ERJ-135/-145 maintenance analysis & budget

The ERJ-145 family has a relatively simple maintenance programme, and most engines are maintained with fleet-hour agreements.

The ERJ-145's maintenance programme is optimised for operators flying 2,500 flight hours (FH) and 2,500 flight cycles (FC) per year. Operators with lower or higher utilisations, flying short or very long sectors, will find maintenance planning more complicated. Many tasks will have to be performed without using a high proportion of their interval, or the aircraft will have to be grounded and opened up for maintenance more frequently.

The ERJ-145 has a base maintenance cycle of 20,000FH, and many aircraft have been though their first base cycle. In fact the fleet leader, a PGA - Portugalia aircraft, has accumulated over 30,000FH and is halfway through its second base maintenance cycle. With a structure designed for a minimum economic life of 60,000FC, some aircraft may go through three, or even four, base maintenance cycles during their service lives.

ERJ family in operation

In North America the ERJ-135/-140/-145 are used almost exclusively to provide regional services for the major airlines. The only major exception to this is ExpressJet, which has 30 aircraft dedicated to its ExpressJet Corporate Aviation business.

Discounting non-scheduled airline operators, the average annual utilisation by North American ERJ-145 operators is 2,750FH and 2,100FC. This equates to an average flight time of 79 minutes.

In Europe the scheduled operators achieve an average annual utilisation of 2,250FH and 2,000FC, equating to an average flight time of 67 minutes.

The equivalent figures for the ERJ-135 are: 2,450FH, 2,150FC and 68 minutes in North America; and 1,800FH, 1,900FC and 57 minutes in Europe. Utilisation of the ERJ-140 is close to that of the ERJ-145 at 2,800FH, 2,175FC and 77 minutes.

Excluding the few aircraft operating as corporate shuttles or those with non-commercial operators, all the ERJ-145s are in operation as passenger aircraft and their maintenance costs are analysed here for aircraft completing 2,500FH and 2,000FC per year, at an average flight time of 75 minutes.

Maintenance programme

The ERJ-145 family has a Maintenance Steering Group 3 (MSG3) maintenance programme. "Embraer only published a maintenance review board (MRB) document, and did not publish a maintenance planning document (MPD) that has a maintenance programme, unlike most aircraft types," explains Stefan Kontorravdis, director of engineering at Flybe. "Each operator devises its own maintenance programme from the MRB. Several groups of tasks have similar or equal intervals, however, so maintenance programmes are similar."

Carlos Almeida, director of market strategy at Ogma, explains that the ERJ-145's maintenance programme is divided into two manuals: the scheduled maintenance requirements document (SMRD); and the MRB. "The SMRD outlines the scheduled minimum maintenance requirements. The first part has the MRB, and all sections are mandatory," says Almeida. "The second part has additional information and data, and helps each operator develop a maintenance programme that is compatible with their operation. The second part also allows the operator to prepare their own unique operations specification for approval by their authority. This would be its additional line checks for its own requirements. The MRB outlines the minimum scheduled maintenance requirements."

The tasks fall into four categories: systems and powerplant inspections; structural inspections; zonal inspections; and corrosion prevention and control programme (CPCP) inspections.

System tasks have intervals specified in FH, FC and calendar time. The tasks of the auxiliary power unit (APU) are specified in APU hours, and some engine-related tasks are specified in engine cycles. Some tasks have two criteria and intervals, and are therefore performed when the first one is reached.

All tasks in the structural programme have FC intervals. There are also CPCP tasks in the structural programme, which have intervals specified in calendar time.

Zonal tasks have their intervals specified in FH. These are the same groups as the C check tasks: the 1C every 5,000FH, the 2C every 10,000FH, and the 4C every 20,000FH.

There are more than 1,000 tasks in the MRB. Embraer explains that 380 have FH intervals, 30 have both FH and calendar intervals, and 300 have FC intervals. There are 16 landing-gear-related tasks with FC and calendar intervals, 290 tasks with calendar intervals, and 10 APU tasks with APU hour (APUH) intervals.

The maintenance plan also has initial thresholds for most structural and CPCP tasks. There are about 130 tasks with FC thresholds, and 100 with calendar thresholds.

The intervals for the FH tasks range from 100FH to 30,000FH, and for FC tasks from 2,500FC to 30,000FC. The calendar intervals start at 48 hours, and include tasks in the 48-hour line check. They go up to 180 months, or 15 years.

