A300-600/A310 maintenance analysis & budget

The maintenance costs of the A300-600 & A310-300 in their varied passenger roles are examined.

The A300-600 and A310 have become niche aircraft, with about 485 operating in a variety of models and roles. They are powered by four major engine groups, and were among the pioneers of extended range twin-engine operations (Etops) in the mid-1980s.

The A300-600 and A310 were used by many major airlines as short-, medium- and long-haul flagships. They have now been relegated to secondary roles, with many A310s having been converted to freighter. While most A300-600s are still in passenger operation, about 100 are factory-built freighters. The aircraft are no longer manufactured, but ages range from one to 25 years, so most are mature in maintenance terms.

A300-600 & A310 in operation

The A310-200 was launched in 1982, and designed as a short- and medium-haul aircraft. Only 85 were built, and all 65 remaining -200s are in operation with Fedex as freighters. These aircraft are used in the US and Europe as package carriers, and generate low rates of utilisation of 1,500-2,000 flight hours (FH) per year, and have average flight cycle (FC) times of 1.2-2.2FH.

The A310-300 is a higher gross weight model with a wing centre box fuel tank. Its longer range made it more appealing, and 170 were built. A small number of these have been converted to freighter, and are used as medium-haul aircraft. Most are still in passenger service, and large fleets are operated by Air India, Air Transat, Pakistan International Airlines (PIA), Turkish Airlines THY, and TAP Air Portugal. Passenger -300s are used on medium-haul operations, with FC times of 2-4.5FH. Annual utilisations are 3,000-4,000FH per year. TAP, for example, operates its aircraft at average FC times of 5.4FH, generating 4,100FH per year, on routes from Lisbon to Europe, Africa and Brazil. THY uses the aircraft from Istanbul on services mainly to Middle Eastern cities, with aircraft averaging FC times of 2.8FH and generating 3,400FH per year.

A total of 309 A300-600s were built. There are 33 passenger-configured -600s in service. Of the original 155 longer-range passenger-configured -600Rs built, 85 are still in operation as passenger aircraft, and 70 have been converted to freighters. There are also 101 factory-built -600R freighters in operation.

Most A300-600Rs are operated by American, which has 34. Other carriers are Korean Air, Thai International and Japan Airlines. Most of these aircraft generate 2,500-3,000FH per year at FC times of 1-3FH.

The majority of the 171 -600RFs are operated by FedEx and UPS, both of which use them at low rates of utilisation on short and medium FC times.

Overall, the A310 and A300-600 are mainly used on FC times of 1-3FH, although a small number of A310-300s are used on longer operations by a few carriers.

The maintenance costs of the A300-600 are analysed here on a short-haul operation with an average FC time of 1.2FH, and the aircraft generating 2,500FH and 2,000FC per year.

The maintenance costs of the A300-600R and A310 are analysed on medium-haul operations with average FC times of 2.8FH, and annual utilisations of 3,400FH and 1,200FC.

Maintenance programme

The A300-600 and A310 have a maintenance programme that is derived from the standard programme for all Airbus types. This comprises a cycle of eight C checks with an individual original interval of 15 months and cycle interval of 10 years, plus two sets of structural inspections with original intervals of 60 and 120 months. The first set at 60 months could therefore be combined with the fourth C check, the C4 check, to form what is usually known as the IL check. The first set would then become due again at 120 months together with the second set of structural inspections and combined with the eighth C check, the C8 check, to form the D check.

There have been 24 revisions to the maintenance planning document (MPD) since its original development.

The line maintenance programme is the standard for all types, with a daily check that has a maximum interval of 48 hours, a pre-flight (PF) check performed prior to the first flight of each day's operation, a transit (TR) check performed prior to all other flights in a day's service, and a weekly check that has a maximum interval of eight calendar days. As with most aircraft types, most operators have PF and TR checks performed by flightcrew, while daily and weekly checks are carried out by mechanics. The A300-600 and A310 are still frequently used for Etops services, however, in which case TR checks have to be performed by line mechanics.

The original A check interval was 400FH. There have been three revisions with some operators having intervals of up to 600FH in their maintenance programmes.

There is a cycle of eight C checks. The basic C check multiple has an interval of 15 months. The remaining multiples are the 2C, 4C and 8C tasks with intervals of 30, 60 and 120 months. The C2 check therefore includes the 1C and 2C tasks, the C4 check the 1C, 2C and 4C tasks, and the largest check, the C8, has the 1C, 2C, 4C and 8C tasks.

"The basic C check interval was later revised upwards to 18 months," explains Erhan Ozcan, manager production planning and control at Turkish Technic. This takes the full interval for the complete cycle of the eight C checks to 144 months.

In parallel with the C checks, there are also the two main groups of structural checks. Their original MPD intervals were five and 10 years, which conveniently coincided with the MPD intervals of the C4 and C8 checks.

The escalation of the C check interval to 18 months means that the C4 check now has an interval of 72 months, and the C8 check an interval of 144 months.

"The C2 check with the 1C and 2C tasks has an interval of 36 months, the C3 check an interval of 54 months, and the C4 check an interval of 72 months," says Thorsten Rauer, manager system engineering structure at Lufthansa Technik.

