The PW4000-94 family is representative of long-life commercial operation, having powered some of the best known widebodies. Operators are now faced with how to manage these ageing engines. Various techniques that can be used to control costs during this period are explored here.

PW4000-94 MRO & engineering support

The Pratt and Whitney (PW) PW4000 family has been in operation for 30 years. There are three main engine variants, starting with the PW4000-94. This has a 94-inch diameter fan, and was the original engine to enter service. It was also the first jet engine to be certified for 180-minute extended range twin engine operations (ETOPs).

The PW4000-94 powers the 747-400, and 767-200 and -300 series, McDonnell Douglas (MDC) MD-11, and the A310-300 and A300-600/-600R. The -94 series variants powering these aircraft types are rated between 52,200lbs and 62,000lbs.

Many of these types have been superseded by new aircraft families. The fleets powered by these engines are ageing and becoming less cost-effective.

The PW4000's other series are the PW4000-100 and -112. These two series refer to their fan diameters.

The PW4000-100 was developed exclusively for the Airbus A330 aircraft family. The -100 series is rated at 64,000-68,000lbs of thrust. It entered service in 1994, and achieved 180-minute ETOPS in 1995.

The PW4000-112 powers the 777-200, including its extended range counterpart (the 777-200ER) and the 777-300.

The PW4000 is listed in a variety of ways. For example, PW4000-94 variants are named to describe characteristics that are influenced by certain factors, including: the PW4052, PW4056, PW4060, PW4062, PW4152, PW4156, PW4158, PW4460, and PW4462.

The second digit indicates the airframe manufacturer application for which the engine variant is used. A zero indicates an engine for a Boeing aircraft, a 1 indicates an Airbus aircraft, and a 4 indicates an MDC aircraft.

The last two digits indicate the engine's thrust rating. PW4052, for example, indicates the engine is rated at 52,000lbs thrust. The use of 56, 58, 60 and 62 therefore indicates thrust ratings of 56,000lbs, 58,000lbs, 60,000lbs and 62,000lbs.

The suffix 'A' denotes that the variant has an improved take-off rating 'boost' option for hot-and-high operations. This general guide explains the format for engines in operation today. The A300-600 is powered by the PW4158; the 767-200/-300 by the PW4052, PW4056, PW4060 and PW4062; the 747-400 by the PW4056 and PW4062A; and finally the MD-11 by the PW4460 and PW4462. The PW4000 fleet has accumulated more than 120 million engine flight hours (EFH).

The PW4000 family configuration, performance analysis and operating costs have previously been explored extensively *(see PW4000-94 owner's & operator's guide, Aircraft Commerce, October/November 2007, page 9)*. All PW4000-94s have the same core architecture and stage configuration. The -94 series has a single-stage fan, four-stage low pressure compressor (LPC), an 11-stage high pressure compressor (HPC), a two-stage high pressure turbine (HPT) and four-stage low pressure turbine (LPT).

The oldest PW4000-94s have been operating for almost 30 years. Demand for the engine has reached its peak, and is now in decline. The typical maintenance demands seen by operators and service providers are explored in this feature.

The marketplace

In 2007, the market for the PW4000 was on the cusp of imploding. Operators were starting to consider, although not action, the need to phase out and replace progressively ageing fleets. There were close to 2,200 PW4000-94s in operation that powered about 720 aircraft. The active fleet of PW4000-94-powered aircraft is smaller.

About 150 of those active aircraft have now retired, and 125 are in storage. Comparing the 2007 market place with today's, the steady decline of the fleet of operational PW4000-94-powered aircraft is evident.

In 2007 there were 225 747-400s in commercial service. This active fleet has declined by 80 to 145 aircraft. The number of 767-200 and -300/-300ERs in service has declined to from 200 to 160.

The A300-600 and A310-300 families have all but completely been retired, with fleet numbers reducing from 147 and 48, to 110 and 22 aircraft since 2007. The PW4000-94-powered MD-11 fleet is also in decline, with about 50 still flying today compared to about 80 in 2007.

