E-Jets maintenance analysis & budget

The E-Jets family members follow a relatively simple maintenance programme. Maintenance costs are in-line with aircraft of their size and generation.

The Embraer E-Jets are sub-divided between the E-170/-175 and larger E-190/-195. The smaller E-170 first entered service in 2002, while the larger variants started operations later in 2004. The two main type groups are certified as two different aircraft types, and have different landing gears and engines, so they have two separate, although similar, maintenance programmes. Airlines which operate both type groups therefore need to have both maintenance programmes approved.

There are 530 E-jets in operation with airlines: 270 E-170s/-175s, and 260 E-190s/-195s. There are about another 362 on firm order. The aircraft are powered exclusively by the CF34 engine, but the E-170/-175 are equipped with the -8E5 variant, and the E-190/-195 are equipped with the higher-rated -10E5.

The E-Jets have a base maintenance programme of four base checks, with a basic interval of 6,000 flight hours (FH) and 5,000 flight cycles (FC). The fourth check in the cycle therefore has an interval of 24,000FH and 20,000FC. An eighth check at the end of the second base check cycle is heavier than the fourth check.

Most aircraft are operated at annual utilisations of 2,000-2,500FH, so they will have a base check every 25-30 months. On this basis, the earliest-built E-170s will have the first of their fourth base checks coming due in about three years. The fleet leader is an E-170LR operated by Republic Airlines, which has accumulated about 12,800FH and 9,100FC.

E-Jets in operation

The E-170 accounts for the majority of the two smaller variants. The E-170 and E-175 have been selected by airlines to operate in a variety of roles, including regional feeder services for larger carriers, lower-density routes for major airlines, and thinner markets served by small carriers.

Operators using the aircraft for regional feeding services include Chautauqua Airlines, Republic Airlines and Compass Airlines. Major airlines using the type include Alitalia, Egyptair, Finnair, LOT Polish Airlines, Saudia, South African, Air Canada and Royal Jordanian. Small operators are those such as Baboo, Cirrus Airlines, Fuji Dream Airlines and Hong Kong Express Airways.

Most E-170 and -175 fleets are operated on short sectors with average FC times of 0.9-1.4FH. Annual rates of utilisation are 1,900-2,500FH. The E-175 is operated at longer FC times.

Annual utilisation rates are close at 2,000-2,500FH for Alitalia Express, Egyptair Express, Finnair, LOT Polish Airlines, Saudia and Air Canada. US airline Republic Airlines, which provides feeder services for Delta and United Express, has longer average FC times of 1.35-1.50FH. Shuttle America, which also operates feeder services as Delta Connection and United Express, has FC times of about 1.60FH, one of the longest FC times of all E-Jet operations. Republic Airlines and Shuttle America also have higher annual utilisations of 2,600-3,000FH.

The E-190/-195 have similarly been acquired to operate in a variety of roles, although a few operators are regional airlines, affiliated with larger carriers, using the aircraft for feeder services. The E-190/-195 have mainly been selected to operate thinner routes for major and medium-sized airlines. Examples include Air Canada, COPA, Finnair, Hainan Airlines, jetBlue Airways, Lufthansa, TACA and USAirways.

The E-190 has similar rates of utilisation to the E-170/-175. Most E-190 operations achieve annual utilisations of 2,100-2,600FH and 1,350-1,900FC. Average FC time is about 1.50. Exceptions to this are Air Canada and jetBlue, two of the E-190's largest operators, which both accumulate averages of about 3,000FH per year and have average FH times of 1.80-2.00FH.

While there are 11 E-195 operators, only two have sizeable fleets that have been operating for two or more years. These are Flybe and Royal Jordanian, which have annual utilisations of 2,200-2,600FH and 1,900-2,000FC, and an average FC time of 1.20-1.35FH.

The two main type groups are therefore operated at similar rates of utilisation. Their maintenance costs are analysed here for aircraft completing 2,300FH and 1,800FC per year, at an average FC time of 1.28FH.

Maintenance programme

The E-Jets have a Maintenance Steering Group 3 (MSG3) maintenance programme. "The E-170/-175's maintenance planning document (MPD) is on its fifth revision, having been released in November 2008," explains Mikko Koskentalo, manager marketing and sales at Finnair Technical Services. "The E-190/-195's MPD is on its third revision, which was released in November 2008." Embraer expects to release its next revisions in the third quarter of 2009.

"The maintenance programme includes about 1,400 tasks for the E-170/-175 and 1,200 for the E-190/-195 in average configuration," continues Koskentalo. "The MPD has systems, structural, zonal, high-intensity radiated fields (HIRF)/lightning, and corrosion prevention and control programme (CPCP) inspections."

