V2500 maintenance analysis & budget

The V2500's most numerous sub-family is the -A5 powering the A320 family. Its operation, removal intervals, shop visit pattern, and maintenance reserves are analysed.

There are about 1,520 A320 family aircraft and 116 MD-90s in airline operation that are powered with International Aero Engines (IAE) V2500 engines. There about another 920 A320 family aircraft on firm order for which the V2500 has been specified. This makes a total of more than 2,440 A320 family aircraft for which the V2500 has been selected, out of a total firm order for more than 5,800 aircraft. The V2500 also powers a small number of corporate and government A320 family aircraft. With orders still being placed for both the A320 family and V2500 engine for at least another five years, the airframe-engine combination can be expected to continue operating for a further 30 to 40 years.

The V2500 powers three A320 family variants *(see V2500 specifications, page 10)*, and the MD-90. The flight cycle (FC) times of these aircraft vary from 1.0 flight hours (FH) to 4.2FH. The majority of operations are within a 1.5-2.5FH range of FC times.

The V2500 family has nine different thrust ratings, varying from 23,040lbs to 31,600lbs take-off thrust. These are summarised *(see table, page 20)*.

V2500 in service

The V2500 first entered service with the A320 in 1988, as the alternative to the CFM56-5A1. The new engine, the V2500-A1, was rated at 24,800lbs take-off thrust, and was chosen by Adria Airways, Indian Airlines, Cyprus Airways, Mexicana and several other carriers.

There are now 135 V2500-A1-powered A320s in operation, with Air India having the largest fleet of 48 aircraft, which it acquired after merging with Indian Airlines. The average engine flight cycle (EFC) time for the fleet is 2.0 engine flight hours (EFH), and the average age is about 16 years. The highest-time aircraft has accumulated 60,000FH.

The -A1 was superseded by the -A5 series as the A320 family was developed with the larger A321 model and smaller A319. There are six -A5 variants, which all have the same turbomachinery, and are controlled with a full authority digital engine control (FADEC) unit to vary thrust ratings.

The first three variants are the V2522-A5, V2524-A5 and V2527M-A5 for the A319, which are rated at 23,040lbs, 24,480lbs and 24,800lbs take-off thrust respectively *(see table, page 20)*. These are the second most numerous V2500-powered aircraft in operation, with more than 310 A319s in service and more than 200 on order. The V2524-A5 is the more popular variant, powering 184 of the 310 A319s in operation and having been specified for another 128 aircraft on firm order.

There are more than 125 A319s in service with the V2522-A5, operated by Air China, British Midland, British Airways, South African Airways and United Airlines. With the exception of United, all operators have average FC times of 1.0-1.7FH.

The larger fleet of V2524-A5-powered aircraft is operated by China Southern, Lan Airlines, Spirit Airlines, TAM and USAirways, plus several other smaller carriers. In most cases average FC times are less than 2.0FH, although USAirways aircraft operate 2.3-2.6FH per FC.

The V2527-A5 is also rated at 24,800lbs take-off thrust and powers the A320. The V2527-A5 is the largest fleet of all variants, powering more than 600 A320s. It has also been specified for more than 600 A320s on firm order.

There are about 30 operators of the V2527-A5, the largest including Air Deccan with 22 aircraft, British Airways (17), China Southern (26), Jetstar Airways (24), TAM (43), Ted (58), United (39) and USAirways (39). By far the largest fleet, however, is operated by jetBlue Airways with 103 aircraft. There are many other operators with smaller fleets, including British Midland, Freedom Air, IndiGo, Kingfisher, Qatar Airways, Sichuan Airlines, Spanair and Turkish Airlines.

The A320s are used on a variety of missions and styles, and most operators have FC times of more than 1.2FH and up to 2.5FH. A median FC time of 1.5-1.9FH applies to most A320s in the fleet. There are now two broad groups of operation: one with an average EFC time of 1.3EFH; and another with an average

The V2527-A5 powering the A320-200 is the most numerous of V2500 family members in operation. jetBlue is the largest operator, with more than 100 aircraft. Average EFC time for the A320 fleet is about 1.8EFH.

V2500 SERIES THRUST RATINGS & APPLICATIONS

Engine variant	Thrust rating lbs	Flat rated temperature deg C	Application	New EGT margin deg C	Mature EGT margin deg C
V2500-A1	24,800	30	A320-200	to 90	65
V2522-A5	23,040	55	A319	90-115	75-100
V2524-A5	24,480	55	A319	90-115	75-100
V2527M-A5	24,800	46	A319	70-80	55-65
V2527-A5	24,800	46	A320	70-80	55-65
V2530-A5	29,900	30	A321	50-60	35-45
V2533-A5	31,600	30	A321	40-50	25-35
V2525-D5	25,000	30	MD-90	65	50
V2528-D5	28,000	30	MD-90	75	60

EFC time of 2.8EFH.

The -A5 fleet has an average age of almost six years, but the highest-time aircraft has accumulated more than 50,000FH. The fleet overall has an average EFC time of 2.0EFH.

The largest orders placed for V2527-A5-powered A320s are from Air Deccan (60), British Airways (27), China Eastern (95), IndiGo (70), jetBlue Airways (95), Kingfisher (30) and Wizz Air (32).

The V2530-A5 and V2533-A5 are rated at 29,900lbs and 31,600lbs take-off thrust respectively, and power the A321. There are about 60 A321s in service with V2530-A5 engines. These are mainly found in small fleets with carriers such as Air Astana, Air Macau, Asiana, Kingfisher, SAS and Transasia. The largest fleet is Lufthansa's, with 20 aircraft. All these airlines have FC times of 1.1 to 1.7FH.

