The CF6-50 will continue to operate in large numbers for another 20 years. The engine has to be managed carefully, but can contribute to reasonable total maintenance costs of the aircraft it powers. The CF6-50's costs are on a par with those of the JT9D.

Ageing CF6-50 delivers acceptable maintenance costs

There are about 2,100 CF6-50s powering about 590 747-200/-300s, DC-10-30s and A300B4s. The CF6-50's most important role has evolved into powering a large fleet of widebody freighters. The portion of passenger aircraft will continue to decline.

The CF6-50 won majority market share on the 747-200, and CF6-powered 747s are the most popular with freight carriers. This is underwritten by dominant Atlas Air's insistence on acquiring only CF6-powered 747-200s. Demand for Rolls-Royce- and Pratt & Whitney-powered aircraft is weaker.

The DC-10-30 and A300B4, which are almost exclusively powered by the CF6, are also popular freighters. A smaller number of 747s and DC-10s will continue in passenger configuration. These three aircraft types will continue in operation for another 15 years and will support a global population of about 1,900 engines. This will generate about 1,000 shop visits a year.

CF6-50 in operation

The CF6-50C2 powering the A300B2/4 is rated at 52,500lbs thrust. About 80 A300B4s have been converted to freighter, and it is expected that only another 20 aircraft will be modified. Most other A300-B2/4s will be scrapped, leaving a surplus of engines for the aftermarket.

The majority of A300B4Fs operate short to medium flight cycles (FCs) in the 1.5-2.0 flight hour (FH) range, carrying small package freight. Exceptions are carriers that operate the aircraft over the Atlantic with technical stops. Aircraft utilisations on most freight operations are in the region of 2,000-2,500FH and 1,200-1,400FC per year.

While FCs are short, freight operation can mean engine thrust derate is low. Most aircraft operate in a cool environment.

The CF6-50C2 on the DC-10-30 is rated at 52,500lbs thrust. There are 50 DC-10-30Fs and about another 10 being modified or awaiting conversion. The majority of these are operated by FedEx and Gemini Air Cargo.

About another 110 operate as passenger aircraft. Major carriers are Northwest, Garuda, Air Canada/Canadian. Average FC times for passenger and freight carriers are 2-5FH. Several airlines also operate in hot environments. Engine thrust derates are variable, with corresponding differences in intervals between removals. DC-10 operations generate 3,000-3,500FH per year. Annual FC will be 600-1,500 per annum.

The CF6-50E2 powers the 747-200, rated at 52,500lbs. Many CF6s installed on fleets operated by major passenger carriers fly on Combi configured aircraft. Consequently aircraft gross weights are higher than many passenger operations. The same is true for freighter aircraft. Again, low thrust derates are common in many cases, but most airlines operate in cool environments. FC times average 5-8FH. Annual utilisations are about 4,200FH and 600FC per year for passenger aircraft. Freighters operate the shorter cycles and so gain about 800FC per year.

Major carriers are KLM, Air France, Lufthansa, Alitalia, All Nippon Airways and Atlas Air.

Engine management

The CF6 requires the same level of management for maintenance as all other engines in many respects. The CF6-50 has the added complication of a wide variation in the engine flight cycle (EFC) life limits of life-limited parts (LLPs).

To achieve the lowest possible maintenance costs per engine flight hour (EFH), airlines and maintenance facilities have to strike a balance between on-wing times between removals, shop visit workscope and consequent cost, and replacement intervals of LLPs.

Finnair provides a total maintenance support agreement and manages CF6-50 maintenance for DC-10-30 and A300B4 operators. "We manage engines so that we can remove them and customise shop visit workscopes so they achieve the optimum cost at the bottom of the cost per EFH U-curve," explains Tuomo Karhumaki, manager powerplant department at Finnair. "This takes into account effects of on-wing time on workscope costs, LLPs' lives and cost of routine and total labour for an engine workscope. With more than 25 years' experience with the CF6-50 we have been able to optimise the balance between workscope and removal interval".

