The CFM56 family has provided airlines with a durable engine with low EGT margin erosion. Despite this, a few problems have prevented the CFM56-5A/B series achieving the smooth on-wing intervals that were expected. An understanding of the engine's problems and careful planning allows economic maintenance reserves to be realised.

The juggling act of CFM56-5A/B maintenance

A320 sales have caught a lot of attention in the past 15 years. This has been partly due to the aircraft's high operating efficiency to which maintenance costs have contributed. The CFM56 has won orders from the majority of A320 customers. The CFM56-5A/B series therefore has a large impact on the A320 family's maintenance cost, and so influences its market appeal.

Maintenance reserves

What an airline should budget for CFM56-5A/B maintenance depends on several inter-acting and complex factors. On-condition maintenance provides the opportunity for flexible on-wing times to be used in terms of engine flight hours (EFH) possible that will result in the lowest cost per EFH. These on-wing times can be compromised or limited by the need to replace parts with lives shorter than possible on-wing times, deterioration in a few parts of the engine which force a removal, or airworthiness directives (ADs) or modifications.

Airlines have options for managing the maintenance and repair of engines. Sub-contracting maintenance can be bought on the basis of being charged for man-hours (MH) and materials used, or by paying a pre-agreed and predictable power-by-the-hour rate per EFH.

This analysis examines how airlines can manage their CFM56-5A/B engines with respect to on-wing times and planned removal intervals, what workscopes they perform, what inputs of labour time and materials are used, and what costs per EFH or engine flight cycle (EFC) an airline should budget for.

CFM56-5A

The -5A series was conceived before the A321 and its thrust requirements were known. The -5A series did not evolve to have a variant with the thrust rating for the A321. The first model was the -5A1 and rated at 25,000lbs for the A320. The -5A4 and -5A5 are rated at 22,000lbs and 23,500lbs for the A319. The -5A3 was later developed at 26,500lbs for the A320 with a higher gross weight and suitability for operating in a hot environment.

It is possible to use and manage this small family of engines to increase potential on-wing times by re-rating engines. The erosion of exhaust gas temperature (EGT) margin is a main cause of removing engines for shop visits. The EGT margin is higher for a lower thrust rated engine *(see table, page 28)*. The EGT margins shown are test cell measurements and are generally higher when measured on-wing. The -5A5 has been designed for high temperature environment operations, and so has a higher EGT margin than the -5A1 in standard conditions.

The higher thrust rated engines can be used on-wing until their EGT margin has been eroded, and then re-rated at a lower thrust to regain some EGT margin which will allow another on-wing run of several more thousand EFHs.

This commonality benefit is limited by the fact that there are many other causes of engine removal which do not allow longer potential on-wing times to be exploited. Few airlines therefore actually use re-rating for their -5A engines, although some airlines do use it for the -3 and -7 series.

-5B series

The -5B series was developed to provide a range of thrust ratings for the entire A320 family *(see table, page 30)*. The thrust ratings for the -5B series range from 22,000lbs to 32,000lbs. This includes three ratings for the A321 and a higher rating at 27,000lbs for the A320 than offered by the -5A series.

-The -5B series has higher EGT margins than the -5A *(see table, page 30)* for similar thrust ratings. This allows potentially even longer on-wing times for the -5B. Like the -5A series, these on-wing times could be limited by many other removal causes.

CFM56-5A/B SERIES THRUST AND EGT MARGIN CHARACTERISTICS

Engine variant	-5A3	-5A1	-5A5	-5A5
Thrust rating (lbs)	26,500	25,000	23,500	22,000
Aircraft application	A320	A320	A319	A319
EGT margin (degrees centigrade)	78	62	77	107

Engine variant	-5B3	-5B2	-5B1	-5B4	-5B6	-5B5
Thrust rating (lbs)	32,000	31,000	30,000	27,000	23,500	22,000
Aircraft application	A321	A321	A321	A320	A319	A319
EGT margin (degrees centigrade)	66	97	117	167	203	221

-5A management

Airlines manage their engines and removals for shop visits to achieve the lowest costs per EFH or EFC. The potential on-wing times allowed by EGT margins will be interrupted by other issues forcing earlier removals and shop visits.

