There are now about 600 E-Jets in operation. The CF34-8E and -10E powering the E-170/-175 and E-190/-195 have high EGT margins, low rates of EGT margin erosion and high reliability. In many cases engines are achieving first removal intervals of 14,000EFC. Maintenance costs are examined.

CF34-8E & -10E maintenance costs

The CF34-8E and -10E series exclusively power the Embraer E-Jets. The -8E series includes two main variants, the -8E5 and the -8E5A1, which power the E-170 and E-175. The -10E series includes five variants, which power the E-190 and E-195.

CF34-8E & -10E in service

The CF34-8E5 and -8E5A1 have a fan diameter of 52 inches, and are rated at 13,520lbs take-off thrust and 14,050lbs thrust. The -8E5 has a bypass ratio of 5.0:1, while the -8E5A1 has a bypass ratio of 4.9:1.

The -8E series was derived from the smaller -8C series, which powers the Bombardier CRJ family. The -8E series is a two-shaft turbofan, with the following configuration: no low pressure compressor (LPC) stages; 10 high pressure compressor (HPC) stages; two high pressure turbine (HPT) stages; and four low pressure turbine (LPT) stages.

The -8E5 and -8E5A1 both have a take-off flat rating of 15 degrees centigrade, so maximum power is maintained for an outside air temperature (OAT) of up to 15 degrees centigrade.

The engines also have relatively high exhaust gas temperature (EGT) margins. "The initial EGT margins with our -8E engines that entered service in 2005 were about 60 degrees centigrade," says Adrian Catherall, CF34 programme engineer at Finnair Technical Services.

Others report lower initial EGT margins. "We have seen an average of 40-50 degrees centigrade," says Axel Eichner, customer support engineering CF34 at Lufthansa Technik Aero Alzey.

There are 310 E-170s and E-175s in operation. The E-170 first entered service in 2002, so there are more than 620 -8E series engines in operation. The lead E-170 has accumulated about 17,000 flight hours (FH) in operation, while the lead E-175 has accumulated 12,000 FH.

Main E-170 operators include Egyptair, Finnair, Royal Jordanian, Delta Express and Delta Connection.

While the majority of E-170s and E-175s accumulate 2,200-2,500FH per year, most aircraft are also operated at an FH to flight cycle (FC) ratio of 1.2-1.4:1. The engines are therefore operated at the same engine flight hour (EFH) to engine flight cycle (EFC) ratio.

Although they share the same nomenclature convention, the -8E and -10E series are technically different. The -10E is closer to the CFM56 in configuration and has a compressor based on the -7B's.

The -10E series has an intake fan diameter of 53 inches, a bypass ratio of 5.4:1, and take-off thrust ratings between 16,960lbs and 18,820lbs. The engine's configuration comprises: three LPC stages; nine HPC stages; a single HPT stage; and four LPT stages. The variants all have a take-off flat rating of 30 degrees centigrade.

Like the -8E series, engines in the -10E series have a generous initial EGT margin. "Our engines had initial EGT margins of about 70 degrees centigrade when they first entered service in late 2006," says Catherall.

Not all operators report such high initial EGT margins. "Our engines have had initial EGT margins of 30-40 degrees centigrade," says Stefan Kontorravdis, director of engineering at Flybe.

Eichner quotes an initial EGT margin of 50-60 degrees centigrade.

There are about 360 E-190s and E-195s in operation, with more than 720

The majority of E-Jet operators are experiencing good performance and high reliability with the engine. EGT margin is high, and in some cases EGT margin erosion is negligible.

CF34-10Es in active service. The E-190/-195 are relatively young, and the lead aircraft has accumulated about 13,500FH and 10,000FC since it entered service.

Major E-190 and E-195 operators include Air Canada, jetBlue, KLM Cityhopper, Lufthansa Cityline, Republic Airlines, USAirways and Flybe. Most E-190-195s are operated at FC times of 1.2-1.8FH. "Our operation averages about 1.45FH per FC, and we accumulate about 2,600FH per year with our E-190s," says Catherall.

Flybe, which operates the E-190 on its longer routes from the UK, averages about 1.2FH per FC. "The fleet average is about 1.48FH per FC," says Eichner.