Many engine types have a narrower range of LLP life limits, or even a uniform life limit, compared to the CF6-50. The CF6-50 is a modular engine and can be broken down into the fan, high-pressure compressor (HPC), combustor and high-pressure turbine (HPT) and low-pressure turbine (LPT) sections. The CF6-50's LLPs even have a high degree of variance of limit limits within modules. Through the whole engine, LLP lives are 9,700-30,000EFC *(see table, this page)*.

Engine on-wing times generally fall within the range of 1,300-1,800EFC, although many operated on shorter cycles by the A300B4F achieve times of 2,000-2,500EFC. These intervals have to be considered against the remaining life of LLPs. The high variation of life limits means different LLPs are replaced in many engines at each shop visit. This then results in a wider variation of remaining LLP lives throughout an engine. Some LLPs will have remaining lives reduced close to a number of EFCs similar to an on-wing removal interval. Others will have several thousand EFCs left until life expiry.

This is in contrast with many other engine types, which have simpler management with regard to shop visit intervals and LLP life limits. The PW4000, for example, has uniform lives of either 15,000 or 20,000EFC, depending on thrust rating, throughout the engine.

Most engine shops and airlines manage their engines by having a workscope designed to achieve a target on-wing time between scheduled removals; many in the region of 1,500EFC. Operators then remove any LLPs with remaining lives that are less than a few hundred EFCs higher than their target scheduled interval.

For example, if the average on-wing time is 1,500EFC, then longer intervals of 2,000EFC will be achieved by some engines. Airlines will then have a policy of removing any LLPs at a shop visit that have a remaining life of less than 2,000EFC. This policy of removing a few LLPs, which could reach zero life while the engine is otherwise capable of remaining on-wing, avoids early removals.

Further complications arise with the CF6-50, since the life limits of LLPs have increased over the years since its first manufacture in 1972. This means different engines will have different part numbers and life limits for the same LLP *(see table, this page)*.

Many CF6-50 operators also had mixed fleets of 747s and DC-10-30s, or additional A300Bs. Engines were therefore swapped between two or three types. While annual utilisations on the 747-200 might only have been about 400-600EFC, they would have approached 2,000-2,500EFC on the A300. LLPs would therefore use their life limits at varying rates.

The CF6 has also entered the secondary market on many of the aircraft it powers. Major shops, such as KLM Engineering & Maintenance, also pool their engines with those of its customers.

The CF6-50's modular concept and variation in LLPs means most shops manage the engine's maintenance in a modular concept, rather than a complete engine. Modules are therefore swapped between engines, and also airlines and aircraft types.

Airlines will avoid unscheduled early removals and high maintenance costs if they monitor LLP lives.

Removal intervals

Operating on the 747 and DC-10-30, the CF6-50 achieves on-wing times in a close range of EFCs. These average 1,300-1,800 in most cases.

KLM Engineering & Maintenance manages a pool of 110 CF6-50s for 747-200/-300 and DC-10-30 operators. Half are customer engines. "The CF6-50E2s operate a cycle of about 6.2FH on the 747-200/-300. Including unscheduled shop visits, the average interval is 6,300EFH, or 1,100EFC. This is similar to the CF6-50's fleet average of 6,700EFH.

"Our -50C2s have a shorter interval for all removal causes of 5,900EFH. The average is brought down by one of KLM's pool customers' DC-10 fleet, which operates short cycles in a hot environment. Another pool customer does longer and cooler cycles and achieves 7,700EFH," says Peter van Altena, senior engineer powerplant engineering at KLM Engineering & Maintenance. "The DC-10s operate

