# CFM56-5A/-5B maintenance analysis & budget

**The CFM56-5A/-5B series has a large number of variants. The removal patterns and maintenance of the three main groups are examined.**

The CFM56-5A and -5B series are operated in fleets of 1,040 and 2,300 engines each. These collectively power 1,730 A320 family aircraft, equal to 57% of the global A320 family fleet. A further 640 A320s are on order with the CFM56-5B as the specified engine choice. The A320 will also continue to sell for at least another seven years before a replacement is launched, meaning that the CFM56-5A/-5B fleet is likely to exceed 6,000 units before A320 production is ceased.

The A320 family is operated globally, but the majority of aircraft are used in Europe. The second largest numbers are utilised by carriers in North America. An increasing number are also being used in China, the Asia Pacific and the Indian sub-continent, where high traffic growth rates are prevalent. Smaller numbers are also used in Africa, the Middle East and Latin America. The CFM56-5A and -5B therefore operate in a wide range of temperatures, which can vary from minus 20 or 25 degrees centigrade in parts of Northern Europe, the US and Canada during the winter, and up to 35-40 degrees centigrade (95 to 104 degrees Fahrenheit) in many parts of the world during the hottest months of the year.

Operating temperature is one factor that affects the maintenance costs of the many -5A and -5B variants. Maintenance costs and reserves are also affected by engine thrust rating, take-off derate, engine flight hour (EFH) to engine flight cycle (EFC) ratio, and previous engine management.

## Engine in operation

Many A320 family aircraft are utilised as short-haul workhorses in Europe and North America, but are also generally used on longer average route lengths than those traditionally flown by narrowbodies. Lionel Maisonneuve, engineer at Total Engine Support (TES) explains that the average EFC time for the -5A and -5B fleets is 1.8EFH. This average disguises the fact that the shortest operations have cycle times of 0.7EFH, while the longest are up to 6.3EFH. The A320 and A321 are now used by many carriers as medium-haul aircraft. "We use our A320 family types across our European network, and many of these routes have flight times exceeding 2.0EFH," says Nuno Jesus, CFM56-5A/-5B powerplant engineering manager at TAP Maintenance & Engineering. "We also use the aircraft on routes from Lisbon to Dakar in Senegal and the Cape Verde Islands off the west African coast. These routes have flight times of about 4.0 hours. We also have domestic Portuguese routes of 30-40 minutes."

Finnair operates a fleet of 29 A321s, A320s and A319s equipped with -5B3, -5B4 and -5B6 engines. "Our fleet of CFM56-5Bs is one of the few fitted with dual annular combustor (DAC) engines," says Tuomo Karhumaki, vice president of the powerplant department at Finnair Technical Services. "We have a mix of -5B3, -5B4 and -5B6 engines for our fleet, and we operate at an average EFC time of 2.0EFH. We experience cooler temperatures than most airlines, often lower than zero degrees centigrade in winter. In summer they average 20 degrees centigrade, although we can experience temperatures of 25 or 30 degrees on some parts of our route network."

The relatively long average cycle time of most operators means that high rates of annual utilisation are also achieved. Compared with annual flight hours (FH) of 2,000-2,200 typically experienced by short-haul aircraft in the past, A320 family aircraft are generating 2,500-3,000FH per year in most cases.

The -5A went into service in 1988 with the first A320s. The first variant, the -5A1, is rated at 25,000lbs thrust. The -5A series was widened to four variants. The highest rated -5A3 at 26,500lbs also powers the A320, while the -5A4 and -5A5 are rated at 22,000lbs thrust and 23,500lbs thrust *(see CFM56-5A/-5B series specifications, page 6)*, and power the smaller A319.

The -5A series did not have the capacity to be developed for the higher thrust ratings that were required for the A321. This led to the development of the -5B, whose main difference over the -5A was an additional low pressure compressor (LPC) stage. This allowed the -5B series to be developed to deliver up to 32,000lbs thrust. The -5A and -5B both have a 68.3-inch diameter fan and single-stage high pressure turbine (HPT).

The -5B has nine different variants with eight different thrust ratings between 21,600lbs and 32,000lbs thrust *(see table, page 18)*. The highest rated variant is the -5B2 at 32,000lbs for the A321, while the


*The CFM56-5A/-5B are now operated in large numbers by a large number of airlines across the globe. The -5B series has high EGT margins, and consequently there is limited shop visit experience of these engines.*

*Most variants of the CFM56-5B series can remain on-wing up to LLP limits, but engines also start to experience mechanical degradation after about 25,000EFH. One particular problem is the wear of high pressure compressor VSV bushings.*

-5B9 is rated at 21,600lbs for the A318. The nine variants have the same engine hardware, and thrust rating is changed via the engine's full authority digital engine control (FADEC). The engine can therefore quickly be re-rated *(see CFM56-5A/-5B specifications, page 6)*. For example the -5B2 can be re-rated after using all its exhaust gas temperature (EGT) margin on the A321 to a lower thrust for the A320 and A319.

There are three main variant groups of the -5B series. The majority of engines are the second group of /P engines, but the /3 engines will be the standard production engines from late 2007. These will have several hardware improvements to reduce fuel consumption and NOx emissions, a higher EGT limit and standard lives for all life limited parts (LLPs) *(see CFM56-5A/-5B specifications, page 6)*.

## EGT margin

EGT margin is an important factor in engine performance. EGT margin deterioration is more significant in engines used on short-haul operations, while mechanical deterioration of engine hardware is experienced after long EFH intervals on-wing.

The initial EGT margin of newly produced engines is generally high for the -5B series compared to the -5A engines.

There are four 'classic' or original variants of the -5A series, three of which have also had a modification that installed specific hardware to allow the engines to run with a higher EGT temperature certification of 915 degrees centigrade. This gives the engine up to a 25 degree higher EGT margin.

The lowest rated -5A4 engine has an installed EGT margin of 55 degrees centigrade, while the -5A4/F has an installed margin of 80 degrees centigrade. The -5A5 has a margin of 50 degrees, and the -5A5/F an EGT margin of 75 degrees. The -5A1 has a margin of 57 degrees, and the -5A1/F a margin of 82 degrees. The -5A3, which has not had the /F upgrade, has an EGT margin of 71 degrees *(see table, page 18)*.

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

EGT margins generally increase with reduced thrust ratings. The -5B4 and -5B7 rated at 27,000lbs have an initial margin of 109 degrees, while the -5B6 rated at 23,500lbs and used to power the A319, has an EGT margin of 145 degrees centigrade. The -5B5 has a new margin of 163 degrees, and the -5B8 and -5B9 at higher ratings have margins of up to 180 degrees *(see table, page 18)*.

The EGT margins are therefore high on most -5B variants, with only the -5B1, -5B2 and -5B3 variants generally experiencing a loss of EGT margin that forces removals for shop visits.