The structural tasks have initial thresholds varying from 10,000FC to 30,000FC, while the CPCP tasks have initial thresholds of 48 to 96 months. This indicates that the aircraft's maintenance requirements and routine inspection tasks start to increase from an age of four years.

Maintenance checks

Line checks

The ERJ-145's maintenance programme starts with line checks. The line maintenance programme consists of a 48-hourly 'service' check and a two-weekly/14-day (or 100FH whichever comes first) 'routine' check. There are no pre-flight checks specified in the Maintenance Review Board Report (MRB), although many operators add them into their own maintenance programmes.

"Although there are no pre-flight (PF) or transit checks (TR) in the MRB, we still have PF checks in our own maintenance programme," says Kontorravdis. "The difference between a PF and TR check depends on which tasks have to be done by mechanics and which by flightcrew. The smallest check in the MRB is the 48-hour check. We actually do this every night, and the 48-hour interval means we can skip it if the aircraft is at an unserviced outstation overnight. We then do a PF check, which we call a pre-departure inspection (PDI) after the 48-hour check and prior to the

The majority of ERJ-145 family aircraft operate at average FC times of 70-80 minutes, and generate annual utilisations of about 2,500FH and 2,000FC per year.

first flight of the day, and this can be done by the flightcrew. Most aircraft types then have a TR check prior to each subsequent flights of the day, and this is a check that has to be done by mechanics. We do not need to have these, and so have a PF check prior to each flight and these are done by the flightcrew. There are, of course, a few occasions when defects occur. Pilots can decide of the defect can be deferred by referring to the minimum equipment list, or if the fault has to be rectified prior to flying again. If it has to be rectified then mechanics are required to work on the aircraft.

The PF and checks can be performed by the flightcrew and use only a minimal amount of materials and consumables. No labour from mechanics is used, however, except for non-routine defects that occur at random during PF checks.

In addition to the service and routine checks, the ERJ-145 family has a system of A, C and structural checks which are independent of each other. The ERJ-145's maintenance programme has undergone 11 revisions since the aircraft entered into service in 1997, and the twelfth is due in the first quarter of 2009. The original maintenance programme had basic intervals of 400FH for A-checks, 4,000FH for C-checks and multiples of 2,000FC for Structural Inspection (SI) tasks and two years for CPCP tasks.

A major revision of the MRB in September 2004, with the release of issue 9, increased the A check interval from 400FH to 500FH, the basic C check interval from 4,000FH to 5,000FH, SI tasks to multiples of 2,500FC, and CPCP tasks to multiples of 30-month intervals.

A-checks

In most operators' programmes, there are five different multiples of A check tasks: the 1A, 2A, 3A, 4A and 5A tasks. The interval for the A tasks was 400FH under the original maintenance programme. The 2A tasks had an 800FH interval, and were performed at the second and fourth A checks, the A2 and A4 checks respectively. The 3A tasks had a 1,200FH interval and were carried out at the A3 check, while the 4A tasks had a 1,600FH interval and were carried out at the A4 check. The 5A tasks had a 2,000FH interval and were carried out at the A5 check. After the 5A is complete the cycle restarts at the A1 check.

The basic A interval was escalated to 500FH in September 2004, so that the A1 check is performed at 500FH, the A2 at 1,000FH, the A3 at 1,500FH, the A4 at 2,000FH and the A5 at 2,500FH, thereby completing the cycle *(see table, page 18)*.

UK operator bmi Regional has local approval for an amended A-check cycle with the 1A tasks at 550FH, 2A tasks at 1,100FH, 4A tasks at 2,200FH and the 5A tasks at 2,500FH. Flybe has escalated its A check interval to 600FH, and so the A check would be complete at 3,000FH.

Kontorravdis explains that in addition to the 48-hour, 14-day and A checks, some out-of-phase (OOP) tasks have intervals between the checks. "These OOP tasks fall between subsequent A and subsequent C checks, so they are brought forward to the nearest A or C check," he explains. "If a task can be carried out during a 48-hour check we refer to it as a line station requirement (LSR) task."

Base checks

There are three main groups of system C check tasks: the 1C, 2C and 4C tasks. These have intervals of 5,000FH, 10,000FH and 20,000FH.