The V2533-A5 powers 156 aircraft which are in operation with about 20 airlines. There are another 122 A321s on firm order with V2533-A5s specified. The largest fleets include British Airways (10), China Southern (23), Monarch Airlines (11), Turkish Airlines (9) and Vietnam Airlines (10).

Overall, the A321 fleet has an average age of six years and has achieved an average FC time of 1.8FH. The oldest aircraft has accumulated 36,000FH.

The MD-90 developed in the late 1980s was a stretch, a re-engined and higher gross weight development of the MD-80. The V2500-D5 was developed for the aircraft. There were two gross weight variants of the MD-90, and the V2525-D5 and V2528-D5 rated at 25,000lbs and 28,000lbs take-off thrust were developed for the aircraft. There are 57 lower gross weight aircraft with V2525-D5 engines in operation with China Eastern, China Southern, Japan Airlines (JAL), and Uni Air. There are another 59 V2528-D5-powered high-gross-weight aircraft in operation with Delta, JAL, Lion Airlines, Saudia and Uni Air. Most MD-90s have FC times of 1.1-2.1FH.

Maintenance factors

The original V2500-A1 variant experienced several technical problems which limited first and second removal intervals after going into service in 1998. These problems have since been overcome and the mature -A1 engines are providing reliable service and better removal intervals. The later -A5 and -D5 variants have proved to be more reliable and have achieved longer removal intervals. Overall, the V2500 has matured to be an engine that has only a minority of its removals caused by loss of performance and exhaust gas temperature (EGT) margin.

While the V2500 operates at FC times longer than those of earlier generation short-haul engines, some V2500 operations are at FC times where removal intervals are more related to FH time on-wing and deterioration of engine hardware. This differs from engines operated on short-haul missions where removal intervals are more closely related to FC times on-wing and EGT margin loss.

Besides FC times and EGT margin, the other factors that affect removal intervals are: operating environment and outside air temperature (OAT); level of take-off de-rate; airworthiness directives (ADs) forcing inspections and possibly removals; the engine's modification status; and the remaining lives of life limited parts (LLPs).

Take-off de-rate is an important factor, since it reduces actual EGT and engine hardware deterioration, and therefore improves on-wing life. A curve of take-off de-rate versus relative maintenance costs indicates that the first 5% of take-off de-rate reduces maintenance costs by about 8%, and the next 5% of de-rate reduces maintenance costs by another 10%. "The range of de-rates for most V2527s is 6-15%," says Ralph Teschner, director of customer programme management at MTU Maintenance.

Average de-rates for V2527-A5 engines are 13%, average de-rates for V2522-A5 engines are 12%, while average de-rates for V2530-A5 engines are 16%.

EGT margin

The age of V2500s varies from new to 19 years. This means that there are several hundred engines still operating on only their first removal interval, while others will have had one or two removals for shop visits, and there will be several hundred engines that have reached maturity in maintenance terms. The EGT margins of engines that have been through a shop visit or have reached maturity are lower than those of new engines.

The standard EGT margin is the difference between the engine's actual EGT when flat rated and the maximum allowable EGT. The maximum EGT at take-off is 635 degrees for a V2522-A5, and 650 degrees for a V2530/33-A5. This temperature can only be held for 10 seconds.

The actual EGT at take-off for new engines and those following a shop visit is less than the maximum allowable EGT. The actual EGT at take-off gradually rises, however, as the engine's hardware deteriorates with continued operation.

With thrust maintained at the variant's maximum take-off level by the engine's FADEC, EGT rises at a constant rate of 2.5-2.6 degrees per one degree increase in OAT up to the flat rating or 'corner point' OAT.

For OATs higher than the corner point temperature, the engine's FADEC maintains the EGT at a constant level by reducing thrust for increases in OAT. The EGT, which is held constant for all OATs higher than the corner point temperature, will gradually rise as the engine's hardware deteriorates with continued operation.

There are three different corner point or flat rating temperatures for the V2500 family *(see table, this page)*. The V2500-A1, higher rated -A5 variants for the A321 and the -D5 variants for the MD-90 all have a corner point temperature of 30 degrees centigrade. The lower rated

VARIATION OF AVAILABLE EGT MARGIN WITH OAT FOR V2500 SERIES ENGINES

V2530-A5
EGT margin variation, with 30 deg C corner point temperature

OAT deg C	5	10	15	20	25	**30**	35	40
Available EGT margin	107.5	95	82.5	70	57.5	**45**	45	45
OAT deg C	5	10	15	20	25	**30**	35	40
Available EGT margin	62.5	50	37.5	25	12.5	**0**	0	0

V2527-A5
EGT margin variation, with 30 deg C corner point temperature

OAT deg C	10	15	20	25	30	35	40	**46**	50
Available EGT margin	160	147.5	135	122.5	110	97.5	85	**70**	70
OAT deg C	10	15	20	25	30	35	40	**46**	50
Available EGT margin	90	77.5	65	52.5	40	27.5	15	0	0

V2527-A5
EGT margin variation, with 30 deg C corner point temperature

OAT deg C	15	20	25	30	35	40	45	50	**55**
Available EGT margin	170	157.5	145	132.5	120	107.5	95	82.5	**70**
OAT deg C	15	20	25	30	35	40	45	50	**55**
Available EGT margin	130	117.5	105	92.5	80	67.5	55	42.5	**30**

V2527-A5 for the A320 has a higher corner point temperature of 46 degrees centigrade, and the lowest rated V2522/24-A5 have a corner point temperature of 55 degrees.

The advantage of having a higher corner point temperature is that maximum take-off thrust can be used at high OATs up to 46 or 55 degrees centigrade. These high corner point temperatures allow most A320 and A319 operations to proceed uninhibited by performance limitations in areas such as the Middle East, India and parts of the Asia Pacific.

