The CF6-80C2 is now mature in most operators' fleets. The CF6-80C2 has the widest application of any widebody engine, and has caused few technical problems to airlines. Removal intervals are stable and predictable, as are shop visit inputs and workscope costs that contribute to competitive aircraft maintenance costs.

Mature CF6-80C2 provides steady maintenance costs across wide applications

The CF6-80C2 is a widely used widebody engine, with applications on six aircraft types. These are the 767-200, -300, 747-400, A300-600, A310-300 and MD-11. There are more than 2,850 CF6-80C2s installed on 1,135 aircraft. The CF6-80C2 repair and overhaul market is estimated to be about 1,000 shop visits per year.

CF6-80C2 in operation

The CF6-80C2 operates a wide range of flight cycle times on the aircraft it powers. The shortest are routes where it powers the A300-600R, with flight times of one flight hour (FH). The other extreme is ultra long-range sectors on the 747-400 for carriers such as Japan Airlines, All Nippon Airways and Air New Zealand. The longest 747-400 routes operated by these airlines are in the region of 12-13 flight hours (FH). Between these two extremes are more typical long-haul routes operated by the 747-400, 767-300ER and MD-11, and medium-haul routes operated by the A310-300 and the 767.

The different aircraft variants and average flight times means that different thrust ratings are required by the CF6-80C2. There are a family of CF6-80C2 variants, with thrust ratings between 53,500lbs and 61,500lbs. These are summarised *(see table, page 24)*, along with the aircraft type they power and their standard thrust rating. This difference in ratings means that engines in operation are subject to different power settings (and therefore rates of deterioration), with a consequent variation in on-wing reliability.

The -80C2D1 on the MD-11 has the highest thrust rating and is operated on relatively long flight sectors. The MD-11's configuration means engine de-rate is the lowest of most CF6-80C2s in operation. Most MD-11 long-haul operations have average flight cycle (FC) times of 6-7FH. "We operate our aircraft to New York, Tokyo, Bangkok, Singapore and Beijing," says Janne Tarvainen, CF6 engineering manager at Finnair. "Although these have flight times longer than 6-7FH, one aircraft operates charter flights, which reduces the average."

KLM is another MD-11 operator of the CF6-80C2, and also has a 6.0FH flight time for the -80C2D1F, with operations from Amsterdam to the Caribbean and South America. Alitalia has a high FC time for MD-11 operators of 8.0FH.

The -80C2B1F/B5F is also rated at 61,500lbs for the 747-400, as well as the -80C2B7F for the 767-300ER. Most 747-400 operations operate average FC times of 8FH, since the average FC time is reduced by airlines making multiple stop flights. KLM, for example, operates the 747-400 from Amsterdam to Bangkok, and then on to Taipei.

There is wider variation in 767 operations, since the aircraft is used on short-, medium- and long-haul operations by airlines. KLM, for example, uses the 767-300ER from Amsterdam to London, and also on longer flights to the Middle East, Africa and the US. Its average FC time is 4.5FH.

Delta Airlines uses the CF6-80C2 on its 767-300ERs and 767-400s. US domestic operations average 2.5FH, while international are about 6.7FH. Average FC time across the fleet is 4FH.

In contrast, Alitalia and Air France use the 767-300ER strictly as a long-haul aircraft, and both have an average FC time of 8.0FH.

The A310-300 is used by most carriers for medium-range operations. Air France operates an average FC time of 4.5FH, using the A310-300 for operations from Paris to West Africa, the Middle East, and the Persian Gulf.

Lufthansa has one of the widest applications of the CF6-80C2, since it operates it on the 747-400, MD-11F, A300-600 and A310-300. "In recent years one half of the Lufthansa A300-600 and A310-300 fleet was operated with a cycle time of 3FH and the other half with a cycle time of 1FH," says Burkhard Culeman, propulsion systems engineering of the CF6-80C2 at Lufthansa Technik. "Currently all of our A300-600s and A310-300s are operated with a cycle time of 1FH, primarily within Germany."

