The management of life limited parts in engines powering widebody aircraft is dependent on average cycle times. Engines used in long-haul operations may have parts replaced every 20 years or more, while engines used in short-haul operations may be replaced every three or four years.

LLP management for widebody engines

Life limited parts (LLPs) in long-haul engines account for a smaller portion of total engine reserves than they do in short-haul engines. This is because LLPs have lives fixed in engine flight cycles (EFC), and can last for more than 30 years due to the low number of flight cycles (FC) aircraft accumulate each year. LLPs account for a varying portion of total engine maintenance costs, and also influence the maintenance management of engines.

The majority of engines powering widebodies are used on medium- and long-haul missions, although some are still used on short-haul operations. LLPs always account for a high proportion of total engine maintenance costs on short-haul operations because of short average cycle times and the high rate of accumulation of FC.

Engines in operation

The main engine types powering widebodies are the CF6-80C2, PW4000-94, PW4000-100, PW4000-112, Trent 500, Trent 700 and Trent 800.

The RB211-524D4D and CF6-50, but these are declining in numbers. The Trent 900 and GP7200 will power the A380, but have yet to enter service.

The CF6-80C2 and PW4000-94 are the oldest generation of these engines and both power the same aircraft types with a wide variety of applications. These are the A300-600, A310, 767-200, 767-300, MD-11 and 747-400.

The A300-600 is used in short- and medium-haul operations. Lufthansa, for example, uses the aircraft on high-density short-haul operations with average cycle times of 1.0 flight hour (FH). Other airlines, such as American, use the aircraft on medium- and long-haul operations. The average cycle time for most operators rarely exceeds 3.0FH.

The A310-200 is used on short-haul mission lengths similar to the A300-600, while the -300 is used on medium-haul operations where average FC and EFC time is about 3.0 hours.

There are a variety of different gross weight and range variants of the 767-200. The majority of aircraft with the small fuel capacity are operated by US carriers on domestic routes, and have similar average EFC times to the A310. The 767-200s with higher fuel capacities are used on long-haul missions by a variety of carrier. Some aircraft are used as long-haul flagships and consequently have average FC times of up to 8.0FH.

The situation is similar for the 767-300 series, where there are -300s with low fuel capacity and -300ERs with high fuel capacity and longer range capability. The range of average FC/EFC times is similar to the 767-200.

The MD-11 is principally a long-haul aircraft, and average FC times are in the region of 7.0FH. The PW4000s and CF8-80C2s powering this aircraft are therefore used on long-haul missions.

The same applies to these engines powering the 747-400, where all aircraft except those operated on high-density domestic sectors for Japanese carriers are used on average FC times of 7.0-9.0FH.

The next generation engines power the A330. These are the PW4000-100, CF6-80E1 and Rolls-Royce Trent 700. The first-introduced A330-300 is used on medium- and long-haul operations. Carriers such as Cathay Pacific, Thai and Garuda in the Asia Pacific use the aircraft on high-density regional operations. Others, like Air Canada and USAirways, use the aircraft on transatlantic operations, and it is also frequently used for medium-haul operations. Average FC times thus vary between 2.0 and 8.0FH.

The A330-200 is used by most operators as a medium- or long-haul aircraft, and so has longer average FC times in many cases than the A330-300.

There are many gross weight variants of the 777. The earliest models, with a maximum take-off weight (MTOW) of 506,000-535,000lbs, are used by carriers such as United on US domestic, by Japan Airlines (JAL) and All Nippon Airways (ANA) on Japanese domestic and medium-haul operations. These aircraft are powered by the lowest thrust rated models of the GE90 and PW4000-112.

Gross weight specifications for the higher gross weight aircraft go up to an MTOW of 632,500lbs and 660,000lbs. These aircraft are used on long-haul operations with typical average FC times in the region of 8.0FH. These aircraft are powered by the higher thrust rated models of the GE90, PW4000-112 and Trent 800.

The ultra long-range 777-200LR and -300ER models have MTOWs of 766,000-775,000lbs, and will be operated on cycle times of more than 10FHs in most cases. These aircraft are powered exclusively by the GE90-110/-115.

Main principles

Short-, medium- and long-haul operations provide extremes in LLP management. The lives of most engines are fixed at 15,000-20,000EFC, but in some powerplants they are as low as 10,000EFC.

Some individual parts in engines have lives shorter than this, such as when individual part numbers for a particular LLP have restricted lives because technical issues and airworthiness directives (ADs) have been issued to impose a life limit.