EGT margins, however, are measured at different corner point temperatures. The engine's EGT and EGT margin are kept constant at all outside air temperatures (OATs) above this corner point temperature. This is achieved by the engine's FADEC reducing engine thrust as OAT rises. Thrust is kept constant below the corner point temperature, so EGT margin varies with OAT. EGT changes at a rate of 2.9-3.4 degrees per degree of OAT for the -5A and -5B series.

The corner point temperature is where the EGT is the highest when operating at maximum thrust. An engine with a high corner point temperature will be able to operate at maximum thrust in a higher OAT, compared to an engine with a lower corner point temperature, which will have to operate at less than maximum thrust when experiencing the same OAT.

The corner point temperatures for EGT margin measurement differ for the four -5A and nine -5B variants. The EGT margins and their respective corner point temperatures are summarised *(see CFM56-5A/-5B specifications, page 6)*. The lower rated variants have higher corner point temperatures, as well as higher EGT margins.

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

The -5A4 has a corner point temperature of 45 degrees centigrade (113 degrees Fahrenheit), the -5A5 a corner point of 37 degrees (99 degrees Fahrenheit) and the -5A1 and -5A3 a corner point of 30 degrees centigrade (86 degrees Fahrenheit).

Similarly, the -5B8, -5B9, -5B5, -5B6, -5B7 and -5B4 which power the A318, A319 and the A320 all have corner point temperatures of 45 degrees centigrade. The -5B1, -5B2 and -5B3 have corner point temperatures of 30 degrees.

The implications of this are that A320s equipped with -5A1 and -5A3 engines, and A321s powered by -5B1, -5B2 and -5B3 engines, will have low EGT margins that will limit shop visit intervals.

The drop in engine EGT below the corner point temperature increases the EGT margin available when operating at OATs lower than the corner point.

## Restored EGT margin

Besides the EGT margins of new production engines, operators have to consider the EGT margins of engines

**CFM56-5A & -5B EGT MARGINS**

| Engine variant | -5A3 | -5A1/ -5A1F | -5A5/ -5A5F | -5A4/ -5A4F |
|---|---|---|---|---|
| Thrust lbs | 26,500 | 25,000 | 23,500 | 22,000 |
| Application | A320 | A320 | A319 | A319 |
| Initial EGT margin (deg C) | 71 | 57/82 | 50/75 | 55/80 |
| Restored EGT margin (deg C) | 42-56 | 34-45 49-65 | 30-40 45-60 | 33-44 48-64 |

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

following a shop visit. The margin of the new production engines cannot be reattained, and the percentage of the original margin that can be regained depends on the shop visit workscope. Clearances between blade tips and engine casings, for example, will increase the EGT margin that is recovered, but the rate of initial EGT margin loss that is experienced following a shop visit will generally be high.

Virtually all the -5A series engines have been through their first shop visit, while the first -5B series engines were delivered in 1993. The early produced engines have been removed for at least two shop visits, while later built engines will have only been removed for their first shop visit. The youngest engines will have not yet been removed, which means that the shop visit experience of later built engines is limited.

Maisonneuve estimates that the restored EGT margin following the first shop visit is only 60-80% of the initial margin, depending on the workscope. "Only 60% can be regained if a hot section restoration is carried out, but a higher recovery of 80% can be realised if a full performance restoration is performed. A hot section restoration is usually performed for most engines at the first removal, and then a full performance restoration is usually made at subsequent shop visits. The workscope selected is influenced by the EFH interval, EFH:EFC ratio, as well as the remaining LLP lives, since the EGT margin will affect the on-wing life," explains Maisonneuve.

Jesus explains that the initial shop visits applied to the first engines off the production line were to replace early HPT blades installed in the engines. "These engines then had a second removal interval after which engines reached their LLP limits, and a core performance restoration which resulted in a better EGT margin recovery. Later built engines, with improved HPT blades, experienced longer first intervals. The -5B3 will have an average EGT margin of 40 degrees centigrade following a shop visit, but the scatter around this average will be 20-60 degrees centigrade. The -5B4 engines will have an average margin of 70 degrees, and the -5B5 an average of 130 degrees following a shop visit."

## Take-off de-rate

Engine thrust is often less than the maximum rating at take-off. Take-off thrust de-rate is often applied for moderate temperatures, and when the aircraft is operating at a take-off weight less than maximum and from long runways. It also prolongs on-wing life. The average EFC time of 1.8EFH for many operations means that most aircraft are being flown on routes that are a fraction of their maximum range. "We can apply up to 18% derate in our operation," says Jesus. "We have a mix of -5A1s, -5B3s, -5B4s, -5B5s, and -5B6s in our fleet and we can apply rates of derate ranging from 11.4% to 18.3% in our trans-European operation."

Finnair, which also has an average EFC time of 2.0 EFH, has an average de-rate of about 10%.

The effect of derate on prolonging engine on-wing life can be anticipated using a severity curve, which predicts relative rates of engine deterioration in relation to average EFC time and take-off derate. The severity curve shows that engines operating at an average EFC time of 1.9EFH will have a 10% reduction in severity when increasing de-rate from 5% to 10%, and a further 7% reduction in severity when increasing de-rate to 15%. The same 10% reduction in severity can be experienced for engines with a 5% de-rate, but a longer EFC time of 2.6EFH.

"Data shows that a 6% de-rate can increase on-wing life by 10% compared to zero de-rate, and increasing de-rate to 15% will increase on-wing life by 25%," says Maisonneuve.

## EGT margin deterioration

EGT margin loss is often a prime removal driver for engines operated on short-haul missions. While the average EFC for all operators is 1.8EFH, some airlines have cycles as short as 1.0EFH, while others are as long as 3.0EFH.

The rate of EGT margin deterioration is affected by average EFC time. As with most engine types, the initial loss of EGT margin is highest in the first 500-1,000EFC on-wing following a shop visit. Rates then reduce to a more steady level.

"The -5A3 loses eight degrees of EGT margin per 1,000EFC for the first 2,000EFC on-wing. This rate then slows to three degrees per 1,000EFC thereafter," says Lothar Haertel, propulsion system engineering CFM56-5A at Lufthansa Technik. "The -5A1 has a higher rate of 10-11 degrees per 1,000EFC during the first 2,000EFC on-wing, and the rate reduces to four degrees per 1,000EFC. The lower rated -5A5 has the slowest rate of EGT margin loss. In the first 2,000EFC it loses six degrees of margin per 1,000EFC, and then slows to 2-3 degrees per 1,000EFC."