A look at average cumulative flight hours (FH), flight cycles (FC) and annual utilisations suggests when these aircraft typically retire. A comparison to the operational fleet data seen today shows how close these aircraft are to retirement, part-out and storage. Retired aircraft had average total times of 17,000EFC and 60,000EFH. The average total times for today's active PW4000-94-powered fleet is more like 10,700EFC and 50,00EFH. Typical annual utilisation is 3,000FH and 600FC; meaning a FH:FC ratio of 5.0:1.0.

In terms of freighter aircraft, UPS has been the market leader with almost 80 A300-600s in operation alone. Singapore Airlines Cargo has 10 747s in its fleet.

In March, United Airlines announced that it will phase out the last of its 22 747-400s by the end of 2018, two years before their originally planned retirement.

The fleet of PW4000-94-powered aircraft has declined by a third over the past six to seven years. The fleet of PW4000-powered 747-400s has declined from 225 in 2007 to about 145. The fleet is set to decline further, with United Airlines accelerating the retirement of its last 747-400s.

In early 2015, United Airlines announced fleet changes and conversions involving much of its ageing fleet. While the main focus was most notably the addition of 25 new 777-300ERs, it had originally said that just four 747-400s would leave the fleet over the next two years. It is thought that lower fuel prices had given the 747-400 an operational extension. This is now no longer the case. Delta, another key operator, has also confirmed it is phasing out its 747-400s.

With fewer aircraft in operation now and in years to come, retired PW4000-94 engines can provide aftermarket support to engines still in service.

Delta TechOps is a division of Delta Air Lines, and has MRO repair station facilities at Hartsfield-Jackson Atlanta International Airport (ATL) and Minneapolis-St. Paul International Airport (MSP). It also has a joint venture operation with Aeromexico in Queretaro, that has been providing MRO services for the PW4000-94 engine since 1990. "The operational PW4000-94 fleet has declined in recent years, since many of the aircraft they power (A300, A310, 747, 767 and MD-11) have been retired," explains Jack Arehart, president MRO services at Delta TechOps. "Nevertheless, we continue to see demand for PW4000-94 engine maintenance services. Delta is supporting the new PW4000-94-powered KC-46 aircraft, which is just entering service."

Maintenance reserves

Maintenance reserves are key when protecting an engine's asset value, so they remain of high importance to lessors and other owners. These reserves are based on the industry norm for that aircraft type, or in the case of a new aircraft, are based on manufacturers' recommendations.

Maintenance reserves are payments made by the aircraft lessee to the lessor to provide sufficient funds for major or heavy maintenance events, alongside other regular scheduled maintenance. Areas of maintenance typically covered by reserves include engine performance restoration, and engine life limited parts (LLPs). For a small operator, or airline with insufficient credit resources, agreeing to pay maintenance reserves is crucial to allowing it to lease an airframe or engine from the lessor.

Maintenance reserve payments are calculated on an FH, FC, and/or calendar basis. The amount the operator pays is tracked, and any unused reserve may be paid back to the lessee after heavy maintenance is completed. The reserve is calculated by working out the cost of maintenance (for example an engine hot section inspection) and dividing it by the anticipated interval for that inspection. This depends on the aircraft's FH:FC ratio, and on the age of the engine.

A lessor will typically determine LLP reserves by dividing the anticipated catalogue costs for the LLPs at expected date of replacement by the EFC life limit of the installed parts. This is easier to determine than the performance restoration reserve.

Ethiopian Airlines implements maintenance reserves on all of its 15 PW4000-94 engines. Ethiopian's fleet includes six 767-300ERs that have been in operation from new since 2002. It also maintains a pool of three spare engines. Ethiopian's average FH:FC ratio is 4.0:1.

"LLP reserves are carried through until the engine is phased out," says Nathnael Gebremichael, senior aircraft maintenance planner at Ethiopian Airlines. "Ethiopian decides to phase out engines based on an analysis of the cost of shop visit repair, maintenance reserves, new engine cost, used engine cost and the resale value of the older engine.

