The CF34-3 & -8C series power about 1,300 Bombardier RJ family aircraft. These engines all operate on short flight hour: flight cycle ratios. The management of these engines and the resulting shop visit costs and maintenance reserves over three removal intervals is examined.

CF34-3 & -8C maintenance management & budgeting

The General Electric (GE) CF34-3A/-3B and -8C5 series of engines powers the five main variants of the Bombardier CRJ family. There are about 1,300 of these aircraft in active service, and another 250 that are parked. Many of the aircraft are young, with the CRJ-700, -900 and -10000 still being manufactured. Most of the CRJ-100/-200 fleet are in their teens.

The four/five CF34-3 and -8C main variants are rated at 8,700-14,500lbs thrust. The large number of CRJs they power, and their age, means most engines are young or mature in maintenance terms.

CF34-3 & -8C5 series

The CF34-3/-8C5 family is a two-shaft turbofan. As described, there are seven variants rated at 8,700-14,500lbs *(see table, page 31)*.

There are two main series that power the CRJ family. The first to be introduced was the -3A1, powering the CRJ-100ER/LR, in late 1992. This has the same turbomachinery configuration as the -3B1 introduced in 1993, which powers the CRJ-200ER/LR.

CF34-3A1/-3B1

The CF34-3A1/3B1 are both rated at 8,729lbs thrust *(see table, page 31)*. These two variants have a higher take-off thrust of 9,220lbs with automatic power reserve (APR). The APR is activated as a security system that allows an increase in thrust when a failure of another engine is detected, for example during take-off when the thrust levers are in the take-off detent, and when the flap setting is greater than 20 degrees during a go-around. APR power can also be used for both engines by the flightcrew by advancing thrust levers for both engines to the APR position.

These two variants have a fan with an intake diameter of 49.0 inches. Unlike most two-shaft turbofan engines, their core engine configuration does not have any low pressure compressor (LPC) stages. The engine has a 14-stage high pressure compressor (HPC), a dual-stage high pressure turbine (HPT), and a four-stage low pressure turbine (LPT).

This configuration provides the engine with a bypass ratio of 6.2:1 at the relevant take-off thrust ratings. The two engines have analogue main fuel control (MFC) systems.

"Although the -3A1 and -3B1 have the same configuration, they have different turbomachinery hardware," says Albert Schrichte, director of engine maintenance at Delta TechOps. "The -3A1 can be converted to a -3B1 by changing the hardware during a shop visit."

Eduardo Santos, team leader of CF34 engineering & customer support at Iberia Maintenance, explains that most of the parts in the -3A1 and -3B1 are common, and that both variants use the same manual and illustrated parts catalogue (IPC). "There are some significant differences, however," says Santos. "For example the -3A1 uses a stage 1 HPC disk with inserted blades, while the -3B1 uses a blisk."

Upgrading a -3A1 to a -3B1 can be achieved relatively easily by performing a relatively simple service bulletin (SB) on the engine. Lauraline Paradis-Robert, systems engineer at Lockheed Martin Commercial Engine Solutions (LMCES) in Montreal, explains that it is even possible to operate a CRJ-100 with a -3A1 installed on one side of the aircraft, and a -3B1 on the other side. This does pose limitations on the potential operation of the aircraft, however. "The conversion to a -3B1 when installing a -3A1 requires the engine to go through a heavy shop visit. Some modules, such as the HPT stator, are completely different between the -3A1 and -3B1."

Besides the HPC and HPT, there are also major hardware differences in the LPT. The full change from a -3A1 to a -3B1 is through SB72-0099. Jens Arend, senior manager engineering at MTU Maintenance, comments that this conversion is expensive, however, and so few engines have been modified.

CF34-8C1/-8C5 series

The CF34-8C1 and -8C5 series first entered service in 1999 and 2003 with the CRJ-700. The -8C5 has two other variants which power the CRJ-900 and -1000.

The -8C1 and -8C5 series have a different configuration to the -3A/-3B engines. The -8C1 and -8C5 have a wider intake fan diameter of 52.0 inches, and a larger core to generate higher take-off thrusts of 12,670-14,510lbs thrust. The core engine has a 10-stage HPC, a dual-stage HPT, and a four-stage LPT.

This basic engine configuration is used by five different variants.

The first is the -8C1 rated at 12,670lbs thrust. This was the original engine to power the CRJ-701ER *(see table, page 31)*.