Engine management

In maintenance terms, the CF6-80C2 is a mature engine, with the majority having gone through their third shop visit. All have had their first shop visit, and only a minority have yet to go

CF6-80C2 SERIES FAMILY THRUST RATINGS AND APPLICATIONS

Engine variant	Thrust rating (lbs)	Aircraft application
CF6-80C2B2	52,500	767-200/-200ER
CF6-80C2B2F	52,500	767-300ER
CF6-80C2A2	53,500	A310-200ADV, A310-300
CF6-80C2B4/B4F	57,900	767-300/-300ER
CF6-80C2B1F	57,900	747-400
CF6-80C2A3	58,950	A300-600
CF6-80C2A8	59,000	A310-300
CF6-80C2A1	59,000	A300-600
CF6-80C2B6/B6F	60,800	767-300ER
CF6-80C2-B1F1/F2/B5F	61,500	747-400
CF6-80C2A5F	61,500	A300-600R
CF6-80C2B7F	61,500	767-300ER
CF6-80C2D1F	61,500	MD-11

through their second. The implications are that on-wing intervals have matured.

"Our first run engines on the 767 and 747 achieved an average interval of 22,000 engine flight hours (EFH)," says Didier Verte, product manager GE engines at Air France Industries. "Second and third run engines achieved 16,000-18,000EFH, and we now expect mature engines to achieve 14,000EFH on both aircraft. The engines on the A310-300, operating shorter average flight times, will have a mature interval of about 11,500EFH. These intervals have to be considered against our maintenance policy of aiming for the longest possible on-wing time."

The on-wing times of other operators also indicate maturity. "We had intervals of about 20,000EFH for first run engines on the 747-400, but they are now at their third or fourth run and achieve in the region of 12,000EFH," says Peter Van Altena, senior engineer powerplant engineering at KLM Engineering & Maintenance. "Mature engines have steady removal intervals."

In parallel to this, the CF6-80C2 is also regarded as being an engine that is not sensitive to exhaust gas temperature (EGT) margin. The rate of CF6-80C2 EGT margin erosion is low enough for it not to be a main driver of removals for shop visits.

The CF6-80C2 is managed by most operators with shop visit workscopes determined by thresholds of on-wing times for each module, rather than whole engines. A performance restoration can be performed on one module, while an overhaul can be performed on another.

Although applications for the CF6-80C2 vary, the mature average on-wing times between removals have matured at levels exceeding 10,000EFH. For most aircraft applications this is less than 2,500 engine flight cycles (EFC). The life limited parts in the engine have lives of 15,000FC or 20,000FC in most cases. The replacement of LLPs will thus only start at the fifth shop visit for long-haul engines, unless engines operate shorter average FCs. Most operators have an LLP 'stub life' policy to avoid early engine removals. LLPs on engines used on short cycles can still be swapped with ones operating longer cycles, as is practised by Lufthansa Technik.

Removal intervals

The CF6-50 series had removal intervals more consistent with EFCs than EFHs. The CF6-80 series also appears to have removal intervals more consistent with EFCs.

Lionel Van Buylaere, engineering manager at TES, says engines with lower thrust ratings and shorter average FC times achieve on-wing times in the region of 2,500FC, while engines with higher ratings and longer average FC times achieve about 1,800FC.

Delta, which has an average FC of 4FH, has an average interval of 2,257EFC, equal to 9,100EFH.

The -80C2D1F powering the MD-11 has the highest thrust rating, as well as one of the lower de-rates in operation. "We have got intervals as high as 20,000EFH, but our average varies around 10,500EFH," says Tarvainen. This equates to about 1,750EFC.

Alitalia achieves 14,000-20,000EFH on its MD-11s, equal to about 2,000-2,500EFC. The airline, however, operates longer average FC times than Finnair. KLM achieves similar times to Finnair on the MD-11, averaging 12,000EFH and 2,000EFCs.

EFH and EFC intervals for the -80C2B1F on the 747-400 vary. KLM achieves 12,000EFH, similar to the MD-11, but has longer flight cycles and so achieves about 1,500EFCs.

