The V.2500 has the advantages of high EGT margin and uniform LLP lives. These allow long and predictable removal intervals and simplify engine maintenance workscope planning and management. This results in maintenance costs per EFH that are proportionate with thrust rating.

V.2500 demonstrates simple maintenance management

In recent years the V.2500 has increased its share of orders for A320 family aircraft, despite its late arrival on the market and slow initial sales compared to the CFM56-5A/B. International Aero Engines (IAE) claims the higher thrust-rated variants of the V.2500 family now power a larger number of aircraft than the higher-rated models of the CFM56-5B. The growing importance of the V.2500 therefore merits an examination of its maintenance costs.

Engine configuration

There are three sub-families, or series, of the V.2500: the -A1, the -A5 and -D5. The -A5 is the most numerous and the only one still being manufactured.

There is only one variant of the V.2500-A1: the 25,000lbs rated engine which powers the A320. The-A1 entered service in 1989, and its main operators include Indian Airlines and Cyprus Airways. It powers about 170 aircraft.

There are two -D5 models rated at 25,000lbs and 28,600lbs, which powers about 140 MD-90 aircraft. The -D5's main operators are Delta Airlines, SAS and Saudia.

There are five variants of the -A5 series *(see table, this page)*, which are rated at: 22,000lbs and 24,000lbs for the A319; at 26,600lbs for the A320; and 30,400lbs and 32,000lbs for the A321.

The -A5 entered service in 1993 and succeeded the -A1 as the engine for the A320 family. The -A5's major customers include America West, JetBlue, United Airlines, British Airways, TAM and Dragonair. The V.2500-A5 series powers more than 600 A320 family aircraft.

Two of the V.2500's main attributes are its high exhaust gas temperature (EGT) margin and relatively low EGT margin erosion rate, which have meant that most engines are not removed for maintenance due to EGT margin erosion.

The high levels of EGT margin for new engines are shown as up to 123 degrees centigrade for the V.2522 and V.2524*(see table, this page)*. The higher rated V.2527, V.2530 and V.2533 have EGT margins of 60-80 degrees centigrade.

Installed EGT margins differ from test cell EGT margins. "A new V.2527 has an installed EGT margin of 70-80 degrees centigrade, whereas this would only be about 30 degrees in the test cell," says Ralph Teschner, manager engineering IAE engines at MTU Maintenance. "Higher-rated engines have a lower EGT margin of about 60 degrees, while lower-rated engines have a high enough margin to never be removed due to EGT margin erosion, even when operated on short cycles in hot environments."

The lower margin of higher-rated variants is illustrated by Lufthansa Technik's experience with the V.2500-A5. "We started operations with a 30,000lbs rated V.2500-A5, and this had an initial margin of 40-60 degrees, although we never had any problems or removals related to EGT margin," says Ralph Gaertner, propulsion systems engineering V.2500 at Lufthansa Technik.

V.2500-A5 FAMILY THRUST RATING & EGT MARGIN

Variant	V.2522/24-A5	V.2527-A5	V.2530/33-A5
Thrust rating-lbs	22,000/ 24,000	26,600	30,400/ 32,000
Installed EGT margin -degrees centigrade	90-115	70-80	40-60/
Bypass ratio	4.9	4.8	4.6/4.5

The V.2500 family generally has a high EGT margin, which prevents removals due to EGT margin erosion in most cases. The highest rated variants, at 30,400lbs and 32,000lbs, have EGT margins of 40-60 degrees centigrade which still allows on-wing intervals of up to 14,000EFH. Removal intervals of lower rated versions are not limited by EGT margin.

On-wing performance

The V.2500 is used by airlines on average engine flight cycle (EFC) times of about 2.0 engine flight hours (EFH). There is a broad range of average EFC times, however, from less than one hour to about three. Teschner estimates that average EFC time is 2.5EFH, and annual utilisation in the region of 3,000EFH.

The V.2500 has established itself as having a low rate of EGT margin deterioration, which will allow long on-wing intervals. The engine has, however, experienced other technical problems which have caused unscheduled removals. These issues have been addressed by IAE via modifications to be incorporated at shop visit inputs.

