There are almost 2,000 PW4000-94 engines in operation powering about 700 aircraft; including 575 active aircraft. The majority of engines power the 747-400 and 767-300ER fleet, but the number of active engines will decline as many aircraft are retired.

PW4000-94 support & maintenance market

Pratt and Whitney (PW) has built over 2,150 PW4000-94 engines since the PW4000-94 entered into service in 1987. This was the first engine series that went on to form the PW4000 family. There are 1,958 engines powering 709 aircraft (the 767, 747, A300, A310 and MD-11). About 125 are fitted to parked aircraft. This equates to just 6.4% of the global fleet of PW4000-94 engines, or 37 aircraft. The majority are found in North America. The engine is still popular, with both first-tier airlines as well as freighter and charter operators, mainly due to the continuing popularity of the 767 and 747-400, and MD-11F.

With regard to the A300-600 and A310-300, it can be expected that the number of active engines will greatly reduce over the next 20 years as many aircraft are retired. Some A300-600s and A310-300s have been converted to freighter, along with most MD-11s. This could see the number of aircraft equipped with PW4000-94 engines reduce by just over 400 globally, if the small number of 767 and 747 retirements is taken into account. This is likely to result in a surplus of spare engines on the market, resulting in a drop in PW4000-94 values and shop-visit activity until excess numbers have been reduced.

Despite the likelihood of an excess in spare engines in future years, operators still require a continuous level of service from maintenance, repair & overhaul (MRO) facilities and engine shops for the 709 PW4000-94-powered aircraft that still require engine maintenance.

Capabilities could include the breakdown of the engine to module and piece-part level, as well as high-tech parts repairs. The suppliers of these services, as well as specialist services and component repairs are surveyed here. Suppliers of parts manufacturer approved (PMA) parts and maintenance programmes, and hi-tech and specialist engine parts repairs are also discussed.

PW4000-94 market

The entire fleet of PW4000-94 engines in operation stands at 1,958, while over 2,150 have been manufactured. This means that about 190 additional engines are being kept as spare engines or have retired.

The largest number of PW4000-94 engines (802) can be found in North America, followed by Asia Pacific (744). These regions account for 41% and 38% of the global fleet respectively. This breakdown is reflected by the facilities offering maintenance capabilities on these engines. About two-thirds of global shop visits are undertaken annually by shops in North America and Asia Pacific.

There are three main models of the engine, each with a number of variants. The PW4052/PW4056 & PW4060/PW4062 power 208 767-200/-300s and 232 747-400s.

The PW4056 is in fact the most popular PW4000-94 model, with 864 engines fitted to 216 747-400s, over half of which are currently operated by Asia Pacific carriers. This equates to 44% of the global PW4000-94 engine fleet. The oldest 747-400 and 767 aircraft fitted with PW engines are just over 20 years old, while the youngest 747-400 is only 18 months old, and the youngest 767 was delivered in mid-2010. This fleet will ensure a continuous need for shop capability for the foreseeable future.

The PW4152 and PW4156A power 47 A310-300s, while the PW4158 powers 146 A300-600s. A small majority of these engines can be found in North America, again followed by Asia Pacific. The oldest A310 is 25 years old, and is now a freighter for FedEx. The youngest four examples are 12-14 years old and are still operated as passenger aircraft. The oldest A300-600 is nearly 23 years old and is now a freighter, again for FedEx. The youngest is three years old and a freighter for TMA, although the majority of the A300-600 aircraft under 10 years old are operated by United Parcel Service (UPS).

The MD-11 is powered by PW4460 (51 aircraft) and PW4462 (25 aircraft) engines. There are only five aircraft currently parked, showing the popula rity of the MD-11F. The largest portion of the fleet can be found in North America (58), while just two are in the Middle East. The oldest MD-11 is nearly 20 years old while the youngest is 11.5 years old. Both are freighters.

In total there are currently orders in place for 10 PW4000-94 engines to be delivered between 2011 and 2013, says Katy Padgett at Pratt and Whitney Commercial Engines & Global Services. Additionally, the PW4000-94 was selected by Boeing for a military version of the 767 as an in-flight refuelling tanker, leaving potential for more -94 orders if the Boeing platform is selected.