There are various intervals for these inspection tasks, which are based on multiples of 24 hours, FHs, FCs, calendar hours, and calendar months. These tasks are not pre-packaged into defined maintenance checks in the MPD.

Operators are free to package tasks into line and base maintenance checks, according to their rates of utilisation and FH:FC ratio. Tasks with calendar month intervals are more likely to be included in base checks.

There are several inspections with intervals close to 600FH and multiples of 600FH, and these are grouped into 'intermediate' or 'A' checks by most airlines. Some, such as Flybe, have chosen to equalise the tasks with the lower intervals into smaller line maintenance checks.

There are many inspections with intervals close to 6,000FH, and airlines group these into 'base' or 'C' checks. There are many tasks that have intervals lower than 6,000FH, and so they cannot be grouped into 'base' checks. "We have chosen to add a 3,000FH check package, and group these tasks into a 'B' check. The downtime for this also allows us to complete cosmetic tasks and to catch up with service bulletins (SBs) that cannot be completed during line checks. This

The E-170/-175 and E-190/-195 are certified as two different types, and so have two different maintenance programmes. These are similar, however, with most tasks the same between the two.

interval compares to our annual utilisation of 2,200FH," explains Stefan Kontorravdis, director of engineering at Flybe.

Many system tasks have multiples of 600FH. "Many operators group these tasks into phases or multiples of 600FH," explains Abdel-Aziz Masoud, chairman advisor at Egyptair Maintenance & Engineering. "The 600FH interval is regarded as a Phase 1 interval, and the 6,000FH interval of base checks is regarded as the Phase 10 interval."

Many system tasks have intervals that are a combination of FH and calendar time, usually expressed in months. The task is performed when either the FH or calendar interval is reached first. Tasks related to the landing gear have FC intervals.

Many structural tasks have intervals that are a combination of FC and calendar time. The tasks are performed when either the FC or calendar interval is reached first.

The CPCP tasks have intervals based on calendar time.

The zonal tasks have intervals that are multiples of 6,000FH.

HIRF/lightning inspections have to be performed in the event of the aircraft being struck by lightning. "This is because metal and composite material can separate after being struck by lightning," explains Koskentalo.

The total number of tasks and their intervals varies according to aircraft configuration and operator's maintenance programme. There are up to 730 inspections with FH intervals, 20-40 inspections with combined FH and calendar intervals, 350-430 tasks with FC intervals, about five tasks with FC and calendar intervals, 330-365 tasks with calendar intervals, and up to 10 tasks with FH and FC intervals.

The lowest FH intervals are 100FH, and go up to 40,000FH for the E-170/-175, and up to 30,000FH for the E-190/-195.

The FC intervals range from 600FC up to 40,000FC.

Calendar intervals range from 48 hours up to 240 months.

The FH, FC and calendar tasks with the highest intervals are the base check tasks, which are performed in the heaviest base checks. The FH:FC ratio and annual FH and FC utilisation have to be taken into consideration when packaging tasks into maintenance checks in order to ensure that the inspection intervals are utilised to their highest possible level.

Maintenance checks

Airframe maintenance checks can be split into three groups. These are line checks, A checks and base checks. The workscopes of these checks, and their labour and material inputs are reviewed.

Line checks

The line check maintenance programme in the MPD is simple. It does not have any of the pre-flight or transit checks that are standard for older aircraft types. The smallest line check specified in the MPD is a 48-hour check, which was a 24-hour check in many older aircraft types. The next highest line check for the E-Jets is the 14-day check, which was the weekly check of many older types.

Despite the simplicity of this maintenance programme, operators have added their own checks. Finnair, for example, has added a pre-flight check to its own maintenance programme. "We have a pre-flight check, the 48-hour or 'Service' check of the MPD, and a 'Routine' check with an interval of 120FH or 14 days," says Koskentalo. "We also add some additional line checks so that we can maintain technical despatch reliability (TDR), and also keep a good standard in the interior."

Egyptair's line maintenance programme also differs from the MPD. "The first check in our programme is an after-landing check, which is performed after arrival at base and for stops that last more than four hours. This includes checks on engine oil and fluid levels, and cockpit seats and belts, as well as an external walkaround visual inspection, which checks for physical damage, missing parts, hydraulic fluid leakage, and brake discs. The aircraft technical log, cabin logbook and engine indicating and crew alerting system (EICAS) screens are reviewed for error messages," explains Masoud. "There is also a transit check at outstations where the aircraft stop is less than four hours. This is an external walkaround visual inspection, and aircraft technical log review."

