There are due to be up to 3,100 V2500-powered A320s in service. These aircraft could remain in service for up to another 25 years. This fleet will therefore remain an important one. The maintenance requirements and costs of the five main -A5 variants are examined here.

The maintenance and management of V2500-A5 engines

There are about 5,600 A320 family aircraft in service. Almost 2,400, or 43%, of these are equipped with International Aero Engines (IAE) V2500-A1 and -A5 engines. There are therefore about 5,500 V2500-A1 and -A5 engines in operation.

The -A1 engines were manufactured from 1989 to 1994 for 143 of the earliest-built A320-200s. The V2500-A5 accounts for most V2500 engines powering the A320 family, and were manufactured for the A320 and A321 from 1993, and for the A319 from 1997.

There are almost 700 V2500-A5-powered aircraft still on firm order, prior to the first A320neo being delivered. The number of V2500-powered A320 family aircraft could therefore exceed 3,100.

V2500-powered aircraft are in operation with a large number of airlines on all continents. While the oldest A320s have already been retired, many young aircraft should remain in operation for up to another 25 years.

With such a large number of engines likely to remain in service for so long, the management and maintenance of these engines is examined here.

V2500 series

The V2500 series is one of two engine choices for three members of the A320 family. The -A1 has a single variant, rated at 24,800lbs of thrust. The -A5 series has five variants rated at 23,000lbs to 31,600lbs thrust.

The V2500 is a two-shaft turbofan. Unlike many engines with this configuration, the V2500 has a two-stage high pressure turbine (HPT) to extract more energy and so achieve a higher core pressure ratio. This is coupled with a 10-stage high pressure compressor (HPC), and an annular combustor to form the high pressure (HP) system.

The -A1 series has a 63-inch diameter intake fan, a three-stage low pressure compressor (LPC), and a five-stage low pressure turbine (LPT). The engine overall has a bypass ratio of 5.4:1.

The original -A1 had a relatively low exhaust gas temperature (EGT) margin, and so had a short on-wing life before EGT margin had eroded to near-zero.

This configuration was insufficient for the engine to generate the higher thrust ratings that were required for the A321, without experiencing a severe reduction in EGT margin. The first variants of this aircraft entered service in 1993.

The -A5's higher thrust ratings were achieved by increasing fan diameter to 63.5 inches and core engine airflow, as well as a higher overall engine flow. Coreflow was raised by adding a fourth stage to the LPC, and making efficiency improvements to the HPC. This efficiency improvement in the core offset the effect of a higher coreflow that reduced the bypass ratio.

The two lowest-rated -A5 variants are the V2522-A5, rated at 23,000lbs, and the V2524-A5, rated at 24,500lbs, for the A319. These have bypass ratios of 4.9:1.

The V2527-A5 is rated at 26,600lbs for the A320, and has a bypass ratio of 4.8:1. The V2527-A5 has an enhanced variant, the V2527E-A5, which provides additional thrust for A320s operating at hot and high altitudes; and the V2527M-A5, which is used by corporate versions of the A319.

The V2530-A5 and the V2533-A5 are rated at 30,400lbs and 31,600lbs for the A321-100/-200, and have bypass ratios of 4.6:1 and 4.5:1.

These five variants have the same turbomachinery hardware, and the different thrust ratings are achieved through the use of a full authority digital engine control (FADEC) unit.

The -A5's increased coreflow is an important feature in terms of reducing combustor exit temperature that results in an increase in EGT margin. The medium- and lower-rated -A5 variants have high EGT margins, and are usually not removed for maintenance because of EGT margin erosion. However, the higher-rated variants powering the A321, have lower EGT margins, so EGT margin erosion is a factor in their shop-visit removals.

All -A5 variants, however, have the problem of reduced EGT margin and higher rates of margin erosion when operating in an environment of high outside air temperature (OAT).

In 1999, a modification package was released for the -A1 variant. This was referred to as the 'Phoenix Standard', and incorporated some of the -A5's features with the aim of increasing EGT margin.

In 2011, IAE issued a SelectOne modification package for the -A5 series. This modification was incorporated on the production line and became standard specification for all manufactured engines from 2011.

The modification package included improvements to components in the HPC, HPT and the LPT. These are mainly aerodynamic improvements to the airfoils, which have improved EGT margin by about 12 degrees centigrade (C), increased on-wing removal intervals, and reduced fuel burn by about 1%.

The A320 accounts for the largest portion of V2500-powered aircraft, with more than 1,300 aircraft in service out of a total of 2,400 V2500-powered A320 family aircraft.

