, even though they originally cost less." Pearce estimates that buyers of new CFM56-3s paid the manufacturer about $300,000 extra for each thrust rating increase.

An additional incentive to buy the two lower thrust variants is that the cycle lives of their rotating LLPs depreciate at a slower rate than do the same LLP part numbers in -3C1s, because CFM56-3B1s and -B2s operate at lower exhaust gas temperatures (EGTs) and higher EGT margins than do -C1s. Pearce estimates that for each cycle a rotating part depreciates in a -3B1 or a -3B2, the same part depreciates at a rate of 1.33 cycles in a -3C1 operated to its maximum thrust.

"This difference can create up to a couple of years of extra flying with a -3B1," says Tom MacAleavey, senior vice president of sales and marketing for the Americas, Europe and the Middle East for Willis Lease Finance Corporation.

Overall, younger and higher-thrust CFM56-3s have better residual value performance than older ones because they remain more attractive to airlines that are interested in continuing to operate the engines. Willis notes that older engines tend to have accumulated more cycles and wear in non-replaced parts, such as turbine cases, than newer ones. They also often require larger and more expensive repairs if purchased for continued operation. Willis also comments that buyers of engines for tear-down find that non-replaced parts in older engines are scrapped at a higher rate than parts in younger engines. Parts cannot be repaired three times, so those that have already been repaired twice must be scrapped. The older the engine, the more likely it is that its non-rotating parts have been repaired more than once.

Jon Sharp, chief executive of Engine Lease Finance, notes that there are two leasing markets for the CFM56-3, which are mainly counter-cyclical to each other: the long-term market for leases of one to five years; and the short-term market for leases lasting less than a year.

The short-term 'spot' market, in which parts companies often participate, looks to generate revenue from engine leases of six months to a year. Owners seek to obtain rental revenue and maintenance reserves from engines that have some 'green time' remaining until their next scheduled shop visit, when they will be torn down. Non-replaced parts with acceptable wear and LLPs with remaining life are sold.

"Conditions in the short-term leasing market are determined by engine supply and demand," says Sharp. "If 10 aircraft are suddenly parked, 20 engines will immediately become available, thereby causing the bottom to drop out of values and short-term lease rates." Willis notes that in 2002 and 2003, when engine supply was plentiful, parts companies were able to buy CFM56-3B1s and -3B2s cheaply because the market was valuing stored aircraft at purely the tear-down value of their engines.

Market conditions are different today. Virtually every 737 Classic not scrapped during the recession has been pressed back into service, and lease rates and market values for this aircraft have now soared. "Availability of engines for tear-down or short-term lease has become so tight that there is now a perceived shortage of engines," says MacAleavey.

Combining estimates given by each of the executives contacted, it appears that short-term lease rates for a CFM56-3C1 are $1,600-1,800 per day and, according to MacAleavey, can exceed $50,000 per month. A typical short-term daily rate for a -3B2 is $1,400-1,600 and $1,300-1,500 for a -3B1.

These ranges apply to any CFM56-3 engine with more than three months remaining to its next shop visit. To obtain maintenance reserve payments to help pay for a shop visit or for repair of torn-down parts, short-term lessors sometimes offer airlines pricing incentives to take an engine on a 'stub lease' when the engine has less than three months remaining to its next shop visit. Willis comments that such powerplants are often unattractive to lessees, because of the work involved in swapping out the engine after a short period on-wing and the unanticipated problems that often occur as an engine approaches a shop visit. A 30% lease-rate discount for a stub lease is normal.

"The long-term lease market is fundamentally different from the short-term market," says Sharp. "The rate offered by a lessor depends on four factors: the lessor's cost of funds; its depreciation rate for the engine; its overheads; and the level of competition in the market. Competition has become intense with about 10 new competitors entering the market since 2002.

"Long-term lease rate factors for engines today tend to be lower than those for aircraft," says Sharp. Rates for engines typically fall to 0.75-1.0% per month in terms of current market value. According to MacAleavey, long-term lease rates for the popular CFM56-3C1 variant reached $60,000 a month before the onset of recession in 2001. Even after recession hit, lessors were able for a while to persuade airlines to take a short-term lease at $60,000 a month, rather than spend up to $2 million on a complete overhaul on a run-out engine before re-leasing it. This was a boom time for parts companies looking to buy and tear down run-out CFM56-3s, as airlines and lessors shed their run-out engines in numbers.

"Airlines are now having to perform their deferred overhauls. While nobody has parked an aircraft for lack of an engine, people are not confident about the future availability of CFM56-3s for their 737 Classics," says MacAleavey. He says that monthly rentals for leases of six months to one year on -3C1s have risen to $42,000-45,000. Pearce says longer-term rates are in the $35,000-40,000 range, but MacAleavey notes that with a few exceptions in Latin America, airlines are not contracting new leases of much more than six months on CFM56-3s.

Despite an improvement in long-term lease rates, it is clear to MacAleavey that they are unlikely ever again to reach $60,000 a month, even for -3C1s. "Most 737 Classics are back in service and you have to assume they have gone back with a lot of time on their spare engines," he says. Airlines have had time in the past two years to overhaul their powerplants. Demand for long-term leases of CFM56-3s has probably peaked.

The situation affecting trading values is subject to similar factors. Purchase prices paid for run-out engines are dependent on the availability and value of parts with remaining lives, and the maintenance reserves that can be collected before the next shop visit.

Willis says that parts companies today would pay about $700,000 for a 'really weak' -3B1 engine for tear-down, but $1.2-1.3 million for one with a 'strong disc stack' in terms of remaining cycle life, and 'more recent parts numbers' on its non-replaceable parts. Pearce says that a 'strong' disc stack would have at least 6,000 cycles remaining, enough for at least three years of continued operation.

MacAleavey suspects parts companies would pay $1.8-2.0 million for a run-out but strong -3C1 in today's market, depending on just how good the engine's condition is. This estimate is a function of availability and the cost of adjusting an engine's non-replaceable parts and the LLPs in its disc stack to half-life condition. This is $1.4-1.5 million in total. This adjustment range implies a current market value of $3.3-3.5 million for a -3C1 in half-life condition. Lessors and traders do provide estimates of $3.4-3.5 million for a half-life -3C1 in today's market. According to MacAleavey, good-condition, half-life CFM56-3B2s and -3B1s would trade for up to $700,000 less, but should still fetch $3 million or a tiny fraction more.

Sharp adds that 60-70% of each engine's total value is accounted for by the operating time the engine has accumulated since its last shop visit, and the total number of cycles the engine has operated since new.

Even though Pearce estimates that a half-life value adjustment is worth $1.4-1.5 million, he stresses this does not imply that a CFM56-3C1 fresh from a shop visit could be sold for $5 million in today's market. Freshly overhauled or repaired engines are worth only about $4 million today, he says. One reason for this is that instead of spending $5 million on an engine freshly zero-timed after a scheduled shop visit (less an adjustment for test-cell running time), airlines and lessors would rather buy a half-life engine, run it down on-wing and then control the engine's rebuild standard when it next visits the shop.

Another reason for not buying a zero-timed CFM56-3 is that even though examples of the 737 Classic family are expected to remain in service for at least another 20 years, the CFM56-3 is no longer in volume production. Today may thus well represent the top of the future market for the CFM56-3 family as it gradually enters its declining years.

Sharp suggests as much. "Virtually all remaining CFM56-3-powered 737s are back in service. Mass retirements of 737 Classics and their CFM56-3 engines are expected to start in 2015," he says. Engine Lease Finance plans to end its CFM56-3 exposure several years before that. AC