ATR 42 & 72 maintenance analysis & budget

The ATR 42 & 72 have a complex base maintenance programme, but engines and rotable components are the highest elements of maintenance costs.

There are 630 ATR 42s & 72s in operation, and another 120 aircraft on order. The aircraft continue to sell well, and both can be expected to continue in operation for another 20 years. The aircraft's main role is as a regional passenger carrier, but the number being converted to freighters will steadily increase. The maintenance costs of mature aircraft are analysed here.

ATR 42 & 72 in operation

The majority of ATR 42s & 72s are operated by airlines in the US and Europe, with large numbers in service in Africa and India. Most are operated as regional feeders, flying sectors of 35-50 minutes in most cases. Few airlines have operations where the average cycle time exceeds one flight hour (FH). Cimber Air in Denmark, for example, operates a fleet of three ATR 42s and four 72s on domestic services between Copenhagen and smaller Danish cities, with flight times averaging only 30 minutes.

Other carriers have similar styles of operation. Finnair's ATR fleet, for example, accumulates 2,000-2,400FH per year with an average FC time of 45-50 minutes. Most passenger operations have operations with similar average FC times and annual rates of utilisation, and so accumulate 2,600-2,900FC per year.

Freight operators generally use the aircraft on longer cycles of about one FH, but accumulate fewer FH per year as a result of the nature of their operations.

Maintenance costs

All elements of the ATR 42's & 72's maintenance costs are examined and analysed here, starting with the aircraft's maintenance planning document (MPD) and maintenance programme, line and ramp checks, A checks, C checks and related base check items, heavy components, rotable components and engine maintenance.

Many elements of the aircraft's maintenance are related to FCs, and the total maintenance cost per FH is influenced by the aircraft's pattern of operation, average FC time and rates of utilisation. This analysis assumes that an aircraft accumulates 170FH per month, or 2,000FH per year. The average FC time is 50 minutes, so the aircraft completes 200FC per month or six to seven flights per day. This is equal to 2,400FC per year.

Maintenance programme

The ATR 42's & 72's maintenance programme is based on A checks, C checks and other base check inspections (calendar) that operators usually combine with C checks. The programme is based on maintenance steering group 3 (MSG3) principles.

"The ATR 42 and 72 have almost identical numbers of inspections in their MPDs," explains Pascal Pastor, senior vice president of sales at Sabena technics. "The ATR 72 has 2-8% more MPD tasks (depending on the operator and the systems installed), which are mainly structural and system items that are related to the engines, and additional fire extinguishers and oxygen bottles."

The ATR's A check has a basic interval of 500FH, and there are tasks with multiple intervals that result in a cycle of four block checks. These are the A1, A2, A3 and A4 checks. The A4 check and the cycle therefore have an interval of 2,000FH. "The A checks only include system items," says Pastor. "The checks have a downtime of about two days to complete, including rectifications and supplemental tasks due at that time."

The base check programme comprises several groups of tasks. First there are the actual C check items. "There are the 1C, 2C and 4C tasks, with intervals of 4,000FH, 8,000FH and 16,000FH. These are just system tasks," explains Pastor. "When performed as block checks, the C1 and C3 checks have just 1C tasks, the C2 check has 1C and 2C tasks, and the C4 check has 1C, 2C and 4C tasks. The average downtime to complete one of these checks is one to two weeks, depending on the check combination."

The next group of base check tasks comprises the structural inspections. These are divided between fatigue damage items with FC intervals and environmental and corrosion-related items with calendar intervals.

The maintenance programme of FC fatigue tasks is complex. "Fatigue tasks

The ATR 42's & 72's base maintenance programme comprises three major portions of system, FC-fatigue and calendar-fatigue tasks. Despite the aircraft operating on average cycle times of less than one hour, inputs for base checks result in maintenance reserves of less than $100 per FH.