The maintenance requirements for these engines will depend on many factors. The maintenance programme of an airline, as well as the demands of an owner at the end of a lease term, will dictate the removal intervals. These are affected by the utilisation ratio of engine flight hours (EFH) to engine flight cycles (EFC). The more that is required on a shop visit, the more expensive the visit will be. Therefore, ideally an airline may want to increase their removal intervals as much as possible. This could increase the risk of unscheduled removals, with increased costs. In addition life limited parts (LLPs) do not always have the same life as the longer removal intervals of which the engine is capable, so it can prove more cost-effective to plan more regular shop visits and ensure that downtime is productive, thereby reducing the number of unscheduled visits.

Between Eagle Asia and PW's Cheshire facility, PW deals with the majority of shop visits. SR Technics undertakes 35-45 shop visits a year through SR Technics Switzerland and SR

PW4000-94 GLOBAL FLEET OF ENGINES CURRENTLY IN OPERATION

Engine Model	Aircraft model	Africa Active	Africa Parked	Asia Pacific Active	Asia Pacific Parked	Europe Active	Europe Parked	Middle East Active	Middle East Parked	N. America Active	N. America Parked	S. America Active	S. America Parked	Aircraft sub-total
PW4052	767-300									18	2		2	22
PW4056	747-400			468	20	80	4	56		192	44			864
PW4056	767-200/-300	6		32	2	2				2	2	12		58
PW4060	767-200/-300	12		10		76	2	10		152	14	14		290
PW4062	747-400			40										40
PW4062	767-300	14				12		2		8		8		44
PW4062A	747-400			24										24
PW4062A	767-300					2								2
PW4152	A310-300		2	18		6	8	2		30	2			68
PW4156A	A310-300			8		10		4			4			26
PW4158	A300-600	12	2	98		8		14		158				292
PW4460	MD-11			12	6	3		6		123	3			153
PW4462	MD-11				6	21				48				75
Geographical sub-totals		44	4	710	34	220	14	94	0	731	71	34	2	1,958
sub-totals		**48**		**744**		**234**		**94**		**802**		**36**		**1,958**

Source: Flight Global's ACAS system

Technics Airfoil Services Ltd, a specialist repair shop in Ireland. Delta TechOps calculates that it deals with 75 shop visits annually. GE Engine Services Malaysia only undertakes 12 engine shop visits a year.

Chromalloy calculates that 4,000MH are used for an engine overhaul, which includes: module removal and installation; module assembly and disassembly; piece-part inspection; engine testing; and minor repair of engine components. If more in-depth repair is required, the MH figure will rise.

Sourcing maintenance

The skills of engine shops that offer PW4000-94 capabilities will vary from basic disassembly into modules, to the most detailed and complex component repairs.

Information on the capabilities of each facility is divided into two parts.

The first part is the main engine level, which can be as simple as disassembly of the engine into modules, disassembly of each module to piece-part level, and complete overhaul of the module. The engine's six main modules comprise: the fan and four-stage booster or low pressure compressor (LPC) assembly; an 11-stage high pressure compressor (HPC); a two-stage high pressure turbine (HPT); four-stage low pressure turbine (LPT); the combustor; and the gearbox.

The survey results summarise the capability level of the main shops for each of these modules. There is a table for each module, and each shop's capability with respect to that module *(see tables, pages 38 & 40)*. Three main levels of capability are listed: minimum (M), refurbishment (R) and overhaul (O). A minimum workscope involves a simple external inspection and a borescope. Refurbishment involves some disassembly and inspection, but the module is not completely disassembled to piece-part level, and some repairs will be carried out. An overhaul involves a complete disassembly of the module to piece-part level, and an inspection of all parts, and repairs. If the shop lacks the required capability for an overhaul, the work is sub-contracted, which is denoted by S.

The second part of the survey concerns specialist and high-technology repairs of piece-part components.

Shop module capability

All the main global PW4000-94 engine shops were consulted for this survey, and their module and main engine maintenance capabilities are listed *(see tables, page 38 & 40)*.

The main shop, with over 22% of current contracts, is PW's own Cheshire Engine Center in the United States. Another PW facility, Eagle Services Asia Pte Ltd in Singapore, has a market share of nearly 12%. This means that PW has about 35% of the market. This is helped by the large number of freighter aircraft using PW facilities, such as FedEx, Singapore Airlines Cargo and UPS (which also uses Lufthansa Technik) and major airlines including Air Canada, Delta Air Lines (which also uses Delta TechOps), El Al Israel Airlines, Japan Airlines International and Singapore Airlines.