CF6-50 LIFE LIMITED PART EFC LIFE LIMITS & LIST PRICES

Engine LLP part	EFC life limit	List price $
Fan Rotor		
Fan disk	20,800	111,820
LPC booster disk	21,000	139,480
Forward shaft	22,000	71,210
Mid shaft	21,000	153.360
Compressor Rotor		
Compressor stage 1 disk	18,500	55,790
Compressor stage 2 disk	19,000	18,880
Compressor stage 3-9 disk	12,000-20,000	213,720
Compressor stage 10 disk	13,000-20,000	35,090
Compressor stage 11-14 spool shaft	18,000	320,540
Number 4 bearing seal	10,000-18,000	44,230
Number 4 bearing seal support	11,500	34,600
HPT Rotor		
Forward shaft	11,500	108,460
Stage 1 disk	12,000-15,000	101,630
Impeller spacer	3,000-15,000	49,020
Stage 2 disk	6,750-9,700	88,720
Rear shaft	30,000	61,830
Forward air seal	30,000	8,766
Rear air seal	30,000	12,190
Pressure tube adapter	30,000	15,760
LPT Rotor		
Forward shaft	30,000	76,300
Stage 1 disk	12,350	69,380
Stage 2 disk	10,000-17,500	72,870
Stage 3 disk	12,400	72,270
Stage 4 disk	30,000	62,960
Rear shaft	30,000	38,570
Stage 2 seal	30,000	26,640
Stage 3 seal	30,000	7,521
Stage4 seal	30,000	7,142
Air seal number 7	30,000	6,067
Air tube	26,500	9,566

The CF6-50 achieves average on-wing times between all removals in the region of 7,000EFH when operating on 747-200/-300s. Maintenance reserves, including LLPs, work out at just over $200 per EFH, and about $830 per aircraft FH.

shorter cycles than the 747s. So, overall, we are constantly achieving average intervals of 1,000-1,400EFC for all removals".

Van Altena explains that KLM Engineering & Maintenance's engines are built to a standard at which a minimum on-wing scheduled interval of 1,500EFC can be achieved. This on-wing target is used for 747 and DC-10 applications. This interval is possible for scheduled removals, but the overall average is reduced by unscheduled removal causes, such as foreign object damage (FOD).

"High time engines do get intervals of 1,500-1,900EFC," says van Altena. "We have the policy of replacing all LLPs with remaining lives less than 1,500EFC. That is, we manage engines to avoid early, unscheduled removals forced by LLP stub lives. It is possible for LLPs to hit zero life remaining after an on-wing interval of 1,500EFC while the engine still has good exhaust gas temperature (EGT) margin left".

Finnair has the policy of removing LLPs with stub lives of less than 2,000EFCs. "We customise our workscopes with the intention of getting a scheduled removal interval of 8,000-10,000EFH," says Karhumaki. "The average removal interval is about 1,300EFC, or about 7,000EFH, for the DC-10 engines".

Lutz Winkler, manager engineering GE engines at MTU Maintenance, explains that scheduled on-wing intervals are affected by an airline's operation and environment. "Engine life on-wing is close in EFC, but varied in EFH," says Winkler. "The CF6-50's average operation is a cycle time of 3.5EFH, but this is within a range of 1-8FH per FC. The average scheduled on-wing interval an operator can get is up to 2,000EFC, or 6,000-7,000EFH. Longer cycles, such as those operated on passenger 747s, will achieve fewer cycles, but more EFH than the average. A short cycle operation for the A300B4 would be harsher on the engine. All factors considered, thrust derate will be 5-20%. A typical range of on-wing intervals is 1,400-2,000EFC".

Air France Industries has some of the greatest experience with the CF6-50 and processes about 120 shop visits per year. This is for powerplants on all three aircraft applications, although the majority are for the 747 and DC-10-30.

"On-wing intervals for all removal causes for the 747-200 are 1,300EFC/ 8,500EFH. It is slightly less for the DC-10-30 at 7,500EFH, but with a similar EFC interval of 1,300," says Didier Verte, Product Manager GE Engines at Air France Industries.

