A320 family maintenance analysis & budget

The A320 family has the benefit of a low line and ramp check maintenance requirement and a long base check cycle interval.

The oldest A320s are now more than 18 years old. They have completed their first full heavy-cycle check and are approaching their second. New aircraft continue to be delivered at a high rate.

More than 1,400 A320s, 750 A319s and 340 A321s are in operation. The A320 is already the second most popular jetliner in service, making it an important aircraft for most maintenance providers. Its order backlog, and the likelihood that it will remain in production for another eight to 10 years, will take the total number built beyond the 6,000 mark, until a successor is launched. This implies that the A320 could continue operating in large numbers for another 40 years.

A320 in operation

Most A320s operate average flight cycle (FC) times of about 1.5 flight hours (FH), and accumulate about 2,800 FH per year. The A320 has been embraced by several low-cost carriers in recent years, including jetBlue, easyJet, Frontier and Air Asia. These airlines achieve utilisations closer to 10FH per day. In some cases aircraft are flown on routes where flight times approach 2-3FH.

The pattern of operation, average FH:FC and annual utilisation all influence the number of checks and MH consumed over a year of operation or a complete heavy-cycle check. This analysis assumes an average FC time of 1.5 FH, and annual utilisation of 2,800FH and 1,850FC. Based on 355 days of actual operations, with an average of 10 days for downtime for base checks and other maintenance, the aircraft completes an average of 5.3FC and 8.0 per day.

Aircraft operating for 10FH per day, at an average FC time of 2.0FH, would complete up to 3,500FH per year.

Aircraft older than nine years will be approaching their second heavy-check cycle, and experiencing maturity in their airframe and engine maintenance costs.

Maintenance programme

Until the latest revision to its maintenance planning document (MPD), the A320's maintenance programme was similar to that of all other Airbus types, comprising three main groups of independent checks: A Check, C check and structural inspections. The basic 1A group of tasks had three multiples and an interval of 500FH. If performed as block checks, the A cycle would be completed at the fourth check, the A4, which has an interval of 2,000FH.

The 1C tasks had an interval of 15 months, and comprised four multiples of 1C, 2C, 4C and 8C items. These could be grouped into block checks, forming a programme that terminated at the C8 check with an interval of 120 months, equal to 10 years.

The two structural checks had intervals of five and 10 years. For the sake of simplicity, most operators combined the five-year structural check with the C4 check and the 10-year structural check with the C8.

The ability of most operators to utilise intervals between base checks meant that the D check was being performed after eight or nine years of operation. The oldest aircraft that entered service in 1988 and 1989 will therefore go through their second D checks between 2005 and 2007.

The latest revision to the A320 family's MPD contains several changes, including the introduction of some new tasks. Its main effect, however, is to replace letter checks with a usage parameter concept and to further escalate intervals. Former A and C check tasks, for example, now have intervals in one of three task primary usage parameters of FH, FC or calendar time.

"The interval for 1A check tasks was changed from 500FH into system tasks with an interval of 600FH or 750FC based on the primary usage parameter, and zonal tasks with an interval of 100 days," explains Damir Ostojic, project manager of maintenance programmes at Lufthansa Technik. "The decision to perform those tasks together in one work package or to split them into two or three separate ones depends on the operator's FH:FC ratio, monthly utilisation and available downtimes for maintenance. Performing all former A check tasks together for an operator with an FC time of 1.5–2.0FH would mean only about 300-400FC would be reached when the 600FH interval was reached. It is likely, however, that most operators will still perform a generic A check."

While A check inspections have been split into three different interval categories, Emil Frehner, planning at SR Technics, explains that there are still three multiples. "The 600FH tasks have multiples of 600FH, 1,200FH and 2,400FH. The 500FC tasks have multiples of 1,000FC and 2,000FC. The calendar items have intervals of 100, 200 and 400 days. The utilisation pattern of most operators means that these intervals coincide relatively closely, so most perform generic A checks and group these three types of tasks together. Most carriers accumulate about 400FC and 600FH in about 80 days, so they will take advantage of the escalated interval."

"Some operators that Lufthansa Technik supports have an FH:FC ratio of about 1:1 and fly about 200FH per month, so we try to make maximum use of their intervals," continues Ostojic. "We give system tasks an interval of 600FH and zonal tasks a 100-day interval. This different grouping of tasks means we now have to consider complex planning issues such as labour requirements, spares availability, and the discovery of non-routine work in the case of short maintenance downtimes."

A similar escalation and re-definition of task intervals has been made to C check items. "C check items have been split into three groups based on task-specific primary usage parameters of 6,000FH for system tasks, 4,500FC for structural items and 20 months for zonal tasks," says Ostojic. "This allows greater flexibility in planning. Some fleets we support get to 4,500FC and 4,500FH at about the same time, so we would lose about 1,500FH of our 6,000FH interval on system tasks."

Like the A check items, the C check items have retained their multiple intervals. "The four intervals in the old MPD have been retained, so the multiples are now: 6,000FH, 12,000FH, 24,000FH and 48,000FH for tasks with an FH parameter; 4,500FC, 9,000FC, and 18,000FC for tasks with an FC parameter; and 20, 40 and 80 months for tasks with calendar time as a primary usage parameter," says Ostojic.

The structural tasks have also been escalated from five- and 10-year to six- and 12-year intervals. These new intervals allow more flexible planning of base checks, but Frehner explains that most operators will still group the three groups of C check tasks together which causes difficulties in planning. "The generic 4C and 8C checks have intervals of 80 and 160 months, compared to the 72- and 144-month intervals of the structural checks. The timing of the C4/6-year and C8/12-year checks closely coincides, because the full structural check intervals can rarely be utilised due to factors relating to operating schedules, and maintenance planning and availability. Combining these checks avoids increased maintenance downtime and simplifies base-check planning."

