A340-300 maintenance analysis & budget

The A340-200/-300 are burdened by the four-engined configuration. This gives it high engine-related maintenance costs and high maintenance costs overall.

The A340-200/-300 are niche aircraft, having had limited success. There are only 241 in operation, the majority of which entered service from 1993 to 2000.

The A340-300 has a base check maintenance cycle of 10 years, and many aircraft have been through their first base cycle and are now in their second. Airlines and operators are likely to put the aircraft through two or three heavy checks, but they are unlikely to put them through a fourth heavy, which means that many A340-200s/-300s could remain in operation for more than 30 years.

A340-200/-300 in operation

The A340-200/-300 were launched in early 1987 as sister aircraft to the twin-engined A330. These two were aimed at the DC-10 and L-1011 replacement market, but they were more specifically targeted at the ultra-long-haul markets, such as the trans-Pacific, the liberalisation of which was being predicted at the time. However, liberalisation did not take place at the predicted rate, and the demand for the A340-200/-300 was weaker than forecast.

The A340-200/-300's other main attraction was as an alternative to the 747, which was too large for many carriers to operate it economically. The A340-200/-300 offer operators a more desirable combination of 230 to 280 seats and ultra-long-range capability. The A340-200's standard range of 8,000nm and the -300E's standard range of 7,300nm allow them to operate most city-pairs non-stop.

The A340-200/-300 were selected as the long-haul flagships for carriers such as Lan Chile, Air Mauritius, Air Lanka, Aerolineas Argentinas, Gulf Air, Air Portugal, Olympic Airways, SAS, Turkish Airlines, Air Macau and Air Jamaica. The aircraft are also a major long-haul choice for airlines including Air Canada, Cathay Pacific, Jet Airways, Qatar Airways, Virgin Atlantic, Air France, Lufthansa, Iberia, China Eastern and Air China.

A small number of aircraft have been traded and are now being used by secondary operators. Airlines that have disposed of aircraft include Singapore Airlines (SIA), Lufthansa, and Virgin Atlantic. Used aircraft have been acquired by airlines including Cathay Pacific and South African Airways (SAA).

The A340-200/-300 are used almost exclusively for ultra-long-haul services by all their operators, who also have multiple stop services on their networks. These reduce average flight cycle (FC) time. One example is Air Portugal, which operates a fleet of four aircraft on routes from its hub at Lisbon to Brazil and Africa. "Our aircraft have accumulated an average cycle time of 6.1 flight hours (FH) per flight cycle (FC)," says Mario Araujo, engineering director at TAP Maintenance & Engineering. "This average has increased to 8.0FH per FC since we reorganised our operation in 2006. Our aircraft are 12-13 years old and accumulate about 5,500FH and 680FC per year."

Iberia has a fleet of 16 -300s, ranging in age from five to 12 years old, which it operates to the Canary Islands, North and South America and South Africa. The fleet has an average FC time of 7.1FH, and accumulates about 5,000FH annually.

Swiss achieves one of the highest rates of utilisation, with 5,500-6,000FH per year at an average FC time of 8.5FH.

All A340-200/-300s are in operation as passenger aircraft, and their maintenance costs are analysed here for aircraft completing 5,000FH and 700FC per year, at an average FC time of 7.2FH.

Maintenance programme

The A340-200/-300 have a maintenance steering group 3 (MSG3) maintenance programme, which was developed in conjunction with their sister aircraft the A330.

The A340-200/-300's line and ramp maintenance programme consists of pre-flight, daily and weekly checks. The A340-300 is used by most carriers as a long-haul aircraft, so it consequently operates only two FCs per day. The aircraft therefore leave their homebase for an outstation and then make a return flight home. Most operators perform daily checks while the aircraft is at the homebase. These checks have a maximum interval of 48 elapsed hours. Pre-flight checks are performed at the outstation. Weekly checks have a maximum interval of eight days, so they are usually performed every sixth to seventh daily check, depending on the aircraft's pattern of operation.

A checks

In addition to pre-flight, daily and weekly checks, the A340-200/-300 have a system of A, C and structural checks, which are independent of each other. The A340-200/-300's maintenance programme has undergone 15 revisions since the aircraft was introduced into service in 1993, and the latest revision was made in 2006. The 16th revision is expected in July or August 2007. "The original maintenance programme had basic intervals of 400FH for A checks, 15 months for C checks, and five and 10 years for structural tasks," explains Jose-Luis Rosario, aircraft maintenance planning and production control manager at TAP Maintenance & Engineering. The two structural checks are sometimes referred to as the IL and D checks, or S1 and S2 checks.

There are four different multiples of A check tasks: the 1A, 2A, 4A and 8A tasks.

The original interval for the 1A tasks was 400FH under the original maintenance programme. The 2A tasks had an 800FH interval, so they were performed every second A check. The 4A tasks had a 1,600FH interval and were carried out every fourth A check, while the 8A tasks had a 3,200FH interval at the eighth A check. The A check tasks are therefore grouped according to their intervals into block checks as shown *(see table, page 20)*, with all tasks coming into phase and the cycle of A checks being completed at the A8 check.

The 1A interval was then escalated to 500FH in 1998. "The 1A interval was escalated again to 600FH at the 15th revision in 2006," says Pedro Saez Minguez, line maintenance & engineering vice president at Iberia Maintenance. "At the current interval of 600FH, the A1 check is performed at 600FH, the A2 check at 1,200FH, and the cycle finishes at the A8 check at 4,800FH."

Many operators of the A340-200/-300 now use 600FH as their basic interval for the A check. Lufthansa Technik, however, has managed to escalate its A check interval to 700FH. "A general escalation of the A check interval by Airbus to 800FH is expected

A340-200/-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
Equalised A check system		
A1-A8 checks	1A + 1/2 2A + 1/4 4A + 1/8 8A tasks	Every 600FH, cycle completing at 4,800FH
Block base check system *		
C1	1C	15 months
C2	1C + 2C	30 months
C3	1C	45 months
C4 + S1	1C + 2C + 4C+ S1	60 months
C5	1C	75 months
C6	1C + 2C	90 months
C7	1C	105 months
C8	1C + 2C +4C +8C + S2	120 months

*** C check intervals have recently been increased to 18 months and S1 check intervals to 72 months. The S2 check interval is expected to be increased to 144 months.**

in 2008 when the maintenance planning document (MPD) gets its annual revision," explains Minguez. "This would take the full A check cycle interval up to 6,400FH."