The tasks are arranged in a series of four basic checks: the C1 at 5,000FH, the C2 at 10,000FH, the C3 at 15,000FH, and the C4 check at 20,000FH. The C1 check has the 1C tasks, the C2 check the 1C and 2C tasks, and the C3 check the 1C tasks. All four task groups come in phase at the C4 check, making it the largest C check *(see table, page 18)*.

The C4 check has an interval of 20,000FH, which at an annual utilisation of 2,500FH equates to eight years of operations. The second largest check is the C2 check every four years. Many operators also choose to carry out other large tasks such as major modifications, component changes and interior refurbishments at these checks.

The interval for the C tasks was 4,000FH under the original maintenance programme. The 2C tasks had an interval of 8,000FH, so they were performed every second C check, at the C2 and C4 checks. The 4C tasks had a 16,000FH interval, so they were performed at the C4 check.

From September 2004 operator experience was allowed to escalate the 1C and 2C tasks by 25% to 5,000FH and 10,000FH respectively. The interval for the 4C tasks, however, initially remained at 16,000FH, and was not escalated until Revision 10-4 of the MRBR was issued in January 2007 when the interval was raised to 20,000FH.

The basic interval for the 1C tasks has been escalated to 6,000FH by some operators, taking the C4 interval up to 24,000FH.

In addition to the system task inspections, there are SI and CPCP tasks, both of which are independent of the C check tasks.

The SI tasks are fatigue-related inspections. There are three main groups: the 1CS, 2CS and 4CS tasks. These initially had intervals of 4,000FC, 8,000FC and 16,000FC, which have since been extended to 5,000FC, 10,000FC and 20,000FC. Many of these inspection

ERJ-145 FAMILY A & BASE CHECK TASK COMPOSITION

Airframe check	Routine inspection tasks	Interval
A1	1A	500FH
A2	1A + 2A	1,000FH
A3	1A + 3A	1,500FH
A4	1A + 2A +4A	2,000FH
A5	1A + 5A	2,500FH
C1	1C +1CS +1CC	5,000FH/4,000FC/30 months
C2	1C + 2C +1CS +2CS +1CC +2CC	10,000FH/8,000FC/60 months
C3	1C + 1CS + +1CC	15,000FH/12,000FC/90 months
C4	1C +2C +4C + 1CS + 2CS + 4CS +1CC +2CC +4CC	20,000FH/16,000FC/120 months

tasks also have an initial threshold of 20,000FC, so that many will not be carried out until the C4 check. Some SI tasks do not fit into the multiples of 5,000FC intervals, and so do not fit in well with any of the C check inspections. These are treated as OOP items.

The CPCP tasks inspect for corrosion on structures. These initially had three tasks grouped into intervals that are multiples of two years (24 months): the 1CC tasks at 24 months; the 2CC tasks every four years (48 months); and the 4CC tasks every eight years (96 months). These three groups have subsequently been extended to 30 months, 60 months and 120 months.

Both the SI and the CPCP tasks coincide reasonably well with the C1, C,2 C3 and C4 checks at most operators' average annual utilisation rate of 2,500FH and 2,000FC, and FH:FC ratio of 1.25FH per FC. That is, the 2,500FC SI 1CS and 30-month CPCP 1CC tasks are grouped in every C check every 2,500FH, the 5,000FC SI 1CS and 60-month CPCP 1CC tasks are grouped in the C2 and C4 checks, and the 10,000FC SI 4CS and the 120-month CPCP 4CC tasks are grouped in the C4 checks *(see table, this page)*.

At typical rates of utilisation most operators will be performing the SI tasks and CPCP tasks earlier than required. Alternatively, they can carry out the system tasks first and then the SI/CPCP tasks separately. This is unlikely, however, since it would incur more labour man-hours (MH) for repeated access and an increased downtime for the aircraft.

The base cycle is therefore completed at the C4 check. At this stage the 4CS and 4CC tasks are performed. Some SI and CPCP tasks have initial thresholds of up to 30,000FC and 96 months. The aircraft's routine maintenance tasks will therefore increase after the first C4 check during the second base check cycle.

Line & A check contents

FlyBe has a PDI check in its line maintenance programme that it performs prior to the first flight of each day. This has nine tasks, which include: checking the deferred defects recorded in the aircraft's technical log; a walkaround visual inspection; checking wheels and tyres; removing all blanks and flags; removing landing gear locking pins; and de-icing the aircraft as necessary.

