OWNER'S & OPERATOR'S GUIDE: V2500

V2500 family specifications

The V2500 family has nine variants in three sub-families. A description of the engines' design & capabilities is given.

The V2500 is the product of International Aero Engines (IAE), a multi-national consortium led by senior shareholders Rolls-Royce (RR) and Pratt & Whitney (PW), with JAEC and MTU Aero Engines. The engine is a dual-rotor, axial-flow family of high bypass turbofans with: a single stage fan; three- or four-stage low-pressure compressor (LPC); 10-stage high-pressure compressor (HPC); annular combustor, two-stage high-pressure turbine (HPT); and a five-stage low-pressure turbine (LPT).

The V2500 is available for the A319, A320, A321 family of jetliners, and the Airbus Corporate Jetliner (ACJ) aircraft of these same types. It also powers the now out-of-production Boeing MD-90.

One V2500 is being produced a day, rising to 400 a year by the end of 2008, and even more for 2009. FlightGlobal's ACAS aircraft fleet database says there are 1,600 V2500-powered aircraft in operation. A small number have been parked, retired or destroyed.

The V2500 incorporates technologies developed by IAE's partner companies, like the RR RB211's hollow wide-chord fan blades and the PW PW4000's 'floatwall' combustor. Technology for the 10-stage HPC was derived from the RR RC34B research compressor programme in the 1960s. The partners in the JAEC originally collaborated with RR in the late 1970s to develop the 20,000lbs thrust RJ500 for the Boeing 737-300, but the programme was cancelled in the early 1980s after the rig testing of two engines.

In 1982, attention was focused on developing an engine in the 25,000lbs-thrust class for the 150-seat market. The engine was initially called the RJ500-35, but when PW, MTU and FIAT joined the consortium, the engine was renamed the V2500. The 'V' prefix denoted the five original partners, and '2500' the original thrust level of 25,000lbs. FIAT later withdrew from the consortium.

The V2500 is more advanced than the RJ500 demonstrator, with a larger diameter of 63.0 or 63.5 inches. Three booster or LPC stages raise the overall pressure ratio. There are two extra LPT stages to drive the larger fan mass-flow and support the higher bypass ratio.

V2500-A1

The first version of the V2500 to be developed, V2500-A1, was FAA-certified in June 1988 for use on initial models of the A320-200. This engine was rated at 24,800lbs thrust at ISA+15°C and has a bypass ratio of 5.4:1 *(see table, page 12)*. No A320-100s were equipped with the V2500-A1. These aircraft were all CFMI-powered. Of the 143 original V2500-A1-powered A320s built, 136 are still in active service. Air India operates the largest fleet, with 48.

In 1994 IAE replaced the original V2500-A1 with the -A5 series. This was more capable, had higher thrust ratings and significantly improved EGT margin. It also achieved longer removal intervals.

In total, 362 -A1 model engines were manufactured before production switched to the -A5.

The -A5 added a fourth LPC booster stage and a larger main fan. The fan-diameter increased from 63 inches on the -A1, to 63.5 inches on the -A5. The -A5 series has five thrust ratings of 23,040lbs, 24,480lbs, 24,800lbs, 29,900lbs and 31,600lbs with corresponding bypass ratios of 4.9, 4.8, 4.6 and 4.5:1 *(see table, page 12)*. All future deliveries of V2500-powered A319, A320 and A321 aircraft will therefore have engines with identical turbomachinery.

V2522-A5 and V2524-A5

The V2500-A5 family has five variants, with a nominal thrust rating of 22,000-33,00lbs *(see table, page 12)*. For the actual thrusts listed it is assumed that the engine inlet air has: a temperature of 59 degrees Fahrenheit and a density of 29.92 inches of Hg; no fan or compressor air bleed or load on accessory drives; ideal inlet pressure recovery; and a mixed exhaust system with no internal pressure losses and a mixed primary nozzle velocity coefficient equal to 1.0. Under these conditions, the V2522-A5 and V2524-A5, as offered on the A319, are FAA-certified at 23,040lbs and 24,480lbs respectively (both at or below ISA+40°C).

The V2522-A5 powers 127 delivered aircraft. United has the largest fleet of V2522-A5 powered A319s with 55 in service and 23 on order. Its sibling, the V2524-A5, powers 188 A319s in active service, with 87 still on order. US Airways flies the largest fleet of 39 aircraft.

The V2500 is now dominated by the -A5 series for the A320 family. The V2500 has been designed for fuel efficiency, and features a two-stage HPT. The engine also has a reputation for good EGT margin retention.

V2500 SERIES THRUST RATING & SPECIFICATION DATA

Engine model	Aircraft application	Take-off thrust lbs	Maximum EGT take-off Deg C	Maximum EGT continuous Deg C	Bypass ratio
V2500-A1	A320-200	24,800	650/635	625/610	5.4
V2522-A5	A319	23,040	625/635	610/610	4.9
V2524-A5	A319	24,480	635/635	610/610	4.9
V2527M-A5	A319	24,800	645/635	610/610	4.8
V2527-A5	A320	24,800	645/635	610/610	4.8
V2530-A5	A321	29,900	650/650	610/610	4.6
V2533-A5	A321	31,600	670/650	610/610	4.5
V2528-D5	MD-90	28,000	635/635	610/610	4.7
V2525-D5	MD-90	25,000	620/620	610/610	4.9

V2527-A5

The V2527-A5 for the A320's three maximum take-off weight (MTOW) variants is certified at 24,800lbs thrust at or below ISA+31°C *(see table, this page)*. The V2527-A5 is the most popular variant of the V2500, powering 607 A320s in service, and with an order backlog of 468 aircraft. The largest sub-fleet is operated by jetBlue Airways with 103 A320-200s powered by these engines, with another 73 on order.

There are two supplementary options for the V2527-A5: the V2527E-A5 and V2527M-A5. The first is the 'enhanced take-off' model which provides increased take-off thrust for A320s at higher airport elevations than the V2527-A5 base model. The V2527M-A5 provides 'enhanced' climb thrust for the A319 and the A319-based Airbus Corporate Jetliner (ACJ). There are 63 V2527E-A5-powered A320s in service; TACA International Airlines is the largest operator with 22. The V2527M-A5 subvariant accounts for another 31 A320s.