Some airlines, such as THY, choose to carry out their A checks as equalised checks. In this case the A check packages are similar in size, and each check includes the 1A tasks, about half the 2A items, one-quarter of the 4A items and one-eighth of the 8A tasks.

Base checks

There are four main groups of C check tasks: the 1C, 2C, 4C and 8C inspections. These have to be carried out in the respective multiples of the basic 1C interval, and all tasks come in phase at the C8 check. All four groups of inspections are performed at this check, making it the largest C check. The C8 check has an interval of 120 months, equal to 10 years. The second largest check is the C4 check, which has an interval of 60 months and comprises the 1C, 2C and 4C items *(see table, this page)*.

The two groups of structural inspection items are independent of the C check tasks, and initially had intervals of 60 and 120 months. These are known as the five- and 10-year or S1 and S2 inspections. They therefore conveniently coincide with the C4 and C8 checks, and combine to make two large checks: the IL and D checks *(see table, this page)*. Many operators also choose to carry out other large tasks such as major modifications, component changes and interior refurbishments at these checks.

The major revisions to the A340-200/-300's maintenance programme started in 1998. "A major revision took place in 2002, when the basic C check interval was escalated from 15 to 18 months," explains Rosario. "This raised the interval for the full cycle of eight checks to 144 months, which is equal to 12 years. This therefore put the C4 and C8 checks at 72 and 144 months, and also put them out of phase with the S1 and S2 checks at 60 and 120 months." These changes could have forced some operators to perform the C4 and C8 checks separately to the S1 and S2 checks, although doing this can increase the total downtime for maintenance, and incur a higher use of labour man hours (MH) for repeated access for heavy inspections.

The 15th revision in late 2006 was also an important one, which increased the interval for the smaller group of structural tasks, the S1 tasks, from five to six years. This therefore put the S1 tasks back into phase with the C4 check at 72 months, although some tasks have not been escalated and have remained with the five-year interval.

The interval for the larger group of structures tasks, the S2 tasks, was kept at 10 years, although it is generally expected that this will be increased to 12 years at some point. The current interval of 120 months for the S2 tasks means that it is out of phase with the C8 check, which now has an interval of 144 months. The consequence of this is that operators have to choose between performing the checks separately, or still combining them at an interval of 120 months and losing 24 months from the C8 check's maximum interval as a result.

The escalation of the S1 tasks from 60 to 72 months was relatively recent, however, so few aircraft will therefore have actually been able to take advantage of it. Airlines will so far have only been able to extend the timing of their combined C4 and S1 checks by up to 12 months. Moreover, there still remain about six years for Airbus Industrie to escalate the interval of the S2 tasks from 120 to 144 months. This will allow the S2 tasks to be combined with the C8 check so that they can both use their full intervals.

Turkish Technic follows a system of planning the C checks and structural checks separately. "Although the C checks are usually carried out separately from the structural checks, we will perform them together if: they come close to each other as a result of hangar slots; the airline operating schedule does not allow two different checks to be performed; or the two checks fall close together," says Ozcan. "In the case of one aircraft the C12 check, which is the C4 check in the second base maintenance cycle, will be performed in February 2008, while the S3 check is planned for November 2008. There is therefore a nine-month gap between the two. It will become more difficult to combine C and structural checks if the C check interval is extended to 20 months."

Line, ramp & A check inputs

Workscopes for pre-flight, daily and weekly checks for most operators include MPD tasks and interior checks. These interior items usually involve checking and rectifying the appearance of the cabin, making small repairs and repairing any defects to passenger seats.

Defects also occur during operation, and operators use line checks wherever possible to clear and rectify them. Rectifications will be made during the ground time if allowed, or if the defect is a no-go item. If the defect is large and can be deferred, the airline will rectify it at a larger check, such as a daily or weekly check, or an A check if one is due in a relatively short time.

In addition to MPD items, workscopes for pre-flight, daily and weekly checks also include interior checks and deferred items, hard-timed tasks, troubleshooting and component changes.

The A340-200/-300 has had several increases in its A check interval. It is currently 600FH, but could be increased to 800FH. The aircraft's lower checks are pre-flight, daily and weekly checks.

Total labour inputs for these checks are variable, due to variation between airlines' operations, patterns of utilisation and operating environment. Approximate inputs for pre-flight checks are an average of 2MH, and a budget of $50 should be allowed for materials and consumables. Using a generic labour rate of $70 per MH results in a total cost of about $200 for the check. The daily check can use an average of 12MH and an allowance of $200 should be made for materials and consumables, thereby taking the total cost for the check to about $1,000. The weekly check can use an average of 20MH and $500 in materials and consumables, thereby taking the total cost to about $1,900.

Under the utilisation pattern described, the aircraft will require about 350 pre-flight checks, 350 daily checks and 50 weekly checks per year. On this basis the line and ramp checks will incur a total annual cost in the region of $520,000, equal to $105 per FH *(see table, page 32).*

Despite the differences in the routine tasks contained in the A checks, Rosario explains that these only have a small effect on the total number of MH used for the check. "The A check workpackage includes routine MPD inspections, non-routine rectifications, clearing deferred defects, component replacement, inspections driven by the operator's experience, and exterior and interior cleaning," says Rosario. "The total labour used for the whole workpackage averages about 630MH, only about 110MH of which is accounted for by routine MPD tasks. The check also uses about $25,000 of materials and consumables."

Similar inputs are recorded by Turkish Technic. "We use an average of 600MH for the whole A check, and have a corresponding cost of $35,000 for materials and consumables," says Ozcan.