The MRB has a higher 48-hour 'service' check, whose tasks include: checking tyre pressures and brake wear indicators; checking the technical and cabin defect logs; checking OOP task requirements; checking all safety equipment; various landing gear and gear bay inspections; making wing and engine nacelle inspections; and a series of flightdeck and cabin inspections.

The tasks for the two-weekly or 14-day 'routine' check consist largely of visual inspections. These are similar to the 48-hour check, but there are additional requirements.

Defects also occur during operation, and operators use line checks wherever possible to clear and rectify them, 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 an A-check, if one is due in a relatively short time. In addition to the MPD tasks, workscopes for these line checks also include interior checks, deferred items, hard-timed tasks, troubleshooting and component changes.

Labour inputs for each PF check are about 0.3MH. These are performed by flightcrew, but an allowance has to be made for mechanics when required for non-routine defects. A budget of 0.3MH per PF check is this used on a conservative basis.

Labour inputs for the 48-hour 'service' checks are estimated at 1.5MH, and for the routine 14-day/100FH checks are estimated at 3.0MH. An allowance of $50-60 for consumable and material consumption can be used for 48-hour checks. These use oil, nitrogen, oxygen and skydroil. An allowance of $150 for materials and consumables for 14-day/100FH checks is used.

Under the annual utilisation assumption of 2,500FH and 2,000FC, the aircraft will require 2,000 PF checks, 183 48-hourly checks and 26 14-day checks every year. This will use a total of about 960MH per year for these aircraft. At a labour rate of $75 per MH, these three types of line check will incur an annual labour cost of $72,000. Once the cost of materials and consumables for all these checks are considered, the total cost for line maintenance is about $86,000 per year. This is equal to $35 per FH *(see table, page 22)*.

The lighter A checks are the A1 and A3 checks *(see table, page 22)*. These only need 30-35MH. The A2 uses about 50MH, the A4 75MH and the heaviest A5 check 125MH. These five checks will consume 315MH. At a labour rate of $75 per MH, this is equal to $24,000.

The lighter A checks will use about $1,000 of materials and consumables for the routine and non-routine rectification. The heaviest 5A check is estimated to need $5,000 of materials and consumables. The total consumption of materials and consumables for the five checks will be $9,000-10,000, taking the total cost for the checks to $34,000. While the checks have a limit of 500FH, few operators fully utilise this. It is assumed about 80% of this interval is used, meaning that the A check cycle is completed about every 2,000FH. On this basis, the A checks will have a reserve of about $17 per FH *(see table, page 22)*.

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. As a result, it is possible for two airlines with similar operations to have wildly differing check costs. The importance of distinguishing between basic check costs and these 'additional' items is particularly important for lessors, since claims on maintenance reserve funds are typically only payable against work carried out directly on routine inspection tasks and their related non-routine rectifications. Other issues that should be considered are analysed here.

The ERJ-145's base maintenance programme consists of three groups of system, structural and CPCP checks. Most operators have a base maintenance check programme cycle of four checks, that have a basic interval of 5,000FH, 4,000FC and 30 months.

Routine inspections

The arrangement of MRB tasks for the base checks is summarised. These are covered by the current MRB revision.

Check planning and workscope contents first take into account probable interval utilisation. This cannot be 100% due to the constraints of aircraft operational requirements, check planning limitations, and appropriate hangar and facility availability. Given the nature of the relationship between the system inspection tasks (2,500FH intervals), SI tasks (2,500FC intervals) and the CPCP tasks (30-month intervals), most operators will typically achieve 85% of the System check intervals, and will lose some of the life of the SI and CPCP task intervals by grouping them in the checks as described. This means the C1 check will be performed after about 4,250FH, the C2 check after 8,500FH, the C3 check after 12,750FH, and the C4 check after 17,000FH or seven years' operation.

As well as the MPD tasks, operators may add items unique to their own maintenance programme, such as deep cabin cleaning and other interior work.

The aircraft's age and serial number will also have an impact. Early production aircraft are particularly affected and, as they undergo inspections, particularly the first round of C4 checks, inspection findings are reported back to the manufacturer in order to develop repairs, and where necessary issue Service Bulletins (SBs) to prevent a repeat of the problem. Later-serial-numbered aircraft will have had many of these improvements incorporated on the production line, so they will benefit from having a lower level of non-routine requirements than earlier-built aircraft.

