The CF34 is a reliable engine which has good performance retention. Its removals for maintenance are mainly dictated by LLP lives. These increase the number of removals in the case of the -3A1/-3B1, but the -8C5 series has a simpler shop visit programme.

CF34-3/-8C series maintenance analysis

The General Electric (GE) CF34-3 and -8C series power the CRJ-100, CRJ-200, CRJ-700 and CRJ-900. With the success of the Bombardier regional jets (RJs) there are now about 3,000 of these engines in operation. Another 80 CRJ-700/-900s are on order, which means that another 160 -8C engines will go into service.

The CF34-3 was derived from the military TF34 engine, which was used to power the American A10 strike aircraft and other military types. The TF34 has been operating in large numbers since the 1960s, so it accumulated millions of hours of operational experience prior to the development of the CF34.

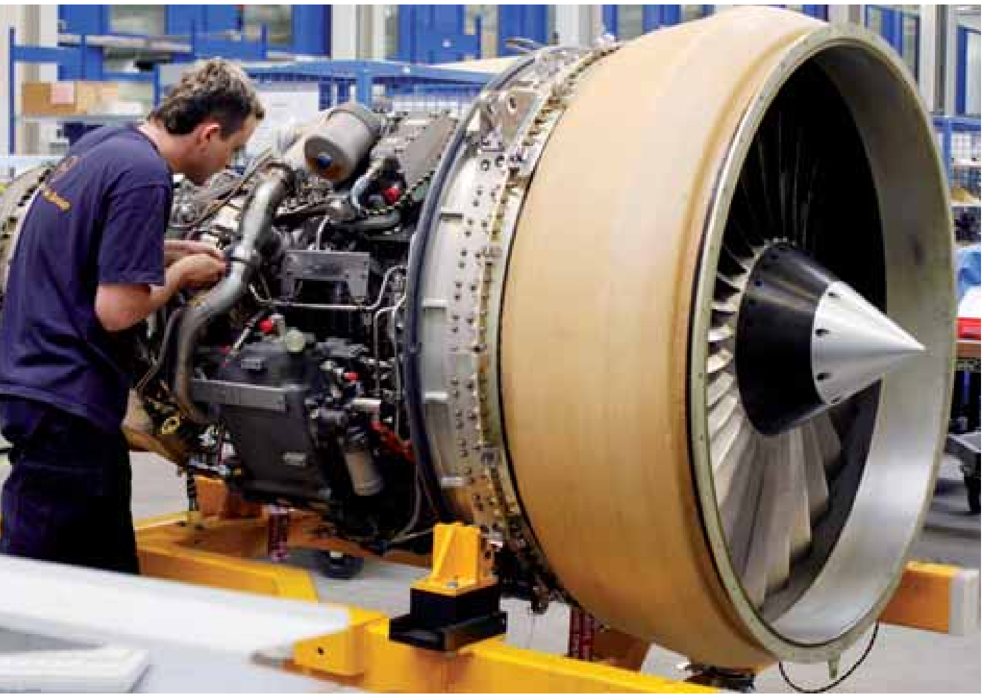
The CF34-1A and -3A were developed in the early 1980s, and first entered service in 1983 powering the Bombardier Challenger 601 corporate jet. The CF34-3 then entered service in 1992, as the -3A1 series, powering the Bombardier CRJ-100. The -3A1 is a two-shaft engine, with a 44-inch diameter single-stage fan, 14-stage high pressure compressor (HPC), two-stage high pressure turbine (HPT), and four-stage low pressure turbine (LPT). The engine is rated at 8,465lbs thrust, and flat rated to 86 degrees Fahrenheit (30 degrees centigrade). Below this 'corner point' temperature, the exhaust gas temperature (EGT) reduces at a rate of three degrees centigrade for every one degree centigrade drop in outside air temperature (OAT).

