A330-200/-300 maintenance analysis & budget

The A330-200/-300 have some of the lowest maintenance costs of current generation aircraft, and outperform the A340-200/-300 by $400-500 per FH.

The A330-200/-300 family is among the most successful widebody twinjets in operation. The A330-300 was originally pitched as a DC-10-30 replacement in the late 1980s. The shorter -200 variant was launched in 1994 and widened the A330 family's appeal. Orders are still being placed in large numbers prior to their replacements, the A350-800 and -900, going into service in 2013. With more than 500 A330s in service and another 370 aircraft on firm order, the A330-200/-300 can be expected to remain in operation for another 30 years. The A330-200/-300 are powered by three main powerplants: the General Electric (GE) CF6-80E1; the Pratt & Whitney (PW) PW4000-100; and the Rolls-Royce (RR) Trent 700. The aircraft's complete maintenance costs are analysed here.

A330-200/-300 in operation

The A330-200 and -300 are used as medium- and long-haul workhorses by most of their operators. The A330's main markets of operation include the transatlantic, Europe-Middle East, and trans-Asia Pacific.

The aircraft's earliest operators were Cathay Pacific, Thai International, Aer Lingus, Air France and Emirates. It is also operated in large numbers by USAirways (9 aircraft), Air Canada (8), KLM (9), Lufthansa (10), THY (5), Qatar Airways (28), TAM of Brazil (12) and Qantas (10). Smaller operators include Cyprus Airways, Middle East Airlines, Finnair and TAP Air Portugal.

The A330-200 is used almost exclusively as a long-haul flagship. Its most prominent operators are Air France (16 aircraft), Northwest (32) and Swiss (11).

Most operators have the aircraft in a dual-class configuration, with 220-260 seats. The aircraft has a range of up to 6,450nm with this number of passengers.

Airlines that use the aircraft as their long-haul flagship include TAM, THY and Northwest. Average annual utilisation is 4,500 flight hours (FH). Average flight cycle (FC) time is 6.7FH.

Airlines that use their aircraft on medium-haul operations have FC times of 2.2-3.5FH and generate 3,500-4,500FH per year.

The A330-200 is also popular with European charter carriers, which use the aircraft in high-density seating configurations. Major operators include Monarch Airlines, MyTravel Airways, LTU and Thomas Cook Airlines.

The A330-300 is also used as a long-haul flagship by some operators, including Air Canada, USAirways and Lufthansa. For these operations most aircraft are in a dual-class configuration with 280-300 seats.

The A330-300 is also used for medium-haul and high-density regional operations, particularly in the Asia Pacific, by Air China, Cathay Pacific and Thai International. Most of these other operators configure the aircraft in two cabin classes with 300-320 seats.

Annual rates of FH and FC utilisation and average FC times are similar to the -200 fleet, with the -300 being used either for medium- or long-haul operations.

The maintenance costs of the A330-200 and -300 are analysed here in medium- and long-haul operations. The medium-haul operation assumes 3,750FH and 1,250FC per year, with an average FC time of 3.0FH. The long-haul operation assumes 4,750FH and 700FC per year, with an average FC time of 6.7FH.

Maintenance programme

The A330-200/-300's maintenance programme has the same basic structure as all other Airbus types. Since its entry into service, 15 revisions have been made, with the last one in September 2007. The next revision is expected in May 2008.

"There has been about one revision per year," says Michel Pebarthe, product support director at Air France Industries. "We follow the maintenance planning document (MPD), and we use the 14th revision of the MPD. Operators can, however, devise their own maintenance programmes and get extensions of the basic task intervals."

Line checks

The line checks start with the usual system of daily checks performed when the aircraft is at its homebase. This is usually every day, although the maximum interval is 48 hours.

Following a daily check and release to service the aircraft will have a pre-flight (PF) check. This includes mostly visual inspection tasks, and can in most cases be performed by the flightcrew, reducing the need for mechanics. Defects may require rectification by mechanics, however.

Transit (TR) checks are performed before all other flights operated during the day, usually by flightcrew. The content is slightly less than for pre-flight checks. Defects can arise, although it is possible to defer the rectification of most until the aircraft returns to its homebase. Since most A330s operate on long-haul services and consequently perform only two or three flights per day, only one or two TR checks will be made each day.

The routine content of PF and TR checks is mainly external visual inspections that include: the pitot tubes; lights; bay doors and access panels; slats and flaps; wheels and landing gears; and engine inlets. There are also a few interior inspections, of items like high frequency (HF) radios, fire detectors, flightdeck oxygen and other emergency equipment. The technical log will also be examined for outstanding defects in case any have exceeded their legal deferment time. "The routine tasks will also include items for extended range twin-engine operations (Etops). This will include ensuring the back-up generator is operational, the oxygen cylinder is functional, and that engine oil levels and consumption levels are within limits," explains Stephane Trochet, station manager at Paris Charles-De-Gaulle for Stella Aviation. "The routine tasks and Etops tasks can be performed by flightcrew in some jurisdictions. Some aviation regulatory authorities still require line mechanics to perform PF checks. Where flightcrew can perform routine tasks, mechanics may be needed for non-routine items, particularly those defects that cannot legally be deferred."

Daily checks are slightly larger than PF and TR checks, and can be performed by one line mechanic. The routine tasks are those of the PF and TR checks, plus additional items for line mechanics which combine external and internal visual inspections. "These include the manual checking of tyre pressures and brake disc wear, and visual inspections of shock absorbers," says Trochet. "In addition to routine tasks, the engine oil levels can be checked via the electronic centralised aircraft monitoring (ECAM) on the flightdeck. The bay for the auxiliary power unit (APU) also has to be opened to check the component. Any defects must be written up in the technical log, while there is a cabin log to record cosmetic items such as lights, coffee makers and the in-flight entertainment (IFE) system. Additional tasks include cleaning the cabin, flightdeck centre pedestal and ECAM screens."

Weekly checks have a maximum interval of eight days, and can also be performed by one line mechanic. They include a few tasks on top of the daily check: examining engine magnetic chip detectors and landing gear shock absorbers; draining water; refilling water tanks; and checking emergency gas bottles, the hydraulic accumulator, and cargo compartment doors. A flightdeck test on Cat IIIa equipment must be made.