GE introduced a conversion package for the -8C1. This changes the engine to the -8C5B1 variant during a shop visit, and is performed to improve operating performance and engine durability. More than 500 -8C1 engines were modified to -8C5B1. The -8C5B1 is rated at 13,123lbs thrust and powers the CRJ-701LR and -702ER.

The -8C5 was later introduced in 2003 to power the CRJ-705LR, and is rated at 13,123lbs thrust. It also powers the CRJ-900.

The -8C5A1/2 are rated at 13,280lbs thrust and power the CRJ-1000. The -8C5A3 is rated at 14,510lbs and also

CF34-3 & -8C1/-8C5 SERIES VARIANTS, THRUST RATING & APPLICATIONS

Engine variant	Thrust rating (lbs)	Bypass ratio	Fan dia - inches	HPC stages	HPT stages	LPT stages	Aircraft application
CF34-3A1	8,729/ 9,220 with APR	6.2	49.0	14	2	4	CRJ-100ER/LR
CF34-3B1	8,729/ 9,220 with APR	6.2	49.0	14	2	4	CRJ-200ER/LR
CF34-8C1	12,670	4.9-5.0	52.0	10	2	4	CRJ-701ER
CF34-8C5	13,123	4.9-5.0	52.0	10	2	4	CRJ-705LR/-900
CF34-8C5B1	13,123	4.9-5.0	52.0	10	2	4	CRJ-701LR/-702ER
CF34-8C5A1/2	13,280	4.9-5.0	52.0	10	2	4	CRJ-1000
CF34-8C5A3	14,510	4.9	52.0	10	2	4	CRJ-1000

powers the CRJ-1000 *(see table, this page)*.

The -8C5A1/2/3 incorporates new aerodynamic first stage HPT nozzles, 30% fewer vanes, improved geometry, cooling and coating on the HPT airfoils, and up to 10% lower maintenance costs. It is also standard hardware on the CF34-8 family since it entered service in 2010.

The -8C variants are all controlled with a full authority digital engine control (FADEC) system.

All of the -8C1 and -8C5 variants have a bypass ratio of 4.9-5.0:1 for their relevant take-off thrust ratings *(see table, this page)*.

"The core hardware of the -8C1 is different to three -8C5 variants. This is especially the case with LLP P/Ns," explains Arend. "The core hardware for the -8C5, -8C5A1 and -8C5B1 are the same, but the three have different thrust ratings.

"While the -8C1 differs from the others, the -8C1 and -8C5B1 are interchangeable on the CRJ-700," continues Arend. "Because the -8C1 is limited in its thrust rating, it poses different operating performance limits on the aircraft."

There are hardware differences between the -8C1 and the -8C5B1, because of the conversion from one to the other. "The -8C5B1 is only introduced as a conversion engine from the -8C1. The -8C5B1 can be operated at a higher take-off thrust. The conversion to the -8C5B1 variant is described in SB72-0120. The -8C1s were modified to -8C5B1s at a total of about 8,000 engine flight cycles (EFC) during the first shop visit," says Arend. "The main changes and upgrades to the hardware when converting from the -8C1 to the -8C5B1 are: the HPC 3-5 stage vanes, the HPC rotor, the first stage HPT nozzle assembly, the HPT rotor, the third-stage LPT blades, and the LPT shaft."

The -8C1 and the -8C5B1 have practically the same performance, except the inter-turbine temperature margin, which increases by an average of 17 degrees centigrade due to the -8C5B1's increased redline limits. "The main improvements are that the maintenance costs are reduced by about 15%," explains Santos. "The projected removal interval is also forecast to be 10,000-16,000EFC, since all LLPs in the -8C5B1 have a life limit of 25,000EFC.

Schrichte explains that the three -8C5 variants (the -8C5, the -8C5A1/2/3 and the -8C5B1) all have the same turbomachinery configuration and can be converted from one thrust rating to another.

CF34-3/-8C in operation

As described, there are 1,300 CRJs in active service. The 50-seat CRJ-200ER/LR account for the largest number, with 581 aircraft. The majority of this fleet is 10-16 years old.

The CRJ fleet also comprises: the CRJ100ER/LR, with 57 active aircraft; the 70- to 75-seat CRJ-700, with 326 active aircraft; the 90-seat CRJ-900, with

298 active aircraft; and the 100-seat CRJ-1000, with 39 active aircraft.