The -3A1 was followed in 1995 by the -3B1 used to power the CRJ-200, which is a higher gross weight variant of the CRJ-100. The -3B1 has the same thrust rating and flat rating temperature as the -3A1. "The -3B1 uses a stage 1 compressor blisk and a different HPT design," explains Volker Knell, manager product line GE engines at Lufthansa A.E.R.O. "This gives the -3B1 engine a better climb and altitude performance than the -3A1-powered CRJ-100."

The larger -8C series was developed to power the growth developments of the CRJ-100/-200: the 70-seat CRJ-700 and the 86-seat CRJ-900. The -8C series is a larger engine, with a 46.2-inch diameter fan, depending on thrust rating, 10-stage HPC, and the same turbine configuration as the -3 series.

The -8C1 was the initial engine to power the CRJ-700, which entered service in 2001, and is rated at 12,500lbs thrust and flat rated to 30 degrees centigrade. "This engine has been improved by the redesigned -8C5 version, so GE offered an upgrade programme to get the -8C1 to an -8C5B1 configuration," explains Joerg Witaseck, director sales CF34 Europe, Middle East & Africa at MTU Maintenance Berlin-Brandenburg. "The -8C1 is the old configuration and is no longer built. The -8C5B1 has the same rating as the -8C1."

The upgrade from the -8C1 to the -8C5B1 includes replacement of the entire HPC, combustion liner and HPT. "The -8C1's main problem was EGT margin retention," says Knell. "GE announced it would introduce an upgrade programme to take the -8C1 engine to -8C5 standard by a modification that would take the -8C1 to the -8C5B1. About 460 -8C1 engines are affected, and so far only 60 of these have been upgraded. Many of the



The CF34 has the benefit of being derived from the rugged and reliable TF34 military engine. The CF34 has good performance retention, and is seldom removed due to eroded temperature margins.

life limited parts (LLPs) in the -8C1 have lives of 9,000EFC, and these are replaced in the modification. This means that the upgrade has to be performed before the engine accumulates 9,000EFC. The engine is removed at this stage for a shop visit and has the upgrade package incorporated, after which it is like a zero-timed engine in many ways.

"The main parts affected by the upgrade are the HPC rotor, the HPT, the combustion chambers in some of the engines, and the LPT," continues Knell.

The -8C5 was developed to power the CRJ-900. The first variant, the -8C5A1, is rated at 13,630lbs thrust. The -8C5A2 is rated at 14,50lbs thrust, and the -8C5A3 at 14,510lbs thrust. The -8C5 is now the standard engine for the CRJ700 and -900, and is also flat rated up to 30 degrees centigrade.

CF34-3/-8C in service

The CF34-3 has been in service since 1992, and there are more than 2,200 in service. The CRJ-100/-200 is prevalent in the US, operating as hub feeder aircraft for regional airlines. Most aircraft were acquired in the 1990s to replace turboprops. The nature of their operation means that the aircraft's average flight cycle (FC) time is 1.16 flight hours (FH). The CF34-3 fleet has to date accumulated more than 27 million EFH and 24 million EFC in service.

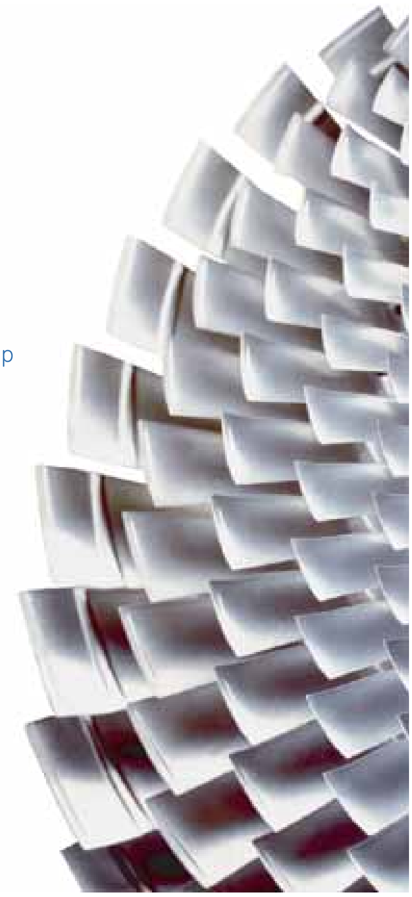
The -8C series has acquired less operational experience, with only 750 engines in operation with 20 different operators. The CRJ-700/-900 have a wider geographical spread than the CRJ-100/-200, with many of their customers operating in Europe. As a result, the engine's average EFC time is 1.35EFH. The fleet has accumulated 3.9 million EFH and 2.9 million EFC in service.