A checks

The maintenance programme is a system of A checks, with a group of 1A tasks that have an interval of 600FH. "Originally 400FH, this was extended to 500FH in 1998, and then 600FH in 2002," says Robert Bernhard, head of maintenance programmes and reliability at SR Technics. The 16th revision of the MPD in May 2008 is expected to increase the 1A task interval to 800FH.

There are another three multiples of these tasks: the 2A, 4A and 8A tasks with corresponding intervals of 1,200FH, 2,400FH and 4,800FH.

The 2A tasks will have their intervals escalated to 1,600FH and the 4A items escalated to 3,200FH at the next MPD revision. The 8A tasks will also be increased to 6,400FH.

The A2 check has an interval of 1,200FH and comprises the 1A and 2A tasks *(see table, this page)*. The A4 check has an interval of 2,400FH and comprises the 1A, 2A and 4A tasks. The A8 check comprises the 1A, 2A, 4A and 8A tasks, and is the last check on the A check cycle.

Base checks

The base maintenance programme is based on a cycle of eight checks that all Airbus aircraft have followed. "The group of 1C tasks has an interval of 18 months, which was escalated in 1998 from the original interval of 15 months," says Bernhard. "There are three multiples of this group of tasks: the 2C tasks every 36 months; the 4C every 72 months; and the 8C every 144 months. Not all items can be escalated, so they drop out of the regular calendar intervals and become out-of-phase (OOP) tasks."

These tasks are arranged into block C checks, so the C2 and C6 checks have 1C and 2C items, and the C4 check has 1C, 2C and 4C tasks *(see table, this page)*.

"The MPD interval for the C check tasks was 15 months, so the full cycle of eight checks had an interval of 120 months," says Pebarthe. "The 18-month interval now extends this cycle by 24 months or two years to 144 months for the eight checks. The evolution exercise for the 1C and 2C tasks is expected to be completed by 2009, and the next revision of the MPD may extend the 1C interval to 24 months. This would increase the length of the cycle to 192 months, or 16 years. It is not clear when this will happen, however.

"There are also two groups of structural inspections: the 6-year tasks and the 10-year tasks, which were called IL and D tasks in earlier Airbus models. Their original intervals when the A330 went into service were 60 and 120 months. The 60-month tasks had their interval extended to 72 months, so they now coincide with the C4 check," continues Pebarthe. "The 10-year structural inspections are still at their original interval of 10 years/120 months. This used to coincide with the C8 check's original interval of 120 months. The 10-year interval may be increased to the C8's new interval of 144 months at the next revision in May 2008. This would be ideal for maintenance planning. Our own D check interval is 11 years, and we have a sampling programme to escalate it to 12 years."

The groups of inspections included in each base check are summarised *(see table, this page)*. The two heavy checks are the C4 and C8 checks. The C4 will comprise the 1C, 2C, 4C and 6-year groups of tasks. The C8 will comprise the 1C, 2C, 4C, 8C and 10-year tasks. While the MPD intervals of the 8C and 10-year inspections no longer coincide, actual utilisation of check intervals by most airlines and the desire to minimise downtimes for base checks mean that the two groups of tasks will be scheduled together in most cases.

A330-200/-300 A & C CHECK TASK ORGANISATION

Check	Check task groups	Interval
Block A check system		
A1	1A	600FH
A2	1A + 2A	1,200FH
A3	1A	1,800FH
A4	1A + 2A + 4A	2,400FH
A5	1A	3,000FH
A6	1A + 2A	3,600FH
A7	1A	4,200FH
A8	1A + 2A + 4A + 8A	4,800FH
Block base check system		
C1	1C	18 months
C2	1C + 2C	36 months
C3	1C	54 months
C4/6-year	1C + 2C + 4C + 6-year	72 months
C5	1C	90 months
C6	1C + 2C	108 months
C7	1C	126 months
C8	1C + 2C + 4C + 8C + 6-year + 10-year *	144 months

The 10-year tasks are likely to be extended to a 12-year/144-month interval in the next MPD revision that will be issued in May 2008.

Line & A check inputs

The labour and material inputs for PF and TR checks are minimal. Trochet estimates that these checks use only one man-hour (MH) of labour, if a mechanic is used. "The only materials needed are two cans of oil for servicing the engine oil, and a litre of shock absorber cleaner," says Trochet. "This will cost a total of $15-20. There may also be a few non-routine items to add to this, such as various-sized lightbulbs. A small lightbulb will cost $35, while a landing lightbulb can cost $60. There are four or five non-routine occurrences every 10 flights on average, related to problems with passenger seats or IFE equipment. A total budget averaging $50 of materials per check can be used." The replacement of major components will be accounted for in rotable costs.

A daily check will use a little more labour, and Trochet estimates that this will be 1.5-2.0MH, with one mechanic required to complete the check. "Non-routine items can be added, such as deferred defects at the request of the customer," says Trochet. "This depends on the findings, and they are usually interior-related tasks. The other non-routine tasks are similar to those in the PF and TR checks.

"Other requirements include nitrogen gas to reinflate the wheels," continues Trochet. "Changing a main wheel can

The A330's maintenance programme has evolved since it entered into service. Base checks now have an interval of 18 months, and the C8 check finishes the cycle at an interval of 144 months. The first group of structural inspections have had their interval escalated to 72 months to coincide with the C4 check, but the second group of tasks still have an interval of 120 months. These may be increased to 144 months. Further base check interval escalations may be to 24 months and a cycle of 192 months.

add 2.5MH, and changing a light can add 1MH. Another problem, for example, is opening a thrust reverser and engine cowl to access a line replaceable unit (LRU) on the engine. Labour consumption on these checks is likely to be 2.5-3.0MH when non-routines are included. The related cost of materials and consumables will be that used for PF/TR checks plus the cost of nitrogen and hydraulic fluid. The total cost will be $100-120."