"EGT margin erosion rate is initially about four degrees per 1,000 EFH, but then reduces fairly quickly to three degrees per 1,000EFH," explains Gaertner. "In addition to the 30,000lbs -A5 engine we also operate the 33,000lbs -A5 engine which has an EGT margin of about 40 degrees centigrade. These are young engines, but the oldest has accumulated about 9,800EFH on-wing and is getting close to its EGT limit, implying an average deterioration rate of about four degrees per 1,000EFH and a maximum possible removal interval of 10,000EFH. We operate our 33,000lbs engines at an average EFC time of 1.4EFH, so this interval is equal to about 7,000EFCs. Engines rated at 26,600lbs and lower do not seem to have removals due to EGT margin erosion."

Teschner believes EGT margin deterioration rate is four to five degrees per 1,000EFH. "This means the first removal interval of a 26,600lbs engine will not be limited by EGT margin erosion, since it can stay on-wing for more than 18,000-20,000EFH, but other factors will cause removals."

In addition to a wide range of thrust ratings and average EFC times, there is also a variance in operating conditions. Some carriers, such as TAM, America West and Qatar Airways, operate in hot environments, while others operate in temperate or cold ones.

The engine is also known for being able to recover a high portion of its lost EGT margin after each shop visit. IAE estimates the recovered EGT margin to be about 90% of the original. The actual level of EGT margin restoration depends on the shop visit workscope. "A hot section refurbishment will restore only about 25 degrees of lost EGT margin, while a core engine refurbishment that includes performance restoration in the high pressure compressor (HPC) will regain about 35 degrees of lost EGT margin," says Teschner.

"Engines often get within 15 degrees of their original margin after an overhaul," says Joseph Dunne, vice president of customer support at IAE.

Teschner's estimate that 25-35 degrees of the V.2527's lost margin is restored at the first shop visit takes the installed margin back up to 50-60 degrees centigrade after the first shop visit; close to the original margin of 70-80 degrees. "The EGT margin deterioration rate on the second on-wing run is similar to the first on-wing run," says Teschner. "I expect the same for later intervals when the engine is mature, and for them to rarely be limited by EGT margin. Some removals due to EGT margin erosion do occur, however, when the engine is operated in a harsh environment, such as the desert. These have reduced removal intervals."

The ability to restore a high level of original EGT margin is verified by Gaertner. "A 30,000lbs -A5 engine will have an EGT margin of about 50-60 degrees centigrade after the first shop visit, with a core refurbishment, including work on the HPC."

The most severe operations would be high rated engines operating short cycles of about 1.0EFH per EFC, or less. These engines would have a higher rate of EGT margin deterioration, and so would be more likely to be removed due to EGT margin erosion.

Removal causes

The V.2500-A5 suffered several early technical problems when operated by some airlines, which resulted in relatively short on-wing intervals and unscheduled removals. "We have had to deal with technical issues such as a damper wire protrusion, sixth-stage HPC blade failure," says Gaertner. "Currently our biggest problem is the sixth-stage HPC case lining detachment causing HPC blade distortion. This and earlier problems caused lots of our removals. Another problem was caused by the failure of fourth-stage HPC blades with relatively few but very severe engine failures. Sixth-stage blade fractures resulted in hard time limits of 5,000EFC between removals being imposed on us only until all engines were modified. Modifications to fix some of these problems have not quite finished."

One major problem from which the V.2500 suffered is burn back of the fuel

Aircraft operating short cycles and in hot environments can still achieve on-wing intervals that allows a simplified engine management of alternating light and heavy shop visit workscopes, with LLP replacement at the overhaul. Lower rated engines can expect to have long removal intervals that allows almost all LLP lives to be used by the time replacement comes due at overhaul.

nozzle guide on the combustor, which resulted in early removals. IAE tested the engine to see if burn back of the material affected engine performance and restarting capability at high altitudes, and decided that a higher degree of burn back could be tolerated and allowed longer intervals. "The burn back is monitored through regular borescope inspections. It has been found that there are no secondary consequences of the burn back," says Teschner. "IAE made flight tests to confirm this, and so reduced the limitation of the problem. This means future removal causes will be items such as hot section distress or high-pressure turbine (HPT) blade oxidation. There will, however, be a new design HPT blade from April 2004 which should be more tolerant to oxidation, and this should allow longer on-wing times."