The range of EGT margins of new engines depends on thrust rating. The lowest rated engines naturally have the highest EGT margins, with new V2522-A5 and V2524-A5 engines having installed EGT margins of 90-115 degrees centigrade *(see table, this page)*.

The EGT margins of new V2527-A5 engines are 70-80 degrees centigrade, and are 40-70 degrees centigrade for the highest rated V2530/33-A5 variants *(see table, this page)*.

New V2500-A1 and V2525/28-D5 engines have installed EGT margins of up to 90 degrees centigrade and 65-75 degrees centigrade respectively when new *(see table, this page)*. All V2500-A1 and V2525/28-D5 engines are now mature in maintenance terms, however, so they have lower installed EGT margins as a result.

As described, EGT margins reduce as the engine's hardware deteriorates in operation and service. EGT margins are restored following a shop visit, although it is not possible to recover the original EGT margins. The V2500 generally has a reputation for being able to regain a high percentage of its original EGT margin. "The V2527-A5 engine will have a restored EGT margin of about 70 degrees," estimates Teschner. "This compares to about 85 degrees centigrade for a new engine, so that the recovery rate is 80-85%."

EGT margins for other variants following a shop visit are 75-95 degrees centigrade for the V2522/24-A5, 40-45 degrees centigrade for a V2530-A5, and 33-40 degrees centigrade for a V2533-A5 *(see table, this page)*.

The EGT margin for mature V2500-A1 engines is 55-65 degrees centigrade, while the margins for V2525/28-D5 engines are 50-60 degrees centigrade.

Available EGT margin

The available EGT margin at a particular OAT lower than the corner point temperature in real operating conditions is important to operators for aircraft performance considerations. EGT reduces as OAT also reduces below the corner point temperature, thereby increasing available EGT margin. Given that EGT changes at a rate of 2.5 degrees per one degree in OAT, the available EGT margin therefore increases for reductions in OAT below the corner point temperature. A V2530-A5 engine, for example, will have an additional 25 degrees of EGT margin at an OAT of 20 degrees, since the OAT is 10 degrees lower than its corner point temperature. A standard EGT margin of 45 degrees will therefore translate into a margin of 70 degrees at an OAT of 20 degrees *(see table, this page)*. Even with the standard EGT margin reduced to zero, the engine will still have an available EGT margin of 25 degrees at an OAT of 20 degrees centigrade, and 12.5 degrees at an OAT of 25 degrees centigrade *(see table, this page)*.

The available EGT margins for lower rated engines, with higher corner point temperatures, are higher. A V2527-A5 engine, for example, with a standard EGT margin of 70 degrees centigrade for OATs of 46 degrees and higher, will have an additional available EGT margin of 15 degrees at an OAT of 40 degrees, an additional 40 degrees at an OAT of 30 degrees, and an additional 65 degrees at an OAT of 20 degrees centigrade *(see table, this page)*. This example clearly illustrates the benefit of a high corner point temperature.

The V2522/24-A5 with corner point temperatures of 55 degrees centigrade clearly benefit the most. As these engines have standard EGT margins of 75-95 degrees at corner point temperatures of 55 degrees, they will therefore have an additional 37.5 degrees of EGT margin at an OAT of 40 degrees, an additional 62.5 degrees at an OAT of 30 degrees, and an additional 87.5 degrees of EGT margin at an OAT of 20 degrees *(see table, this page)*. The engines will therefore have a lot of available EGT margin at an OAT of

The V2500 family had demonstrated an ability to retain EGT margin and can remain on-wing for long intervals, with removals being forced by degradation of hardware after accumulating a large number of EFH.

20-40 degrees, even when the standard EGT margin is reduced to zero.

This demonstrates how medium- and low-rated engines still have ample available EGT margin in high operating temperatures.

EGT margin erosion

As with most engine types, the EGT margins of the V2500 family are high for the initial period on-wing when new or following a shop visit. EGT margin loss rates can be measured per 1,000 EFC or EFH. The appropriate parameter depends on how the engine is operated. Engines that are operated on short cycle times should have EGT margins considered in terms of EFCs on-wing, while the EGT margins of those engines that are operated on medium and long cycle times should be considered in terms of EFHs on-wing.

"The initial rate of EGT margin loss is up to about 5 degrees centigrade in the first 1,000EFH on-wing," explains Ralph Gaertner, propulsion systems engineering V2500 at Lufthansa Technik. "The rate then stabilises at 3-4 degrees centigrade per 1,000EFH thereafter."

Teschner reports similar rates of EGT margin loss. "Taking a V2527-A5 engine as an example, the mature rate of EGT margin loss is 6 degrees centigrade per 1,000EFC, but this can be up to 8 degrees. This is equal to 3-4 degrees per 1,000EFH for an engine operated at an EFC time of 2.0EFH. The initial rate is slightly higher, and the EGT margin loss rates do not differ much for other variants."

Phil Seymour, managing director at the IBA Group, comments that the V2500 has a reputation for having a stable rate of EGT margin loss, rather than a high initial rate of loss during the first 1,000-2,000EFH on-wing.

Wayne Pedranti, programme manager at Total Engine Support (TES), reports that rates of EGT margin loss vary with thrust rating, with the -30/33-A5 engines having the highest rates. "Engines rated at 33,000lbs thrust lose about 4.1 degrees of EGT margin per 1,000EFH, while engines rated at 27,000lbs thrust lose about 3.0 degrees per 1,000EFH," says Pedranti. "The lower rated engines at 24,000lbs lose about 2.3 degrees per 1,000EFH, and engines rated at 22,000lbs lose about 2.1 degrees per 1,000EFH."