Engine management

Managing the CF34-8E and -10E to achieve the lowest possible maintenance costs per EFH will require the operator to have an engine removal and shop visit pattern that matches the engine's life limited parts (LLPs). The planned heavy workscope on the engine should be close to LLP expiry so that the majority of LLP lives are used.

"The initial LLP lives vary, from 10,500EFC for the lowest and 25,000EFC for the highest current life limit. The target, however, is a life of 25,000EFC for all LLPs. The projection for these engines is that most modules would have LLPs replaced at the second or third shop visit, assuming all LLPs get their lives extended to 25,000EFC. The first two visits would therefore not require a full overhaul," says Catherall. "The EGT margin and rate of EGT margin loss is so good on these engines that we expect to only have one shop visit prior to a full overhaul at the second shop visit in our operation."

LLPs

Current lives of LLPs are staggered throughout the engine, in the case of both the -8E and -10E.

The CF34-8E has 23 rotating and two stationary parts. Parts can be sub-divided between those in the lower thrust rated -8E5 and the higher rated -8E5A1.

The seven parts in the HPT module have different lives for those operated in the -8E5 and those operated in the higher thrust -8E5A1 *(see table, this page)*. The target life for parts in the -8E5 is 25,000EFC, while target life for parts in the -8E5A1 is 20,000EFC. These seven parts have a list price of about $400,000.

All other LLPs in the engine have ultimate life targets of 25,000EFC. The two parts in the fan module have Chapter 5 life limits of 25,000EFC. These two parts have a list price of about $400,000.

There are six parts in the HPC module, three of which have attained Chapter 5 life limits of 25,000EFC. The other three parts have lives of 20,000-24,000EFC, and so are close to their target limits. The six parts in this module have a list price of about $600,000.

All eight parts in the LPT have reached their target lives of 25,000EFC. These eight parts have a list price of about $400,000.

The list price for the complete shipset of 23 rotating LLPs is about $1.8 million.

The two stationary parts are the compressor case and combustion chamber. These have high list prices, but also long life limits. The compressor assembly has a Chapter 5 life limit of 41,000EFC, and the target life is 60,000EFC. While the list price is $356,000, these two parts are unlikely to be replaced during the aircraft's lifetime.

It is therefore the HPT module which has LLPs with the most limiting lives. The -8E5 variant has two parts with lives of 25,000EFC, but the other five parts have Chapter 5 life limits of 15,000-18,000EFC *(see table, this page)*. The -8E5A1 has one part with a life of 20,000EFC and one with a life of 18,000EFC, while the other five are all short at 13,000-15,000EFC *(see table, this page)*.

Most parts are expected to reach their projected lives of 25,000EFC by early 2011. Given that most aircraft accumulate about 1,800FC per year and that the oldest E-170s/-175s are eight years old, all LLPs should have had their projected lives extended before they accumulate the same number of FCs in service. Current LLP lives should therefore not force early removals for shop visits in the case of the -8E series engines.

The -10E series has 17 rotating LLPs, and a further two stationary parts. Like the -8E, the target life for all parts is 25,000EFC. Nine of the parts have already reached this life limit.

The fan module has three parts: two with Chapter 5 life limits of 25,000EFC; and one with a life of 20,000EFC. These three parts have list prices of about $300,000.

The HPC has five parts. Two had reached their projected life limit of 25,000EFC, and two more have Chapter 5 life limits of 20,000EFC. One part, the HPC 4-9 spool, has a short life limit of 13,000EFC *(see table, page 30)*. The five parts have list prices of about $400,000.