Air France's 747/767 engines currently achieve average intervals of about 18,000EFH/2,250EFC, but Verte expects this to reduce to about 14,000EFH/1,750EFC when the engine matures. Verte says the -80C2 family's removal intervals are more consistent with EFCs, since Air France's own engines have a wide variation in average FC times and EFH intervals, but similar EFC removal intervals. "The mature engines on the A310-300 average about 11,500EFH/2,500EFC," says Verte. This illustrates Van Buylaere's point of lower thrust rated engines having intervals close to 2,500EFC, and higher rated engines in the region of 1,800EFC.

Lutz Winkler, manager engineering at GE engines illustrates this point even further. "The -80C2A2 powering the A310-200 and low gross weight A310-300s, rated at 53,500lbs, has intervals as high as 4,000EFC. Engines powering the MD-11 or A300-600R will have shorter intervals closer to 2,500EFC."

Engines powering the 767 have intervals similar to those on the 747-400 when similar average FC lengths are operated. Van Altena, for example, explains that when engines on the 767 are operated at long FC lengths of 5.0FH it achieves intervals of about 1,2000EFH/2,000EFC. This comes down to about 10,000EFH when they operate at average FC times of 4.0FH, but this represents an increase in EFC interval to 2,500.

Lufthansa's intervals between removals demonstrate consistency of the CF6-80C2's reliability. The -B1F on the 747-400 has an interval of 14,000-15,000EFH (1,700-1,800EFC), while the A2/3/5 on the A310-300/A300-600 achieves about 4,000EFC. The -D1F on the MD-11 is too young for us to see what the mature interval will be, but we expect 12,000-13,000EFH.

Removal drivers

Like many engines designed for long-haul operations, CF6-80C2 removals are not driven by EGT margin erosion. Restored EGT margin after a shop visit varies, but erosion during the on-wing interval leaves a wide EGT margin at removal. Removals for shop visits are therefore driven by other factors.

"The test cell EGT margin depends on the engine variant and the workscope performed," explains Winkler. "A refurbished margin of the lowest rated variant may be 60 degrees centigrade on a hot day, while the highest rated engine will be 30-35 degrees in the same

CF6-80C2 removal intervals are stable and predictable. Intervals range from 1,700EFC for engine operated on long cycles to 4,000EFC for engines flying one hour cycle missions.

conditions". This has to be considered with the fact that test cell margins and on-wing margins are different.

"We have a restored margin of 25-30 degrees and remaining margin of 5-10 degrees centigrade at removal," says Tarvainen. "This means margin erosion on the MD-11 is about 2.2 degrees per 1,000EFH on-wing time. We also have on-wing cleaning to extend removal interval."

Van Altena says his experience of the -80C2 is similar with respect to EGT margin erosion. "It is not actually a goal of a shop visit workscope to get a high EGT margin. The way the engines are used means they have a good application. Only the highest rated -80C2D1F on the MD-11 is sensitive to EGT margin erosion, since it has high take-off thrust level and we also use it in a hot environment. This explains why the engine has a similar on-wing time to the engines used on the 767, despite the MD-11 engines having a longer FC time."

Van Buylaere puts typical EGT margin erosion rate at about 12 degrees centigrade per 1,000EFC. Only the highest rated -80C2s usually have removals due to EGT margin erosion.

There are several other factors which cause engine removal for a shop visit before EGT margin is fully eroded in most cases.

"The CF6-80 is generally regarded as a very reliable engine, presenting few problems or unscheduled removals. Most CF6-80s are maintained on an 'on-condition' basis," says Van Buylaere. "There are various technical problems which force removals. These include problems with the high pressure turbine (HPT) stage 2 nozzle guide vanes (NGV), which is the engine's weakest problem. Despite new parts being introduced, they still experience burning, cracking and chipping. This causes damage to HPT stage 2 blades, which is detected during borescope inspections.

"Other problems are stage 1 and 2 HPT blade distresses, and various airworthiness directives (ADs) that cause removals. These include low pressure turbine (LPT) blade shroud replacement, inspection of the 3-9 stage high pressure compressor (HPC) spool and inspections of the fan mid-shaft," explains Van Buylaere.