The rate of EGT margin erosion determines potential on-wing time. EGT margin erosion rate in terms of degrees centigrade per 1,000EFH or EFC is influenced by thrust rating, thrust de-rate, operating conditions and environment, and the average flight cycle (FC) time the aircraft is operated at.

The CFM56 generally has a low rate of EGT margin erosion. In the operating conditions of most airlines the -5A series is expected to lose about 50 degrees centigrade after about 15,000EFH.

Many A320 operators use their aircraft on short-haul networks and so have FC times of 45-90 minutes. Some charter airlines have longer flights. Iberia has an average FC time of 1.5 flight hours (FH) for its -5A1s, Air France 0.93-1.5FH for its -5As and Lufthansa 1.1-1.2FH for its -5A1s and 1.2-1.3FH for its -5A5s.

EGT margin erosion is fast for the first few 1,000 flights and cycles. "We experience a rate of about eight degrees centigrade per 1,000 EFH for the -5A1 and six degrees per 1,000 EFH for the -5A5 in the first 2,000 EFH," says Hinnerk Behn, propulsion systems engineering CFM56-5A/B at Lufthansa Technik.

"After the first 2,000EFH, after a loss of about 15 degrees centigrade, this rate reduces to about 3 degrees per 1,000EFH," continues Behn. "The -5A3 engines we manage for Condor operate longer cycles of about 3.0 FH, but still have a similar level of EGT margin erosion.". This reinforces the issue that the CFM56 is durable and has low EGT margin erosion.

"One technique we try to encourage airlines to use is water washing the engines," says Marc Ventre, chief executive officer at Snecma Services. "This can gain another 10-15 degrees centigrade of EGT margin".

EGT margins of delivered engines indicate that the -5A5 could remain on-wing for up to 33,000EFH, while the highest rated -5A3 could achieve about 22,000EFH. These on-wing times have not actually been achieved. "It is certainly possible to have scheduled on-wing intervals of 15,000EFH, which are allowed by the EGT margins," explains Behn.

EGT margin is high in all CFM56 models and does not generally force removals. "There is a limit of 93 degrees of EGT margin that can be used before a removal is required," explains Ventre. "There is usually a need to replace LLPS before EGT margin is eroded. EGT margin erosion is therefore not a removal driver".

Airlines have found other problems which have caused earlier removals. This means engines are removed with high EGT margins remaining, which have helped to reduce the workscope and cost of shop visits. The high EGT margin remaining before a removal means margins after a shop visit are also high. "We get about 85 degrees centigrade after a shop visit," says Jose Valbuena, CFM56 product manager at Iberia.

-5A removal causes

Airlines have experienced a variety of removal causes for the -5A series. These are items such as oil leaks, bearing failures, blade cracks, and overall deterioration of the engine's condition. "The majority of causes are LLP replacement, the need for performance restoration and high pressure turbine (HPT) blade deterioration," says Ventre.

The CFM56-5A has had some major problems which have required modifications and so have limited first and second on-wing intervals. The two most prominent problems are the limited life of the forward rotating outer airseal LLP and nozzle guide vane modification programme. "The three most common removal causes have been the nozzle guide vane modification, forward airseal and EGT margin erosion," says Behn.

The forward airseal has curtailed first run on-wing intervals. The LLPs in the CFM56-5A all have lives of 15,000-30,000EFC. Most therefore have lives two or three times longer than on-wing removal intervals that would be possible on the basis of EGT margin erosion.

The forward outer airseal was found to have cracks on the earliest CFM56-5A removals. The issue of the forward rotating airseal was covered by AD 99-06-16 and was issued in April 1999.