"The first set of structural tasks had their interval escalated to 72 months in 1999, meaning that the IL check was also extended to a 72-month interval. The cycle of C checks is repeated and the first set of structural tasks comes due again at 144 months. The second set of structural tasks for the D check still has an interval of 120 months, which means that all the tasks that formed the D check do not come due at the same time. This gives flexibility in planning base maintenance, but it also means that the aircraft can

A300-600/-A310 C CHECK TASK ORGANISATION

Check	Check task groups	MPD interval
C1	1C	15 months
C2	1C + 2C	30 months
C3	1C	45 months
C4/IL	1C + 2C + 4C+ 5-year	60 months
C5	1C	75 months
C6	1C + 2C	90 months
C7	1C	105 months
C8/D	1C + 2C +4C +8C + 10-year	120 months

require increased downtime for heavy maintenance. Given that most operators are unable to use all their check intervals, it is still likely that they will have the usual cycle of the IL check at the fourth C check and the D check after the next fourth C check in succession."

This means that most operators are likely to complete the maintenance cycle in eight to ten years. This will be equal to 24,000-32,000FH for aircraft operating at 3,000-4,000FH per year.

The number of FH accumulated during the calendar interval between subsequent C checks and over the full cycle of eight checks influences reserves per FH for base checks.

Line check inputs

The total amount of inputs for labour, materials and consumables depends on the number of each type of check being performed annually. This would be 50 weekly and 250-300 daily checks, irrespective of the number of FH and FC that the aircraft completes in a year.

Annual rates of utilisation and average FC times determine the number of PF and TR checks required each year. However, PF and TR checks for aircraft on non-Etops services are performed by flightcrew so they only require a few man-hours (MH) to be expended by mechanics for a minority of TR checks when no-go defects occur. Aircraft operated on Etops services have a higher MH requirement from mechanics for the TR checks performed at outstations.

PF and TR checks require a few materials and consumables. Airlines can expect to use an average of 1MH for each PF and TR check, and $5-10 in materials and consumables. Most airlines now use flightcrew to carry out PF and TR checks, so these checks do not incur labour costs.

Mario Araujo, engineering director at TAP Engineering & Maintenance, estimates that daily checks consume an average of 10MH. An aircraft will therefore need 2,500-3,000MH per year for its daily checks. Each daily check will use $80 of materials and consumables.

Araujo estimates that labour requirements for the larger weekly checks are 16MH, so an aircraft will consume 800MH for its weekly checks. A budget of $125 for materials and consumables should be used.

The total annual labour requirement for the PF/TR, daily and weekly checks is 5,800-6,300MH. About $55,000 of materials and consumables is required for aircraft operating on short-haul operations completing 3,000FH and 2,500FC per year.

The total input for aircraft used on medium-haul operations completing about 3,400FH and 1,200FC per year will be 4,500-5,000MH and $40,000 in materials and consumables.

Assuming a labour rate of $70 per MH for line maintenance and mechanics, the total cost for labour and materials is $460,000-495,000 for aircraft used on short-haul operations, and $355,000-390,000 for aircraft on medium-haul operations *(see tables, page 27)*.

This is equal to $155-165 per FH for aircraft used on short-haul operations, and $105-115 per FH for aircraft used on medium-haul operations *(see tables, page 27)*.

A check inputs

As described, the A check interval has been escalated from its original 400FH to as high as 600FH in some operators' cases. Actual intervals will be 350-500FH considering the usual limitations on using all of the check's interval.

"The labour required for the routine portion of an average A check is about 350MH," says Ozcan. "This requires another 250MH for non-routine work. An A check will also have some engineering orders (EOs), and will use an average of 30MH for this. This will need another 70MH for the non-routines that result. This takes the total labour expenditure to 700MH for the average A check on a mature aircraft."

Araujo estimates a similar labour requirement for the A310's A checks, with a total of 760MH required for the complete check. Using a generic labour rate of $70 per MH, the labour portion would cost $53,000. The associated cost of materials and consumables for the check is $13,000-15,000.

The total cost for the check would therefore be $66,000-70,000. Amortised over an interval of 350-500FH this would result in a reserve of $140-190 per FH *(see tables, page 27)*.

Base check contents

The C, IL and D checks in the maintenance programmes of Airbus aircraft provide airlines and operators with the opportunity to carry out tasks in addition to the routine inspections specified in the MPD and the rectifications that may arise as a consequence. These tasks include: service bulletin (SB) modifications; airworthiness directive (AD) inspections; inspection, testing, removal and installation of rotable components; clearing deferred defects; cleaning; interior refurbishment; and stripping and repainting. These elements will create large workpackages, particularly for the IL and D checks.

The IL and D checks are the larger checks, where most of these additional items are added. While operators are not forced to use these checks to complete these additional tasks, IL and D checks do provide the best opportunity for operators to complete them. Using other or additional checks will increase aircraft downtime.

"We use the C checks to make a deep clean of the whole interior of the aircraft," says Holger Jacobi, engineer maintenance planning services at Lufthansa Technik. "This does not involve the removal of seats, galleys or toilets. We do remove the complete interior at the IL and D checks. Here the items are refurbished. We also have a smaller refurbishment half-way between the IL and D checks without removing the interior."