A generic labour rate of $70 per MH for line and light maintenance would take the total cost for an A check to $65,000-75,000.

Given the escalated A check interval of 600FH, operators will probably be able to to perform A checks every 450-480FH once scheduling and operational constraints are taken into consideration. On this basis, the reserve for A checks will be $135-170 per FH *(see table, page 32).*

Base check contents

Many operators take advantage of the extended downtime and access provided by base checks to perform additional tasks such as: modifications and upgrades; engineering orders (EOs); removing rotables for overhaul; engine changes; clearing deferred defects; exterior and interior cleaning and refurbishment; and stripping and repainting. The combined effect of these tasks is to create large workpackages which consume a large number of MH and materials.

Inspections

The arrangement of MPD tasks for the base checks is summarised *(see table, page 18).* These tasks are covered by the current MPD revision. The revision made in late 2006 increased the S1 check interval to 72 months, so that it now coincides with the C4 check. The S2 check interval is likely to be extended from 120 months to 144 months over the next five to six years in time for most operators to combine it with the C8 check.

Check planning and workscope contents first have to consider probable interval utilisation. This cannot be 100% due to the constraints of aircraft operational requirements and appropriate hangar and facility availability. A typical interval utilisation rate of 85% means that C checks will be performed about every 15 months. The C8 check will therefore be performed every 120-122 months. This means that most operators will be able to combine the C8 check with the S2 check. The C4 check and S1 tasks will be performed in a check at about 61 months. If the S2 task interval is extended to 144 months, operators will have to strive to increase interval utilisation to 90-95% to take full advantage of the escalation. This would take the C8/S2 interval to 130-136 months.

"In addition to the MPD tasks, each operator also adds items unique to their own maintenance programme," explains Rosario. "These are items such as regular cabin cleaning and other interior work which increase the routine inspections. The C2 check in the second base check cycle, for example, requires about 940MH for routine inspections, and an additional 1,200MH for non-routine rectifications. This represents a non-routine ratio of 125-130%. The additional items that we have in our maintenance programme take the total MH for the routine tasks from 940 to 1,530. This is an increase of about 600MH.

"The IL check, which includes the C4 and five-year or S1 structural tasks, requires about 4,100MH when our additional items are added," continues Rosario. "The C8 check, together with the five-year/S1 and 10-year/S2 tasks, requires a total of about 6,750MH for routine labour once all our own items are added to the MPD tasks. This is split between 4,600MH for the C8 tasks and 2,150MH for the five- and 10-year tasks."

The aircraft's age and production number must also be taken into consideration. "There are large differences between the oldest and more

The A340-200/-300's base check system is a cycle of eight C checks. The fourth and eighth checks are combined with the S1 and S2 structural tasks to form two larger checks. The basic C check interval has been increased from 15 to 18 months, and the S1 interval to 72 months. The S2 interval is still at 120 months, but is likely to be increased to 144 months.

recently built aircraft in terms of routine requirements and findings," explains Fernando Velasco Agudo, A340 overhaul manager at Iberia Maintenance. "We have six aircraft that are line numbers 135 to 250, and we found about 200 major findings in the C8/D checks. These are reports from findings following inspections that require special attention. These findings have repairs developed for them which have to be approved by Airbus Industrie. Repetitive repairs get included in the structural repair manual, and sometimes Airbus will issue a service bulletin (SB) to prevent the cause of the problem. Younger aircraft will have had improvements incorporated on the production line, so they will benefit from having a lower level of findings and non-routine requirements that older aircraft have."

Engineering orders

The A340-200/-300 has had two major airworthiness directives (ADs). The first of these relates to the frame 40 modification. This was covered by AD 99-448-126 and is mandatory. "There are two compliance thresholds for the A340-300, depending on which configuration a particular aircraft falls into," explains Velasco. "Aircraft with configuration 1 have to comply before they accumulate 35,270FH or 6,170FC, while aircraft with configuration 2 have to comply before they reach 28,790FH or 5,260FC."

The compliance threshold for the A340-200 is 65,500FC and 42,000FH, whichever is reached first.

"Both labour MH and a kit are required to complete this modification," says Stan Pugh, senior sales executive at Gamco. "Aircraft with configuration 1 require about 700MH according to the AD, but this should be multiplied by a factor of about 3.5. The price of the kit is about $12,000. Aircraft with configuration 2 require about 400H, but again this should be multiplied by a factor of 3.5 The price of the kit is about $7,000."

This modification was incorporated into IL1 or D1 checks by most operators.

A second major modification addresses the problem of cracking caused by heavy loads at the sixth wing rib, where the main landing gear is attached to the wing structure. This modification is covered by AD CNF-2006-0098, which is mandatory and has to be complied with by 31st December 2010. The repair requires landing gear removal, and Velasco says it uses about 400MH to complete.

A third major modification on the A340-200/-300 is the engine pylon modification. This relates to AD 00-179-147, issued in 2000, and is a reinforcement plate installation on the engine pylons. This consumes about 750MH.

A future modification relates to engine thrust reversers. The outer fixed structure of the thrust reversers will have to be modified because of dis-bonding in the structure. The modification has to be completed before 11,600FC since new, which is equal to 15-20 years of operation. Eight reverser halves have to be modified, and a shipset has to be borrowed while the work is done. Pugh estimates that each thrust reverser half will require up to 300MH, so the full shipset of eight halves and the four reversers will use a total of 2,400MH, plus cost of materials.

Rotable components

Base checks will also involve the removal of a small number of rotable components that have hard times for repair and overhaul. The exact number of part numbers installed on each aircraft first depends on customer configuration, because it will be affected by the specification of interior equipment and the modification and upgrade status of its numerous systems.