The AD basically reduced life of the part from 15,000EFC to 11,000EFC for -5A1, 7,700EFC for the -5A3 and 9,100EFC for the -5A5 engines if the engine had not already reached 6,000EFC.

If the engine had already reached 6,000EFC then the full original limits of 15,300EFC in the -5A1, 13,000EFC in the -5A3 and 9,100EFC in the -5A5 could remain, although not more than another 7,000EFC could be accumulated.

Some engines therefore were able to achieve longer first on-wing runs, and a lot of variation in on-wing runs for -5A engines resulted. "Many of our -5A1s had reached more than 6,000EFC when the AD was issued, and so got on-wing runs of about 15,000EFH," says Behn. "Our -5A5s had not reached the limit and these had much shorter runs".

"The AD has effectively reduced the maximum first run interval for newly delivered engines, or scheduled interval, to their respective forward airseal limits. At an average flight cycle time of 1.2FH,t this is 13,200EFH for the -5A1, 9,200EFH for the -5A3 and 10,900EFH for the -5A5," explains Behn.

CFMI is currently working on a replacement forward airseal part which will have an extended life of 15,000EFC.

The nozzle guide vane has also forced many early removals, but this has now been overcome with a modification programme.

-5A on-wing intervals

Most airlines operate the A320 at an average cycle time of 1.1-1.5 FH. Although most engines do not achieve on-wing times of 22,000-30,000EFH between shop visits, Air France and Lufthansa say it is possible to get planned first run on-wing times of 12,000-15,000EFH/10,000-12,500EFC and second runs of about 10,000EFH/8,000EFC.

"We estimate on-wings runs should be 18,000EFH for the first run, 10,000EFH for the second and 8,000EFH for the third," says Ventre. "First on-wing runs started low, but this increased with new engines not having the problems of the first engines. Newly delivered engines can now expect a first run of 18,000EFH".

Actual planned removals will be restricted or dictated by the forward airseal. The -5A1 has the longest possible interval of 11,000EFC, equal to 13,200EFH. All newly delivered engines should achieve this on the first run. The -5A3 and -5A5 will be limited to 7,700EFC/9,200EFH and 9,100EFC/10,900EFH respectively.

According to workscopes that most airlines follow all three variants will achieve second on-wing runs of about 9,500EFH/8,000EFC, although the -5A3 will still be restricted to 7,700EFC.

Total times for the first and second run will then be 21,800EFH/19,000EFC for the -5A1, 18,500EFH/15,400EFC for the -5A3, and 19,800EFH/17,000EFC for the -5A5 *(see table, page 30)*.

These removal patterns will have to be followed for replacement of the forward airseal at every shop visit.

Once the life of the forward air seal has been extended to the expected 15,000EFCs, on-wing intervals could be increased. The forward air seal will still need replacing at the first shop visit, or the second if two intervals total about 15,000EFCs. Planned removals will be easier to manage.

Unscheduled removals account for about 20% of all removals. That is, there is one unscheduled removal on average for four planned removals. A removal pattern of two planned removals will see one unscheduled removal every second planned removal cycle of two removals on average. If an unscheduled removal is made, an airline will perform a repair workscope so that the planned on-wing run which was interrupted can be extended by about a further 2,000-4,000EFH. A run of 18,000EFH for the two runs might then be increased to 21,000EFH when an unscheduled removal has been added.

The third and fourth intervals for the -5A series are expected to be about 16,000EFC. This added to the first two intervals and the addition of an unscheduled interval will result in total intervals for the five removals that make an average interval of 9,100EFH/7,600EFC for the -5A1, 8,300EFH/6,900EFC for the -5A3 and 8,600EFH/7,200EFC for the -5A5.

-5A shop visit pattern

Airlines are finding that despite removals being forced relatively early by the need to replace the forward airseal and other deterioration, EGT margin is still high at each removal.