Line & ramp checks

Traditional line and ramp maintenance schedules and programmes have specified pre-flight (PF), transit (TR), daily and weekly checks. These checks have included routine inspections from the MPD, but have also been used to clear technical defects as they arise in operation. "The MPD is not intended to be a complete maintenance programme, and so, with the exception of some 'weekly' tasks with an eight-day interval, it only suggests maintenance items below the former A check. The MPD does not actually have any inspections or tasks with an interval lower than 36 hours," explains Ostojic. "Operators define checks that are smaller than the former A check. Many A320 operators have found there are no actual PF or TR checks, but still retain them. The routine tasks can be performed by the flightcrew. Only some technical defects have to be cleared between flights, which is the only time that line mechanics are required."

The 36-hour interval for the 'daily' check means that operators are no longer forced to do this check every single night. On most occasions the check can now be done at an operator's home base, when the aircraft returns home. "We actually have a 48-hour interval for the daily check on the aircraft operated by Swiss," says Jean-Marc Lenz, line maintenance Switzerland at SR Technics. "This allows virtually all of these checks to be done at the home base."

Besides the daily checks, the weekly check is the largest in the line-and-ramp check cycle. PF checks are performed before the first flight of the day, and TR checks prior to all subsequent flights. "The PF check is actually a requirement of Joint Aviation Requirements Operations (JAROPs) or the European Aviation Safety Agency (EASA), so it is the responsibility of operators to include it in the maintenance concept. Most local authorities accept delegation of those tasks to the flightcrew, but some may still require the PF check to be performed by the station mechanic," says Ostojic. "The PF check is mainly limited to a visual walk around and check of emergency equipment that can be performed by the flightcrew, so that no man hours (MH) have to be consumed by line mechanics for the routine parts of these checks."

Nevertheless, on some occasions line mechanics do carry out the routine parts of these checks. "Longer ground times between flights when there is a change of flightcrew may result in line mechanics having to perform the visual inspection," explains Lenz. As a result of these inspections or technical defects that arise in operation, line mechanics are required to work on non-routine maintenance.

Daily checks generally include the visual inspection of PF and TR checks on items such as engines and the brake system, as well as items such as draining fuel tanks, replenishing engine oil, and checking tyre pressures. These checks are usually done overnight and are also often used to clear technical defects. Weekly checks comprise daily checks plus more in-depth inspections of items such as cabin lighting, crew oxygen system, and emergency actuators.

Technical defects

The process of clearing technical defects starts with logging and trouble-

The A320's MPD does not require routine items for transit or pre-flight checks. These can be accomplished by flightcrew, although defects would have to be cleared by line mechanics. The routine tasks in the MPD with the lowest interval are 36 hours.

shooting, followed by either clearing or deferring them. This is streamlined with the aid of the on-board fault detection and analysis system, transmission of default messages to ground stations and automatic on-the-ground analysis.

The A320's centralised fault display system (CFDS) receives system failure messages from the aircraft's components' built-in test equipment (BITE). These messages are displayed on the electronic centralised aircraft monitor (ECAM), which is the top screen in the centre of the flightdeck's main panel. These ECAM messages are sent to the centralised fault display interface unit (CFDIU), which sends them to the multifunction control and display unit (MCDU), but can also transmit them to the operator's maintenance operations control centre via the aircraft communication and reporting system (ACARS) if this is installed on the aircraft. This allows maintenance control staff to analyse fault messages while the aircraft is in flight. Technicians can independently analyse many of the fault messages to a deeper level using the MCDU. The flightcrew are also required to log ECAM messages in the post-flight technical log. The ECAM messages are automatically recorded and produced by the CFDIU, and in addition, these fault and BITE codes can be printed and downloaded. The messages and data on the post-flight report (PFR) are used by line mechanics to isolate and troubleshoot the faults. Fault messages that are transmitted in flight by ACARS can automatically be analysed and displayed by AIRMAN, a computerised tool developed by Airbus that analyses fault codes using electronic versions of troubleshooting and fault isolation manuals, as well as the minimum equipment list (MEL).

This system is designed to reduce both the time spent analysing faults, and the number of MH spent on non-routine maintenance in line-and-ramp maintenance. The system also makes it possible for line mechanics to be ready with the required line replaceable units (LRUs), other spare parts, tools and required labour when the aircraft arrives at the gate. This can avoid an extension of scheduled time at the gate, thereby leading to fewer flight delays and cancellations.

While the system cannot influence the number of MH spent on routine items in line-and-ramp checks, it has contributed to a reduction in MH expenditure on non-routine items. "The on-board computer provides good indications for troubleshooting defects," says Lenz. "The system saves operational time and MH in clearing defects because it provides more accurate information, and is more efficient in locating the exact component with the problem. This reduces the incidence of no-fault-found."

Line & ramp inputs

As described, there are routine and services tasks in PF and TR checks. These are defined by the operators and are required by local authorities in addition to the MPD.

Some airlines can therefore avoid using line mechanics for PF and TR checks, although they may be required on some occasions when the flightcrew are unavailable. "Zero MH are required for PF and TR checks, although some will be used when technical defects arise that cannot be deferred until the daily check is performed," explains Ostojic.

While PF checks for A320s are mostly carried out as a visual walkround inspection of the aircraft, followed by flightdeck systems checks performed by the flightcrew, MH are consumed for non-routine work that arises. An allowance of 0.5MH and $7.0 for materials and consumables, but excluding rotables and LRUs that might be exchanged, should be made for PF checks. On the assumed pattern of operation, 355 PF checks will be performed each year. These will consume about 180MH per year, and cost about $12,600 at a labour rate of $70 per MH. The additional annual cost for materials will be $1,260. The total annual cost for PF checks will be about $14,000.