First run intervals

On-wing intervals were initially hard to estimate for earlier build engines suffering from an array of technical difficulties. "The initial first on-wing removal intervals were about 8,000EFH, because of -A5 30,000lbs engines affected by the damper wire," explains Gaertner. "When this problem was overcome engines were affected by the hard time limit of 5,000EFC due to sixth-stage HPC blade failure. Younger engines, which will have had modifications built in on the production line, will not have these problems and so should avoid more unscheduled removals."

The removal intervals of -A5 33,000lbs engines are more related to EFC on-wing, and so a high EFH:EFC ratio would result in a longer EFH interval. IAE expects the interval to be about 10,000EFH.

The 26,600lbs -A5 engine is more representative of the performance most airlines can expect. "Putting aside the unscheduled removals, the 26,600lbs engine will typically have a first interval of 16,000-17,000EFH (6,000-8,000EFC) when operating a flight cycle time of 2.0-2.5 EFH, although EFCs on-wing have the highest influence because most damage is done at take-off. Engines operating shorter cycles will probably have times of less than 16,000EFH. Engines with cycle times of 1.5-2.0EFH will probably only achieve about 14,000EFH (7,000-10,000EFC) to first removal," says Teschner. "Operators with average cycle times in the region of 1.0EFH will only achieve about 12,000EFH on-wing, but this is also about 12,000EFC. Overall, removal intervals will be 6,000-11,000EFC, which is a wide variation."

Lower rated engines will have longer intervals for the same cycle time as 26,600lbs engines. On a 24,000lbs engine, removals caused by hot section deterioration could be expected at about 19,000EFH based on a cycle time of 2.5EFH.

First shop visit workscope

The workscope for most engines after the first on-wing run is generally a hot section refurbishment, although tailored individually. "This involves a hot section refurbishment and and some repair on the HPC. The HPC may, however, be left alone, as may the low-pressure turbine (LPT), low-pressure compressor (LPC) and fan. These are only visually inspected, and may be left until the first life limited part (LLP) replacement is due. Teschner explains that the fan rotor needs to be disassembled at least partially, because the hollow design fan blades require a high level non-destructive test at every shop visit.

Higher-rated engines may require a larger workscope. "The 33,000lbs rated engines will have a hot section refurbishment and typically a HPC repair due to findings," says Gaertner. "The workscope may be lighter for lower-rated engines dependent on the time on-wing."

Second run intervals

As described, restored EGT margin after the first shop visit is usually a high portion of original EGT margin. "Restored 26,600lbs engines will have an EGT margin of about 60 degrees centigrade. The actual restored margin will depend on the first shop visit workscope, since it will be higher if performance restoration work has been done on the HPC," says Teschner. "EGT margin erosion rate will be similar to the first on-wing interval, so the engine should last 12,000-15,000EFH. I would expect about 15,000EFH for a 26,600lbs engine operating an average cycle time of 2.5EFH. This is equal to about 6,000EFC. The total time on-wing for the two intervals will therefore be about 31,000-32,000EFH, or 14,000-16,000EFC depending on the average cycle time."

A total time of 16,000EFC or more provides airlines with a simple engine management strategy. All LLPs in the later V.2500-A5s have lives of 20,000EFC, making the timing for replacement and removal with respect to

V.2500-A5 MAINTENANCE COST SUMMARY

Thrust variant-lbs	22,000/ 24,000	26,600	30,400/ 32,000
EFH:EFC	2.0	2.0	2.0
1st on-wing interval-EFH	19,000	16,000-17,000	12,000-14,000
1st on-wing interval-EFC	9,500	8,000-8,500	6,000-7,000
1st shop visit workscope	Hot section inspection	Hot section inspection	Hot section inspection
1st shop visit cost-$	800,000	830,000	850,000
2nd on-wing interval-EFH	17,000	12,000-15,000	11,000
2nd on-wing interval-EFC	8,500	8,000-8,500	5,500
2nd shop visit workscope	Overhaul + LLP replacement	Overhaul + LLP replacement	Hot section inspection + HPC
2nd shop visit cost-$	1,200,000	1,300,000	1,200,000
3rd on-wing interval-EFH	N/A	N/A	9,000
3rd on-wing interval-EFC			4,500
3rd shop visit workscope			Overhaul + LLP replacement
3rd shop visit cost-$	N/A	N/A	1,400,000
Total on-wing interval-EFH	36,000	31,000-32,000	32,000-35,000
Total shop visit inputs-$	2,000,000	2,130,000	3,450,000
$/EFH	56	66-69	99-108
LLPs-$/EFH	47	53-55	49-53
Total $/EFH	103	109-134	148-161

stub lives simple.