V2500 in service

The A319 fleet has 465 V2500-A5-powered aircraft, representing about 33% of all A319s in service. The A319 is powered by the V2522, V2524 and V2527 variants. The V2527 powers a minority of aircraft, and has mainly been selected by some Chinese operators.

The V2524 is the most numerous engine, powering more than 260 aircraft. Its main operators include Capital Airlines, Germanwings, Spirit Airlines, Turkish Airlines (THY), and US Airways. Airlines operating in high ambient temperatures include Air Macau, Bangkok Airways, China Southern Airlines, TAM, LAN/LAN Peru and Volaris.

Average annual rates of utilisation are 3,200 flight hours (FH) and 1,930 flight cycles (FC), while the average FC time is 1.8FH.

The V2527M-powered aircraft are operated at higher annual rates of utilisation, while V2522-powered aircraft are operated at lower rates of 2,900FH per year.

There are about 1,400 A320s equipped with V2500s, equal to 42% of the 3,300 A320s in operation.

There are 82 aircraft still in service with V2550-A1 engines, including original operators Air India and US Airways.

There are another 1,312 aircraft with V2527-A5 engines, split between 1,194 aircraft with V2527-A5 engines, and 118 with the V2527E-A5 engines.

The V2527-A5-powered A320 is in use with over 40 airlines. Those operating in temperate climates include Air Astana, Air New Zealand, Asiana Airlines, British Airways (BA), Cyprus Airways, jetBlue Airways, Spirit Airlines, United Airlines, US Airways and Wizz Air.

A large number of airlines operating in hot environments have also selected the V2527-A5. These include Aegean Airlines, Bangkok Airways, Dragonair, Egyptair, Etihad Airways, Indigo Airlines, Middle East Airlines (MEA), Onur Air, Qatar Airways, TAM, Tigerair, LAN Argentina, Volaris, several Chinese operators, and Jetstar Airways.

Airlines that operate the V2527E-A5 include those that operate in hot and high environments: TACA, the LAN group of carriers, TAM and TAME.

The V2527-powered fleet operates at average annual utilisations of 3,400FH and 1,700FC, with an FH:FC ratio of 2.06:1. There is also a wide variation of utilisation rates and FH:FC ratios around these averages.

There are about 530 A321s equipped with V2500-A5s, equal to 62% of the global fleet. These are split between 75 aircraft with the V2530-A5, and 454 with V2533-A5 engines.

Most A321 operators have specified the V2500-A5 engine. V2530-A5 operators include Asiana, Air China, Atlasjet, SAS, Lufthansa, Nordwind Airlines, TransAsia Airways and THY.

More than 26 carriers have chosen the V2533-A5 engine, including Aegean Airlines, Air Astana, Air Busan, Air Macau, Asiana Airlines, Atlasjet, BA, Jetstar, Lufthansa, MEA, Monarch, Onur Air, Qatar Airways, TACA, THY, US Airways and Vietnam Airlines.

Perhaps surprisingly, the A321 has lower rates of utilisation than the A319 and A320. V2533-A5-powered aircraft have an average annual utilisation rate of 3,200FH and operate at 2.15FH per FC. "Lufthansa operates its fleet at about 1,750FC per year, and at a FH:FC ratio of 1.9-2.0," says Hatice Ege, engine services, at Lufthansa Technik.

V2500-A5 LLPs

The V2500 has 25 life limited parts (LLPs) in the four main modules. The fan and LPC have three parts; the HPC, four parts; the HPT, six; and the LPT, 12.

The 2013 list price for a complete shipset of parts is about $3 million. All 25 parts have a uniform life of 20,000 engine flight cycles (EFC), simplifying engine management.

The three parts in the fan/LPC have a combined list price of $452,000 *(see table, page 42)*. The four HPC parts have a combined list price of about $740,000, while the six HPT components have a combined list price of $825,000. The LPT's 12 parts have a list price of $977,000.

Fan blades are not classed as LLPs, and can be repaired.

V2500 management

The V2500's uniform LLP lives make the engine easier to manage than a type such as the CFM56-5B that has variation in LLP lives within modules and between the main modules.

The V2500 generally has good EGT margin retention, and is not removed for shop visits due to EGT margin erosion in most cases. Engines for most variants with low and medium thrust ratings have sufficient EGT margin to remain on-wing for to or beyond 10,000EFC. Removals are due to several types of hardware deterioration.

First removals are typically followed by a hot section refurbishment (HSR) or a core refurbishment shop visit workscope.

They can then be followed by similar second removal intervals. Total accumulated on-wing time at this stage is therefore close to 20,000EFC. This coincides with full LLP lives, providing an opportunity for a heavier shop visit, which is often a full workscope, so that LLPs can be removed and replaced.