While TR checks can also be made by flightcrew, some carriers use line mechanics instead. Non-routine work also arises, so MH from line mechanics are consumed. United Services terms its TR checks Number 1 service checks, and uses an average of 0.5MH for the routine inspection and 2.1MH for the non-routine work. LTU Maintenance records a similar total expenditure of 3.0MH for the check. A similar budget of $7 can be used for materials and consumables. The assumed pattern of utilisation means that about 1,480 TR checks will be performed each year. This will take annual total MH consumption for these checks to about 4,40MH, which will cost in the region of $275,000. Use of consumables and materials will be about $10,400 per year.

Daily checks can be performed by one mechanic, and are often done overnight. Estimates of total MH required vary, and largely depend on the number of defects that are selected to be cleared, or remain deferred until weekly checks or A checks. Realistic MPD task quantification estimates are that up to a total of 3.5-5.0MH are consumed during a daily check, being split about 50:50 between routine and non-routine work. A budget of $500 should be allowed for materials.

Given that the pattern of operation will be 355 days per year, 250 daily checks will be performed annually, resulting in a total MH expenditure in the region of 1,250MH, with a cost of about $90,000. Annual cost of materials for these checks will be about $125,000.

Taking into account the MPD tasks for weekly checks, it is estimated that they require about 8MH to complete.

Again, the split between routine and non-routine is about 50:50. Others consume up to 12.0MH, and United Services says that average routine consumption is 3.7MH, and for non-routine work it is 7.6MH. The actual MH used will depend on an operator's policy for clearing defects. About $700 of materials and consumables are used.

While the MPD interval for weekly checks is eight days, operational and planning constraints mean that checks are actually made every six to seven days.

Considering the aircraft will operate for 355 days a year, about 60 weekly checks will therefore be performed. Taking a conservative average of 11.0MH for a weekly check means that about 660MH will be consumed annually for these checks, at a cost of $46,000. Materials and consumables will cost about $42,000.

The total annual cost for these line-and-ramp checks will be $595,000, equal to a rate of $212 per FH *(see table, page 31)*. This cost per FH would fall with a longer average FC time of 2.0FH. The number of TR checks would be reduced to about 950, with a consequent drop in total MH and materials consumed. Small reductions in the number of MH used in line and ramp checks can significantly lower maintenance costs.

A checks

A check intervals have been extended, and tasks split into three groups, as a result of revision 28 to the A320's MPD.

The pattern of operation, average FH:FC ratio and level of aircraft utilisation mean that many operators group these tasks together as a generic A check. This also simplifies planning.

The interval of 600FH for system tasks means that the interval of 500FC for structural tasks will only be partially used if these two groups are performed together. With an annual utilisation of 2,800FH, the 600FH limit will be reached in about 78 days, meaning that the calendar limit of 100 days will not be reached. A checks are more likely to be performed every 450FH, given typical operational and planning constraints. On this basis, six to seven A checks will be performed each year.

Realistic MPD quantifications estimate MH consumption for routine tasks to be 80MH, versus about 27MH specified by the MPD. "About another 10% should be added to this for non-routine items and clearing defects. Interior work, such as cleaning and replacing a few items will add about another 10MH to the total," says Ostojic."

Other maintenance providers report similar MH consumption. "The generic A check consumes about 80MH in the case of the aircraft that we manage," says Lenz. LTU Maintenance reports up to 86MH for larger A checks, while United Services records an average total of 75MH for A checks.

This will will result in about 520MH per year being consumed for A checks, with a cost of up to about $36,500, when charged at a typical industry rate of $70 per MH.

Material and consumables consumption is in the region of $5,000-6,000 per check. Six or seven A checks per year will use about $40,000, taking the total annual cost for A checks to about $77,000. This will be equal to a rate of $28 per FH *(see table, page 31)*.

Base check inputs

Despite revision 28A splitting C check tasks into three groups, many operators still combine these as a generic C check. The content of these checks is different to the C checks under the previous MPD," explains Ostojic. "This is due to 'drop out' tasks, ones that have not been escalated under Revision 28A."

Under the new MPD, the C4 check has an interval of 80 months, which is eight months longer than the six-year structural check. The C8 check has an interval of 160 months, 16 months longer than the 12-year structural check. Since the basic C check has a 6,000FH and 20-month limit, and most airlines will only be able to use about 18 months of this interval, an aircraft completing about 2,800FH per year will have a C check performed about every 4,200FH. This means that the C4 check will actually come due after about 16,800FH and 72 months, making it convenient to combine it with the six-year structural check.

The C8 check will come due after about 34,000FH and 144 months, so it will be convenient to combine it with the 12-year structural check.

This compares to a shorter actual C8/D check interval of about nine years and 26,000FH that aircraft have been achieving under the previous MPD. Since Revision 28A is only about a year old, most airlines will still be bridging their aircraft onto new maintenance programmes.

Under Revision 28A, the six light C checks in the base-check cycle will include routine inspections and non-routine work arising as a result, cabin cleaning, modifications and service bulletins (SBs).

The two heavy checks, the C4 and C8 checks, will include these items, as well as interior refurbishment and stripping and re-painting. The extended interval of the full base-check cycle means that some airlines decide to strip and re-paint at every heavy check.

Since no operators have experience of an aircraft completing a base-check cycle under Revision 28A, all MH and materials cost inputs are drawn from aircraft operating under earlier MPDs.

Light C1, C3, C5 and C7 checks include the C1 tasks and require about 800MH for routine tasks. In the first base-check cycle, they experience a non-routine ratio of 20-30%, which adds about 200MH. Ignacio Diez-Barturen, commercial director at Iberia technical division, explains that it records a non-routine ratio of 20-30% for C1 and C3 checks. This takes the number of routine and non-routine MH for the C1 check to 1,250-1,500, and to between 1,600 and 1,750 for the C3 check.