With 13% of PW4000-94 engines seeming to be maintained in-house, just 52% of the market is open to other facilities. The only other original equipment manufacturer (OEM) to undertake PW4000-94 maintenance is GE at its Malaysian facility, for Malaysia Airlines. OEMs will generally offer a complete overhaul service, and the PW & GE facilities in the US, Singapore and Malaysia are no exception. This involves disassembly of all modules to piece-part level and complete repair.

Another type of facility is the airline engineering division. Lufthansa Technik (LHT) offers full overhaul capabilities, even though Lufthansa no longer operates this engine type. It is the next largest overhauler of the PW4000-94 after PW, with 14% of engine overhaul contracts. As well as its main Hamburg facility, LHT has a joint venture (JV) in China: Ameco Beijing. This results in an increased share of 20% of the market for LHT. Other airline shops, such as Korean Air and EgyptAir Maintenance & Engineering, may only undertake small areas of engine maintenance, and will send many modules away to specialist shops.

The PW-, GE- and LHT-related facilities in Asia Pacific represent a fifth of global activity. North America sees over a third and Europe nearly a sixth. While the figures do not exactly match that of the geographical fleet split, the order stays the same, with Europe increasing its share slightly.

As the PW4000-94-powered aircraft mix changes, so too will the type and location of engine shops. Many operators of newer aircraft may choose to have an OEM care package, thereby potentially increasing PW's share. Older aircraft are likely to either transfer to lesser airlines or be converted into freighters, leading to different decisions on the engine shop intervals and potential changes in contractor geography. For example, Aveos Fleet Performance used to have a comprehensive capability on the PW400-94, but it no longer offers repair on this engine, in part due to the reduction in Air Canada's 767 fleet, as it takes delivery of 777s and eventually the 787.

Nearly 3% of shop-visit contracts are

The annual number of global shop visits for the PW4000-94 is 350-370. The majority of these are performed by Pratt & Whitney Engine Services . Delta TechOps is another larger provider, performing about 75 shop visits each year. SR Technics estimates it performs 35-45 shop visits each year.

up for tender, while nearly 7% are unknown, although they are likely to be in house.

As well as the total fleet of engines fitted to active and parked aircraft, there are also a number of spare engines. Delta TechOps maintains a ratio of 6.4% spare engines for Delta AirLines' fleet of PW4000-94-powered aircraft. PW monitors the number of spare engines globally every month, and calculates that there are 50-100 serviceable spare engines at any given time. Total Engine Support (TES) believes that there are currently 50-70 spare 94-inch engines globally and it expects values to remain relatively steady over the next 12 months and then drop as the 787 progressively comes into service. Delta TechOps and SR Technics agree that values will remain relatively stable and only see a slight decline, but this will not be for 5-10 years. This is because the engines will remain in operation at significant levels in that time, meaning that engines and spares will still be required, until at least the retirement of passenger 767s. PW comments that as engines get older, they will require more parts to be reconditioned, and/or replaced with new parts, so shop visits will become increasingly important. PW is keen to add that it is always looking to improve on the original design, based on the actual operation and performance of the engine.

Values for this engine vary widely, says IBA, showing that the market contains both good and bad examples. It adds that if bad ones are removed permanently, then values should remain stable. Chromalloy values a basic PW4000-94 at $4-4.5 million, but adding a quick engine change (QEC) kit increases this figure by $2 million.

Africa

With only 2.5% of the global PW4000-94 fleet currently in Africa, there seems to be little or no need for major maintenance, other than line maintenance. The largest operator in Africa is Ethiopian Airlines, with 10 767s powered by PW4060 and PW4062 engines. These engines currently have a maintenance contract up for tender. One option is the only African engine overhaul facility: EgyptAir Maintenance & Engineering. This is where EgyptAir's PW4000-94 engines are sent, although their engines are PW4158s powering just two A300-600s. As these aircraft retire, it is likely that this capability will cease. The PW4158s of Libyan Airlines are currently maintained by PW at their Cheshire Engine Center. The maintenance contracts for the engines from Air Madagascar, Camair Co and Sudan Airways are either unknown or up for tender, while Air Zimbabwe uses LHT.

Asia Pacific

With the second largest fleet of PW4000-94 engines, it makes sense for Asia Pacific to have plenty of maintenance facilities. Although 38% of the fleet is located in this region, just 20% of contracts are with facilities here.