One European operator saw the MH required to incorporate SBs on the first C checks drop from 675MH on its first aircraft to 320MH on its third aircraft, even though their build dates were only separated by 12 months. The first aircraft later underwent its first C4 check where SBs only accounted for 105MH.

Engineering orders

The ERJ-145 has not been affected by any major airworthiness directives (ADs). Those ADs that have been issued for the type have generally required inspections using relatively small numbers of MH.

Operators of the ERJ-145 have the option of increasing the design weights of their aircraft. For 145ER/EP/EU variants, SB145-53-0064 increases the maximum zero fuel weight (MZFW) by 250kg and for 145LR/LU variants SB145-53-0068 increases the design weights as follows:

MTOW	22,000kg to 22,600kg
MLW	19,300kg to 19,800kg
MZFW	17,900kg to 18,400kg

For the ERJ-145LR/LU the SB requires the installation of reinforcements to stringers and frames in the central and rear fuselage. These modifications are likely to be performed along with a C2 or C4 check.

Rotable components

Base checks will also involve the removal of a small number of rotable components that have hard times for repair and overhaul. A minority 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 units.

Most of the rotables on the ERJ-145 are maintained on an on-condition basis. These will be removed as they fail during line maintenance or A checks, and replaced with serviceable items. As well as hard-timed rotables, base checks will be used to change engines, landing gear sets, the APU and thrust reversers as 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.

Most aircraft in the ERJ-145 family fleet do not have thrust reversers installed, however, because the aircraft can land satisfactorily on most airport runways. Only aircraft using short runways, such as at London City Airport, need to have thrust reversers fitted. Thrust reversers can be retrofitted through an SB available from Embraer.

Apart from the difficulties of scheduling the removal of on-condition components without an excessive waste of useful life, the difficulty with engine removals is that most are under the Rolls-Royce Total Care programme. An operator therefore cannot send an engine to the shop at its sole discretion. Rolls-Royce has to agree that there are technical grounds for an engine's removal. It is clear that, on a fixed price contract, Rolls-Royce does not want to waste any of the potential on-wing life that can be extracted from the engines.

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

Interior work

The use of the ERJ-145 for short-haul operations means that work on the aircraft's interior will be relatively minor. The absence of different cabin classes, complex seats and in-flight entertainment

The ERJ-145's base checks typically include routine inspections, non-routine rectifications, interior refurbishment, removal and replacement of rotable components, implementation of engineering orders, and stripping & repainting.

systems greatly reduces the amount of unscheduled maintenance compared with aircraft used for long-haul, widebody operations. Also, while the interiors of long-haul widebody aircraft will be periodically reconfigured to adjust for variations in the different classes of traffic, almost all ERJ-145s will remain in their original configuration throughout their working lives. Even regional aircraft need refurbishment, however, and the C2 and C4 checks provide operators with the ideal opportunity.

Other work

As well as routine inspections, non-routine rectifications, EOs and modifications, interior cleaning and refurbishment, removal and reinstallation of rotable components and interior work, operators have further items to add to the workscope of base checks. These include repetitive inspections that are in addition to the C check task cards, such as: cleaning; engine changes (typically requiring 50MH of experienced labour); changing other large rotables such as the landing gear or APU; clearing deferred defects; and performing OOP tasks. Repetitive inspections are imposed by SBs and ADs, while others are those that an operator's engineering department thinks will improve reliability. OOP tasks are items whose intervals do not match those of the basic A and C checks.

Base check inputs

There are several elements to the base checks. There are three different multiples of C check tasks, and as a result the base maintenance cycle consists of two light base checks and two heavier checks.

C-checks

The lighter checks are the C1 and C3 checks *(see table, page 18)*. These only need the 1C tasks, while the heavier C2 and C4 checks also have the 2C and 4C tasks.

The C1 check needs a routine labour input of 700-800MH, the C2 a further 300-500MH and the C4 an additional 50-100MH. The heaviest C4 check will therefore use 1,050-1,400MH for the routine inspections.

Non-routine rectifications from the 1C tasks add a further 200-400MH, and those from the 2C tasks another 300MH. For the heaviest C4 check, 500-700MH are required for defect rectification, equal to a non-routine ratio of 50%.