The -5B1/2/3 engines powering the A321 have the highest rates of EGT margin loss of the -5B series variants. "These average 12-13 degrees centigrade in the first 1,000EFC on-wing, and then reduce to 5-6 degrees per 1,000EFC thereafter," explains Karhumaki. "This means that these engines will have lost 20 degrees of EGT margin after 3,000EFC on wing, which is a lot of the initial margin. This also means that after 6,000EFC on wing the highest rated -5B3 engines will only have 10 degrees of EGT margin left. A -5B3 will therefore lose all its initial margin of 60 degrees after 9,000-11,000EFC in most operations, since the mature rate of EGT margin loss is 3-4 degrees per 1,000EFC." The highest rated -5B3 will lose all its EGT margin before reaching the life limit of the LLPs with the shortest lives. "In the case of all engines except the early production engines, the shortest LLP lives are 15,000EFC. It is expected that performance problems or fully eroded

EGT margin will start to occur before an interval of 15,000EFC is reached," says Jesus. "The -5B3 can normally last for 10,000-11,000EFC before all EGT margin is lost. It is possible for some engines to reach LLP limits before losing all their EGT margin. The engine can, however, be re-rated to a lower thrust for the A320 or A319 and get another 5,000EFC on wing, up to a total time of 15,000EFC, before being removed."

Karhumaki reiterates the value of re-rating the highest rated -5B3 and -5B2 engines to get the maximum possible on-wing intervals. "We test all our engines at the -5B3 rating to see its EGT margin, but we also test them for lower ratings. The EGT margins are higher when the engines are derated, and there are some -5B6 engines that still have margins of 80-100 degrees after having been on wing for several thousand EFC. We re-rate engines used on the A321s after they have used most of the available EGT margin. They last 10,000-12,000EFH, which is 6,000-7,000EFC in our operation. They are then re-rated at 23,000lbs or 27,000lbs and regain about 60 degrees of EGT margin at this point, and can probably last about another 10,000EFH or 6,000EFC."

The lower rated -5B2 and -5B1 engines will lose EGT margin at about the same rate as the -5B3 engines, but the -5B1 and -5B2 engines have higher margins of 115 and 95 degrees centigrade, so they will still have 35-55 degrees of EGT margin left after 9,000EFC on-wing. These engines may therefore be able to reach the shortest LLP limit of 15,000EFC before losing all their EGT margin.

The initial rates of loss for -5B4 engines powering the A320 are similar to the higher rated -5B1/2/3 engines in the first 1,000EFC, but have a lower mature rate of loss. "The EGT margin loss curve is less pronounced than for the higher rated engines, and on average a -5B4 will have lost 38 degrees after 9,000EFC on-wing," says Jesus.

"Initial rates in the first 1,000EFC are slightly lower for -5B5 and -5B6 engines powering the A319s, and are 11-12 degrees," continues Jesus. "Total loss is 16 degrees after 2,000EFC, and reaches 30 degrees after 9,000EFC. Mature rates of loss are 3 degrees per 1,000EFC for these lower rated engines. Moreover, these engines have initial and post shop visit margins in excess of 100 degrees centigrade, so they have enough EGT margin to remain on wing for up to 30,000EFC. This exceeds the life limits of LLPs."

Possible or probable removal intervals that are determined by EGT margin would ideally be matched to LLP lives. LLP lives therefore have to be taken into consideration.

**RANGE OF LLP LIVES FOR ALL CFM56-5A VARIANTS**

| Engine variant | -5A1/ -5A1/F | -5A3 | -5A4/ -5A4/F | -5A5/ -5A5/F |
|---|---|---|---|---|
| Fan disk | 25-30 | 23-30 | 25-30 | 25-30 |
| Booster spool | 22.4-30 | 21.1-30 | 21.1-30 | 21.1-30 |
| Fan shaft | 30 | 30 | 30 | 30 |
| | | | | |
| Front shaft | 20 | 20 | 20 | 20 |
| Stage 1-2 spool | 20 | 20 | 20 | 20 |
| Stage 3 disk | 20 | 20 | 20 | 20 |
| Stage 4-9 spool | 20 | 20 | 20 | 20 |
| Compressor CDP seal | 20 | 20 | 20 | 20 |
| | | | | |
| Front shaft | 20 | 20 | 20 | 20 |
| Front air seal | 8-17.8 | 7.7-17.8 | 8-17.8 | 8-16.7 |
| HPT disk | 9.1-19.5 | 7.1-17.3 | 9.1-17.3 | 9.1-17.3 |
| Rear shaft | 19.5-20 | 18.5-19.5 | 18.5-19.5 | 18.5-19.5 |
| | | | | |
| Stage 1 disk | 25 | 25 | 25 | 25 |
| Stage 2 disk | 25 | 25 | 25 | 25 |
| Stage 3 disk | 25 | 25 | 25 | 25 |
| Stage 4 disk | 25 | 25 | 25 | 25 |
| Shaft | 25 | 25 | 25 | 25 |
| Conical support | 11.3-25 | 25 | 19.8-25 | 19.8-25 |

## Life limited parts

The -5A series has 18 LLPs: three in the fan/booster module, five in the high pressure compressor (HPC) module, four in the HPT, and six in the low pressure turbine (LPT). These 18 parts have a total list price of $1.75 million, split between $375,000 for fan/booster parts, $460,000 for HPC parts, $419,000 for HPT parts and $500,000 for LLP parts.

The -5B series also has 18 LLPs, with the same number in the four main modules as the -5A. The -5B's full set of LLPs has a list price of $1.83 million, split between $406,000 for fan/booster parts, $447,000 for HPC parts, $474,000 for HPT parts and $503,000 for LPT parts.

Certain turbine rear frame and LPT case part numbers also have limited lives in some -5B variants. These are limits between 14,900EFC and 30,000EFC, and their list prices total $404,000.

CFMI's LLP policy is to set target lives of 30,000EFC for LLPs in the fan/booster module, target lives of 20,000EFC in the HPC and HPT modules, and target lives of 25,000EFC in the LPT module. The latest /3 engines, which will start being manufactured in late 2007, will have all their LLPs certified at these targets from the start.

Many of the LLPs of earlier produced engines have lives restricted to less than the target lives. CFMI's objective, however, is to get these restricted lives removed or gradually extended during operational experience. This will be done by testing LLPs removed from leading high time engines, with the aim of extending the lives of the LLPs in most engines before they reach their restricted life limits.

Each LLP can have up to 13 different part numbers. Some part numbers have been introduced after lives on earlier part numbers were continuously restricted. There is a wide range of life limits for each LLP, and the life limit for an individual engine will depend on the part number installed. The range of lives allowed for the various part numbers for each LLP in the -5A and -5B engines is summarised *(see tables, pages 19 & 20)*.

These tables disguise the fact that some LLPs have part numbers with short lives, others have part numbers with long or complete target lives, and there are also some part numbers with a wide range of lives.