The importance of these lives depends on annual rates of aircraft utilisation and

LLPs should ideally be replaced when the engine is due for a high level workscope. This way the engine will already need to be in a high level of disassembly, and so the additional man-hours required to make LLP replacement possible will therefore be minimal.

average FH:FC ratios in operation. Aircraft used in short-haul operations will have average FC times of 1.0-1.5FH. These aircraft will also generate 2,500-2,750FH per year, and so in the region of 1,800-2,700FC.

LLPs with lives of 20,000FC, which are able to utilise 17,000FC of these lives, are thus replaced about once every six to nine years of operation and about every 18,000-25,000FH. This is as short as three or four years of service and 7,500-12,000FH for LLPs with lives of 10,000EFC. The amortisation or reserves of LLPs is is therefore the highest rate per FH in short-haul operations.

Aircraft on medium-haul operations typically accumulate 3,000-3,500FH per year, and have average FC times of 3.0-4.0FH. The aircraft thus accumulate 750-1,000FC per year.

LLPs which are able to utilise about 17,000FC of their 20,000FC lives will therefore be replaced about once every 17-20 years of operation. This is equal to 51,000-70,000FH of service, and so the reserve for LLP amortisation is less than for short-haul engines.

LLPs with lives of 10,000FC, are therefore replaced every 8-10 years and 25,000-35,000FH.

Aircraft on long-haul operations with average cycle times of 8.0-9.0FH generate about 4,500FH and 500FC per year. LLPs with lives of 20,000EFC may thus only require replacement up to every 34 years, equal to more than 130,000FH. Amortisation and reserve rates are thus the lowest for all types of operation. Engines with LLPs that have lives of 10,000EFC will still only require replacement about every 16-18 years or 65,000-80,000FH. This is still a long period, despite the relatively short lives of the parts.

Replacement timing

LLP replacement should ideally be made during a heavier engine shop visit, when it has gone through a high level of disassembly. Engines generally go through patterns of workscopes that vary in size. The lowest possible maintenance reserves per FH are achieved when LLPs with a short remaining 'stub life' are replaced at a heavy shop visit. The need to replace LLPs during a lighter shop visit increases the workscope and therefore the cost of an otherwise light shop visit.

The optimum timing of LLP replacement is less critical for engines operated on long or ultra-long average FC times, since it is done after long periods. Moreover, it is done only once every seven or more shop visits. LLP replacement during a light shop visit is therefore not so critical to overall engine maintenance costs. It can come due when the first and even second operator no longer operates the aircraft.

LLP replacement timing becomes more critical for engines that are operated on medium- and short-haul missions. Some engines may go through shop visit patterns that generally follow an alternating sequence of light and heavy shop visits, or two light visits followed by a third heavy visit or overhaul. Ideally, LLPs would be replaced during these heavier visits to avoid increasing the workscope of lighter shop visits. Shop visit intervals therefore have to be considered more carefully in relation to LLP lives in these cases.

This raises the issue of 'stub lives', or remaining lives of LLPs. Stub lives of LLPs at a shop visit should not be less than the probable time on-wing an engine can achieve before other factors, such as exhaust gas temperature (EGT) margin erosion, force a removal. LLPs should also have a clear surplus of EFCs over this stub life. LLPs with remaining lives at a shop visit that are less than the probable subsequent on-wing interval should therefore be removed to prevent an early shop visit. An engine, for example, which is likely to remain on-wing for 3,000EFC until its next shop visit should have all LLPs with lives less than 3,500EFC removed.

LLPs with lives of 15,000EFC in an engine with an average on-wing interval of 3,000EFC, are likely to be replaced at the fourth shop visit after about 12,000EFC in most cases. Leaving LLPs in the engine at the fourth shop visit might force a removal due to LLP expiry after a total time of 15,000EFC, but most operators do not manage engines this way. Replacement at either the fourth or fifth shop visit would be less than ideal if the engine conforms to a shop visit pattern of two light followed by one heavy workscope.

Replacement at 12,000EFC would be convenient for an engine which had a clear alternating pattern of light and heavy shop visits. LLP replacement timing would be complicated, however, in the case where the average shop visit interval was longer at 6,000-8,000EFC.