Paul Graf, head of customer support and product management at SR Technics, estimates that there are about 2,100 serial numbers installed on the A340-300. The number of different rotable components installed on the aircraft can be as high as 2,600. These are accounted for by about 1,400 different part numbers, so there is an average of almost two parts for every different rotable part number installed on the aircraft. "The part numbers installed not only vary between operators, but also between different aircraft in the same fleet," explains Saron Faria, logistics material planning at TAP Maintenance & Engineering. "While the average number of different part numbers on an aircraft is 1,400, our fleet of four aircraft uses a total of about 1,700 different part numbers, which we have to stock in our inventory."

Graf estimates that about 400 of the rotable units installed on the aircraft are maintained on a hard-time basis. These are mainly safety- and emergency-related items that include escape slides, oxygen bottles and life rafts. There are a small number of system components, such as batteries, that also have hard-time maintenance programmes. These items will be removed during A or base checks. Their repair cycle time may allow the same items to be reinstalled on the same aircraft, while parts with repair cycle times longer than the downtime of the check will have to be exchanged with serviceable items.

The majority of rotables on the A340-300, about 80% or 2,000 of the units, are maintained on an on-condition basis. These will be removed during line maintenance and checks and replaced with serviceable items.

As well as hard-timed rotables, base checks will be used to change engines, landing gear seats, the auxiliary power unit (APU) and thrust reversers as

Besides routine tasks, most operators use base checks to perform major SBs and ADs, undertake refurbishment of the aircraft's interior, perform heavy component and engine changes, and strip and repaint the aircraft.

required. The landing gear overhaul interval is calendar-time and FC-related, while the APU and thrust reversers are maintained on an on-condition basis.

The relatively small number of hard-timed components means that the MH used for their removal and replacement are small in relation to other elements of the base checks.

Interior work

The use of the A340-300 as a long-haul aircraft means that the work on the aircraft's interior will be substantial. The five- to six-year intervals between heavy C and structural checks, their downtime of four or five weeks and the high level of deep access provide operators with the ideal opportunity to refurbish aircraft interiors. Airlines also periodically undertake interior redesigns for marketing reasons.

Iberia, for example, used the IL1 and D1 checks as opportunities to reconfigure its aircraft from a tri-class to a dual-class layout, and install a new business-class cabin with lie-flat seats and in-flight entertainment (IFE) system. These interior reconfigurations, however, use more MH and materials than a refurbishment of an existing interior.

Airlines use lighter C checks on the A340-200/-300 for interior cleaning and on-condition repair and refurbishment of interior items as required. Refurbishment of the interior during heavy checks will include the removal and refurbishment of seats, overhead bins and passenger service units (PSUs), bulkheads, ceiling and sidewall panels, toilets, galleys and carpets.

Other work

Operators have further items to add to the workscope of base checks, in addition to routine inspections and non-routine rectifications that arise as a consequence, EOs and modifications, interior cleaning and refurbishment, removal and reinstallation of rotable components and interior work. These extra items include repetitive inspections that are in addition to the C check task cards, such as: cleaning the fuselage exterior; engine changes; changes of other large rotables such as the landing gear or APU; clearing deferred defects; and performing out-of-phase (OOP) tasks. Repetitive inspections are inspections imposed by SBs and ADs, and other inspections that an operator's engineering department thinks will improve reliability. OOP tasks are items without intervals, which are multiples of the basic A or C inspections.

Examples of the labour used for component changes are 100MH for an engine, 500MH for a landing gear shipset, and 20MH for the APU.

Up to another 100MH can be used for OOP tasks, and 20MH for clearing defects.

Base check inputs

As described, there are several elements to the base checks. There are six light base checks with just C check inspections, and the two heavier checks. Operators have some flexibility in organising their base checks. One option is to have relatively large C checks with a large number of inspections. This results in medium-sized heavy checks. An alternative is to have relatively light C checks, with many inspections performed in the two heavy checks, thereby increasing their content.

The option of relatively large checks and medium-sized checks is considered first.

C checks

The lighter checks are the C1, C2, C3, C5, C6 and C7 checks *(see table, page 18)*. Four of these appear on 1C tasks cards, while the C2 and C6 checks include the 1C and 2C inspections. "The difference in MH required for routine inspections and maintenance programme items between checks with just 1C and those with 1C and 2C inspections is small, and only equal to about 200MH," explains Rosario. "MPD items in a C2 or C6 check for an aircraft in its second base check cycle require about 940MH. About another 600MH are required for our own additional items, taking the total to 1,530MH for routine work for the maintenance programme part of the check. This compares to 1,300MH for C1, C3, C5 and C7 checks, which have just the 1C tasks.

"The maintenance programme portion of 1,300-1,530MH generates another 1,000-1,200MH for non-routine rectifications. This is a non-routine ratio of about 80%," continues Rosario. "EOs, SBs and modifications consume an average of 840MH for this type of check, while changing hard-timed rotable components uses about 100MH. The three elements of routine inspections, EOs and component changes total 2,100-

The total cost for engine-related maintenance is about $210 per EFH. This cost is comprised of the three elements of shop visit costs, LLP reserves, and reserves for the QEC. The total cost per FH for all four engines is relatively high compared to the larger 747-400.

2,500MH. Non-routine work adds a further 4,500MH, including some cabin cosmetic items, while other items add 1,350MH. This takes the total for a C2 check to the region of 8,300MH." This total is similar for the C6 check. Totals for the C1, C3, C5 and C7 checks will be about 7,800MH for aircraft in their second base check cycle.

The larger C2 and C6 checks will use about $345,000 of materials and consumables. The maintenance programme portion of the check uses about $39,000 of materials and consumables, which is just 22% of the total. Another $210,000 are required for the non-routine portion of the check. About $40,000 of materials and consumables are used for EOs, and the balance of $55,000 is for the other items of the check. Smaller C1, C3, C5 and C7 checks will use $300,000 in materials and consumables.

Heavy checks

Rosario estimates that the C4/five-year checks use about 4,100MH for the routine maintenance programme items of the MPD inspections and the airline's additional routine work. "EOs, SBs and modifications use about 3,600MH for this check. This was used for a total of 91 modifications performed on the aircraft, the large majority of them being retrofits, since we operate aircraft between serial numbers 41 and 91."