The -5A series is relatively simple with just four main variants and only seven variants overall. The LLPs in the fan/booster and LPT modules are all at or close to their target lives of 30,000EFC and 25,000EFC. There are a few part numbers for the fan disk and booster spool which have lives of 21,100-28,600EFC, and a few in the LPT which have lives of 11,300EFC and 19,800EFC, however. All parts in the HPC module have their target lives of 20,000EFC *(see table, this page)*.

The HPT, however, has parts with the most limitations. "The -5A series has had a problem with the front rotating air seal. The part in the first -5A1s had a life of 15,300EFC, but cracks reduced the life to 11,000EFC," explains Haertel. "There are other part numbers with lives as short as 8,000EFC, 9,000EFC and 15,000EFC. The part number with the longest life has a life of 17,800EFC. This particular part

### RANGE OF LLP LIVES FOR ALL CFM56-5B VARIANTS

| Engine variant | -5B1 | -5B2 | -5B3 | -5B4 | -5B5 | -5B6 | -5B7 | -5B8 | -5B9 |
|---|---|---|---|---|---|---|---|---|---|
| Fan disk | 23-25 | 20-23 | 20 | 20-25 | 23-25 | 20-25 | 20-25 | 24.7-25 | 24.7-25 |
| Booster spool | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Fan shaft | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Forward shaft | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Stage 1-2 spool | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Stage 3 disk | 18.2-20 | 18.2-20 | 18.2-20 | 18.2-20 | 18.2-20 | 18.2-20 | 18.2-20 | 18.2-20 | 18.2-20 |
| Stage 4-9 spool | 15.6-20 | 15.6-20 | 20 | 15.6-20 | 15.6-20 | 15.6-20 | 14-20 | 20 | 20 |
| Compressor CDP seal | 17.2-20 | 17.2-20 | 17.2-20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Front shaft | 14.6-20 | 14.3-20 | 14.3-20 | 14.3-20 | 14.6-20 | 14.6-20 | 7.7-20 | 17.6-20 | 17.6-20 |
| Front air seal | 17.7-20 | 17.7-20 | 20 | 17.7-20 | 17.7-20 | 17.7-20 | 7.9-20 | 20 | 20 |
| HPT disk | 14-20 | 14-20 | 15.3-20 | 14-20 | 14-20 | 14-20 | 6.4-20 | 13.1-20 | 13.1-20 |
| Rear shaft | 9.8-20 | 9.8-20 | 12.4-20 | 9.8-20 | 9.8-20 | 9.8-20 | 7.1-20 | 12-20 | 12-20 |
| Stage 1 disk | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Stage 2 disk | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Stage 3 disk | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Stage 4 disk | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Shaft | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Conical support | 15.1-25 | 15.1-25 | 24.9-25 | 15.1-25 | 24.9-25 | 15.1-25 | 24.9-25 | 25 | 25 |

has limited the on-wing intervals achievable by the -5A series engines. With the HPT disk, some part numbers have lives of 7,100EFC and 9,100EFC. Others have longer lives of 17,300EFC or 19,500EFC."

The -5B series is more complex. The six variants of the original -5B engines have mainly part numbers in the fan/booster, LPT modules and HPC modules that are close to their target lives. There are parts in the HPC that are limited to 15,600EFC, however. Most HPT parts have lives close to the target of 20,000EFC, but some part numbers for the rear shaft are limited to 9,800EFC.

There are four sub-variants of the /P group of engines. Most part numbers for the fan disk have lives of 20,000-25,000EFC. All other part numbers in the fan/booster module have lives of 30,000EFC. Similarly, all part numbers for LPT parts have lives of 25,000EFC. Most HPC part numbers have lives of 20,000EFC, but a few are limited to 17,200-18,200EFC *(see table, this page)*. The HPT is the limiting module, with some part numbers having lives as short as 12,000-15,300EFC, and presenting a probable limitation to on-wing life for engines with these parts installed.

The caveat to the currently restricted part numbers is that they may yet have their lives extended. "CFMI will publish a notice that lists a group of part numbers, their current and projected life limit, and the expected date of life limit extension," explains Kleinhans, propulsion systems engineering CFM56-5B at Lufthansa Technik. The /3 engines will all have parts that are at the target lives.

## Removal causes & intervals

### -5A series

The -5A series has been limited by the LLP limits of the front rotating air seal and HPT disk. Some part numbers of the front rotating air seal had their limit reduced to 11,000EFC in the -5A1, 7,700EFC in the -5A3 and 9,100EFC in the -5A5. Other part numbers for this part also have restricted life limits.

"The -5A series has good EGT margin, but the LLP lives and other problems like HPT blades are still a major removal cause," says Haertel. The restored EGT margin for -5A1s and -5A5s is 45-52 degrees, and for -5A3s is 62-67 degrees. This should allow the -5A1 to remain on-wing for up to 9,000EFC, the -5A3 for up to 17,000EFC, and the -5A5 for up to 13,000EFC.

The -5A has faced other difficulties, however. Most -5As were built between 1987 and 1995, although a small number were produced up to 2003. Most engines accumulate 1,700EFC per year, so virtually all -5As will have been through their first shop visit, and most will have been through their second and third removals.

"Besides the limits imposed by the two LLPs, the early -5As had a problem with the HPT nozzle guide vanes, and our first -5A1s only lasted for 4,000EFH on-wing," says Haertel. "The HPT blade has also been a consistent problem, with successive blades having short lives. The original HPT blade in the original engines suffered cracks in the airfoil trailing edge cooling air exit slot just above the blade platform. These HPT blades were replaced with a second generation blade which utilised a DSR142 material. These also experienced problems, however, so a third generation HPT blade was introduced with a platinum-aluminium coating, although the on-wing life was limited to 14,400EFC, as recommended by CFMI. Several blade fractures had occurred and a service bulletin (SB) cancelled all repairs.

"There is now a fourth generation HPT blade, which uses an N5 single crystal material. These are expected to have an on-wing life of 10,000-12,000EFH, after which a repair to the blades will allow a second run of similar duration. A third run may be possible following a second repair, but I think it is more likely that the blades will have to be replaced after the second removal," continues Haertel. "This interval will be an extension of the current mature interval, which is in the region of 8,000-9,000EFH. This is equal to 6,800-8,200EFC in our operation at an average EFC time of 1.1-1.2EFH."

Maisonneuve makes the point that -5As operating on average EFC times up to 2.0EFH can remain on wing up to their respective forward air seal LLP limits of 7,700-11,000EFC. This is equal to 15,500-22,000EFH for engines operating at 2.0EFH per EFC. Even when operating at longer average cycle times, the time on wing is not expected to exceed 22,000EFH for the -5A1, -5A4 and -5A5 engines due to deterioration of engine hardware. The highest rated -5A3


*Finnair is in operator that practices re-rating of engines between different thrust ratings. It re-rates -5B3 engines used on the A321 to lower ratings to then be used on the A320 or A319. This allows them to accumulate about 6,000EFC while operating on the A321, and then achieve another 6,000EFC on the A320 or A319.*

engines average 15,500EFH on wing.