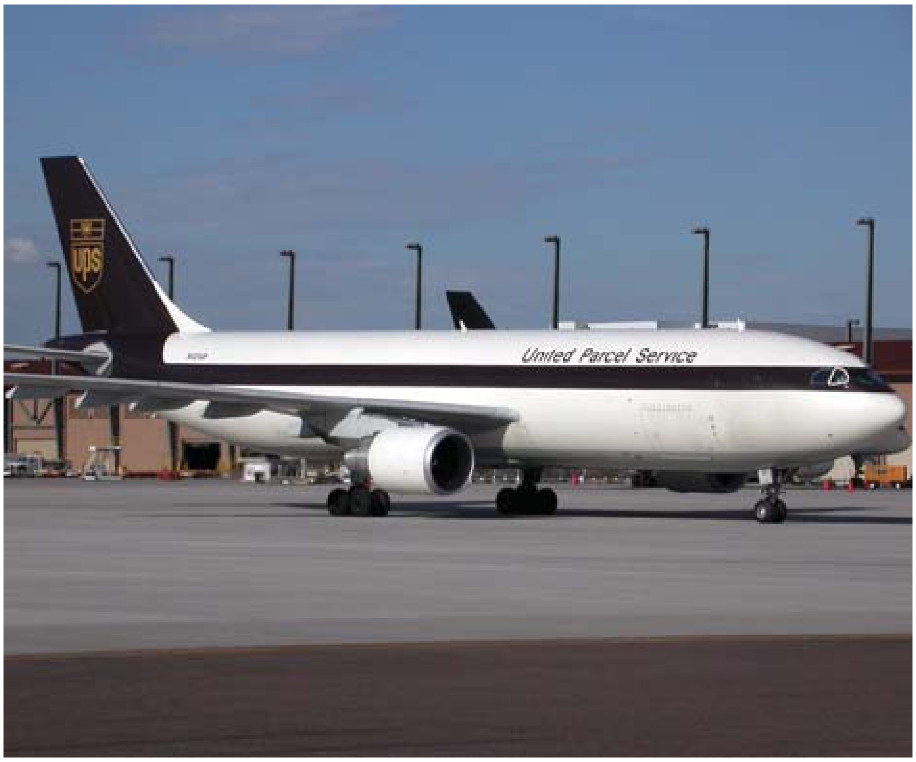
Optimum timing of LLP replacement becomes even more critical when lives are shorter, for example 10,000EFC.

CF6-80C2

The variety of operations on which the CF6-80C2 is used means it has average FC times of 1.0-9.0FH. There are actually 20 different versions of the CF6-80C2 family, which also has several thrust ratings for its aircraft applications that are between 52,500lbs and 61,500lbs. This causes a variation in removal intervals, but they tend to be more consistent in terms of EFC.

Engines operated on average EFC times of 1.0-3.0EFH have intervals of 2,500-3,500EFC, the longest intervals being achieved by the lowest thrust rated engines operating on the shortest cycle times.

Engines used on medium-haul operations, on aircraft such as the 767 and A310 or A300-600 with average EFC times of 4.0EFH, have removal intervals



The CF6-80C2 is rated between 52,500lbs and 61,500lbs of thrust and operated in a wide variety of roles. These can be short-haul operations where average cycle times are 1FH, and well as medium- and long-haul operations with average cycle times as high as 8.0-10.0FH. Engines operated on short-haul missions have on-wing times in the region of 2,500-3,500FC.

of about 2,200EFC.

Engines in long-haul operations with cycle times averaging 6.0-9.0EFH have intervals of 1,500-1,800EFC.

Removal intervals are now mature for most engines in service, and are mainly due to wear of engine hardware. These intervals have to be considered in relation to LLP stub lives.

Stub lives will have to be as high as 4,000EFC for engines operated on short-haul missions where intervals can be as short as 3,500EFC. Stub lives can be reduced to about 2,500-3,000EFC for engines used on medium-haul operations, and 2,000-2,500EFC for those on long-haul operations.

CF6-80C2 shop visit workscopes are based on the workscope planning guide. This provides EFC thresholds for three different workscope levels for each module: repair, performance restoration and overhaul.

The threshold for a performance restoration on high-pressure modules is 1,500-2,000EFC since overhaul, depending on thrust rating. The threshold for an overhaul is 3,000-4,000EFC since the last overhaul.

Thresholds are higher for low pressure modules at about 2,500EFC since last overhaul for a performance restoration, and 5,000EFC for an overhaul.

Many airlines alternate performance restoration and overhaul workscopes for HP modules, and repair and overhaul workscopes for LP modules. Even if this simple alternating pattern can be followed for LP and HP modules, the timing of overhaul workscopes will still be out of phase.

The implication is that overhauls for the HP system will be performed every second removal for most engines, except those which had the longest intervals exceeding 3,000EFC. These would require an overhaul every shop visit.