On this basis, it is clear to see why most variants do not have removals caused by loss of EGT margin. A V2522/24-A5 engine with an EGT margin of 90 degrees centigrade following a shop visit, can remain on-wing for up to 39,000-43,000EFH with a rate of EGT margin erosion of 2.1-2.3 degrees centigrade per 1,000EFH. This is equal to 20,000-23,000EFC if operating at an average EFC time of 1.9EFH.

A V2527-A5 engine with an EGT margin of up to about 75 degrees could remain on-wing for about 25,000EFH, which is equal to 12,000-13,000EFC at most operators' average EFC times.

A V2530-A5 engine with an EGT margin of 50 degrees could remain on-wing for about 12,500EFH, which is equal to 6,000-6,500EFC.

IAE points out that the latest -A5 production engines have benefited from improvements to the high pressure turbine (HPT) blades, better tip clearance control, and improved compressor airfoils which have all contributed to the reduction of EGT margin loss by about 10 degrees centigrade over 8,000EFC on-wing.

Removal causes

"Engines rated at 24,000lbs and 27,000lbs thrust are rarely removed due to EGT margin loss," says Teschner. "Most V2500s are removed due to deterioration of hardware after the accumulation of long EFH intervals, and due to LLP limits. Since all or the majority of LLPs have lives of 20,000EFC, most operators try to manage their engine removals around two or three removals within this 20,000EFC limit. Most lower- and medium-rated engines can achieve on-wing intervals close to, or even longer than, 10,000EFC before losing all of their EGT margin. This means that they can have two removals and shop visits for each LLP life and use almost all of the 20,000EFC life. Operators that manage their engines well can get stub lives down to as low as 500EFC, while the stub lives of LLPs in more poorly managed engines can be as high as about 3,000EFC. Good LLP management usually develops when operators have kept their engines for a long time.

"Only the highest rated engines have their on-wing life and removal intervals affected by loss of EGT margin," continues Teschner. "An EGT margin of about 50 degrees centigrade and loss rate of about 4 degrees per 1,000EFH will allow the engine to stay on-wing for 12,000-13,000EFH for full loss of EGT margin, which is equal to 5,500-6,500EFC. In this case, operators are likely to manage their engines so that the LLPs are replaced every third shop visit."

These rates of EGT margin loss and removal interval allowed by EGT margin are for engines operated in moderate climates and at EFC times close to the average of 1.9-2.1EFH.

Since these rates of EGT margin loss allow long removal intervals and a high percentage of LLP lives to be utilised, there are several other removal causes, due mainly to hardware deterioration. "One major removal cause is hot section distress," says Gaertner. "This involves deterioration of the HPT and combustor, and oxidisation of the combustion chamber. Other technical problems have included difficulties with the number three bearing. This is a relatively recent problem, which was discovered by metal chip detectors. It can be fixed by a surgical strike to remove the bearing, which avoids the need for complete engine disassembly."

At higher thrusts and operating temperatures the main removal drivers are combustion liner distress and EGT margin erosion. Many lower rated versions are removed due to first-stage HPT blade and vane distress.

The V2500 suffered from other technical problems in its early years of operation. These included protrusion of a damper wire between the seventh and eighth stages of the high pressure compressor (HPC) into the space between the blades. The wire would break up, causing airfoil damage and fractures downstream of the protrusion. This problem was fixed with service bulletin (SB) 72-0300.

Another issue was the sixth-stage HPC blade root failure, which would occur after 4,500-7,000EFC on-wing. This resulted in hard-time limits of 5,000EFC being imposed on one operator. This problem was fixed with a new blade design, covered by SB 72-0332.

A third major problem was failure of the fourth-stage HPC blade root, causing secondary damage in the engine.

Engines operated on short EFC times and in hot climates are more likely to have their removals caused by loss of EGT margin. "While medium-rated engines operated in a moderate climate can remain on-wing for 12,000-18,000EFH, the same engines used on operations in the Middle East where OATs are frequently 45-55 degrees centigrade, will often have removal intervals of only 6,000EFH," explains Gaertner.

A recent problem has been an AD relating to vibration found on the second stage HPT airseal. Pedranti explains that the AD requires trend monitoring, and if vibrations are detected then the seal has to be removed, which of course leads to an engine's removal and replacement in the shop.

Life limited parts

The V2500 has 25 LLPs. These are divided between groups in four modules. The fan and low pressure compressor (LPC) module has three LLPs. The HPC has four LLPs, and the HPT/combustor module has six LLPs. The low pressure turbine (LPT) is the largest module, with 12 LLPs.

IAE's objective with the V2500 has been to have a uniform life of 20,000EFC for every LLP in the engine. This would simplify engine shop visit management because engines have to be removed and