The 50-seat CRJ-100/-200 were popular with US regionals providing feeder services for the major carriers. US regionals ordered large numbers of CRJ-100s/-200s in the 1990s and early 2000s. A relatively small number of CRJ-100s were built from 1993 to 2001. It was followed by the higher gross weight CRJ-200s, most of which were built from 1997 to 2006.

The CRJ-100ER/LR fleet is operated in a mix of small fleets by a selection of small airlines. Skywest is one US regional that still operates a small fleet of six aircraft. There are another 72 parked CRJ-100ERs/LRs.

The CRJ-200ER/LR fleet accounts for nearly half of all active CRJs. Most of the 581 active aircraft are accounted for by those operated by US regionals, including: Air Wisconsin, which operates 71 aircraft; Endeavor Air (80 aircraft); ExpressJet (88); Air Canada group carrier Jazz (26); PSA Airlines (35); and SkyWest Airlines (148).

There are also another 130 CRJ-200s operated in smaller fleets in other continents. These include operations with Iberia group regional carrier Air Nostrum, China Express, Shandong Airlines, J-Air, and SA Express. There are also another 160 parked CRJ-200s. These include aircraft that were operated for US majors and regionals, and include Delta Airlines and Endeavor Air. A total of 232 CRJ-100s and -200s are parked, mainly due to persistently high fuel prices. Some aircraft may now be reactivated and brought back into service following substantial drops in global oil and jet fuel prices.

The CRJ-100ER/LR and -200ER/LR fleet is operated on short regional feeder routes, and operate at 1.15-1.20 flight hours (FH) per flight cycle (FC).

Most CRJ-700s were built from 2001 to 2011. The CRJ-700 fleet is the second largest of the CRJ family, with 326 active aircraft. Like the CRJ-200, the majority of CRJ-700s are operated by US regionals: ExpressJet, Envoy Air, GoJet Airlines, Mesa Airlines, PSA Airlines, SkyWest Airlines, and Jazz. These airlines collectively operate 281 aircraft. The average operating ratio is higher than the CRJ-100/-200 fleet at 1.45-1.50FH per FC. There are only six parked CRJ-700s.

The CRJ-900 has been in production since late 2002. Of the 298 active ones, 203 are operated by US carriers Endeavor Air, ExpressJet, Mesa Airlines, PSA Airlines, and SkyWest Airlines.

Another 95 aircraft are operated by various airlines, including 11 aircraft operated by Air Nostrum, 23 by German Wings, 12 by Lufthansa Cityline, 12 by SAS, and six by Adria Airways. The CRJ-900 is operated at an average ratio of about 1.40FH per FC. There are also 13 parked CRJ-900s.

The CRJ-1000 has attracted few orders. The first aircraft entered service in 2010, and there is an active fleet of 39. These are operated by Garuda Indonesia (15), Air Nostrum (10), and French operator Hop! (13). The fleet is operated on short distance services by these carriers at ratios of 0.90FH to 1.20FH per FC.

Across the entire CRJ fleet, aircraft are accumulating 1,700-2,000FC per year, so engines are accumulating 1,700-2,000 engine flight cycles (EFC) per year.

LLP configuration

-3A1/-3B1 LLPs

The -3A1/-3B1 are configured differently, so they have a different configuration of life limited parts (LLPs) to the larger -8C1 and -8C5 engines.

The -3A1/-3B1 engines have a total of 29 LLPs in four modules. The modules are the fan, HPC, HPT and LPT.

The fan has three parts: the fan disk, fan forward drive, and the fan drive shaft. Some of these parts and certain part numbers (P/Ns), in particular the fan

Unlike earlier variants, the CF34-8C5A1/2/3 has LLPs with longer lives. The implications of this are that EGT margin erosion is a main removal driver for shop visit maintenance.

disk, had short life limits of as little as 6,000EFC. Others had short lives of about 15,000EFC. Currently available P/Ns have lives of 22,000EFC in the -3A1 and 24,300EFC in the -3B1.

The HPC has eight parts. These start with the compressor forward shaft, including five parts that are blisks or disks in the HPC, and also the compressor rear shaft and the CDP seal. These have target lives of 15,000EFC in the -3A1 and 25,000EFC in the -3B1. Some P/Ns in this module, however, have shorter lives.

The HPT has nine parts. Besides two disks for the two HPT stages, there are also the shaft and various other parts. The target lives for parts in this module are 15,000EFC for the -3A1 and 18,000EFC for the -3B1. Some of the P/Ns in this module can have the shortest life limits in the whole of the engine.