The main location is Eagle Services Asia Pte Ltd, a JV between PW and SIA Engineering Company. This facility alone undertakes nearly 12% of engine shop visit contracts. Customers with large fleets include Air Canada and Japan Airlines International as well as Singapore Airlines. The next shop is Ameco Beijing, a JV between Air China and Lufthansa with just over 5% of the market. Customers include Thai Airways International and Air China. Both Ameco Beijing and Eagle Services Asia have full engine overhaul and hot section inspection (HSI) capabilities, as well as engine component repair capabilities.

Another OEW, General Electric (GE), has a shop in Malaysia with full overhaul and component capabilities on the PW4052, PW4056 &PW4060 engines, although its main client seems to be just Malaysia Airlines. This explains a small share of the contract market of just over 2.5%. Other airline-related facilities also offer engine overhaul, such as Air India (PW4056 only), ANA Engine Services, China Airlines (PW4056 only) and Uzbekistan Airways Technics. Uzbekistan Airways has A300-600s, A310s and one of the youngest 767 fleets, delivered from late 1996 to mid-2007. As well as using its own facility, this airline also uses P&W Cheshire for engine overhauls. Korean Air undertakes both engine overhaul, HSI and engine component repair on the PW4158/4056/4062/4460 variants. According to ACAS, it accounts for less than 1% of the contract market, but it also deals with Grandstar Cargo's 747 as well as its own engines.

Other facilities in the Asia Pacific area that have some PW4000-94 overhaul and/or component repair capabilities are: Fuel Accessories Services Technology; Goodrich Aerostructures Asia; Nordam Singapore Pte Ltd; ST Aerospace Systems; Thai Airways International; and Mitsubishi Heavy Industries (MHI). MHI was also in charge of parts for the compressor, turbine, and combustor during the manufacturing of the engine.

Europe

Despite having one-eighth of the global PW4000-94 engine fleet, Europe deals with just over one-sixth of global shop visits. The vast majority are undertaken by LHT in Germany. Its size and capabilities in a large number of aircraft and engines make it one of the top facilities globally. LHT customers come from many different locations, not just Europe, and include Air Zimbabwe, Cathay Pacific Airways, Libyan Airlines and UPS. Cathay Pacific's agreement with LHT involves shop visits for 56 PW4056 engines and six spare engines.

Like LHT, SR Technics is considered a one-stop-shop, because it offers most, if

PW4000-94 MAJOR ENGINE SHOP CAPABILITIES

Maintenance Provider	Fan	Low Pressure Compressor	High Pressure Compressor	High Pressure Turbine	Low Pressure Turbine	Combustor	Gearbox & Accessories	Sub-contracted items
Ameco Beijing	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O Partial O on Accessories	
Delta TechOps	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	
Eagle Services Asia Pte. Ltd	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	
EgyptAir Maint. & Eng.	M/S	S	M/R	M/R	S	M/R	M/R/S	
GE Engine Services - Malaysia	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	
Lufthansa Technik	M/R/O	M/R/O	M/R/O	M/R/O/S	M/R/O/S	M/R/O	M/R/O	HPT-T1/T1 blades HPT-duct segments LPT-blades & vanes
P&W Cheshire Engine Center	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O/S	Some LRU & accessory items
SR Technics	M/R/O	M/R/O	M/R/O	M/R/O/S	M/R/O	M/R/O	M/R/O	HPT airfoils
United Services	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	M/R/O	

In-house Shop visit levels
M - Minimum
R - Refurbishment
O - Overhaul
S - Module sent away

not all aspects, of engine MRO. Although SR Technics' market share is smaller, most of its engine shop visits come from non-European operators such as Aeromexico, Air Macau, Lion Airlines in Indonesia and Maximus Air Cargo in Abu Dhabi. The latter also has an integrated engine solutions agreement with SR Technics.

Other facilities in Europe that offer PW4000-94 capabilities include Chromalloy Holland, Goodrich (Prestwick), Nordam Europe Ltd, PWA International in Ireland (a JV between SIA Engineering Company and PW), Sinair in Spain, and ST Aerospace Solutions A/S (formerly SAS Component).