"Ethiopian manages its engines on an 'on-condition' basis, and we usually see higher than average material scrap rates," continues Gebremichael. "Since we are replacing scrapped parts with OEM parts (as a policy we do not use PMA parts and DER repaired parts), the replacement cost is higher."

Engine repair & management

As covered in the widebody engine support survey *(see Hi-tech engine parts repair providers, Aircraft Commerce, April/May 2015, page 46)*, a number of operators and Pratt & Whitney services partners offer repair and shop visit maintenance on the engine for third-party customers. PW performs PW4000 part repairs at 13 facilities around the world. Its PW4000 part repair facilities include: Asian Compressor Technology Service, which is located in Taiwan and repairs PW4000 compressors, stators, shrouds and HPC seals; Component Aerospace Singapore, which repairs combustion chambers, fuel nozzles, fuel nozzle guide vanes and HPT stage one supports; and Connecticut Rotating Parts, based in the USA, which can service all rotating parts of the PW4000 engine family.

Its sister facility, Connecticut Stators and Components, repairs HPC stators and honeycomb seals. Dallas Airfoil Repair Operations, based in Texas, repairs HPT/LPT blades and vanes, and airfoil coatings.

International Aerospace Tubes, located in Singapore, Asia, specialises in tube, duct and manifold repairs; and North Berwick Part Repair Operations, based in Maine, USA, focuses on airseals, shrouds, ducts, vane supports and bearing components.

Pratt & Whitney Auto Air is based in Michigan, USA and repairs thrust reversers, nacelle components, and composite materials; while Pratt & Whitney Component Solutions, based in Singapore, carries out hi-tech repairs on LPC stators, HPC ducts, airseals and split cases.

The last major fleet of PW4000-powered widebodies is the 767-300ER fleet. This fleet is due to decline at a faster rate over the next few years as many of the remaining aircraft get replaced with 787s, A330neos and A350s.

Pratt & Whitney PSD, in Arkansas USA, specialises in all major casings in the PW4000 family, while Repair Supplier Logistics, also located in Connecticut, supports all aspects of part repair logistics.

Singapore Part Repair Operations performs HPC/LPC stator repair, alongside variable vane and honeycomb seal rectification. Turbine Overhaul Services is also located in Singapore, and supports PW4000 HPC, HPT and LPT airfoil repair, alongside transition ducts.

As an engine nears the end of its life, careful management and the flexibility to address its individual requirements will allow the operator to keep costs down.

Common examples of engine management agreements seen in the market for engines are as follows.

Time & materials

Under a time-and-materials contract a customer only pays for the cost of labour in addition to the cost of materials used, including new parts. For clients, the biggest appeal of time-and-materials contracts is the transparency and simplicity of the management arrangement. When an engine enters the shop under a time-and-materials contract, the maintenance provider defines the workscope for the maintenance required, and draws up a cost estimate. The customer is kept informed as the engine progresses, and is immediately notified of any additional damage detected as the engine is being torn down, and of the associated costs.

Materials costs can account for 60-70% of engine shop visit costs. Materials costs cannot be accurately predicted in the cost estimate stage, so the client's costs can be higher than anticipated with ageing engines. While these costs can be mitigated, time-and-materials contracts are not economic for owners of older engines. This is because costs rise as heavier workscopes are required in later life. This can be mitigated or partially offset by using parts and material from time-continued and green-time engines.

Power-by-the-hour

Power-by-the-hour (PBH) contracts have different incentives. Based on a fixed price, the supply, repair and overhaul of engines is provided, is typically by a channel partner in the OEM's service network. PBH or fixed-rate contracts typically include: component cover; access to a rotables pool; component repair and overhaul management; engine management; contractual purchasing and logistics; and transport services.

PBH and fixed-rate contracts provide operators with predictable maintenance costs. PBH contracts, however, often require the payment of reserves for all levels of maintenance. Not all, such as reserves for LLP replacement or fan module shop visits, are actually required in the last few years of operation.

Not to exceed (NTE)

Not-to-exceed contracts exclude certain items, and the scrap rates for blades and vanes can be covered up to 100%. This depends on what the customer wants. Any scrap rate above the agreed percentage will incur extra costs.