The -5A series has now reached maturity in most cases, and has an average interval of 9,000EFH and 8,000EFC for a 1.1EFH operation. With this interval the core LLPs would require replacement every second shop visit, after an interval of 16,000EFC. The LPT and fan/booster LLPs would have to be replaced every third shop visit, after an interval of 24,000EFC *(see table, page 19).*

In this case, the engine could conform to a simple alternating shop visit pattern of a performance restoration followed by an overhaul. A heavier core workscope would be required at the second shop visit to replace LLPs. It may be possible to leave the LPT until the third shop visit, but a workscope is likely to be required at the second. The fan/booster can usually last until the third shop visit *(see table, page 19).*

If the fourth generation, single-crystal HPT blade extends the removal interval to 10,000-20,000EFH as Haertel predicts, then at the same EFC time of 1.1EFH, the interval of 9,000-11,000EFC will allow all core LLPs to be completely used and LPT LLPs to be scrapped every second shop visit. Fan/booster LLPs would therefore have to be replaced every third shop visit having utilised all their life. This would allow an alternating shop visit pattern of core performance restoration and overhaul for the core modules. A full disassembly and overhaul would be required on the LPT every second shop visit, while the fan/booster modules would have a full disassembly at the third removal.

## A321 -5B engines

The -5B series has not experienced the same degree of mechanical and parts-related problems that the -5A series has. The first and subsequent on-wing intervals are expected to be limited by EGT margin degradation and LLP expiry.

The highest rated -5B3, with an EGT margin of 66 degrees, can theoretically last up to 11,000EFC for its first interval with the rates of EGT margin degradation described. "We can run our -5B3 engines for up to 14,000-16,000EFH, or 7,000-8,000EFC, before EGT margin expires. These engines will lose 20-22 degrees of EGT margin in the first 3,000EFC on-wing, and will be left with only 40 degrees. We will lose another 18 degrees in the following 3,000EFC, and so only have 10 degrees left after 6,000EFC. All the -5B3's EGT margin will be eroded after 7,000-8,000EFC," says Karhumaki. "We then regain 60 degrees centigrade of EGT margin by re-rating them to 22,000-27,000lbs thrust for the A319 and A320. This way they can possibly get another 10,000EFH or 5,500EFC on wing before losing all their performance. This would be a total time of up to 24,000-26,000EFH and 12,500EFC."

TAP has so far not experienced any problems with its -5B3 engines, which were first delivered in 2001. "There tends to be full performance loss for -5B3 engines after 11,000-13,000EFC, equal to 22,000-26,000EFH in our operation," says Jesus. "These engines can then be re-rated for the A320 or A319 so they can completely use LLP lives. Some LLPs in the HPT module are limited to 12,000-13,000EFC.

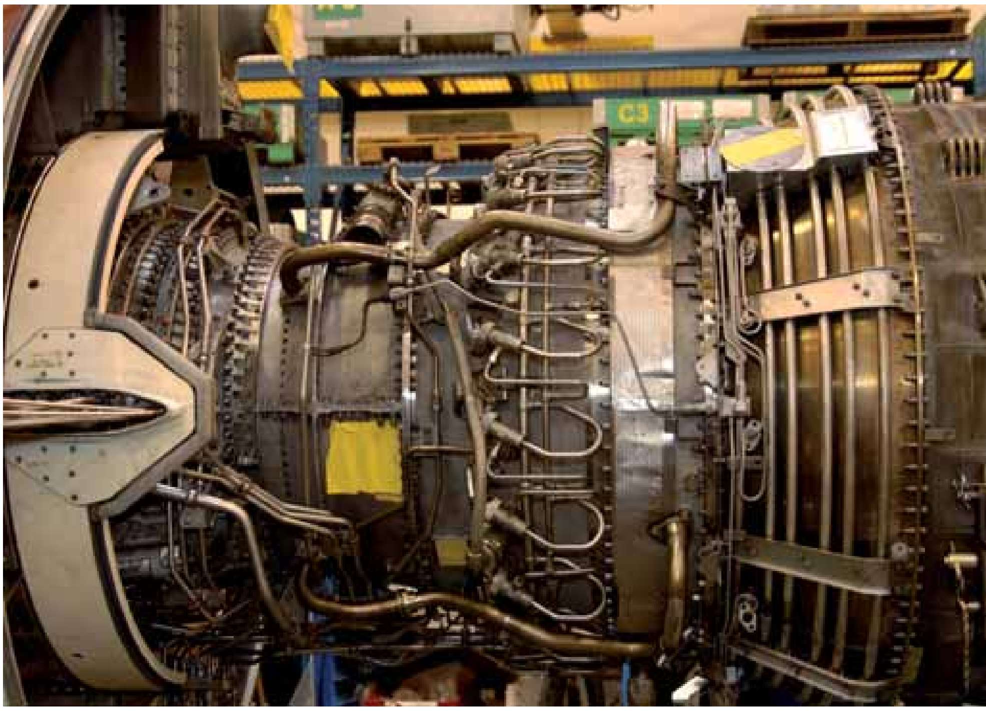
"When following this policy of re-rating the engines to get up to 15,000EFC on wing, we have to consider the remaining lives of other LLPs," continues Jesus. "This will be just a few thousand EFC for core LLPs, so these will be replaced at the first shop visit. The next limit is the 25,000EFC for LPT parts, so we aim to get to this limit on the second run, which means a second interval of 10,000EFC."

Kleinhans estimates that the -5B3's first removal interval is limited by EGT margin, which is up to 14,000EFC. "This would mean replacing all core LLPs at this stage so as not to limit the second interval to just 6,000EFC. The second interval would be limited by the LPT LLPs, and a maximum of 11,000EFC. If the engines only manage 9,000-10,000EFC for their first run, then the core LLPs would be left in the engine and the second run would be determined by LLP limits. This might only be optimal, however, if the core LLPs had remaining lives of at least 8,000EFC. If we re-rate engines after they have used their EGT margin at a high rating, so that we can use the full 20,000EFC lives of their core LLPs, we must take into consideration the fact that mechanical problems start to arise once engines have been on wing for longer than 25,000EFH." One example is the degradation of variable stator vane (VSV) bushings in the HPC. An interval of 20,000EFC is equal to 36,000EFH for an average cycle time of 1.8EFH. Re-rating might therefore be more practical for shorter cycle operations, where the limit of 25,000EFH coincides with the total cycles accumulated at the two ratings for the A321 and the A320/319.