The PW120 series engines powering the ATR family are relatively simple, with just 10 LLPs. Engine removal intervals of 7,500EFC and 15,000EFC can be targeted, which conveniently match LLP lives of 15,000EFC and 30,000EFC.

have intervals that are multiples of 3,000FC. There are a small number of tasks with initial and repeat intervals of 3,000FC, 6,000FC and 12,000FC, and the FC-related fatigue tasks only get to be a significant amount when the aircraft has accumulated 24,000FC. This is because there is a large increase in the number of 3,000FC, 6,000FC and 12,000FC tasks at this point. Before this threshold is reached, fewer than 10 tasks have to be performed in a C check. These only generate 10-15 routine man-hours (MH)," explains Gareth Rees, managing director Cimber Air Maintenance.

If the C1, C2, C3, C4 and C5 checks were performed every 4,400FC, then the C5 check would be due after 21,700FC. The single 3,000FC tasks would be performed every check, the single 6,000FC task in the C1, C2 and C4 check, and the five 12,000FC tasks done in the C2 and again in the C4 checks.

The C5 check is therefore when there is a large increase in the number of FC-related tasks, since the C6 check would be at 26,000FC. Here a larger number of 3,000FC, 6,000FC and 12,000FC tasks must be performed.

The next large group would be at 36,000FC, in this case the C8 check at about 34,700FC, when all groups of tasks would come due. Given that most aircraft accumulate 2,000-3,000FC each year, the 36,000FC limit is reached after 12-18 years. It is therefore unlikely that these inspections will have to be performed twice in the aircraft's operational life. The next largest check would be the C11 check, after about 48,000FC, when the 3,000FC, 6,000FC and 12,000FC tasks come due.

The environmental and corrosion inspections have intervals of two, four, eight and 12 years. These are zonal checks. Fuel tanks, for example, are inspected at the 12-year check, either by a video inspection, which can only be done by ATR, or by a full opening of the tank, which uses more MH but can be done by the operator or an independent maintenance facility.

Check planning

The three categories of base check inspections have to be organised and planned to minimise downtime. "We try to plan base checks on the ATRs so that no base maintenance is required for up to two years," says Veijo Paakkonen, ATR & S340 project engineer at Finnair Technical Services. "The C check's 4,000FH interval is twice that achieved by most operators on an annual basis. Obviously aircraft that generate more than 2,000FH per year would require base maintenance more frequently than every 24 months. A 4,000FH interval in our case is close to about 6,000FC."

In the case of an ATR42 or 72 achieving a utilisation of 2,000FH and 2,400FC per year, the aircraft would accumulate 4,800FC after a 4,000FH interval.

First, C checks can be performed every two years for an aircraft accumulating 2,000FH per year. Actual planning and operational constraints at most airlines mean that this is more likely to be every 3,600FH, rather than using its full interval. This would be equal to 21-22 months. The aircraft will therefore accumulate 3,600FH and 4,400FC between C checks. The number of cycles will be higher for aircraft operating short average cycle times. Some operators accumulate up to 3,000FC per year with their aircraft, and so 5,250-5,500FC between C checks.

The cycle of C checks, finishing with the C4 check, will therefore be completed after 86 months, equal to seven years.

The FC-related fatigue tasks have various intervals, and how they fall into each of the C checks has been described.

The calendar-related fatigue tasks similarly have to be combined into the base checks. The eight-year tasks will come due every fourth check, at the C4, C8 and C12 checks. The 12-year tasks will come due at the C6 check, and can be done again at the C13 check. The four-year items will come due at the C2 and C10 checks, and the two-year tasks at all other checks.

The overall effect of base check organisation is a varying amount of routine base check tasks that have to be performed in each check. The first of the largest base checks is the C4 check, performed at eight years, with all C tasks, three groups of FC-related, and the eight-year calendar-related fatigue tasks. The C8 check is the largest, with all C tasks, most FC fatigue tasks and three groups of calendar-related fatigue tasks to perform.

The C2, C6, C10 and C11 checks are relatively large, with 1C and 2C items, and several groups of FC and calendar tasks to complete.

The approximate number of MH to complete these routine inspections is about 350 for the 1C items, while the 1C and 2C together use 700MH. The 1C, 2C and 4C tasks require 900MH, which is the largest MH requirement for the system-related tasks.