Other work consumes an average of 250-300MH for C1 and C3 checks, increasing to 350-500MH for C2 and C4 checks. Incorporating SBs consumes an average of 300-350MH for mature production aircraft (early production aircraft were higher as discussed earlier). Exterior cleaning will add 45MH, and interior cleaning a further 60MH.

This takes the total labour consumption to 1,750MH for the C1 and C3 checks, to 2,650MH for the C2 check, and to 2,700MH for the C4 check. The total for the four checks is therefore about 8,800MH. At a labour rate of $75 per MH, this is equal to $660,000.

It is difficult to estimate typical materials consumption for the C checks, since the data provided by different operators fails to quantify what has been included. Figures for the smaller C1 and C3 checks range from $40,000 to $80,000, although about $50,000 is probably typical. Similarly figures for the C2 and C4 checks range from $50,000 to 110,000, although about $85,000 is not unreasonable. The total consumption of materials and consumables for the four checks is therefore about $270,000.

The total cost for the four checks in the cycle is therefore about $930,000, equal to a reserve of $55 per FH *(see table, page 22)* when amortised over the likely cycle interval of 17,000FH.

Typically operators will undertake some form of major interior refurbishment after five to six years of service. With the ERJ-145 it is possible to carry this out at the C3 check after five to six years, or push it out to the C4 at seven to eight years. This work will include removing and refurbishing: seats; overhead bins; passenger service units (PSUs); bulkheads; ceiling and sidewall panels; toilets; galleys; carpets; and the cargo compartment. Such an extensive interior refurbishment is estimated to use 850MH in labour and $30,000 in materials. At a generic labour rate of $75 per MH the total cost of refurbishment will be $93,750. If interior refurbishment takes place at the C4 check, about every 17,000FH, the reserve will be $6 per FH *(see table, page 22)*.

Stripping and painting is also likely to be performed at the same time. Most operators lack the facilities to carry out external painting, so this is usually outsourced to specialists. A typical cost estimate for the strip and paint of an ERJ-145 is $75,000. Again, assuming painting takes place at the C4 check, about every 17,000FH, this equals a reserve of $5 per FH *(see table, page 22)*.

The total reserve for the base checks, interior refurbishment, and stripping and repainting is therefore about $62 per FH.

Heavy components

Heavy components comprise four categories: the landing gear; wheels and brakes; thrust reversers; and the APU. The installation of thrust reversers is an option on the ERJ-145 family, and the majority do not have them fitted. Thrust reversers can be retrofitted if required.

The landing gear overhaul interval is 20,000FC or 12 years, whichever is reached first. Given the average annual utilisation of 2,000FC, most landing gears will be removed before the 12-year calendar limit is reached. At a typical overhaul cost of $160,000 and exchange

The ERJ-145 has a simple maintenance programme and straightforward requirements, and its maintenance costs are predictable.

fee of up to $50,000, this gives a reserve of about $10 per FC *(see table, page 22)*, equal to about $8 per FH.

The thickness of brake units is monitored during operation, and these are removed for repair and overhaul. Estimates for the cost of wheels and brakes vary between operators, but a typical operator reserve for the shipset of brakes is $20 per FC *(see table, page 22)*, This is equal to $16 per FH. Reserves for the wheels and tyres are $18 per FC, equal to $14.4 per FH.

There are two APU choices for the ERJ-145 family: the original Hamilton Sundstrand Model T-40C11; and the newer full authority digital engine controlled (FADEC) T-40C14. Overhaul is on an on-condition basis for both types. For the T-40C11 a typical overhaul cost would be $90,000 and a mean time between overhauls (TBO) would be 4,500 APUH. This gives a reserve of $20 per APUH *(see table, page 22)*. Assuming an APU utilisation of 0.8APUH per FH, this is equal to $18 per FH. Some operators have obtained lower hourly costs from overhaul providers.

For the newer T-40C14 model the overhaul cost will be the same but the mean TBO increases to 8,000 APUH. This gives a much lower reserve of $11.25 per APUH, although the higher figure is used in this analysis.

The installation of thrust reversers is an option on the ERJ-145 family. Many customers have chosen not to have them, and others have deactivated them because of their maintenance costs. Thrust reverser maintenance is on-condition and varies with condition and findings at removal. Although thrust reversers are intended to reduce brake overhaul costs, this is difficult to quantify. The cost of maintaining thrust reversers varies from $5 to $12 per FH.