Middle East

Like Africa, this is another area where the share of the global fleet is small. The majority of Middle Eastern operators' contract details are unknown. After this group, the next popular option is PW's facilities. Eagle Services Asia Pte Ltd is used by Dubai Air Wing, Qatar Airways and Yemenia, and P&W Cheshire Engine Center is used by El Al Israel Airlines. SR Technics is also used.

Bedek Aviation (Divn of IAI) aims to increase shop capability within the Middle East, since it has just gained a contract from Avianca. This will last five years and cover Avianca's PW456 and PW4060 engines.

North America

North America is the location for well over a third of the global PW4000-94 fleet. The number of shop visits matches the share of the market. There are three main shops: P&W Cheshire Engine Center with nearly 23% of global engine shop visits; United Services with just over 9%; and Delta TechOps with 7%. All three facilities are considered one-stop-shops due to the complete engine service they can offer clients. In addition, PW has smaller specialist capabilities at P&W Autoair, P&W Dallas Airfoil Repair and P&W East Hartford Part Repair. Large customers include China Cargo Airlines, El Al Israel Airlines, Federal Express, Hawaiian Airlines, Martinair Holland, UPS, Uzbekistan Airways and Delta AirLines. Delta also uses its own facility, Delta TechOps, with just the PW4056 going to PW. Delta TechOps' main customers include Air Atlanta Icelandic, LAN Airlines and World Airlines (on a time and material contract). United Services' large market share is due to the large number of PW4000-94 engines operated by its parent airline, United Airlines, which is the largest global operator of this engine type on both 747s and 767s. Another airline-related facility is Aeromexico, with a few capabilities on the PW4056 and PW4062.

North America is full of specialist service providers, including independent facilities, and those that are part of a global company. Chromalloy is a global service provider that has four locations in North America (one each in Connecticut and Georgia, and two in Texas), as well as its facility in the Netherlands. Nordam also has a facility in the United States, as does Goodrich, which has one in Foley, as well as Goodrich Aerostructures. While a few facilities offer a number of repair capabilities, some are specialists in small areas of the manufacture and repair of engine parts. These include Accel Aviation Accessories, Aircraft Ducting Repair, Component Repair Technologies, Condor Technical Services, Eaton Aerospace, First Wave MRO Inc, Fokker Aerotron, GKN Aerospace Chem-Tronics, Hawker Pacific Inc USA, JFJ Industries, Middle River Aircraft Systems, PAS Technologies Inc, TCI, The Fuel Cell, Triumph Accessory Services Grand Prairie, Triumph Airborne Structures, Twin Manufacturing, Westfield Gage Company O&R, Wood Group Fuel Systems Inc and Woodward Governor Co.

South America

Other than operators' line maintenance capabilities there is no major PW4000-94 engine maintenance capability in South America. Those carriers that have known contracts use Delta TechOps because it is the closest geographically, thereby reducing downtime.

Overview

With the PW4000-94 fitted to five types of aircraft ranging in age from less than a year to over 20 years, the needs of the maintenance market are very varied.

As older aircraft are converted to freighters (many already have been), the older fleet will shift towards the large cargo operators, mostly in North America and Europe, or developing economic regions. This will increase the maintenance undertaken by, and therefore the market share of, those facilities that have contracts with those operators. There will also be more need for facilities in Africa for the developing fleets. Eastern Europe will also develop a need for maintenance facilities with developing economic areas, as will the growing new fleet of Uzbekistan Airways.

The main engine shops of the OEMs and large airline maintenance divisions

ANNUAL PW4000-94 SHOP VISITS

	2009	2010F	2015F	2019F
Africa	10	6	10	6
Asia Pacific	169	186	217	118
Europe	35	49	34	19
Middle East	6	8	14	14
North America	96	106	116	112
South America	12	14	18	8
Total	328	369	410	277

Source: Aerostrategy OAG

are likely to retain their capabilities and therefore their market share. Although others have the opportunity to increase their capabilities and market share, this is unlikely to happen with the engine fleet only declining from 2011 onwards. In fact GE expects there to be no more PW4000-94 operators in the Asia Pacific beyond 2015. TES echoes this by saying that as the 787 becomes available, 767 retirements will ramp up, affecting PW4000-94 asset values. More aircraft will be torn down and more spare engines will become available.

Engine removals

Many different factors affect engine removal rates, including average flight time, thrust rating, operating base temperatures, engine variant and engine age. The hotter the operating location, and the older the engine, the more likely it is to have shorter removal intervals, as well as unscheduled removals.