The target would be for the engine to achieve 10,000EFC in the first interval before being re-rated for the A320/A319 to gain another 5,000EFC, or an interval up to the first core LLP limit after a total time of 15,000EFC. Core LLPs would be replaced at this shop visit, and a relatively heavy workscope would be used to regain the maximum possible EGT margin. LPT LLPs would limit the second interval to 10,000EFC *(see table, page 26).*

A second interval at the -5B3 rating might first allow 6,000EFC on wing, and LPT LLPs would then limit a re-rated interval to 4,000EFC. LPT and fan/booster LLPs would be replaced at this stage, meaning that full workscopes

*Once engines have been through their first shop visit, subsequent removal intervals will be in the range of 10,000EFC for all variants. This will be because operators will have to compromise between EGT margin loss and maximising the use of LLP lives.*



would be required on these modules *(see table, page 26)*.

All removal intervals would ideally be 10,000EFC at this stage, thereby allowing core and LPT LLPs to be replaced every 20,000EFC at every second shop visit. The core could therefore have alternating restoration and overhaul workscopes, while the LPT would only have to be worked on every second removal. Fan/booster LLPs would be replaced every third shop visit at 30,000EFC, when this module was fully disassembled *(see table, page 26)*.

The -5B2 and -5B1 have initial EGT margins of 95 and 115 degrees, so they could last up to 15,000EFC and 19,000EFC, and remain on wing up to their first LLP limit. These intervals could be equal to 27,000-34,000EFH, however, and the engines would be expected to start experiencing mechanical degradation problems after 25,000EFH. All core LLPs would then be replaced at the first shop visit, which would be a full core disassembly and workscope.

In the case of the -5B2, the LPT LLPs would be left in, and would influence the length of the second interval. Assuming the -5B2 could regain an EGT margin of 57 degrees after the first shop visit, its second interval would be 8,000EFC. This would be a total time of 21,000-23,000EFC. The core would require a performance restoration, while the LPT would need a full workscope to replace LLPs.

The third interval would be 7,000-8,000EFC, so the core LLPs installed at the first shop visit would require replacement. The core would therefore require a full workscope, as would the fan/booster module which would need to have its LLPs replaced.

The mature engine would require core LLPs to be replaced every second shop visit, LPT LLPs every third and fan/booster LLPs every fourth shop visit.

In the case of the -5B1, the LPT parts would probably be left if the first interval was up to 17,000EFC, but they would be replaced if the interval was longer than this, in which case the second interval would be limited to 30,000EFC. The -5B1 can be expected to have an EGT margin of 70 degrees after the first shop visit, and so have an EGT limited interval of up to 10,500EFC.

A shorter first run and lower subsequent EGT margin would mean the second interval would be up to LPT LLP replacement, as in the case of the -5B2. The optimal removal intervals and shop visit pattern for maximising LLP life utilisation are similar to those described for the -5B2.

### A320 & A319 -5B engines

The lower rated -5B series engines have high enough initial EGT margins to remain on wing up to the limits of core LLPs. This is even the case where all core LLPs are 20,000EFC. "We did have some initial -5Bs engines with HPT blade problems that forced early removals, and 22 had their first shop visits before reaching 11,000EFC. It is possible for later build engines to get to their first LLP limit of 15,000EFC," says Jesus. "This is equal to 27,000EFH on wing for our operation. Mechanical degradation problems start to emerge after this amount of time on wing, however. Contact between the rotors and stators in the HPC due to VSV bushing attachment wear starts to occur after 24,000EFH. The interstage seal metal sheet can wear through due to this contact and go into the flowpath. We therefore start borescope inspections after 18,000EFH on-wing, and get findings at this stage. Engines can just about stay on wing for 15,000EFC and 27,000EFH."

Kleinhans estimates that -5B4/P and -5B7/P engines operating at cycle times of 1.0EFH have enough EGT margin to allow first intervals of 18,000EFH and 18,000EFC, although some core LLPs in the /P engines have lives as short as 12,000EFC. This will change to 14,000-15,000EFC and 25,000EFH for engines operating at cycle times of 1.8EFH. First removal intervals would not be much longer than 25,000EFH for aircraft operating at longer cycle times. The same applies to -5B5, -5B6, -5B8 and -5B9 engines with lower ratings.

The -5B4 and -5B7 would have restored margins of 84 degrees, so second intervals would last 11,000-12,000EFC on wing. This will influence the first shop visit workscope. "The rate of EGT margin loss in the second interval is expected to be the same as the first, but it is too early to say," says Jesus. "The aim is to take lower rated engines to the second removal at a total time of 25,000EFC, where LPT and fan disk LLPs will have to be replaced. All core LLPs will be replaced at the first shop visit."

Consideration has to be given to the two booster LLPs, which have lives of 30,000EFC. If left in the engine these would limit the third interval to just 5,000EFC. It is therefore better to replace them at this second shop visit.

If all core LLPs were replaced at the first removal after 14,000-15,000EFC, they would be replaced with new parts that had target lives of 20,000EFC in the case of most engines. The second interval would be limited to 10,000-11,000EFC because of the LPT LLPs. The objective would be to have a mature interval of 10,000EFC, with core and LPT LLPs being replaced every second removal at 20,000EFC, and booster LLPs replaced every third shop visit *(see table, page 26)*.

"While it is possible to run lower rated engines to 15,000EFC, there are several technical drivers that force removals. These are factors such as LPC blade cracking and combustor cracking," says Karhumaki. "An interval of 15,000EFC is the limit, while our top engines have reached 18,000-19,000EFH.

*The three main groups of LLP lives means the CFM56-5A and -5B will not follow a simple shop visit pattern, with the fan/booster module requiring work every third shop visit, and the LPT needing a full disassembly every second shop visit.*

We expect our highest time A319 engines to run to 30,000EFH and reach LLP limits, but we are assuming the average will actually only be 20,000EFH, or 11,000EFC. This will leave a stub life of 5,000EFC. There is relatively little shop visit experience with the -5B, but we have found that the LPT on all -5B variants requires work as well as the HPC and HPT modules. The fan/booster section should last to the second shop visit.

"We are one of the few operators with DAC engines. These had early reliability problems related to vibrations affecting the LPT blades," continues Karhumaki. "There was a modification programme to fix this, and the DAC is now comparable to the single annular combustor (SAC). The DAC had a modified combustor liner, and our engines have the latest combustors."

## Workscope inputs

There are three main categories of inputs: labour; cost of materials and parts; and cost of sub-contract repairs. The amount of labour used varies according to the percentage of parts being replaced and their associated cost. There is also a converse relationship between the cost of materials and labour versus the cost of sub-contract repairs, since a shop that performs a large number of repairs on parts will use a lot of its own labour and materials, and spend less on sub-contract repairs. The opposite is true for shops that do relatively few parts and component repairs.