Higher-rated variants, or engines operating in hot environments, however,

The majority of A320 family aircraft operate at average EFC times of 1.8-2.0EFH. Annual utilisations average about 3,000FH.

are limited by EGT margin and its erosion, and so achieve shorter intervals. This can complicate shop-visit workscope planning and management, since the timing of the engine's second removal interval can compromise the efficient use of LLP total life utilisation. Average removal intervals of about 6,500EFC mean full LLP life will not be utilised until the third removal.

In the case of high-rated variants operating in temperate climates the second shop visit will be similar to the first. The third workscope will require full disassembly for LLP replacement.

Engines operating in hot environments, such as the Middle East, will follow a similar shop visit workscope pattern of alternating HSR and overhaul workscopes to engines operating in temperate climates. The difference, however, may be that excessive erosion in the LPC would add to the workscope. The engine would go through more shop visits prior to LLP replacement due to shorter removal intervals.

V2500 performance

Some V2500 variants have high performance in relation to available EGT and EGT margin. Three of the five -A5 variants have a high corner point temperature, which is the OAT up to which thrust can remain constant. That is, the engine is flat-rated at operating temperatures up to the corner point OAT. This is because the engine's EGT will not exceed the red line temperature limit up to this point.

For OATs higher than the corner point temperature, engine thrust has to be steadily reduced to prevent EGT exceeding the red line limit.

The V2522-A5 and V2524-A5 powering the A319 have high corner point temperatures of 55 degrees centigrade (C). These two engine variants can thus operate at high OATs in hot environments without restrictions on operating performance.

The V2527-A5, powering a small number of A319s and the A320, has a corner point temperature of 46 degrees C. This allows the engine to operate without any limitations to its operating performance in most environments and operating conditions.

The V2500-A1 has a corner point temperature of 30 degrees C. The engine will therefore face thrust and performance limitations on more occasions than its main operators.

The V2530-A5 and V2533-A5 have a corner point temperature and are flat-rated to 30 degrees C.

EGT margins

EGT margin and the rate of erosion of this margin can be main factors influencing removals for shop-visit maintenance.

The base V2500-A5 engines have good EGT margins for most variants. The SelectOne standard engines, however, have a hardware standard that results in a higher EGT margin. "This is especially beneficial for the higher-rated variants that power the A321," says Mark Byrne, programme manager at Total Engine Support (TES). "The SelectOne engines' EGT margin is 10-15 degrees C higher than standard specification engines."

SelectOne engines are mainly those manufactured since 2011, but also include a small number built prior to this date that were subsequently modified.

V2522-A5 & V2524-A5

"Installed EGT margins for new engines will depend on OATs, but for standard temperature they are 100-115 degrees C for V2522-A5 and V2524-A5 engines," says Byrne. The similar EGT margins for both variants, despite the difference in thrust rating, is because the V2522-A5's red line temperature is 10 degrees lower than that of the V2524-A5.

SelectOne versions of these two variants will have higher EGT margins. "The EGT margins of the base versions of these variants are high enough for EGT margin erosion not to be a shop visit removal cause. These engines experience hardware deterioration before their EGT margin is fully eroded," says Byrne. "The SelectOne variants of the V2522 and V2524 therefore do not benefit in terms of EGT margin."

V2527-A5

The V2527-A5 base versions can have installed EGT margins of up to 105 degrees C, although it is more likely to be 85-90 degrees. Individual engines with lower margins may, therefore, be removed due to the complete erosion of margin. SelectOne versions of the engine will have higher EGT margins, that will benefit the individual engines with lower EGT margins.

The V2500-A1 had an installed EGT margin of about 90 degrees C when new. All -A1s are mature, and therefore have a lower post-shop-visit EGT margin.

V2530-A5 & V2533-A5

The highest-rated V2530 and V2533 standard variants have installed EGT margins of 70-75 degrees C and about 70 degrees C when new. "These margins are low enough for erosion to be a main cause of removals for shop visits.

SelectOne versions will therefore benefit from a higher EGT margin. "These are about 70 degrees C on a hot day," explains Ege.

The EGT margin will thus be 10-15 degrees higher for moderate OATs. This is more likely to extend on-wing life and

The lower-rated V2500-A5 engines powering the A319 and A320 have sufficient EGT margin not to be removed due to loss of performance. These engines are mostly removed due to deterioration of hardware, such as first stage HPT blade distress.

removal interval, but EGT margin erosion will still be a main removal cause for these engines.