"Generally the core undergoes a performance restoration every shop visit,"says Behn. "The low pressure turbine (LPT) roughly has an alternating workscope pattern of minimum and restoration workscopes. This pattern actually had to start with the performance restoration, because seals were deteriorating. These have now been modified so that the minimum workscope can occur first".

"We try to keep the workscope on the low pressure compressor (LPC) a minimum," continues Behn. "Only when the LLPs need replacing does the workscope increase. This is usually at the third shop visit".

-5A shop visit inputs

Typical inputs for a planned CFM56-5A shop visit are 3,700MH labour. Materials total $800,000-900,000 and sub-contract repairs are $100,000-120,000. This material and sub-contract repair cost includes quick engine change components and mark-up fees, but not engine rotables and LLPs.

A labour cost of $70 per MH results in a total shop visit cost of $1.2-1.3 million.

An unscheduled repair workscope will cost in the region of $200,000.

-5A LLP management

The replacement of LLPs has to be managed carefully with respect to typical on-wing intervals.

The cycle of two intervals totals about 19,000EFCs for the -5A1, about 15,500EFCs for the -5A3 and 17,000EFCs for the -5A5. These will be followed by a third interval of another 7,500EFCs. The opportunity to replace most LLPs will come at the second or third removals. LLPs should only be left in the engine at the second removal if they do not risk cutting the third interval short.

The interval for the three runs for the -5A1 will be about 26,500EFCs. The majority of LLPs in the high pressure system are 20,000EFCS, except the forward airseal and HPT. These two should be replaced at the first removal, and the remainder at the second.

Parts in the LP system have lives of 25,000EFCs and 30,000EFCs. Parts with 25,000EFC lives would force an early third removal if not replaced at the second shop visit. Parts with lives of 30,000EFCs could be removed at the third interval.

A full set of LLPs costs about $1.26 million. Using this pattern of replacement, LLP reserves would be in the region of $73/EFC.

The -5A3 and -5A5 will be different,

SUMMARY OF CFM56-5A REMOVAL PATTERNS AND MAINTENANCE RESERVES

Engine model	-5A1	-5A3	-5A5
Average EFC time (EFH)	1.2	1.2	1.2
1st interval (EFH/EFC)	13,200/11,000	9,200/7,700	10,900/9,100
1st shop visit inputs ($)	1,200,000	1,200,000	1,200,000
2nd interval (EFH/EFC)	9,600/8,000	9,600/8,000	9,600/8,000
2nd visit inputs ($)	1,200,0000	1,200,000	1,200,000
Total interval (EFH/EFC) (including unscheduled removal)	25,200/21,000	21,200/17,700	22,900/19,100
Total shop visit inputs ($)	2,500,000	2,500,000	2,500,000
Shop visit reserves ($/EFH)	100	119	110
LLP reserves ($/EFH)	61	63	58
Total reserves ($/EFH)	161	182	168

because of their limits in the forward airseal different totals for the first two runs.

-The -5A3 will have a run of 15,500EFCs. This interval, and the subsequent third interval, will mean all HP system parts should be replaced at the second shop visit and LP system parts at the third. EFC reserves are then about $76/EFC.

The -5A5's removal intervals will allow a similar LLP replacement pattern, but longer intervals will reduce reserves to about $70/EFC.

-5A maintenance reserves

Taking inputs of $1.2 million for the planned shop visits and a further $100,000 for an unscheduled removal for half the engines in the first two runs will give an indication of what reserves for time and material, not including LLPs, will be.

Reserves then will be $100/EFH and $120/EFC for the -5A1, $120/EFH and $142/EFC for the -5A3 and $110/EFH and $132/EFC for the -5A5.

Adding amortisation for LLPs, total reserves will climb to about $161/EFH or $193/EFC for the -5A1, $182/EFH or $218/EFC for the -5A3 and $168/EFH and $202/EFC for the -5A5.