All of the described items will be included for passenger-configured aircraft, particularly in the D check. Freighter aircraft require fewer MH for the element of interior cleaning and refurbishment, but do nevertheless require some labour input to maintain the aircraft's freight loading and handling system. This means that freighters will require only slightly fewer MH than passenger aircraft for the IL and D checks.

Engineering orders

The A300-600 and A310 has had few major ADs and SBs.

The A310 has recently had an AD relating to cracks that were found in the fuselage centre wingbox: AD 07-184.

A large number of A300-600s and A310s operate with their primary operators on short- and medium-haul services. Most airlines' aircraft operate at flight cycle time of 1.0 to 3.0 flight hours.

There are two SBs relating to this AD. The first SB is A310-53-2111, and is a mandatory inspection with threshold intervals of 6,200-7,100FC and 14,300-31,000FH depending on aircraft configuration. The inspections add only 2-5MH.

The second is SB A310-53-2119, and requires a modification to rectify cracks in the event of findings during the inspection. This is usually done in an IL or D check, and Sebastian Eichentopf, aircraft system engineer at Lufthansa Technik, estimates that it requires 590MH and $1,500-2,000 for each side of the aircraft.

A second major AD is French AD number CN-F 200-5-084, and has two SBs related to it. The first is SB A310-53-2117, relating to a mandatory inspection of the nose area of the fuselage at frame 12A. This is not needed until the aircraft has accumulated 12,700-19,300FC, and is estimated to use about 99MH.

The second SB is SB A310-53-2116, and is a mandatory modification in the event that findings arise from the inspection. It involves improving the fitting on frame 12A with the frame 12A cabin floor crossbeam. Eichentopf estimates that this uses 360MH and $5,500 in materials and consumables.

This AD also affects the A300-600. The two SBs for the aircraft are SB A300-53-6138 for the inspection and SB A300-53-6137 for the modification.

A third major AD is French AD number CN-F 2005-001. Ozcan refers to the mandatory inspection, covered by this AD, on the rear spar internal angle and tee fitting. SB A310-57-2047 is estimated to use 600MH and up to $18,500 in materials for completion. The threshold for the inspection is 9,100-41,300FC and 16,600-66,500FH depending on aircraft type and configuration.

A fourth major AD relates to a mandatory modification required on the A310, which was the reinforcement to the fuselage at the butt joint at frame 55 and 58. The inspection is covered by AD07-0111 and the modification by SB A310-53-2125. The modification would be completed in an IL or D check, and Eichentopf estimates that completion of the modification uses 2,500MH, while the kit of parts costs $4,640.

A fifth major AD affecting the A310 is covered by AD 2007-0195. This concerns a mandatory inspection of the main landing gear attachment at the fifth wing rib on the rear wing spar. This is covered by SB A310-57-2091. The initial inspection interval is 12,000FC, and only uses about 6MH. The recommended modification is covered by SB A310-57-2090 and involves fixing bushings at the main landing gear attachment. This would be done during an IL or D check, and would use about 350MH and $4,000 in materials for each side of the aircraft.

There are three major ADs affecting the A300-600/-600R. The first is AD 2007-0173, which concerns a mandatory modification to change a fastener at frame 91 of the fuselage. This is covered by SB A300-53-6156 and has an initial threshold of 2,500FC accumulated from November 2006. Eichentopf estimates that completion of this requires 61MH and $38,000 of materials.

The second major AD is French AD CN-F-2006-016, which concerns a mandatory inspection of the upper radius of the frame 47 in the fuselage. This is covered by SB A300-53-6029, and has an initial interval of 10,000FC. It should be done during an IL or D check and uses 30MH and $125-750 on materials. The repair to the frame 47 upper radius required in case of findings is covered by SB A300-53-6114. It should be completed during an IL or D check.

The third major AD is not yet applicable, but is expected to be issued within one year. This is a mandatory inspection covered by SB A300-57-6107 for the rivets at frames 47 and 48 at a threshold of 12,000FC, but only uses 5MH. The recommended modification is covered by SB A300-57-6106 and requires an improvement to the drainage of the forward fuselage section. This is estimated to require 40MH and $4,000 in materials for each side of the aircraft.

A major modification affecting several aircraft types, following the in-flight deployment of a thrust reverser of a PW4000 engine on a Lauda Air 767-300 in 1991, also affects the A300-600 and A310. This involved a safety mechanism to prevent in-flight deployment referred to as the 'third line of defence'. This affects both PW4000 and CF6 engines. Jose Luis Rosario, planning and production control manager at TAP Maintenance & Engineering, estimates that completion of the modification requires a total of 800MH, and involves a material cost of $100,000.

Base check inputs

The C, IL and D checks comprise several elements, as described.

The C1, C2, C3, C5, C6, and C7 checks are lighter C checks, and although the number of routine MH varies for the element of routine tasks, there is a big difference between the total MH used for the checks. The C1 and C3 checks are smaller than the C2 check because there are many 2C tasks.

For the A310, 1,500MH are used for the routine element of the check. Another 700MH are used for findings arising from the routine inspections and 400MH are used for the interior cleaning and refurbishment. Another 300MH can be budgeted for ADs and SBs, 500MH for out-of-phase (OOP) tasks and 50MH for component changes. This takes the total to about 3,500MH. The associated cost of materials and consumables for the check is $72,000.