"The problem of the CF6's 3-9 HPC spool has a long history. The spool basically has crack problems, and there have been a few uncontained failures. A succession of AD notes were issued and these have increasingly resulted in more frequent non-destructive test (NDT) inspections," explains Culeman. "The consequences are the currently active AD notes 99-24-15 and AD 2000-16-12 are forcing early removals, so the 3-9 spool can be inspected. These inspections are about every 2,000-3,500EFC. Generally spools which have accumulated more than 10,500EFC cannot be reinstalled. A new AD note which will supersede the existing two ADs is expected to be released in early 2002. There are new post-Service Bulletin 72-937 parts which are not affected by forced or early removals for inspection and Lufthansa will introduce these parts on an accelerated basis."

Other removal drivers include 3-5 HPC blade failures and variable stator vane (VSV) bushing wear.

Besides these individual problems, general deterioration of performance forces the requirement for a performance restoration shop visit workscope.

Verte explains that Air France Industries has analysed the prime removal causes for the CF6-80C2. "The most common cause is deterioration of the stage 2 NGV, which results in a removal at an average interval of 15,000EFH. The second is the VSV with an average interval of 20,000EFH. Thus, if the stage 2 NGV problem was eliminated we would probably achieve an average interval of 20,000EFH. The third most common problem is the stage 1 HPT blades with an average failure interval of 30,000EFH, and fourth is oil leaks at an

On-wing intervals for the CF6-80C2 operated on the longest flight cycles times powering the 747-400 are managed by most operators to be in the region of 14,000EFH. Air France, however, believes the lowest cost per EFH can be achieved by extending on-wing intervals, and aims for 18,000EFH between removals.

average interval of 16,000EFH. That is, even though the average interval for problems due to oil leaks is 16,000EFH, the number caused by this is few compared to other problems. If we could eliminate the most common causes in turn, our average on-wing interval would increase."

Air France Industries' maintenance philosophy on the CF6-80C2 is to achieve the longest on-wing intervals possible. "Most airlines aim to find the optimum on-wing time that results in the lowest maintenance cost per EFH, in the belief that long on-wing times can start to increase shop visit workscope costs disproportionately," says Verte at Air France Industries. "We believe in extending on-wing time for as long as possible, since we think this will continue to reduce cost per EFH. Our experience is that the workscope after an on-wing time of 10,000EFH will have similar scrap rates of expensive parts as a workscope for an engine removed after 14,000EFH. Factors that increase on-wing times are good line maintenance and condition monitoring."

Shop visit workscopes

Shop visit workscopes for the CF6-80 series are based on workscopes for the modules, rather than the whole engine. Airlines and engine shops have two or three workscope levels and different on-wing removal thresholds for them for each module. The thresholds are based on a workscope planning guide, and are generally lower for the higher pressure sections of of the engine.