This is only about $30-50 per EFH lower than the CF6-50 used on the 747-200 *(see Ageing CF6-50 delivers acceptable maintenance costs, page 18, Aircraft Commerce, November/December 2000)*. Engine reserves on widebodies operating similar cycles to the A320 are much higher, however. Reserves of $440 per EFH should be made for the PW4000 on the A300-600R.

-5B management

The -5B series has features which distinguish it from the -5A. Although most of the turbomachinery configuration is the same for both series. The -5B has one more stage in the booster and has improved blades.

The -5B has not experienced the problems the -5A has with the forward airseal and nozzle guide vane. The -5B has unique features which have caused some operators difficulties. The -5B series has the option of having a double annular combustor (DAC). This reduces NOx emissions. This has caused some teething problems and forced early removals and shop visits for modifications to be made.

-5B management

Like the -5A series the -5B series has high EGT margins for all variants *(see table, page 28)*. The -5B series is also durable and EGT margin erosion is slow. Generally, the -5B will have lost only about 37 degrees centigrade of EGT margin after 10,000EFH on-wing. On-wing times could therefore be long with respect to EGT margin. The -5B series, however, has experienced other problems which have reduced on-wing times.

Swissair operates the -5B series with the DAC. "The -5B had cracks in the DAC and turbine rearframe and this forced early removals after just 1,800EFH," says Peter Singer, product manager CFM56 powerplant maintenance at SR Technics. "After these have been modified we expect to get the expected on-wing intervals and removal pattern for shop visits".

Swissair operates its A320 family aircraft at cycle times of 1.17FH, close to the average for the global fleet. "The DAC caused the engine to run hot," explains Singer. "This meant the turbine rearframe had to be re-designed. Singular-annular combustor -5B engines were not affected. Having sorted out the problems with the DAC we then had difficulties with the airfoils in the HPC. We had fixed removal intervals until all the necessary modifications were performed. We started operating the -5B in 1995, but have only just finished modifying all the engines. We now, therefore, have got the engines into a good condition and expect to get proper removal intervals".

The rate of EGT margin erosion is low, at about 3-4 degrees centigrade per 1,000EFH; similar to the rate for the -5A series. This means the highest thrust -5B3 variant, at 32,000lbs, could have an on-wing time of up to 20,000EFH. EGT margin erosion rates for the -5B series do not seem to differ much between variant and thrust rating.

Like most other A320 operators, Swissair does not use a system of re-rating engines to lower thrusts to gain longer on-wing times. "This has not been possible so far because of the upgrade programme and removals. Even if it was possible," says Singer "longer intervals would not be feasible because of other removal causes. The other issue with re-rating is that when an engine is removed at a higher thrust rating to be re-installed on a smaller aircraft, an inspection is required. This may reveal cracks and then it will not be legally possible to re-install and a shop visit must be performed".

-5B removal causes

To date Swissair's -5B engines have had to be removed because of problems with the DAC, turbine rearframe, HPC

blades, and HPT blade fracture. Most of these problems have been associated with the need for modifications, and so Swissair has not been able to see what removal causes will be once engines have accumulated longer on-wing times. "EGT margin in the -5B is good, and so we expect other problems to force removals," says Singer.

-5B removal intervals

Now Swissair has fully modified its -5Bs it expects on-wing intervals which should conform to a removal interval and shop visit pattern. "The highest time engine has accumulated 5,000EFH since all modifications have been completed and the first shop visit is expected at the end of 2001," says Singer. "Following all modifications the engines are in an as-new condition".

The expected removal pattern is interrupted by unscheduled removals, or removals caused by non-basic problems.

"These will account for about 15-20% of all removals, and of course can occur at at any time before or after a shop visit. We expect the -5B to have an alternating light-heavy shop visit pattern and corresponding removal intervals," says Singer. "The first planned interval will be about 10,000EFH and followed by a performance restoration. The second interval will be about 8,000EFH and followed by an overhaul. This cycle of or planned removals will be repeated.