There are four main types of workscope: a core or performance restoration; an LPT module workscope; a fan/booster module workscope; and a full engine overhaul, which includes all modules. There are lighter and heavier inputs for each of these four types.

For the -5A engine, the amount of labour for a performance restoration will vary from 1,900 man-hours (MH) for a light workscope up to 2,800MH. Using a standard labour rate of $70 per MH the resulting labour cost will be $133,000-196,000. Similarly, the cost of materials varies from $650,000 for a light workscope to as much as $900,000 for a heavy workscope performed by a shop that does few sub-contract repairs. The total cost for the shop visit will be $1.1-1.35 million.

A medium fan/booster module workscope on the -5A will use a total of 200-250MH, while a heavier one can require more than 300MH, incurring a labour cost of $15,000-22,000. The cost of materials will be $100,000 and sub-contract repairs $10,000-20,000, taking the total cost of the workscope to $140,000.

A light LPT workscope on the -5A series will use 250-300MH, costing $18,000-20,000. Additional materials will be $150,000 and sub-contract repairs $50,000, taking the total cost to $220,000. A heavier workscope uses up to 550MH, uses $200,000 of materials, and up to $40,000 of sub-contract repairs, taking the total cost to about $280,000.

A full overhaul on the -5A will use 3,700-4,400MH, depending on several factors. This will incur a labour cost of $260,000-310,000. The cost of materials will vary from $1.1-$1.5 million, while sub-contract repairs will be $120,000-$450,000, depending on shop capability. This will take the total cost to $1.7-$2.25 million.

The associated costs for the same workscopes for the -5B series are marginally higher than for the -5A series engines. A performance restoration, for example, will use more labour and materials, increasing the total cost by $100,000.

The related cost for the fan/booster module will be $10,000-20,000 higher, while the cost for the LPT will be $50,000 higher.

An overhaul is expected to use $200,000 more in material and sub-contract repairs than a -5A, while using a similar amount of labour.

## Unscheduled removals

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

Light visits will usually involve incidents such as oil leaks, and will incur a shop visit cost of up to $300,000. Heavy visits can be the result of an event such as a bearing failure, which can incur some of the highest shop visit costs, and exceed more than $2 million.

Non-engine related removals will be due to events such as foreign object damage (FOD) and birdstrikes. These will require a similar shop visit workscope to heavy engine-related removals and cost in excess of $2 million. Light visits do not interrupt planned removals and removal patterns, so they can be considered separately. Heavy and non-engine related visits should be considered together because they incur shop visit workscope costs, interrupt the schedule of planned removals and shop visits, and also reduce the average planned removal interval.

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

Heavy and non-engine related events occur on average once every 70,000EFH. An engine, for example, with an average planned removal interval of 17,500EFH would therefore see an unplanned heavy shop visit once every four shop visits. The randomness of these unplanned heavy events, however, means that they can occur shortly before a planned event or halfway between planned events, thereby

**CFM56-5A/5B SERIES SHOP VISIT MANAGEMENT & MAINTENANCE RESERVES**

| Removal | First | Second | Third |
|---|---|---|---|
| **CFM56-5A series** | | | |
| EFH:EFC ratio | 1.2 | 1.2 | 1.2 |
| Removal interval-EFC | 8,000 | 8,000 | 8,000 |
| Removal interval-EFH | 9,600 | 9,600 | 9,600 |
| Accumulated interval-EFC | 8,000 | 16,000 | 24,000 |
| Shop visit workscope | Performance restore | Core overhaul & LPT | Performance restore & fan/booster |
| Shop visit cost-$ | 1,150,000 | 1,500,000 | 1,300,000 |
| LLP replacement | - | Core | LPT & Fan/booster |
| LLP cost-$ | - | 880,000 | 875,000 |
| Shop visit reserve-$/EFC | 144 | 188 | 163 |
| LLP reserve-$/EFC | 92 | 92 | 92 |
| Total reserve-$/EFC | 236 | 280 | 255 |
| Total reserve-$/EFH | 196 | 233 | 212 |
| Average reserve-$/EFH including unscheduled shop visits | 240 | 240 | 240 |
| **CFM56-5B3/2/1** ¶ | | | |
| EFH:EFC ratio | 1.8 | 1.8 | 1.8 |
| Removal interval-EFC | 15,000 | 10,000 | 10,000 |
| Removal interval-EFH | 27,000 | 18,000 | 18,000 |
| Accumulated interval-EFC | 15,000 | 25,000 | 35,000 |
| Shop visit workscope | Core overhaul | Full overhaul | Performance restore |
| Shop visit cost-$ | 1,400,000 | 2,100,000 | 1,250,000 |
| LLP replacement | Core | LPT & Fan/booster | Core |
| LLP cost-$ | 921,000 | 909,000 | 921,000 |
| Shop visit reserve-$/EFC | 93 | 210 | 125 |
| LLP reserve-$/EFC | 99 | 83 | 86 |
| Total reserve-$/EFC | 192 | 293 | 211 |
| Total reserve-$/EFH | 107 | 163 | 117 |
| Average reserve-$/EFH including unscheduled shop visits | 150 | 150 | 150 |
| **CFM56-5B4/7/6/5/9** | | | |
| EFH:EFC ratio | 1.8 | 1.8 | 1.8 |
| Removal interval-EFC | 15,000 | 10,000 | 10,000 |
| Removal interval-EFH | 27,000 | 18,000 | 18,000 |
| Accumulated interval-EFC | 15,000 | 25,000 | 35,000 |
| Shop visit workscope | Core overhaul | Core restore, LPT & fan | Core overhaul |
| Shop visit cost-$ | 1,400,000 | 1,600,000 | 1,400,000 |
| LLP replacement | Core | LPT & Fan/booster | Core |
| LLP cost-$ | 921,000 | 909,000 | 921,000 |
| Shop visit reserve-$/EFC | 97 | 145 | 140 |
| LLP reserve-$/EFC | 104 | 89 | 87 |
| Total reserve-$/EFC | 201 | 234 | 227 |
| Total reserve-$/EFH | 111 | 130 | 126 |
| Average reserve-$/EFH including unscheduled shop visits | 145 | 145 | 145 |

simply reducing the average planned interval, rather than adding a full additional shop visit. Such unplanned heavy events have therefore been budgeted for by increasing maintenance reserves by adding the equivalent cost of half a shop visit to the number of planned shop visits over the 70,000EFH interval.

## Maintenance reserves

These have been calculated using the removal intervals, shop visit workscope patterns and LLP replacement timings described. The -5A has been examined as a mature engine, with an interval of 8,000EFC, and an average cycle time of 1.2EFH. The -5B series has been examined as new, and with consequent maintenance over the second to fourth removals. The -5B series has been examined with the -5B1 being used first on the A321 and then re-rated for the A320 or A319 to maximise removal interval, and the -5B2/-5B1 being used on just the A321, as all other lower rated variants can achieve longer removal intervals. All -5B variants have been examined at an average cycle time of 1.8EFH.