Overhauls for the LP system, however, would be every second shop visit for engines used on short-haul operations where the average interval was about 2,500EFC or more. The LP system would, however, only have an overhaul every third shop visit where removal intervals averaged 1,500-2,000EFC.

"The CF6-80C2 has 21 LLPs, and there are up to 30 part numbers for each LLP," explains Rod Curtis, team leader engineering group at Total Engine Support Limited. "The majority of LLPs in the LP system have lives of 20,000EFC. The fan and low pressure compressor (LPC) modules have four LLPs, all of which have lives of 20,000EFC. In some cases these lives are reduced to 15,000EFC where thrust ratings are high.

"The fan disk has a life of 20,000EFC, while the Stage 2-5 LPC spool has a life of 15,000EFC for high thrust ratings and 20,000EFC for low thrust ratings. The fan forward shaft and fan mid shafts have lives of 20,000EFC," continues Curtis. "The low pressure turbine (LPT) has six LLPs: the stage 1-5 disks and LPT rotor shaft, which all have lives of 20,000EFC. Some of the LLPs in the HP system have shorter lives than those in the LP system. The stage 1 HPC disk has a life of 20,000EFC, but the stage 2 HPC disk has a life of 15,000EFC for high rated engines and 20,000EFC for low thrust rated engines. Lives for the stage 3-9 HPC spool vary with part number: the latest part part number has a life of 20,000EFC, and the rest have lives of 15,000EFC. There are two HPC rotor configurations. The first consists of a S10 disk and S11-14 spool. While the S10 disk has 20,000EFC for lower and 15,000EFC for higher thrust ratings, the latest part number S11-14 spool has 20,000EFC for all ratings. The second rotor configuration consists of a spool with 20,000FC for all ratings. The CDP seal disk has a life of 15,000FC for high thrust and 20,000FC for all other applications."

The high pressure turbine (HPT) has some LLPs with lives that are shorter than others in the engine. The stage 1 HPT disk has had its life reduced by an AD. The part in high rated engines is reduced to 10,720EFC by AD 2004-07-13. The same part has a life of 15,000EFC for all other ratings. The lives of the stage 2 HPT disk and vane diffuser are similarly reduced to 9,000EFC in high rated engines, but kept at 15,000EFC in low rated engines. The HPT spacer/impeller has a life of 15,000EFC.

Engines achieving the highest intervals of 3,500-4,000EFC will have a HP overhaul almost every shop visit and a LP overhaul every second shop visit. A stub life of 4,000EFC is likely, and and so parts with lives of 15,000EFC would have to be replaced at the third shop visit, after an accumulated time of 10,500-12,000EFC. This is equal to a similar number of EFHs. It may be possible to extend removal until the fourth shop visit at about 14,000EFC and 14,000EFH.

LLPs with lives of 20,000EFCs would have to be replaced every fourth shop visit, at 14,000-16,000EFC/EFH. A possible extension to a fifth shop visit at 17,500-19,000EFC/EFH would improve LLP utilisation, but it would increase the workscope which might otherwise be a performance restoration.

Engines in short-haul operations, with an average EFC time of 1.5EFH, will achieve shorter removal intervals of about 2,500EFC. Stub life policy in this case is likely to be nearer about 3,000FC. LLPs with lives of 15,000EFC would thus be replaced at the fourth shop visit, after a total time of about 10,000EFC and 15,000EFH. Replacement could possibly be extended to 12,500EFC and

19,000EFH, but this would increase the workscope of the performance restoration likely to occur at this point.

LLPs with lives of 20,000EFC would be replaced at the sixth or seventh shop visit, after 15,000-17,500EFC and 22,500-26,500EFH. The seventh shop visit is more likely to be a performance restoration, so LLP replacement at this stage would increase the shop visit workscope but lower LLP amortisation due to better life utilisation.

Engines in medium-haul operations, with average EFC times of 3.0-4.0EFH and shop visit intervals of about 2,200EFC will have a stub life policy of 2,500-3,000EFC. This leaves 12,000EFC for parts with lives of 15,000EFC, which will be replaced every fifth or sixth shop visit at about 11,000-13,000EFC and 33,000-52,000EFH. LP system parts can be utilised for up to about 17,500EFC and 52,500-70,000EFH, and so get replaced at about the eighth shop visit in succession.

Engines operating the longest average cycle times of 6.0-9.0EFH and achieving removal intervals of 1,600-1,700EFC will have stub life in the region of 2,500EFC. They will therefore utilise about the same number of cycles that engines operating medium-haul operations will. LLPs with lives of 15,000EFC will thus be replaced at about 12,000EFC, equal to 72,000-110,000EFH. LLPs with lives of 20,000EFC will thus be replaced after about 17,500EFC, equal to 105,000-157,000EFH.