The number of MH required for the FC-related tasks is only 10-15MH for the C1, C2, C3 and C4 checks. The labour requirement rises to 150MH, however, at the C5 and C7 checks. The threshold of 36,000FC results in a requirement of 1,600MH for the routine FC inspections. The C11 and C12 checks both use 850MH for these tasks.

The calendar-based tasks vary in their labour requirement from 226MH for two-year check items, to 1,221MH for eight-year check items.

Overall, the variation in labour requirement for system tasks, FC inspections and calendar-based inspections results in the routine MH requirement for C checks varying from 590MH for a C1 check to 3,685MH for the C8 check. The C4 check will use 2,121MH, and the C12 check 2,956MH. The other checks have smaller MH requirements.

Line check inputs

The ATR's line check programme includes transit checks prior to each flight, a daily check performed every 24 hours, and a weekly check. Transit checks use an average of one MH, but as these can be performed by the flightcrew, they rarely require input from line maintenance. They also use a minimal amount of consumables.

About 350 daily checks will be performed each year. The checks may only use one or two MH of labour, and three MH can be used as a conservative budget, and $40 of materials. A labour rate of $70 per MH for line maintenance takes the total cost for the check to about $250.

A weekly check will use five to 10MH and about $200 in materials and consumables. A theoretical labour rate of $70 per MH will take the check's cost to $350-700. About 50 of these checks will be performed each year.

The total cost for daily and weekly checks for the year will be $120,000-140,000, equal to $60-70 per FH *(see table, page 20).*

A check inputs

While the A checks have an MPD interval of 500FH, the actual interval achieved by airlines is more likely to be 350-400FH. This means that the aircraft will require four to six A checks each year, depending on how each operator utilises the 500FH interval. "The total labour cost for the A check package averages about 150MH for a mature aircraft," says Pastor. "Use of materials and consumables is about $2,000-2,500."

A theoretical labour rate of $70 per MH would take the cost of the labour portion of the A check to $10,500, and the cost for the entire check to $12,500-13,000. If five of these checks are performed each year, it will take the total cost to $62,500. This will be equal to $32 per FH when amortised over the annual utilisation of 2,000FH (see table, page 20).

Base check contents

In addition to these routine tasks, non-routine rectifications will increase the workscope of the check. Other items will include service bulletins (SBs), airworthiness directives (ADs) and engineering orders (EOs). The aircraft will also require interior work. This will mainly consist of cleaning, but it will also include some refurbishment work. Because of their role as regional aircraft, ATRs will not require the same level of interior refurbishment as jetliners. Base checks will also include the removal and installation of hard-timed rotable components.

"The base check workpackages will also include work for ADs, SBs and EOs," continues Rees. "This portion of the check varies widely between 50 and 800MH, depending on what work is due. There have been several large SBs and ADs due on the ATR 42 and 72. One of the largest of these is the insulation blanket modification, which also affected the MD-11. This required about 500MH to complete on the ATR 42 and about 800MH on the ATR 72." Not all ATRs are affected by the AD, however, since this only applies to aircraft that have certain types of insulation blanket material installed.

"There have also been several major

ATR FAMILY HEAVY COMPONENT MAINTENANCE COSTS

FH & FC per year Average FC time of FH	ATR 42	ATR 72
Number of main & nose wheels	4 + 2	4 + 2
Tyre replacement interval-FC	800	800
Tyre shipset replacement cost-$	4,650	5,250
$/FC retread & replace tyres	**6.0**	**7.0**
Wheel inspection interval-FC	2,400	2,400
Main & nose wheel inspection cost-$	7,400	7,400
$/FC wheel inspection	**3.0**	**3.0**
Number of brakes	4	4
Brake repair/overhaul interval-FC	2,000	6,000
Brake repair cost-$	14,000	72,000
$/FC brake repair cost	**7.0**	**12.0**
Landing gear interval-FC	18,000	18,000
Landing gear exchange & repair fee-$	220,000-240,00	280,000
$/FC landing gear overhaul	**12.0-13.0**	**16.0**
Total-$/FC	**28.0-29.0**	**38.0**
Total-$/FH @ 0.8FH per FC	**25.0**	**32.0**

avionic upgrades required on the ATR, which include installation of a 8.33MHz VHF radio, enhanced ground proximity warning system (EGPWS) and emergency location transmitter (ELT). The compliance date for all of these upgrades has now passed. There is also SB 57-0038, which is a wing modification that requires the fasteners holding the skin to be changed. This requires about 385 MH for just the routine portion.