Component changes require a further 120MH, and the sub-total for these three elements reaches 7,900MH.

The MH for non-routine rectifications that arise out of these three elements total about 5,000MH, which is equal to a non-routine ratio of 65%. This gives a sub-total of 13,000MH.

The refurbishment of the interior at this check consumes in the region of 2,500MH, with the same process consuming more MH in the larger C8/10-year (D) check. A further 750MH are used for other items, taking the total for the check to 16,000MH for an aircraft's first C4/five-year check (IL1). This could reach 20,000MH for the second check, which is the IL2 check.

The cost of materials and consumables for the IL1 check will approach $400,000. The maintenance programme portion of the check will use about $35,000. A further $41,000 will be required for EOs and $20,000 for other items. The largest portion of $304,000, however, is used for non-routine rectifications and interior refurbishment.

The first heavy C8/10-year check that the aircraft undergoes will consume in the region of 26,000MH. The maintenance programme portion of the check uses about 6,800MH, with 4,600MH coming from the C8 element of the check and 2,200MH coming from the 10-year structural inspections. The corresponding cost of materials and consumables for this part of the check is $122,000.

EOs account for another large portion, using up to 5,300MH. This check included three major modifications. The first of these was the cockpit door installation, which used about 700MH. The second was the installation of lie-flat seats, which used about 500MH. The third was the engine pylon modification, covered by AD 00-179-147, which used about 750MH. These three modifications therefore used 1,950MH and $260,000 of materials and consumables. This amount only covered the cost of the modification kits, however, not the lie-flat seats.

Component changes use about 130MH and $800 of materials and consumables. Non-routine items use 9,400MH and the large interior refurbishment at this check uses about 3,500MH. The corresponding cost of materials and consumables for the non-routines and interior refurbishment is in the region of $400,000.

Other items added about 1,250MH and $107,000 in materials and consumables.

The total for the check will be 26,000-27,000MH, with about 1,950MH of this being accounted for by the installation of the cockpit door, new lie-flat seats and the pylon modifications. The total cost of materials and consumables for the check is $875,000.

The total MH used for the six C checks in the base check cycle will therefore be 46,000-48,000. Each check uses $300,000-350,000 of materials and consumables, so the six checks in the cycle will use a total of $1.7-1.9 million.

The two heavy checks will use 42,000-44,000MH and $1.2-1.3 million in consumables and materials, including items for interior refurbishment.

The eight checks in the cycle will therefore consume a total of 88,000-92,000MH and $3.1-3.3 million in materials and consumables. A standard labour rate of $50 per MH would take the total cost for the eight checks in the cycle to $7.6-7.8 million. On the basis that the base check cycle is completed every 120-122 months, this cost will be amortised over an interval of about 50,000FH. The reserve for base maintenance will therefore be $150-155 per FH *(see table, page 32)*.

Light C & heavy IL/D checks

The option of relatively light C checks and heavier C4/five-year and C8/10-year checks will have a similar consumption of labour, materials and consumables over the base check cycle.

Lufthansa operates a system of relatively light C checks for its fleet of 28 A340-300s, which were delivered from 1993 to 2001. The aircraft are now mature in maintenance terms, with most having gone through their IL1 and D1 checks, and the first coming due for their IL2 checks in the winter of 2011.

Lufthansa first operated a smaller fleet of A340-200s, which have since been sold to SAA. "The -200 fleet had a lot of inspections implemented via EOs (modifications). These were introduced into the -300's maintenance programme, as additions to the -200's maintenance programme. Many of these items are related to structural tasks," explains Andreas Drosdowski, leader of maintenance planning services at Lufthansa Technik. "The MH used for routine inspections and EOs in the base checks are about equal for the -200 and -300, but the -200 has a relatively high number of MH for EOs, while the -300 has a higher number for routine inspections.

"Another additional large modification required on the A340-200 and -300 was the frame 40 modification. This concerns the structure in the wing-to-fuselage joining area, where cracks required a large modification and insertion of a new piece of structure," continues Drosdowski. "This was covered by a mandatory AD, which had to be completed by 2003. "This heavy modification was included in the IL1 or D1 checks of aircraft, depending on their age. It required the aircraft to be raised on jacks, a process that was sensitive to weight changes on the aircraft. This modification used a large number of MH in addition to the other elements of the base checks."

A340-200/-300 HEAVY COMPONENT MAINTENANCE COSTS

Number of main & nose wheels	10 + 2
Tyre retread interval-FC	270/220
Tyre retread cost-$	600/450
Number of retreads	4
New main & nose tyres-$	1,200/1,000
$/FC retread & replace tyres	**32**
Wheel inspection interval-FC	270/220
Main & nose wheel inspection cost-$	1,000
$/FC wheel inspection	**45**
Number of brakes	10
Brake repair interval-FC	2,000
Brake repair cost-$	40,000
$/FC brake repair cost	**200**
Landing gear interval-FC	7,000
Landing gear exchange & repair fee-$	1,200,000
$/FC landing gear overhaul	**171**
Thrust reverser repair interval-FC	6,000
Exchange & repair fee-$/unit	215,000
$/FC thrust reverser overhaul	**143**
APU hours shop visit interval	3,500
APU hours per aircraft FC	2.6
APU shop visit cost-$	200,000
$/FC APU shop visit	**149**
Total-$/FC	**740**
Total-$/FH passenger aircraft @ 7.2FH per FC	**102**

C checks

Drosdowski explains that the routine inspections of the lighter C checks use about 1,500MH. "The non-routine ratio for long-haul aircraft is generally 1:1, so another 1,500MH will be used for non-routine rectifications in these checks," explains Drosdowski. "A few modifications that are covered by SBs or small ADs will add some MH, and while this is unpredictable and variable, 500-1,000MH can be expected to be required. Other items, like light interior refurbishment or cleaning, will take the total to 4,000-4,500MH. A further 500MH can be added for exterior cleaning, which we do about every base check interval. This can therefore result in about 5,000MH for light C checks for a mature aircraft in its second base check maintenance cycle. The associated cost of materials and consumables is $80,000."