PW4000-94

Like the CF6-80C2, the PW4000-94 has a large number of thrust ratings and variety of applications and is used on the same aircraft types.

The 52,000lbs thrust rated engine is used on the 767-200 and A310-200. These aircraft are the lowest weight variants of their type and are generally operated on short-haul sectors with EFC times of 1.0-1.5EFH per EFC, and in some cases on the 767-200 on medium haul sectors where average EFC times are 2.0-3.0EFC.

Engines used on short-haul operations with an average EFC time of 1.0-1.5EFH have intervals in the region of 3,700-4,000EFC, whereas engines with average EFC times of 2.0-3.0EFH have intervals in the region of 3,300-3,500EFC.

The PW4056, rated at 56,000lbs thrust, is used on the 767-200ER, lighter models of the 767-300ER, A310-300, lower gross weight models of the A300-600 and 747-400.

In the case of lower gross weight 767s, the A300-600 and A310, the PW4056 is operated on medium-haul sectors with average EFC times of 3.0-5.0EFC. These engines will have on-wing intervals of about 3,300EFC in the case of shorter EFC times, and 2,800-3,000EFC in the case of longer average EFC times.

Engines powering higher gross weight models of the 767-200ER and -300ER and 747-400 are operated on longer cycles. The average for the 767 in most cases is about 6.0EFCs, while the average for the 747-400 will be 7.0-9.0EFH for most operators.

Engines powering the 767 will have average removal intervals of about 2,800EFC, while engines used on the 747-400 with the longer cycle times will have shop visit intervals in the region of 2,200-2,400EFC.

The PW4058, rated at 58,000lbs thrust, powers the A300-600R. This aircraft is mainly used for medium-haul operations. Depending on operator, the engines have average EFC times of 2.0-4.0EFC, and expect to have average removal intervals of 3,000-3,300EFC.

The PW4060 and PW4062, rated at 60,000lbs and 62,000lbs, power the 767-300ER and MD-11. These are some of the highest gross weight variants of the 767-300ER and they are used on long-haul missions where many operators have average EFC times of 6.0-7.0EFH. The MD-11 is used mainly on long-haul operations with similar average cycle times as the 767-300ER. Average removal intervals for most operators are in the region of 1,800-2,300EFC.

"LLPs in the PW4000-94 are almost uniform, with nearly all part numbers for engines rated at 56,000lbs thrust or lower having lives of 20,000EFC," says Curtis. "Nearly all part numbers for engines rated at 58,000lbs thrust or higher have

The PW4000 is operated on a variety of missions where average cycle times can be between 1.0 and 8.0FH. Engines rated at 52,000lbs and 56,000lbs have uniform LLP lives of 20,000EFC. Engines rated between 58,000lbs and 62,000lbs have uniform LLP lives of 15,000EFC. In most cases, the engine conveniently conforms to an alternating pattern of light and heavy shop visits. The target for LLP replacement should therefore be heavy shop visits.

lives of 15,000EFC".

These lives have to be considered against typical shop visit removal intervals, which are relatively consistent with EFCs on-wing. As with the CF6-80C2, the intervals achieved by the PW4000-94 are related to EFH:EFC ratio and thrust rating.

Maintenance of the PW4000-94 is also relatively simple, because it conforms to an alternating pattern of light and heavy shop visits. Light shop visits involve performance restoration to the HP system in the engine, while heavy shop visits will overhaul all modules.

This simple maintenance management makes LLP replacement easier to plan, since workscopes and shop visit costs will not be escalated if LLP replacement can be accomplished during heavier shop visits.

The PW4052 and PW4056 have LLPs with lives of 20,000EFC. The PW4052, when operated on short-haul missions, will have shop visits every 3,500-4,000EFC. The LLP stub life policy for these engines will thus be about 4,000EFC, meaning about 16,000EFC can be used. The engine will have accumulated 15,000-16,000EFC at the fourth shop visit, which is the appropriate timing for LLP replacement. Higher utilisation of LLPs might be possible if the time accumulated at the fourth shop visit was 14,000-15,000EFC, and a further on-wing run was possible. Replacement at this number of EFCs would be equal to 15,000-23,000EFH.