There are also examples of small ADs and SBs that have to be incorporated on the ATR. "One AD, which affects all older aircraft, is the fuel safety programme, which followed after the TWA 747 crash," explains Pastor. "A computer has to be installed, and the aircraft has to comply with the AD by December 2009. The modification uses about 200MH.

"There was also the Mode S transponder, but this had to be complied with in Europe by September 2006," continues Pastor. "Installation of EGPWS uses about 450MH plus the cost of the computer. Besides these, there are no major ADs affecting the aircraft."

Interior cleaning and refurbishment can be another major item. Some operators refurbish the interior work as necessary, on an on-condition basis, since the interior is not as important as it is in larger aircraft. "The interior is often refurbished when the aircraft changes operators," says Pastor. "The eight-year checks have a requirement for floor panels to be removed for an inspection, so this is a chance for the interior to be refurbished. The range of labour used in a base check can be 300-1,2300MH."

Stripping and painting is also treated as an on-condition maintenance task, and may only be performed when the aircraft changes operators. "We outsource the task to a specialist, as do many other operators, because of environmental limitations," says Rees.

"We have to dry strip and paint the aircraft at our facilities in Dinard," says Pastor. "The process takes about one week and uses about 800MH. It is often combined with an eight-year check, because a non-destructive test that requires the paint to be stripped has to be done at this check."

As is the case with other modern aircraft types, the majority of rotable components on the ATR are maintained on an on-condition basis. "The aircraft has about 700 different rotable components, and about 550 of these are maintained on an on-condition basis and the other 150 on a hard-time basis," says Paakkonen. "Hard-time components include emergency items such as oxygen generators, oxygen bottles, some electrical items, engine starters, engine fire extinguishers, and the propeller hub and propeller blades. The propeller hub and blades have a fixed overhaul interval of 10,000FH."

Base check inputs

The actual tasks performed in each check will vary between operators according to rates of utilisation and FH:FC ratio. "The heaviest check we have performed on an ATR was on a 13-year-old ATR 42, and included an A check, all C check system tasks, the two-, four- and eight-year tasks, 24,000FC fatigue items and 36,000FC fatigue items," says Pastor. "This whole package used about 7,000MH to complete, which is the largest base check package required for an ATR."

The routine MH used for each of the first 12 base checks in an aircraft's life have been described. Rectifications from routine inspections will add the largest portion of MH to a check. "The non-routine ratio will vary between 30% and 70% of routine MH for an aircraft during its first six or seven base checks," says Paakkonen.

Rees at Cimber Air adds that a non-routine ratio of 30-50% is typical of an aircraft in its first 12 years of life, but that the ratio will continue to increase as the aircraft gets older. "The ratio will reach 1:1 from about the C8 check, and so start to increase the number of MH used in the check."

In the case of the base checks described, a non-routine ratio of 30% in the C1 check will add about another 180MH, and up to another 1,500MH to the C4 check with a non-routine ratio of 70%. The aircraft could be expected to experience a non-routine ratio of 100% by the C8 check, which would therefore add another 3,700MH, while it would also add another 1,500MH to the C10 check, and another 3,000MH to the C12 check.

While the number of MH required for ADs, SBs and EOs varies, as they are issued by the airworthiness authorities and can require a large number of MH in individual cases, a budget of 250MH can be used as an approximate guide for base checks.

Interior refurbishment can be assumed to be performed every fourth base check, and use about 800MH. An additional 100MH can be included for interior work and cleaning for all other base checks. Another 50MH can be added to each base check for rotable removals and installations.

Stripping and repainting can be assumed to take place every fourth base check, and 800MH are used for this element.

Overall, the C4, C8 and C12 checks have the largest MH requirement, with the C4 using about 5,500MH, the C8 up to 9,000MH and the C12 about 7,800MH.