The LPT has nine parts. This includes four disks, three seals between the four disks, the turbine rear cone, and the turbine rear shaft. These have target lives of 22,000EFC in the -3A1 and 25,000EFC in the -3B1. Many of the original P/Ns in older engines had parts with shorter life limits of 15,000EFC.

A complete shipset of LLPs has a list price of $1.56 million in the -3A1, and $1.61 million in the -3B1 *(see table, page 38)*. In the -3A1 and -3B1, these break down as: $306,000-320,000 for the fan; $469,000-490,000 for the HPC; $382,000-400,000 for the HPT; and $391,000-408,000 for the LPT.

The annual rate of utilisation of 1,700-2,000EFC means that parts with the shorter lives of 15,000EFC will have completely utilised these LLPs after seven to nine years of operation. Aircraft built before 2005 should therefore have had these original parts in their engines removed and replaced with P/Ns that have longer life limits.

-8C1 & -8C5 LLPs

The -8C1 and -8C5 engines have 26 LLPs.

The fan has two parts; the fan disk and the fan shaft. These have target lives of 20,000EFC. The HPC has six parts: the blisk compressor for the first two HPC stages; the third-stage rotor; the rotor for the remaining seven stages; three shaft and rotor parts; and the CDP seal.

The HPT has eight parts in the -8C1, and there are seven parts in the -8C5. The LPT has eight LLPs. These include four disks, three inter-stage seals, and a turbine rear shaft.

The -8C1 has target lives of 20,000EFC in the fan, 8,000EFC in the HPC, 9,000EFC in the HPT, and 26,000EFC in the LPT. The HPC has some parts that are 14,000EFC, and the HPT has some that are 10,000EFC and 15,000EFC.

The -8C5B1 and the -8C5A1/2/3 have longer target and certified lives compared to the -8C1. Arend explains that these three variants have target lives of 25,000EFC in the fan, HPC and LPT; and 24,200EFC in the HPT. A complete shipset of LLPs for the -8C1 and -8C5 series engines has a list price of about $2.3 million.

EGT margin

The CF34-3 and -8C1/5 engines all operate at short average EFH:EFC ratios. Despite this, the engine's exhaust gas temperature (EGT) margin and its erosion during operation are not a main driver of engine removals for shop visit maintenance in the case of most variants. This is because the engine has high initial EGT margins and experiences a relatively low rate of EGT margin erosion.

The -3A1 is flat-rated to 20 degrees centigrade, so take-off thrust rating is constant up to an outside air temperature (OAT) of 21 degrees. The thrust rating has to be reduced at a steady rate for higher OATs so that the engine's EGT does not exceed the engine's red line limit. This relatively low flat-rating temperature can limit the engine's and aircraft's operating performance in certain conditions.

The -3A1 has a relatively low EGT margin, and is about 40 degrees centigrade in some cases. Mature rates of EGT margin erosion can be as high as 3 degrees per 1,000EFC. "Initial rates of EGT margin loss are higher at five to 10 degrees centigrade in the first 1,000EFC on-wing," says Paradis-Robert. The implications are that the -3A1 will have eroded all of its EGT margin after 11,000-12,000EFC on-wing on its first removal interval.

The -3B1 is flat rated to 30 degrees centigrade, and so can operate at maximum thrust at high OATs and in hot operating conditions. The engine's initial EGT margin is also generally higher at up to 55 degrees centigrade for a new engine.

Initial rates of EGT margin erosion are about 5 degrees centigrade in the first 2,000EFC on-wing, and then about 2.5 degrees centigrade per 1,000EFC thereafter. The engine should therefore be able to remain on-wing for up to 16,000EFC.

Santos at Iberia Maintenance estimates that the installed EGT margin of an engine after a shop visit is 40-50 degrees centigrade when new material has been installed, and 30-35 degrees centigrade when overhauled and repaired material is used.

LMCES says that the CF34-3B1 engines it releases into service following a performance restoration have EGT margins of 45-50 degrees. "We put a lot

The CF34-8C5A1/2/3 have LLPs with life limits of 24,000EFC and 25,000EFC. This allows the engine to be managed with a straightforward shop visit programme of a performance restoration, followed by an overhaul when all LLPs are replaced.

of effort into identifying the key factors affecting engine performance, and are able to produce engines with a fairly stable output," says Paradis-Robert.

The -8C1 and -8C5 engines have different EGT margins. In the case of the -8C1, the initial EGT margin can be as low 45 degrees for a new engine. The -8C5 variants have higher initial margins of 60-80 degrees centigrade.