Egyptair's next highest check is the daily check, which has an interval of 48 hours. "This check includes the after-landing check tasks plus several others. These comprise a review of the central maintenance computer (CMC), an oxygen-pressure test, an emergency lighting and battery voltage check, an inspection of the galleys and lavatories, several emergency equipment checks, tyre pressure checks, and navigation light checks," continues Masoud.

"Then there is the weekly check, with an interval of eight calendar days. "Some tasks have to be performed every 100FH or 120FH. Our aircraft operate at about 7FH/8FC per day, so this is equal to 12-14 days," explains Masoud. "These items are included in the weekly check. The tasks in this check include the after-landing check, the daily check and several inspections. The inspections are a full history database download. This encounters downloading of all system

Egyptair is one operator that has substituted jetliners with the E-Jets on some if its routes that have lower traffic densities. The aircraft are operated at high frequencies, and maintain a high level of technical despatch reliability.

faults within the past eight days for further analysis, inspection of the landing gear, brake and tyre assemblies, engine master-chip detector inspections, horizontal stabiliser-ball screw inspection, cargo-lighting and safety-net inspection, passenger emergency equipment, and toilet-waste line cleaning."

A checks

Although there are no pre-defined A checks in the MPD for the E-Jets, there are a large number of tasks that most operators group into a 600FH interval. These packages are generically referred to as 'A' or 'Intermediate' checks by many operators.

The inspections have intervals close to 600FH, or multiples of 600FH. The maintenance programme can also be customised to suit the operators' pattern of operation and rate of aircraft utilisation. The inspection and tasks are mainly system-related tasks of low complexity that require little deep access. They can also be performed overnight, thereby minimising the disruption to the aircraft's operation. Embraer explains that these checks can be performed without the use of a hangar. Most of the tasks have FH intervals, although there are a few with FC and calendar intervals.

In Finnair's case, the Intermediate checks are arranged into a cycle of 10 checks. "The first check in the cycle, the Int-1 check, has an interval of 600FH," explains Koskentalo. "Tasks with intervals from 600FH to 6,000FH are grouped into the 10 Intermediate checks. The second check is the Int-2 with an interval of 1,200FH, and the tenth check is the Int-10 with an interval of 6,000FH. There are some tasks which have intervals that prevent them from being conveniently grouped into one of the 10 packages. These are considered as out-of-phase (OOP) tasks, so they normally have to be packaged with Service checks."

Masoud explains that the A check inspections include: changing oil and fuel filters; cleaning air conditioning and anti-icing filters; visual inspections; serviceability system checks; operational and functional checks; and lubricating flight controls. "There are a few tasks with intervals specified in FC, ranging from 3,000FC to 5,000FC. Bearing in mind our FH:FC ratio of about 1:1, these fall within the cycle of 10 A checks with the full interval of up to 6,000FH."

Kontorravdis explains that Flybe's basic A check interval is 600FH and 500FC. The airline operates its E-195s at about 2,200FH per year at an average FC time of 1.14FH. "We have a system of equalised checks to provide similar-sized workpackages of the tasks that have the basic 600FH interval and multiples of this interval," says Kontorravdis. "These equalised A checks fit in with the downtime provided by an overnight check. We also add some tasks specific to Flybe, as well as some SBs."

Line& A check inputs

Labour and material inputs for annual line maintenance depend on the operator's actual maintenance programme. A generic line maintenance programme can be used, and in this case it is assumed that the programme of checks will include a pre-flight or transit check prior to every departure, a daily or service check once every two days, and a weekly or routine check once every 14 days.

The pre-flight check is not actually part of the MPD, but those airlines that have it comment that labour requirements are relatively low. The check has been included in this analysis for the sake of conservatism, and a labour allowance of 0.5MH has been used. This check will be done at the start of each day. In addition to the routine tasks, it is used to clear any lighter defects that can easily be addressed, so some materials and consumables will be used, in addition to rotables that might get exchanged. A budget of $10 is used to reflect average material and consumable consumption.

The Transit checks follow for the rest of the day prior to each flight. These are usually carried out by the pilots, but an allowance of 0.5MH for labour by line mechanics and $10 of materials and consumables is again used.

The daily check is performed by line mechanics, and a labour consumption of 2.0MH and material consumption of $150 has been used.

A budget of 5.0MH and $200 of materials and consumables can be used for the weekly or service check.