According to TES, the average daily utilisation for these engines is 7.3 EFH or 1.6 EFC, meaning the average cycle is 4.6EFH. For Chromalloy, the mean time between engine removals (MTBR) is 16,000EFH or 4,200EFC. Delta TechOps calculates the majority of engines will range from 14,000-19,500EFH or 2,500-4,000EFC. For engines with EFCs of 4.0EFH, they work to a little less for performance restoration at 12,000-15,000EFH. GEES Malaysia on the other hand often removes engines after 25,000EFH due to performance deterioration. The shorter the average EFC time, the smaller the removal interval (measured in EFHs) is likely to be. GEES Malaysia deals with engines generally used on long-haul operations.

LHT's removal rates fall in the middle with removals between 19,000EFH and 23,000 EFH generally stipulated due to scheduling requirements. Delta TechOps expects overhauls after 15,000-21,000EFH if the cycle is longer than 8.0EFH. This echoes SR Technics, which expects a time on-wing of 15,000-20,000EFH for engines on long-haul operations, although this can depend on the operational environment. PW says that some legacy carrier customers are achieving more than 20,000EFH on-wing. SR Technics adds that newer engines have no removals driven by engine gas temperature (EGT) margin loss or performance loss. Chromalloy comments that common reasons for engine removal include: HPT & HPC blade, vane and disk damage; high oil consumption and leaks; cracks in the combustor; and high time and cycle use. LHT echoes the issues with oil leaks and turbine vane distress. Data from Aerostrategy shows that there were just over 328 shop visits globally for 2009. According to TES, over 20% were standard time-expired engine overhauls, and 12% were scheduled maintenance or refurbishments. Stage 2 turbine vanes and blades each account for 11% of global shop visits. The outer combustion chamber was the cause of 6% of visits, while the stage 1 turbine blade is responsible for 5% of shop visits, and high oil consumption for 3%.

Shop visits range from a repair workscope to a full overhaul. "The limited information we see on this specific engine alludes to an alternating light then heavy check pattern," adds Stuart Hatcher, head of valuation and modelling at The IBA Group. "The light checks include repairs and some hot section repair. The heavy check is a full overhaul. The heavy overhauls can be expensive and the light ones can be particularly cheap." The exact division of work on each shop visit can be led by the customer and PW's maintenance planning guide (MPG). PW says that shop visits typically require full performance restoration of gas path hardware, airfoil repair and rub strip restoration. The unplanned removals typically address the removal root cause within the specific module. The first shop visit, according to Chromalloy, is likely to include the HPC, Combustor, HPT, main gearbox (MGB) and accessory gearbox (AGB). The second shop visit includes all modules, and sometimes excludes the fan case. Chromalloy adds that most shop visits are due to the main removal causes listed above, and are at the intervals stated in the MPG. The shop-visit workscope pattern therefore alternates core restorations or overhauls and full overhauls of all engines modules.

Removals can also be dictated by the lives of LLPs. These are generally 15,000EFCs, although some are 20,000EFH, as stated in the Engine Manual Chapter 5 life limits. While these figures work well with the general removal rates that SR Technics work to, they are slightly lower than other shops or operators would like in order to streamline engine shop visits with LLP replacement. "The low pressure shafts have longer LLP life limits of 30,000EFC, which fits in better with accepted engine removal intervals," says Hatcher. "For those engines above 56k (56,000lbs thrust), the latest certified lives are 15,000EFC, below this the majority are 20,000EFC." A stack (LLP set) price, for example, is currently nearly $5.5 million, which represents an increase of almost 6% on 2009 prices.

Component repairs

There are a number of specialist repair providers for the PW4000-94 engine. Some are able to offer repairs on most, if not all, components of the engine. PW is the main provider of this service through its two main facilities as well as smaller support shops. Other facilities that offer this complete service on all PW4000-94 engines include Ameco Beijing, GEES Malaysia, Korean Air, LHT and SR Technics. SR Technics has capabilities for all parts repair other than HPT airfoils. United Services also has extensive capabilities, but it is restricted to just the PW4056/4060.