V2500 FAMILY LIFE LIMITED PARTS

Life limited part	Unit cost $	EFC limit V2500-A5	EFC limit V2500-A1*/-D5*
Stage 1 fan disk	116,000	20,000	20,000/20,000
Stub shaft (LPC)	27,700	20,000	20,000/20,000
Stage 1.5 to 2.5 disk	191,400	20,000	20,000/20,000
Stage 3 to 8 disk (HPC)	164,500	20,000	15,000/20,000
Stage 9 to 12 disk (HPC)	265,400	20,000	15,000/20,000
Rear shaft (HPC)	93,300	20,000	15,000/20,000
Rear rotating seal (HPC)	24,800	20,000	15,000/20,000
Stage 1 HPT disk	181,700	20,000	15,000/20,000
Stage 1 HPT inner seal	32,600	20,000	15,000/20,000
Stage 1 HPT outer seal	84,200	20,000	15,000/20,000
Stage 2 HPT seal	111,600	20,000	10,000/20,000
Stage 2 HPT disk	144,800	20,000	15,000/20,000
Stage 2 HPT plate	56,000	20,000	15,000/20,000
Stage 3 LPT disk	58,400	20,000	20,000/20,000
Stage 4 LPT disk	70,300	20,000	20,000/20,000
Stage 5 LPT disk	64,300	20,000	20,000/20,000
Stage 6 LPT disk	94,100	20,000	20,000/20,000
Stage 7 LPT disk	69,000	20,000	20,000/20,000
Stage 3 LPT seal	45,100	20,000	20,000/20,000
Stage 4 LPT seal	79,000	20,000	20,000/20,000
Stage 5 LPT seal	77,000	20,000	20,000/20,000
Stage 6 LPT inner seal	40,400	20,000	20,000/20,000
Stage 6 LPT seal	20,300	20,000	20,000/20,000
Stage 7 LPT seal	35,300	20,000	20,000/20,000
LPT shaft	70,700	20,000	20,000/20,000
Total	**2,217,900**		

* List prices of LLPs for -A1 & -D5 engines are $300,000 & $100,000 less than -A5 engines.

completely disassembled if the life limit of any LLP is due to be reached. Uniform lives would also minimise the stub lives of LLPs removed for replacement.

Not all LLPs used in early production engines had lives certified at 20,000EFC, however. While there are 25 LLPs in the engine, several part numbers have been manufactured for each LLP. Early part numbers for some LLPs had limits of less than 20,000EFC.

Only 15 of the 25 LLPs in the V2500-A1 powering early built A320-200s have lives certified at 20,000EFC, and these are in the fan/LPC and LPT modules. Of the 10 parts in the HPC and HPT, nine have lives of 15,000EFC, and one has a life of 10,000EFC. These three different groups of lives would force operators to remove engines at compromised intervals, resulting in those LLPs with lives of 15,000EFC being removed early, even though they have several thousand EFC of life remaining.

The 10 parts in the HPC and HPT have a list price of $1.012 million. The 15 parts in the two low pressure modules have a list price of $903,000.

The current parts numbers for all 25 LLPs in the V2500-D5 engine powering the MD-90 all have lives of 20,000EFC. The three parts in the fan/LPC have a list price of $335,000, the four parts in the HPC have a list price of $547,000, the six parts in the HPT have a list price of $616,000, and the 12 parts in the LPT have a list price of $640,000. This takes the total for the full shipset to $2.14 million.

This set of uniform lives simplifies engine maintenance management. If the engine removals can be managed to allow LLPs to be removed with a stub life of 1,000-2,000EFC, LLPs' reserves will be $112-119 per EFC.

All current LLP part numbers for the V2500-A5 have uniform lives of 20,000EFC, regardless of thrust rating. There are some older part numbers on some variants with limits of less than 20,000EFC. Earlier part numbers for the stage 3-8 disks and stage 9-12 disks in the HPC, for example, had lives of 16,000EFC and 12,000EFC respectively. Like the -A1 series, earlier part numbers for all six parts in the HPT have lives of 15,000EFC. These are gradually disappearing from the fleet. Pedranti explains that some older LLPs can have their lives extended by reworking via specific SBs.

The total list price for a shipset is $2.22 million *(see table, this page)*, and would result in an LLP reserve of $117-123 per EFC if the parts could be removed for replacement with a stub life of 1,000-2,000EFC.

Removal intervals

The largest influences on removal intervals are EFC time and thrust rating. Teschner explains that engines operated on short EFC times will generally achieve a larger number of EFCs between removals than engines operated on medium and long cycle times. "A medium-rated engine such as the V2527, operated at 1.0-1.2EFH per EFC, will achieve up to 10,000EFC, while engines on medium EFC times of 1.2-1.5EFH will achieve 8,000-10,000EFC. Engines operated on ratios of 2.0-2.5EFH will achieve 7,000-8,000EFC between removals," explains Teschner.

Thrust ratings are a main influence, with low rated engines of 22,000lbs and 24,000lbs thrust, running at lower temperatures, being able to achieve up to 14,000EFC between removals when operated at medium EFC times. These engines have intervals of 9,000-11,000EFC at EFC times of 1.8-2.0EFH.

"High-rated engines of 30,000lbs and 33,000lbs might usually only achieve 6,000-7,000EFC for similar EFC times," says Teschner. "Therefore low-rated engines or those operated on short EFC times can usually achieve removal intervals that allow two removals for an LLP life of 20,000EFC. High-rated engines and those operated on long EFC times will have shorter removal intervals that allow three removals for an LLP life limit of 20,000EFC." Low- and medium-rated engines with EFC times of up to 2.0EFH, and high-rated engines with EFC times of up to 1.2EFH can have two intervals for each set of LLP lives. Low- and medium-rated engines with EFC times higher than 2.0EFH and high-rated engines with EFC times of more than 1.2-1.3EFH are more likely to have three removals for each set of LLP lives. Pedranti cautions, however, that while the intervals are averages for most younger engines, there are still some older examples being removed after shorter intervals because of as yet unresolved technical problems.

The V2500 not only enjoys stable rates of EGT margin erosion, but is also able to recover a high percentage of its original EGT margin after a shop visit. The engines therefore generally have second and third removal intervals that are similar to, or only up to 1,500EFC less, than the first removal intervals.

Low-rated engines with thrust ratings of 22,000lbs and 24,000lbs have first and second intervals of about 9,500EFC and 8,500EFC. This totals about 18,000EFC, and so would allow LLPs to be removed for replacement with a stub life of about 2,000EFC.