Bonus Aerospace is a joint venture between Air France Industries/KLM Engineering and Maintenance (AFI KLM E&M) and Centurion Air Cargo. Bonus Aerospace is based in Miami, FL and offers full technical and maintenance based support for the PW4000-94.

It has held this capability for just over three years, and anticipates 10 PW4000-94 shop visits for 2016. Typically, Bonus Aerospace sees clients opt for NTE for fixed-price contracts on maturing engine types. "Customers like to know up front the cost of repairing and maintaining an engine's serviceability," says Han Dieke, general manager at Bonus Aerospace.

Engine health monitoring

Vibration data are often one indicator of sudden changes of an engine's health. Performance parameters, which include pressure and temperature data, usually track slower changes in engine condition.

OEMs, maintenance providers and airlines track these data on a flight-to-flight basis to detect subtle changes that can predict when an engine may require a substantial shop visit. Condition monitoring is beneficial in that it addresses conditions that would shorten normal removal interval and on-wing life before they develop into a major fault.

Delta TechOps provides a full range of engine maintenance management services. Independently from the OEM, Delta TechOps provides Engine Condition Monitoring (ECM) services for the PW4000-94 and other engine types. "Delta TechOps provides its ECM customers with automated alerts, performance trending, and technical analysis," explains Arehart. "It can also provide engineering management services of removal forecasting, maintenance planning, workscoping, and technical assistance. Shop visit workscopes may follow OEM recommendations, or be tailored to the customer's specific needs."

SR Technics also offers engine condition monitoring, which is independently managed. Headquartered at Zurich airport, it offers a range of maintenance contracts to customers, including PBH, time-and-material, and NTE contracts. "Customers tend to opt for fixed-price contracts to avoid potentially high shop visit costs and BER (beyond economic repair) situations," says Roberto Furlan, vice president of engineering engine services at SR Technics. "In any case, BER situations can be avoided by using other types of contract."

Operators have choices when selecting style of maintenance contracts. These need to be considered carefully when managing an ageing fleet.

Israel Aerospace Industries Ltd (IAI) is part of the Bedek Aviation Group, Engines Division, located at Ben Gurion International Airport (TLV), Israel. As a designated service provider (DSP) of PW, IAI offers engine fleet management to third-party customers alongside an engine off-load agreement. It independently manages these customers' engine fleets. "IAI offers fixed prices for full shop visits; NTE Price; and Cost-per-Hour, either payable monthly or upon engine induction; as well as Time and Materials," explains Michael Michaeli, director of PW engines at Bedek Aviation. "The most popular programmes are the NTE and the Cost-per-Hour options."

Shop visit intervals

Frequency of maintenance is highly dependent on the airline operation. "For example, an operator that flies 767 missions at 7-8FH per FC will differ greatly from an operator that flies short operations at 1FH per FC," explains Arehart at Delta. "A long-haul operator may reach 25,000-30,000EFH and 3,500-4,000EFC time since overhaul (TSO), whereas a short-haul operator may have shop visits every 8,000EFH and 6,000-6,500EFC.

"A factor that results in longer on-wing run times and removal intervals is the ring case compressor (RCC) modification completed in 2009 after an airworthiness directive (AD)," continues Arehart. "Many of the engines in operation are also Phase 3 build standard. The Phase 3 upgrade improved a suite of turbomachinery airfoils, seals and other materials. The modification package resulted in lower operating temperatures and longer removal intervals. "A typical maintenance practice after a full on-wing run is to complete a heavy shop visit of all rotating modules, or a hybrid shop visit with a hot section heavy maintenance and a gas path restoration or repair on the HPC and LPT, with the concept of a heavy workscope at every second shop visit on the HPC and LPT," continues Arehart. "A typical PW4000-94 operator will run the engine for five years between major shop visits."

IAI has had maintenance and repair capabilities on the PW4000-94 for seven years. It also carries out on-wing and on-site AOG repairs, provides spare engines to support engine removals and offers regular engine leases. "We typically see engines arrive for heavy maintenance checks every seven to 10 years, depending on EFH:EFC ratio flown," says Michaeli.