Engine modules

There are many parts to each module and, as well as the main facilities, there are many companies that overhaul and repair these parts, which include the blades, vanes & stators for the LPC and HPC. Chromalloy is one of the market leaders in such repairs, with at least five relevant locations globally, as is PAS Technology in Missouri. By including advanced repairs that reduce scrap percentage and improve engine life, Chromalloy calculates that its repairs are as durable as an OEM repair with cost savings as high as $300,000 per engine for DER repairs only. If operators then use PMA parts, Chromalloy estimates that as much as $500,000 can be saved.

Delta TechOps, LHT and SR Technics also offer these repairs. PW uses Connecticut Rotating parts for fan blades, Turbine Overhaul Services for LPC/HPC blades & vanes and North Berwick Repair Operations for LPC stators. For HPC stator repairs PW uses both Connecticut Stators & Components

and Asian Compressor Technology Services (ACTS). ACTS in Taiwan is a JV between SIA Engineering Company and United Technologies Corporation (PW's parent company) and China Airlines. It specialises in the overhaul and repair of HPC and LPC components for the PW4000-94 engines, including stators, variable vane inner shrouds (VVIS), outer air seals and honeycomb shroud guides. While ACTS has traditionally found work in Asia and North America, it is now increasing its customer base in Europe. Another JV for SIA Engineering Company is Asian Surface Technology (AST) in Singapore. AST is a JV with PAS Technologies and United Technologies International Corporation, which repairs and overhauls fan blades, and has capabilities such as plasma-coating and thermal spray.

LHT offers many aspects of engine module repair including many services on-wing, such as fan blade changes and LPC changes. This means less disruption to an operator's schedule. It also offers a borescope inspection of the HPC, combustion chamber, HPT and LPT, to give a better picture of an engine's condition prior to removal and/or prior to breaking into piece-part. Another large fan blade repairer is GKN Aerospace Chem-Tronics in the United States.

The main components of the combustion chambers are combustion cans and fuel nozzles. As well as the main facilities, companies such as Chromalloy offer repairs for these parts. In addition, PW uses Combustor Airmotive Services for the repair of combustion cans and fuel nozzles, as well as Connecticut Stators & Components. Dallas Airfoil Repair Operations and Japan Turbine Technologies deal with HPT blades & nozzles guide vanes, as well as the former repairing LPT blades and vanes. As well as the blades and vanes in the LPC & HPC, Turbine Overhaul Services also repair them for the HPT and LPT.

Repair is always cheaper than replacement. LHT offers an HPT stage 1 vane full repair for $1,490, plus $89 for cleaning and inspection, compared to $13,700 for the cost of a new part.

Honeycomb & knife-edge seals

Honeycomb seals are the non-rotating component of seals in the LPT. Knife-edge seals are the rotating component of seals in the LPT and other modules.

Major repair providers include PAS Technologies, LHT, Delta TechOps and GE-Malaysia, as well as those involved in the specialist repair of seals and blades. PW offers honeycomb repairs at Singapore Part Repair Operation and Connecticut Stators & Components, and repairs knife-edge seals at Connecticut Rotating Parts.

LLPs

There are many LLP repair providers, with new parts again being either OEM or PMA. There are 24 LLPs in a PW4000-94, with the cost of a complete LLP set increasing by just over 20% since 2007 *(see PW4000-94 maintenance analysis & budget, Aircraft Commerce, October/November 2007, page 18)*.

With the majority of engines used for long-haul operations, LHT believes that the number of LLPs reaching full life limits will increase. This means that there will be an increased demand for new, repaired and surplus LLPs in years to come, although LHT believes that it will see longer running times due to better performing HPT parts (both OEM and PMA).

As well as the capabilities offered by PW (through Connecticut Rotating Parts mainly) and the main engine shops, part repairers, such as Chromalloy and Component Repair Technologies, offer cleaning, repair and specialist coating.

Cases & frames

As non-rotating parts, cases and frames are some of the simplest parts to repair. The usual major facilities repair these parts, as well as Chromalloy, PAS Technology, Component Repair Technologies, PW (Ireland and US).

GEES Malaysia says that a report on a turbine exhaust case alone can cost $60,000, with a list price of $490,000.

Accessories & LRUs

The main components mounted on the outside of the engine can be divided between accessories and QEC components. The main accessories are the

The majority of PW4000-94 engines power 747-400s and 767-300ERs. This should ensure the majority of the PW4000-94 fleet remains in operation for the forseeable future. Estimates are that the global maintenance market will be about 280 shop visits per year.

main engine control (MEC), fuel pump, pneumatic starter motor, variable stator vane actuators, and sensors.