V2530-A5 and V2533-A5

The V2530-A5 and V2533-A5, certified at 29,900lbs and 31,600lbs thrust both at or below ISA+15°C *(see table, this page)*, are available for the A321's five MTOW options. The V2530-A5 powers 60 A321 aircraft. Lufthansa is the largest operator with 20. The V2533-A5 with greater thrust powers 156 A321 aircraft, and has an order backlog of 102 A321s. The largest operator is China Southern Airlines, with 23 aircraft.

V2500-D5

The Boeing MD-90, a derivative of the JT8D-200-powered MD-80, was powered by the V2500-D5. This has internally identical turbomachinery to the V2500-A5 powering the Airbus aircraft.

The -D5's main external differences relate to the fan case and its rear-fuselage-mounted configuration for the MD-90. Take-off thrusts are 25,000lbs and 28,000lbs both at ISA+15°C *(see table, this page)*. Of 116 delivered MD-90s, 115 are still active, powered by the V2525-D5 (56 aircraft) and V2528-D5 (59 aircraft). The largest MD-90 operator is Saudi Arabian Airlines with 29 aircraft.

Thrust and EGT capabilities

From 1994, the -A5 replaced the -A1 for all models of the A320 family, which includes the smaller A319 whose engines are derated to 22,000lbs or 24,480lbs thrust. Unsurprisingly, even at the higher of these two ratings the engine is, for all practical purposes, unlimited in terms of EGT margin at the highest operating temperatures an aircraft is ever likely to experience. This is borne out by its ability to operate at full A319 thrust levels at temperatures of up to ISA plus 40 degrees.

The EGT margins on the lower rated variants are high, and these engines are flat rated at outside air temperatures of 55 degrees. This is because flat-rating is normally required with engines to preserve some EGT margin at take-off at high ambient temperatures, but these variants' EGT margin of 120 degrees centigrade is more than high enough for flat rating to be unnecessary.

For the same ambient take-off ISA conditions of ISA plus 15 degrees, the V2500-A5's higher core airflow and EGT margins permit higher thrust ratings up to 31,600lbs, higher than the V2500-A1's maximum permissible thrust of 24,800lbs. When the V2500-A5 is operating in de-rated mode at the same 24,800lbs thrust achieved by the V2500-A1 at ISA plus 15 degrees, the -A5 can still deliver this thrust even under 'hot and high' conditions of ISA plus 31 degrees, and with a superior EGT margin.

For operational redline temperatures, full authority digital engine control (FADEC) software is capable of biasing indicated versus actual EGT values to provide consistent displayed EGT limit values to the aircraft. The actual versus indicated EGT values are controlled by a combination of the software, and data entry plug (DEP) wiring scheme. Engine EGT limits are controlled by the FADEC and DEP, and are only implemented by specific service bulletin instructions. The engine data plate also reflects the engine's thrust limits. The maximum permissible approved EGT values for individual engine models *(see table, this page)* may not be implemented on all models. The Installation and Operating Manual, document No. IAE-0174(D5) or IAE-0043(A5) fully defines the EGT limit values assigned to specific engine models.

Life limited parts (LLPs) in the V2500-A1's fan, LPC and LPT modules all have lives of 20,000 engine flight cycles (EFC). Those in the HPC and HPT have lives of 12,000-17,000EFC.

The improved V2500-A5 (and -D5) series has 25 LLPs. All current LLPs have lives of 20,000EFC for all thrust ratings, with one exception. Earlier part numbers of the stage 3-8 HPC drum had lives limited to 10,000-16,000EFC. A newer part number 6A7705 increases the life to 20,000EFC in line with the rest of the set.

Major upgrades

There were operational concerns about the EGT margin capability and time on-wing of the baseline V2500-A1 configuration (due to hot-section deterioration) especially when operated from hot-and-high airports like Phoenix, Arizona. IAE therefore offered a hot-section and booster upgrade for existing V2500-A1 engines, dubbed the 'Phoenix Standard', with obvious reference to the hot and dusty conditions there. In 1999, the first V2500-A1 Phoenix Standard engine entered service, updating the original -A1 with the latest hot-section technology from the -A5 engine, to extend the on-wing life of the -A1 and lower maintenance costs by 25%.

The new V2500-A5 build standard, SelectOne, will enter service in the second half of 2008 and, with the V2500Select aftermarket package, will offer more fuel savings and time on-wing, and lower emissions and maintenance costs. AC

V2500 family modification & upgrade programmes

The V2500 has been relatively free of major ADs that have impaired its economic performance. The engine has some major performance upgrades & minor modifications which are described here.

The original V2500-A1, delivering 25,000 pounds of thrust, entered service in 1989. It could achieve removal intervals of up to 8,000 flight hours (FH), but longer intervals were limited by turbine deterioration.

International Aero Engine's (IAE) first remedial action was a series of turbine durability improvements, including improved airfoil cooling and improved airseal materials. These were phased into production engines and offered as standard spare parts for installation during hot section refurbishment. The resulting '1992 standard' -A1 engine improved hot-section life by 50% over the original production standard.

V2500-A5 and -D5

IAE's partners developed higher thrust variants of the V2500: the -A5 for the A321, which entered service with Lufthansa in 1994; and the -D5 for the MD-90, which entered service with Delta Air Lines in 1995. The basic model could have been 'throttle-pushed' to deliver the 33,000lbs of thrust needed for the A321, but the higher temperatures required would have severely reduced exhaust gas temperature (EGT) margin, and had a negative impact on the engine's on-wing life. IAE increased the core flow instead to produce increased thrust at a similar temperature to the basic V2500-A1.

To achieve the necessary increase in airflow the fan diameter was increased by half an inch to 63.5 inches, although this did not require a new fan case. To increase the core flow, the core annulus line was adjusted and a fourth stage was added to the front of the low pressure compressor. The associated increase in fuel flow involved changing the fuel pump and the gear ratios within the engine gearbox.

The combustor and high pressure turbine (HPT) were refined to reduce nitrous oxides (NOx) emissions and extend the engine's life. Other design changes addressed emerging in-service issues, and parts that would experience significantly higher loading due to the increased engine rating were strengthened.

Efficiency improvements in the high pressure compressor (HPC) countered the potential adverse impact on fuel burn of the reduction in bypass ratio caused by increasing core airflow. Aerodynamic re-design of the HPC and re-matching of the stages within the compressor eliminated one row of variable stators, while an additional booster stage increased the engine-pressure ratio and improved overall cycle efficiency. Despite its lower bypass ratio, the engine's specific fuel consumption (sfc) remained unchanged.