The number of MH required to complete modifications, SBs and out-of-phase items varies, but an average of 700MH can be used for lighter C checks on aircraft in their first base-check cycle. Airlines will also have to add about 100MH for interior cleaning and cabin work, taking the total to about 1,800MH. Base maintenance labour charged at $50 per MH takes this cost to about $90,000.

Diez-Barturen adds that the totals for C1 and C3 checks vary. The total MH for C1 checks will be about 1,700MH, but up to 3,000MH for C3 checks.

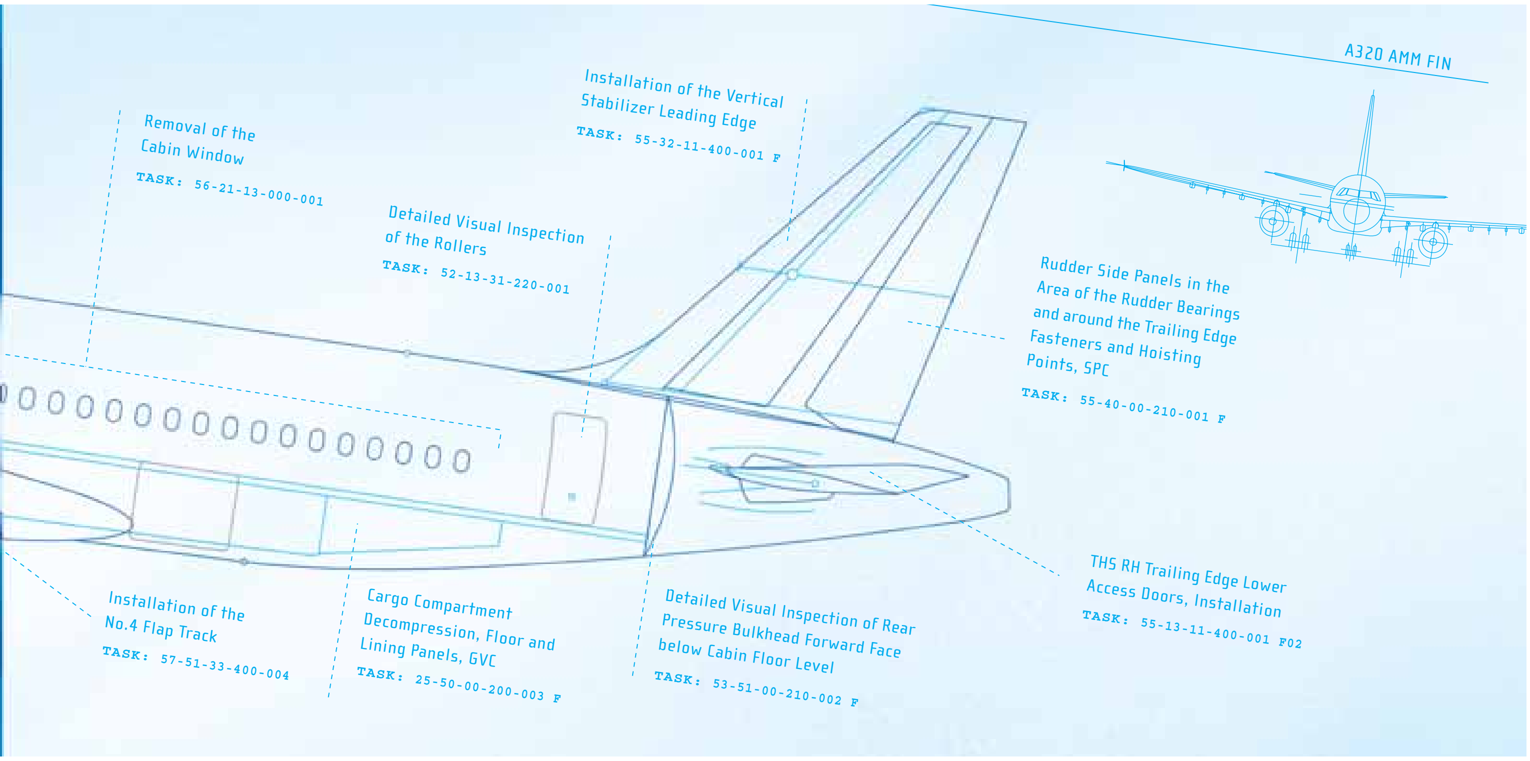
Consumption of materials and consumables is at $20 per MH, so $36,000 should be budgeted for these checks. The total check cost will be about $126,000.

C2 and C6 checks include the C1 and and C2 task items. This increases the number of routine MH to about 950, while a non-routine ratio of about 30% adds a further 300MH. Diez-Barturen says that Iberia uses about 1,250MH for routine work, with a non-routine ratio of 25-40% adding about another 650MH.

Modifications, SBs and interior works add another 800MH, taking the total to 2,050-2,500MH, equal to $102,500.

Materials and consumables will be about $41,000, taking the total cost for the check to $143,500.

The C4 check includes routine items for C4 tasks and five- or six-year structural inspection, and so requires a lot of access. MH for routine tasks and access will total in the region of 4,500. A non-routine ratio of 55% will add another 2,500MH, and modifications another 1,800MH. A further 4,000MH will be used for interior refurbishment



and in the region of 1,500MH for stripping and painting. Diez-Barturen estimates that stripping and painting during this check will add about 1,200MH and a further $14,000 for the cost of the paint. This takes the total for the check to about 14,300MH. Aircraft that have lower non-routine ratios, and use fewer MH for interior work, will have lower total MH consumptions of about 12,500MH. The labour portion will have a cost of about $625,000-715,000.

Materials and consumables will total $250,000-285,000. An additional cost of about $50,000 can be expected for the repair of soft-time or on-condition components removed during the check, as well as another $60,000 for materials used in cabin refurbishment. The total for materials and component repairs will therefore be $360,000-395,000.