Heavy checks

"The first C4/five-year or IL check (IL1 check) had a downtime of about 23 days," says Drosdowski. "Excluding painting, this check under our programme used 12,000-13,000MH for routine inspections and a similar number of MH for non-routine rectifications, taking the sub-total for the check to 25,000-27,000MH. About 400MH of the routine inspections were used for cabin work and 2,500-3,000MH of the non-routine rectifications were used for cabin refurbishment. Another 2,500MH are required for SBs and smaller ADs. More labour can be required for component changes. Changing a shipset of engines can use about 800MH, while changing the landing gear will use 600MH. Engine changes are likely to be made over several checks, while the landing gear will be changed every 10 years or so, and will therefore probably done at the D check. An allowance for some engine changes and other heavy components will take the total for the check to 28,000-30,000MH. The associated cost of materials and consumables will be about $800,000. This does not include large modifications, like the frame 40 AD. We expect that the IL2 check will be heavier, because there will be more routine inspections and the non-routine ratio will increase with age."

The first D checks were about 30% larger in total than the IL1 checks. "The routine inspections for the D1 check used about 16,500MH, and a similar number of MH were required for non-routine rectifications," says Drosdowski. "Like the IL1 check, this sub-total of about 33,000MH includes 3,000-3,500MH for cabin inspections and refurbishment. We refurbish the interior about every six years. Component changes will require another 1,000-1,500MH, while EOs will use another 2,500MH. This will take the total up to about 36,000MH, but stripping and repainting will take the overall total for the check close to 40,000MH. The associated cost of materials and consumables will be $1.0-1.1 million. The downtime for this size of check was about 36 days."

This takes the total consumption for the eight checks in the cycle to about 100,000MH and $2.6-2.8 million in materials and consumables. A standard labour rate would take this to a total cost of $7.6-7.8 million. Amortised over the interval of about 50,000FH, this would be equal to a reserve of $150-155 per FH *(see table, page 32)*.

Heavy components

Heavy components comprise four categories: the landing gear; wheels and brakes; thrust reversers; and the APU.

The A340's landing gears comprise the following: four landing gear legs with two main outboard landing gears, each supporting four wheels; a centre main landing gear that supports two wheels; and a nose landing gear that also supports two wheels. The 10 wheels on the main gears have carbon brakes.

The landing gear overhaul interval is a calendar time of 10 years or 20,000FC; whichever is reached first. The landing gear is therefore likely to be removed at the D check. Most operators use exchange programmes with specialist landing gear overhaul shops. These charge exchange and overhaul fees, with an average of $1.2 million for the A340-200/-300. Over a 10-year interval equal to about 7,000FC, this gives a reserve of $171 per FC *(see table, page 27)*, or $23 per FH at the stated FC time.

The thickness of brake units is monitored during operation, and these are removed for repair and overhaul. Average repair intervals are 2,000FC and the repair cost for a single unit is in the region of $40,000. Reserves for the shipset of 10 brakes are $200 per FC *(see table, page 27)*, equal to $28 per FH.

Wheels are removed when tyre treads are worn. Tyres are remoulded up to four times and then replaced at the fifth removal. Wheels are inspected at removal. Taking typical tyre remould and replacement costs, the overall cost for the complete shipset of 12 tyres is $32 per FC *(see table, page 27)*, equal to $5 per FH.

Reserves for inspecting and repairing the full shipset of wheels are about $45 per FC *(see table, page 27)*, equal to $6 per FH.

The A340-200-300 are equipped with the GTCP 331-350 APU. Martin Matthews, engineer at Total Engine Support, explains that the first removal interval has increased from about 1,600 APU hours when the aircraft entered service in the 1990s. Reliability has improved and mature intervals are about 3,500 APU hours. This is equal to 1,300 aircraft FC. The average shop visit cost is about $200,000, which equals a reserve of $150 per FC *(see table, page 27)*, or $21 per FH .

Thrust reverser removals are on-condition, and average 6,000FC. Shop visit costs also vary with condition and findings at removal, but average $215,000 per reverser. The reserve for each unit is thus $36 per FC, equal to $144 per FC for the shipset of four *(see table, page 27)*.

Overall, the reserves for these four groups of components are equal to a cost of $740 per FC. This is equal to $102 per FH at the FC time of 7.2FH.

Rotable components

As described, the A340-200 and -300 have 1,100-1,400 rotable part numbers, and up to 2,000-2,600 different rotable components installed on the aircraft, depending on configuration.

A minority of up to only 400 rotable components are maintained on a hard-time basis. The remainder are maintained on an on-condition or condition-monitored basis.

Operators can use a number of specialist providers to provide them with turn-key rotable support packages. Rotable support package providers for the A340-200 and -300 include AJ Walter, Avtrade, SAS Component and Lufthansa Technik.

Once failed or hard-time parts are removed from the aircraft by the operator, the rotable support provider handles all transport, testing, repairing, documentation and return of serviceable parts to the inventory. The provider also maintains an inventory of rotables at a pre-agreed level of availability. A core of parts is provided to the operator through a lease agreement. The remaining parts are available from the support provider's inventory pool, and access is paid for by a power-by-the-hour (PBH) rate. The operator pays a third PBH rate to the support provider for the repair and management of the logistics process.

Actual costs depend on fleet size, location of homebase, route network and position of outstations, and style of operation. Simon Clements, director of business development manager at AJ Walter says that a fleet of 10 A340-300s operating at about 5,000FH per year would require homebase stock of inventory with a value of about $5 million. The monthly lease for this stock would be about $60,000, and would be shared between the 10 aircraft. This would be equal to about $15 per FH.

"PBH rates for the access pool fee will be about $77 per FH," says Clements. "The third element of the PBH repair and management fee would be about $170 per FH."

The total of the three elements would therefore be about $262 per FH *(see table, page 32)*.