Air France had a specific workscope for engines operated on 1.0FH cycles on the A300B2/4 fleet. "This used to get average intervals of 4,000EFC," says Verte, but it was a heavy and expensive workscope. We had to pay attention to key items affecting performance and reliability. For example, we had a limited number of HPT vane repairs".

For all removal causes, Lufthansa Technik has an interval of about 10,000EFH and 1,250EFC for Lufthansa's 747-200s, and 8,000EFH and 1,450EFC for Lufthansa Cargo's 747-200Fs. These two fleets have average FC times of 8.1FH and 5.5FH respectively. While the engines for the two fleets are pooled and treated in the same way, the freight aircraft operate shorter cycles, and in hot environments. Lufthansa's average interval for all removal causes is about 9,000EFH for its 747 engines. This is higher than the global average of 6,600EFH.

"Our A300 customers, which operate shorter cycles of 1.3-2.0EFH, achieve intervals of 1,800-2,100EFC," explains Dirk Maue, Propulsion Systems Engineering CF6-50 at Lufthansa Technik.

To summarise: the CF6-50 operating on the DC-10-30 and 747-200/-300 will achieve average intervals of 1,100-1,400EFC. This translates to 5,500-7,000EFH for DC-10s operating longer cycles, but comes down to 3,000-4,000EFH for aircraft being used regionally.

Engines on the 747-200 flying 5-8FH cycles will achieve intervals of 5,500-10,000EFH, and an average of about 6,500-7,000EFH.

Most A300B4 operators can expect an average interval of about 2,000-2,500EFC, equal to about 5,000EFH.

Removal causes

Like all other powerplants, the CF6-50 will have several removal causes for shop visits. Maue explains that after a shop visit the CF6-50E2 has an EGT margin of about 26 degrees centigrade, and the CF6-50C2 a margin of 21 degrees centigrade. This erodes at the rate of about 2.7 degrees per 1,000EFH for the CF6-50E2.

"In a perfect situation the EGT margin will reach zero at the same time that LLP stub lives are reduced to zero," says Maue. "This rarely happens, and removals are forced by one reaching zero first, or by other causes. About 25% of removals are caused by EGT margin degradation, and another 25% by LLP lives reaching zero. The remaining 50% are unplanned removals and are due to factors such as damage in the HPT, oil leaks or FOD.

"It is possible to have a heavier and more expensive workscope that will deliver an engine with an EGT margin of 35-40 degrees after a shop visit," explains Maue. "This should give the engine a scheduled removal interval of about 20,000EFH, but this rarely happens

Some airlines use DC10-30s regionally, while others still use it for long-haul operations. Average cycle times are less than when used on the 747-200/-300. Consequently reserves on the DC10-30 are higher, at about $225 per EFH.

because parts start to fail. The CF6-50's design is old. The casings, for example do not last like they do on the more modern CF6-80 series. The CF6-50**,** therefore**,** has to be managed to achieve scheduled removal intervals of 1,500EFC".

Besides EGT margin erosion, LLP expiry and other removal causes, Karhumaki also cites reaching target scheduled on-wing times that will allow Finnair to reach the optimum costs per EFH as a major removal cause.

Shop visit workscopes

Shop visit workscopes for the CF6-50 series are more customised for each engine than in most other types. The JT8D, for example, has a planned shop visit pattern of alternating light and heavy workscopes used by many carriers.

The CF6-50's modular concept facilitates tailored workscopes for each module, coping with the variations in condition and LLP life limits per module. "Workscopes are defined at each shop visit for each of the four main modules, using the General Electric customised Workscope Planning Guide (WSPG) with inspection, repair and overhaul thresholds for each module as a basis. Trend monitoring data, incoming inspection results, AD requirements and LLP information will be added to the WSPG derived thresholds providing the initial workscope, fine-tuned when required by condition" explains Van Altena. KLM defines workscopes that target a scheduled or planned on-wing life of 1,500EFC.

