The A330-200/-300 has now sold in as many numbers as commercial variants of the DC-10. The A330 is employed in several roles by airlines around the world. The A330-200/-300's airframe- and component-related maintenance costs are analysed for medium-haul and long-haul operations.

A330-200/-300 maintenance cost analysis

The current fleet of all A330 models comprises more than 265 aircraft operated by about 45 airlines. The -300 variant was joined by the shortened and longer range -200 series in 1998. The age of A330s in operation varies between new aircraft and 10 years.

The A330-300 was targeted at high-density medium-haul markets, but has a range of up to 5,000nm. Some operators, such as Air Canada, US Airways, Sabena, Air France and Aer Lingus, use the A330-300 on long-haul missions. Typical average flight cycle (FC) times for these are 7.0 flight hours (FH).

Other airlines, including Korean Air, Thai, Garuda and Cathay Pacific, use it for medium-haul operations on sectors of 2.0-4.0FH.

The smaller A330-200 has a range of 6,400nm, and has been acquired by many carriers for low/medium-density long-haul operations. Examples are Air France, Austrian, KLM, LTU and Gulf Air. A few airlines use the A330-200 for medium-haul operations.

Current orders will take A330 production to at least the same level as the DC-10. A330 production will probably continue for at least another 10 years. This highlights the aircraft's importance and need to examine its airframe- and component-related maintenance costs. The total of these costs will depend on style of operation.

The ratio of FH to flight cycles (FC) varies between operators. The A330's C and heavy check schedule is set at calendar limits, but these vary little by operator.

The maintenance schedule for line checks is also the same for most airlines, and some checks have FC and calendar intervals. Aircraft operating a higher number of short FCs will also have a high number of line checks relative to FH. Conversely, aircraft operating long-haul missions and generating a small number of FCs will have a small number of line checks relative to FH.

Analysis of maintenance costs per FH can be made for typical medium-haul and long-haul operations. These might have FH:FC ratios of 3.0:1 and 7.0:1, and annual utilisations of 3,000FH and 4,500FH *(see table, page 30)*. The medium-haul aircraft will generate about 1,000FC per year, an average of 2.74FC per day. The long-haul operation will generate about 640FC annually, or about 1.75FC per day.

Maintenance elements

All elements of airframe-related and component-related elements of line maintenance are analysed. Airframe-related maintenance can be sub-divided into line and base check maintenance.

Line maintenance includes all checks up to A checks. Base maintenance includes the following: C checks; heavy checks; structural modifications, service bulletins (SBs) and airworthiness directives (ADs); typical cabin refurbishment; and stripping and re-painting.

Component-related maintenance can be split into four broad groups: consumables; heavy rotables, including wheels and brakes, thrust reversers, auxiliary power unit (APU), and landing gear; line replaceable units (LRUs), which are removed and replaced during line checks; and other rotable and repairable components, such as flight controls and components related to the hydraulic, pneumatic and electrical systems. This last group of items is maintained on an 'on-condition' basis, as are LRU items. While some require deep access for removal and replacement, others can be tested and inspected while in place on the aircraft.

The maintenance costs for components in the third and fourth groups are usually accounted for together.

Line maintenance schedule

The A330's line maintenance schedule consists of pre-flight/transit, daily, weekly and A checks. The daily check is performed every 24 hours before the start of a day's operation, and then pre-flight or transit checks are performed prior to all other flights during the day. The number of pre-flight/transit checks increases with the number of daily FCs.

Air France operates 10 A330-200s on its routes to Africa, South America and the US. The fleet generates 5,050FH and 950FC per year, with an average FC time of 5.4FH and will generate two or three flights per day. "The daily check, which is heavier than the pre-flight check, is performed once a day at the home base," explains Regis Boniau, manager of A330/340 fleet at Air France Industries. "Pre-flight checks are performed for all other flights that day. We are permitted an extension on the daily check interval to give us time to get home. This is because more resources are required for the daily check, and it is desirable to avoid doing one away from home." Usually, the daily check interval is not allowed to exceed 48 hours.