The increased core flow also reduces combustor exit temperature (CET) by 75 degrees centigrade, while improved materials in the turbine airfoils allow them to run hotter for the same life, and improved cooling allows CET to be increased without increasing metal temperature. The 31,400lbs thrust V2530-A5 therefore runs cooler than the 25,000lbs -A1 did at service entry. The -A5's increased EGT margin due to the larger core increases the interval between overhauls: removal is driven by on-condition limits rather than EGT margin.

The V2500-D5 engine uses the same turbomachinery as the -A5, but the fan case and turbine exhaust case are modified for the fuselage side mounting.

V2500-A1 Phoenix Standard

In 1999 an improved 'Phoenix standard' version of the -A1 entered service. Incorporating the new features of the -A5, it was designed to increase the original version's on-wing life by 25% through improved performance retention.

As well as bringing the -A1's hot section up to the technological standards of the -A5, the Phoenix standard added the product introduced on later production -A1 engines. Its components supersede existing parts, so ultimately all 361 V2500-A1 engines will be upgraded as they are overhauled.

The V2500 has had relatively few problems with major ADs. The recently-certified SelectOne modification is a new build standard that is aimed at reducing fuel burn by about 1% and increase removal intervals by up to 20%.

There are numerous small modifications for the V2500 that have gradually improved its performance and reliability since being introduced into service.

SelectOne

The newest build standard of the V2500, SelectOne, was certified by the FAA in late 2007. It will become standard-build specification and enter service in the second half of 2008 on an IndiGo Airlines A320 following Airbus flight testing and certification.

The three-engine test programme suggests that SelectOne will: reduce fuel burn, and therefore carbon dioxide emissions, by 1%; improve time on-wing by 20%; add 12 degrees to the EGT margin; reduce miscellaneous shop visits by as much as 40%; and comply with the most stringent CAEP/6 NOx standards.

SelectOne modifications focus on the HPC, high pressure turbine (HPT) and low pressure turbine (LPT). The HPC has aerodynamic and mechanical modifications, elliptical leading edges on the blades and improved surface finish. The HPT has redistributed internal and film cooling, plus a minor restagger of the first stage for optimum cycle performance. There is a minor restagger of the LPT first stage.

Special ratings

IAE also offers two special ratings: the V2527E, which is an enhanced rating for the A320, providing additional thrust at high altitude airports; and the V2527M rating used on A319 airliners and the A319-based Airbus Corporate Jet to enhance payload and range capabilities.

Low noise bleed valve

In 2005 Dunlop Equipment, now a Meggitt subsidiary, announced that, under contract to IAE's partner Rolls-Royce, it had developed a replacement bleed valve for the V2500 capable of reducing overall noise output by 3dB. The valve controls the internal air pressure to reduce engine torque during starting and idling.

HPT duct segment repair

IAE's partner MTU has developed a repair for the HPT outer air seal duct segments, stages 1 and 2, to improve repair yield and durability, based on work with highly stressed military engines. IAE says it has developed a new multilayer, erosion-resistant, thermal-barrier coating with improved rub-in capabilities.

The repair starts by removing the coating from the outer duct segments and brazing the cooling holes. The air seal surface is restored, the abradable ceramic coating is applied, and the cooling holes are restored using the latest laser drilling process. Benefits of this repair include tailoring the thermal barrier coating for improved rub-in capability, and increased service life because of the better erosion resistance and improved thermal cycle resistance compared with competing repairs. Turnaround time is 28 days, including the final inspection.

HPT nozzle guide vane repair

In 2000 Lufthansa Technik (LHT) developed a repair for the HPT nozzle guide vanes, which are subject to more thermal stress than any other component. A ceramic thermal barrier coating protects the cobalt-alloy first-stage and nickel-alloy second-stage vanes, with a bonding coat to bind the brittle ceramic layer to the metal substrate. This process involves 53 steps, starting with grit blasting to remove the ceramic coating and chemically stripping the bonding coat. After cleaning and repair the bonding coat is applied by low-vacuum plasma spraying, then the zirconium oxide ceramic layer is applied using an air-plasma spray process, and a laser creates the cooling holes. The repair is one-eighth the cost of a replacement.

Fuel nozzle guide upgrade

Another LHT repair process enhances the original design of the V2500's combustion chamber fuel nozzle guide. The guide can exhibit cracking and severe oxidation as a result of its exposure to severe thermal stress during operation. If the protective thermal barrier coating bursts or spalls it can sustain heat damage. The LHT repair removes the damaged segment of the nozzle guide and replaces it with a new SPAD ring using electron beam or plasma arc welding. The repaired guide has the material properties of a new part.

To improve the outer ring's long-term reliability, laser cutting is used to apply multiple saw cuts to the ring to prevent future heat cracks from occurring, in combination with an improved thermal barrier coating. The thermal protection of the repaired nozzle guide is more comprehensive than the OEM coating. As well as reducing the scrap rate from 90% to 30%, the new repair extends the service life of the component beyond that of a new part.

Inlet cowl acoustic panel

The inlet cowl acoustic panels on the V2500-A1 and -A5 consist of a carbon composite sandwich structure covered by a fine wire mesh. LHT says problems with partial disbonds of the wire mesh started in 1998, and in 2002 the first 100% disbond occurred, effectively rendering the component non-airworthy. To avoid the high cost of replacement, LHT developed a method of replacing the installed wire mesh, a repair that it calculates can save an operator with just three aircraft more than $1 million. AC

V2500-A5/-D5 fuel burn performance

The fuel burn performance and economics of the three A320 family members and MD-90 aircraft powered by V2500-A5/-D5 engines are analysed and assessed.

The V2500-A5 series of engines powers three of the four members of the A320 family of aircraft currently in production: the A319, A320 and A321.In addition, a virtually identical but tail-mounted -D5 variant powers the MD-90.

The aircraft and engines

Although each respective A320 family member offers operators a wide variety of maximum take-off weights (MTOWs), maximum landing weights (MLWs) and fuel capacity options, the aircraft and engine hardware (V2500-A5 series) is identical for each version. This is because the capability differences are merely 'paper changes', which depend on the operator-specific contract and certification documentation. Airlines can therefore choose from various aircraft configuration permutations to specify different engine thrust ratings with different specification weights to suit a particular operation. The highest MTOW and thrust options are not specified by all customers as standard because the purchase price of the engine reflects the required thrust level, while the MTOW and MLW capability and the fuel capacity affect the price of the delivered aircraft as well as airport fees. Only where mission demands dictate the highest possible thrust level, such as hot-and-high departure/limited runway profiles, will an operator be willing to pay more for this.