Santos explains that the -8C series engines lose 5-6 degrees centigrade of EGT margin in the first 2,000EFC on-wing. The mature rate is similar at about 3 degrees per 1,000EFC, although the rate can be higher than this in hot operating environments. "This is only possible, however, if the engine is regularly washed to clean deposits from the fuel injectors."

The implications of this are first removal intervals of about 15,000EFC for the -8C1 with a low initial EGT margin, and longer intervals of 20,000EFC or more for -8C5 engines with higher initial EGT margins.

Santos explains that the average restored margin for the -8C1 is about 35 degrees, although Schrichte explains that the actual margin depends on the workscope performed, and whether new or repaired material is installed. The restored margin for -8C5 engines is similar.

Removal causes

Unlike most engines operated on short-haul missions, the CF34-3A1/-3B1 are not primarily removed due to EGT margin erosion. EGT margin erosion, and loss of performance, is also not so much of a removal driver for the-8C1. Santos explains, however, that once EGT margin starts to fail or decrease faster than usual it can be uncontrollable and decline at a relatively fast rate. "The -8C5 series has LLPs with longer lives, so EGT margin loss and deterioration is more of a removal driver with this variant," says Santos. The CF34-3 and -8C1/-8C5 engines have several issues with mechanical and hardware deterioration, however.

"EGT margin loss is a minor cause of influence on removal drivers, and only a few engines are removed before reaching LLP life limit," says Arend. "The relatively short lives of some LLPs in the -3 engines are such that LLP expiry is a main removal driver."

The CF34 variants all generally experience mechanical deterioration in the HPT and the combustor module. "The main sections of the engine influencing on-wing performance and driving removals are the HPT nozzle segments and blades, as well as the combustion liner," says Arend. "While there have been no major ADs that have affected early or staggered engine removals, the modifications for upgrading the variants to a higher performing standard have driven individual engines into a different shop visit schedule plan."

Schrichte adds that the -3 series experiences combustor baffle liberation and subsequent first-stage HPT blade damage. Paradis-Robert, also comments on combustor liner damage as being a main removal cause, and adds that loss of EGT margin is a not a big removal driver for the -3 series. "This is because most engines have now been through at least one shop visit, and a removal and shop visit is required every 5,000-7,000EFC because of the engine's LLP configuration," says Paradis-Robert. "Because of these short LLP-limited intervals, a large EGT margin is not required. If limited LLP lives do not drive engine removals, HPT hardware deterioration will be the main cause of removals. This is mainly due to deterioration of the combustor liner or the HP nozzle guide vanes (NGVs). Maintenance cost per EFH and EFC can be optimised by matching the probable on-wing life of the hot section with the LLPs installed. LMCES has developed tailored maintenance solutions to optimise LLP life utilisation and likely time on-wing based on the customer's operation."

There are a few other issues that affect the -3, such as high oil consumption, but these can be solved with on-wing procedures during airframe line and A checks. Santos points out, however, that another issue the -3 has to deal with is the HPC variable vanes operation. "The variable HPC vanes need to be calibrated regularly, since an inappropriate operation can cause them to stall, or even result in the liberation of a blade," explains Santos. "Such an event can result in the destruction of the engine's turbomachinery. There are some SBs that can be carried out to avoid these situations."

Arend comments that some of the -8 series variants, with generally longer LLP lives than the -3 series, have EGT margin erosion as a main removal driver, and that engines have to be removed for a performance restoration.

Besides the various issues of mechanical and component deterioration, the -8 series of engines also have a problem with carbon deposits in the fuel injectors in the combustion chambers which affect engine operation. This problem can be minimised or alleviated with regular water washing.

Removal intervals

-3A1/-3B1 engines

As described, the majority of CF34-3A1/-3B1 engines are 10-16 years old. The implications are that these engines have accumulated 20,000-32,000EFC total time since new. The older engines will have therefore have had most or all of their original LLPs replaced with new parts. The youngest engines will be close to replacing the original LLPs with the longest lives. The engines will therefore be mature in maintenance terms.

"The first planned removal for each variant is usually fixed by the most restrictive LLP," says Santos. In the case of -3A1 and -3B1 engines this is as short as 15,000EFC in the case of many earlier-built engines. Some later-built engines had LLP P/Ns in the HPT with lives as short as 18,000EFC.