Sabena Technics maintained Sabena's A330-200/-300 fleet prior to its demise. Sabena Technics now maintains Birdy Airlines' fleet of three A330-300s, and operates them on missions to Africa, generating 4,745FH and 1,095FC annually, at a FH:FC ratio of 4.3:1.

Both Air France's and Birdy's aircraft are operated on extended range twin-engine operations (Etops). "This adds a small amount of maintenance to the A330's line checks," says Boniau. "The Etops line maintenance items are performed with daily or pre-flight checks, which involves checking the logbook for items that affect the aircraft's ability to operate Etops missions or related to the APU."

Daily and pre-flight checks involve the

The A330-200 and -300 are used on a variety of missions but airlines around the globe. These vary from average FC times of 2.0FH to as long as 7.0 or 8.0FH.

checking of items such as tyres, oil levels, LRUs and the aircraft's logbook. Daily checks are heavier, however, because they deal with faults on minimum equipment list items, and replace failed LRUs and heavy components such as wheels and brakes.

At a higher level weekly checks have an interval of seven days, with an extension of eight granted to allow aircraft to return home. Boniau explains weekly items are similar to daily check items.

Heavier line checks are A checks. "The initial A check interval for our A330-200s was 650FH, but we increased this to 700FH due to our experience with the A340," says Boniau. "There are eight A checks in the cycle, with light checks in each case and heavy checks at the A4 and A8 checks. The light checks are equalised so that they are equal in content and MH consumption."

Smaller operators, like Birdy, have shorter A check intervals. "Our A check interval is about 600FH," says Guy Schepers, director of engineering at Sabena Technics. "The full A check cycle therefore has an interval of 4,800FH, equal to about one year's operation."

A and weekly checks are used to rectify some of the deferred defects which arise from inspections made during lighter line checks. "Some deferred defects are rectified straightaway, and these are no-go items,"says Boniau. "Other deferred items are rectified later at daily, weekly or A checks depending on ground time, resources and provisioning required. Some are even deferred to C checks. The reliability and quality of the operation also has to be considered when deciding in which line checks to rectify defects."

Line check inputs

Air France's young fleet has low MH consumption for line checks, but this is expected to increase.

"Routine labour for a daily check is about 2MH, but non-routine items that arise from the rectification of defect items add another 10MH to the check," says Boniau. "This compares to transit checks which are performed by one person. Those which are done at home bases consume a similar number of MH to daily checks, while ones completed at outstations usually only require one person, and use less MH. Defects will be deferred for us to perform at the home base. Line transit checks only consume about 1MH."

Boniau estimates pre-flight checks consume about $150 in materials.

Air France's experience is that labour for weekly checks is similar to daily checks. "There are some additional checks for cabin safety and the cargo compartment. The weekly check consumes 12-13MH,"says Boniau.

Sabena Technics has similar MH for transit, daily and weekly checks.

Similarly, FLS Aerospace records about 2MH and $150 in materials for transit checks, about 12MH and $500 of materials for daily checks and 18MH and $1,000 of materials for weekly checks.

While inputs for checks up to weekly checks are similar between operators, larger differences are seen in A checks. Air France's young A330-200s have relatively low inputs. "The light A checks use about 185MH, although this does not include work for in-flight entertainment equipment (IFE)," explains Boniau. "This includes about 80MH of routine, an additional 28MH for SBs and other additions, 42MH to rectify deferred defects and 42MH for non-routine items. This total includes 57MH for cabin-related items." Boniau adds that about $3,300 is consumed in materials and consumables. Air France's aircraft are young and he expects both MH and material inputs to escalate.

"Heavier A checks consume about 350MH in total," says Boniau. "This includes 206MH for routine items, 28MH for items such as SBs, 57MH for rectifying deferred defects and 58MH for non-routine items. About 112MH of the total are used for cabin-related items. Cost of materials is about $3,500.