"For the -94 engine, 15,000-22,000EFH is the most common interval between heavy shop visit maintenance, whereas it is more like 12,000-14,000EFH for the -100 engine, with a maximum of 16,000EFH seen in some cases," says Furlan at SR Technics.

"The smaller shop visit is heavy core maintenance (CHM)," says Michaeli. "This also occurs every seven to 10 years. There is a cycle of one CHM followed by a Full Heavy Maintenance (FHM) shop visit. We have noticed a slight decrease in the number of operators requiring shop visit services. Some smaller operators have gone bankrupt, while others are buying other engines with green time ahead of the CHM, or leasing engines instead of performing more costly maintenance."

Given that EFH:EFC ratios vary for different operations, the LLP replacement interval will vary with style of operation. There are 25 LLPs in the PW4000-94, with two in the LPC, eight in the coupling, seven in the HPC, six in the HPT and nine in the LPT. "LLP life limits for a 56,000lbs thrust engine are based on 20,000EFC limit, and a 60,000lbs thrust engine is based on a 15,000EFC limit," outlines Arehart. "ADs have been introduced which reduce life limits to 13,000-18,000EFC in some cases. A long-haul operator benefits from the low cycle utilisation and can go through three or four engine overhauls over the life of a LLP shipset, whereas a short-haul operator can face a full or half-life LLP stack at each shop visit."

"There is no EFH limit for LLPs," says Michaeli at IAI. "LLP lives are determined in EFCs, so life on-wing or the replacement interval depend on the EFH:EFC ratio flown by the operator. IAI has found only one LLP that was scrapped early on inspection, which was the HPC front drum, so we believe that the specified life limits are accurate."

Similarly, SR Technics finds that PW4000-94 LLPs can be operated to their hard time limits. "The HPC front and rear drums are often subject to cracking and/or wear that leads to their removal from service," says Furlan. "Cracked AVT shelf slots can be seen in the front drum, whereas cracked 14th and 15th stage blade locking slots are not uncommon in the rear drum."

"Ethiopian's mean time between removal (MTBR) for the PW4000-94 fleet is 12,000EFH, or three years on-wing operation," says Gebremichael. "We estimate that our average maintenance cost per engine over this period is $4.5 million."

Used serviceable material

In terms of volume, the PW4000-100 market has remained stable. Availability of spare PW4000-94s has increased.

"On mature engine types, airlines are looking deeper into customised workscoping," says Furlan at SR Technics. "They are also interested in buying serviceable and green-time engines. SR Technics proactively manages shop visit costs by using used serviceable material (USM). These are mainly LLPs."

"As engine fleets age, engine fleet managers have more and more options for maintaining their engines," says Arehart. "Generally, as an engine type, such as the PW4000-94, ages there is a

The retirement of several hundred PW4000-powered widebodies over the past seven years has caused an implosion in the fleet of active PW4000-94s. This has made large numbers of green-time engines available.

high availability of USM on the market than there is in the earlier period of its life. Such material does not adversely affect engine reliability, provided it is properly sourced and inspected.

"Engine fleet managers can minimise shop visit costs by installing USM instead of new material," adds Arehart. "There may also be some engines available in serviceable condition and with LLP life remaining, commonly known as 'green-time' engines. Engine fleet managers may forego engine shop visits by replacing engines with these green-time engines."

Green-time engines are taken from retired or scrapped aircraft. They have time left in maintenance cycles, and are airworthy to install on an aircraft. Some of the aftermarket suppliers and leasing companies like to utilise these remaining cycles before they tear down the engine. These engines can be used after inspection if they are serviceable, or after repair if they were initially unserviceable. Green-time engines can make a worthy investment for the owner, depending on the repair costs to make it serviceable. Bonus Aerospace keeps the repair costs low by using up to 98% used material.