EGT margin erosion

EGT margin erosion will be offset to some degree by take-off thrust de-rate, which averages about 15% for engines powering the A319 and A320. Take-off de-rate will reduce actual EGT, and so lessen EGT margin erosion.

V2530-A5 & V2533-A5

EGT margin erosion rates are highest for the highest-rated V2530 and V2533 variants. "This makes the problem of low initial EGT margin worse," explains Byrne. "It is almost certain that EGT margin will fully erode after a relatively short on-wing interval. The V2533 experiences EGT margin erosion at an average rate of 10 degrees per 1,000EFC. This means the engine can remain on-wing for about 7,000EFC before full EGT margin is fully eroded."

V2527-A5

By comparison, the V2527 has an EGT margin erosion rate of 5 degrees per 1,000EFC; a much better rate than the higher-rated variants. "For this reason it is quite rare for the lower-rated variants to be removed due to full EGT margin loss. EGT margin and rate of erosion alone would allow the engine to remain on-wing for up to 20,000EFH," says Byrne. "These variants tend to be removed for several other reasons, related to the deterioration of hardware that starts to take effect while the engine still has a lot of remaining EGT margin.

V2524-A5

"The V2524 has an even lower rate of erosion of 3.7 degrees per 1,000EFC, so it has enough EGT margin to remain on-wing for more than 20,000EFH," says Byrne. In certain operating conditions, the rate of EGT margin loss could be less than 3 degrees per 1,000EFC.

Removal causes

As described, the highest-rated V2500 variants powering the A321 are removed mainly due to EGT margin erosion.

The medium- and lower-rated variants powering the A319 and A320 are removed for deterioration of hardware in most cases. "The first problem with engine hardware is distress in the high-pressure turbine (HPT). This was an issue particularly with the V2527-A5 engines and the lower-rated variants," says Byrne. "The problem was originally with cracking of the first stage HPT blade. This was cured with the development of new part numbers, which provided blades with better durability."

With the issue of the first stage HPT blades solved, and longer on-wing intervals achieved, problems with cracking and deterioration of the second stage HPT blades have been revealed. There has only been one part number for the second stage HPT blade, so the issue has not yet been resolved.

"The second main problem has been with the damper wire in the 3-8 stage HPC drum," continues Byrne. "This problem has persisted in the engine. The damper wire comes loose, wearing through its locating diameter and protrudes from the HPC drum into the gasflow path. The wire then comes loose and breaks off, and causes airfoil damage downstream. This problem is solved by a new HPC drum, which has a list price of $210,000."

Other major problems relate to various issues with the HPC, including blade fractures and failures, and casing detachment.

These first two main hardware deterioration issues and the loss of EGT margin for higher-rated engines are main causes of engine removals.

There have also been, however, issues with several airworthiness directives (ADs). AD 2009-22-06 forces the removal of the stage 9-12 HPC drum on the V2527-A5 due to low cycle fatigue.

AD 2010-06-18 requires the HPC stage 3-8 drum to have fluorescent penetrant dye inspection to detect the previously described fatigue.

AD 2012-09-09 relates to the same HPC drum, and requires an ultrasonic inspection.

AD 2011-25-08 requires inspection of the first stage HPT blade outer air seal for distress. This follows some reports of bulging of the HPT cases.

There are other issues that cause or influence the removal of some engine types. These include engine flight hour (EFH) to EFC ratio, the OAT in which the engine operates, and the rate of take-off de-rate used. "The OATs in our A321 route network range from cold temperatures experienced in Norway to the high temperatures we experience on operations to the Middle East. We have de-rates in the typical range of 15-20%, given our A321 operation in the European Union (EU)," says Ege.

Differences in EFH:EFC ratio tend to have little effect on the number of EFCs between shop visit removals.

"A high OAT affects some operators in the Middle East," says Byrne. "These airlines generally see removal intervals that are about half the number of EFCs of engines operated in temperate climates. For this reason some Middle East airlines prefer the CFM56-5B engine, which lasts longer on-wing in hot environments. It is less clear what effect on removal interval the rate of take-off de-rate has."

The eMMP provides soft times for the different levels of shop visit workscope for each module based on time accumulated since new or the last full workscope. Most engines will have a level 2.9 workscope for their HP modules at the first shop visit, but are less likely to have work performed on the LP modules.

1st removal intervals

The majority of the installed V2500 fleet is past its first removal and shop visit. There are, however, younger engines that have yet to reach their first shop visit.