"The workscope process is exacerbated by airworthiness directives (ADs) which influence workscopes and shopload. For example, there is the 3-9 spool in the HPC which suffered cracking and so requires more frequent exposure for non-destructive testing. A certain spool population requires early replacement, making engine removal management harder. The enhanced inspection initiative by the Federal Aviation Administration (FAA), applicable for the whole industry, requires opportunity piece part inspections leading to extra shop load," says van Altena.

Shops generally have devised three levels of workscope for the CF6-50 from General Electric's workscope planning guide. These fall into the three broad categories of minimum, performance restoration and overhaul. These three levels are applied individually to modules, rather than to complete engines.

A performance restoration will involve EGT margin restoration and HPT blade repairs, HPC blade and vane measurements, cleaning and polishing and re-application of blade coatings.

An overhaul involves the same workscope as a performance and, further, includes work for a full gas path restoration. This will involve zero-timing the engine rotor structure.

A minimum workscope, which will be an inspection and light repair, can be performed on one module, while a performance restoration or overhaul is done on others.

The CF6-50's modular concept means that once modules have been worked on, they can be swapped with others to re-build an engine. This will be done to manage LLPs more efficiently. The CF6-50's modular nature also means there is not a general workscope pattern followed by the engine or modules, unlike other engine types.

The workscope planning guide has inspection repair and overhaul thresholds for each module and unit. "The incoming inspection and data on all LLPs will be used to define the workscope, as will the trend monitoring data," says van Altena.

KLM defines workscopes that target a scheduled or planned on-wing life of 1,500EFC. Other shops have similar targets, but can aim for longer lives. "We try to build for a 1,400-2,000EFC life, depending on aircraft application,"says Winkler at MTU. "The EGT margin is a limiting factor of on-wing life. EGT margin can start at 25 degrees centigrade. A higher margin of 35-40 degrees is possible, but often erodes just as fast. The remaining life of LLPs then defines those that need replacing and the workscope. We actually aim to avoid LLP replacement at every shop visit, and try to replace LLPs every second removal. This means we remove any LLPs with lives of twice the target removal interval. This avoids disassembly of the HPC, for example.

"This effectively means we are unique in that we have adopted a rough workscope pattern of alternating light and heavy shop visits," explains Winkler. "The light workscope will be a performance restoration, where we repair airfoils, but avoid complete disassembly. The second visit will be a complete overhaul, and LLPs will be replaced. These will be ones with lives shorter than 3,000-5,000EFCs. This way it is fairly easy to manage engines with on-wing times of 6,000-8,000EFH and achieve a shop visit pattern of alternating light and heavy workscopes. Ultimately, engines and modules still have to be managed individually".

Other CF6-50 shops follow different philosophies when defining workscopes. Finnair, for example, strikes a balance between on-wing time and workscope to achieve the lowest cost per EFH. Karhumaki says he believes in building good EGT margin into the CF6-50, since it provides good fuel burn performance and also affects the level of scrapped materials at the subsequent shop visit.

Air France Industries tries to have a

consistent build standard for every engine, by matching the maintenance status of each module. "For our own fleet we allow a minimum LLP life of 1,750EFC," says Verte. "Our intervals average about 1,300EFC, so LLP expiry accounts for just a few removals. We do have an approximate workscope pattern for modules, but keep getting new removal causes because the engine is ageing. We go by soft times, but usually overhaul the HPC and HPT every second removal, with performance restoration in between. Workscope variance is wide, however, and it is hard to generalise".

Lufthansa targets an on-wing time of about 9,000EFH, but bases workscopes on the same factors as the other shops. Workscopes are again customised for each engine and module. "We try to overhaul the high-speed rotor system (HPC, combustion area and HPT) every shop visit," says Ulrich Rademacher, programme manager CF6 overhaul and Lufthansa Technik. "We then aim to overhaul the low pressure spool every second shop visit, but the LPT fails at every removal on 90% of occasions because of vane and casing failures. Our lighter workscopes are therefore heavier than in the PW4000, for example. A rough pattern of alternating 'medium' and 'heavy' shop visits is therefore followed".