Engine maintenance

The A340-200 and -300 are powered exclusively by the CFM56-5C series. This engine is the highest rated of the CFM56 family. The -5C was developed from the -5B series, which has a highest rating of 32,000lbs thrust.

There are three main variants of the -5C series: the -5C2 rated at 31,200lbs thrust; the -5C3 rated at 32,500lbs thrust; and the -5C4 rated at 34,000lbs thrust.

The basic -5C2 variant has a redline exhaust gas temperature (EGT) limit of 950°C, the basic -5C3 a red line temperature of 965°C, and the basic -5C4 variant a redline temperature of 975°C.

There are several sub-variants of each each variant. These different sub-variants are a result of several modification and upgrade programmes that have been introduced since the engine entered service.

The -5C series has generally suffered from a high rate of EGT margin erosion since entering service, mainly because the CFM56 has been developed to the limit of its thrust capability.

The first series of upgrades was applied to the -5C2 and -5C3 engines to bring their redline temperatures up to 965°C and 975°C. The /F suffix on the variant's name denotes the upgrade to an EGT limit of 965°C, while the /G suffix denotes the upgrade to an EGT limit of 975°C *(see A340 modification programmes, page 13).*

Engines were later built to the standard of the -5C4, therefore giving them the potential to operate at 34,000lbs thrust. This is denoted by a /4 suffix. The -5C2/G4 and -5C3/G4 are therefore the -5C4 de-rated to 31,200lbs thrust and 32,500lbs thrust, where the operator does not require 34,000lbs thrust.

CFMI also introduced an upgrade programme, whereby the /P suffix denotes that the engine has been upgraded with the 3-D aerodynamic configuration. This modification reduces EGT and increases EGT margin by about 13°C and reduces specific fuel consumption by about 1% *(see A340 modification programmes, page 13).* All engines with the /P modification have a redline limit of 975°C, and the increase in EGT margin can increase time on wing by 2,000-3,000 engine flight hours (EFH).

CFM56-5C in operation

As described, the A340-200 and -300 are generally used as long-haul aircraft. This analysis uses an average FC time of 7.2FH. FC times of this length generally mean that removal intervals are more related to EFH time on wing and to mechanical deterioration, rather than EFC time on wing and performance loss. The CFM56-5C is an exception, however, with rapid performance loss being a problem for most operators. This explains the various modification programmes that have been introduced.

"There have been two major ADs for the engine," says Gurkan Darende, chief engine shop engineer at Turkish Technic. "The -5C has only a small EGT margin recovery following a shop visit, and the EGT margin retention is also poor. This is a major problem with the engine. The average EGT margin of new -5C4 engines was 62°C, with a standard deviation of 9°C. This new EGT margin did increase, however, as the manufacturing of the engine progressed. The last engines built had an average EGT margin of about 87°C, although there was a large variation.

"The average EGT margin for -5C4s following a shop visit is 36.5°C," continues Darende.

Matthews explains that the EGT margins of the later-produced new engines are: 90°C for the lowest rated -5C2; and 80°C for the -5C3. "The restored EGT margin of engines following a shop visit up to about 2001 was typically about 60% of new engines," explains Matthews. "From 2002 CFMI aimed to increase this to about 70% with various modification and improvement programmes."

This will result in post-shop-visit EGT margins of 55-63°C for -5C2 engines, 48-55°C for -5C3 engines and 36-42°C for -5C4 engines. Later built engines should have slightly higher margins, however.

The significance of EGT margin is greater for engines operating in hot environments. Many A340 operators are European and experience temperate climates, while some operate in higher temperatures.

All variants have a corner point temperature of 30°C, so they will experience a reduction in EGT margin for operating temperatures higher than this. Engines may have to be removed before all EGT margin at standard temperature is eroded, due to a lack of EGT margin at higher operating temperatures.

Matthews estimates that the initial rate of EGT margin loss following a shop visit is about 14°C in the first 2,000EFH. This then settles to a rate of 2-3°C per 1,000EFH. This would allow intervals of up to 18,000EFH for -5C2 engines, 15,000-16,000EFH for -5C3s, and 11,000-12,000EFH for -5C4 engines. "Mature rates of EGT margin loss can be higher, however, for airlines operating in hotter climates, or those not using water washing to recover some lost EGT margin," comments Matthews.

The main removal cause for the -5C is EGT margin loss, with about 70% of engines removed for this reason. The majority of other removal causes relate to mechanical deterioration. These include high pressure turbine (HPT) and high pressure compressor (HPC) blade distress, and HPC rotor-to-stator contact.

"We find that most engines are being removed due to performance and EGT margin loss, but a large number of engines are also being removed due to number four bearing failure," says Darende. "The feature of long-haul operations is that most engines only accumulate about 700EFC per year. This compares with life limits of 15,000EFC and 20,000EFC for most life limited parts (LLPs). This means that most of the oldest engines delivered in 1993 will have accumulated up to about 10,000EFC so far, so LLP expiry is not yet forcing many removals."

Shop visit activity

Most engines are now mature, although a minority are still on their first removal interval. "The first removal intervals naturally depended on the initial EGT margin, the style of operation and the operating environment, but these were 15,000-25,000EFH," says Matthews. This is equal to three to six years of operation.

"The -5C2 was not a good engine, and experienced rapid EGT margin loss. Many of these engines had modifications made at their first removal," adds Darende. "Some of the-5C2s were forced off wing early, so their intervals were not representative of what the engine was capable of. The first removals for the -5C4 were up to about 30,000EFH, however. The /P modification increases on-wing time, but we find it too expensive.

"We are experiencing mature removal intervals of 11,000-13,000EFH with our -5C4 engines, which is about what would be expected with the EGT margin," continues Darende. Matthews adds that second-run engines can expect to have intervals of 14,000-17,000EFH, depending on several factors.