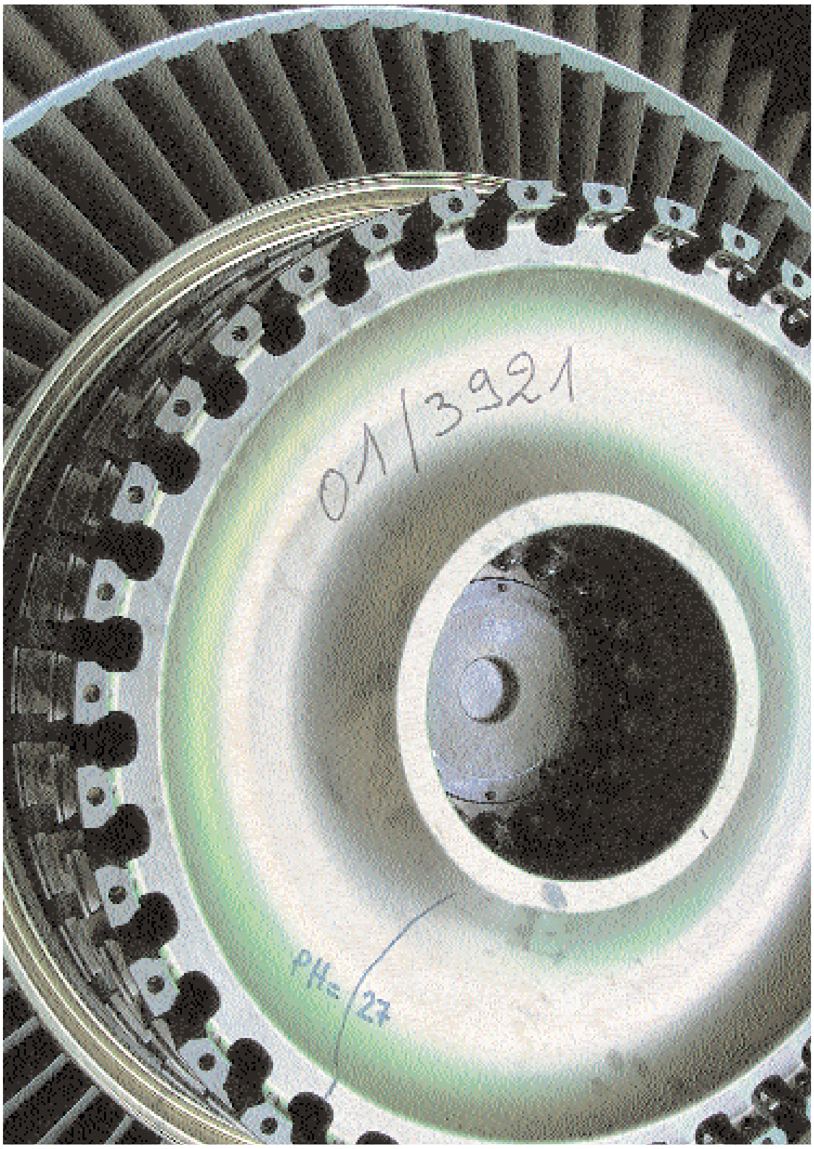
The three workscope levels are minimum repair, performance restoration and overhaul. "The lower threshold of the hot section means the other modules could remain assembled until a performance deterioration occurs at a higher threshold," explains Van Buylaere. "The HPT is the most likely to fail, so one or two performance restorations could be done for every HPC refurbishment and the fan and LPT opened as necessary."

Finnair tries to maintain a simple and consistent pattern of shop visit workscopes. "We aim to have performance restorations at each shop visit," explains Tarvainen. "This pattern reduces component repairs, and also allows us to find the optimum time on-wing for removing the engine. This makes it possible to increase the portion of parts repaired. We find the cost of materials and sub-contract repairs are similar for on-wing times of 10,000EFH and 18,000EFH. The problem is that specific on-wing inspections force removals."

Most other airlines work to an approximate shop visit workscope pattern for each module. Winkler explains the approximate pattern of workscopes. "The first shop visit will see a minor repair or possibly performance restoration of the HPC, and an overhaul and LLP management at the second. The second workscope is designed such that the third shop visit requires the same workscope for the HPC as the first shop visit. Because the condition levels and workscope will be different for each module, the modules in the engine will be at three different levels of work status".

Alitalia operates a system whereby the core section of the engine (the HPC, combustor and HPT) has an alternating pattern of performance restorations and overhaul. The low pressure system goes through an alternating system of repair and overhaul.

Culeman explains that Lufthansa Technik's goal is to have an optimised workscope that will achieve the average on-wing intervals it has established for the aircraft type it operates. "The aim is to have a core engine refurbishment or overhaul on the core engine modules, which includes the HPC, combustors and HPT every shop visit. We overhaul the low pressure system, the LPT and LPC, every second shop visit, with lighter workscopes on the alternating shop visits." Like other operators, Lufthansa Technik uses thresholds of accumulated time on-wing as a guide to the level of workscope that should be performed on each module. As an example, the threshold for an overhaul on the HPC is an accumulated utilisation exceeding 24,000EFH/6,000EFC. Thresholds for a performance restoration are 12,000-24,000EFH or 3000-6,000EFC, while a minor repair is performed for lower accumulated time on-wing than this. "These are guides, and the actual workscope carried out also depends on the results of the inspection made when the engine comes into the shop as well as the condition monitoring results while the engine was in operation. Other issues also influence workscopes. The problems with the VSV bushings may result in an overhaul on the HPC, and the AD on the turbine disk can require inspections of