First removal intervals are shorter for the higher-rated V2530-A5 and V2533-A5 that power the A321, than they are for medium- and low-rated variants. As described, the V2530 and V2533 are limited by EGT margin and their high rates of EGT margin erosion. This generally results in first removal intervals of 7,000-7,500EFC for standard specification V2530-A5 and V2533-A5 engines. This interval is equivalent to approximately four years of operation.

The interval will be affected, however, by EFH:EFC ratio, and will be shorter in EFC at 5,500-6,500EFC for V2533-A5 engines operated at average EFC times that are longer than 2.0EFH.

While the other three variants have sufficient EGT margin to remain on-wing up to or close to their full LLP life limits of 20,000EFC, they are also limited by the issue of HPT distress and the HPC drum case damper wire.

The standard V2527-A5 engine generally reaches an interval of 10,500EFC for its first removal, equal to five or six years of operation. The standard-build V2524-A5 and V2522-A5 engines achieve slightly longer intervals of about 11,500EFC for their first removals, equal to six years of operation at typical rates of utilisation. These intervals are generally caused by the deterioration of hardware as described. Intervals will be shorter at 8,000-9,500EFC for V2527-A5 engines, and 5,500-6,500EFC for V2522-A5 and V2524-A5 engines operated on longer EFH:EFC ratios.

Engines operating in the Middle East, where the sand and high temperatures result in a high rate of hardware, and, consequently EGT margin deterioration, have removal intervals that are about half the number of EFC.

SelectOne standard engines, built from 2011, will have higher EGT margins. This will be beneficial for the higher-rated V2530-A5 and V2533-A5 variants. It is too early, however, to be clear about the amount by which the higher initial EGT margin will increase first removal intervals. Ege comments that while it is too early to predict first removal intervals for SelectOne engines, they are showing fewer early removals.

Shop-visit workscopes

The electronic maintenance manual plan (eMMP) defines two main levels of workscope for each main module. A full workscope is a level 3.0 workscope for each module. A lighter workscope is a level 2.3 for the fan, LPC, and LPT, while it is a level 2.9 for the HPC, combustor and HPT modules.

The eMMP sets soft on-wing lives, or EFH and EFC thresholds since new or the last level 3.0 workscope, to define the limits for level 2.3/2.9 and level 3.0 workscopes.

A level 2.9 workscope for the high-pressure modules requires a large number of the non-performance-critical components, such as the HPC, to have a general visual inspection (GVI). This is only required if cracks are observed after the module has been disassembled. If components look acceptable, then the module can be re-sealed. In the high-pressure modules that have a 2.9 level workscope, performance-critical parts, however, have to be measured accurately. That is, the dimensions that affect their aerodynamics have to be verified.

In the case of the low-pressure modules that have a 2.3 level workscope, the eMMP allows for a GVI on some of the airfoils. A level 2.3 workscope on the LPC, for example, is just a check and repair. This is just to remove it from the engine, and disassemble it as required to fix any problems, such as cracked blades.

The eMMP also describes smaller shop visit workscopes. Some modules have a level 2.1 workscope, which is a light repair. The HPC has a level 2.5 workscope, specifically designed to restore bleed hardware.

It is possible to have a light shop visit, where the LPT can be removed if a crack has been detected in the first stage blades. The LPT module can be removed, and the first stage rotor can be visually inspected. The affected blades can be removed and replaced without any further disassembly of the module or the rest of the engine.

1st shop visit workscope

The first shop visit workscope will usually be a hot section refurbishment (HSR) or a core refurbishment. "This will include refurbishing the intake fan blades by restoring their leading edges," says Byrne. "It will also involve refurbishing the HPC, the combustor, and both stages of the HPT. There may also be a minimum workscope for the LPT."

The first shop visit is, therefore, usually a level 2.9 workscope for the HP modules. The requirement to work on the LPC and LPT modules is purely down to condition, but most engines will not need work on these modules at the first shop visit.

"The engine's operating environment will have a large effect on the percentage of stage 1 HPT blades that need to be scrapped," explains Martin Matthews, programme manager at AerFin Ltd. "The percentage that can be expected to be repaired at the first shop visit is about 80% of engines operating in a temperate environment. The percentage that can be repaired will be much lower at 20% or less for engines operated in a hot, non-benign environments. Overall scrap rates are expected to be low at the first shop

The lower-rated V2500-A5 variants powering the A319 and A320 are able to have two removal intervals that will nearly or completely total the full LLP lives of 20,000EFC.

visit.

"On exposure of the HPC, an increasing high cost element is the percentage of HPC 3-8 drums scrapping out due to a problem of damper wire wear between stages 7 and 8," says Matthews. "This has been evident on lower life drums at less than 50% of their declared life of 20,000EFC requiring replacement of the HPC 3-8 drum. This implies the cost of the shop visit will be high, since the cost of an LLP will be added.