The hull weights or operational empty weights (OEWs) are the same for each specification option for the current production A319-100, A320-200 and A321-200 aircraft. All weight options would therefore exhibit identical actual take-off weights and resultant fuel burns, regardless of their specification MTOW.

The A319 can be powered by either the V2522-A5 rated at 23,040lbs thrust, or the mechanically identical V2524-A5 rated at 24,480lbs (both at or below ISA plus 40°C). Meanwhile, the V2527-A5 is offered for the A320's three MTOW variants and is certified at 24,800lbs thrust (at or below ISA plus 31°C). There are also two supplementary options for the V2527-A5-powered A320: the V2527E-A5 and V2527M-A5. The former is the 'enhanced take-off" model, which provides increased take-off thrust for A320s at high airport elevations relative to the V2527-A5 base model. The largest A320 member, the A321, is offered with the V2530-A5 or V2533-A5, certified at 29,900lbs and 31,600lbs thrust (both at or below ISA plus 15°C). These engines are available for the A321's five different MTOW options.

The MD-90 can be powered either by V2525-D5s rated at 25,000lbs thrust, or V2528-D5 engines rated at 28,000lbs thrust. Both these thrust ratings apply at ISA plus 15°C.

Flight plans for only one base engine for each aircraft model were studied in this fuel burn analysis of aircraft powered by V2500-A5 and V2500-D5. The alternative thrust options are not included because they would make very little difference, if any, to the sector fuel-burn results, given that the aircraft and engine hardware are identical. The aircraft and engine model combinations covered in this analysis are as follows:

- V2524-A5 on the A319-100
- V2527-A5 on the A320-200
- V2530-A5 on the A321-200
- V2525-D5 on the MD-90-30

The A320-200 version incorporates all the latest modifications developed over its 20-year production life. The same applies to the V2500 engines. The first powerplant version was the V2500-A1, but is not included in this analysis.

Sectors analysed

The route used to analyse these different aircraft is Toronto (YYZ) to Atlanta (ATL). Aircraft performance has been analysed in both directions to illustrate the effects of wind speed and direction on the actual distance flown, also referred to as equivalent still-air distance (ESAD). The chosen city-pair is typical of many A320 family operators, and would also be applicable to the MD-90, since this sector has a block time of about two hours at Mach 0.76-0.78. In this case the diversion or alternate airports used are Nashville (BNA) when travelling to Atlanta, and Pittsburgh (PIT) when travelling to Toronto.

Actual flight time is affected by wind speed and direction, and 85% reliability winds and 50% reliability temperatures for the month of June have been used in the Airbus and Jeppesen flight plans.

There are several MTOW variants on the A320 family. These different weights are achieved through 'paper changes'. Fuel burn performance is therefore only affected by differences in actual take-off weights.

FUEL BURN PERFORMANCE OF V2500-POWERED PASSENGER AIRCRAFT

City-pair	Aircraft variant	Engine type	Seats	Payload lbs	MTOW lbs	Actual TOW lbs	Fuel burn USG	Block time mins	ESAD nm	USG per pax-nm
YYZ-ATL	A319-100	V2524-A5	124	27,280	166,450	132,092	1,379	129	722	11.12
YYZ-ATL	A320-200	V2527-A5	150	33,000	169,750	142,850	1,474	132	723	9.82
YYZ-ATL	A321-200	V2530-A5	185	40,700	196,210	166,110	1,709	127	722	9.24
YYZ-ATL	MD-90	V2525-D5	155	34,100	156,000	141,415	1,691	129	728	10.91
ATL-YYZ	A319-100	V2524-A5	124	27,280	166,450	132,005	1,352	127	705	10.90
ATL-YYZ	A320-200	V2527-A5	150	33,000	169,750	142,540	1,427	129	705	9.52
ATL-YYZ	A321-200	V2530-A5	185	40,700	196,210	165,918	1,682	125	704	9.09
ATL-YYZ	MD-90	V2525-D5	155	34,100	156,000	141,146	1,626	127	705	10.49

Departure temperature at YYZ is 18°C, and 24°C at ATL. For an 85% reliability annual wind, a headwind component of 31 knots *(see table, this page)* means that in 85% of cases in June, the headwind component is at least 31 knots. The remaining 15% of the time, the headwind component is weaker, at less than 31 knots. The table shows that in all cases, YYZ-ATL has a headwind component of 31 knots, while ATL-YYZ has a reduced wind component of 20 knots.

The aircraft analysed have been assumed to have full passenger payloads: 124 passengers for the A319; 150 for the A320; 185 for the A321; and 155 for the MD-90 *(see table, this page)*. The standard weight for each passenger plus baggage is assumed to be 220lbs and no additional under-floor cargo is carried. The payload carried in both directions by each aircraft is therefore: 27,280lbs for the A319; 33,000lbs for the A320; 40,700lbs for the A321; and 34,100lbs for the MD-90.

On the YYZ-ATL route, the 31-knot headwind increases the tracked distance of 675nm to an ESAD of between 722nm and 728nm. This route has a block time of 127-132 minutes *(see table, this page)*.

On ATL-YYZ, with the headwind of 20 knots, the 675nm tracked distance flown increases to an ESAD of 704-705nm, depending on the aircraft. This has a block time of 125-129 minutes.

Flight profiles

The flight profiles are based on domestic FAR flight rules, which include standard assumptions on fuel reserves, standard diversion fuel (for the alternate airports mentioned above), contingency fuel, and a taxi time of 20 minutes for the whole sector. This is included in block time. Taxiing typically accounts for a fuel burn of 275-300lbs, at either end, depending on the specific aircraft-engine combination. All sectors presented here are flown using optimum long-range-cruise (LRC) Mach number. The Airbus aircraft's LRC is Mach 0.78, while the MD-90's is Mach 0.76.

If the aircraft fly any faster than this, the block fuel consumption will increase, due to the exponential onset of transonic drag over the lifting surfaces and also fuselage, especially at the nose.

Fuel burn performance

The fuel burn for each aircraft/engine combination and the consequent burn per passenger are shown *(see table, this page)*. The fuel burn performance of the different aircraft-engine variants is compared on the YYZ-ATL sector.