CF34-8E SERIES ROTATING LIFE LIMITED PARTS

LLP Part description	-8E5 Current life (EFC)	-8E5 Projected life (EFC)	-8E5A1 Current life (EFC)	-8E5A1 Projected life (EFC)
Fan module				
Fan disk	25,000	-	25,000	-
Fan drive shaft	25,000	-	25,000	-
HPC module				
Stage 1-2 blisk	20,000	25,000	20,000	25,000
Forward shaft	25,000	-	25,000	-
Stage 3 blisk	24,000	25,000	24,000	25,000
Vortex spoiler	25,000	-	25,000	-
4-10 spool	23,000	25,000	23,000	25,000
CDP seal	25,000	-	25,000	-
HPT module				
IBP seal	25,000	-	18,000	20,000
OBP seal	18,000	25,000	14,500	20,000
Stage 1 FCP	17,500	25,000	13,000	20,000
Stage 1 disk	17,500	25,000	15,000	20,000
OTC	15,000	25,000	13,500	20,000
Stage 2 disk	17,500	25,000	13,000	20,000
Stage 2 ACP	25,000	-	20,000	-
LPT module				
Rear turbine shaft	25,000	-	25,000	-
Stage 3 disk	25,000	-	25,000	-
Stage 4 disk	25,000	-	25,000	-
Stage 5 disk	25,000	-	25,000	-
Stage 6 disk	25,000	-	25,000	-
Stage 3 & 4 seal	25,000	-	25,000	-
Stage 4 & 5 seal	25,000	-	25,000	-
Stage 5 & 6 seal	25,000	-	25,000	-

CF34-10E SERIES ROTATING LIFE LIMITED PARTS

LLP Part description	Current life (EFC)	Projected life (EFC)
Fan module		
Fan disk	25,000	-
Fan booster spool	20,000	25,000
Fan drive shaft	25,000	-
HPC module		
HPC forward shaft	20,000	25,000
HPC 1-2 spool	20,000	25,000
HPC stage 3 disk	25,000	-
HPC 4-9 spool	13,000	25,000
HPC CDP seal	23,000/25,000	25,000
HPT module		
HPT forward shaft	25,000	-
HPT forward outer air seal	19,000	25,000
HPT disk	21,000	25,000
HPT rear shaft	25,000	-
LPT module		
LPT stage 1 disk	25,000	-
LPT stage 2 disk	25,000	-
LPT stage 3 disk	14,000	25,000
LPT stage 4 disk	25,000	-
LPT fan drive shaft	20,000	25,000

The HPT module has four parts, including two with Chapter 5 life limits of 25,000EFC. The other two parts have life limits of 19,000EFC and 21,000EFC. The four parts have a list price of about $400,000.

The LPT has five parts. Three have reached the target life of 25,000EFC, and a fourth has a life of 20,000EFC. One part, the stage 3 disk, has a more limited life of 14,000EFC *(see table, this page)*. These five parts have a list price of about $400,000.

The 17 rotating parts in the engine have a total list price of $1.53 million.

The two stationary parts in the CF34-10E are the combustor case and turbine rearframe, which have list prices of $448,000 and $273,000 respectively. These currently have lives of 39,000EFC and 32,000EFC, which are likely to be extended to the point where the parts are unlikely to need to be replaced during the lifetime of the aircraft.

There are therefore two LLPs in the -10E with lives that have the potential to force early removals: the HPC 4-9 spool and the stage 3 disk in the LPT.

The lead E-190/-195 has accumulated about 10,000EFC, and generates 1,600-1,800EFC per year. Some of the youngest aircraft could therefore have engines removed due to the expiry of these two parts in about two years. The projected life for all parts is 25,000EFC. Six of the parts that have not reached their projected lives need extensions of 4,000-6,000EFC. Most engines in the fleet have accumulated less than 8,000EFC, and operate at 1,800EFC per year. They will therefore reach their current limits of 19,000-20,000EFC after another six years of operation. Most LLPs should therefore reach their projected life targets of 25,000EFC during this period, which means that most engines should avoid early removals forced by LLP expiry.

The uniform target lives of 25,000EFC throughout the two engine variants should make engine management relatively simple with respect to workscope patterns and achieving the lowest possible maintenance costs per EFH.

CF34-8E management

As described, the CF34-8E has initial EGT margins of 40-60 degrees centigrade. "The rate of EGT margin erosion is low compared to other engines used on short-haul operations," says Catherall. "We have experienced an erosion of only about 5 degrees per year; equal to about 2 degrees per 1,000EFH". On this basis the engine could remain on-wing for 20,000EFH or more.

"EGT margin erosion is not a problem for the CF34-8E, and removals have been or will be due to other causes," continues Catherall. "The majority of removals have been due to mechanical deterioration, because of long on-wing intervals, and foreign object damage. The -8E's first removal interval is lasting up to as much as 16,000-17,000EFH, equal to 12,000-14,000EFC."