These average EFC times affect the engine's performance, performance degradation and removal intervals for maintenance. Some operators assess the engine's performance in terms of EGT margin. "The EGT margin of new engines is 45-50 degrees centigrade for new -3A1 and -3B1 engines, and about 50 degrees centigrade for -8C1 and -8C5 engines," says Knell. "EGT margins deteriorate at 5-10 degrees centigrade in the first 1,000EFC, but then the loss rate levels out to 2-3 degrees per 1,000EFC after this if regular water washing is used. The EGT margin will deteriorate faster if it is not. The EGT margin after a shop visit can be similar to those of new engines, especially if tight clearances in the HPC and HPT are achieved through the use of match grinding."

Operators and some maintenance providers, however, follow the inter-turbine temperature (ITT). "This is the temperature between the HPT and LPT sections, and increases as the engine deteriorates in the same way that EGT increases as the engine's hardware deteriorates," explains Witaseck. "The ITT margin for new -3 and -8C engines is 25-45 degrees centigrade. Higher ITT margins would be expected for the -8C5B1 engines, which have a better hardware standard.

"After engines have been through a restoration the ITT margin is 20-25 degrees centigrade, and 30-35 degrees centigrade following a full performance restoration," continues Witaseck. "The engines powering the CRJ-700 and CRJ-900 are young, however, so there is limited experience of shop visits and the performance standards of these engines following performance restorations and overhauls."

The TF34's extensive operational experience allowed GE to develop the CF34 as a reliable and robust engine. "The ITT margin erosion rate on the CF34 is only about 1.0-1.5 degrees centigrade per 1,000EFC. Although the initial rate is faster, it then flattens to this level," says Witaseck. "This means that the engines have enough ITT margin to



CF34-3A1/-3B1 SERIES LLP LIVES

LLP	Current EFC life	Planned EFC life
Fan disk	24,000	24,000/25,000
Fan forward shaft	22,000/25,000	22,000/25,000
Fan drive shaft	22,000/25,000	22,000/25,000
Stage 1 HPC disk	15,000/20,000	15,000/25,000
Stage 2 HPC disk	22,000/25,000	22,000/25,000
3-8 front HPC spool	22,000	22,000
Stage 9 HPC disk	23,000/25,000	23,000/25,000
10-14 rear HPC spool	22,000/25,000	22,000/25,000
Rear shaft	23,000	23,000/25,000
CDP seal	22,000/30,000	22,000/30,000
HPT shaft	30,000	30,000
HPT stage 1 disk	15,000	15,000/18,000
HPT stage 2 disk	15,000	15,000/18,000
Stage 1 forward CP	30,000	30,000
Stage 1 aft CP	15,000	15,000/18000
Stage 2 forward CP	15,000/30,000	15,000/30,000
Stage 2 aft CP	30,000	30,000
OBP seal	15,000	15,000/18,000
Outer torque coupling	30,000	30,000
Stage 3 LPT disk	22,000/25,000	22,000/25,000
Stage 4 LPT disk	22,000	22,000/25,000
Stage 5 LPT disk	22,000/25,000	22,000/25,000
Stage 6 LPT disk	22,000/25,000	22,000/25,000
Stage 3/4 LPT seal	22,000/23,000	22,000/25,000
Stage 4/5 LPT seal	22,000/25,000	22,000/25,000
Stage 5/6 LPT seal	21,000/25,000	22,000/25,000

last up until the first LLP limit. However, the -3 series rarely gets removals due to ITT erosion. These are due mainly to LLP expiry or hardware deterioration. The -8C is relatively new and removals have so far been mainly due to technical reasons."