The data shows that for the respective Airbus models the block fuel burn increases in relation to actual take-off weights and aircraft size. The A319-100, the smallest aircraft here by overall length has the lowest OEW (89,000lbs) and the lowest actual take-off weight (132,092lbs). On the YYZ-ATL sector, its resultant block fuel burn is 1,379USG, compared to 1,474USG for the A320-200, with a heavier OEW of 93,500lbs and actual take-off weight of 142,850lbs resulting in a higher block fuel burn of 1,474USG. The other influence is the higher induced drag due to the increased wetted area of the A320's fuselage, which is longer than the A319's. The even larger A321-200 has an OEW of 106,300lbs and an actual take-off weight of 166,110lbs. Unsurprisingly, it has the highest block fuel burn, 1,709USG.

The MD-90 carrying 155 passengers is shown to burn almost as much fuel on the sector (1,691USG) as the largest A321 (1,709USG) carrying 185 passengers. This is especially surprising, given that the MD-90 has the same OEW, 89,500lbs, as the smallest Airbus here, the A319. Engine efficiency is not a factor since the V2500-D5 is virtually the same as the V2500-A5, sharing the same turbomachinery and thermodynamic cycle. Nor is flight profile a factor, since all the Airbus aircraft and the MD-90 are subject to the same ISA/temperature, runway and cruise conditions. They are also flying the same sector, with light payloads, carrying low fuel loads, from runways where they are not constrained, and cruising at their most efficient cruise speed with virtually the same tracked distance, winds and resultant ESADs.

The MD-90's high fuel burn in comparison with the Airbus aircraft can only be due to its older-generation wing aerodynamics. Indeed, the MD-90's wing owes its design heritage to the 1960s-1970s McDonnell Douglas DC-9/MD-80 era. The A320 family wing is a second-generation 1980s supercritical design with a significantly better lift-to-drag ratio. Similar trends are observed in the reverse ATL-YYZ direction. The main differences in fuel burn *(see table, this page)* are due to the reduced headwind component, which proportionally reduces the ESAD on each aircraft by 2-4%.

Economics

Absolute block fuel burn is only part of the story. The critical measure is fuel burn per passenger. As the aircraft size increases, all specification weights and actual take-off weights increase. So too does the required engine thrust, as does the quantity of overall fuel consumed. However, for the A320 family with its different fuselage lengths, the fuel burn per passenger *(see table, this page)*, is nevertheless lowest with the aircraft which holds the most passengers.

The table shows the relative fuel burn efficiencies of the V2500-powered A320 family members, and of the MD-90. On the YYZ-ATL sector, the V2524-A5-powered A319 carrying 124 passengers burns the most fuel per passenger, 11.12USG, while the V2530-powered A321 carries 185 passengers with a fuel burn of only 9.24USG per passenger. The V2525-D5-powered MD-90 carrying 155 passengers, sits between the A319 and A320 in terms of fuel burn per passenger at 10.91USG. AC

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

V2500 technical support providers

There are about 1,400 aircraft in operation with V2500 engines. A global survey of six major levels of support identifies the major providers.

This survey summarises the major aftermarket and technical support providers for the International Aero Engines (IAE) V2500 family of turbofan engines. It is grouped into six sections covering the services offered by each provider.

1. Line maintenance and in-service operational support *(see table, page 33)*;
2. Engine management *(see first table, page 34)*;
3. Engine provisioning *(see second table, page 34)*;
4. Engine components *(see third table, page 34)*;
5. Shop visit maintenance *(see first table, page 35)*;
6. Specialist repairs *(see second table, page 35)*.

Companies listed in most or all of the six sections are 'one-stop-shop' service providers for the V2500 family. This means that they provide most, if not all, the technical support services that a third-party customer would require. The tables show the range of services that the V2500 overhaul shops are capable of offering. Unlike other engine original equipment manufacturers (OEMs), IAE does not own and operate specific overhaul facilities, relying instead on those owned and operated by each of its partners. These facilities, which are fully authorised to perform complete V2500 overhauls, include: MTU's facilities in Hannover, Germany and Zhuhai, China; Pratt & Whitney's (PW) 'Global Service Partner' (GSP) facilities in Columbus, GA and Christchurch, New Zealand; Rolls-Royce's facilities in East Kilbride, Scotland and Montreal, Canada (from 2008); and IHI in Tokyo, Japan.

V2500 overhaul and repair work is also supported at three non-shareholder shops: Lufthansa Technik in Hamburg, Germany; Jet Engine Overhaul Complex (JEOC) in India; and EGAT in Taipei, Taiwan.

Several airlines have performed their own module removal work with a view to eventually becoming full maintenance facilities. Indeed, Egyptair, Saudi Arabian Airlines and Turkish Technic have set up shops at their main bases to work on V2500 engines.

IAE reports that more than a quarter of the fleet is under an IAE maintenance programme. This is growing, and is likely to increase to 50% by 2010 given that 95% of new airline orders now specify an IAE maintenance programme.

"Most operators are locked into power-by-the-hour (PBTH) agreements," observes Wayne Pedranti, project manager at Total Engine Support (TES-UK). "This is how IAE decided to sell this engine, although many lessors did not opt for PBTH, and neither did United, a very large operator."

IAE recently launched V2500Select, which encompasses everything, including traditional fleet-hour agreement (FHA) services. IAE underwrites all the risk, in contrast to typical third-party FHAs which can contain many exclusions. IAE has also coupled these services with certain upgrades to target reliability and fuel burn, which it calls 'SelectOne'.

With the V2500Select programme, all elements of engine product risk and cost relating to scheduled and unscheduled events are transferred to IAE. Technology retrofit upgrades can also be included for the life of the programme, and optional services are available for no excess cost.

"The major problem engine shops are dealing with is excessive wear on the third-stage high pressure compressor (HPC) blades," observes Pedranti. "These have a mid-span clapper shroud which is driving engines off. There is now a modification for that, which replaces the worn part with a new designed blade. Other problems include combustor distress, and an airworthiness directive (AD) specifying inspections and removals for the second-stage high pressure turbine (HPT) air seal. Other than that, there are not really many other factors driving these engines off-wing."

V2500 overhaul market

In terms of shops performing full V2500 overhauls, MTU Maintenance has done 852 individual engine visits: 28% of 3,000 overhaul contracts so far logged by Flightglobal's ACAS aviation database.

The shop with the next largest number of V2500 visits is Rolls-Royce's (RR) East Kilbride facility with 350 of the 3,000 visits, accounting for 12% of the market. Next is MTU Maintenance's Zhuhai facility with 308, followed closely by PW's Columbus, Georgia facility with 304, and independent Lufthansa Technik with 262.

The ACAS database lists IAE with

Despite the V2500 being operated in large numbers, the support market is shared by relatively few players. MTU Maintenance & Rolls-Royce perform about 40% of shop visits.