This is higher than Lufthansa Technik Aero's projection of 10,000-11,000EFC. "Main removal causes for the first removal interval are deterioration of the HPC VGV system, cracking of the HPC bleed port and hot section distress," says Eichner.

Finnair, however, operates in a cold environment and EGT margin will be less of an issue. EGT margin erosion will be of greater concern for engines operating in a warmer environment. Some operators are only expecting first intervals of about 12,000EFH for the lower rated -8E5, and about 10,000EFH for the higher rated -8E5A1.

"Where engines are able to remain on-wing for an extended period, the main problem of mechanical deterioration is the bushings on the variable stator vanes (VSV) in the engine's HPC module. The VSV actuators have had some cracking and breaking, which has led to in-flight shutdowns. This has been dealt with by a service bulletin (SB)," explains Catherall. "The main removal cause, however, will be the wear on the HPC and HPT modules. There are in fact some soft times for shop visits for these modules. The -8E has also had problems with combustor distress."

Other main removal causes are combustor baffle distress and HPT stage 1 nozzle guide vane deterioration. "Engines operated in European and North American environments should typically have first removal intervals of 9,000-12,000EFC, and removal causes will be HPT stage 1 distress, combustor liner baffle distress, vibrations, and incorporation of SBs for the stage 3 and 4 vanes," says Josef Holtzenbein, CF34 sales at MTU Maintenance Berlin-Brandenberg.

"The workscope at the first shop visit, which will be after about 17,000EFH and 12,000EFC in our case, will include work on the HPC and HPT modules and the combustor," continues Catherall. "The fan and LPT are left, depending on condition. That is, they will undergo a visual inspection and the fan blades can be removed and polished. No other work will be done on these modules, unless there are findings. The workscopes in the three core modules can be full disassembly and a workscope to restore durability and performance. In the case of the HPC, the casings will be removed to expose the rotor. The rotor will be kept in one piece, although it is possible to remove individual blades if they are damaged. All rotor blades can be polished, and the VSV bushings at the front stages of the HPC can be repaired or replaced. No LLPs will need to be

The CF34-8E and -10E both have LLP shipsets with target lives of 25,000EFC. Both variants are expected to be capable of removal intervals that results in total accumulated on-wing time at the second shop visit being close to LLP lives. Some engines will achieve shorter removal intervals and reach LLP expiry at the third removal.

replaced at this stage, unless their lives are still limited to less than 20,000EFC."

Catherall expects the -8E's restored EGT margin following the first shop visit to be 40-45 degrees centigrade, or 15-20 degrees lower than the initial EGT margin. "We are fortunate to be operating in a cool environment," says Catherall. "Aircraft operating in hot environments have several SBs directed at them because there have been a lot of problems with the HP modules and the combustor."

Two removals and shop visits up to LLP replacement should certainly be possible for airlines operating in cool environments. "We expect the -8E to complete two on-wing intervals with a total time of close to the LLP limit of 25,000EFC. The engine will therefore have a full workscope and disassembly on all modules to allow LLP replacement at the second shop visit," continues Catherall.

Catherall explains that GE's projection is that the -8E will require two lighter shop visits prior to a complete overhaul at the third shop visit where LLPs will be replaced. This is due to most operators experiencing shorter removal intervals, and will mean a different shop-visit workscope programme.

First removal intervals for most operators are expected to be 11,000-12,000EFC. The second removal interval is expected to be shorter, at 7,000-9,000EFC, and the third interval is projected to be similar to, or slightly shorter than, the second. "The second projected removal interval is explained by the restored EGT margin after the first shop visit being 25-35 degrees centigrade," says Eichner.

Total accumulated time at the second shop visit would therefore be 19,000-21,000EFC. A potential third removal interval of about 8,000EFC means that LLPs would be replaced at the second shop visit, leaving LLP stub lives of 4,000-6,000EFC.

Subsequent intervals of 7,000-8,000EFC mean that the engine would thereafter have a full disassembly to allow LLP replacement every third shop visit. The second replacement of LLPs would therefore come due close to the end of the engine's operating life.