Most LLPs in the CF6-80C2 have lives of either 15,000EFC or 20,000EFC. Depending on average flight cycle time, on-wing interval and stub life policy, reserves for LLPs should be in the region of $22-57 per EFH.

turbine LLPs, thus requiring full engine disassembly," explains Culeman.

KLM Engineering & Maintenance has a similar system of thresholds for each module for the three levels of workscope. "The low pressure compressor module, the booster and fan, has a performance restoration threshold of 2,500EFC and overhaul threshold limit of 5,000EFC," says Van Altena. "The modules which have higher temperatures and pressures, and so faster rates of wear, have lower thresholds for the same workscope. The HPC's performance restoration threshold is 1,500EFC. These are guidelines, but actual workscope performed will also depend on the damage assessment at inspection, which can require a higher workscope. Our customers which are part of our pool agreement use the same system. Others define their own workscopes."

Air France also uses different thresholds for performance restorations and overhauls, and again inspections at removal and findings from condition monitoring also determine the exact workscope. "It is possible the HPC can have accumulated more time on-wing than the threshold for a performance restoration but the inspection may reveal it is in excellent condition. In this case we will do a lighter workscope," says Verte. "The maximum accumulated time on-wing for performance restoration workscopes are 2,000EFC for the HPC and HPT and 6,000EFC for the LPT. The overhaul thresholds are 2,500EFC for the fan, 6,000EFC for the booster, HPC and LPT and 4,000EFC for the HPT.

"The condition of the first stage turbine blades are the main factor driving the workscope in the HPT. Work always has to be done on the HPT, so even if it is removed 1,500EFC after an overhaul, a performance restoration will have to be done even though it has not reached the threshold of 2,000EFC. The same threshold of 6,000EFC for both a performance restoration and overhaul are the same because the workscopes are similar. Because we have an engine pool we mix modules when we reassemble engines. After three removals the workscope status of modules throughout the engine will be mixed," explains Verte.

Workscope inputs

Workscope inputs fall into three broad categories. These are man-hours (MH), cost of materials and cost of sub-contract repairs. The workscope will determine the balance between materials and sub-contract repairs.

Higher workscopes incur a higher level of parts replacement, and thus material cost. A higher level of repaired parts will have a higher input for MH and sub-contract repairs. The relative differences between these two will depend on the in-house repair capability of the engine shop. A shop with high repair capability will have a high MH input and low sub-contract repair cost.

Lufthansa Technik has developed improved in-house repair techniques to increase the percentage of parts repaired. This comes in the light of the increasing cost of new parts. "The improvement in repairs we have made has taken into consideration the effect of repaired and new parts on engine on-wing life," explains Holger Buenning, sales executive, engine parts and accessories at Lufthansa Technik. "That is, repaired parts may result in poorer on-wing life, so high quality repair techniques have to be devised which result in longer on-wing times. We have to do this in parallel with reducing the cost of repairs, so that there is an overall economic improvement. If these are adopted the engine operator will experience a long-term reduction in maintenance cost. This is because parts with high quality repairs can last an additional engine shop visit. For example, we have developed the advanced re-contouring process. This is a method of grinding the leading edges of HPC blades with robots. These improve the aerodynamics of the blades and the efficiency of the compressor. So the engine has better fuel consumption and higher EGT margin than one with blades repaired using conventional techniques.

"Engine on-wing life is increased, and the optimum on-wing life that achieves the lowest maintenance cost per EFH is also increased. This has other knock-on benefits, such as reducing the number of spare engines, says Buenning."

Shop visit inputs will vary according to module workscopes, but at a labour cost of $70 per MH total cost varies between $1.5 million and $1.8 million.