The A300-600 & A310 have a base maintenance programme base on a cycle of eight C checks, with a standard interval of 15 months. This interval has been escalated to 18 months. The complete cycle of eight checks consumes 75,000-85,000 man-hours.

The inputs for the A300-600/-600R are marginally higher, with most elements requiring another 100MH, taking the total to 3,900MH. The associated cost of materials is $75,000.

The IL and D checks consume the majority of MH in the cycle of eight base checks. In the case of the A310, the IL check will use about 25,000MH, depending on age and non-routine ratio. The routine tasks will use about 13,000MH, the non-routine findings another 7,000-10,000MH, the ADs and SBs 1,500MH, OOP tasks 800MH, component changes about 500MH and interior cleaning and refurbishment about 1,500MH. The ratio of material and consumable consumption per MH used is about twice the rate as for C checks, and the IL check will require $1.05 million.

The A300-600/-600R will use 2,000-3,000MH more, the routine element using about 1,500MH more and the resulting non-routines another 1,000MH. The check will also use $1.08 million of materials and consumables.

The D check uses another 5,000MH and $170,000 more in materials than the IL check in the case of both aircraft types.

Stripping and repainting should be added to this. Intervals between new paint jobs vary, but many operators will take the opportunity to strip and repaint the aircraft at the IL and D checks. This uses 1,500-1,900MH and about $50,000 in materials. A generic labour rate of $50 per MH will take the total cost to $125,000-145,000.

The total cost for the eight checks for the A300-600 is 85,000MH and $2.6 million in materials and consumables for the A300-600 operated on short-haul services with an average FC time of 1.2FH. Using a generic labour rate of $50, this is equal to a total of $6.85 million. Amortised over the interval of 22,500FH that would be accumulated over nine years *(see first table, page 27)*, this is equal to $310 per FH.

The total expenditure for the eight checks is about 79,000MH and $2.8 million in materials and consumables for the A310. Using a generic labour rate of $50 per MH for base maintenance, this takes the total to about $6.8 million. Amortised over the nine-year interval for the cycle of base checks, in which the aircraft accumulates about 31,000FH in its medium-haul operation, the reserve is equal to $220 per FH *(see second table, page 27)*.

The total cost for the eight checks for the A300-600R is about 89,000MH and $2.9 million in materials and consumables for the A300-600/-600R. This is equal to a total of $7.4 million at a generic labour rate of $50 per MH. This is equal to $240 per FH when amortised over the same interval *(see second table, page 27)* for an aircraft that is used on short-haul operations of about 1.2FH and completes its base maintenance cycle every eight to nine years.

Rotable components

Like all modern types, the majority of rotable components on the A300-600 and A310 are maintained on an on-condition basis. The two aircraft share many of the same component part numbers, and each uses about 800 different rotable part numbers. Each type has a total of about 1,500 rotables installed, although the number varies according to aircraft configuration.

About 120 parts numbers and 250 installed parts on the aircraft are maintained on a hard-time basis, while the remaining 1,270 or so are maintained on-condition.

Total support rotable packages will have three cost elements: a lease rate for a consignment of homebase stock at $20-30 per FH; a pool access fee for the remaining stock of parts which will be $55-60 per FH; and a power-by-the-hour (PBH) fee for repair and management of about $150 per FH. This will total $225-240 per FH *(see tables, page 27)*.

While some operators choose to depend on all-inclusive rotable support packages, rotables are required during A and base checks, as well as during line maintenance and operations. Operators therefore have to source on-condition rotables that fail on test during base checks. Rotables are repaired at several different facilities and providers. Northeast Aero repairs a large number of rotables on the A300-600 and A310, in particular pneumatic system components originally manufactured by Honeywell, and hydraulic system components made by Parker Eaton. "We also repair many of the flight control and other hydraulic components," says Vic Calabrese, vice president of operations and quality control at Northeast Aero Inc. "We specialise in pneumatics, hydraulics and electro-mechanical actuators for the A300-600 and A310."

The A300-600 and A310 have entered the secondary market, and some have been converted to freighter. The disposal of some fleets provides opportunities for airlines to dispose of their rotable inventories, and for new carriers to acquire surplus stock from the aftermarket. Northeast Aero's sister company Jetaway Aviation Services (JAS) is a specialist component aftermarket consumable and rotable supplier, which offers exchange rotable components, and acquires and provides rotable inventories. "We have bought and disassembled various aircraft types for their rotables and then either made them available for sale on the aftermarket or made them available for exchange," says Cliff Lorenzo, operations manager at JAS. "We also buy packages of surplus rotable stocks from airlines, and would also consider entire rotable inventories. We have also previously provided complete rotable support packages for airlines, and in the past supported Polar Air Cargo's European 747 operation at its base in Prestwick, Scotland. We could potentially support small fleets of A300-600s and A310s for an airline that might be operating a fleet of freighter converted aircraft. Our advantage is that we share some facilities and overheads with our sister company Northeast Aero, which can provide repair services for many of the rotables and so save time and costs."