Medium-rated engines with thrust ratings of 27,000lbs will achieve 8,000-8,500EFC for their first and second removal intervals, and so achieve a total of 16,000-17,000EFC. Again, LLPs would be removed for replacement at the second shop visit, and have a stub life of 3,000-4,000EFC.

The highest-rated engines of 30,000lbs and 33,000lbs would have short first intervals of 6,000-7,000EFC. These would be followed by subsequent removal intervals that would average 5,500EFC, and therefore allow LLP life to be utilised as much as possible before replacement every third removal and shop visit after accumulating 17,000-18,000EFC. This would leave a stub life of 2,000-3,000EFC.

An example of high-rated engines are the V2530/33-A5s operated by Lufthansa. Most of these operate at an EFC time of 1.2EFH. "The first engines were delivered in 1993 and we had several technical problems to begin with," says Gaertner. "These have mainly been resolved, and the mature intervals are now about 8,000EFH and 6,700EFC, and are generally increasing."

Teschner explains that unscheduled removals account for about 10% of all removals. "These are solely considered as check and repair shop visits, and therefore do not have an impact on the planned removal intervals."

As expected, engines that are operated in a hot environment suffer high rates of EGT margin erosion, especially if the environment is also sandy. "Sand erodes engine airfoils fast, and the MD-90 in particular experiences difficulties with this," says Teschner. "The MD-90's main wheels throw sand up into its intakes, so its engines therefore achieve only about one-third of the normal removal intervals. This means that the MD-90's engines have more expensive shop visits because of high airfoil erosion. Intervals can be as low as 3,000-4,000EFC. Engines on the A320 suffer less from sand erosion, but still only achieve 70-85% of normal removal intervals, and have a higher rate of HPC blade replacement."

Shop visit pattern

Like most Pratt & Whitney engines, the V2500 follows a simple shop visit pattern of a hot section or performance restoration, followed by an overhaul. In many cases the first shop visit would involve a full disassembly and repair of the fan and HPT modules, and a performance restoration on the HPC. Other modules would be left. This workscope often allows engines to achieve second-run removal intervals that are 90% of the first interval.

This pattern of alternating visits is when the timing of the overhaul comes close to LLP expiry, since an overhaul requires complete engine disassembly. This requires engines to have actual removal intervals for these shop visits of 8,000-9,000EFC to make good use of LLP life. Engines achieving 5,500-7,000EFC will have three removals for the life of a set of LLPs, and so they will have a shop visit pattern of two consecutive hot section restorations, or performance restorations and an overhaul at the third removal.

Seymour explains that IAE's maintenance management plan (MMP) for the V2500 has three levels of workscope for all the engine's modules and major components or systems. The lightest is a level 1, and is a time-continued level and a module inspection only when it is removed in the shop. Level 2 is a repair level, while level 3 involves a full piece-part overhaul. There are different on-wing thresholds for each of these levels for each module and

V2500-A5 SERIES MATURE REMOVAL INTERVALS

Thrust rating lbs	22,000/ 24,000	27,000	30,000/ 33,000
EFC time			
1.0-1.2EFH	To 15,000EFC	10,000-12,000EFC	8,000-10,000EFC
1.2-1.5EFH	13,000-14,000EFC	8,000-10,000EFC	7,000-9,000EFC
1.8-2.0EFH	9,000-11,000EFC	7,500-8,500EFC	5,500-7,000EFC
2.0-2.5EFH	8,500-9,000EFC	7,000-8,000EFC	5,000-6,000EFC

component. These thresholds are provided either by the MMP or are soft times established by the operator. "So, if you want an engine to achieve a 19,000EFH and 10,000EFC removal interval, then you have to do a level 3 workscope on most parts of the engine because of the accumulated time on-wing," explains Seymour. "This means doing a high level workscope on most modules and parts. One issue that should be considered is the V2500's two-stage HPT design which has been used to provide a fuel burn advantage over the CFM56-5B. Having two HPT stages means that shop costs for the V2500 could be potentially higher than those for the CFM56-5B, because of the number of blades that may require repair or replacement.

"At a performance restoration it may not be necessary to replace HPT blades until the second shop visit, so they will be just repaired at the first shop visit," continues Seymour. "Replacement costs are high, with a full set of 68 blades in the first stage costing $478,000, and a full set of 72 blades in the second stage costing $393,000. The stators are also expensive to replace."

Pedranti explains that the hot section refurbishment includes some HPC repair. "There is a little improvement in engine performance from doing more work on the HPC, but the cost of this is disproportionately high. The fan blades may be removed for lubrication."

Teschner explains that the detail of a hot section refurbishment or a performance restoration includes re-establishing the tip clearances of HPC and HPT blades. "The hot section airfoils should be refurbished and combustor liner segments should be replaced," says Teschner. "This workscope is relatively similar for engines with different thrust ratings and EFC times, although there are differences in the level of wear and deterioration of airfoils. The fan gets refurbished at every shop visit. IAE has recommended a mandatory inspection of fan blade dovetails at every shop visit."

Gaertner explains that the difference between a hot section refurbishment or a heavier hot section performance restoration depends on whether the engine has experienced only hot section distress, or has suffered EGT margin erosion. "A performance restoration will include a hot section refurbishment and a workscope on the HPC, since the HPC will recover lost EGT margin. The LPC and LPT modules are not normally touched at the first shop visit," says Gaertner.

A full engine refurbishment will be required every second or third shop visit, as described. The core or high pressure modules will be worked on at every shop visit. If a hot section refurbishment is sufficient at the first shop visit, then a performance restoration and heavier workscopes on the HP modules will be required at the second visit. The fan, LPC and LPT modules will require work every second or third shop visit. This will require a complete engine disassembly to piece-part level, and full repair and overhaul of all parts and components.