The weekly check, which is the largest of all line checks, requires 1.5MH for the routine items that are included in the daily check plus another 1MH for the additional tasks. "The non-routines are the same as those included in the daily checks, but the weekly checks will have some additional cabin items," explains Trochet. "These can be quick-to-fix items, such as coffee makers or life vests. The total labour required can be 3.0-6.0MH. The materials and consumables used will be the same as for daily checks, plus o-rings that are replaced each time a magnetic chip detector is inspected. Findings when magnetic chip detectors are inspected can cause an aircraft-on-ground (AOG) situation, especially if an engine has to be removed and replaced. Emergency gas bottles may also have to be replaced, and toilet pipes must be cleaned with crushed ice and a special fluid. The cost of materials for the routine portion of the check will be $150, while it will be highly variable for the non-routine part of the check. Replacement of an oxygen bottle, for example, can cost $1,500 and is required every three years. Hydraulic system fluid, engine oil and nitrogen for tyres will always need to be replaced, adding several hundred dollars. A wheel may also have to be changed. A budget of $250-350 can be used for non-routine materials and consumables, taking the total cost to $400-500."

The aircraft will therefore require 350 daily and 350 TR checks each year, plus 900 PF checks, and 50 weekly checks on medium-haul operations. The total annual cost of these line and ramp checks will be $340,000, assuming a labour cost of $70 per MH. This is equal to $90 per FH *(see first table, page 32)*, but the estimate is conservative, however, because it assumes that the TR and PF checks are performed by mechanics, not flightcrew.

For long-haul operations, the aircraft will need 350 each of daily, TR and PF checks per year, plus 50 weekly checks. The total cost of labour and material inputs, assuming mechanics perform all checks, is $250,000 per year, equal to $70 per FH *(see second table, page 32)*.

A check inputs

A checks start with routine inspections, which inevitably lead to non-routine rectifications. There will also be outstanding defects that have arisen during operation, and have been deferred for clearing during A checks.

Airlines will also schedule some minor modifications, cleaning and cosmetic items, some component changes, and some additional customer-specific items. "The cabin and cosmetic, and customer-specific items will vary widely between operators," says Benno Schlaefli, head of project management at SR Technics. "Traditional airlines may have time to clear defects that arise during operation in daily and weekly checks, while inclusive tour operators, which utilise the aircraft more heavily, will defer more defects until the A check. These airlines will also do a lot more cabin cleaning and interior cosmetic work during A checks, since little will have been done during lighter line checks. Traditional scheduled airlines do less interior work during A checks, and more during daily and weekly checks. The routine tasks in the A check require 120-140MH, with the 1A tasks accounting for most of these. The additional 2A, 3A and 4A tasks in some checks need relatively few additional MH. Non-routine rectifications add another 25-30% to the routine MH, equalling 30-45MH. The remainder of the check involves minor modifications, clearing defects, cleaning and cosmetic work, and customer-specific items. A total of 180-450MH is required for the check, with the cost of materials and consumables varying from $11,000 to $30,000."

Air France is an example of a scheduled passenger operator. "Our A checks, which are performed as block checks, use an average total of 300MH. About 120MH are used for the routine inspections, another 70MH are required for component changes, 70-100MH used for cabin cleaning and refurbishment work, and the remaining 40MH is for non-routine rectifications," says Pebarthe. "We do some interior refurbishment work in the A check, which includes seat cover replacements and work on IFE screens. The check also uses $12,000-15,000 in materials and consumables."

Similar inputs are used by Abu Dhabi Aircraft Technologies for several of its customers. "An A check varies in workscope, but uses 300-400MH of labour and $12,000-15,000 in materials and consumables," advises a planning expert planning Abu Dhabi Aircraft Technologies. "Routine inspections use 150-200MH of the total, with component changes, interior work and non-routine rectifications accounting for the balance of MH input."

Taking average inputs of 400MH labour at $70 per MH and $20,000 for materials and consumables, the total cost for the check is $48,000. While the maintenance programme interval is 600FH, the actual interval achieved by operators will be 450FH, resulting in a cost per FH of $110 *(see tables, page 32)*.

The A330 has heavy checks at six year intervals. Most operators elect to perform interior refurbishments and strip and repaint the aircraft during these visits. Heavy modifications are also performed during these checks.

Base check contents

The grouping of the routine tasks and inspections in the cycle of eight base checks has been described. The routine inspections include corrosion prevention control programme (CPCP) items that were added to older types after several years of service.

Besides routine inspections, the base checks have several other elements to complete the total workscope. There are also OOP tasks, which are inspections that do not have the same intervals as A or C check inspections. These are often safety-related items which have life limits and intervals expressed in FCs.

There are also component changes. Some components and rotables are tested as part of the routine inspections, but others have soft or hard times for removal and testing that coincide with the base checks.

A large part of a base check workscope is accounted for by service bulletins (SBs), airworthiness directives (ADs), and modifications. Inspections detailed in ADs result in findings, so ADs can include modifications.

These three groups of tasks and the routine inspections will all lead to rectifications being required.

In most cases operators will use the downtime provided by base checks to perform at least some interior cleaning and refurbishment. The longer downtime of the C4/5-year and C8/10-year checks is often used for refurbishing the interior, involving the complete removal of the seats, overhead bins, sidewall and ceiling panels, bulkheads, toilets and galleys.

Most airlines will also use the extended downtime of these two heavy checks to strip and repaint the aircraft.

Routine inspections

The organisation of routine base check inspection tasks is summarised *(see table, page 21)*. The C4 and C8 checks are the heaviest. While the 10-year tasks have been included in the C8 checks and have an interval of 120 months, the actual utilisation of base check intervals, planning of check workscopes and downtimes required for several checks must be considered.

Most airlines use 85-90% of base check intervals, so they are likely to carry out a base check on the A330 once every 15-16 months. The complete cycle and C8 check is therefore likely to come due every 122-130 months. It would therefore make sense for most operators to perform the C8 check at 120 months, and still combine the 10-year tasks with the other four groups of C check tasks to simplify maintenance planning and minimise downtime.