Heavy components

Besides rotable components, consideration must be given to the costs of the four categories of heavy components: wheels and brakes; landing gear; thrust reversers; and the auxiliary power unit (APU). The removals of wheels and brakes, and thrust reversers are related to FCs, and therefore the cost of these components, are affected by aircraft utilisation and FC time.

The two main engine types on the A300-600 and A310 are the PW4000 and CF6-80, which both have similar thrust reversers with similar removal intervals in the region of 6,000FC. The workscope for repair and overhaul varies with condition, which worsens as removal interval increases. Disbonding on panels and materials results in the highest costs. A typical shop visit cost of $320,000 results in a reserve of $54 per FC for each shipset, and $108 per FC for the two units *(see table, page 24)*.

Landing gear exchange and overhaul fees at current market conditions are in the region of $600,000, which is low compared to the figure for other widebody types. Landing gear overhaul has a calendar interval of eight years, which is equal to 9,600FC for the A300-600R and A310 used on short-haul operations and accumulating about 1,200FC per year. The interval for an A300-600 on short-haul operations and accumulating about 2,000 per year will be 16,000FC.

Reserves for landing gear will therefore be about $65 per FC for aircraft used on medium-haul operations and $38 per FC for aircraft used on short-haul operations *(see table, page 24)*.

The A300-600 and A310 both have eight main wheels and two nose wheels. Wheels are removed when tyre treads have become worn. Tyres are then remoulded four or five times before being replaced. Wheels are also inspected when tyres are removed for remoulding. Average intervals for wheel removals are about 300FC.

Brake units are removed for repair when disc thicknesses have worn to the legal minimum.

Typical tyre remould costs are $500-600 per tyre, while new tyres cost $900-1,200. Wheel inspections cost in the region of $1,000, while brake unit repairs cost $40,000 per unit.

The overall cost for remoulding and replacing the aircraft's complete shipset of tyres, inspecting the wheels, and repairing the eight brake units is about $224 per FC *(see table, page 24)*.

The A300-600 and A310 use the GTCP 331-250 APU. The GTCP 331-250 had poor reliability, but this has improved and shop visit intervals have now increased to about 3,000 APU hours. How this relates to aircraft FH and FC depends on how the APU is used during turnarounds between flights. The APU is used for one hour in many cases, and so the shop visit removal interval will be equal to about 3,000FC. An average shop visit cost of $250,000 will see APU reserves of $85 per FC *(see table, page 24)*.

Total costs per FC for aircraft used on short-haul operations and accumulating about 2,000FC per year will be about $455 per FC. This will be equal to about $380 per FH *(see table, page 24)*.

Total costs per FC for aircraft used on medium-haul operations and accumulating about 1,200FC per year will be about $485 per FC. This will be equal to about $175 per FH *(see table, page 24)*.

A300-600 & A310 HEAVY COMPONENT MAINTENANCE COSTS

Number of main & nose wheels	8 + 2
Tyre retread interval-FC	270/220
Tyre retread cost-$	600/450
Number of retreads	5
New main & nose tyres-$	1,200/1,000
$/FC retread & replace tyres	**26**
Wheel inspection interval-FC	270/220
Main & nose wheel inspection cost-$	1,000
$/FC wheel inspection	**38**
Number of brakes	8
Brake repair interval-FC	2,000
Brake repair cost-$	40,000
$/FC brake repair cost	**160**
Landing gear interval-FC	16,000/9,600
Landing gear exchange & repair fee-$	600,000
$/FC landing gear overhaul	**38/65**
Thrust reverser repair interval-FC	6,000
Exchange & repair fee-$/unit	320,000
$/FC thrust reverser overhaul	**108**
APU hours shop visit interval	3,000
APU hours per aircraft FC	1.0
APU shop visit cost-$	250,000
$/FC APU shop visit	**85**
Total-$/FC	**455/485**
Total-$/FH passenger aircraft @ 1.2FH per FC	**380**
Total-$/FH passenger aircraft @ 2.8FH per FC	**175**

Engine maintenance

The A300-600 and A310 fleets are powered by four main engine types. A minority of A300-600s and A310-200s are powered by the JT9D-7R4 series and CF6-80A2 engines. A larger number of the higher gross weight A300-600Rs and A310-300s are powered by the PW4000 and CF6-80C2 engines.

Engine maintenance costs are dependent on thrust ratings and average FC times of operation.

PW4000

The PW4000 is rated at 58,000lbs thrust for the A300-600R (PW4158), and at 52,000lbs and 56,000lbs for the A310-300 (PW4152 and PW4156A).

The PW4000 can be sub-divided into two fleets of engines which have had the Phase III upgrade to improve exhaust gas temperature (EGT) margin and EGT margin retention during operation. Auvanish Narayen, engine programme manager at Total Engine Support, explains that the PW4152 Phase III engine has a mature EGT margin following a shop visit of about 50 degrees centigrade. This compares to about 36 degrees for non-Phase III engines. These are test cell EGT margins, and on-wing installed EGT margins are 5-10 degrees higher than this.

Narayen explains that initial rates of EGT margin loss are about 13 degrees in the first 1,000EFC on-wing. This rate then reduces to 5-10 degrees centigrade per 1,000EFC, although the rate depends on the operating environment and whether the practice of water washing is used.