In Bonus's experience, many are wary of buying green-time engines. "Although there is certainly an active market for green-time PW4000-94s, some see an element of risk," explains Dieke. "For example, one cannot guarantee how long a green-time engine will actually have until it requires its next heavy shop visit, no matter how extensive and detailed the maintenance history that is recorded. Customers will typically compare the repair price on their existing engine with the asking price of a green-time engine before making a decision. Buying green-time engines, however, remains attractive, particularly for small operators."

Bonus Aerospace's sister company Bonus Tech, has a PW4000-94 teardown line, which enables direct access to parts that can be certified for re-use. "If a customer needs 4,000-5,000EFC while phasing out its PW4000-94 engines, replacing a spool or a shaft with a new part is highly uneconomic. USM is either certified by the OEM or a certified repair station like us," continues Dieke. "Our quality team inspects the certification paperwork before approving the part for use on a client's engine."

Residual value is also important for an operator or owner looking to phase out its PW4000-94 fleet. "Customers that own their engines try to maintain the value of the engines by continuing their previous shop visit intervals and build standards, so that the engines retain sale value even after the phase-out of the aircraft/engine," says Michaeli. "Customers that lease their engines are looking for more ways to save instead of performing costly shop visits. In many cases, these customers remove engines early to meet the lease re-delivery conditions, and then look to buy the green-time engines with the remaining life that they require, or to lease other engines that will meet their requirements without having to perform heavy maintenance.

"As engines age, and airlines near their expected phase-out plan, they prefer to install used or overhauled materials, except for HPT airfoils," continues Michaeli. "Airlines are more inclined to install LLPs with few remaining EFCs, with a much lower associated cost, but which will meet the expected remaining life of the aircraft. This depends on whether the airline owns or leases the engine. Most engine leases state a minimum LLP build which requires the airline to install LLPs with higher remaining cycles than they would for their own purposes.

"Some airlines also prefer to perform 'repair as necessary' shop visits, without overhauling the engine modules, to reduce costs for older engines. This is instead of the standard core heavy maintenance or full heavy maintenance shop visits," concludes Michaeli.

IAI provides everything from full engine overhaul to minor repairs, on-wing repairs, spare/lease engines at favourable terms, and building engines to exchange with green-time engines to avoid shop visits. IAI has also produced one serviceable engine from the parts of two engines sent in by a customer, at low cost.

General repair demands

Operators' and lessors' attitudes vary when it comes to component repairs. "Airlines with a specific maintenance programme for components, based on a soft TSO, have a strategy to avoid high-time component issues, whereas other operators have an on-condition maintenance programme," says Arehart. "The key is whether the soft time programme is in place, because a typical run time is 20,000-30,000EFH or 4,000-6,500EFC. An on-condition programme can result in a component having a significant TSO on a second engine run. The most overlooked components are the wiring harnesses."

Bonus says that common repairs include the LPT and HPC and HPT duct segments.

"The engines require more repairs/replacement as the fleet ages," explains Michaeli. "There is now a large supply of used parts available at fairly low prices, because of the number of engines that have been taken out of service, many of which have been torn down for parts. It is cheaper to buy an overhauled-condition part than to repair a removed one. The total cost of maintenance for PW4000-94 owners is therefore falling."

"With the engine ageing, there are certain limitations on repairs, due to the limited repeatability of repairs and dimensional limitations resulting in scrapping parts instead of repairing them," continues Furlan at SR Technics.

Airlines that continue to operate the PW4000-94 can avoid the cost of full shop visit events by making use of time-continued material and parts, and green-time engines and modules that are available on the market. Engines can be operated with minimal maintenance outlay in their last years of operation.

SR Technics offers the full range of services, including engine and module overhaul and repair, provisioning spare parts, and performing piece part repairs. Most of this work takes place in-house.

ADs and SBs

"There have been a few important ADs in recent years, including for the engine LLPs," says Michaeli. "These ADs have meant buying tools and equipment to perform specialised NDT inspections."

"Eleven ADs have been issued since 2010 for the PW4000-94," says Arehart at Delta. "Compliance with these ADs has added additional man-hours (MH) and material expense which affect the overall cost of a shop visit. There is minimal impact, however, on the MRO operation otherwise."