"The workscope will of course include other items, such as repair of combustion chambers," continues Matthews. "Combustion chamber panels can be repaired regularly, and panels and liners can be replaced if necessary."

Ege at Lufthansa Technik says it typically a HSR workscope, but will perform a level 3.0 workscope on the combustor, HPT module, and number four bearing. It may also include the fan module. This high level workscope can result in higher EGT margins.

Subsequent performance

EGT margin following the engine's first shop visit will be several degrees C lower than the margins of new engines, having implications for second and subsequent removal intervals.

"The margin for standard-build V2524 and V2527 engines is 60-80 degrees C," says Byrne. These margins are 20-40 degrees lower than the margins of new engines. The restored margins for the V2530 and V2533 engines are 40-50 degrees.

"It is too early to know what the restored EGT margins for SelectOne engines will be," says Byrne. SelectOne engines are still relatively young and it will be another two years before the initially manufactured engines have been through their first shop visits.

The rate of EGT margin loss means the standard-build V2530 and V2533 engines will have second and subsequent removal intervals limited by EGT margin. "The V2533-A5 has a post-shop visit EGT margin of 27-33 degrees C. Typical rates of EGT margin loss means the subsequent removal interval will be 4,000-5,000EFC," says Matthews.

Ege, however, says that Lufthansa Technik has seen post-shop-visit EGT margins on standard-build V2530/33 engines as high as 60 degrees.

While Lufthansa Technik does not yet have experience of SelectOne engines post-shop visit, based on its test cell experience of standard engines, it expects SelectOne engines to have an EGT margin that is about 10 degrees higher.

The SelectOne modification will clearly help these high-thrust variants. "The increase by 12 degrees C EGT margin offered by the modification programme should allow a second and subsequent removal interval to extend by a further 3,500EFC compared to the standard-build engines," says Matthews.

The lower rate of EGT margin loss for the V2527 variant means it should be able to remain on-wing for 11,000-13,000EFC. The V2524 and V2522 variants will be able to achieve longer intervals of 18,000-22,000EFC.

"The medium- and lower-rated V2500-A5 variants will have enough EGT margin after each shop visit for this not to be a main removal cause. The deterioration of hardware will still be the main removal drivers for these variants," says Byrne. "These variants will therefore be able to achieve removal intervals that are similar to the first."

Second shop visit

In hand with the issue of removal intervals that are possible due to EGT margin erosion and engine performance and hardware deterioration, the intervals and workscopes of successive shop visits are also influenced by the LLPs' life limits. As described, all 25 parts have uniform lives of 20,000EFC.

This makes it relatively easy to manage the engine and the pattern of shop visit workscopes in the case of the V2522, V2524 and V2527 engines.

"The shop-visit pattern will be restricted by the fact that a removal at or close to 20,000EFC will require the full disassembly and a full workscope to remove and replace all LLPs," says Byrne.

The removal intervals that the V2522, V2524 and V2527 generally achieve mean they can follow a relatively simple pattern of an HSR or core refurbishment at the first shop visit, up to 11,500EFC. This will then be followed by an interval that consumes the balance of the 20,000EFC life limit of the engine's LLPs, and then by a full workscope at the second shop visit. These medium- and low-rated engines can all generally follow this relatively simple shop-visit pattern for the remainder of their operating lives.

The second shop visit will be a level 3.0 workscope for all modules, driven by the fact that this depth is necessary to remove and install LLPs.

"The fan/LPC module will only require a general visual inspection at a lower shop visit. Repairs to outlet guide vanes are sometimes required. Fan blades can also be easily removed and nicks and dents blended, according to EMMP soft times. LLP replacement will force a level 3.0 workscope," says Matthews. "At this stage fan blades will undergo an eddy current inspection, fan abradable lining may require replacing, acoustic panels will be checked for delamination, and the 2.5 bleed system will be repaired as required."

Matthews adds that stage 3 LPT blades often suffer sulphidation, and this can force module disassembly, although not every stage would necessarily be fully de-bladed.

The higher-rated V2530 and V2533

The fan and LPC modules only usually require a full level 3.0 workscope when having a full overhaul for the purpose of complete disassembly and replacement of the full shipset of LLPs.

engines are compromised by their shorter intervals. Byrne explains that these engines are generally forced into a pattern of three shop visits over the LLP life interval of 20,000EFC.

The first shop-visit workscope, after an interval of 7,000-7,500EFC, will be an HSR or core refurbishment, as in the case of the lower-rated engines. It is likely to require level 2.9 workscopes for the HP modules. The LP modules are unlikely to require any work, unless their condition states otherwise.