Removal patterns

The main causes of -3 removals are LLP expiry and technical distress. "The portion of removals due to ITT margin erosion is low, since the CF34 is a very solid and reliable engine," says Witaseck. "Because LLP expiry is the main removal driver, LLP lives should be examined."

-3 series engines

The -3 series have 26 LLPs: three in the fan module, seven in the HPC, nine in the HPT/hot section and seven in the LPT.

LLPs in the -3A1 powering the CRJ-100 can be divided into three groups, with planned lives of 15,000EFC, 22,000EFC and 30,000EFC *(see table, this page)*. Most of the parts with lives of 15,000EFC are in the HPT and hot section of the engine, while other parts in this module have lives of 30,000EFC. LLPs in the fan, HPC and LPT modules have lives of 22,000EFC. Most LLPs are now at their planned lives, and only a few have shorter lives to be extended.

The -3B1 powering the CRJ-200 has different groupings of LLPs, with planned lives of 18,000EFC, 25,000EFC and 30,000EFC. Like the -3A1, LLPs with parts with lives of 18,000EFC and 30,000EFC are in the hot section, and parts with lives of 25,000EFC are in the HPC, LPT and fan section *(see table, this page)*.

"Loss of performance of EGT margin is not a main removal driver for the -3A1," says Knell. "Removal intervals and shop visit workscopes are primarily driven by LLP lives."

Other maintenance providers agree. "The -3A1 engines have sufficient ITT margin to remain on-wing until they reach their first LLP life limits, which is 15,000EFC," says Witaseck. "These parts are replaced at this visit, so the hot section will require a full disassembly."

Parts with lives of 22,000EFC can either be replaced at this stage, or kept in the engine until a second removal after another 7,000EFC. "The -3A1 will have a major refurbishment at this stage and a performance restoration," says Knell.

It is best to keep LLPs with lives of 22,000EFC in the engine to use their full life, and so have a second removal and shop visit after another 7,000EFC. "The fan, HPC and LPT modules in the engine have LLPs with lives of 22,000EFC, so all require complete disassembly. This means that the engine will go through a major refurbishment, and most of the LLPs will be replaced," explains Knell.

There is a third removal after another 8,000EFC on-wing at a total time of 30,000EFC. At this stage the lives of 15,000EFC that were installed at the first shop visit would also be replaced, as well as the four LLPs in the HPT with lives of 30,000EFC. "Therefore the workscope would only affect the HPT," says Knell.

"The case with the -3B1 is slightly different, with the shortest lives at 18,000EFC. Ideally the aim is to keep the engine on-wing for this interval," adds Witaseck. "A first interval of 18,000EFC is a little too long, however, so there is usually a mid-time inspection after 10,000-12,000EFC where a hot section inspection restores ITT margin."

"The -3B1 deteriorates faster than the -3A1 on-wing, since the -3B1 runs hotter, and cannot last the full 18,000EFC to the LLP life limits," says Knell.

The second shop visit is therefore after another 7,000EFC, at a total time of 18,000EFC, and involves LLPs in the HPT. "The HPT and hot section can be removed with the engine on-wing," says Knell. "The new LLPs can be installed and then the HPT is installed back on-wing. The whole engine will require a complete workscope, however, after this interval on-wing," explains Knell.

The third removal will be after just another 4,000EFC when LLPs with lives of 22,000EFC are expired, or another 7,000EFC for engines that have had the lives of these LLPs extended to 25,000EFC. The older engines are mainly those which still have lives of 22,000EFC, while the younger and currently built engines have lives of 25,000EFC. This removal and workscope only requires work on the fan, HPC and LPT modules that are affected by LLP expiry.

There is a fourth event at the longest LLP limit of 30,000EFC, which involves one LLP in the HPC and five in the HPT.