The composition of C8 checks is similar to C4 checks. MH for routine items and access have been in the region of 7,500MH for aircraft in their first cycle. Defect ratios of 50-60% increase this to 11,500-12,000. An additional 2,000MH should be allowed for modifications and SBs, 5,000MH for cabin and interior refurbishment, and 1,500MH for stripping and painting. This will take the total MH to about 20,000. The total expenditure for many aircraft drops when MH used for modifications, SBs, and routine, non-routine and interior work are reduced. This has taken labour down to 18,000MH, equal to charge of $900,000.

Consumption of materials will be at a rate of about $25 per MH, so equal to about $450,000. Additional materials for interior refurbishment will be in the region of $100,000, while the cost of on-condition and soft-time component repairs will be about $60,000. This will take the total cost for the check to about $1.5 million.

A total of 43,500MH are used for the first base-check cycle. The total labour and material cost for the full base-check cycle will be $3.3-3.5 million. When amortised over the interval of 26,000FH that is achieved by most airlines over a nine-year period, the total reserve for these base checks is $128 per FH *(see table, page 31)*. If the MH and material consumption are the same for an aircraft completing 34,000FH in its base-check cycle, when operating under a Revision 28A MPD, this reserve will fall to $98 per FH.

There are, however, small differences between the A320, and the smaller A319 and the large A321. While many tasks are the same irrespective of aircraft type, Diez-Barturen estimates that on average there is a difference of about 5% between the A320 and its two smaller counterparts.

Aircraft that have been through their second base-check cycle will experience an increase in MH, due to more routine tasks, higher non-routine ratios and a higher level of modifications and SBs. Total MH for the base-check cycle can reach 48,500. The consumption of materials will also rise with MH, and as more components are removed for repair. Total material expenditure will reach up to $1.5 million. This will take total cost for the eight base checks to about $3.9 million, which will increase the base-check reserve to about $150 per FH. This could be kept down to about $115 per FH for aircraft operating under a Revision 28A MPA and with a base-check interval of 34,000FH.

Heavy components

Heavy components comprise four groups: wheels, tyres and brakes; landing gears; thrust reversers; and the auxiliary power unit (APU). These are sometimes referred to as 'off-aircraft components', because they have independent maintenance programmes.

The maintenance of these four groups of components is FC related, and their costs are summarised *(see table, page 26)* by repair intervals, factors affecting the number and cost of repairs, the total cost for repairs and replacement over the repair cycle, and the resulting cost per FC. This is $15 per FC for the retreading and replacement of tyres, $9 per FC for wheel inspections, $64 per FC for brake repairs, $19 per FC for landing gear exchange and repair, $29 per FC for thrust reverser repairs and overhaul, $44 per FC for APU maintenance. This totals $180 per FC for all heavy components, and equals $120 per FH for the aircraft operated at an FC time of 1.5FH *(see table, page 31)*.

Rotable support

The majority of the A320's rotable and repairable components are on-condition. While some will be inspected and may be removed during base checks, the majority can be removed relatively easily during line, ramp and A checks. Few airlines have their own repair shops and complete inventories to be self-sufficient in rotable and repairable component support.

Rotable support contracts can be provided on the basis of the airline leasing a homebase stock from the rotable support provider. This usually includes high-failure-rate and 'no-go' components. "The value of stock for a fleet of 20 A320s each operating at about

A320 FAMILY HEAVY COMPONENT MAINTENANCE COSTS

Tyre retreads & replacement	Number	Removal FC	Number retreads	Total life FC	Retread cost/tyre	Shipset retread $	Total all retreads $	New tyre $	Shipset new tyre $	Total cost $/FC
Main wheels	4	300	4	1,500	600	2,400	9,600	1,600	6,400	11
Nose wheels	2	200	4	1,000	300	600	2,400	400	800	4

Wheel inspections	Number	Removal FC	Repair $	Shipset repair $	Repair $/FC
Main wheels	4	300	450	1,800	6
Nose wheels	2	200	250	500	3

Brake repairs	Number	Heat pack life FC	Repair $	Repair $/FC	Shipset repair $/FC
	4	2,100	33,000	16	64

Landing gear	Interval	FH interval	FC interval	$ exchange	$/FC
	10	28,000	18,350	340,000	19

Thrust reversers	Number	FC interval	Workscope	Repair $	Total $	$/FC
	2	12,000	Intermediate	170,000	340,000	29

APU : GTCP 331-250	APU hours SV interval	APU hours/FC	FC interval	Shop visit $	$/FC
	5,500	1.2	4,600	200,000	44

2,600-2,800FH per year will be $10 million, and will have a lease rate of $120,000 per month," says Joerg Asbrand, manager aircraft component services at Lufthansa Technik. "This equates to about $28 per FH for each aircraft."

Rotable support providers also give airlines access to serviceable units of all other types of components as they fail and need to be removed. These are provided within an agreed time limit and on an exchange basis.

Asbrand says the cost for this element of the contract will be about $30 per FH. The largest element, however, will be the fee for the repair and management of the failed components. "This will be $110-115 per FH for an airline that has reasonable transport time and customs costs when considering the location of the support provider," continues Asbrand. This results in an overall cost of $170-180 per FH. The SB and modification status of the components must also be considered.

Engine maintenance

As described, the A320 family is dominated by aircraft powered by the CFM56-5B series and V.2500-A5 series *(see A320 family fleet analysis, page 9)*. These two engine types provide the aircraft with similar levels of operational performance, and so their maintenance cost is an important issue in influencing engine selection.

The information here applies to the CFM56-5B/P and V.2500-A5 engines, under a generic operation with an FH:FC ratio of 1.5. Actual figures obviously vary with specific operating conditions.