Moreover, the interval for the 6-year tasks was extended from five years in 2002. Aircraft up to this point, and some aircraft after this MPD revision, would therefore have had these structural tasks performed at the 5-year interval, so the 10-year tasks would be in-phase with the C8 check for most of these aircraft. It is only since 2002 that some aircraft will have had this first group of structural tasks performed at the 6-year interval. The extension of the 10-year structural inspections to 12 years in 2009 means that only some of the aircraft in the fleet will have the second group of structural tasks out of phase with the C8 check for a few years.

Engineering orders

Like its sister aircraft the A340-200/-300, the A330-200/-300 have had several major ADs. "One of these is the inspection of the main landing-gear aft-bearing lugs at the sixth wing rib," says Pebarthe. "This requires the aircraft to be immobilised for six days, and uses 100MH just for the inspection."

AD 2007-22-10 relates to this inspection, and is the cover AD for the European Aviation Safety Agency (EASA) AD 2007-0247R1E. This affects all A330s, as well as all variants of the A340. The inspections are detailed in SBs A330-57-3096, -4104 and -5009.

"Inspections are required every 1,500FH and 300FC for the A330-200, and every 900FH and 300FC for the A330-300," says Frank Koch, quality manager at LTU Aircraft Maintenance. "If there are findings, however, up to 600MH and a kit costing $10,000 are required to make the modification."

Another major AD is AD 2007-0148, which incorporates an inspection detailed under SBs A330-57-3085/-3087/-3088. This relates to an inspection and modification on the left and right sixth wing ribs, due to cracks being found that could affect the structural integrity of the wing. This must be done before aircraft have accumulated 25,000FH and 8,000FC.

This requires a non-destructive test (NDT) type of inspection between wing stringers six and 20. It is usually done during a C4 check and is estimated to need 8MH. If there are findings at these inspections, the necessary modifications will require more labour and materials.

A third major AD relates to the protection of fuel tanks, which also requires six days of immobilisation. AD 2007-0278 encompasses SB A330-28-3092s and is required to inspect p-clips in the fuel tanks to stop electrical arcing. Koch comments that this needs the downtime of a C4 or C8 check to be done. It is estimated that it requires 300MH to complete.

A fourth major AD is AD 2001-070, which incorporates SB A330-53-3093 and relates to a heavy inspection and modification on frame 40 of the fuselage. "This uses 1,400MH to complete and a kit that costs $25,000," says Koch. Line number 234 is the highest affected, and

Heavy maintenance visit workscopes will include routine inspections, non-routine rectifications, ADs & SBs, removal and replacement of rotable components, customer items, interior cleaning and refurbishment, and stripping & repainting.

all affected aircraft have passed the thresholds for compliance.

An example of a major SB on the A330 is alert SB A330-54A-3025. This is mandated by AD 2006-0125. "This relates to the engine pylon. It is carried out during a C4 or C8 check, and requires the removal of both engines and engine pylons," explains Koch. "The pylons are disassembled, an intermediate rib is installed inside, and then they are re-assembled. This is mandatory and has a threshold for compliance of 120 months of age. Most operators will therefore do it at the C8 check. The whole process takes 1,000MH for both sides of the aircraft."

Two major ADs were issued in 2007, relating to the reinforcement of the rear fuselage: AD 2007-0269 and AD 2007-0284. These are required on A330s that have had Airbus modification 44205, and both require an eddy current inspection in the upper shell structure of the fuselage tail cone. The thresholds for these first inspections are 10,700-13,500FC.

AD 2007-09-09 became effective in June 2007, and also affects the A340-200/-300. It concerns an undamped extension of the main landing gear, and requires replacement of the landing gear retraction links. It is estimated that it will take 10MH to comply.

AD 2007-16-02 became effective in September 2007, and affects the A330-200/-300 and A340-200/-300. It relates to the inspection of ruptured fasteners at the keel beam skin panel, which in turn concerns the structural integrity of the area. It is estimated to require 12MH and $400 of parts to comply with this AD.

The third AD issued in 2007 was AD 2007-23-02 in December 2007. It affects the A330-200/-300 and A340-200/-300. It has been issued because of missing fasteners on a longitudinal stringer between fuselage frames 18 and 19. Inspections are required to detect missing fasteners and their replacement. About 4MH are needed to achieve compliance with this AD.

A major SB on the A330 is SB A330-25-3289, which modifies dado or decompression panels. De Motte estimates that it uses 500MH, and says that it requires extensive access for the modification, and for removal of seats, galleys and toilets.

"SB A330-57-3100 is a typical SB incorporated during a base check. This modifies the rear spar trailing edge, and introduces a new thicker, bottom skin panel to the shroud box on each wing," says a planning expert at Abu Dhabi Aircraft Technologies. "The new bottom skin is installed with bolts in place of the rivets currently used. The whole process uses 100MH to complete."

Rotable components

Base checks will also include a small number of MH for the removal and replacement of some hard-time rotable components. The A330 has 2,500 rotable components installed, accounted for by 1,400 different part numbers.

Of these, 2,100 are maintained on an on-condition basis. The remaining 400 are maintained on a hard-time basis. Half of these are cabin-related items. Rotables that are maintained on a hard-time basis are mainly airworthiness, safety or critical items which are life-limited.

Interior work

Interior work is split between cleaning and light refurbishment, and heavy refurbishment and installation of an all-new interior. "We usually change plastics and carpets, remove all seats for overhaul, and remove the carpet during the six lighter C checks," says Pebarthe. "We completely remove the interior during the C4 and C8 checks, which involves removing galleys, seats, toilets, and panels. Most items can be refurbished and do not require replacing. The interior is refurbished every four base checks, an interval of five to six years."

Stripping and repainting are carried out at every fourth base check, or every five to six years by most carriers, who take advantage of the downtime of the C4 and C8 checks, since stripping and repainting take up to 12 days. Stripping takes three to four days, while painting two layers takes eight days.

Other work

Most operators include some additional tasks in base checks. These will be OOP tasks that do not have intervals that coincide with most checks, and have to be added before reaching their own intervals and thresholds.