Shop visit inputs

The pattern of shop visits that engines usually follow has been described. The first workscopes are hot section inspections of performance restorations. This level of workscope can consume about 800 routine man-hours (MH) and about another 1,400 non-routine MH, taking the total labour input to about 2,200MH. Using a standard labour rate of $70 per MH, this labour portion would cost about $155,000. The labour required not only varies with the depth of the workscope, but also the percentage of parts that are repaired and the percentage replaced. In turn, shops with a high repair capability will use more labour and parts and have relatively low sub-contracted repair costs. Engine shops with low capability will have higher sub-contract repair costs and parts and labour consumption.

The use of materials at this level of shop visit will be $800,000-1,000,000, depending on various factors. The cost of sub-contract repairs will be $200,000-250,000. These three elements will take the total cost of the shop visit to $1.15-1.40 million.

It is possible to have workscopes that just affect the fan and booster module, and the LPT.

A fan and LPC workscope may consume 200-350MH of labour, $30,000-$50,000 for materials depending on the depth of the workscope, and up to about $20,000 for sub-contract repairs. The total cost for the workscope would therefore be $70,000-95,000.

A workscope on the LPT would use 500-600MH, $100,000-190,000 in materials, and up to about $20,000 for sub-contract repairs. The total cost would be $155,000-250,000.

A full engine overhaul uses about 2,500MH routine labour, and the total labour can be up to 5,300MH. At a standard labour rate of $70 this equals a cost of $371,000. The use of materials depends on the depth of the workscope, the percentage of parts that are replaced and the percentage that can be repaired. This cost can therefore range from $1.5 to $1.8 million. The cost of sub-contract repairs ranges from $200,000 to $300,000. This takes the total cost of the workscope to $2.1-2.5 million.

The total cost of a cycle of a hot section inspection or performance restoration followed by an overhaul will be $3.3-4.0 million. This depends on thrust rating, degree of parts degradation, level of parts replacement, and average EFC time.

A cycle of three workscopes, with two hot section or performance restorations, followed by an overhaul will have a total cost of $4.8-5.4 million.

These have to be considered in relation to probable EFC and EFH intervals.

Reducing shop visit costs

As with all engine types, engine parts and components account for the highest percentage of a shop visit cost. Several manufacturers now provide parts manufacturing approval (PMA) parts and components that have lower list prices than the same parts produced by the original equipment manufacturers (OEMs).

Parts and components fall into several categories, with the ones comprising the blades and vanes having the highest list prices. Less expensive parts and components include repairable parts and consumables. These parts include items such as tubes, seals, washers, liners and filters.

HEICO Aerospace is one PMA parts

V2500-A5 ENGINE SERIES MAINTENANCE RESERVES

Removal	First	Second	Third	Average/ Total
V2522/24-A5				
EFH:EFC ratio	1.9	1.9		1.9
Average removal interval-EFC	11,000	9,000		
Average removal interval-EFH	20,900	17,000		
Accumulated interval-EFC	11,000	20,000		20,000
Accumulated interval-EFH	20,900	37,900		37,900
Shop visit workscope	Performance restoration	Overhaul		
LLP replacement		Full set		
Shop visit cost-$	1,250,000	2,250,000		3,500,000
LLP cost-$		2,250,000		2,250,000
Shop visit reserve-$/EFC	114	250		175
LLP reserve-$/EFC	111	111		111
Total reserve-$/EFC	225	361		286
Unscheduled reserve-$/EFH	10	10		10
Total reserve-$/EFH	128	200		161
V2527-A5				
EFH:EFC ratio	1.9	1.9		1.9
Average removal interval-EFC	8,750	7,750		
Average removal interval-EFH	16,625	14,725		
Accumulated interval-EFC	8,750	16,500		16,500
Accumulated interval-EFH	16,625	31,350		31,350
Shop visit workscope	Performance restoration	Overhaul		
LLP replacement		Full set		
Shop visit cost-$	1,400,000	2,400,000		3,800,000
LLP cost-$		2,250,000		2,250,000
Shop visit reserve-$/EFC	160	310		230
LLP reserve-$/EFC	135	135		135
Total reserve-$/EFC	295	444		365
Unscheduled reserve-$/EFH	10	10		10
Total reserve-$/EFH	165	244		202
V2530/33-A5				
EFH:EFC ratio	1.9	1.9	1.9	1.9
Average removal interval-EFC	7,000	5,750	5,750	
Average removal interval-EFH	13,300	10,925	10,925	
Accumulated interval-EFC	7,000	12,750	18,500	18,500
Accumulated interval-EFH	13,300	24,225	35,150	35,150
Shop visit workscope	Performance restoration	Performance restoration	Overhaul	
LLP replacement			Full set	
Shop visit cost-$	1,300,000	1,300,000	2,500,000	5,100,000
LLP cost-$			2,250,000	2,250,000
Shop visit reserve-$/EFC	186	226	435	276
LLP reserve-$/EFC	120	120	120	120
Total reserve-$/EFC	306	346	555	396
Unscheduled reserve-$/EFH	10	10	10	10
Total reserve-$/EFH	171	192	302	218

provider for various engine types, including the V2500. "We have been supplying PMAs for the V2500 for seven to eight years," says Rob Baumann, president of HEICO parts group. "The V2500 fleet is concentrated on a relatively small number of large operators, such as jetBlue, United and TAM. Many of the smaller operators send their engines to the OEMs for shop visit maintenance.