Line replacement units (LRUs) are dealt with by all the main shops and a number of specialists. LRU repair and overhaul are carried out in North America by: Accel Aviation Accessories, Chromalloy (at all five locations), Component Repair Technologies, Eaton Aerospace, Fokker Aerotron, GKN, JFJ Industries, PAS Technologies, TCI, Triumph Accessory Services Grand Prairie, Twin Manufacturing and Westfield Gage Company.

There are companies that are involved with the lubrication, fuel and electrical systems of the engines. These systems can be part of the QEC components and accessories. Additional companies involved in these areas include Aircraft Ducting Repair, Hawker Pacific Inc., The Fuel Cell, Wood Group Fuel Systems Inc and Woodward Governor Co, all in the United States. In Europe, Chromalloy Holland deals with fuel systems, while in Singapore there is Fuel Acc Services Technology and ST Aerospace Systems. This is in addition to the major shops.

Nacelles & thrust reversers

Repair of nacelles, cowls and thrust reversers is a specialist capability. Thrust reversers are maintained on-condition, although Delta TechOps estimates that the removal interval is equal to about 35,000EFH for Boeing aircraft fitted with this engine. With Delta AirLines' average utilisation being 4,000EFH per year, Delta TechOps expects thrust reversers to be overhauled on average every eight or nine years.

Goodrich repairs and overhauls both nacelles and thrust reversers at four locations: two in the US, one in the UK and one in Singapore. Nordam has the same capability, with shops in the UK, US and Singapore.

In North America, Auto Air (for PW), Aircraft Ducting Repair, Condor Technical Services, First Wave MRO inc, Fokker Aerotron, Middle River Aircraft Systems and Triumph Airborne Structures offer thrust reverser repair and overhaul. While in Europe, ST Aerospace Solutions deals with thrust reversers. There is a large number of facilities in North America, but there are major shops elsewhere that repair and overhaul thrust reversers, such as Ameco Beijing, Eagle Services Asia, GEES Malaysia and SR Technics.

PMA parts

PMA parts are non-OEM manufactured parts that have been certified by the Federal Aviation Administration (FAA) as suitable alternatives. The list price for a PMA part can be as much as 50-70% lower than that of OEM parts, although 30-50% is more realistic.

Chromalloy is a major PMA manufacturer, offering a saving of 30-35% over OEM parts. LHT uses PMA parts if permitted by the customer, and has seen savings of up to 70%.

Modifications & upgrades

An operator needs to know when to expect a shop visit in order to plan aircraft down time. Fortunate airlines will have access to spare engines to cover the time an engine is at a shop, but there will still be some downtime due to the changing of the engine. With scheduled changes, this is not as much of a problem. But if an engine develops issues that necessitate an engine change and shop visit, the effect on schedules can be huge.

Many modifications and upgrades have been developed to reduce the chances of unplanned shop visits as well as rectifying issues raised on some engines before they affect the whole fleet. PW has issued upgraded HPT parts, to be implemented by upgrade modifications or scrap replacement. LHT says that this will eliminate the HPT weak points of the T2 vanes, T2 blades and duct segment coating spalling. Delta TechOps intends to upgrade the HPT blades in the engines it maintains.

To avoid an engine change in case of a bearing number 1 oil leakage, SR Technics has developed an on-wing repair procedure which can be performed by a field team to replace all the affected seals.

In 2010 PW launched a major upgrade. The Advantage Performance Upgrade package takes selected configurations from the PW4170 engine model and inserts them into the basic PW4000-94 Phase III engine model. PW says that the upgrade will address several key durability concerns and improve the thrust-specific fuel consumption of the in-service engine by 1%. Other benefits include lower greenhouse gas emissions, lower gas exhaust temperatures and increased time on-wing.

Future outlook

Many analysts and engine shops agree that with the fleet declining, so too will the maintenance market. SR Technics believes the number of annual shop visits will drop slightly but steadily over the next 10 years, with some potential peaks if aircraft are re-activated. It adds that the maintenance market will remain competitive thanks to a significant availability of used material. Chromalloy is more specific and says it expects a 10-15% drop in five years and a 25-30% drop in 10 years. This will be due in part to a reduced fleet, but could also be the effect of longer running times between shop visits due to better performing parts, such as mentioned by LHT earlier. AC