Removing and installing some rotable components can involve items as large as the APU, thrust reversers or the landing gear. These have their own removal intervals or are maintained on an on-condition basis. Defects that have been deferred from lower checks will have to be cleared. There will also be some customer items, such as cleaning the fuselage exterior.

Base check inputs

The A330's base check programme has a cycle of eight checks. The C4/6-year and C8/10-year checks are the heaviest. The remaining six checks are light, with the C1, C3, C5 and C7 checks having the smallest number of routine tasks with just the 1C group of inspections. The C2 and C6 checks are slightly larger, including the 1C and 2C inspections.

A planning expert at Abu Dhabi Aircraft Technologies explains that the routine 1C tasks and inspections in the C1/3 checks consume 1,300MH, although this varies depending on which base check cycle the aircraft is on. As aircraft age, additional structure/sampling tasks will be added to the 1C tasks, thereby increasing the MH required.

There are several other groups of routine inspections in addition to the basic 1C tasks. These can include lower A check items, OOP tasks, the removal and replacement of rotable components, and regular interior work and cleaning. This can increase the MH required for routine tasks considerably. For example, Didier Cojan, director of airframe maintenance at Montreal-based ACTS, estimates that the total package of routine tasks for these lower C1/3 checks can require up to 2,900MH.

Cojan adds that additional items, such as clearing of defects, engineering orders (EOs) and ADs, can add several hundred MH.

Schlaefli estimates the routine portion of the C1/3 check to use 2,000MH, but hard-timed components, OOP tasks and interior cleaning can add another 400-500MH, taking the sub-total to 2,500-2,600MH. The labour required to complete various EOs, ADs and modifications will vary. The number of MH will be influenced by what ADs and SBs have been issued, and what inspections and modifications each operator can include and wants to perform during these lighter base checks. A typical amount of labour used would be 350-500MH. These would take the total labour required to 3,500-4,000MH.

Other major elements of the check will be non-routine rectifications, which can require as little as 500MH for a new aircraft that is in the early stages of its first base check cycle. A planning expert at Abu Dhabi Aircraft Technologies estimates that the amount of non-routine labour required for a mature aircraft, which is in the latter part of its first base check cycle or early part of its second base check cycle, will be similar to routine labour. This will add 1,300-1,400MH for the basic 1C tasks, but will add another 2,500MH when all routine items are considered. The total for these checks for young aircraft can therefore be 3,500MH, and 5,000-6,000MH for mature and ageing aircraft. Using a standard labour rate of $50 per MH, the labour portion of the check would be $175,000 for a younger aircraft, and $250,000-300,000 for a mature aircraft.

The cost of materials and consumables will vary from $40,000 to $80,000, depending on the amount of non-routine labour and the interior items that require work.

Heavier C2/6 checks will have the 1C and 2C tasks, and so require higher MH for routine inspections. A planning expert at Abu Dhabi Aircraft Technologies estimates 2,000MH to be required. When other items of lower checks, OOP tasks, and interior work are added the routine portion will increase. Cojan says the complete routine package can exceed 4,000MH. Several hundred more MH can be added for clearing defects and EOs. This can add more than 1,000MH, taking the sub-total to 5,000-5,500MH.

A330-200/-300 HEAVY COMPONENT MAINTENANCE COSTS

Operation	Medium-haul	Long-haul
FH:FC	3.0	6.7
FH per year	3,750	4,750
FC per year	1,250	700
FH:FC	3.0	6.7
Number of main & nose wheels	8 + 2	8 + 2
main/nose tyre retread interval-FC	350/340	305/290
Tyre retread cost-$	600/450	600/450
Number of retreads	4	4
New main & nose tyres-$	1,200/1,000	1,200/1,000
$/FC retread & replace tyres	**19**	**23**
Main/nose wheel inspection interval-FC	260	230
Main & nose wheel inspection cost-$	**1,000**	**1,000**
$/FC wheel inspection	**38**	**43**
Number of brakes	8	8
Brake repair interval-FC	1,500	1,100
Brake repair cost-$	40,000	40,000
$/FC brake repair cost	**213**	**291**
Landing gear interval-FC	12,500	7,000
Landing gear exchange & repair fee-$	900,000	900,000
$/FC landing gear overhaul	**72**	**129**
Thrust reverser repair interval-FC	6,000	6,000
Exchange & repair fee-$/unit	215,000	215,000
$/FC thrust reverser overhaul	**72**	**72**
APU hours shop visit interval	8,000	8,000
APU hours per aircraft FC	1.0-2.0	2.0-3.0
APU shop visit cost-$	275,000	275,000
$/FC APU shop visit	**40-55**	**40-55**
Total-$/FC	**469**	**612**
Total-$/FH	**156**	**91**

Consideration again has to be given to non-routine rectifications and rectifying cabin items. A planning expert at Abu Dhabi Aircraft Technologies estimates labour for non-routine work on the basic 1C and 2C tasks to be 2,800MH for a mature aircraft. This can increase to 3,000-3,500MH when all items are considered. The total labour input for the check would therefore rise to 8,000-9,000MH. This would cost $400,000-450,000 when a standard labour rate of $50 per MH is used.

The cost of materials and consumables for this check would therefore be $70,000-100,000.

The C4/6-year check is when most operators take the opportunity to refurbish the interior and also strip and repaint the aircraft.

The basic package of routine inspections in this check requires 3,500-4,000MH.

The aircraft can also use 1,000MH or more on regular EOs and modifications, and may use a further 1,000MH or more when large ADs are included. Several hundred MH will be added for component changes and customer items. Another 500-800MH will also be needed to clear defects that have accumulated on the aircraft during operation. A total of 11,500-13,500MH will be required, depending on the level of non-routine rectifications and EOs being incorporated into the check, and the quantity of customer and other items added to the workscope.

Interior refurbishment will be a major element, and Schlaefli estimates that this can add up to 5,000MH. A further 1,500-2,000MH will be used for stripping and repainting the aircraft, taking the total for the check to 18,000-20,000MH. Cojan similarly estimates the total input for the check at 19,000MH. This would have an equivalent cost of $900,000-1,000,000 at the standard

Total inputs for the cycle of eight base checks will consume 80,000-90,000MH and incur a total cost of $4.7-6.0 million. Consumption will be lower for aircraft operated on medium-haul operations, but reserves per FH will be higher than for long-haul aircraft.

labour rate of $50 per MH.