Both time on wing and thrust rating influence the cost of a shop visit, and so maintenance reserves. This is because thrust rating has an impact on the scrap rate of engine airfoils. Costs can vary by 30% between the lowest and highest rated engines. The -5B9 or -5B6, for example, would have lower airfoil scrap rates than the -5B4. The lower rated engines would then have lower reserves, despite possibly having similar removal intervals.

The cost of a shop visit will also rise for longer intervals. Costs start to rise when airfoil coatings start to fail, which causes a rapid rate in the scrap rate of airfoils. Both interval and parts scrap rates have to be taken into account when considering maintenance reserves.

Reserves for the -5A series engines are compromised by the expected interval of 8,000EFC. This forces core and fan/booster LLPs to be replaced with a remaining stub life of 4,000-6,000EFC. This puts LLP reserves to an average of $91 per EFC. The short removal intervals put the shop visit cost reserves at a high level. The overall effect is for an average reserve of $268 per EFC, which is equal to $223 per EFH when operated at a cycle time of 1.2EFH.

This reserve increases to $240 when reserves for heavy unscheduled visits are added *(see table, this page)*. A further reserve of $9 per EFH should be added for light unscheduled removals.

Reserves for planned shop visits on the -5A series would fall by $14 per EFH to $206 per EFH if the interval could be extended to 9,000EFC, as is expected by the fourth generation HPT blade.

Reserves for the -5B3 can be minimised by achieving the expected mature interval of 10,000EFC that will allow the lives of most LLPs to be fully used. Shop visit reserves will also be kept low by the long removal intervals that are possible by re-rating the engine. The overall reserves for planned maintenance are $131 per EFH, but these are increased to $150 per EFH when heavy unscheduled visits are budgeted for *(see table, this page)*. An additional $9 per EFH should be added for light unscheduled removals.

The -5B2's and -5B1's higher EGT margins can allow them longer on-wing lives than the -5B3. This should allow the -5B2 and -5B1 to have similar planned intervals to the -5B3 without having to be re-rated to lower thrust ratings, or to have longer intervals when re-rated. The probable limit would be 25,000-27,000EFH, equal to 14,000-15,000EFC. This potential interval is compromised, however, by the different lives of core,

*Large savings for shop visit costs can be made through the use of PMA parts. These are estimated to be up to $150,000 for an overhaul.*

LPT and fan/booster LLPs. The engines would therefore have to follow the same planned intervals as the -5B3 and so have similar maintenance reserves.

The lower rated engines for the A320, A319 and A318 can benefit from long intervals that allow the highest utilisation of core and fan/booster LLPs. This also provides long intervals between workscopes on all major modules. The overall reserves for planned shop visits are $126 per EFH, but these should be increased to $145 per EFH when considering heavy unscheduled removals *(see table, page 26)*. An additional $9 per EFH should be added for light unscheduled removals.

## Reducing shop visit costs

Some of the CFM56-5B's main removal drivers are loss of EGT margin, particularly in the case of the higher rated engines for the A321, and mechanical deterioration. Constant improvements in parts reliability should reduce the impact of mechanical deterioration, for example in the case of HPC VSV bushings. Loss of EGT margin can be minimised by water washing, and re-rating to lower thrusts can extend on wing intervals.

The costs of shop visit inputs are dominated by the cost of parts and materials, and to a lesser extent by sub-contract repairs, which also include an element of material cost. Original equipment manufacturers' (OEMs) list prices generally increase at a rate higher than inflation. Some operators have sought to circumvent this cost by using parts manufacturing approval (PMA) components and materials. There are several providers of PMA parts and components for the CFM56-5A/-5B. "The price gap between our parts for these two engines series and the list prices of those provided by the OEMs continues to widen," says Rob Baumann, president of HEICO Parts Group. "Our prices start at 50-60% of the OEMs', but sometimes are as low as 25%, meaning a discount of 75%. The discount rates we offer on CFM56-5A/-5B parts are 25-65%.

"We supply parts mainly for the -5B, and offer about 500 different part numbers for this engine series," continues Baumann. "These range from simple consumables to shrouds, and unit prices range from $0.42 to about $15,000. Moreover, these include some of the blades and vanes used in the engine. One example is HPC blades. We are also developing other blades and vanes, which are parts that overlap with the CFM56-5C and -7B series. It is worthwhile developing these parts, since there is a global fleet of 6,000 engines in these three series. Another benefit of these engines is the long production run and in-service period.

"It is also worth noting that as the engine passes from its early years of operation to its first shop visits and then maintenance maturity, each type of part experiences different levels of demand from the market," adds Baumann. "Some parts need to be replaced at the first shop visit, while others can be repaired once or twice before being replaced. The number of different parts we can offer for the -5B will therefore continue to evolve as the engine continues in operation. Our customers so far include Air Canada, Iberia, Alitalia and Air Portugal."

Baumann estimates that PMA parts can generate savings of at least $150,000 for a heavy shop visit or overhaul, and a saving of up to $100,000 can be possible for performance restorations. This saving translates into $5-10 per EFH when considered over a series of removals and shop visit workscopes.

## Summary

The costs of shop visit inputs and LLP reserves in accordance with the shop visit intervals and workscopes described are summarised *(see table, page 26)*. These are described in rates per EFH, and include an allowance for the extra maintenance required for heavy unscheduled and non-engine related shop visits. An additional $9 per EFH should be budgeted for light unscheduled shop visits.

These reserves are based on average EFC times of 1.2EFH for the -5A series and 1.8EFH for the -5B series. Reserves vary with removal intervals and shop visit workscopes, but the averages with an additional allowance for unscheduled visits are shown *(see table, page 26)*.

Reserves are influenced by EFC removal intervals, which in turn are influenced by LLP lives. High rated -5B engines therefore have reserves that are only marginally higher than lower rated engines for the A320 and A319. This is because the intervals of lower rated engines are compromised to a degree by the core engine LLPs with lives of 20,000EFC.

Reserves are high for the -5A series because EFC intervals are currently limited by HPT blade material, but also by the EFC time of 1.2EFH. EFH intervals would be longer for longer cycle times, thereby diluting reserves per EFH.

Many -5A operators have longer cycle times, and so longer EFH removal intervals, and therefore achieve lower maintenance reserves. A cycle time of 1.7EFH would bring reserves down by $40 per EFH compared to those shown.

The main benefits that /3 engines should enjoy are longer first intervals due to better EGT margin and unrestricted LLP lives. Mature engines may also be able to have longer intervals due to lower rates of mechanical deterioration, but they will continue to have removal intervals of 10,000EFC because engine maintenance will still be based around LLP limits. AC