CFM56-5B series

The CFM56-5B series can be split into three main groups that power the A319, A320 and A321. The majority of A319s are powered by the CFM56-5B5 and -5B6. These are rated at 22,000lbs and 23,500lbs thrust and have high initial production exhaust gas temperature (EGT) margins of 110-165 degrees centigrade. Most A320s are powered by the CFM56-5B4 rated at 27,000lbs thrust, which has an initial production EGT margin of about 110 degrees centigrade. The majority of A321s are powered by the CFM56-5B3 rated at 33,000lbs thrust, which has an initial production EGT margin of about 66 degrees centigrade.

"The initial rate of EGT margin loss is about 15 degrees in the first 1,000 engine flight cycles (EFC)," says Russell Jones, programme manager at Total Engine Support. "This then falls to about five degrees per 1,000EFC thereafter." This implies that the -5B3 could theoretically remain on-wing for up to about 11,000EFC before losing all EGT margin. Lower-rated engines with higher margins can remain on-wing for longer.

Actual rates of EGT margin vary with the engine flight hour (EFH) to EFC ratio. "After the initial loss, EGT margin will deteriorate by 2.0-2.5 degrees per 1,000EFH at an average EFC time of 1.5EFH," says Pierre-Emmanuel Gires, vice president of customer operations at Snecma Services. This is equal to 3-5 degrees per 1,000EFC.

First removal intervals for the lower-rated engines powering the A319 can therefore be up to about 16,000EFC. "The -5B series will have first on-wing intervals of 10,000-15,000EFC in most cases when operating in average conditions with a take-off temperature of 64 degrees fahrenheit, a 10% de-rate and an average EFC time of 1.5EFH," says Gires.

"Most first on-wing intervals for the -5B5 and -5B6 engines on the A319 are 10,000-16,000EFC in average conditions," says Jones. "The -5B7 powering the A320 averages about 10,000EFC for its first interval in the same circumstances, while the -5B3 powering the A321 will have intervals in the region of 7,000EFC."

All engines usually require a hot-section restoration at their first shop visit. "The amount of EGT margin that engines recover depends on their shop visit workscope, but will be about 60% of initial margin following a hot-section restoration or inspection, and 80% following a full performance restoration or overhaul," explains Jones, "A hot-section restoration will result in margins of about 40 degrees centigrade for the highest-rated engines that power the

The latest revision to the A320's MPD has extended the basic C check interval to 6,000FH, and the C8 to 48,000FH. The structural checks have had their intervals increased to 6 and 12 years. Considering planning and operational constraints, this will allow the base check cycle to be completed about every 12 years, the C8 and 12-year check combined.

A321." This implies that the engine could have a second on-wing run of up to 6,000EFC. Lower-rated engines will be capable of longer intervals of about 7,500EFC, but other limiting factors have to be considered. One factor concerns the remaining lives of life limited parts (LLPs). The lives of some LLPs can be completely used during the second on-wing run, depending on engine thrust rating, and so force removals. Some lower-thrust-rated engines achieve longer intervals in friendly environments, and a core performance restoration is likely to be more suitable.

The CFM56-5B series has 19 LLPs with varying lives. Jones explains that the three parts in the fan section have lives of 25,000EFC when powering the A319 and A320, and 20,000EFC when powering the A321, with a list price of $380,000.

The high-pressure compressor (HPC) LLPs have lives of 18,200EFC for engines powering the A319 and A320, and lives of 17,200EFC for higher-rated engines powering the A321. They have a list price of $440,000.

LLPs in the high-pressure turbine (HPT) have a list price of $450,000, and lives of 17,600EFC when powering the A319 and A320. They have shorter lives of 14,300EFC when powering the A321.

LLPs in the low-pressure turbine (LPT) have lives of 25,000EFC when powering all A320 variants, and a list price of $610,000 (including LPT case).

The engines powering the A321 are likely to have accumulated a total of 12,000-13,000EFC by the second removal, with only a little over 1,000EFC remaining on their HPT LLP lives. These LLPs certainly have to be replaced at the second shop visit, but careful consideration must be given to HPC LLPs. These will have about 5,200EFC remaining, which is about equal to the expected interval following the second shop visit, and so could be left in the engine and removed at next shop visit.

Lower-rated engines will have accumulated a total time of about 17,500EFC at their second shop visit, which will be forced by expiry of the HPT and HPC parts. LPT and fan LLPs will remain in the engine until the third shop visit after about another 7,500EFC and a total time of 25,000EFC. At this stage the engines will have accumulated a total time of about 25,000EFC, equal to the life limits of the fan and LPT parts.

Probable on-wing intervals and timing of LLP replacement have to be considered together with shop visit workscopes. "While all engines will have a hot-section restoration at their first shop visit, the level of parts replacement or repair will depend on engine rating, with higher-rated engines requiring heavier restorations," says Jones. "The lower-rated engines powering the A319 and A320 will require a full performance restoration as well as the replacement of HPT and HPC LLP limits after accumulating about 17,500EFC. Their LPT and fan LLPs would be replaced at the third shop visit, after a total time of 22,000-25,000EFC. The engine powering the A321 will have accumulated a shorter time of about 12,000EFC at the second visit, and so only require a full core performance restoration. HPT LLPs should be replaced at this stage, but HPC LLPs could be left in. Engine management would probably be simpler if all core LLPs were replaced, with a stub life of 5,000-6,000EFC, and sold on the aftermarket." In this scenario, and with probable mature on-wing intervals of about 5,000EFC, fan and LPT LLPs would be replaced at the fourth shop visit. While the varying lives of LLPs in the CFM56-5B require careful management with respect to on-wing intervals and shop visit workscopes, many of the LLPs can be used in other variants. Parts with stub lives can probably be used on other CFM56 engines, such as the CFM56-5C, due to its low cycle usage of only a few hundred EFC per year.

"Most engines will follow a shop visit pattern of alternating core restorations and full overhauls, with on-wing intervals for mature engines on the A321 being in the region of 5,000EFC, and 7,000-8,000EFC for engines on the A319 and A320," says Gires.