"The cost of materials and consumables for this size of check will be $220,000, including materials and consumables used for interior refurbishment. It does not include major parts used for the interior refurbishment, such as new panels, carpet and covers," explains Schlaefli. "Another $100,000 can be used for paint."

New interior items will cost $250,000-300,000, taking the total of materials and consumables for the check to $470,000-520,000.

The total cost of these checks would therefore be $1.3-1.4 million. The total inputs required depend on the utilisation of the aircraft up to the check, the workscope, level of interior refurbishment, and the inclusion of stripping and repainting.

The C8/10-year check will be larger than the C4/6-year check. The C8 check has more routine inspections, and A planning expert at Abu Dhabi Aircraft Technologies says this portion of the check will consume 8,000MH for the basic 4C, 8C, 6-year and 12-year routine tasks. This will increase when other groups of OOP tasks, customer items and hard-time rotables are added. Once non-routine rectifications are considered, the sub-total for the routine and non-routine portions will be 18,000-20,000MH.

EOs and heavy modifications can add 1,500-4,000MH, depending on the aircraft's modification status. The total for the workscope would therefore be 20,000-24,000MH.

Labour for interior refurbishment and stripping and repainting will add another 7,000MH, as in the C4/6-year check. This will take the total for the full workpackage up to 31,000MH, which is typical of this type of check.

Schlaefli estimates the cost of materials and consumables for the workpackage, excluding the interior refurbishment, to be $280,000. The inclusion of interior refurbishment and stripping and repainting would have similar costs to the C4/6-year check of $350,000-400,000.

This would take the total cost of the check to $2.2-2.3 million. Like the C4/6-year check, the total inputs required for the C8/10-year check would depend on aircraft utilisation, check workscope, and level of interior refurbishment.

Base check reserves

The aircraft are analysed on medium- and long-haul operations with annual utilisations averaging 3,750FH and 4,750FH. The base check interval is 18 months, with the C4/6-year check having a 72-month interval. The C8 check has a 144-month interval, and is usually combined with the 10-year structural tasks, although these have an interval of 120 months. The C8 check and 10-year tasks do not have intervals that coincide.

Typical rates of check interval utilisation are 80-85% with most operators, so most would perform a base check every 14-15 months with the MPD interval of 18 months. The C8 check would therefore come due every 116 months, so it could be combined with the 10-year structural tasks.

With a base check being performed once every 14-15 months, aircraft used on medium-haul operations would have a base check once every 4,500FH. Aircraft used on long-haul services would have a base check once every 5,700FH.

The cycle of eight base checks would therefore be completed in 36,000FH in the case of medium-haul operations, and 45,000FH in long-haul operations.

The total inputs for the eight base checks can reach $4.7-5.2 million for aircraft used on medium-haul operations. The cycle would be completed once every 10 years and 36,000FH. The reserves for the checks would therefore be $145 per FH *(see first table, page 32)*.

The total inputs for the eight base checks for aircraft used on long-haul operations will be $5.5-6.0 million. This would be over an interval of 45,000FH, so reserves will be $130 per FH *(see second table, page 32)*.

Heavy components

Heavy components include wheels and brakes, landing gear, APU and thrust reversers. The maintenance costs of these four component groups are analysed for medium- and long-haul services at FC times of 3.0FH and 6.7FH per FC *(see tables, page 32)*.

The cost of wheels and brakes, landing gear, and thrust reversers is driven by FC intervals. APU costs are dependent on the ratio of APU hours per aircraft FH, APU shop visit interval and shop visit cost. The cost for these four components per FC is analysed, and translated to cost per FH according to the relevant FC time.

The interval for tyre retreads and wheel inspections depends on the condition of the tyres and depth of tread. This is influenced by weight at landing and severity of braking. Intervals are generally longer for medium-haul operations than for long-haul operations.

Tyres can be remoulded four or five times before being replaced. Wheels are inspected when tyres are remoulded, while brakes are repaired after disc thickness has been reduced.

The overall cost per FC of tyre retreads and replacement, wheel inspections, and brake repairs is summarised *(see table, page 27)*, totalling $270 per FC for medium-haul operations, and $357 per FC for long-haul.

The landing gear overhaul interval is up to 10 years, and driven by an FC interval. This is equal to 12,500FC for medium-haul aircraft and 7,000FC for long-haul aircraft. The current market rate for a landing gear exchange and overhaul fee is $900,000. The reserve for this is $72 per FC for medium-haul aircraft, and $129 per FC for long-haul aircraft *(see table, page 27)*.

The aircraft has two engines, and two thrust reverser shipsets. Removal for maintenance is done on an on-condition basis. Longer intervals result in higher workscopes due to deteriorating condition. Average removal intervals are 6,000FC, while a typical intermediate shop visit will incur a cost of $215,000 per shipset, resulting in a reserve of $72 per FC for both units.

The A330-200/-300 are equipped with the GTCP 331-350 APU. Reliability rates for this have varied, but in recent years it has achieved intervals of 8,000 APU hours.

The APU-related cost per FC depends on how the APU is utilised between flights, and the number of APU hours per FC. The APU is usually started after landing. It can be left on for the complete turn time, in which case the APU will run for 1.5 to 3.0 hours per FC. In this scenario the APU will require a shop visit every 2,500-5,000FC.

The APU can be turned off once ground power is connected after parking and then re-started prior to push-back and engine start. This can save APU time per FC, and reduce it to 1.0-2.0 APU hours per FC. In this case the APU will require a shop visit every 4,000-8,000FC.

The average shop visit costs $275,000 for an intermediate workscope. On this basis the APU-related maintenance cost will be $40-55 per FC where the APU is used for two to three hours between flights. This is equal to $18 per FH for aircraft used on medium-haul operations, and $8 per FH for aircraft used on long-haul operations.

The total cost per FC for these heavy components is $469 for medium-haul operations at 3.0FH, equal to $156 per FH. A higher reserve of $612 per FC for long-haul operations is equal to $91 per FH *(see table, page 27)*.