The A check cycle for a medium-haul aircraft is completed after about 4,300FH. About 935 transit, 500 daily and 72 weekly checks are completed; as well as the eight A checks. Total MH consumed will be about 11,000, while about $490,000 of materials will be used. At a labour rate of $70, this is equal to a total cost of $292 per FH *(see table, page 30)*.

The A check cycle for a long-haul aircraft is completed after about 4,100FH. About 210 transit, 315 daily and 45 weekly checks are completed; as well as the eight A checks. Total MH used will be about 6,800, while about $263,000 of materials will be used. At a labour rate of $70, this is equal to a total cost of $181 per FH *(see table, page 30)*.

Base maintenance schedule

The A330-200/-300's base maintenance schedule is a series of eight C checks, with an interval of 15 or 18 months, and two heavy checks.

There are 1C items with an interval of 15 or 18 months and 2C items with an interval of 30 or 36 months. 2C items can be equalised to go in every C check. Alternatively C2, C4, C6 and C8 checks will have 1C and 2C tasks, while C1, C3, C5 and C7 checks with just 1C items.

The first of the two heavy checks, the C4 check, is a combination of 1C, 2C and 4C items, five-year tasks and 60-month items.

The second heavy check, the C8, consists of 1C, 2C, 4C and 8C tasks, 10-year items and 120-month items. Although in some cases the intervals of C4 tasks and five-year/60-month items do not coincide, most operators perform these as a single check for convenience. This may mean some compromise has to be accepted with the C check interval.

Only the oldest A330-300s have had their first C8 checks and C check cycles completed. The aircraft that have had their first C8 checks have consumed about 41,000MH; similar to the MH used by A340-200/-300s in their first C8 checks.

Also, the intervals of C8 and 10-year/120-month items do not always coincide exactly for some operators' maintenance schedules, but are performed for convenience.

Sabena's C check interval is 18 months. The intervals for the C4 and C8 tasks, however, are only 60 and 120 months, and not 72 and 144 months. "Our basic C check interval was extended from 15 months, but the intervals for the heavier C4 and C8 tasks are still at the original 60 and 120 months," explains Schepers. "These heavy check intervals were for the first maintenance cycle, which was recently completed on the oldest aircraft. Airbus may extend these heavy check intervals to 72 and 144 months for the second maintenance cycle. Until they are extended we have a choice of keeping C check intervals at 15 months, so that the 4C/5-year and 8C/10-year items can be combined with C4 and C8 checks at 60 and 120 months; or use the 18-month interval for the C checks and perform 4C and 8C items at the C3 and C6 checks at intervals of about 54 and 108 months. This would mean the C4 and C8 checks have just C1 and C2 tasks.

"The aircraft we manage will go through their first C8/10-year check at which time everything in the C check cycle will be zeroed. We will then start the cycle again with an 18-month interval and hope that the 4C and 8C items are extended to 72 and 144 months in time for the C4 and C8 checks," explains Schepers. "After 36 months we will do the C2 check and we will have had time to evaluate what to do for the C3 and C4 checks, and hopefully the 4C items will have been escalated to 72 months."

Air France has the benefit of A340 experience and has an escalated C check interval of 18 months. "We equalise our light C checks, so that C1/2/3/5/6/7 checks are equal in size," says Boniau. "The C4/5-year checks for the A340 are done at six years, that is four times 18 months, and we plan to have the same interval for the A330. So far we have had a 10-year interval for the C8/10-year check on the A340, but plan to increase this to 11 years, and also for the A330."

Airline schedules and operations also have to be considered, and a 15-month C check interval is not practical for all carriers. Most airlines also only utilise 85-90% of their check intervals, and so C checks with an interval of 15 months would actually be performed at about 13 months. Operators with an interval of 18 months would actually have checks done at 15-16 months. This means full C check cycles for a 15-month C check interval would be completed at 8-9 years, and cycles with an 18-month basic C interval would be completed after 10 years.