Engines only achieving first removal intervals of up to about 10,000EFC, and a shorter second interval, would therefore have a heavy shop visit at the third removal for full LLP replacement at a total time of close to 25,000EFC.

In this scenario, the first and second shop visits would have similar workscopes. These would involve complete disassembly and refurbishment of the combustor and HPT. The HPC would have limited disassembly for individual blade replacement as required, blade polishing and VSV repair or replacement. The fan and LPT modules would only require visual inspections, subject to findings.

The third shop visit would be a complete disassembly and overhaul of all modules to allow LLP replacement.

CF34-10E management

As described, the CF34-10E has a varying initial EGT margin of 40-70 degrees, depending on operation. The first E-190s entered service in later 2005 with jetBlue, and the first E-195 started operation about one year later in December 2006 with Flybe.

"We have found that the initial EGT margin in our case is only about 40 degrees centigrade, but we have had relatively low rates of EGT margin deterioration," says Flybe's Kontorravdis. "We had a few early removals on some of the youngest engines. We expected the planned or scheduled first interval to be more than 7,000EFH. There is only really one main removal cause, and that is high oil consumption. There have been no other problems, and without this problem the engine would be very good."

Catherall also reports strong engine performance and durability on the -10E. "The rate of EGT margin erosion is actually too low to measure in our operation. This is probably explained by our cool operating environment, but also by the fact that we use a regular waterwash system to save fuel," says Catherall. "We have not yet estimated what the first removal interval will be, but GE has projected it to be about 13,000EFC; equal to 19,000-20,000EFH. The -10E is close in design to the CFM56-5B. We will probably get removals due to wear and tear."

Removal intervals will also depend on the variant's thrust rating. "We expect the lower rated variants to have a first removal interval of 12,000-13,000EFC," says Eichner. "The higher rated variants will have first intervals of about 10,000EFC.

It is expected that the -10E's removal interval could be as long as 16,000EFC. The -10E is basically a scaled-down CFM56-7B, and the lower rated variants of the -10E are achieving very long first removal intervals. The lower-rated -10E variants are basically the same, and should achieve the longer intervals.

Despite high EGT margin and low erosion rates, the engine has experienced some introductory reliability and deterioration problems. "The main removal causes for the first shop visit will be high oil consumption, and the need for combustor and HPT refurbishment; with the engines having achieved relatively long removal intervals," says Eichner. "The workscope is likely to comprise a hot section refurbishment, and aft oil sump modification to deal with the high oil consumption". The HPC may have a limited disassembly workscope and other modules would be time-continued, subject to findings.

The second removal interval will then be up to the remaining life of the LLPs,

and the EGT margin should allow about 10,500EFC. The second removal will therefore be forced by LLP expiry at a total time of 25,000EFC, or close to it. The second shop visit will therefore be a full disassembly and overhaul of all modules to allow LLP replacement.

The third removal interval is projected to be about 8,500EFC. Given that engines tend to reach maturity by the third shop visit, and planned removal intervals tend to reach a similar length by this time, the engine could follow a removal and shop visit pattern of a complete overhaul for LLP replacement every third shop visit.

Maintenance reserves

There are three scenarios that need to be considered for both the -8E series and the -10E series.

In the case of the -8E series, the first scenario has first and second removal intervals of about 14,000EFC and 10,000EFC; equal to a total time of about 24,000EFC and 32,000EFH. The first shop visit will involve hot section refurbishment, and light workscopes or just visual inspections on the other modules. This will incur a shop visit cost in the region of $950,000. The second shop visit will involve complete disassembly and refurbishment of all modules, and LLP replacement. This will incur a cost of about $1.5 million. Average reserves for these two shop visits over the combined interval will be in the region of $76 per EFH. LLP reserves over this interval will be $76 per EFC, based on current LLP list prices. The combined reserves result in a total equal to approximately $130 per EFH over the two intervals *(see table, this page)*. LLP prices are escalated at a rate of about 5.5% per year, however, which must be taken into consideration by operators.

The second scenario is with shorter first and second intervals of 11,000-12,000EFC and 8,000EFC; resulting in LLP replacement at 19,000-20,000EFC. Shop-visit costs will be similar to the first scenario, resulting in a higher reserve of about $90 per EFH. Reserves for LLPs will also be higher at about $90 per EFC, with the total reserve being equal to $156 per EFH *(see table, this page)*.