PW4056 engines operating shorter cycles of about 3.0EFH and intervals of 3,300EFC would have a stub life of about 3,500EFC. Replacement could occur after about 16,500-17,000EFC, at the fifth shop visit, which would be equal to 50,000-53,000EFH. Replacement could be extended to the sixth shop visit if an operator was prepared to take the risk of limiting the interval by LLP life, but this would of course achieve a high level of LLP life utilisation. If this were done almost all 20,000EFC of LLP lives would be used: equal to about 60,000EFH.

PW4056 engines used on longer medium-haul operations of about 5.0EFH per EFC with intervals of 2,800-3,000EFC, could have their LLPs replaced at the sixth shop visit. This would be equal to 18,000EFC and 90,000EFH.

PW4056s operated on 747s in long-haul missions, with removal intervals in the region of 2,200-2,400EFC could have stub lives of about 2,500EFC and so have LLPs replaced at the seventh or eighth shop visit. This will be equal to 15,500-18,000EFC and 109,000-145,000EFH.

"The PW4058, PW4060 and PW4062 have LLP lives of 15,000EFC, and so will only be able to use about 12,000-13,000EFC of these when stub lives are taken into account," explains Curtis.

The PW4058, operated in most cases on cycle lengths in the region of 3.0EFH, will have on-wing intervals of about 2,700-3,000EFC. With lives of 15,000EFCs, stub life policy will have to be about 3,500EFC. Only 11,500EFH can therefore be used, and so LLPs will have to be replaced at the fourth shop visit. This will be after about 12,000EFC, or 36,000EFH.

PW4060/62, with average cycle times of 6.0-7.0EFC and shop visit intervals of 1,800-2,200EFC, will have stub lives of about 2,500EFC. LLPs will thus be replaced at about 12,500EFC, which will coincide with the sixth shop visit. This will be equal to about 75,000-90,000EFH.

PW4000-100

The PW4000-100 series is rated between 64,000lbs thrust and 68,000lbs thrust, and powers the A330-200 and A330-300. Most engines in operation are certified at 68,000lbs thrust.

Like the CF6-80E1, the PW4000-100 is operated on a mixture of medium- and long-haul routes. These have average cycle times of 3.0-4.0EFH and 6.0-7.0EFH. The average cycle time across the fleet is almost 4.0EFH.

The LLP lives in the PW4000-100 have uniform lives of 15,000EFC, making management simple.

Like the PW4000-94, the -100 engine conforms to an approximate shop visit pattern of alternating hot section inspection and overhaul shop visits.

Engines used on medium-haul operations achieve in the region of 4,000EFC between removals. This is equal to 12,000-16,000EFH. Aircraft generate about 1,000EFC per year, so removals occur about once every four years.

Stub life policy for most cases will be removal at 11,000-12,000EFC utilised life, at the third shop visit and after about 33,000-45,000EFH.

Engines used on long-haul operations have intervals of 2,500-3,000EFC, equal to 15,000-21,000EFH. A stub life policy of about 3,000 will mean target replacement timing of 11,000-12,000EFC, at the fourth shop visit in succession. This will be equal to an interval of 66,000-84,000EFH.

PW4000-112

The PW4000-112 is rated between 74,000lbs and 90,000lbs thrust, and powers the 777-200 and -300 series.

The three variants rated at 74,000lbs, 77,000lbs and 84,000lbs thrust all have LLP lives of 20,000EFC, except for two parts in the HP system with lives of 15,000EFC and two shafts in the LP

The Trent 700 is used to power the A330-200 and -300; which are used on mainly medium- and long-haul operations with average cycle times between 3.0FH and 6.0FH for most operators. LLPs in the intermediate and low pressure spools have target lives of 15,000EFC, while parts in the high pressure spool have target lives of 10,000EFC. Most parts have reached their target lives, but some are restricted.

system with lives of 40,000EFC. The objective is to get lives of 20,000EFC throughout the engine.

These three engines power the 777-200 with an MTOW of 537,000-634,000lbs and a range capability of 4,000-5,800nm. Only Vietnam Airlines, which has a young fleet, uses the PW4084 engine.

Aircraft with the PW4074 and PW4077 are used for short-haul operations with cycle times of 1.0-1.5EFH by Japanese carriers and on high-density US domestic and long-haul operations with cycle times averaging between 3.0 and 7.0EFH.

Annual utilisations will be in the region of 1,700-2,200EFC for short-haul operations, 1,000-1,200EFC for medium-haul operations and 650EFC for long-haul services.

This has to be considered in relation to LLP lives and shop visit removal intervals. Parts in the LP system on these lower rated engines have lives long enough for replacement to be made every 17 or more years when annual utilisations and stub lives are considered.