"An unscheduled removal, caused by foreign object damage or birdstrike, for example, often leads to a repair workscope," explains Singer. "For example, if this happened after accumulating 6,000EFH and 4,000EFH before the first planned removal, we would perform a repair which would allow an on-wing time of at least another 4,000EFH. We try to optimise the workscope of the repair so that the total cost of the repair and performance restoration is a little bit higher (for example, $200,000) than just the performance restoration on its own".

"This will raise costs per EFH, so if we can we will do a repair which will allow another planned interval of 6,000-8,000EFH so the cost per EFH is not raised too excessively," says Singer. "Obviously, unscheduled removals happen randomly, so the workscope will depend on the level of damage caused. Overall, we expect average soft on-wing times of about 9,000EFH, but times will vary by aircraft type".

Including unscheduled removals, average interval will be about 7,000EFH, since the average of 9,000EFH for planned removals will be reduced by unscheduled visits. Some planned intervals will be interupted by unscheduled removals.

SUMMARY OF CFM56-5B REMOVAL PATTERNS AND MAINTENANCE RESERVES

Engine model	-5B
Average EFC time (EFH)	1.2
1st interval (EFH/EFC)	10,000/8,300
1st shop visit inputs ($)	840,000
2nd interval (EFH/EFC)	8,000/6,700
2nd visit inputs ($)	1,000,000
Total interval (EFH/EFC) (including unscheduled removal)	20,000/16,600
Total shop visit inputs ($)	1,950,000
Shop visit reserves ($/EFH)	98
LLP reserves ($/EFH)	80
Total reserves ($/EFH)	178

-5B shop visit inputs

The on-wing times most airlines expect for the -5B means EGT margin will still be high at removal. This may help reduce shop visit inputs.

Inputs for the first shop visit will be 2,750-3,300 MH and about $610,000 for materials and sub-contract repairs. The figure for materials and sub-contract repairs does not include engine LRUs or LLPs, but does include quick engine change components and mark-up for materials and handling fees. At a labour rate of $70 per MH, the first shop visit will cost about $803,000-841,000. The total price varies according to how the engine is operated and the percentage of parts that are scrapped.

The second shop visit will be larger. Consumption will be 3,700-4,000 MH and about $730,000 for materials and sub-contract repairs. This will take the total shop visit cost to about $1.0 million.

LLP management

Unlike the -5A, the -5B is fortunate enough for on-wing times not to be compromised by LLPs which have had their lives reduced due to problems.

Most aircraft will operate average cycle times of 1.2H. Removal intervals of 10,000EFH and 8,000EFH will therefore be about 8,300EFC and 6,700EFC.

LLPs in the high pressure section have lives of 8,700-20,000EFCs. Those in the turbine are in the 8,700-12,000EFC region and HPC parts have 20,000EFC lives.

The HPT LLPs will therefore require replacing every shop visit, since their lives are not long enough for two intervals. At list price, the reserves for replacement of these parts will be about $40 per EFC. The need to replace them every shop visit will increase the workscope.

LLPs in the HPC will be replaced every second visit, or overhaul and so have a reserve of $20/EFC.

Parts in the low pressure system have longer lives of up to 30,000EFCs, although there are some which still require replacing every overhaul because they have lives of 15,000-20,600EFCs. The fan shaft and parts in the LPT have the longest lives and so can be replaced every third or fourth shop visit. Overall, LLP reserves in the low pressure system will be $35/EFC. Throughout the whole engine, reserves will total about $95/EFC, or $80 per EFH.

-5B maintenance reserves

The cost of the two planned shop visits will be about $1.84-1.90 million, but this will be increased by about another $200,000 for the unscheduled repair workscope. This total cost of about $2.04-2.1 million will correspond to an on-wing interval of about 21,000EFH. Reserves for shop visit inputs will be about $100 per EFH. A further addition for LLP replacement will take total cost to about $180/EFH. AC