Byrne explains that the second shop visit would have a similar workscope to the first, that is, level 2.9 workscopes on the HP modules. Again, workscopes are unlikely to be required on the LP modules, because total accumulated on-wing time at this stage would be 11,500-13,000EFC, which is relatively short.

The third shop visit will be up to a total on-wing time of 20,000EFC. A level 3.0 workscope on the HP modules will thus be required at this stage. Byrne advises that if a total time of 18,000-20,000EFC has been reached, and the LP modules have not yet had a workscope, they will also need a level 3.0 workscope.

SelectOne engines

The SelectOne modification is intended to increase EGT margin, and therefore improve on-wing life. The low- and medium-rated engines will not benefit from it, because removal intervals can only be extended by up to 2,000EFC. The V2527-A5, for example, is expected to have a first removal interval of 12,000EFC. The first manufactured SelectOne engines are expected to have their first removals in 2016.

These engines will still require two removals and planned shop visits within the constraint of the 20,000EFC LLP life. Low- and medium-rated engines will benefit, however, from reduced shop-visit costs as a consequence of the improved airfoil materials.

The higher-rated V2530-A5 and V2533-A5 engines will probably benefit more from the SelectOne modification programme in terms of maintenance costs. The first and second removal intervals are expected to be increased to 8,000EFC. The implications are that the engines could have accumulated 15,000-16,000EFC by the second removal and shop visit. It would then make sense for them to have a full level 3.0 workscope at this stage, and have all LLPs replaced. This may be more economic than having a series of three shop visits with a total interval of about 20,000EFC.

Another option for higher-rated engines is possible where they are operated in a mixed fleet of V2527-A5 and low-rated engines. The V2530/33-A5 engines are likely to have a first removal of 8,000EFC. These could be de-rated via the FADEC and installed on A319s or A320s after the first shop visit. These can be expected to achieve 10,000-12,000EFC on the second removal interval, and so achieve a total interval of 18,000-20,000EFC by the second shop visit.

In the meantime, V2522/24/27-A5 engines could be up-rated via the FADEC to a V2530/33-A5 rating and then installed on A321s. These could then be expected to achieve a second interval of up to 8,000EFC, and so a total time close to 20,000EFC.

The high-rated and low-/medium-rated engines could therefore be swapped between A321 and A320/19 fleets at the first removal, so that all engines achieve a total time close to 20,000EFC by the second shop visit.

Shop-visit inputs

The three main elements of shop visit inputs are labour, materials and parts, and vendor repair scheme (VRS) repairs. The cost of VRS repairs is divided between in-house repairs and sub-contract repairs. Labour is divided between the routine man-hours (MH) used for disassembly, inspection, standard repairs, reassembly and testing; and the non-routine portion for repairs, including hi-tech repairs of airfoils.

Materials and parts are those used for the repairs of parts performed in-house, or the replacement of scrapped parts.

In-house repairs are usually charged to airline customers at fixed prices by engine shops. These are the repairs that the engine shop can perform in-house.

Sub-contract repairs is the all-inclusive cost of repairing parts that cannot be repaired in-house. These are usually hi-tech repairs to the most complex parts, such as HPT blades.

There is a trade between the cost of in-house and sub-contracted repairs. Shops with a larger in-house component repair capability will thus use a large number of MH, and incur a high cost for materials and parts and in-house repairs; and have a smaller cost for sub-contract repairs. Conversely, shops with a small in-house repair capability will use less labour and have a smaller cost for materials and parts, and have a high sub-contract repairs cost.

There is also a trade between the labour MH used, cost of parts, and cost of repairs according to what percentage of parts are repaired in-house, and what percentage are replaced.

There are several variations in shop visit costs for the five variants in the V2500-A5 family. A V2522 or V2524 will achieve longer first removal intervals than higher-rated variants. The lower-rated engines will therefore have a high percentage of airfoils that scrap, especially 1st stage HPT blades, compared to higher-rated variants that have shorter removal intervals. The cost of a new set of 1st stage HPT blades is $600,000-700,000, while the sub-

V2500-A5 SHOP VISIT REMOVAL INTERVALS & MAINTENANCE RESERVES

V2500-A5 variant	V2522/24/27-A5	V2530/33-A5
EFH:EFC	1.80-2.0	2.0-2.15
1st removal interval		
EFC	10,500-11,500	7,000
Shop visit input	$2.13-2.56 million	$2.0-2.25 million
2nd removal interval		
EFC	8,500-9,500	5,000-5,500
Shop visit input	$3.0-3.25 million	$2.17-2.63 million
3rd removal interval		
EFC		5,000-5,500
Shop visit input		$3.0-3.25 million
Total all removals		
EFC	20,000	17,000-18,500
Shop visit inputs	$5.15-5.80 million	$7.15-8.15 million
LLP replacement	$3.0 million	$3.0 million
Total shop visit & LLP reserve: $/EFC	406-440	$600
Total shop visit & LLP reserve: $/EFH	204-245	$280-300

contract cost of repairing a shipset is less at about $150,000.