The third scenario is for an engine achieving even shorter intervals, with the result that LLPs are replaced at the third shop visit. The first two shop visits will therefore have costs of about $0.9 and $1.2 million, and the third shop visit will be heavier at about $1.5 million, not including LLP replacement. This results in average reserves over the three intervals of $107 per EFH. LLP reserves are the lowest possible in this scenario, with parts being replaced at or close to the full interval of 25,000EFC; resulting in a reserve of $72 per EFC. The total reserve for engine maintenance is therefore equal to $160 per EFH over the three shop visits *(see table, this page)*.

The three scenarios for the -10E series engine are similar to the three for the -8E series. The first is for lower rated engines operating in the coolest environments and therefore achieving the longest removal intervals. The combined total for the first two removals is about 24,000EFC, with shop visit inputs of $950,000 and $1.5 million. These two have an average reserve of $76 per EFH. LLP reserves are lower than the -8E series because of the lower shipset list price for the -10E. LLP reserves are $64 per EFC, so total reserves are therefore equal to $123 per EFH *(see table, this page)*.

The second scenario is for lower thrust engines not realising shorter intervals; while operating in warmer environments. Shop visit inputs are not much lower than in the first scenario, with the result that the average reserve over the two intervals is about $89 per EFH. LLPs are replaced at about 20,000EFC, resulting in higher reserves of $77 per EFC. Total reserves are therefore equal to $146 per EFH *(see table, this page)*.

The third scenario of shorter intervals results in an overhaul and LLP replacement at the third shop visit after a total time close to 25,000EFC. The first and second shop visits will have costs similar to the -8E in a similar scenario, and the heavier third shop visit input will incur a cost of about $1.5 million. Average reserve for these three inputs will be about $107 per EFH. LLP reserves will be low at $61 per EFC, and will therefore make total reserves equal to $152 per EFH *(see table, this page)*.

What should be appreciated with these maintenance reserves is that they are based on 2010 engine shop-visit inputs. New parts account for the largest portion of shop visit costs, and parts prices are escalated at a rate of up to 8% per year. This should be taken into consideration by operators. AC

CF34-8E & -10E MAINTENANCE RESERVES

CF34-8E operated at 1.35EFH per EFC

Description	Interval -EFC/EFH	Shop visit cost-$	Reserve $/EFH	LLP reserve $/EFC	Total reserve $/EFH
CF34-8E- 1st scenario					
1st interval	14,000/18,900	950,000	50	75	106
2nd interval	10,000/13,500	1,500,000	111	75	167
Both intervals	24,000/32,400	2,450,000	76	75	131
CF34-8E 2nd scenario					
1st interval	11,500/15,500	900,000	58	90	125
2nd interval	8,000/10,800	1,450,000	134	90	201
Both intervals	19,500/26,300	2,350,000	89	90	156
CF34-8E - 3rd scenario					
1st interval	10,000/13,500	900,000	67	72	120
2nd interval	7,500/10,100	1,300,000	128	72	182
3rd interval	7,500/10,100	1,400,000	138	72	192
All intervals	25,000/33,750	3,600,000	107	72	160

CF34-10E operated at 1.35EFH per EFC

Description	Interval -EFC/EFH	Shop visit cost-$	Reserve $/EFH	LLP reserve $/EFC	Total reserve $/EFH
CF34-10E- 1st scenario					
1st interval	14,000/18,900	950,000	50	64	98
2nd interval	10,000/13,500	1,500,000	111	64	158
Both intervals	24,000/32,400	2,450,000	76	64	123
CF34-10E 2nd scenario					
1st interval	11,500/15,500	900,000	58	77	115
2nd interval	8,000/10,800	1,450,000	134	77	191
Both intervals	19,500/26,300	2,350,000	89	77	146
CF34-10E - 3rd scenario					
1st interval	10,000/13,500	900,000	67	61	112
2nd interval	7,500/10,100	1,200,000	119	61	164
3rd interval	7,500/10,100	1,500,000	148	61	193
All intervals	25,000/33,700	3,600,000	107	61	152