Average removal intervals for engines used on short-haul operations are in the region of 7,500EFC. Replacement will thus be most economic at every second shop visit after 15,000EFC and 15,000-23,000EFH.

Removal intervals for engines used on long-haul operations are 3,000-4,000EFC, equal to more than 20,000EFH. Except for parts with lives of 15,000EFC, a stub life policy of 2,000EFC would allow parts to remain in the engine up to the sixth shop visit in succession, when intervals are in the region of 3,000EFC.

The PW4090 rated at 90,000lbs powers the 777-200ER with an MTOW of 660,000lbs and range of 7,650nm and the 777-300 with an MTOW of 580,000lbs and range of 3,900nm, and the higher gross weight model of the 777-300 with an MTOW of 660,000lbs and range of 5,650nm.

These aircraft are used on a mixture of short-, medium- and long-haul services and so have average cycle times of 1.0-8.0EFH.

LLPs in these higher rated engines have lower lives than lower thrust rated engines. One part in the HPC has a life of 8,000EFC and one in the HPT has a life of 7,500EFC. All other parts in the HP system have a life of 15,000EFC. Pratt & Whitney aims to get these increased to 15,000EFC in the next few years. Two parts in the LPT have lives of 12,000EFC and 13,000EFC, while the other five have lives of 15,000EFC. All parts in the LPC and fan have lives of 15,000EFC. The ultimate objective is for all parts to have a life of 20,000EFC.

Engines operated on short-haul services have removal intervals as high as 6,000EFC, equal to about 10,000EFH and three years of operation. Replacement of LLPs would be best timed at every second removal.

Engines used on aircraft for long-haul operations would have removal intervals of 2,500-3,000EFC. Replacement every fourth shop visit, at 11,000-12,000EFC would be equal to 65,000-85,000EFH and 14-19 years of service.

Trent 500

The Trent 500 powering the A340-500 and -600 has three different thrust ratings. These are 53,000lbs, 56,000lbs and 60,000lbs thrust. The aircraft achieves an average cycle time of 8.0FH and annual utilisations of about 550FC per year in most operations.

Despite being a three-shaft engine, the Trent 500 only has 16 LLPs. Unlike PW and GE engines, most of the Trent 500's LLPs have lives of just 10,000EFC. There are a few parts, however, which have had limits imposed on their lives and are less than 10,000EFC.

The fan section has two LLPs: the fan disk and fan shaft. These both have lives of 10,000EFC.

The intermediate pressure compressor (IPC) has just two LLPs: the compressor drum which holds all IPC blades; and the IPC compressor and rear shaft. Both of these have lives of 10,000EFC.

The high pressure compressor (HPC) has the HPC 1-4 stage drum, which has a life of 5,000EFC, and the HPC stages 5 and 6 disks and cone, which has a life of 10,000EFC.

The HPT has the HPT disk and HPT front cover plate. These two parts have restrictions on their lives, the disk having a life of just 2,600EFC and the front cover plate 4,000EFC.

The intermediate pressure turbine (IPT) has the IPT disk and rotor shaft. The disk also has a restricted life of 5,000EFC and the rotor shaft a life of 10,000EFC.

The LPT has five disks for the five turbine stages and a shaft. All six parts have a life of 10,000EFC.

The target lives of all parts in the engine is 10,000EFC. There is no intention of extending the lives of the parts beyond these limits. The average shop visit interval is expected to be about 3,000EFC, equal to about 24,000EFH, for some operators. The current life of the HPT disk is limited to 2,600EFC due to higher than expected turbine disk metal temperatures. A replacement part is expected to have the target life of 10,000EFC. If this is achieved then the engine on-wing life will be limited by the HPT blades. Rolls-Royce estimates that 3,000FC may be achieved. However, a mature interval of 2,500EFC may be more realistic. This means LLPs will have to be replaced after 8,000-10,000EFC because of stub life limitations.

Depending on EFH:EFC ratio, LLPs will be replaced about once every 64,000-72,000EFH if they all reach the target life of 10,000EFC. One unique feature of all

The Trent 800 has cycle times in the region of 5.0-7.0FH, while first removal intervals have been 3,000-4,000EFC for most engines. This interval is expected to come down to 2,500-3,000EFC as the engines in operation mature.

Trent engines is that its fan blades are also life-limited. The blades have a life limit of 10,000EFC in the case of the Trent 500, and 20,000EFC in the case of the Trent 700, and so have to be monitored.