The C1, C3, C5, C7 and C9 are the smallest checks, using 1,200-1,700MH.

The C2, C6 and C10 are medium-sized checks, using 2,200-3,400MH.

Materials and consumables also have to be considered. "These are about equal to 20% of the labour cost of the routine portion of the check, or about 40% of the total labour cost of the check," explains Rees. This would see the cost of materials and consumables being $25,000-40,000 for lighter C checks, but increasing to $45,000-70,000 for the medium-sized C2, C6 and C10 checks. The heaviest eight-year checks would use about $110,000 in the case of the C4 check, and $160,000-185,000 for the C8 and C12 checks.

Using a theoretical labour cost of $50 per MH for base maintenance, the overall cost of base checks would be about $700,000 for the four checks in the first base check cycle. There would be a reserve in the region of $50 per FH when amortised over the 14,500FH interval. This would increase to about $80 per FH for the next two cycles leading up to the C8 and C12 checks *(see table, page 20)*.

Rotables

As described, the ATR 42 and 72 have about 600 rotable component part numbers, of which 150-200 are maintained on a hard-time basis. The remaining 400-450 are maintained on an on-condition basis. A few of the hard-time components can be classed as heavy components, and their maintenance is described below.

About 700 rotable components are installed on the aircraft.

Support of rotables can be offered by the rotable support provider leasing the operator an inventory of home base stock, which would comprise only high failure rate items. The remaining rotables could then be provided to the operator through a pool system, whereby the rotable provider holds the inventory of rotables and operators pay a pool access fee on a power-by-the-hour basis. Operators also pay a power-by-the-hour fee for the repair and management of the components.

The alternative is for an operator to make a single payment for an all-inclusive service. Rees says this could be $25,000 per aircraft per month for a small fleet. This rate would cover all eventualities, such as failed components that require replacement, and emergency situations. Once the fleet exceeds seven aircraft it becomes economic for the operator to have their own rotable stock and manage repairs themselves. The monthly rate of $25,000 would be equal to $140 per FH. Packages can vary in pricing according to aircraft utilisation, pattern of operation, and the age and modification status of the fleet. The largest factor influencing contract rates is fleet size. Rotable package pricing can be up to $200 per FH *(see table, page 20)*.

Heavy components

The heavy rotable components on both the ATR 42 and 72 are similar for those on turboprops and jet aircraft, and include tyres, wheels, brakes and landing gears. Turboprops do not have thrust reversers, but they do have propeller hubs. The ATR does not have an auxiliary power unit (APU).

These three categories of heavy components are considered here. "The landing gear on the ATR has an overhaul interval of 18,000FC," says Rees. At the annual utilisation used in this analysis this is equal to an interval of about seven years. Most operators use an exchange programme for landing gears, and exchange fees for an ATR 42-300 landing gear set are $220,000, for an ATR 42-500 landing gear they are $240,000, and for an ATR 72-500 they are $280,000.

Amortised over the interval, this equals a reserve rate of $12 per FC for the ATR 42-300, $14 per FC for the ATR 42-500, and $16 per FC for the ATR 72-500 *(see table, page 16)*.

The ATR uses several types of tyres, and some do not have remoulds. Rees says that tyres can last 500-1,200FC before they need replacement. New nose tyres each cost $425, while main wheel tyres each cost $950 for the ATR 42 and $1,100 for the ATR 72. A complete new shipset will cost $4,650 for the ATR 42 and $5,250 for the ATR 72. Amortised over an average interval of 800FC, the reserve for tyre replacement will be $6 per FC for both aircraft types *(see table, page 16)*.

Wheels are inspected once every three tyre removals, so the interval between wheel inspections would be in the region of 2,400FC. The unit cost of nose wheel inspections would be $780, and the unit cost of main wheel inspections $1,450. The reserve for inspections for a shipset of wheels would be $3 per FC *(see table, page 16)*.

The ATR 42 utilises steel brakes. The discs in these brakes have a life limit of 2,000FC, while elements of the brake unit require non-destructive tests (NDT) at a limit of 2,700FC. It is therefore convenient to perform a brake overhaul at an interval of 2,000FC. The average overhaul cost for a brake unit is $3,500, and so $14,000 for a shipset. This is equal to a brake repair reserve of $7 per FC *(see table, page 16)*.