LLP replacement requires deep access, and so provides an opportunity for a full refurbishment. This is therefore the best shop visit workscope to have at the second removal, at a total time of 16,000EFC or more. "The first shop visit will involve a performance restoration or hot section refurbishment. The second shop visit will have a higher high-pressure (HP) spool workscope and generally be a heavy shop visit, and the total time on-wing to the second visit usually coincides well with LLP lives. The ability of engines to regain a high portion of EGT margin means similar on-wing intervals can be maintained for mature engines, and so it is possible to keep a pattern of alternating light and heavy shop visits," explains Dunne.

Lower-thrust engines will be expected to achieve longer on-wing intervals because of their high EGT margins, and so have total times to the second shop visit that allow them to use virtually all LLP lives. They will also conform to a simple shop visit pattern of alternating hot section refurbishments and full refurbishments.

In contrast, high-rated engines will have short intervals. Gaertner expects an interval of only about 11,000EFH/8,000EFC for the second run for a recently built 30,000lbs engine, which has had earlier technical problems circumvented with modifications on the production line. "Higher rated 33,000lbs engines should have second intervals of about 10,000EFH/7,000EFC," says Gaertner. "The LPC and LPT could actually be left alone at the second shop visit, after about 16,000EFCs, but will be worked on if LLPs are replaced."

High-rated engines may only achieve on-wing intervals totalling about 14,000EFCs, or less, at the second removal, leaving engines with LLP stub lives of about 6,000-8,000EFCs. Overall costs per EFH would therefore be reduced if these LLPs were kept in the engine and replaced at a third shop visit when most LLP life had been used. "In this case engines would have the same hot section refurbishment at their first shop visit as other engines," says Teschner. "The second shop visit would then include another hot section refurbishment plus some HPC work, and would constitute a full performance restoration; a full core refurbishment. The third shop visit would then be an overhaul with LLP replacement. It is possible that in extreme cases LLPs would not be replaced until the fourth shop visit, but this would occur in high thrust-rated engines operating in a hot climate which had very short on-wing intervals."

Shop visit inputs

Shop visit inputs will depend on EFH:EFC ratio, thrust rating, operational environment and the shop visit pattern the airline of engine shop decides on.

In the case of engines operating with an average EFC time of 2.0EFH, those rated at 26,600lbs thrust or less are likely to conform to a pattern of alternating hot section inspections and overhauls, with LLPs being replaced during the overhaul after a total time on-wing of 32,000-36,000EFH/16,000-18,000EFC *(see table, this page)*.

It would probably be economic for engines rated at 30,400lbs and 32,000lbs to have LLPs replaced at a third shop visit, since they would have enough stub time left on their LLPs at the second shop visit to allow an uninterrupted third interval. Total time on-wing at the third shop visit would be 32,000-35,000EFH/16,000-17,500EFC.

If managed this way, the shop visit pattern would be a hot section refurbishment at the first removal, hot section refurbishment plus some HPC work and the second followed by an overhaul and LLP replacement at the third.

A hot section inspection would consume 3,500-4,000 man-hours (MH), $400,000-450,000 in materials and $100,000 in sub-contract repairs. A labour rate of $70/MH would take this to a total cost of $800,000-830,000 *(see table, this page)*.