Despite the relatively short life of LLPs, the reserve per FH will be relatively high. Most airlines, however, have total care maintenance packages with Rolls-Royce charged at a flat rate per FH, which includes the cost of engine management and LLP replacement.

Trent 700

There are three variants of the Trent 700. These are the Trent 768, 772 and 772B rated at 67,500lbs and 71,100lbs thrust which power the A330-200 and A330-300.

Like the Trent 500, the Trent 700 is a three-shaft engine. All LLPs in the low pressure (LP) and intermediate pressure (IP) modules have target lives of about 15,000EFC. The LLPs in the high pressure (HP) modules have target lives of 10,000EFC.

The fan and LPC section has two LLPs: the fan disk and fan shaft. The disk has a life of 13,000EFC, and the shaft a life of 15,000EFC.

The IPC has two parts: the drum with a life of 12,600EFC; and the rear shaft with a 15,000EFC limit.

The HPC drum is the only part in this module, but has a life limit of 4,200EFC imposed.

The HPT has only one LLP: the HPT disk with a life of 9,000EFC.

The IPT disk and shaft both have a target limit of 15,000EFC, while the four LPT disks and shaft all have the target limit of 15,000EFC.

The A330-200 and -300 are used in a variety of operations. Some aircraft are used on medium-haul operations with average EFC times of 3.0-4.0EFH, while other aircraft are used for long-haul services with average EFC times of 6.0-7.0EFH.

The target average shop visit removal interval is 4,000EFC, which is also because of an AD currently reducing the life of the HPC drum down to 4,200EFC. This removal interval target means LLPs with lives of 15,000EFC will be replaced every third to fourth shop visit. This will be equal to 24,000-84,000EFH, depending on average EFC length. LLPs with lives of 10,000EFC are likely to be replaced every second shop visit, equal to 20,000-56,000EFH.

As with the Trent 500, management and replacement of LLPs in the Trent 700 is included in the total care maintenance packages that Rolls-Royce provides to its customers.

Trent 800

The Trent 800 powers the 777-200 and -300 series. MTOW of the 777-200 varies between 537,000lbs and 634,000lbs, while MTOW of the 777-300 varies between 580,000lbs and 662,000lbs. The Trent 800 has a wide range of engine thrust variants as a consequence.

The Trent 870/871 is rated at 71,200lbs thrust, and the Trent 877 is rated at 74,900lbs thrust. These two power the 777-200 with gross weights of up to 537,000lbs. These aircraft have a range of about 4,000nm and 5,000nm. Typical operations are longer medium-haul and shorter long-haul routes, with cycle times averaging 4.0-6.0EFH.

The Trent 882 and Trent 884 are rated at 82,200lbs and 84,300lbs thrust and power aircraft with an MTOW of 580,000lbs. This has a range of about 5,900nm, and is consequently used for long-haul services averaging cycle times of 7.0EFH.

The Trent 890 and 892 are rated at 90,000lbs and 92,000lbs. These engines power the lower gross weight models of the 777-300 with an MTOW of 580,000lbs. This aircraft has a range capability of 4,000nm, and so is used on medium- and long-haul operations. Airlines such as Cathay Pacific and Thai use the aircraft for regional operations in the Asia Pacific for example. Average cycle times will be in the region of 3.0-4.0EFH.

The Trent 895 and Trent 898 are rated at 95,000lbs and 98,000lbs and power the 777-200ER with an MTOW of 656,000lbs and range of 7,750nm, and the high gross weight model of the 777-300 with an MTOW of 662,000lbs and range of 6,000nm. These are used for the longest long-haul services.

"The fleetwide average for the Trent 800 is an average EFC time of nearly 6.0EFH. First removal intervals have been 3,000-4,000EFC, equal to 18,000-24,000EFH," says Curtis. "This interval is likely to come down to 2,500-3,000EFC as engines mature, equal to 15,000-18,000EFH. Considering that annual utilisations are 4,000-4,500EFH, removals will occur about once every four years.

"There are currently three flight profiles for the Trent 800, divided into the Trent 875/877, Trent 884/890/892, and Trent 895/898. These are used to determine life limits of LLPs," continues Curtis. "Lives in the Trent 800 vary between about 4,500EFC and 12,500EFC. One part number for the HPT disk, for example has one of the shortest lives, and would have to be removed at the first shop visit. Other parts in the HP spool have lives of 7,000-9,000. Two removals would have a combined interval of up to 7,000EFC, while a third shop visit would take total time to about 10,000EFC. Most parts would have to be replaced at either the second or third shop visit." AC