The ATR 72 utilises carbon brakes. The carbon fibre heatpacks can last between 800FC and 3,000FC before requiring a repair. Two worn discs can be ground and combined to make a new disc, which means that some of the heatpack material is recoverable, and the cost of a complete heatpack, about $10,000, will not be incurred in full each time a heatpack is repaired. The brake unit also requires an overhaul every 6,000FC, which includes some NDT inspections. The average cost for a single brake unit is $10,000.

This means that a brake requiring a heatpack overhaul every 2,000FC might therefore incur a total cost of $18,000 for two heatpack repairs and an overhaul. Amortised over an interval of 6,000FC, this would be equal to a reserve of $12 per FC *(see table, page 16)*.

Engine maintenance

The ATR 42's and 72's engine types and thrust ratings vary between 1,800 and 2,475 shaft horse power (shp). The four main engine variants are the PW120, PW121, PW124 and PW127 *(see ATR 42 & 72 specifications, page 4)*. The first three operate with a four-bladed propeller, while the PW127 uses a six-bladed propeller.

Besides the engine unit, the propeller hub and propeller blades require maintenance. While the engine is maintained on a on-condition basis, the propeller blades and hub are maintained on a hard-time basis.

Like jet engines, turboprop engines are flat-rated. "Engine power reduces with increased outside temperature above the outside air temperature limit (OATL)," explains Paakkonen. "The PW124, for example, powering the ATR 72-200, has a maximum rating of 2,400shp up to an OATL of 34.4 degrees centigrade. The PW127F, which powers the ATR 72-500, is rated at a maximum of 2,750shp up to an OATL of 34.4 degrees centigrade. The PW127E is a de-rated version of the 127F, and powers the ATR 42-500. It has a maximum rating of 2,400shp up to an OATL of 45 degrees."

While the performance of jet engines is analysed in terms of exhaust gas temperature (EGT) margin, inter-turbine temperature (ITT) margin is measured in turboprop engines. "The PW120 turboprop has a core engine engine with two shafts. One high pressure (HP) system has a compressor turned by its own turbine, known as the gas generator turbine. The low pressure (LP) system has a turbine, known as the power turbine, which is used to turn the propeller. A third shaft is used to turn the propeller unit via a gearbox from the LP shaft," explains Paakkonen. "The ITT is measured between the two turbine sections, which gives the best indication of how hot it is inside the engine. There is also the turbine inlet temperature (TIT), which is measured between the combustion chamber and the gas generator turbine.

"There are limits to how high the ITT can climb, and this temperature varies up to 840 degrees centigrade. The actual limit varies according to the phase of flight," continues Paakkonen. "The actual limits are specified in the aircraft flight manual, but each operator also has their own limits. The ITT increases as the

DIRECT MAINTENANCE COSTS FOR ATR 42 & 72 FAMILY AIRCRAFT

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	120,000-140,000	2,000FH		60-70
A check	62,500	2,000FH		32
Base checks-1st cycle	715,000	14,400		50
Base checks-2nd cycle		1,135,000	14,400	80
Heavy components:				25/30
LRU component support				140-200
Total airframe & component maintenance				
Engine maintenance:				
2 X PW120/121/124B: 2 X $125-130 per EFH				250-260
2 X PW127E/F: 2 X $140-145 per EFH				280-290
Total direct maintenance costs:				
With 2 X PW120/121/124B:				557-678
With 2X PW127E/F:				587-702

Annual utilisation:
2,000FH
2,400FC
FH:FC ratio of 0.8:1.0

engine's hardware deteriorates, and ATR has an automated engine health monitoring system on the aircraft which records engine performance data for each flight. This can then be downloaded from the aircraft after each flight."