214 engine overhaul contracts, although these would be assigned to any of the IAE partner shops, from RR, PW, MTU and IHI. Also listed are PW's joint ventures with Air New Zealand in Christchurch, New Zealand and with Turkish Technic in Istanbul, Turkey. These have 84 and 52 of the 3,000 visits respectively.

The other OEM partner, IHI, has overhauled 176 V2500s according to ACAS.

Although these numbers are only approximate since many contracts fall into the 'unknown' category, it is clear that the OEM partner shops or joint ventures (such as Turkish Technic) account for at least 85% of all V2500 engine visits.

Looking at the V2500 overhaul market share by specific contract, the biggest single V2500 overhaul contract was awarded by jetBlue to MTU in Hannover. The total number of engines in this case is 206, according to ACAS. The next biggest customer is United Airlines, with its fleet of 188 V2500s overhauled by PW's Columbus facility. The latter is in addition to United's own 'Ted' low-cost subsidiary, with another 116 engines. Next comes US Airways with 156 V2500s and TAM with 88; both fleets go to MTU Maintenance in Hannover. The largest in-house V2500 overhauler is Air India with 96 engine overhauls, and the largest customer for RR's East Kilbride facility is British Airways, with 66 V2500 visits.

Major providers

Bill Montanile, vice president of sales at Pratt & Whitney Global Service Partners (GSP), continues to see 'steady growth' in V2500 engine overhaul, and forecasts more than a 20% increase, due mostly to increased numbers of V2500-A5s.

He observes that operators continue to approach engine maintenance from multiple perspectives. "We continue to see IAE establishing FHAs with its customers, while GSP customers continue primarily to seek maintenance service agreements and also request maintenance support on a transactional basis."

The highest geographic demand for V2500 overhauls, according to Montanile, comes from the Americas, with just over 40% of total demand. Europe follows at 25%. Operators in the Asia-Pacific and China region equally share the remaining volume. "Over the next five years we anticipate growth in all these regions, with Europe and Asia Pacific reflecting a growth rate slightly higher than the Americas and China."

Montanile does not foresee any particular surge in shop visits. "Our worldwide shop visit forecast indicates a continuing growth in overhaul volume of 8-9% each year until 2010, and then a modest increase to 12% as new engines begin to come off-wing for their initial shop visits. The V2500 fleet is achieving first-run removal intervals of 30,000 flight hours (FH) or more in some cases."

In January 2008 PW signed a joint venture with Turkish Technic to build a new engine overhaul facility in Istanbul, which will overhaul CFM56 and V2500 engines. This facility, 'Pratt & Whitney Turkish Technic Aircraft Engine Maintenance Center', will receive its first V2500 in 2009, and will overhaul up to 200 engines per year once fully operational. This will be PW's third V2500 engine overhaul centre, with other locations in Columbus, Georgia, USA and Christchurch, New Zealand.

As well as its main V2500 overhaul facility in Hannover, MTU Maintenance has commissioned a V2500/CFM facility in Zhuhai, China. This 50:50 venture with China Southern centres around a $200 million facility to address the growing V2500 market in the Asia Pacific region.

MTU has also built up full V2500 hot-section airfoil repair capabilities for HPT and low pressure turbine (LPT) blades and vanes with its recently developed high-temperature braze repair process. The company also performs crack repairs for the LPT vanes, given its experience as an OEM designing and manufacturing the LPT. MTU also conducts full LPT blade and compressor repairs at its joint venture in Malaysia, Airfoil Services AB (ASSB), in conjunction with Lufthansa Technik.

MTU spokesperson, Katia Diebold-Widmer, observes that some operators prefer long-term, cost-per-hour agreements, while others choose a fixed price contract, or conventional 'time and materials' which can either be exclusive or non-exclusive. "We do see a trend towards more long-term agreements. This is due to the current market dynamics, where many start-ups and low-fare carriers outsource engine MRO work. Moreover, there is an increased demand for spare engine support as fewer spare engines are being ordered due to more aircraft being leased rather than being assets owned by operators themselves.

Diebold-Widmer adds that based on the V2500-A5 active fleet worldwide, most visits will be in the Americas (30% North America and 12% South America), followed by Western Europe (22%) and China (12%). "While overall figures will remain relatively similar in the future, the largest growth, from 6% to 12%, will be in India due to very large orders with Kingfisher/Deccan and IndiGo."

MTU reports that the total number of full overhaul shop visits will be about 800 during 2008. This will grow to close to 1,000 by 2012 as a result of the increase in V2500-A5 shop visits. Meanwhile, MTU anticipates that shop visits on V2500-A1 and V2500-D5 will be roughly constant.

Arguably the only true independent with a 'total' V2500 capability is Lufthansa Technik (LHT). The company performs its full engine overhaul in the Hamburg engine facility, while engine component and blades are overhauled in its ASSB joint venture with MTU in Malaysia. LHT overhauls up to 80 V2500s annually at its Hamburg shop. Maintenance covers all areas including B3 (disassembly, assembly, cleaning, non-destructive testing and inspection) and C3 (specialist high-technology repairs involving outside vendors).

Services include: routine tasks, repairs, modifications, testing, FAA-approved PMA (parts manufacturing approval) parts, FAA-, DER-, and EASA-part 21J design organisation approved repairs. Specific repair techniques include: HPC blade-tip plasma spraying, combustion chamber fuel nozzle guide repair, HPT stage-one duct segment coating replacement, LPT knife-edge seal plasma repairs, and diffuser case flange replacement. LHT is approved by EASA

V2500 LINE MAINTENANCE & IN-SERVICE OPERATIONAL SUPPORT

	On-wing maintenance	Line maintenance	Hospital repair/ Quick turn repairs	On-wing support	AOG/field services	Borescope inspection
EgyptAir	Yes	Yes	Yes	Yes	Yes	Yes
Jet Engine Overhaul Complex, India	Yes	Yes	Yes	Yes	Yes	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes	Yes	Yes
MTU	Yes	Yes	Yes	Yes	Yes	Yes
Rolls-Royce Aero Engine Services	Yes	Yes	Yes	Yes	Yes	Yes
Sabena Technics	Yes	Yes	Yes	Yes	Yes	Yes
SAS Technical Services	Yes	Yes	Yes	Yes	Yes	Yes
Turkish Technic	Yes	Yes	Yes	Yes	Yes	Yes
United Services	Yes	Yes	Yes	Yes	Yes	Yes