Santos explains that LLPs in the fan module with short lives can be dealt with by replacing them with on-wing procedures. The fan module had fan disks with P/Ns with lives as short as 6,000EFC. A separate fan module shop visit can be performed if necessary, and so avoid a full shop visit on the whole of the engine.

The LLPs with the most restrictive lives, however, are some of the parts in the HPC and HPT, as described. Santos explains that unlike many other turbofans, it is possible to remove the HPT module from the rest of the engine, without a complete removal. Most operators will prefer to perform a regular shop visit at this stage and after accumulating a large number of EFC on-wing.

Santos estimates that the -3A1 can have had first removal intervals of up to 15,000EFC, which would have been limited by LLPs with a life limit of the same number of EFC. The core or HPC and HPT LLPs would have been replaced at this stage *(see table, page 38)*.

This would have been followed by a second removal after another 7,000EFC and a total time of 22,000EFC *(see table, page 38)*. Again, this removal would have been forced by the expiry of LLPs with a life limit of 22,000EFC. These particular parts would be in the fan and LPT modules.

The -3A1's complete shipset of LLPs would have been replaced in the first and second shop visits. That is, the parts in the core module replaced at the first shop visit, and the parts in the fan and LPT modules replaced at the second shop visit. "Most of the engines in service now have gone through one or two shop visits, but not through a third," says Santos.

The new parts installed in the HPC and HPT at the first shop visit will have lives of 15,000-24,000EFC, depending on P/N, and will have accumulated about 7,000EFC by the second shop visit.

The target mature interval for the third shop visit is about 30,000EFC, at least another 8,000EFC since the second shop visit and at least 15,000EFC since new HPC and HPT LLPs were installed at the first shop visit. This is because the lives of HPC and HPT P/Ns are limited to 15,000EFC, so they will expire for a second time at this interval.

Paradis-Robert comments that after the first and second intervals at total times of 15,000EFC and 22,000EFC, removals and shop visits will then occur about once every 7,000EFC. "This is basically determined by LLP lives. Building engines for lives much more than 7,000EFC is not as cost-effective, since many hot section parts would require a full overhaul, and can instead be maintained on an 'on-condition' basis," says Paradis-Robert.

The -3B1 operates in a similar way. Because the LLPs have longer lives, however, the first removal is longer at up to 18,000EFC because of the life limits of parts in the HPC and HPT. The engine will undergo a similar shop visit to the -3A1 at its first shop visit at this stage, and will have expired core LLPs replaced.

Santos says the -3B1 can be expected to have a second removal after another 7,000EFC and a total time of 25,000EFC. This interval is due to the life limits of LLPs installed at the fan and LPT, and so will require a workscope to replace these.

The third interval will therefore be limited to a maximum of 18,000EFC since the first shop visit, following

CF34-3A1/3B1 MAINTENANCE MANAGEMENT & MAINTENANCE RESERVES

Engine variant	First	Second	Third
CF34-3A1			
EFH:EFC ratio	1.20	1.20	1.20
Removal interval-EFC	15,000	7,000	8,000
Removal interval-EFH	18,000	8,400	9,600
Accumulated interval-EFC	15,000	22,000	30,000
Shop visit workscope	Perf restore	Overhaul/full scope	Perf restore
Shop visit cost-$	1,250,000	1,500,000	950,000
Shop visit reserve-$/EFC	83	214	119
LLP replacement	HPC & HPT	Fan/LPT	HPC & HPT
LLP cost-$	852,000	697,000	852,000
LLP reserve-$/EFC	89	89	89
Total reserve-$/EFC	172	303	208
Total reserve-$/EFH	143	252	173
CF34-3B1			
EFH:EFC ratio	1.20	1.20	1.20
Removal interval-EFC	18,000	7,000	11,000
Removal interval-EFH	21,600	8,400	13,200
Accumulated interval-EFC	18,000	25,000	36,000
Shop visit workscope	Perf restore	Overhaul/full scope	Perf restore
Shop visit cost-$	1,300,000	1,600,000	1,000,000
Shop visit reserve-$/EFC	72	228	91
LLP replacement	HPC & HPT	Fan/LPT	HPC & HPT
LLP cost-$	889,000	728,000	889,000
LLP reserve-$/EFC	79	79	79
Total reserve-$/EFC	151	307	170
Total reserve-$/EFH	126	256	142

installation of the new LLPs in the HPC and HPT modules. This will be up to maximum of a total time of 36,000EFC, or 11,000EFC, since the second shop visit.