"The first removal after 11,000EFC is because HPT blades can usually only last 11,000EFC on the -3B1, since they cannot last 18,000EFC," continues Witaseck. "It is possible for some operators to get three shop visits out of this 30,000EFC limit, however, by having a first shop visit at closer to 18,000EFC."

The -8C series

The -8 series engines are still young, so it is harder to predict exactly how they will perform and what their removal intervals might be.

The three -8C variants have 23 LLPs, although the set of parts differs in the -8C1 from that in the -8C5B1 and -8C5 engines. The -8C1 has two LLPs in the fan module, five LLPs in the HPC, eight LLPs in the HPT/hot section, and eight

CF34-8C5B1/-8C5 SERIES LLP LIVES

LLP	Current EFC life	Planned '07 EFC life	Planned '09 EFC life
Fan disk	25,000/15,000	25,000	25,000
Fan drive shaft	9,000	25,000	25,000
Stage 1 & 2 HPC blisk	9,000	17,000	25,000
Forward shaft	9,000	17,000	25,000
Stage 3 HPC blisk	9,000	17,000	25,000
Vortex spoiler	9,000	17,000	25,000
Spool	9,000	17,000	25,000
CDP seal	9,000	17,000	25,000
IBP seal	24,000	24,000	25,000
OBP seal	12,000	12,000	25,000
Stage 1 CP	17,000/18,000	17,000/18,000	25,000
Stage 1 disk	11,000	11,000	25,000
OTC	15,000	15,000	25,000
Stage 2 disk	17,000	17,000	25,000
Stage 2 CP	25,000	25,000	25,000
Stage 3 LPT disk	9,000	25,000	25,000
Stage 3/4 LPT seal	9,000	25,000	25,000
Stage 4 LPT disk	9,000	25,000	25,000
Stage 4/5 LPT seal	9,000	25,000	25,000
Stage 5 LPT disk	9,000	25,000	25,000
Stage 5/6 LPT seal	9,000	25,000	25,000
Stage 6 LPT disk	9,000	25,000	25,000

LLPs in the LPT. The -8C5B1 and -8C5 have the same LLP configurations in the fan and LPT modules, but the HPC and HPT differ by having six and seven parts.

"It is expected that all -8C1 engines will be upgraded to -8C5B1 status once they reach an on-wing time of about 9,000EFC," says Witaseck.

The -8C5B1 engines, the upgraded version of the -8C1, and -8C5 engines have varying life limits in each module. The fan module has one part with a life of 25,000EFC, but another with a life of 9,000EFC, which is due to be upgraded to 25,000EFC in 2007. The six parts in the HPC all have lives of 9,000EFC, but are due to be upgraded to 17,000EFC in 2007 and upgraded again to 25,000EFC in 2009. The seven parts in the HPT/hot section have lives varying between 11,000EFC and 25,000EFC, but are due to be upgraded to 25,000EFC for all parts in 2009. The eight parts in the LPT all have lives of 9,000EFC, but are due to be upgraded to 25,000EFC in 2007. The whole engine should therefore have all its 23 LLPs with lives at 25,000EFC by 2009. The oldest engines are six years old, and the highest time engine has only accumulated 9,000EFC. It is therefore possible that most engines will be able to have their LLPs upgraded to 25,000EFC before they reach their first limit of 9,000EFC, which would force a removal and a shop visit.

"If all LLP lives are upgraded, then the first shop visit can occur at its probable interval after performance loss at 10,000-15,000EFC. The second removal will be when the engine reaches the LLP limit of 25,000EFC, which would require a full overhaul since LLPs would have to be replaced" says Witaseck. "Not all the LLPs may get their lives extended in time to make this possible, however, so this is an important consideration for operators."

These removal intervals and simple workscope pattern can be followed by most operators. There are no CRJ operators in hot climates, so the effect of high OAT on ITT margin is not a consideration. "The -3A1 and -3B1 engines have fairly sensitive HPT blades, but the CF34 is modular and the HPT and LPT sections can easily be changed. It is also easy to do a top case foreign object damage (FOD) repair or change the combustion liners," says Witaseck.