The PW4000 has high enough EGT margin for most of these engines not to be removed due to EGT margin and performance loss. More common removal causes are deterioration of high pressure turbine (HPT) stage 1 and stage 2 blades.

A large number of engines have had to be removed to comply with the ring case modification, which is covered by AD 2003-19-115. This modification requires each engine to have a new rear case on the high pressure compressor (HPC). The deadline for completing this modification on all PW4000 engines is 2009. The AD also requires stability tests to be done on the HPC on unmodified engines at 2,800EFC since overhaul. The test is done on a complete engine in the test cell. If the the engine fails the test it has to be split in the shop and the modification must be done. This costs about $300,000 and is usually incorporated in a shop visit.

Removal intervals depend on average EFC time. For the PW4152 powering the A310 they are: 4,500EFC and 9,000EFH at an average EFC time of about 2.0EFH; about 4,000EFC and 12,000EFH at an average EFC time of 3.0EFH; and about 3,800EFC and 15,500EFH at an average EFC time of 4.0EFH.

The intervals for the PW4158 powering the A300-600 are about 5,000EFH and EFH at an average EFC time of 1.0EFH, about 7,500EFH and 3,750EFC at an average EFC time of 2.0EFH and about 11,000EFH and 3,500EFC at an average EFC time of 3.0EFH.

There are two main shop visit workscopes for the PW4000: a core heavy maintenance; and an engine heavy maintenance.

The core heavy maintenance is used to restore engine performance and focuses on the HPC and HPT core modules. This includes visual inspections of the low pressure compressor (LPC) and low pressure turbine (LPT) modules. Heavy maintenance is performed on the HPC and HPT, and a check and repair is made on the gearboxes.

This level of workscope will use 3,500-4,000MH of labour, about $1.1 million in materials and parts, and up to about $0.8 million in sub-contract repairs. A generic labour rate of $70 per MH will take the total cost of the shop visit to about $2.1 million.

The engine heavy maintenance workscope performs heavy maintenance on all modules, and is used to restore the maximum amount of performance possible.

This workscope will use 4,500-5,000MH of labour, about $1.7 million in parts and materials, and $1.0 million in sub-contract repairs. The same labour rate will take the cost of the shop visit to about $3.0 million.

Narayen explains that most PW4000s typically follow a shop visit pattern of alternating core heavy maintenance and engine heavy maintenance workscopes.

Engine removal patterns have to be managed around life limited parts (LLPs). All except two LLPs in the PW4000 have lives of 20,000EFC, and a full shipset of parts has a list price of $3.4 million.

The removal intervals of most engines are 3,500-5,000EFC, so most engines could have their LLPs replaced every fourth shop visit. Shorter removal intervals of 3,500-3,800EFC means that LLPs could remain in the engine for a fifth removal interval, but would then force a heavier shop visit when a core heavy maintenance is likely to be required. This would, however, allow most of the LLP lives to be used and overall achieve the lowest possible cost per EFC.

LLPs are therefore likely to be replaced after 18,000-19,000EFC. This would result in reserves of $180-190 per EFC.

The total cost of the two shop visits is $5.0-5.2 million. For the PW4152, this is equal to a reserve of about $278 per EFH for engines operating at 2.0EFH, $215 per EFH for engines operating at 3.0EFH, and $180 per EFH for engines operating at 4.0EFH.

For the PW4158, this is equal to a reserve of $520 per EFH for engines operating at 1.0EFH, $350 per EFH for engines operating at 2.0EFH, and $245 per EFH for engines operating at 3.0EFH.

A third element of engine maintenance reserves is for quick engine change (QEC). This is $15-20 per EFH.

When combined with reserves for LLPs adjusted for EFC time, total reserves vary with average EFH:EFC ratio. For the PW4152 powering the A310, total reserves are $388 per EFH for engines operated at an EFC time of 2.0EFH, $290 per EFH for engines operated at 3.0EFH, and $245 per EFH for engines operated at 4.0EFH *(see second table, page 27)*.

In the case of the PW4158 powering the A300-600R, reserves are about $730 per EFH for engines operating at 1.0EFH, $460 per EFH for engines operated at 2.0EFH, and $320 per EFH for engines operated at 3.0EFH *(see tables, page 27)*.

CF6-80C2

The CF6-80C2 has four thrust ratings for the A300-600R: the -80C2A1 at 59,000lbs thrust; the -A8 at 59,000lbs thrust; the -A3 at 60,200lbs thrust; and the -A5 rated at 61,300lbs thrust. The CF6-80C2 has two ratings for the A310-300: the -A2 rated at 53,500lbs, and the -A8 that is also used for the A300-600R.

The first three variants for the A300-600R are flat rated at 30 degrees centigrade, meaning that thrust reduces from its maximum level when outside air temperature is higher than this. The -A8 is flat rated at 35 degrees, while the -A2 is flat rated at 44 degrees. This gives operators more ability to operate in hot climates without suffering loss of operating performance.

The CF6-80C2 freighter has power management controls (PMC) or a full authority digital engine control (FADEC) system. Engines with FADEC controls tend to have better performance retention.