Airlines have to monitor ITT margin in order to remove engines for maintenance and performance restoration. Paakkonen comments that the PW120 series engines on the ATR family generally have enough ITT margin for them not to be removed due to performance loss. "The engines usually have ITT margins of 20-30 degrees centigrade after a shop visit, which is sufficient to allow engines to remain on-wing long enough for them to be removed due to hardware deterioration and other technical reasons," continues Paakkonen. "Only about half the ITT margin is lost during the on-wing interval of 4,500-5,500 engine flight hours (EFH), which is equal to 7,500-8,000 engine flight cycles (EFC) with our operation. We actually plan for a removal at 8,100EFC, since we have to consider life limited parts (LLPs). There are 10 LLPs in the engine, and five have lives of 15,000EFC, and so the LLP's full life can be completely used and the parts replaced every second removal. The other five LLPs have lives of 30,000EFC. These can be replaced every fourth shop visit.

"The high pressure turbine (HPT) blades also have a 15,000EFC replacement limit, and so the 7,500-8,000EFC removal interval is convenient in several respects. Erosion starts after about 4,000EFH, and they can be inspected at the first removal," continues Paakkonen. "Most blades and vanes get replaced at the second removal and shop visit, and so it is possible to have a shop visit workscope pattern of a hot section inspection followed by an overhaul. It is also possible to have a pattern of two hot section inspections followed by an overhaul at the third removal. This would be the case where the average removal interval is about 5,000EFC. The idea is to match the workscope with the life limits of installed LLPs."

Plans for removal intervals and shop visit workscope patterns do not always go according to plan, however, since unscheduled shop visits will cause interruptions. "Unscheduled shop visits can arise from hot section deterioration, which is discovered through engine borescopes," says Paakkonen. "Other examples are bearing failures, which are picked up through oil detection. Overall, the average interval, including unscheduled removals, is about 5,000EFC. On this basis most engines have two consecutive hot section inspections followed by an overhaul. A borescope is performed every 500 EFH to detect deterioration and anticipate unscheduled removals.

"A hot section inspection requires the engine to be opened from just the combustion chamber to the HPT, while an overhaul is a disassembly of the whole engine, including the gearbox," continues Paakkonen.

Shop visit costs comprise labour cost, materials and parts, and the cost of subcontract repairs. The total for these three elements typically totals $220,000-250,000 for a hot section inspection, and $650,000-700,000 for an overhaul. The cost of two hot section inspections and an overhaul combined is $1.1-1.2 million. When amortised over the full interval of 15,000EFC, the engine shop visit costs have a maintenance reserve of $73-80 per EFC.

A full set of LLPs has a list price of $75,000-80,000. When the price of each LLP is amortised over its life, and allowing for about 500EFC of stub life at removal, the reserves for all 10 parts are about $15 per EFC. Total engine reserves are thus $90-95 per EFC. When corrected for the average FC time, this is equal to $77-80 per EFH. This is based on three shop visits every 15,000EFC. Reserves can be lower where the number of unscheduled visits is reduced, and only two shop visits per 15,000EFC interval are required.

Engine reserves have to be considered together with overhauls of propeller units. Propeller hubs and blades have overhaul intervals of 10,500EFH.

The cost of the hub overhaul can be about $7,500, but can be as much as $50,000 if a high level of corrosion is found. The repair and overhaul cost of each blade is $7,500, totalling $30,000 for engines with four blades and $45,000 for engines with six blades. Assuming an average hub repair cost of $20,000, and a utilised interval of 10,000EFH, the reserve for four-bladed propellers will be $50 per EFH, and for six-bladed propellers $65 per EFH.

This takes the total maintenance reserves for engines with four-bladed propellers to $125-130 per EFH, and the total for engines with six-bladed propellers to $140-145 per EFH *(see table, this page)*.

Summary

Total maintenance costs for young aircraft in their first base maintenance cycle are $557 per FH for aircraft with PW120/121/124 engines, and $587 per FH for aircraft with PW127E/F engines *(see table, this page)*. Costs can be marginally higher, especially where higher rotable-related costs are incurred.

Older aircraft, in their second and third base maintenance cycles, with PW120/121/124 engines have higher costs of up to $678 per FH, while those with PW127 engines have costs of up to $702 per FH *(see table, this page)*. Again, rotable-related costs can vary according to contract terms and operational characteristics. AC