Low-rated engines will therefore have lower inputs relevant to new parts and higher inputs in relation to in-house, VSR and sub-contract parts repairs compared to high-rated V2500-A5 variants.

The total shop visit costs for different variants at the same shop visit, especially the first and the event where a full overhaul is required to replace all LLPs, will be different due to variations in workscope.

Further variations in workscope of shop visits subsequent to the first shop visit will arise depending on the percentages of parts, especially blades and vanes, that were repaired and replaced at the first shop visit.

There are now a variety of engine maintenance contracts that airlines can choose from. These are paying for labour/time and material, fixed price, or not-to-exceed contracts. The shop-visit costs will be examined here on the basis of those that are likely to be paid for when using a time and material type of contract.

The labour used for the main routine elements of a typical first shop visit workscope, which is likely to be a 2.9 level scope for the HP modules plus the possibility of some work on the LP modules, may often be charged as a set labour cost. The labour used will be 2,200-2,500MH. The labour rate for engine shops will be $85-100 per MH.

A set labour cost for the first shop visit, however, may be $280,000-290,000, and this would provide some capacity for the possibility of a larger workscope.

The cost of materials and parts, excluding LLPs, will be $1.1-1.2 million.

The cost of in-house repairs may be $240,000, while the cost of sub-contracted repairs will be $500,000-800,000. There will be a trade between these two sub-elements of the total cost of repairs depending on the shop's in-house capability.

The total cost of the shop visit will therefore be $2.3-2.5 million. There will some variation in the total cost between the different variants according to their thrust rating and removal interval.

A similar, but larger, workscope performed after the second removal will be closer to $2.7 million. This is the shop visit that will be performed for V2530/33-A5 engines at the second removal, and which will have a full workscope and LLP removal at the third shop visit.

The cost of a full level 3.0 workscope for all engine variants will total close to $3.0 million.

The labour element for this workscope may be up by another $50,000, since only up to 500MH more may be required.

The cost of materials and parts will be higher at up to $1.5-1.8 million, since a higher percentage of parts and airfoils will scrap and have to be replaced at this shop visit.

The total cost of VRS repairs will be higher at $0.9-1.1 million. This will include up to $800,000 for sub-contract repairs, and a similar cost of $250,000-300,000 for in-house repairs.

The total for this level of shop visit will be $3.0-3.1 million.

Maintenance reserves

The total cost for two consecutive shop visits for V2522/24/27-A5 engines, operated in a temperate environment, will be $5.1-5.8 million. This will be amortised over an interval that will be close to the full 20,000EFC life of the engine's LLPs.

The additional cost of a shipset of LLPs amortised over the same interval means the total reserves for planned maintenance will therefore be $406-440 per EFC *(see table, this page)*. This is equal to $204-245 per EFH.

The shop visit pattern and planned removal intervals and subsequent workscopes will be disrupted, however, by unscheduled engine removals. These will be triggered by events such as birdstrikes and bearing failures.

The total for the three consecutive shop visits for the V2530/33-A5 engines, operated in a temperate environment, will be $7.2-8.1 million. The cost of each shop visit will depend on the interval achieved, and the parts scrap rate.

This will be amortised over the combined interval of the three shop visits, which could be 17,000EFC to almost the full LLP life of 20,000EFC.

The additional cost of a shipset of LLPs will take the reserve for all costs to about $600 per EFC. This is equal to $280-300 per EFH *(see table, this page)*.

In addition to these examples, engines operating shorter average EFC times or in hot climates, such as the Middle East, should also be taken into consideration.

Engines operating in hot climates could not only have twice the number of shop visits, but the engines are also likely to have a high scrappage rate.

There is also the issue of V2530/33-A5 SelectOne standard engines to consider. As described, they may be able to have longer removal intervals, and so have accumulated a total of 15,000-16,000EFC by the second shop visit. While this will not allow the LLP lives to be completely utilised, the cost of one fewer shop visit means that overall maintenance reserves will be $50-100 per EFC lower than standard build engines going through a cycle of three shop visits for the life of a complete set of LLPs.