The majority of CF6-80C2s powering the A300-600 and A310 are mature, and have been through their first shop visit. EGT margins are less than for new engines, and are generally higher for the block 3 engines that were the last batch to be manufactured. Earlier block 1 engines have been improved, however, with better blades and vanes. This means that the mature EGT margins of the three production groups are similar.

EGT margins are 35-50 degrees, depending on the exact variant and previous shop visit workscope. EGT margin erosion rates are the highest for engines operating on short cycle times.

Engines operating on the A300-600 with short FC times of about 1.0FH can lose 14 degrees of EGT margin in the first 2,000EFH/2,000EFC, and lose four degrees per 1,000EFH thereafter. Engines in this style of operation typically remain on wing for about 5,000EFH and 5,000EFC.

Engines on the A300-600 operating longer cycles of about 2.0FH lose eight degrees of EGT margin in the first 1,000EFH on wing, and then about three degrees per 1,000EFH thereafter. These engines have on-wing intervals of about 4,500EFC and 9,000EFH.

Engines used on the A300-600 at FC times of 3.0FH have lower EGT margin loss rates of 7-10 degrees in the first 2,000EFH, and then 2-3 degrees per 1,000EFH. This would allow a total on-wing interval of about 4,000EFC and 12,000EFH. Longer cycle times of about

The cycle of eight base checks on the A300-600 and A310 is completed about every nine years. Most aircraft in the fleet will have been through one or two base maintenance cycles.

4.0EFH are rare, but intervals of 12,000EFH can be expected, equal to 3,000EFC.

Most A310-300 operations operate at medium-haul cycle times of about 3.0EFH, and -A2 engines can typically achieve intervals of about 5,000EFC and 15,000EFH. This is a 1,000EFC longer interval compared to higher thrust engines used on the A300-600.

Engines used on long-haul operations can enjoy long removal intervals due to the relatively high EGT margin, and hardware deterioration is the main cause for removals. Older engines with PMC controls do, however, experience more removals due to performance loss than engines with FADEC controls.

The CF6-80C2 has several ADs that can force removals. The first of these is AD 2006-16-06, which requires the reworking of the dovetail slots on the first stage HPT blades. This requires an inspection every 3,000EFC, and so will limit removal intervals for engines on medium- and long-haul operations. The slots eventually have to be reworked after an accumulated 10,000-14,000EFC, and the LLP concerning these slots will eventually be replaced.

AD 2002-25-08 affects another LLP, the HPC stage 3-9 spool. It also requires an inspection every 2,000-3,500EFC. This can be avoided by replacing the LLP at a cost of about $250,000.

AD 2004-22-07 requires an inspection of the stage 2 nozzle guide vanes (NGVs) initially after 1,600EFC. This therefore forces an early removal. A new set of NGVs has a list price of about $290,000.

Removal intervals also have to be managed around LLPs. The CF6-80C2 has 20 LLPs: four in the fan and booster module; six on the HPC; four in the HPT; and six in the LPT. The prices of these four groups of parts are $950,000, $950,000, $620,000 and $865,000 respectively, taking the cost of a shipset to about $3.4 million.

There are several part numbers for each part, but many of the latest part numbers have the full lives of 15,000EFC or 20,000EFC. Most variants have LLPs with lives of 20,000EFC in the fan/booster, HPC and LPT modules. The HPT modules have lives of about 15,000EFC.

Unless parts have restricted lives shorter than 15,000 EFC, this allows engine maintenance management to be relatively simple. That is, the typical range of removal intervals of 4,000-8,000EFC allow replacement of LLPs with lives of 20,000EFC every two to five shop visit removals, and replacement of LLPs with lives of 15,000EFC every two or three shop visits. This can be achieved while leaving only short stub lives of LLPs in most cases.

In the case of engines powering the A300-600R, the removal intervals provide convenient LLP replacement timings for engines operated at 1.0EFH cycle lengths. Most parts could be replaced every third or fourth shop visit, depending on their lives. This would result in reserves of about $180 per EFC.

Engines on cycle times of 2.0EFH will still have their LLPs replaced every third and fourth shop visit, but the LLPs will be replaced with more stub life remaining because the EFC removal intervals are shorter than for engines operated at EFC times of 1.0EFH. These longer cycle engines will have LLPs of about $200 per EFC.

Engines operated at 3.0EFH per cycle and with removals of about 4,000EFC will have their LLPs replaced every third and fifth shop visit. The LLPs with lives of 20,000EFC have little or no stub life in this case. This results in LLP reserves of $190 per EFC.

Lower rated engines on the A310-300, which are operated at EFC times of 3.0EFH and achieve longer intervals of 5,000EFC between removals, have LLPs replaced at third and fourth shop visits, with little or no stub life remaining. LLP reserves are therefore about $180 per EFC.

The probable removal intervals will affect shop visit workscopes and workscope patterns. The HPT and HPC will require a heavy scope or overhaul every removal. The two low pressure modules will follow an alternating pattern of light and heavy or overhaul workscopes at a high EFC interval of 1.0EFH.

A similar pattern of module workscopes will be followed by engines operated at longer EFC times of 2.0EFH and 3.0EFH, although workscopes on average will be lighter as cycle times. This will consequently reduce the labour, material and parts inputs required for the workscopes.