V2500 ENGINE MANAGEMENT

	Maintenance management & check planning	ADs/SBs management	Documentation management	Health/ condition monitoring
Aeroturbine/AerCap	Yes	Yes	Yes	Yes
EgyptAir	Yes	Yes	Yes	Yes
Evergreen Aviation Technologies	Yes	Yes	Yes	Yes
GA Telesis	Yes	Yes	Yes	Yes
IASG	Yes	Yes	Yes	Yes
IHI	Yes	Yes	Yes	Yes
Jet Engine Overhaul Complex, India	Yes	Yes	Yes	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes
MTU	Yes	Yes	Yes	Yes
Pratt & Whitney GSP	Yes	Yes	Yes	Yes
Rolls-Royce Aero Engine Services	Yes	Yes	Yes	Yes
Sabena Technics	Yes	Yes	Yes	Yes
SAS Technical Services	Yes	Yes	Yes	Yes
Turkish Technic	Yes	Yes	Yes	Yes
Total Engine Support, UK	Yes	Yes	Yes	Yes
United Services	Yes	Yes	Yes	Yes

V2500 ENGINE PROVISIONING

	Short-term leasing	Medium- & long-term leasing	Engine pooling	Sale & leasebacks
Aeroturbine/AerCap	Yes	Yes	Yes	Yes
AAR Engine Sales & Leasing	Yes	Yes	Yes	Yes
Engine Lease Finance	Yes	Yes	~	Yes
GA Telesis	Yes	Yes	~	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes
MacQuarie AirFinance	Yes	Yes	~	Yes
Rolls-Royce Partners Capital	Yes	Yes	Yes	Yes
Willis Lease Finance	Yes	Yes	Yes	Yes

V2500 ENGINE COMPONENTS

	QEC repair	QEC build-up & engine dressing	LRU repair	LRU pooling & logistics
Aeroturbine/AerCap	Yes	Yes	Yes	Yes
AirLiance Materials	~	~	~	Yes
IHI	Yes	Yes	Yes	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes
MTU	Yes	Yes	Yes	Yes
Pratt & Whitney	Yes	Yes	Yes	Yes
Rolls-Royce	Yes	Yes	Yes	Yes
Sabena Technics	Yes	Yes	Yes	~
SAS Technical Services	Yes	Yes	Yes	~
THY Technic	Yes	Yes	Yes	~
Tradewinds	~	~	~	Yes
Unical	~	~	~	Yes

and the FAA to replace the V2500's number-three bearing in situ without the removal of the engine core.

LHT also provides aircraft on the ground (AOG) airline support teams (ASTs) for on-wing tasks that include borescope inspection, blending, fan blade repair and blade exchange. V2500 teams are located in Tulsa, Oklahoma; Hong Kong; India; and Frankfurt.

With some very large A320 orders recently placed by operators in India, this region will become a significant overhaul market, so overhaul shops for V2500s are already being planned. In 2007, National carrier Indian's Jet Engine Overhaul Centre (JEOC) in Delhi renewed its status as an FAA-approved 'foreign repair station'. This allows Indian to continue to repair and overhaul engines, including the V2500 for third-party customers, in addition to A320s.

In Taiwan, Evergreen Aviation Technologies (EGAT) recently signed an engine overhaul agreement with Indian low-fare carrier, Go Air. The first V2500-A5 engine was overhauled for an Indian carrier in February 2008. EGAT's facilities include two engine shops for assembly, disassembly and testing of aircraft engines, and a 120,000lbs thrust test cell.

In the Middle-East, EgyptAir's Maintenance & Engineering division is finalising a new engine shop. This facility will be capable of processing 40 engines per year. EgyptAir will conduct up to B3-level service for the V2500-A1 and -A5 engines. Its workshop will have a test cell capable of handling engines up to 100,000lbs thrust.

Aftermarket perspectives

Abdol Moabery, chief executive officer at GA Telesis, observes that aftermarket V2500 leasing opportunities are hampered due to the scarcity of available engines. "Many potential customers say they are tied up under a spare engine support programme directly with the OEM, which makes it difficult for us to do engine leasing on the V2500.

"There are probably only a handful of companies which lease V2500 engines. Major lessors include Engine Lease Finance, Aeroturbine, AAR, Willis Lease Finance, Rolls-Royce Partners Capital, and MacQuarie AirFinance.

"We do find whole engines here and there. Last year our target was to acquire a certain number of V2500s, but we only secured 25% of this," says Moabery.

"We are involved in parts and component repairs," he continues. "We supply parts for the V2500 and we repair external components, including quick engine change (QEC) accessory and buyer furnished equipment (BFE), such as actuators. The parts we sell come mainly from part-outs. For example, when we have an engine that comes back off lease, we may decide that the cost of putting it back into leasable condition is not commensurate with the economic value of parting it out. We will then simply disassemble the engine and sell the parts back. In most cases the OEM is the biggest customer, in particular, MTU and Rolls-Royce. We do not have many choices; we are either selling to MTU or Rolls-Royce. But one of them will usually buy the parts because there is not much competition."

Moabery says the main players involved in V2500 leasing opportunities include: PW's surplus sales group; Aeroturbine; AirLiance Materials; GE

V2500 SHOP VISIT MAINTENANCE

	Hot-section inspection	Module change	Module overhaul	Full overhaul	Mods & upgrades	Disassembly/ build-up	On-site test cell	Specialist processes (HVOF/plasma)
EgyptAir, Egypt	Yes	Yes	Yes	Yes	Yes	Yes	Yes	~
Evergreen Aviation Technologies, Taiwan	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IHI, Tokyo, Japan	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Jet Engine Overhaul Complex, Delhi, India	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MTU Maintenance, Germany	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MTU, Zhuhai, China	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pratt & Whitney GSP, Columbus, GA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pratt & Whitney GSP, New Zealand	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rolls-Royce, Montreal, Canada	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rolls-Royce, East Kilbride, Scotland	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Turkish Technic	Yes	Yes	Yes	Yes	Yes	Yes	Yes	~

V2500 SPECIALIST REPAIRS

	Fan blade repair	Vanes & stator repair	Compressor blade repair	Turbine blade repair	Combustor repair	Casing repair	Seals repair	On-site DER authority	PMA parts approved
Airfoil Technologies	Yes	Yes	Yes	~	~	Yes	~	Yes	~
Airfoil Services, Malaysia	~	~	Yes	Yes	~	~	~	Yes	~
Chromalloy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	~
GKN-Chemtronics	Yes	~	Yes	~	~	Yes	~	Yes	~
IHI	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	~
MTU	~	Yes	Yes	Yes	Yes	Yes	Yes	Yes	~
Honeywell Aerospace	Yes	Yes	Yes	~	~	Yes	Yes	Yes	~
Lufthansa Technik	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pratt & Whitney	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rolls-Royce	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Turbine Overhaul Services, Singapore	~	Yes	Yes	Yes	~	~	~	Yes	~

Aviation Materials; AAR; Unical; and Trade Winds Aviation Services.