On the basis of the aircraft completing 2,300FH and 1,800FC per year, the total labour used will be about 1,400MH. This is equal to $105,000 at a labour rate of $75 per MH. Once materials have been included in the cost of the checks, the total annual cost of line checks increases to $150,000. This is equal to a rate of $65 per FH *(see table, page 22)*.

Like line checks, the inputs used by different operators for A or Intermediate checks will vary according to their maintenance programmes. Average inputs for A checks are in the region of 120MH, when rectifications and cabin work are included. Each check will also use about $5,000 of materials and consumables. At the same labour rate, the inputs for the check total about $14,000. Typical utilisation rates of check intervals will be about 500FH, so the A checks will have a reserve of about $28 per FH. An additional $10 per FH can be budgeted for OOP tasks, taking the total to $38 per FH *(see table, page 22)*.

The E-Jets base maintenance programme is comprised of system inspections, with check intervals of 6,000FH and 5,000FC, and structural inspections. These are combined by most operators into a system of four base checks, with a basic check interval of 6,000FH/5,000FC and cycle interval of 24,000FH/20,000FC. The fourth check is usually the heavy check.

Base checks

Base checks include tasks with higher intervals than those described. These form three main groups.

The first of these are mainly system tasks and inspections which have intervals that are multiples of 6,000FH and 5,000FC. There are four main groups: the first with intervals of 6,000FH and 5,000FC; the second with intervals of 12,000FH and 10,000FC; the third with intervals of 18,000FH and 15,000FC; and the fourth with intervals of 24,000FH and 20,000FC.

These groups of tasks are arranged by most operators into block 'C' or 'Base' checks. The first check, with an interval of 6,000FH and 5,000FC, is termed the 'Bas-1' check by some operators, and has just the first group of tasks.

The second, 'Bas-2', check has intervals of 12,000FH and 10,000FC, and comprises the first and second group of tasks. The third, 'Bas-3', check has intervals of 18,000FH and 15,000FC, and comprises only the first group of tasks like the Bas-1 check.

The fourth, 'Bas-4', check has an interval of 24,000FH and 20,000FC. It is the heaviest check, since it comprises the first, second and fourth group of tasks and inspections. This fourth check ends the cycle of the base checks.

There is also a group of additional tasks, which have intervals of 48,000FH and 40,000FC, eight times the interval of the first group of tasks. These come due at the end of the second base check cycle, or the eighth check, the Bas-8 check, which means that this is heavier than the Bas-4 check.

Considering that the average airline utilisation of E-Jets is about 2,300FH and 1,900FC per year, the FH and FC intervals of these system tasks will be reached at about the same time. The 5,000FH interval is equal to about 26 months of operation. Base check intervals are rarely fully utilised, and checks are likely to be completed once every two years. "The four oldest aircraft in our fleet were delivered in the second half of 2005, and they are now going through their Bas-2 checks," says Pekka Helenius, E-Jets programme manager at Finnair Technical Services.

The second and third main groups of base check tasks together form the structural maintenance programme. The second group is the structural tasks which have an initial threshold that starts at 20,000FC and goes up to 40,000FC.

The third group consists of CPCP tasks, which have intervals of 72, 96 and 120 months. "The CPCP tasks are an integral part of the structural maintenance programme, and so the two are performed together," explains Helenius.

"The structural and CPCP tasks are closely linked, and the aircraft is built with corrosion-inhibiting fluids applied on the production line," says Kontorravdis. "The removal and reapplication of these fluids is part of the CPCP requirements."

Combining structural and CPCP tasks depends on operator utilisation. The structural inspections, with a 20,000FC interval, will come due at the same time as the Bas-4 check. This will be about 96 months, which is the same as some of the CPCP tasks. Although the Bas-4 check has not yet come due on any aircraft, it is expected that the structural inspections and CPCP tasks will be combined with the Bas-4 check. One advantage of doing this is that the downtime of the Bas-4 check will allow the most access for the structural inspections.

Consideration has to be given for the CPCP tasks at 72 and 120 months. The 72-month tasks are likely to be combined with the Bas-3 check, if base check intervals are performed every two years. The 120-month tasks are the largest in number, and would come due at the Bas-5 check. However, they are more likely to be included in the Bas-4 check, because they require deep access, which is not possible during the light Bas-5 check, which is similar to the Bas-1 check.

There are also structural inspections with threshold intervals between 20,000FC and 40,000FC. These are likely to come due at various stages between the Bas-4 and Bas-8 checks.

The number of routine tasks that come due in base checks will therefore increase from the Bas-4 check onwards.