Rotable components

The ERJ-145 has about 600 rotable part numbers installed, of which 150 are maintained on a hard-time basis, and the remainder on an on-condition basis. The number of components installed on the aircraft is about 1,300, and 900 of these are maintained on an on-condition basis. The remaining 300-400 are hard-timed components, including: hydraulic actuators and valves; pneumatic valves; fuel control units; fire extinguisher components; batteries; and emergency equipment.

Embraer has offered its 'Parts Pool Program' almost from the beginning of the ERJ-145 project. It covers a standard list of more than 500 rotable parts, with options to include larger items such as the landing gear and APU. Failed or hard-time components are removed from the aircraft by the operator and exchanged with serviceable components from Embraer. The latter then arranges for the repair, testing and return of serviceable parts to the inventory. The operator benefits from predictable costs, and avoids the burden of warranty administration and dealing with large numbers of vendors.

As of October 2008, Embraer had 28 customers for the program. Other companies have offered similar programmes, including Celsius Aviocomp (which became part of Saab Aerotech in 2006), which also acts as a supplier to Embraer's Parts Pool Program.

Actual costs for the Parts Pool Program depend on fleet size, utilisation, route network and style of operation. Typical figures would be: $125 per FH for the FH fee covering repair, transport and administration; and $10,000 per aircraft per month for the pool access fee covering the financing of the pool stock, insurance and administration. This equates to $48 per FH.

A fleet of five ERJ-145s operating 2,500FH per year is estimated to need an on-site stock inventory with a value of $1 million. The monthly lease for this stock would be $15,000 shared between the five aircraft, and equal to $15 per FH.

The total for the three elements for the complete rotable support programme will be $188 per FH *(see table, page 22)*.

Engine maintenance

The ERJ-145 family are powered exclusively by the Rolls-Royce AE3007A. There have been several stages in the development of the basic engine. The original AE3007A, with a 7,580lbs take-off rating, was upgraded early on in production to the AE3007A1/1, although both shared the same 1,690 Fahrenheit (F) inter-turbine temperature (ITT) limit and a 7,580lbs thrust take-off rating. This was superseded by the A1/2, which was followed by the definitive A1, which had an increased ITT limit of 1,738F, but again retained the same thrust rating. Both the A1/1 and A1/2 were the result of modification and upgrade programmes early on in the programme.

The first higher thrust development was the AE3007A1P, which was developed for the ERJ-145LR. This engine offered a take-off thrust of 8,338lbs, but retained the ITT limit of 1,738F. For the ERJ-145XR, Rolls-Royce developed the A1E with a further increase in the take-off rating to 8,917lbs, and an ITT limit of 1,778F. For the smaller ERJ-135, Rolls-Royce offered the A3, derated from the A, to a take-off thrust of 7,201lbs for the ERJ-135ER and the A1/3 for the ERJ-135LR, de-rated from the A1 to a take-off thrust of 7,580lbs.

AE3007 in operation

Typical removal intervals for the AE3007A family are 7,000-8,000EFH. At an annual utilisation of 2,500FH and 2,000FC, this is equal to three years' operation.

For its most recent generation of engines, Rolls-Royce has been very successful in signing up its customers for

DIRECT MAINTENANCE COSTS FOR EMBRAER ERJ-145 FAMILY

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
48-hour & 14-day checks	$86,000	1 year		35
A check	34,000	2,000FH		17
Base checks	1,100,000	17,000FH		62
Landing gear	210,000	20,000FC	10	8
Wheels & brakes				30
APU				18
Thrust reversers				5-12
LRU component support				188
Total airframe & component maintenance				**363-370**
Engine maintenance: 2 X AE3007A: 2 X $119 per EFH				238
Total direct maintenance costs:				**600-610**

Annual utilisation:
2,500FH
2,000FC
FH:FC ratio of 1.25:1

its TotalCare (power-by-the-hour) programmes. Some customers have time and material agreements with Rolls-Royce.

Flybe, for example, has a fleet-hour agreement with Rolls-Royce. It is therefore up to Rolls-Royce to build the best engines, while FlyBe is not too concerned with exhaust gas temperature margins and removal intervals. The engine is removed for several reasons, and the shop visit workscope, and engine and life limited parts (LLP) management is defined by Rolls-Royce, although Flybe gets to see it. Flybe has a contractual commitment to get an on-wing interval of 7,000 engine flight hours (EFH) with an average engine flight cycle (EFC) time of 65-70 minutes.