Moabery predicts more V2500-A5s will come to the market from airlines that actually own them as a result of some of the 'liquidity requirements' that he sees airlines facing in 2008. "The amount of commercial debt available in the market has reduced, so when airlines do not have access to capital this is when the sale and leaseback market flourishes."

Moabery believes the pending MD-90 retirements from China and Saudi Arabia will result in some V2500-D5 aftermarket activity. As for the older V2500-A1-powered aircraft, he says they will definitely reach the stage of part-out, so engines will be coming to the market on the -A1 side as well.

"Both CFMs and V2500s are holding their values, with it being a sellers' and lessors' market," says Moabery. "Market prices and values are staggering. Used and half-time engines are going for 70-85% of the OEM catalogue list price."

"The V2500 maintenance market is relatively flat, with slow growth," says Kevin Michaels, principal at AeroStrategy management consultants. "The V2500 overhaul market is currently worth $1.08 billion a year: comprising $300 million spend for the -A1 variant; $660 million for the -A5; and $110 million on the -D5. The older -A1 variant is steadily declining. The main trend is market growth to more than $1.5 billion by 2012, coming exclusively from the -A5, which will approach $1.2 billion."

Michaels apportions $240 million of the market to North America; $130 million to China and Asia-Pacific; and $215 million to Western Europe. In five years he predicts North America will account for a $410 million spend; Western Europe $256 million; and China, Asia Pacific and India $290 million. In particular he envisages the Indian market itself approaching $100 million by 2012.

Michaels believes the overall PMA penetration in the V2500 is less than the industry's average of 2.8%. "It will certainly be a target for PMA providers and manufacturers, because it is such a popular engine with a highly fragmented supplier base. Challenges remain, though, because incumbent OEMs are relatively strongly positioned on the supply side."

TES-UK's Pedranti agrees. "It may take at least 10 years for the aftermarket to open up. The engine is still in production, and IAE, like RR, is keeping a very tight control over it. While more PMA parts are starting to enter the market, few shops will use them. Maybe MTU, and LHT, but not the RR or P&W shops. There will eventually be more PMA activity on the V2500, but never at the level of the JT8D. As long as these engines are under the fleet-management programmes, there is no economical driver for the 'second' market." AC

V2500 aftermarket & values

The low availability of V2500s has pushed up market values and lease rates to almost twice the levels the market was commanding four to five years ago.

As with all aircraft and engine types, the supply of V2500s is limited. The availability of V2500s is made even more tight by there being a limited number of lessors with large numbers of V2500s in their portfolios. Rolls-Royce Partners Finance has one of the largest portfolios.

A large number of lease contracts on the V2500 are related to sale and leaseback contracts on the engine. Besides these long-term lease contracts, there is a limited supply of engines available for short- and medium-term leases, so lease rates are high. International Aero Engines (IAE) includes the option of spare engine support with the selection of the engine at the original aircraft order.

Current market values as a percentage of fair market values are at some of their highest levels. Abdol Moabery, chief executive officer at GA Telesis comments that used and half-time engines are being traded for 70-85% of the manufacturer's list price.

The list price of engines varies with thrust rating. The -A5 series is the only one being manufactured. "The mid-thrust V2527-A5, the most popular variant, has a list price of about $9 million," says Andrew Pearce, director at MacQuarie Aviation Capital. "Minus the quick engine change (QEC) kit of accessories, the engine's list price is $7.5-8.0 million. Short-term lease rates for engines are $100,000-125,000 per month, which are a lease rate factor of 1.1-1.4% per month."

Moabery agrees, and puts the half-time values of engines at $6.5-8.0 million, depending on their thrust rating. "Long-term lease rates have been higher than $90,000 per month for more than two years now, and short-term lease rates have been up to as much as $140,000 per month in recent years. This compares with lease rates of $60,000-70,000 per month that were being realised in 2003 and 2004. Values were also lower in this period," says Moabery. "The problem is that IAE has little interest in selling spare engines, so other lessors have to acquire engines from the used market. We have only been able to acquire a fraction of the engines we would hope to have added to our portfolio."

Daily lease rates for engines are $3,000-5,000, depending on thrust rating, but any engines which become available are soon leased.

"One issue with the -A5 series is the SelectOne build improvement programme," continues Moabery. "IAE claims this will deliver up to 20% more time on-wing. The modification has recently been certified, and engines manufactured from now on will have the SelectOne kit as standard. There will also be a retrofit kit for existing engines so they can have the same benefits of longer removal intervals and lower fuel burn. This claim of a 20% longer interval is a bold statement, and means engines could remain on-wing for up to one year longer than they currently achieve. It remains to be seen if this actually happens, but if it does it will reduce the demand for engines on short-term leases to provide coverage while engines are in the shop."

While values and lease rates are high, some lessors expect this may be a peak, and as many airlines have requirements for improved liquidity, more engines will become available for sale and leaseback transactions. This will be triggered by the availability of commercial debt reducing.

While values remain strong, there is also the issue of what engines will be developed in the future to replace those in the same thrust class as the V2500. Pratt & Whitney's GTF is a possible V2500 replacement contender, which raises the question of what will happen to the IAE partnership.

There are also the less popular -A1 engines on about 135 of the earliest built A320s, and the -D5 powering about 115 MD-90s. Moabery expects the values of these engines to suffer, since Indian Airlines is expected to retire its A320s, while China Eastern and Saudia will retire its MD-90s. The early A320s and MD-90s are generally regarded as 'black sheep' aircraft, partly because of their engines. While it will be hard to trade or lease these engines as they come available, they can be torn down for parts. Moabery points out that a lot of parts in these two engines can be used in the -A5, including life limited parts (LLPs). One drawback, however, is that SelectOne engines cannot use parts from -D5 engines, which will have a negative impact on the value and marketability of -D5 engines. AC

The values and lease rates of V2500s are generally high due to their low availability. Short-term lease rates have reached levels as high as $140,000 per month.