Workscope inputs

Shop visit inputs that determine costs can be divided into labour, materials and parts, and the cost of sub-contracted parts repairs to third-party vendors. The fourth element is LLPs, and these are dealt with separately.

Engine shops, which target the on-wing EFC intervals described, will design workscopes so that the level of parts and components repairs is maximised and installation of new parts minimised to lower shop-visit costs.

There is also a trade between in-house labour and cost of sub-contract repairs, according to the shop's own in-house repair capability.

Labour for engine repair and overhaul generally has a high man-hour (MH) rate compared to other elements of aircraft maintenance. A typical level for a north American or European shop is about $70 per MH. The labour portion is small, however. "There are many variables which affect the sum of the three parts," says Verte.

Labour will be in the range of 3,000-4,500MH, similar to the various workscopes for a PW4000. Materials can account for 55-60% of the shop visit cost, which will always be at least $1.2million, including LLPs.

Routine labour for inspection, disassembly, cleaning, assembly and test will consume about 2,000MH. A light workscope with in-house repair of parts will use about 4,000MH. "A full overhaul, with in-house repair, will consume up to about 4,500MH," estimates Franz Weinzierl, senior vice president marketing & sales at MTU Maintenance.

Finnair, which has a low in-house repair capability, estimates 4,000-5,000MH for a shop visit.

These levels of MH input will then generate a labour cost of $210,000-350,000, for a shop that charges labour at $70 per MH.

"The cost of materials depends on HPT damage level, but a light workscope will have a cost in the range of $400,000-600,000," continues Weinzierl. "A heavy shop visit will have a material cost of about $800,000". Sub-contract repairs will incur an additional charge of up to $500,000 for a light visit, and $550,000-800,000 for a heavy visit. Shops with lower in-house repairs might have higher sub-contract charges.

A light workscope will therefore have a total cost of $1.2-1.3 million, and a heavy visit about $2.0 million.

For the purposes of estimating maintenance costs per EFH, the CF6-50's costs have to be considered in terms of the 'average' workscope for the average on-wing interval which corresponds to all removal causes. An 'average' workscope, excluding LLPs, will incur a cost of about $1.5 million. The costs will be higher for engines powering the A300. This will be in the range of $1.5-2 million.

Shops can opt for heavier workscopes that achieve longer on-wing times, and could lower costs per EFH. Inputs as high as 6,500MH, $800,000 for materials and $1 million for sub-contract repairs will total $2.25 million. Restored EGT margin will be higher and intervals of 9,000-10,000EFH are then possible.

SUMMARY OF CF6-50 SHOP VISITS AND MAINTENANCE RESERVES

Aircraft application	A300B2/4F	DC-10-30	747-200/-300
FH:FC ratio	1.5-2.0	5.5	6.5
Average shop visit interval for all removals			
EFH:	5,000	7,200	7,800
EFC:	2,000-2,500	1,300	1,200
Shop visit cost $	1,750,000	1,500,000	1,500,000
$/EFH	350	208	192
LLP costs $/EFH	65	15	15
Total costs $/EFH	415	223	207

Maintenance reserves

To provide a guide to maintenance costs per EFH for each of the CF6-50's three applications, average removal intervals for all removal causes should be considered against average shop visit costs in terms of labour and material.

The 747-200/-300 application will average about 1,200EFCs and 7,800EFH between shop visits.

The DC-10-30 will average about 1,300EFCs and 7,200EFH between removals.

The A300B4 is likely to have longer intervals in EFCs in the region of 2,000-2,500, but because of shorter average cycle times this will be equal to about 5,000EFHs.

Engines powering the DC-10-30 and 747-200/-300 will have similar workscopes, averaging about $1.5 million in time and material, with labour charged at $70 per MH, excluding LLPs.