Rotable components

The A330 has 2,500-3,000 rotable components installed on each aircraft, although the number varies with various specification and configuration differences. These 1,400 components are accounted for by 1,400 different part numbers.

Of the rotables installed, 1,800-2,400 are maintained on an on-condition basis, and the remaining 300-400 units have hard-time removal intervals. Another 300 components are condition monitored.

While operators with large fleets tend to own and maintain their own inventories, many carriers find it financially efficient to acquire rotable inventories from third-party sources and have them managed and maintained by specialist providers. Specialist providers that offer these services include SAS Component, Lufthansa Technik, AAR and AJ Walter.

Support packages for airlines can be structured in several ways. One method of providing a one-stop shop is for the airline to lease a homebase stock of components that have the highest failure rates and are the most vital to the continued operation of the aircraft. The value of a homebase stock for a fleet of 10 aircraft is $5 million. A monthly lease rate factor of 1.4-1.5% is typical, and is equal to $70,000-75,000 per month. This is equal to $90,000 per aircraft per year, and so $30 per FH for aircraft on medium-haul operations, and $20 per FH for long-haul aircraft.

The remaining rotables, which account for the majority required by the airline, can be accessed by the airline via a pool provided by the specialist rotable provider. The pool access fee will be $150-175 per FH, depending on aircraft utilisation and other operational factors.

The final element of such a one-stop rotable support package will be the repair and management fee for all the rotables. This can be simplified for airlines via a predictable flat rate per FH. This will be $50-70 per FH, depending on fleet size and several operational factors.

These three elements will total $275 per FH for aircraft used on medium-haul operations, and $220-250 per FH for aircraft used on long-haul services *(see tables, page 32)*.

Engine maintenance

The A330-200/-300 are powered by three engine types *(see A330-200/-300 specifications, page 8)*: the CF6-80E1A2/A4/A3 rated at between 64,350lbs and 68,530lbs thrust; the Trent 4164/68 rated at 64,500lbs and 68,600lbs thrust; and the Trent 768/772 rated at 67,500lbs and 71,100lbs thrust.

The maintenance costs of the A330-200/-300 are examined on medium- and long-haul operations with average FC times of 3.0FH and 6.7FH. These average FC times influence removal intervals, particularly when engines are operated on shorter FC times. The rate of exhaust gas temperature (EGT) margin erosion is higher for engines operated on shorter FC times, and engine shop visit intervals are more related to EGT margin erosion and accumulated engine flight cycles (EFCs). Shop visit intervals for engines operated on long-haul missions are generally more related to accumulated engine flight hours (EFH) on-wing and hardware

The Trent 768/772 powering the A330 have longer removal intervals than the Cf6-80E1 and PW4000-100. The Trent engines, however, also have higher shop visit input costs and so similar reserves per EFH to their competitors.

deterioration, rather than EGT margin erosion.

Removal intervals and EFC times also influence shop visit workscopes and the pattern of workscopes engines follow. An important issue of engine management and resulting maintenance costs are the EFC life limits of life limited parts (LLPs). Engine removals must be managed around these, and the need to remove and replace them results in heavier shop visits. It is therefore convenient to plan removals for heavy shop visits to coincide with LLP life expiry.

The in-service performance, removal intervals, shop visit workscopes, LLP management, and overall maintenance costs of the three main engine types are analysed.

CF6-80E1

The CF6-80E1 powers 101 of the 270 A330-200s in service, and 39 of the 231 A330-300s in service. The engine is more prominent on the -200 fleet, which is used more widely on long-haul operations.

CF6 operators include KLM, Air France, Turkish Airlines and TAM. KLM operates at an average EFC time of 6.25EFH and has the -80E1A3 rated at 68,530lbs. It has had the A330-200 in service since 2004. The engines have an EGT margin of 33 degrees centigrade when new. KLM's engines have so far only been through their first shop visit, and the main removal causes were hardware deterioration. No removals have been due to EGT margin erosion. Most shop visits after the first removal were performance restorations, and the restored EGT margin was 25 degrees.

Turkish Airlines has been operating the CF6-80E1 on the A330-200 since late 2005. The average EFC time is 5.5EFH and the engines are the highest rated variants at 72,000lbs thrust. Turkish reports a higher initial EGT margin of 40-45 degrees, and says that in two years of operation, equal to 9,500EFH, the engines have lost 15 degrees of EGT margin. There have been no removals yet.

Denis Smink, chief operating officer at SGI Aviation Services, estimates that first removal intervals for engines operated at EFC times of 5.0-6.5EFH are 18,000EFH, equal to 3,000-3,600EFC. Second removal intervals will be shorter at 16,000EFH and 2,500EFC. The LLPs will therefore have accumulated 5,000-5,500EFC by the second removal. Mature intervals thereafter will be 2,500EFC.

The engine has LLPs with lives of 20,000EFC in the low pressure modules, and 8,400-20,000EFC in the high pressure modules. This implies most LLPs will not have to be replaced until the fifth or sixth shop visit at 15,000-18,000EFC. A full shipset has a list price of $5.0 million, so reserves for LLPs will be $280-330 per EFC, depending on actual replacement interval. This will be equal to $40-50 per EFH for aircraft operated on cycles of 6.7EFH, and $90-110 per EFH for engines operated in cycles of 3.0EFH.

First shop visits will be performance or core restorations in most cases, and will incur a cost of $2.0-2.5 million.

Second shop visits will be heavier, and will be a full workscope, with all modules requiring work. The cost of this level of workscope will be $3.0-3.5 million.

The average reserves for the two shop visits for the first two intervals will therefore be $175 per EFH. Additional reserves for LLPs will take the total to $220 per EFH for engines operated at 6.7EFH *(see first table, page 32)*.

Mature intervals will be 12,000-18,000EFH, depending on EFC time. Shop visit costs will be $2.8-3.2 million, so reserves will be $165-250 per EFH. With LLPs, total reserves for mature engines will be $210-295 per EFH.