Some airlines find it simpler to schedule C checks annually, meaning C4 and C8 checks are completed at four and eight year intervals, and up to two years are lost on the schedule.

In addition to the regular airframe checks, there have been two airframe upgrade packages. These are the long-range improvement programme (LRIP) and fleet standardisation programme (FSIP), which are both packages of SBs. These affect older build A330s and A340s. "The objective of these two programmes is to address the in-service problems of the aircraft, reduce aircraft-on-ground incidences, improve operational reliability and reduce maintenance burden," explains Schepers. "These packages affect older aircraft, and the -200 series is not at all affected by the LRIP, unlike the -300. The programmes also standardise batches of aircraft line numbers and so reduce spares holdings. These packages have now been completed for most aircraft."

Base check inputs

Most operators have light checks at the C1/2/3/5/6/7 and heavy checks at the C4 and C8. This means light C checks will have similar inputs.

Heavy checks are used by operators to rectify defects, complete modifications, complete out-of-phase items with fixed FH and FC intervals, refurbish the cabin, and re-paint the aircraft. Few A330s have completed their heavy check cycles; some of the oldest are operated by Birdy Airlines and Aer Lingus.

MH consumed during light C checks are low for the first C1 and C2 checks on new aircraft. Air France, for example, only used 812MH on its C1 checks on its A330-200s. "This included about 200MH for cabin items. Another 630MH were for routine items, showing that the non-routine ratio was low," says Boniau. "MH consumed for later C checks should be heavier because of higher non-routine ratios and additional inspections and items. I expect the C5, which will also have 1C items, to consume about 1,100MH. A330s also consume less than A340s in C checks. This is because the A330 does not have a centre landing gear, the aircraft is smaller than the A340 and the A330 has two engine pylons."

Sabena Technics recorded a similar input to Air France Industries for the C1 check on Sabena's A330-300s. "We used about 1,100MH for routine and non-routine items and about $10,000 for materials," says Schepers.

EADS-Sogerma Services is a specialist in A330 and A340 C4 and C8 checks, but also offers light C checks. Its experience with C1 and C2 checks shows MH consumptions of about 2,500 and 5,000, while about of $15,000 and $50,000 are used for materials and consumables.

Few aircraft have completed their first base maintenance cycle and few maintenance facilities have much experience of heavy checks. EADS-Sogerma Services has full docking and stripping and painting facilities. "To date we have completed more than 100 C

A330-200/-300 FLIGHT HOUR (FH) AIRFRAME AND COMPONENT MAINTENANCE COSTS

Maintenance Item	Maintenance interval	MH used	MH cost ($)	Materials cost ($)	Total cost ($)	Cost per FH ($) 3.0FH:FC	Cost per FH ($) 7.0FH:FC
Transit & pre-flight	Every cycle	2	140	150			
Daily	24 hours	12	840	500			
Weekly	7 Days	18	840	1,000			
Light A check	600FH	185	12,950	3,500			
A4 check	2,400FH	350	24,500	3,500			
A8 check	4,800FH	350	24,500	3,500			
Total A check cycle	4,800FH	11,000/6,800		490,000/263,000		292	181
Light C check	15 months	3,500/5,000		25,000/50,000			
C4/5-year check	60 months	25,000		650,000			
C8/10-year check	120 months	41,000		870,000			
Total C check cycle		90,000		1,720,000		245	164
Heavy components							
Main tyre remould & replace	1,800FC				20,000	4	2
Nose tyre remould & replace	1,400FC				3,000	1	1
Main wheel inspection	450FC				5,600	3	1
Nose wheel inspection	350FC				1,300	2	1
Brake repair	1,800FC				345,000	65	27
Landing gear exchange & repair	30,000FH/ 45,000FH				1,150,000	40	27
Thrust reverser repair	6,000FC				410,000	23	10
APU shop visit	7,600FH/15,000FH				300,000	40	20
LRUs/Rotables							
Lease rate						39	30
Pool access						49	45
Fixed FH repair cost						175	155
Total cost per flight hour						**978**	**664**

checks for the A330 and A340," explains Regis Trolliet, executive vice president of aircraft maintenance & modifications at EADS-Sogerma Services. "C4 and C8 checks have several elements, including the basic routine package, non-routine work arising from inspections, out-of-phase items incorporated in heavy checks, individual tasks with fixed FC and FH intervals, SBs, cabin refurbishment, and stripping and painting. The MH required for most of these elements will remain unchanged for an aircraft, although the non-routine items will increase with age as the non-routine ratio rises."