Shop visit workscopes

The effect of LLP lives on removal intervals and removal pattern has been described. A more detailed look at the shop visit workscopes indicates approximate shop visit inputs. When considered together with LLP prices and replacement schedules, total maintenance reserves can be predicted.

The first shop visit for the -3A1 after 15,000EFC on wing will typically involve refurbishing the HPC, the HPT and the combustor section, due partly to the need to replace LLPs with lives of 15,000EFC in the HPT and HPC modules. This is expected to have a total cost for labour, materials, parts and sub-contract repairs, but excluding LLPs, of $750,000-900,000.

The other modules can be left, since the next interval to 22,000EFC will be just 7,000EFC. At this second shop visit, the fan will require refurbishment and replacement of its LLPs, HPC refurbishment and replacement of most of its LLPs, LPT refurbishment and replacement of its LLPs, and work on the accessory gearbox. The HPT may also require some work, but this is on an on-condition basis. Excluding LLPs, the cost of this visit will be $500,000-700,000.

The third removal will be driven by a need to replace LLPs with lives of 15,000EFC that were installed at the first shop visit, and to replace the four LLPs with lives of 30,000EFC in the HPT. Excluding LLPs, this shop visit will cost $800,000-950,000.

The -3B1 has to have four removals and shop visits in the same 30,000EFC interval, because the engine cannot run to 18,000EFC on its first interval. The shop visit at the mid-time interval at 11,000-12,000EFC is likely to involve a refurbishment of the combustor and HPT, but will not require any LLP replacement. This will cost $350,000-550,000.

The second removal after another 6,000-7,000EFC and at a total time of 18,000EFC will be forced by the need to replace four LLPs in the HPT module. This will include refurbishment of the HPC and HPT modules, and may also include some fan blade overhaul or contouring.

The third removal will be forced by the need to replace LLPs with lives of 25,000EFC in the fan, HPC and LPT modules, so the workscope will involve complete disassembly and refurbishment of these modules. It may also include a visual inspection of the HPT, although actual work on the module is unlikely to be required. The cost of this shop visit will be $500,000-650,000.

The fourth shop visit will be forced by replacement of LLPs with lives of 30,000EFC in the HPT module. At this stage the four HPT LLPs that were replaced at the first shop visit will have accumulated 12,000EFC, so it may be prudent to scrap these parts at this stage, with a stub life of 6,000EFC. This depends on whether the probable time on wing to the fifth shop visit could be much longer than the 6,000EFC permitted by these LLPs, however. Excluding LLPs, the cost of the fourth workscope will be $800,000-950,000.

The -8C5 and -8C5B1 engines should follow a simpler shop visit removal and workscope pattern if the lives of all LLPs in the engine have been extended to 25,000EFC in sufficient time for the engines to achieve these intervals. The engine is likely to follow a workscope pattern of a performance restoration at the mid-time inspection after 12,000EFC, which will involve work on the HPT and combustor. This will cost $400,000-700,000. This will be followed by an overhaul after a total time of 25,000EFC, which will cost $900,000-1,200,000.

Maintenance reserves

Total maintenance reserves comprise two elements of shop visit reserves and reserves for LLPs. For shop visit reserves, a mid-range cost from the range of shop visit costs can be taken, and simply amortised over the shop visit interval.

-3A1

Reserves for LLPs are more complex. Taking the -3A1 as an example, the 15,000EFC LLPs are replaced at the first input. Reserves for these parts would be their cost of $187,000 amortised over the 15,000EFC interval, which is equal to $12.50 per EFC. The timing of their next replacement would be after another 15,000EFC, as described. The probable replacement cost over the second interval has to be considered. Ignoring the effects of part price inflation, the reserves for these parts would again be $12.50 per EFC. Reserves for the 22,000EFC LLPs that will be replaced at the second visit will be their cost of $671,000, and equal to $30.50 per EFC. These are likely to be replaced after another 22,000EFC, about 14,000EFC after the third shop visit, and also have a reserve of $30.50 per EFC.