"The saving we can make for an operator using our PMAs at a shop visit is $30,000, although we are now increasing the number of part numbers we offer for the V2500," continues Baumann. "The majority of the parts we supply are consumables and some repairables. Our customers include United and Lufthansa, and other Star Alliance and OneWorld alliance airlines. We have seen demand for PMAs creeping up as the V2500 fleet matures and more engines are removed for shop visits, especially over the past two years. Many operators have a perception problem with PMAs, so consumable parts are a good way of introducing PMAs to operators and getting them accepted. Operators then increase their interest in repairables, and the more expensive blades and vanes."

SelectOne

IAE launched a build-standard improvement package to to improve the performance of the V2500. This is known as SelectOne. The physical improvements to the engine comprise new electronic engine control software, improved HPC blades, a new variable stator vane system, new materials and coatings on the HPT blades, and improved first-stage LPT vanes. SelectOne was certified in late 2007, and will be the build standard for all V2500 engines manufactured from the second half of 2008.

IAE says that SelectOne engines will have about 1% lower fuel burn and have about 12 degrees centigrade higher EGT margin. Most importantly, IAE claims that engines will achieve up to 20% longer removal intervals.

High-rated engines, and those operating short cycle times or in hot environments will benefit the most. These engines have removal intervals of 4,000-7,000EFC, so they require three removals and shop visits per LLP life. Longer intervals, however, mean that more engines will only require two shop visits per LLP life, and will therefore experience a reduction in maintenance reserves.

Longer intervals will be of little benefit to low- and medium-rated engines operating in temperate climates and at EFC times of longer than 1.8EFH, because of LLP life limits. These engines will, however, have lower shop visit costs because of improved parts and components, which will therefore contribute to lower costs for these items as a result.

While SelectOne will be a build standard on new engines, it will also be available as retrofit kit to current engines. Operators that have SelectOne engines will benefit from IAE's V2500Select maintenance programme.

While the V2500 has stable on-wing performance and uniform LLP lives, its LLP and shop visit reserves are relatively high. Engines operating on short cycles and in hot environments will be able to achieve longer removal intervals a few removals per LLP life.

Maintenance reserves

The maintenance reserves for V2522/24-A5, V2527-A5 and V2530/33-A5 engines operated at an average EFC time of 1.9EFH and operating in a temperate climate have been calculated *(see table, page 30).*

The V2522/24-A5 and V2527-A5 are able to complete a cycle of performance restoration and an overhaul within the LLP life limits of 20,000EFC. The V2522/24-A5 has first and second removal intervals that total close to 20,000EFC, so the engine is able to completely use LLP lives. The LLP reserves are therefore the lowest possible, at about $111 per EFC *(see table, page 30).*

The V2527-A5 has a total on-wing time of about 16,500EFC at the second removal, and so its LLPs are removed with a stub life of about 3,500FC. LLP reserves for the V2527-A5 are about $135 per EFC.

While both engines have similar workscopes, the lower rated V2522/24-A5 will have lower shop visit costs because of a lower rate of parts replacement compared to the V2527-A5. The performance restoration and overhauls for the V2522/24-A5 will total about $3.5 million, compared to $3.8-4.0 million for the V2527-A5 *(see table, page 30).* Overall, the V2522/24/-A5 has an average reserve of $286 per EFC, which is equal to about $151 per EFH. An additional $10 per EFH should be added for unscheduled visits. This takes the total to about $161 per EFH *(see table, page 30).*

The V2527-A5 has correspondingly higher reserves of $365 per EFC, equal to about $192 per EFH. An additional $10 per EFH should be added for unscheduled visits. This brings the total to about $202 per EFH *(see table, page 30).*

The V2530/33-A5's shorter removal intervals mean that it has to complete three shop visits within the LLP life of 20,000EFC. The three accumulated intervals total about 18,500EFC and 35,000EFH. The two performance restorations have total costs of $1.2-1.4 million each, followed by an overhaul costing about $2.5 million. The total cost of the three shop visits is about $5.1 million, resulting in a reserve of about $396 per EFC, which is equal to about $208 per EFH. An additional $10 per EFH should be added for unscheduled shop visits. This therefore takes the total to about $218 per EFH *(see table, page 30).*

The issue of engines operated in hot environments also have to be considered. As discussed, -A5 engines powering the A320 family operated in hot environments achieve intervals 70-85% of those used in temperate climates. In the case of engines used on the A319 and A320, the number of removals and planned shop visits is increased to three for each LLP life. While this has little effect on LLP reserves per EFC, it clearly increases shop visits reserves. Compared to the reserves for engines operated in temperate climates *(see table, page 30)*, engines used on the A319 and A320 in hot environments will have total reserves $15-40 per EFH higher.

Summary

The most notable features of the V2500 are its stable removal intervals and good EGT margin retention. These allow the engine to match two or three successive removal intervals closely with LLP lives in most cases. This simplifies engine management for most operators. It also allows the lowest possible LLP reserves per EFC to be realised. The V2500's LLPs, however, have relatively high list prices compared to similar rated engines.

The V2500's shop visit costs are also higher than those of competitor engines. The most likely explanation for this is the V2500's two-stage HPT and associated higher blade replacement and repair costs.

The V2500's EGT margin retention and improved reliability through several modifications mean it should be able to maintain steady and reliable removal intervals for shop visits. This in turn should lead to steady maintenance reserves per EFH.

The SelectOne build standard and retrofit programme should improve removal intervals mainly for engines operated on short-cycle times and those operated in hot environments. This will increase the number of engines that are able to have two removals and shop visits per LLP life, and so aid a reduction in maintenance reserves.

Engines that already operate in temperate environments will also be able to realise lower shop visit costs, and thus experience some reduction in maintenance reserves through lower material consumption, MH inputs and cost of sub-contract repairs. AC