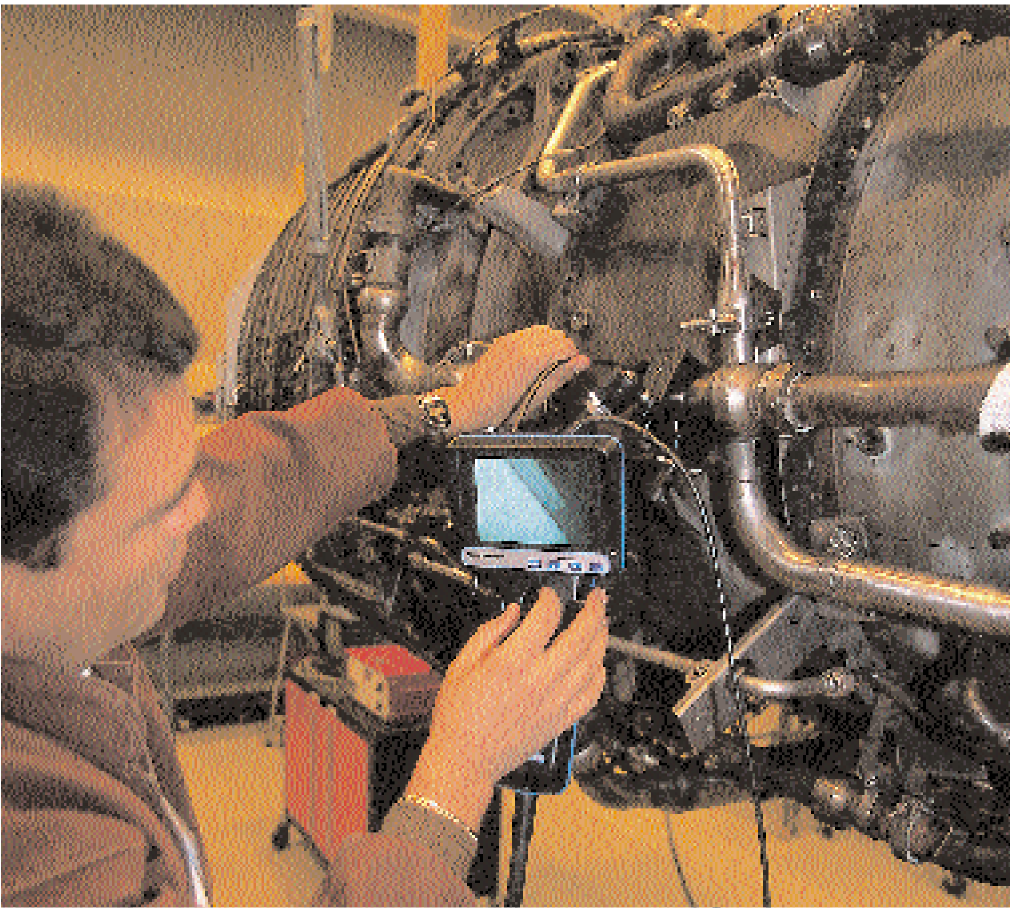
Engines on the 747 will then have amortised costs of about $1,250 per EFC, or $192 per EFH.

Reserves on the DC-10-30 will be $1,153 per EFC, or $208 per EFH.

The costs of an average shop visit for the A300B4 will be higher, in the region of $1.5-2.0 million, to account for the higher level of new materials and repairs. Amortised costs will be $875 per EFC or $350 per EFH.

Life limited parts

The replacement of LLPs will add large costs to total maintenance charges. A full set has a list price in the region of $2.1 million.



The CF6-50's large number of removal causes, and variation in LLP and age, means engines have to be managed individually with respect to shop visit workscopes. They do not conform to a workscope pattern.

With the minimum LLP life policies that most overhaul shops have, most LLPs are likely to achieve life limit utilisation within about 1,500-2,000EFC of their full life limits. For example, the forward shaft in the HPT rotor has a limit of 11,500EFC, but will probably be scrapped after about 9,500-10,000EFC. The lives of LLPs have also been extended by the original equipment manufacturers, and most engines will have parts which have the highest limit *(see table, page 23)*.