Engines operated at shorter EFC times of 3.0EFC will achieve shorter removal intervals, but will also have lower shop visit costs. First intervals will be at 14,000EFH, and second removals will take place at 12,000EFH. The two shop visit costs will total $5 million, resulting in a reserve of $290 per EFH once LLPs are included *(see second table, page 32)*.

PW4000-100

The PW4000-100 powers 63 of the 270 A330-200s in operation, and 83 of the 231 A330-300s. Operators include Air Berlin (formerly LTU), TAM and Swiss. TAM and Swiss are large A330-200 operators.

Air Berlin operates the A330-200 and -300, and started with the -300 in 1995. It uses the PW4168 rated at 68,000lbs thrust, and aircraft operate at an average EFC time of 6.0EFH. The engines have an initial EGT margin of 35 degrees centigrade, and have a relatively low rate of EGT margin erosion. The first removal intervals averaged 18,000EFH and were caused mainly by hot section deterioration. As with all PW engines, most PW4000-100s follow an alternating shop visit pattern of a performance restoration and overhaul. Air Berlin says second removals average 14,000EFH, and again hot section deterioration is the main removal cause. The engines then have an overhaul. Mature engines then have a steady removal interval of about 14,000EFH and usually maintain the alternating pattern of performance restoration and overhaul workscopes.

Swiss operates the PW4168A at an average EFC time of 5.0EFH, and has operated the engines since 1998. Their first removal intervals were 10,000EFH, but this was due to an AD that forced engines off-wing early. The first shop visits were performance restorations.

The second removal interval was an improvement on the first, and averaged 16,000EFH. Removals were mainly due to hardware deterioration, and the

DIRECT MAINTENANCE COSTS FOR A330-200/-300: MEDIUM-HAUL OPERATION

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	340,000	Annual		90
A check	48,000	A check- 450FH		110
Base checks	4.7-5.2 million	36,000FH		145
Heavy components:			469	156
LRU component support				275
Total airframe & component maintenance				**776**
Engine maintenance: 2 X CF6-80E1/PW4000-100/Trent 768/772: 2 X $ 290-325 per EFH				580-650
Total direct maintenance costs:				**1,356-1,426**

Annual utilisation:
3,750FH
1,250FC
FH:FC ratio of 3.0:1

DIRECT MAINTENANCE COSTS FOR A330-200/-300: LONG-HAUL OPERATION

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	250,000	Annual		70
A check	48,000	A check- 450FH		110
Base checks	5.5-6.0 million	45,000FH		130
Heavy components:			612	91
LRU component support				225-250
Total airframe & component maintenance				**625-650**
Engine maintenance: 2 X CF6-80E1/PW4000-100/Trent 768/772: 2 X $ 230-295 per EFH				460-590
Total direct maintenance costs:				**1,085-1,240**

Annual utilisation:
4,750FH
700FC
FH:FC ratio of 6.7:1

engines required an overhaul at their second shop visit.

First shop visit workscopes average $2.5 million, while overhauls cost $3.5-4.3 million, depending on total accumulated time. The reserve for the first two shop visits will cost $6.5 million over an interval of 30,000-38,000EFH, equal to $185 per EFH.

The PW4000-100 has a shipset of LLPs with uniform lives of 15,000EFC, and a list price of $4.8 million. Mature intervals are expected to be 12,000-18,000EFH, depending on style and nature of operation. It will therefore be possible to replace LLPs at an accumulated time of up to 14,000EFC. This results in a reserve of $340 per EFC; equal to $51 per EFH at 6.7EFH per EFC.

The total reserve for shop visits and LLPs will therefore be $230-240 per EFH for engines operated at 6.7EFH for the first two removals *(see tables, this page)*.

Engines operated on medium-haul operations of 3.0EFH per EFC will have first removal intervals of 14,000EFH, and 12,000-13,000EFH for the second removal. First and shop visit workscopes will cost $1.9 million and $3.5 million respectively, resulting in a reserve of $200 per EFH. With LLP reserves added, total reserves will be $315 per EFH.

Trent 768/772

The Trent 700 series has a reputation for durability. It powers 106 A330-200s and 109 A330-300s. First run intervals often average more than 20,000EFH, and can be up to 23,000EFH. A core restoration is usually required at this stage. The second removal interval is typically in excess of 16,000EFH, and can average 18,500EFH.

Despite these long intervals, the engines usually incur high shop visit costs. The first shop visit will cost $2.5-2.7 million, and can often be higher. The heavier second shop visit will be $3.7-4.0 million, so the total cost for the first two shop visits will be $6.5-7.0 million. This will be equal to a reserve of $170-180 per EFH when amortised over the interval of about 40,000EFH and 6,000EFC for the two removals.

The Trent 700 series has LLPs with lives of 10,000EFC in the high pressure modules, and 15,000EFC in the low and intermediate pressure modules. The list price for a full shipset is $4.8 million. Given the typical removal intervals, it should be possible to replace the LLPs within 1,000-2,000EFC of life expiry. On this basis, reserves for LLP replacement will be $420 per EFC, and $60-65 per EFH at an EFC time of 6.7EFH. This takes total reserves over the interval of the first two shop visits to $235 per EFH.

Engines operated on EFC times of 3.0EFH will have first removal intervals of 16,000EFH, and second intervals of 15,000EFH. First and second shop visit costs will be $3.5 million and $5.7 million respectively. This will result in a reserve of $185 per EFH over these first two intervals. Once LLP reserves are accounted for, total reserves will be $325 per EFH *(see first table, this page)*.

Maintenance cost summary

Total maintenance costs are $1,356-1,426 per FH for aircraft operated on medium-haul services, and $1,085-1,240 per FH for aircraft operated on long-haul services *(see tables, this page)*. The aircraft on long-haul operations have maintenance costs of $400-500 per FH less than the A340-200/-300 operated on a similar FC time *(see A340-200/-300 maintenance analysis & budget, Aircraft Commerce, June/July 2007, page 17)*. The main differences between the A330-200/-300 and A340-200/-300 are engine-related costs, and all levels of airframe maintenance. The A330-200/-300 therefore provide a lower cost alternative when mission lengths are within its capabilities. AC