Depending on thrust rating, first shop-visit core restorations require 2,700-3,100MH, and a total of $625,000-700,000 in materials and sub-contract repairs. A labour rate of $70 per MH would take the total shop visit cost to $800,000-920,000, depending on engine rating.

This equals a reserve of $49 per EFH for the engine powering the A319, $56 per EFH for the engine powering the A320 and $87 per EFH for the engine powering the A321.

Second shop visits, which comprise an overhaul, require higher labour inputs of 3,700-4,500MH and $775,000-975,000 in materials and sub-contract repairs. This takes the cost of these heavier visits to about $1.05 million for engines powering the A319, $1.15 million for engines powering the A320 and $1.3 million for engines powering the A321.

This is equal to a reserve of $106 per EFH for engines powering the A319 and A320, and $172 per EFH for engines powering the A321.

Reserves for LLPs have to be added. While LLPs have different lives depending on thrust rating, engines powering the A319 and A320 can generally be expected to replace core LLPs at every second shop visit and every 15,000EFC, while fan and LPT LLPs would be replaced at every third shop visit and every 22,500EFC. Without assuming any remaining value for stub LLPs, reserves would be about $105 per EFC.

In the case of A321 engines, HPT and HPC LLPs would be replaced about every third shop visit, fan LLPs replaced every

The A320's total maintenance costs are influenced most by the cost of line and ramp checks, base checks, rotables, and engines. Bridging to the latest MPD can allow operators to save about $30 per FH on the cost of base check reserves. Increasing average FC time from 1.5FH to 2.0FH reduces total cost per FH by about $110.

fourth, and LPT parts every fourth or fifth. These replacement intervals result in an LLP reserve of about $110 per EFC.

When shop visit and LLP reserves are combined, the lower-rated engines on the A319 and A320 will have a total reserve of $120-126 per EFH for the first interval, and reserves varying between $157 and $176 per EFH for the second and third interval *(see table, page 31)*. The engine powering the A321 will have a reserve of $161 per EFH during the first interval, and then $215-245 per EFH during the second and third interval *(see table, page 31)*.

V.2500-A5 maintenance

Like the CFM56-5B, the V2.500-A5 series has a high EGT margin. "The production margin for new engines is 90-115 degrees centigrade for the V.2522/24-A5 powering the A319, 70-80 degrees for the V.2527-A5 powering the A320, and 40-60 degrees centigrade for the V.2530/33-A5 powering the A321," says Phillip Stott, programme manager at Total Engine Support. Most A319s are powered by V.2522-A5 and V.2524-A5 engines, most A320s by the V.2527-A5, and most A321s by the V.2533-A5.

After initial EGT margin loss, deterioration rates are about 4 degrees per 1,000EFC for low-rated engines, 4.5 degrees per 1,000EFC for medium-rated engines, and about 6 degrees per 1,000EFH for high-rated engines when operating at an average FC time of 1.5FH.

The EGT margin on the higher-thrust V.2530/33-A5 can be low enough for it to limit the on-wing interval achieved by the engine. Typically, however, this will coincide with the third shop visit and LLP replacement. Lower-rated engines are not limited by EGT margin, and removals are forced by distress or replacement of LLPs.

"The V2527-A5 on the A320 will typically run for about 10,000EFC until the first shop visit," says Stott. "The V.2530/33 engines powering the A321 run for 7,000EFC until the first shop visit." It is not unusual to see engines staying on-wing longer.

All engines will go through a hot-section refurbishment at their first shop visit. At this stage probable second on-wing intervals and the remaining life of LLPs should be considered. The V.2500-A5 benefits from having a set of 25 LLPs with uniform lives of 20,000EFC for current part numbers. This simplifies engine management. LLPs removed with more than 3,000EFC remaining can often be sold on the aftermarket to operators that have a long average EFC time.

"The V.2500-A5 has a reputation for being able to recover up to 90% of its initial EGT margin. Lower-rated engines for the A319 and A320 can achieve intervals of about 7,500EFC after their first shop visit, taking total time at the second removal to about 17,500EFC," explains Stott. "These engines can be expected to conform to a pattern of shop visits that alternate between a core restoration and full refurbishment. The total time at the second removal and similar third run of 7,500EFC means the LLPs would have to be removed at this shop visit, with a stub life of about 2,500EFC."

"Higher-rated engines will remain on-wing for about 5,000EFC during the run to the second shop visit, and so will have a total accumulated time of about 12,000EFC at the second removal," continues Stott. "These engines are more likely to go through a pattern of two consecutive hot-section refurbishments, followed by a full refurbishment every third shop visit. The workscope of the second hot-section refurbishment may be a little heavier than the first. Total time at the third shop visit would be about 17,000EFC, making it appropriate for LLPs to be replaced."

Under this pattern of management LLPs in most engines would be replaced after a total time of 17,000-18,000EFC. The shipset list price of $1.9 million means that LLP reserves will be in the region of $105-110 per EFC.

A hot-section refurbishment shop visit will consume 3,500-3,750MH, about $100,000 in sub-contract repairs, and $450,000-475,000 in parts and materials. A labour rate of $70 per MH would take total cost for this shop visit to $795,000-840,000. This results in a reserve rate of $53-56 per EFH when amortised over the first on-wing interval of 15,000EFH. When combined with LLP reserves, total reserve for engine maintenance is $126-130 per EFH for these lower-rated engines on their first on-wing run.

The following refurbishment workscope at the second shop visit will use 4,750-5,000MH, $200,000-250,000 in sub-contract repairs, and $670,000-700,000 in parts and materials. This takes the total cost of this refurbishment to $1.2-1.3 million. Amortised over the shorter interval of about 11,500EFH, this results in a reserve of about $108-116 per EFH. The addition of LLPs takes this to a total of $180-188 per EFH *(see table, page 31)*.