Trolliet estimates the total MH consumed during a C4/5-year check, excluding SBs and modifications, to be about 25,000MH. This compares to inputs of 25,000-30,000MH for the first C4/5-year checks for the A340-200/-300.

Trolliet's estimate for MH for the first C8/10-year check is about 35,000, plus a further 6,000MH can be used for SBs, modifications, and FSIP and LRIP programmes, although the amount varies with operator policy. This compares to inputs of 40,000-45,000MH for the same checks on the A340-200/-300.

Cost of materials and consumables used during C4 and C8 checks varies, but can total more than $1.5 million for the two checks.

A total of about 85,000MH will be consumed over the whole of the base maintenance cycle, although younger aircraft will use a small number of MH in their earlier light C checks. At a labour rate of $50 per MH this equates to $177 per FH for medium-haul aircraft and in the region of $118/FH for long-haul aircraft *(see table, page 30)*. The cost of materials will equate to about $68 per FH for aircraft on medium-haul operations and $46/FH for aircraft on long-haul operations *(see table, page 30)*.

Heavy components

The four main components in this category are wheels and brakes, landing gear, APU and thrust reverser. The maintenance for all these components is FC-related, and so FH:FC ratio has an influence on maintenance cost per FH.

Average interval for main wheel removal for tyre remoulding is 450FC. Tyres are remoulded an average three times before replacement, and so total life is four times this interval at about 1,800FC. Cost per main tyre remould is $370; a total of about $3,000 per main wheel shipset and about $9,000 for the three remoulds. New tyres cost about $1,350; about $11,000 for a shipset. The cost for remoulds and new tyres amortised over the life interval of 1,800FC is equal to about $11/FC, and equates to $4/FH for aircraft operating an average FC time of 3.0FH and $2/FH for aircraft on long-haul missions of 7.0FH *(see table, page 30)*.

Nose wheel tyres have removal intervals of about 350FC between remoulds, and again are remoulded about three times before replacement. Remoulds cost about $230 per tyre, and new tyres cost about $760. The total for remoulding and replacement comes to about $1,600; equal to about $2/FC and less than $1/FH for aircraft operating medium- and long-haul missions *(see table, page 30)*.

Wheel inspections are made at wheel removal for tyre remoulding, with a cost of about $700 per wheel unit; equal to $5,600 for the main wheel shipset and $12/FC. Inspections on nose wheels each cost about $650, equal to about $4/FC for both wheels. All wheel inspection costs are equal to about $5/FH for aircraft on medium-haul missions and $2/FH for aircraft on long-haul

Total maintenance costs per FH for aircraft on medium-haul operations are about 50% than for those on long-haul missions. This is due to a combination of some maintenance tasks being FC-related, while fewer FH are flown between other tasks on medium-haul aircraft compared to long-haul aircraft.

operations *(see table, page 30)*.

Main wheel brake units have carbon disks, and a typical removal interval for inspection is about 1,800FC with an average cost of about $43,000 for each unit. This equates to $24/FC per brake unit, and about $192/FC for the whole aircraft. This is about $65/FH for aircraft operating medium-haul operations and $27/FH for aircraft operating long-haul missions *(see table, page 30)*.