Labour inputs are dependent on in-house repair capability and the degree of parts repaired. A quantity of routine labour will be required for disassembly, inspection, assembly and test. Winkler and Tarvainen estimate that engines with lighter workscopes consume in the region of 4,000MH for a shop visit, while those incurring more overhauls in their modules or higher parts repair will require nearer 5,000MH. Labour cost will thus be $280,000-350,000 according to workscope.

Material inputs by many shops are estimated to be in the region of $1.0 million, although lower estimates are $800,000 and higher $1.15 million.

"Material costs in engines removed for the first or second time were closer to $0.5 million," says Tarvainen "but engines at third or fourth removals are showing maturity and cost of materials has grown rapidly to the $1 million level as the engine has matured. For example, retrofitting of HPT blades, the replacement of LPT blade shrouds and 3-5 HPC blade replacement have raised material costs."

Verte comments that the parts with high scrap rates are stage 2 NGVs and stage 2 HPT blades. "Stage 1 HPT blades now last longer, so there is no need to scrap all of them in engines that are used on long-range missions," says Verte.

Sub-contract repairs are expected to incur in the region of $250,000, with Tarvainen estimating costs of $350,000 for heavier workscopes. This is, however, for the -80C2D1F, which is subject to heavier operating conditions than most other variants.

Lighter workscopes, of engines with a high level of performance restorations on the majority of modules, incur a total shop visit cost of about $1.5 million, excluding LLPs. This cost is a typical rate charged for engines repaired on a third-party basis. "The actual cost depends on the airfoil scrap rates in the HPT. The cost of $1.5 million reflects a light repair on the HPC," says Van Buylaere.

A heavier workscope will have a third-party cost approaching the level of $1.8 million. "If both the HPC and HPT are overhauled then the cost will exceed $2.0 million, excluding LLPs, depending on airfoil scrap rates. If the LPT requires a full overhaul because stage 1 NGVs are creaked then up to another $300,000 will be added, because each stage 1 NGV costs about $20,000," says Van Buylaere.

Verte adds that cost of a shop visit with a heavier workscope will be higher because of a higher level of repairs and material costs. "The cost of heavy shop visit can be 20-50% higher than a light one," warns Verte. A heavy shop visit can therefore cost $1.8-2.3 million. The average shop visit cost of mature engines will therefore be in the region of $1.8 million.

LLPs

A full shipset of LLPs has a list price close to $2.7 million. There are 20 different LLPs, and there are different part numbers for each part. "Generally, LLPs in the N2 system (HPC and HPT) have lives of 15,000-20,000EFC, while N1 parts should have lives of 20,000EFC," says Culeman. "A few part numbers, however, do not meet this goal due to older design or AD requirements. Higher thrust variants like the A5F, B5F, B7F and D1F may have less cycles for

SUMMARY OF CF6-80C2 SHOP VISIT COSTS AND ENGINE RESERVES

Aircraft application	A300-600/ A310-300	767-300ER	MD-11	747-400
Engine	-80C2A5/3	-80C2B6F	-80C2D1F	-80C2B1F
Average EFC (EFH)	3.0	4.0	6.0	8.0
Shop visit interval (EFC/EFH)	2,500/ 7,500	2,200/ 8,800	1,800/ 10,800	1,700/ 13,600
Average shop visit cost-$	1,900,000	1,900,000	1,900,000	1,900,000
$/EFH	253	216	176	140
Stub life LLP (EFC)	3,000	3,000	3,000	3,000
Shop visit replacement for 15,000EFC LLPs	5th	4th	6th	7th
Shop visit replacement for 20,000EFC LLPs	7th	6th	9th	10th
$/EFH LLPs	57	58	31	22
$/EFH total	310	274	207	162

some part numbers. Because parts can be used in different engine applications special calculations have to be made to determine the remaining lives of LLPs. With the exception of the 747-400 (B1F), most of the aircraft require the high thrust variants of the engine."