These ADs include:

- AD 2010-18-13. This concerns the issue of the HPC 13-15 stage drum. Issued in 2012, this AD replaced one that required regular fluorescent penetrant inspections (FPI) for cracks in the HPC drum rotor disk assembly rear drum.

Alongside this continuing inspection requirement, AD 2010-18-13 stipulates mandatory replacement of the 13th, 14th, and 15th stage HPC seals, with re-designed HPC seals. A re-designed HPC drum rotor disk assembly is optional for operators to buy, and would eliminate the requirement for repetitive FPI.

This AD affected about 800 PW4000-94 and -100 engines. Replacement of the seals costs operators about $10,000, with the FPI inspections taking about one MH per engine to carry out.

- AD 2010-24-09. This AD outlines a one-time visual inspection of the third bearing oil pressure tube, specific to certain part numbers. Any tubes that are found cracked or repaired were removed from service. This AD also prevented repaired tubes from being installed due to reports of unscheduled engine removals because of cracked repaired bearing oil pressure tubes.
- AD 2010-24-14. This was effective from early 2011. It set mandatory regular borescope inspections (BSI) or FPI for cracks in the anti-vortex tube (AVT) shelf slots on the 10th stage disk of the HPC drum rotor disk assembly. This AD resulted from 47 reports received since 2007 of HPC 10th stage disks found cracked in the AVT shelf slots during shop visit inspections.
- AD 2011-25-09. This affects PW4000-94 and -100 engines. It stipulated the removal and replacement of the HPT stage 1 airseal and HPT stage 2 airseal; with EFC threshold. This was due to low flight cycle performance analysis undertaken by the OEM.
- AD 2012-06-18 . This AD relates to the LPT #4 scavenge system. It outlined a modification in the No. 4 bearing compartment to prevent build-up of carbon deposits, and re-routed the No. 4 bearing pressure and scavenge tubes.

Per engine, the AD required 8MH to perform an inspection and cleaning of the No. 4 bearing compartment, 7MH to perform the modification, and 33.7MH to reroute the No. 4 bearing pressure and scavenge tubes. Total required parts cost $70,000 per engine.

- AD 2012-14-09. This was effective in 2012, and concerns the 3rd & 4th vanes in the LPT. It limited the treatment of vane repair to only one strip and recoat repair, and outlined steps to remove the LPT 4th stage vanes if it corresponded to certain part numbers and more than one strip and recoat repair had been carried out. The 3rd stage LPT rotor blades and 2nd stage HPT had to be reassembled by alternating heavy blades next to light blades and balancing blades of similar weights 180 degrees across the rotor.
- AD 2012-18-03. This affected almost 450 PW4000-94 and -100 engines at the time, and came into effect in late 2012, using a 1st stage HPT seal support corresponding to certain part numbers. This AD was established following multiple reports of cracked 1st stage HPT air seal rings, leading to some engine shutdowns. Removal and replacement of the 1st stage HPT seal support and inspection of the 1st stage HPT air seal ring was compulsory.
- AD 2012-18-17. This AD also concerns the HPC 13-15 drum seen in AD 2010-18-13, and replaces that AD.
- AD 2012-22-16. This ordered the removal of LPT third stage duct segments. This AD had no additional labour costs for the owner, although parts cost about $50,000 per engine.

"ADs and SBs on the PW4000 engines have different types of impact on MRO processes, including OEM material supply issues, repairability of new parts, and missing manual adjustments," outlines Furlan at SR Technics.

The ADs that significantly impacted overall MRO processes include the AD for the LPT 4th stage inner airseal, fuel nozzle leakage and the reduction in the HPT airseal's life limitation. SBs with high impact on MRO processes mostly included modifications to Adv70.

"SB 72-795 had a significant impact for operators," summarises Gebremichael at Ethiopian Airlines. "It improves the durability of the hot section components, but at a much higher cost."

It appears that the coming years will see an increased rate of decline in the active PW4000-94 fleet; particularly once the larger operators have completed their phase-outs. Technical support is still very much evident from independent providers and OEM channel partners, with operators still able to minimise costs without having to buy new engine parts. AC

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