The initial workscope of the high-rated engine powering the A321 will consume about 4,000MH, $100,000 in sub-contract repairs, and $500,000 in parts and materials, resulting in a shop visit with a cost of about $880,000. This has a reserve of about $84 per EFH. The total reserve will increase to $158 per EFH when reserves for LLPs are added.

The second workscope, a heavier hot-section refurbishment with limited HPC work, will consume about another 500MH and $250,000 in materials, parts and sub-contract repairs, resulting in a total shop visit cost of about $1.15 million. This will have a higher reserve of $155 per EFH. Additional reserves for LLPs will take total reserves to about $230 per EFH *(see table, page 31)*.

The third visit, a full refurbishment, will use up to about 5,000MH and about $1 million in parts and repairs. The higher shop visit cost of about $1.35 million will have a reserve of $180 per EFH, and will total $255 per EFH when LLPs are added *(see table, this page)*.

Engine inventory

Operators must also consider engine inventory. Airlines have the choice of engine ownership and long- or short-term leasing. Engines that are constantly being utilised will always be owned, although the major engine lessors are available for sale and leaseback transactions if operators want to release the cash value of their assets. The supply of V.2500 and CFM56-5A/B engines is tight, and has reduced as the average engine shop-visit rate across the fleet has increased. "V.2500-A5s are effectively at list price, which for a bare engine is about $7.5 million for a V.2527," says Tom MacAleavey, senior vice president of sales and marketing at Willis Lease Finance. "The value increases to about $8.0 million for a V.2530 and is $6.0 million for a V.2522. There are few or no engines available in the market to buy, and values only decrease by an amount equal to the cost of accrued maintenance."

This shortage has also strengthened lease rates. "While there is a shortage of engines to buy, the lease market is strong," says Richard Hough, vice president technical at Engine Lease Finance. "Long-term lease rates are competitive, and lease rate factors are about 0.8% per month of market value. Long-term lease rates for V.2500-A5 engines will therefore be between $48,000-64,000 per month, depending on variant."

The long-term lease market for the CFM56 is similar. "More CFM56-5Bs are available than V.2500-A5s," says MacAleavey. "A CFM56-5B4 for the A320 has a bare engine value of $7.2 million, and $8.7 million when equipped with a quick engine change (QEC)."

Hough estimates similar values for the CFM56-5B, with the -5B3 at $9.1 million for an engine with a QEC, and about $7.2 million for a -5B5 with a QEC. "These values would put long-term lease rates for the CFM56-5B at $58,000-73,000 per month, depending on thrust rating."

Values for CFM56-5As have come under pressure in recent years with a large number of aircraft on the market, but have increased again to about $5 million.

Short-term lease rates also have to be considered, and are relatively high, but Hough explains that few engines are available. "Short-term rates for engines like the V.2500-A5 can be in the region of $4,000 per day, equal to $120,000 per month, due to lack of supply," says MacAleavey. "Short-term rates for the CFM56-5B are lower, with more engines available on the market, and rates are in the region of $2,500-2,800 per day. Daily rates for the CFM56-5A are in the region of $2,300."

DIRECT MAINTENANCE COSTS FOR A319/A320/A321

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	595,000	2,800		212
A check	77,000	2,800		28
Base checks	3,500,000	26,000		128
Heavy components:			180	120
LRU component support				180
Total airframe & component maintenance				**635-700***
*** ±5% variation about $668 per FH for A319 and A321**				
Engine maintenance:				
2 X CFM56-5B5/-5B6 (A319)				314-352
2X CFM56-5B4 (A320)				314-352
2X CFM56-5B1/-5B2/-5B3 (A321)				430-490
2 X V.2522/24-A5 (A319)				360
2 X V.2527-A5 (A320)				380
2 X V.2530/33-A5 (A321)				460
Total direct maintenance costs:				
A319 (CFM56-5B5/-5B6)				950-987
A320 (CFM56-5B4)				982-1,020
A321 (CFM56-5B1/-5B2/-5B3)				1,130-1,190
A319 (V.2522/24-A5)				995
A320 (V.2527-A5)				1,048
A321 (V.2530/33-A5)				1,160

Annual utilisation:
2,800FH
1,830FC
FH:FC ratio of 1.5:1.0

Summary

There is a variation of $160-240 per FH in the total maintenance costs of the A319, A320 and A310 *(see table, this page)*. The main factor in this difference is due to engine-related maintenance costs. The total of airframe- and component-related costs varies between $635 and $700 per FH for aircraft in their first base-check cycle. These can be reduced by about $30 per FH if aircraft are changed to a maintenance programme base on Revision 28A of the MPD. Base check reserves increase by about $20 to $150 per FH for aircraft in their second cycle, but would be about $115 per FH if operating under Revision 28A.

Engines account for up to 40% of total costs. Other main constituents are line and ramp checks, base checks, and LRU component support.

The effect of increased FH:FC ratio to 2.0 would reduce the number of line and ramp checks performed, with a corresponding drop in cost per FH. This would be mainly due to fewer TR checks being required over a given period, and would reduce costs by about $10 per FH.

The same change would also result in a drop in engine reserves. The amortisation of LLPs would be reduced from their current level of about $75 per FH (when the rate of $105-110 per EFC is amortised over 1.5EFH) to about $55 per EFH; reducing total aircraft maintenance costs by about $40 per FH.

Engine reserves would also be reduced by about $30-40 per EFH, and so maintenance costs for both engines would be reduced by about $65 per EFH.

The change of maintenance programmes to one based on Revision 28A of the MPD could also reduce reserves for base-related checks by about $30 per FH.

It is therefore possible for aircraft to have total maintenance costs in the order of $110 per FH less than shown if an average FC time of 2.0FH is flown. AC