Besides actual lives of LLPs, operators also have to consider stub life policy. LLPs should not be kept in an engine after a shop visit if their remaining life is short enough to force a removal when the condition of the rest of the engine would allow continued operation. Most operators with long average EFC times, which usually result in on-wing intervals in the region of 1,700-2,500EFC, usually have the policy of removing LLPs with lives less than 2,500EFC at a shop visit. Engines being operated on short cycles can achieve on-wing intervals of 4,000EFC or more, and so operators will have a stub life policy of removing LLPs with remaining lives less than 5,000EFC, or even 6,000EFC in some cases.

Stub life policy means the actual lives of LLPs that can be used are considerably less than the life limits. A stub life policy of 2,500EFC means LLPs with lives of 15,000EFC will rarely use more than 11,000EFCs before being scrapped. Parts with lives of 20,000EFC will rarely use more than 16,000EFC.

Engines with average EFC times of 6-8 EFH will have 15,000EFC LLPs replaced every six or seven shop visits. The 20,000EFC parts can be replaced every nine or 10 shop visits.

Engines on shorter average cycle times of 3-4EFH will have shorter life LLPs replaced every fourth or fifth shop visit, and longer life parts about every sixth shop visit.

The extreme is engines being operated on 1FH cycles, which therefore have parts replaced every third or fourth shop visit.

Parts with lives of 15,000EFC have a total list price of $740,000, and those with 20,000EFC lives about $1.94 million.

The implications of stub life policy and probable replacement timings means that the amortised cost of LLPs over their used lives is $176 per EFC for engines used on cycle times of 8FH, equal to $22 per EFH *(see table, page 30)*. This increases to $193 per EFC and $64 per EFH for engines operating a 3FH cycle *(see table, page 30)*. Thus engines operating short flight cycles will have high reserves for LLP. These costs will be added to amortised shop visit costs that do not include the cost of LLPs.

Maintenance reserves

Total maintenance reserves will depend on the operation concerned. Shop visit costs vary, but mature engines will have a mixture of shop visit workscopes for the modules in the engine. Shop visit costs will increase after the first removal, but move to a mature level.

Based on an average shop visit cost of $1.9 million, engines operating on the 747-400 (and similarly on the 767-300ER) with an EFC time of about 8FH will have a maintenance cost equal to $140 per EFH *(see table, page 30)*. This is based on an average removal interval of about 14,000EFH. This is high compared to the PW4000, also powering the same aircraft. The PW4000 achieves lower rates per EFH because it has longer on-wing times of about 18,000EFH, despite having similar shop visit costs. Air France's experience. however, demonstrates that intervals as high as 18,000EFH are possible with the CF6-80C2B1F, even though it expects them to reduce to about 14,000EFH once the engine has reached maturity. When reserves for LLPs are added total cost is $162 per EFH *(see table, page 30)*. This equates to an engine maintenance reserve of $650 per FH for the 747-400 and $330 per EFH for the 767-300ER.

While the CF6-80C2 has many applications, it appears that its shop visit costs do not vary much. Thus, the -80C2D1F powering the MD-11 operating a 6FH cycle will have a shorter interval and consequently a higher reserve of about $170 per EFH for shop visits and additional cost of $31 per EFH for LLPs taking the total to $207 per EFH, and $620 per FH for all three engines on the aircraft.

As average cycle times reduce reserves per FH increase. Engines on flight cycles of 4FH, which might power the 767, A300-600 or A310, will have reserves in the region of $190 per EFH, which will total $241 per EFH when LLPs are accounted for *(see table, this page)*.

Total reserves, including LLPs, will total about $350 per EFH when average cycle time is reduced by just one hour to 3FH *(see table, this page)*. Thus the relationship between total reserve per EFH and average cycle time is approximately exponential.

These reserves are at costs incurred by airlines which have their engines repaired on a third-party basis. Reserves for engines which are repaired and overhauled by an airline's own internal engine shop will be less, provided efficiencies are possible. This depends on labour utilisation, which in turn depends on engine shop throughput. Many other factors will influence final costs, some of which include part scrap levels and the quality and cost of repairs.