A hot section inspection and HPC work would consume 4,250-4,500 MH, $600,000-700,000 in materials and a further $150,000 in sub-contract repairs;

The average cycle time of V.2500 operators varies between 1.0EFH and 2.5EFH. Even airlines operating the shortest cycles have good removal intervals and so economic maintenance costs. The uniform life of 20,000EFCs for LLPs simplifies engine maintenance management.

taking total shop visit cost to $1.1-1.2 million *(see table, page 30).*

An overhaul, not including the cost of replacing LLPs, would require about 5,000MH, $800,000 in materials and $150,000 in sub-contract repairs. Total cost would be in the region of $1.3 million *(see table, page 30).*

LLP Management

As previously described, all LLPs in the V.2500-A5 have a life of 20,000EFC, making replacement timing simple. Replacement will occur either every second or third shop visit, depending on removal intervals. A full set of LLPs has a list price of $1.7 million.

This analysis is based on engines operating an average cycle time of 2.0EFH per EFC, although many airlines have shorter and longer cycles.

26,600lbs engines will achieve 31,000-32,000EFH/15,500-16,000EFC to the second shop visit, and so conform to an alternating shop visit pattern of hot section refurbishments and overhauls, with LLP replacement every second shop visit.

The cost of LLP replacement amortised over this interval is equal to $55-55/EFH *(see table, page 30).*

Lower-rated 22,000/24,000lbs engines will have longer on-wing intervals, with the second interval likely to be limited by the need for LLP replacement. Many operators are likely to achieve a total time at the second removal of about 18,000EFC limit, equal to about 36,000EFH. Cost of LLP replacement is equal to $47/EFH *(see table, page 30).*

High-rated engines will have on-wing times of 12,000-14,000EFH/6,000-7,000EFC to the first removal and 11,000EFH/5,500EFC for the second interval. This would take total time to 19,000-21,000EFH/11,500-12,500EFC by the second removal. This provides enough remaining LLP time for a third run of about 9,000EFH/4,500EFC, and takes total time at the third removal to 32,000-35,000EFH/16,000-17,500EFC when LLPs would be replaced. This is equal to $49-53/EFH for LLP amortisation *(see table, page 30).*

Maintenance costs summary

Total costs for shop visits and LLP reserves will naturally vary with operation EFH:EFC ratio, shop visit management and removal intervals achieved.

Using the EFH:EFC ratio of 2.0EFH/EFC, low rated engines that achieve the longest removal intervals should be able to accumulate 36,000EFH up to just their second shop visit, and so have total costs in the region of $105/EFH *(see table, page 30).*

Engines rated at 25,000/27,000lbs will have slightly shorter interval up to their second removal and also incur higher shop visit costs, raising overall costs to $110-135/EFH *(see table, page 30).*

The highest rated engines can make full use of their LLPs with an overhaul at a shop visit, although total shop visit costs by this input will be at about $3.2 million for an interval not much longer than engines rated at 26,600lbs. This would take engine reserves up to $148-161/EFH *(see table, page 30).*

Engines operating shorter cycles will have shorter intervals between removals, although intervals are more related to EFCs on-wing. Engines rated at 26,600lbs, for example, may only accumulate a total time of 25,000-26,000EFH.

Shorter cycles may also result in higher shop visit inputs. Even with similar inputs, amortised costs plus LLP reserves per EFH will be higher, raising total costs to about $155/EFH.

Maintenance cost reduction

IAE has instigated a total maintenance cost reduction (TMCR) programme to identify key drivers in V.2500 maintenance costs, and then use these to reduce costs. The TMCR programme has focused on part repair development, extending part inspection acceptance limits, workscope development, and reducing replacement part prices. The overall objective is to reduce shop visit costs and increase shop visit intervals to reduce engine maintenance cost per EFH.

IAE sends personnel to various shops to review hardware of engines as they are disassembled to determine the main removal causes for each engine. This is done in parallel with shop visit invoice analysis, and a correlation between engine distress and maintenance costs is used to target a reduction in maintenance costs.

As part of its TMCR programme, IAE has undertaken an analysis of shop visit invoices to identify the main cost drivers. These are categorised into workscope items, shop visit cost drivers and effects of engine operation. As a result IAE has, for example, redesigned turbine blades and compressor and combustor components to reduce shop visit costs or increase on-wing lives. Invoice analysis has also been used to extend acceptance limits on parts.

The results of TMCR have seen shop visit invoices reducing and a reduction in premature removals. Improved materials have been used to avoid early removals and reduce module exposure. Examples of increased acceptance limits are a reduction in compressor blade chord widths, which reduced the scrap rate of blades by 75%. AC