The number of EFCs, shop visits, and EFHs a LLP will achieve before it is replaced will be influenced by the aircraft utilisation pattern.

The majority of high-cost LLPs, disks and shafts, have lives of 9,700-22,000EFC. Karhumaki makes the point that the LLPs which drive costs are those within the 10,000-22,000EFC range. Only four high-cost LLPs have lives of 30,000EFC, as do all the low-cost LLPs.

Engines powering A300s achieve about 2,000-2,500EFC and about 5,000EFH between removals. Parts with the shortest lives of 9,700-12,400EFC will be replaced at about 8,000-10,000EFC, or after four or five shop visits. Parts with 15,000-18,000EFC lives will be replaced at about 13,000-16,000EFCs, or at the sixth to ninth removal. Others will be replaced at the 10th or 11th shop visit.

These intervals correspond to theoretical periods of four to 11 years of operation with the A300. Now that A300s are 15-25 years old, and have about another 10-25 years of operation, individual LLPs will need replacing anywhere between zero and seven times.

Operation with the DC-10 and 747 will extend the calendar time between replacement, since utilisations are in the order of 500-700FC per year.

A removal interval of 1,300EFC means a shop visit will only be performed about once every two and a half years. The LLPs with the shortest lives (10,000-12,000EFC) will theoretically be replaced about every sixth or seventh shop visit, or after 15-18 years.

Median life parts with 15,000-18,000EFC limit could last until the 10th or 12th shop visit, or up to 30 years, and so may never require replacement in the engine's operating life.

Parts with even longer lives of 19,000-22,000EFCs will last for 17-20 shop visits, and so are even less likely to ever require replacement.

Depending on the style of operation and aircraft type used, LLPs with the shortest lives will require replacement anywhere between four and 18 years. Parts with intermediate lives will require replacement between six and 30 years, and high-cost LLPs with the longest lives between 10 and 50 years.

Taking the list price of each of these components, the age of the aircraft in the fleet and probable levels of utilisation, and number of times each LLP may need to be replaced until final retirement, engines powering the A300 should have a reserve of $130/EFC for LLPs. An average FC time of 2.0FH will make this equal to $65 per EFH.

With the same considerations, an LLP reserve of $90 per EFC and $14-16 per EFH should be made for the DC-10-30 and 747-200/-300.

For all applications, operators should be able to get lower reserves for LLPs. This is because used LLPs can be acquired on the aftermarket, the number of engines from scrapped aircraft will increase and add to the supply of engine parts, and some operators will swap engines and modules between applications and manage to reduce the number of times they require replacing in their remaining life.

Summary

Management of the CF6-50 centres on average removal intervals of 1,200-2,000EFCs on the DC-10 and 747, and 2,000-2,500EFCs on the A300, and how these relate to remaining lives of LLPs.

Experienced shops customise shop visit workscopes and know how to achieve the lowest costs per EFH. This is achieved by getting a balance between the overall workscope, parts replacement and level of component repairs.

Reserves for shop visits, excluding LLPs, are in the region of $415/EFH for the A300, $223/EFH for the DC-10-30 and $207/EFH for the 747-200/-300.

LLP replacement is now a case of keeping records on each part and selecting each one for replacement when necessary. As engines get older, fewer parts will need replacing and LLP reserves will get cheaper.

Most engines installed on A300s should be able to avoid replacement of LLPs with life limits exceeding about 20,000EFCs. This brings down reserves to about $130/EFC, or $65 per EFH.

Engines powering the DC-10-30 and 747-200/-300 will have even lower LLPs to replace, on account of their much lower annual FC utilisations. LLP reserves for these two aircraft will then be about $90 per EFC, or $15 per EFH.

Engine reserves per aircraft FH are therefore about $830 for the A300, $675 for the DC-10-30, and $830 for the 747-200/-300. These costs are on the same level as for engines of a similar vintage.