The lower rated engines operated on the A310-300 will also follow a similar shop visit workscope pattern when used at EFC times of 3.0EFH.

A light workscope or performance restoration on the HPT and HPC will use about 4,000MH in labour, $1.0 million in parts and materials, and $250,000 in sub-contract repairs. A generic labour rate for engine maintenance of $70 per MH will take this to a total of $1.6 million.

A heavier performance restoration or light overhaul will require about 500MH more labour, $300,000 more in parts and about $50,000 more in sub-contract repairs. This will take the total to $1.8 million.

A heavy overhaul will use about 5,000MH of labour, $1.6 million in parts and materials, and about $300,000 in sub-contract repairs. This will take the total to about $2.3 million.

A light LPT workscope uses about 700MH, requires about $120,000 of parts and materials, and $50,000 in sub-contract repairs, resulting in a total of about $200,000. A heavier LPT workscope will cost a total of $300,000.

A fan and booster overhaul will cost in the region of $250,000.

Total shop visit costs for the complete engine will therefore vary according to average EFC length and particular removal interval. High-rated engines for the A300-600 operated at 1.0EFH will have total shop visit costs of $2.3-2.7 million, while those operated at 2.0EFH will cost $1.9-2.6 million. Engines used at higher cycle times of 3.0EFH will have total costs of $2.0-2.3 million.

A third element of QEC costs at a rate of $15-20 per EFH should be added.

Once LLP reserves are added, this will take total reserves to $700 per EFH and EFC for the -80C2A8 powering the A300-600/-600R operated at 1.0EFH, to $375 per EFH when operated at 2.0EFH, and $265 per EFH when operated at 3.0EFH *(see tables, this page)*.

Shop visit costs for lower rated -80CA2 engines powering the A310-300 will be $2.2-2.6 million, and total reserves for an EFC time of 3.0EFH, including LLPs, will be $240 per EFH *(see second table, this page)*.

Reserves for the JT9D-7R4H1 and CF6-80A3 powering earlier examples of the A300-600 and A310-300 are high by comparison. The JT9D-7R4H1, for example, has reserves in the region of $470 per EFH when operating at an average EFC time of 2.0EFH, about $410 per EFH at an average EFC time of 3.0EFH, and $355 per EFH at an average EFC time of 4.0EFH.

The CF6-80A3 powering lighter examples of the A310-300 has reserves of about $400 per EFH when operating an average EFC time of 3.0EFH.

Maintenance cost summary

The difference between short- and medium-haul operations is clearly illustrated by the total costs per FH. Aircraft operating on an average FC time of 1.2FH have about 60% higher costs. Most of this difference is accounted for by engine maintenance.

As with all aircraft types, engine reserves follow an asymptotic relationship with increasing EFC times. Reserves for the CF6-80C2A8, for example, are about $700 per EFH at 1.2EFH per EFC and $265 per EFH at 3.0EFH.

The result is that total maintenance costs for the A300-600 on short-haul operations are $2,600-2,800 per FH, with engine reserves accounting for 55-60% of this *(see first table, this page)*.

Reserves for the A300-600R operated at 2.8FH per FC are $1,490-1,600 per FH. Engine reserves account for about 35% of the total *(see second table, this page)*.

Total maintenance costs for the smaller A310-300 operated at the same flight cycle time of 2.8FH are $1,345-1,445 per FH *(see second table, this page)*.

There is a smaller difference between the reserves for airframe maintenance and costs associated with heavy components and rotables for aircraft operated on short- and medium-haul missions. AC

MAINTENANCE COSTS FOR PASSENGER-CONFIGURED A300-600

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	490,000	1 year		155-165
A check	66,000-70,000	350-500FH		140-190
Base checks	6,850,000	22,500		310
Heavy components:			455	380
LRU component support				225-240
Total airframe & component maintenance				**1,205-1,315**
Engine maintenance:				
2 X PW4158: 2 X $730 per EFH				1,460
2 X CF6-80C2A8: 2 X $700 per EFH				1,400
Total direct maintenance costs:				**2,600-2,800**

Annual utilisation:
2,500FH
2,000FC
FH:FC ratio of 1.2:1.0

MAINTENANCE COSTS FOR PASSENGER-CONFIGURED A300-600R & A310-300

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	355,000-390,000	1 year		105-115
A check	66,000-70,000	350-500FH		140-190
Base checks - A310-300	6,800,000	30,500		220
Base checks - A300-600R	7,400,000	30,500		240
Heavy components:			485	175
LRU component support				225-240
Total airframe & component maintenance: A310-300				**865**
Total airframe & component maintenance: A300-600R				**960**
Engine maintenance A310-300:				
2 X PW4152: 2 X $290 per EFH				580
2 X CF6-80C2A2: 2 X $240 per EFH				480
Total direct maintenance costs A310-300:				**1,345-1,445**
Engine maintenance A300-600:				
2 X PW4158: 2 X $320 per EFH				640
2 X CF6-80C2A8: 2 X $265 per EFH				530
Total direct maintenance costs A300-600R:				**1,490-1,600**

Annual utilisation:
3,400FH
1,200FC
FH:FC ratio of 2.8:1.0