City Airline of Sweden has a higher than average FC time of 1.7FH. Removals of earlier-built engines have been partly caused by the expiry of LLPs with shorter lives, although it aims to have an accumulated time of 20,000EFC at the engine's second removal when most LLPs expire. Most engines are removed due to LLP expiry, as is the case with bmi Regional, which operates at 1FH per FC.

In the airline business sector, 60% of Rolls-Royce engines are in TotalCare programmes, but in the regional business sector (AE3007 primarily) the total is over 95%. As a result the cost of overhauls is less important than the actual cost of being in the TotalCare programme. For a typical smaller operator operating 2,500FH and 2,000FC per year, the cost of TotalCare is likely to be $75 per EFH.

This does not include an allowance or reserve for life limited parts (LLPs).

Life limited parts

The AE3007A series has 26 different LLPs. All the current production parts have lives of 20,000EFC or 30,000EFC.

There are several different part numbers for many of the LLPs, and the earlier ones have lower life limits. This complicates LLP replacement, engine removals and reserves. There are four main groups of LLPs in: the fan rotor; the high pressure compressor (HPC) rotor; the high pressure turbine (HPT) rotor; and the low pressure turbine (LPT) rotor.

The fan rotor includes the fan disc, which has the life of original parts limited to 19,400EFC, but the latest parts have a 20,000EFC life. The forward blade retainer's life is unchanged since the beginning, and life remains at 20,000EFC. The fan drive shaft's original part numbers had a life of 20,000EFC, but latest parts have a life of 30,000EFC.

The HPC rotor has 15 parts. The original HPC-1 disc had a life limit of 12,500EFC. It was subsequently replaced by a new part number with a 20,000EFC life, and then replaced again with another part number with a 30,000EFC life. The remaining 13 HPC discs originally had lives of 20,000EFC, but all but four are now at 30,000EFC limits. The last LLP in the HPC rotor was the coneshaft, which had a target life of 20,000EFC that was reduced by an AD to as low as 2,400EFC depending on part number and engine model. It was subsequently replaced by a new part with a life of 20,000EFC, which in turn was escalated to 30,000EFC for the same part number.

The HPT rotor has had the most LLP problems. The life of the original HPT-1 disc was 8,400EFC. Later parts were increased to 20,000EFC and then 30,000EFC.

Similarly, the HPT-2 disc was initially 10,000FC, then 20,000FC and finally 30,000FC. An emergency AD issued in late 2008, relating to cracking of the HPT-2 disc, has been superseded by AD 2008-26-16.

The initial target life of 20,000FC for the HPT 1-2 Spacer was reduced by an AD to 9,800FC. It was subsequently replaced by a new part with a life of 12,900FC, which in turn was escalated to 30,000FC for the same part number.

The LPT rotor has five LLPs, all of which originally had 20,000EFC lives, but now are all at 30,000EFC. Three of the five are new parts, but two have simply had their lives extended.

These premature LLP life limits led to a large number of early engine removals. Also, while 95% of operators are in TotalCare, not all have included LLPs in their coverage (available as an option). This created a cost burden to acquire the new parts, although offset to some degree against warranty claims on the old parts.

The list price of the current production standard parts (a total of 26 part numbers and 27 parts, all of which have a life of 30,000FC, except for six part numbers) is $1.4 million. Dividing each individual part cost by its cycle life puts reserves at $50 per EFC for the full shipset. Reserves for LLP replacement depend, however, on the stub life that can be left at replacement. Since typical removal intervals of 7,000-8,000EFH are equal to 6,000EFC, LLP replacement would best take place at the third shop visit and remaining stub lives are likely to be up to 2,000EFC. Assuming the same 10% stub life across all of the LLPs, this would put reserves at $55 per EFC.

When the reserves for engine shop visit maintenance and LLPs are combined the engine's total reserves are equal to $119 per EFH *(see table, this page)*.

Maintenance cost summary

Total maintenance costs are $600-610 per FH *(see table, this page)*.

Costs can be significantly lower for the larger fleet operators, primarily because they will administer their own rotable overhaul and negotiate much lower TotalCare rates with Rolls-Royce. Total maintenance costs nearer to $550 per FH would not be impossible. AC