-8C1 & -8C5 engines

The situation is different for the -8 series engines. First, the -8 series engines are younger than the -3 series powerplants. The -8C1 engines powering some of the earlier-built CRJ-700s are three to 13 years old, and so most will have accumulated 6,000-26,000EFC.

Schrichte says that because of the -8C1's LLPs in the HPC and HPT that have lives as short as 9,000EFC, the engine's first removal is limited to this short interval *(see table, page 39)*. "At this stage the engine is modified into a better-performing -8C5B1, and the remaining LLPs in the engine allow a second removal interval of 16,000EFC, and a total time of up to 25,000EFC *(see table, page 39)*," says Schrichte. "Because all the LLPs in the -8C5B1 have a life limit of 25,000EFC, the third removal will be up to 9,000EFC, and a total time of 34,000EFC since new. That is, 25,000EFC since new core LLPs were installed at the first shop visit *(see table, page 39)*."

The higher-rated -8C5A1/2/3 engines powering the CRJ-900 and -1000 aircraft have LLPs with longer life limits, and so as described will have removal intervals driven by EGT margin erosion rather than LLP expiry.

Schrichte and Santos estimate first removal intervals for the higher-rated -8C5 series engines to be at 10,000-12,000EFC. Because LLP life limits are longer than this, no LLPs will have to be replaced at this stage. The engine will therefore just require a performance restoration *(see table, page 39)*.

This shop visit should provide enough restored EGT margin so that the engine can remain on-wing for a second interval up to full LLP expiry. The parts with the limiting lives are those in the HPT, which have a life limit of 24,200EFC. The second interval will therefore be 12,000-14,000EFC *(see table, page 39)*. The engine will require a full overhaul at this stage to replace all LLPs. The engine and aircraft will be 12-13 years old at this stage.

Schrichte says that the -8C5A1/2/3 should be able to repeat this cycle of intervals and shop visit workscopes. The third interval should therefore be up to 12,000EFC, and the following fourth interval long enough or almost long enough to allow full LLP expiry. The aircraft will have reached an age of about 25 years at this stage. The issue of whether all-new LLPs need to be installed at this stage depends on the supply of time-continued material and engines on the aftermarket.

Shop visit inputs & reserves

-3A1 & -3B1

The shop visit pattern for the -3A1 and -3B1 engines are a performance restoration at the first shop visit, with HPC and HPT LLPs replaced as described *(see table, this page)*.

The first shop visit can use about 1,500 man-hours (MH) of labour, which if charged at $100 per MH will be equal to $150,000.

Excluding LLPs, the cost of parts and materials will be $550,000-650,000, while the cost of additional sub-contract repairs will be $500,000-550,000.

The total cost of the shop visit will therefore be $1.25-1.30 million. Amortised over the first interval, the cost is equal to a reserve of $72-83 per EFC *(see table, this page)*.

The second shop visit can be an overhaul of all major modules, and the replacement of the LLPs in the fan and LPT modules.

This shop visit will use about 2,000MH for labour, have a cost of parts and materials of up to $700,000, and a similar cost for sub-contact repairs. This would take the total cost of the shop visit, not including LLPs, to $1.5-1.6 million. This cost would be accrued over a relatively short interval of 7,000EFC, so the reserve would increase sharply to $214-228 per EFC *(see table, this page)*.

An alternative is to amortise the cost of the first two shop visits over the total interval of 22,000-25,000EFC. In this case the reserve for the shop visit inputs would be $116-125 per EFC.

The third shop visit would occur after a shorter interval, so inputs would be lower than in the first shop visit. Total cost could be expected to be $0.9-1.0 million. This cost would be amortised over an interval of 8,000-11,000EFC, so reserves for these inputs would be $91-119 per EFC *(see table, page 38)*. These reserves for the three shop visits assume equivalent costs over the complete life cycle of the three removals. That is, the costs of the three visits assume zero inflation over the term.

The additional elements of LLP replacement can also be considered on an equivalent-dollar basis. The calculation of reserves is complicated by the fact that the reserves for the replacement of fan and LPT parts are accrued over the period equal to the first and second removal intervals. The reserves for parts replaced are then accrued over the third and probable fourth removal interval.

This is while the reserves for the HPC and HPT parts are accrued over the first interval, and the replacement parts are accrued over the second and third interval.

Overall, the reserves for LLPs will be $89 per EFC for the -3A1 and $79 per EFC for the -3B1 *(see table, page 38)*.