The -5C has few SBs or ADs that influence removal intervals. "There is an SB (72-427) which involves the borescope inspection of the HPC stage 3 and 2 rotor-to-stator contact for high-time engines that have exceeded 24,000EFH since the replacement of variable stator vane bushings," says Matthews. "The engine requires repeat inspections every 1,600EFH, and has to be removed if the 'J' hooks have worn away. SB 72-431 also requires borescope inspections every 3,000EFH or 500EFC for HPT trailing edge cracking."

In addition to having poor performance and EGT margin retention, the CFM56-5C also requires relatively high maintenance inputs. "The engine requires a performance restoration and a minimum workscope on the low pressure turbine (LPT) and low pressure compressor (LPC) modules every shop visit. The workscope on the LPT and LPC can escalate, however," says Matthews.

Darende comments that, in addition to a core performance restoration, the LPT usually requires some work every

DIRECT MAINTENANCE COSTS FOR PASSENGER-CONFIGURED A340-200/-300

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	520,000	5,000FH		105
A check	65,000-75,000	450-480		135-170
Base checks	7.6-7.8 million	50,000		150-155
Heavy components:			740	102
LRU component support				262
Total airframe & component maintenance				**754-794**
Engine maintenance:				
4 X CFM56-5C: 4 X $210 per EFH				840
Total direct maintenance costs:				**1,594-1,634**

Annual utilisation:
5,000FH
700FC
FH:FC ratio of 7.2:1

shop visit. "The core and LPT need improving, and every shop visit some of the HPC blades and vanes and the interstage seals need replacing, making it an expensive module on the engine," says Darende. "The LPT usually requires a full workscope every second shop visit, while the fan and LPC module can last four or five shop visits."

The inputs for a performance restoration are 2,500-3,000MH in labour, $1.1-1.3 million in materials, and $150,000-250,000 in sub-contract repairs. At a labour rate of $70 per MH, this equals a total cost of $1.4-1.75 million.

Workscopes on the LPT will be $500,000-575,000, and $130,000-150,000 for the fan and booster module.

A full overhaul will use 3,500-4,000MH in labour, $1.6-2.0 million in materials and consumables, and $250,000-350,000 in sub-contract repairs, taking the total to $2.1-2.6 million.

The pattern of three workscopes would therefore result in shop visits with costs averaging $1.9 million, $2.1 million and $2.4 million for a mature engine. The total cost of $6.4 million amortised over an interval of 36,000EFH for the three removals would equal a reserve in the region of $178 per EFH.

Life limited parts

The -5C series has 19 LLPs. The majority of parts have lives of 15,000EFC or 20,000EFC. There are several part numbers for many of the LLPs, and life limits are also determined by engine variant and sub-variant.

The fan disk and booster spool have lives of 20,000EFC and list prices totalling $323,000. The fan shaft has a life of 11,000-18,200EFC and has a list price of $95,000.

The HPC module has five parts. There are 10 different part numbers, which have life limits of 15,000EFC or 20,000EFC. The module has a list price of $67,000. The Stage 1-2 spool has a life limit of 15,000EFC in most cases, and 20,000EFC in a few. Its list price is $95,800. The Stage 3 disk also has lives of 15,000EFC or 20,000EFC in most cases, and a list price of $30,000. The stage 4-9 spool has a life of 15,000EFC and a price of $214,000, while the compressor rear air seal is priced at $41,000. The combined list price of these five parts is $448,000.

The HPT has four LLPs. These have the most limited lives, which vary from 10,000EFC to 15,000EFC in most cases. Some parts have more limited lives, however. The combined list price of these four LLPs is $473,000.

The LPT has seven or eight parts, depending on engine configuration, with most lives at 20,000EFC. The LPT case is an additional LLP in engines with the /P modification. The stage 4 disk is limited to 15,800EFC in some cases. The combined list price of the seven parts is $593,000. The LPT case has a list price of $151,000.

Reserves for LLP replacement will depend on the stub life that can be left at replacement. Given the typical removal intervals of 11,000-15,000EFC, remaining stub lives are likely to be up to 2,000EFC. This would put reserves at $78 per EFC for parts with lives of 15,000EFC and a further $51 per EFC for parts with lives of 20,000EFC, thereby taking the total to about $129 per EFC. An additional $9 per EFC would be added for /P engines with the LPT case.

This is equal to a cost of $18 per EFH for an engine operating at 7.2EFH per EFC, and about $19 per EFH for a /P engine.

The third element comprises reserves for the quick engine change (QEC) kit, which is $10-12 per EFH. This takes total reserves to $210 per EFH, and $825-840 per FH for all four engines *(see table, this page)*.

Maintenance cost summary

Total maintenance costs are $1,594-1,634 per FH *(see table, this page)*. This is high in relation to the 747-400. That is, the average seat count for the A340-300 is about 245 compared to about 360 for the 747-400. The 747-400's total maintenance costs are $1,780-1,800 per FH *(see 747-400 maintenance analysis & budget, Aircraft Commerce, April/May 2007, page 14)*. This gives the A340-300 a relatively high maintenance cost per seat.

The main contributors to the A340-300's relatively high maintenance costs are its engine reserves. These are $210 per EFH, and $840 per FH in total, which are comparable to the 747-400's engine reserves. The A340-300 compares poorly with the 777-200ER on this point, because the latter has engine reserves of $280-300 per EFH, or $560-600 per FH.

The A340-300, however, has competitive base maintenance reserves compared with the 747-400, which has base maintenance reserves of $200-220 per FH. The A340-300's reserves for heavy components are also comparable on the basis of its size.

The A340-300's costs related to its line replaceable units (LRU) are, however, similar to the 747-400's. This is not surprising, given that there is little difference in the capital costs of LRU units.

Engine reserves are mature, and LLPs still have several years before expiry. Reserves for A and base checks are the two elements likely to experience any significant increase in maintenance costs as the aircraft ages. The A340-200/-300 are still in high demand, given the current general shortage of widebodies. The aircraft still offer acceptable operating costs, although they will be overshadowed by the 787 and A350 as these enter service and then operate in larger numbers. AC