Reserves for the 30,000EFC LLPs, to be replaced at the third visit, will be their cost of $90,000 amortised over the interval, which is equal to $3 per EFC.

Reserves for LLPs up to the first shop visit will be the reserves for all three groups of LLPs, and will therefore be equal to $45.50 per EFC. Reserves for LLPs up to the second shop visit will be reserves for the second set of 15,000EFC parts plus the other two groups. Ignoring the effects of price parts inflation, this will be equal to $45.50 per EFC. The same LLP reserve applies up to the third removal.

The reserve increases only if the lives of parts are compromised and they have to be removed early with a stub life, as in the case of the -3A1. This ignores the effect of LLP price inflation, however.

Reserves for the shop visit cost up to the first input are $825,000 amortised over 15,000EFC, and equal to $55 per EFC. Plus LLP reserves, the total is $101 per EFC. Reserves for the second shop visit are $86 per EFC, taking the total with LLPs to $132 per EFC *(see table, this page)*. Reserves for the third shop visit are $109 per EFC, and the additional cost for LLPs takes the total to $155 per EFC *(see table, this page)*.

CF34-3/-8C5 SERIES MAINTENANCE RESERVES

	Interval EFC	Cumulative interval-EFC	Maintenance reserve $/EFC
-3A1 series			
1st removal	15,000	15,000	101
2nd removal	7,000	22,000	132
3rd removal	8,000	30,000	155
-3B1 series			
1st removal	12,000	12,000	79
2nd removal	6,000	18,000	178
3rd removal	7,000	25,000	123
4th removal	5,000	30,000	216
-8C5 series			
1st removal	12,000	12,000	111
2nd removal	13,000	25,000	143

-3B1

Making the same assumptions for LLPs in the -3B1, and its probable shop visit removal intervals after the fourth shop visit, reserves for the three groups of LLPs will be $41 per EFC for all intervals, when ignoring the effects of LLP price inflation over the life of the engine.

Reserves for shop visit inputs vary due to the differing intervals and inputs. The first shop visit input will have a cost averaging $450,000 and, amortised over an interval of 12,000EFC, its reserve will be $79 per EFC *(see table, this page)*.

The second input will have an average cost of $825,000, but will be amortised over a short interval of just 6,000EFC, and have a reserve of $137 per EFC. Adding reserves for LLPs, the total reserve will be $178 per EFC *(see table, this page)*. The average reserve for the two shop visits combined over the 18,000EFC interval is therefore $71 per EFC.

The third input will have an average cost of $575,000 and, amortised over a short interval of 7,000EFC, it will have a reserve of $82 per EFC. LLP reserves will take the total to $123 per EFC *(see table, this page)*.

The fourth input will cost an average of $875,000 and, amortised over the 5,000EFC interval, it will have a reserve of $175 per EFC. LLP reserves take the total to $216 per EFC *(see table, this page)*.

-8C5

Calculating the reserves for the -8C5 series is simpler. Average shop visit reserves for the first removal will be $550,000 amortised over an interval of 12,000EFC, and equal to $46 per EFC. The higher average cost of $1.05 million for the second input amortised over a further 13,000EFC will have a reserve of $81 per EFC. The average reserve for both inputs over the whole interval of 25,000EFC is equal to $64 per EFC.

Reserves for LLPs will be the cost of $1.55 million for the full set amortised over the interval of 25,000EFC, equal to a reserve of $62 per EFC. Total reserves to the first shop visit will therefore be $111 per EFC, and $143 per EFC to the second shop visit *(see table, this page)*.

Summary

Despite good performance retention, the CF34-3A1/-3B1 are hindered to an extent by the varying lives of their LLPs. This results in a complex removal and shop visit pattern and relatively high maintenance reserves, especially for the -3B1 which has four removals in an interval of 30,000EFC.

The -8C5 is simpler to manage if its LLPs are extended to the uniform value of 25,000EFC. Despite being larger than the -3B1, the -8C5's simplicity should give it lower overall maintenance reserves. AC