The total reserves for both main elements of maintenance are therefore $172-303 per EFC, and $143-252 per EFH for the -3A1 *(see table, page 38)*. The equivalent reserves for the -3B1 are $151-307 per EFC, and $126-256 per EFH *(see table, page 38)*.

CF34-8C1/-8C5 MAINTENANCE MANAGEMENT & MAINTENANCE RESERVES

Engine variant	First	Second	Third
CF34-8C1/-8C5B1			
EFH:EFC ratio	1.50	1.50	1.50
Removal interval-EFC	9,000	16,000	9,000
Removal interval-EFH	13,500	24,000	13,500
Accumulated interval-EFC	9,000	25,000	34,000
Shop visit workscope	Perf restore/ mod to -8C5B1	Overhaul	Perf restore
Shop visit cost-$	1,000,000	2,000,000	1,200,000
Shop visit reserve-$/EFC	111	125	133
LLP replacement	HPC & HPT	Fan/LPT	HPC & HPT
LLP cost-$	1,360,000	980,000	1,360,000
LLP reserve-$/EFC	151	93	93
Total reserve-$/EFC	162	218	226
Total reserve-$/EFH	108	145	151

CF34-8C5		
EFH:EFC ratio	1.30	1.30
Removal interval-EFC	10,000-12,000	12,000-14,000
Removal interval-EFH	13,000-15,600	15,600-18,200
Accumulated interval-EFC	10,000-20,000	22,000-24,000
Shop visit workscope	Perf restore	Overhaul
Shop visit cost-$	1,200,000	2,000,000-2,100,000
Shop visit reserve-$/EFC	100-120	150-167
LLP replacement	None	Complete shipset
LLP cost-$	0	2,300,000
LLP reserve-$/EFC	92	92
Total reserve-$/EFC	192-202	242-257
Total reserve-$/EFH	148-155	186-198

-8C1 & -8C5

In the case of the -8C1, which is converted to the -8C5B1, the first shop visit will be larger than the regular performance restoration. This will involve the modification kit to covert to the -8C5B1. This includes the installation of new turbomachinery for the HPC and HPT, as well as some of the LPT, including the LPT shaft. The cost of this conversion is expected to be up to $1 million. It will cost less than a core performance restoration, since a lot of hardware is simply replaced. This will save a lot of labour and many of the costs relating to sub-contract repairs. The cost for this first shop visit is accrued over an interval of 9,000EFC, so the reserve is $111 per EFC *(see table, this page)*.

The second shop visit will be a full overhaul of all modules. Not including LLPs, this shop visit has a cost of about $2 million. Accrued over the longer 16,000EFC interval, it has a reserve of $125 per EFC *(see table, this page)*.

The third shop visit will be a core performance restoration, incurring a cost of about $1.2 million. Over an interval of 9,000EFC, it has a reserve of $133 per EFC *(see table, this page)*.

The first shop visit will also include the replacement of LLPs in the HPC and HPT, while fan and LPT LLPs will be replaced at the second shop visit. The HPC and HPT parts installed at the first shop visit will have to be replaced at the third shop visit. On an equivalent dollar basis, the reserves for LLPs over the three intervals will be $151 per EFC for the first interval, but then reduce to $93 per EFC for the second and third intervals. Total reserves will therefore be $162-226 per EFC, and equal to $108-151 per EFH *(see table, this page*.

The -8C5 series will have a simpler shop visit pattern. As described, the first visit will be a performance restoration, without the replacement of any LLPs. This will cost $1.2 million. The reserve for this will be $100-120 per EFC *(see table, this page)*. This will be followed by a full overhaul after another 12,000-14,000EFC. This will have a cost of $2.0-2.1 million, and an associated reserve of $150-167 per EFC *(see table, this page)*. The alternative is to combine the cost of these two inputs and amortise them over the total of the two intervals. The reserve for the full cost over the complete interval is therefore $132-145 per EFC.

The LLPs are all replaced in their entirety at the second shop visit and overhaul. The cost of $2.3 million is accrued over the interval of 25,000EFC, and is equal to a reserve of $92 per EFC *(see table, this page)*.

The total reserve for the shop visit inputs and LLPs is therefore $192-202 per EFC and $148-155 per EFH for the first interval, and $242-257 per EFC and $186-198 per EFH for the second interval *(see table, this page)*. All costs accrued over the two intervals are equal to an average reserve of $224-237 per EFC, and $172-182 per EFH. AC