Landing gears are now exchanged by most carriers, and a flat exchange and shop visit fee is paid, with possible additions for non-routine items. EADS-Sogerma Services has a landing gear shop, and has already performed overhauls on more than 20 A330 landing gear legs. Trolliet puts time between overhauls at 10 years and estimates cost of exchange and shop visit at $1.1-1.2 million for the shipset. This will be about 30,000FH for aircraft on medium-haul operations and 45,000FH for aircraft on long-haul operations. Landing gear maintenance costs equate to about $37-40/FH for medium-haul aircraft and $24-27/FH for long-haul aircraft *(see table, page 30)*.

Thrust reversers are maintained on an 'on-condition' basis and average removal interval is expected to be about 6,000FC. Shop visit costs will depend on condition at removal, but are expected to be about $410,000 for a shipset, and equal to $68/FC. This is equal to about $23/FH for aircraft on medium-haul operations and $10/FH for aircraft on long-haul missions *(see table, page 30)*.

The A330's APU is the GTCP 331-350 and has an average removal interval of about 3,300APU hours. The actual removal interval will depend on the APU hour to cycle ratio and number of APU cycles per FC. Average intervals for medium- and long-haul aircraft are in the region of 7,600FH and 15,000FH. EADS Sogerma Services has an APU shop and has completed more than 40 shop visits for the GTCP 331-350. Trolliet estimates average shop visit cost to be $275,000-300,000; resulting in a cost of $40/FH for medium-haul aircraft and $20/FH for long-haul aircraft *(see table, page 30)*.

LRUs and rotables

There are several ways an airline can attain LRU and rotable support. Most airlines have small fleets which cannot justify owning all types of LRUs or having repair facilities for them. Most carriers have a home base stock which is either owned or leased. The remaining stock is provided from a pool offered by larger carriers, with maintenance capability for the aircraft, or from specialist providers. This will usually be paid for on an access fee at a fixed rate or on a power-by-the-hour (PBH) basis.

The repair and management of both home base and pool stock can also be provided by the pool stock provider on a fixed rate or PBH basis to cover repairs and parts management.

The airline will thus have to consider three cost elements of home stock depreciation or lease rentals, pool stock access fee and repair and management fee. These will vary with FH:FC ratio and age.

Andre Schulte-Bisping, aircraft component services product manager at Lufthansa Technik explains that the advantage long-haul aircraft have of a lower maintenance cost per FH will be offset by a larger home base stock necessary to cover a long-haul operation. This is because extra items are required on line stations and for a flyaway kit.

Schulte-Bisping estimates that a home base stock of $6.5 million is required for a medium-haul operation using 10 mature aircraft; that is, older than four years. These could be leased at a lease rate of 1.5% per month, equal to $97,500 or $1.17 million per year. This will be equal to $39 per FH across the fleet *(see table, page 30)*.

Fees for the pooling stock will be in the region of $49/FH, while fixed rate repair and management fee for all components will be in the region of $175/FH *(see table, page 30)*. This will take total cost to $263/FH *(see table, page 30)*.

Home base stock for a long-haul fleet will be about $7.5 million for a fleet of 10 aircraft, excluding additional line station items and flyaway kits. These could be leased at a lease rate of 1.5% per month, equal to $112,500 or $1.35 million per year. This will be equal to $30 per FH across the fleet *(see table, page 30)*.

Fees for the pooling stock will be in the region of $45/FH, while fixed rate repair and management fee for all components will be in the region of $155/FH *(see table, page 30)*. This will take total cost to $230/FH *(see table, page 30)*.

Schulte-Bisping makes the point that these costs do not include LRUs for engines and the APU, galley, cargo loading or in-flight entertainment equipment. These items would add more cost, but the rates are for a mature fleet.

Summary

The A330's total maintenance costs vary little between the -200 and -300 models. The effect of shorter average FC times can be seen in the differences of total maintenance costs of aircraft operating medium-haul and long-haul missions.

All elements of maintenance for the long-haul have similar costs per FH compared to the A340-200/-300 operating similar missions, with a total of $664 per FH for the A330-200/-300.

Aircraft operating medium-haul operations have higher costs for each element. This is because some are FC-related, while less FH are performed between other maintenance tasks. Total maintenance cost is $978 per FH. AC