Out-of-phase tasks

In addition to the inspections that are included in the line, Int or A-checks, and C or Base checks, there are also several OOP tasks. These are inspections whose intervals do not fit in well with the Int and Base checks. "Examples of OOP tasks are IDG and oil filter changes, which have an interval of 125FH. There are other tasks with intervals of 400FH and 500FH, and we put these in what we call a half-phase check, every 300FH. This is half the A check or basic Phase interval of 600FH," explains Masoud.

Kontorravdis explains that there are many OOP tasks, which are mainly inspections. "These do not have intervals that are multiples of 600FH, and it is possible for operators to package them into previous checks, so they get performed early, or do them on their own as OOP items. Flybe has chosen to amalgamate them into A checks or into a check that we introduced and called the B check, and which is half-way between the base check at 3,000FH."

Base check contents & inputs

The content of base checks clearly includes more than just MPD and maintenance programme inspections, as described. As with all aircraft, the base checks comprise several other elements.

The consumption of labour for the four base checks naturally varies with the routine inspections that come due. These each require 900-1,200MH for the first three base checks, with the second being the largest. The fourth check has a large labour requirement because of the additional structural and CPCP inspections, and can be as high as 5,500MH. This assumes that 120-month CPCP tasks are brought forward and included in the Bas-4 check.

Routine MH for the four checks of the first base check cycle total about 8,700MH.

The first of these additional elements is non-routine rectifications arising from findings due to routine inspections. Routine inspections and non-routine rectifications will form the majority of work performed in the check.

The non-routine ratio is a key factor in the overall size of base checks. These are expected to be low for the first one or two base checks and then increase with age, as is the case with other aircraft.

"We have experienced non-routine ratios of 40-80% in our first base check," says Helenius. "The actual rate depends on how well the aircraft is kept and maintained, but we expect the rate to gradually increase with age."

Like Finnair and many other operators, Egyptair has only had experience with Bas-1 checks. "Our experience with this is a non-routine ratio of about 50%," says Masoud.

At this stage in the E-Jets' life and maintenance cycle, only estimates of likely non-routine ratios can be made. This will be for Bas-3 and Bas-4 checks, with a large number of the fleet now having been through Bas-1 and Bas-2 checks.

Non-routine ratio will typically start at 40-60% for the Bas-1 check, and rise to 60% for the Bas-2 check. The ratios for the Bas-3 and Bas-4 checks are estimated to be 70% and 90% respectively.

MH for non-routine rectifications will be 450-800MH for the first three checks, and be larger at up to 5,000MH for the Bas-4 heck. The sub-total of routine and non-routine MH for the first three checks will therefore be 1,350-1,900MH. The sub-total for the Bas-4 check will be 9,000-10,500MH.

The third main element of base checks involves carrying out inspections and modifications described under airworthiness directives (ADs), modifications described under service bulletins (SBs), and completing engineering orders (EOs). "While there is always a usual amount of SBs required during base checks on the E-Jets, the earlier-built aircraft had to undergo an extensive structural modification programme," explains Helenius. "This meant that our earlier-built E-170s and E-190s required 700-800MH of labour to incorporate these modifications. These were incorporated on the production line of later-built aircraft, so they did not need these modifications in base checks."

One operator has made a provision or budget for as much as 2,500MH to complete all the structural SBs.

Besides these structural modifications, there are always ADs, SBs and EOs that need to be incorporated. The labour inputs required for these will vary according to the ADs that have been issued and their applicability to individual aircraft, and airline policy with respect to incorporating particular SBs.

The E-Jets have been affected by a few ADs. "We have carried out more than 200 modifications on our aircraft," says Koskentalo. "Besides the structural modifications mentioned, we have also made some software and system upgrades."

The CF34 engines powering the E-Jets are divided between the -8E variants powering the E-170/-175, and the -10E powering the E190/-195. Despite the -10Es having a higher thrust rating, the two variants have close maintenance costs.

There have been a few specific SBs that have affected the E-Jets. One of these has been a modification to increase the volume of oxygen for pilot masks from 55 cubic feet to 77 cubic feet.

Another problem has been the need to relocate the drain mast on the belly of the aircraft. The drain was letting dirty water into the air scoop at the fairing for the heat exchanger. An SB was issued to move the drain further aft.

Because of the variation in periodic AD issuance and airline maintenance policy, a typical amount of average labour can therefore only be budgeted for in each base check. Helenius explains that, following the incorporation of the structural modifications, base checks typically use a few hundred MH. A range of 300-400MH has been used for the lower base checks, and 500MH for the Bas-4 check.

A fourth element of base checks will be labour required for additional items that include removing and installing replacement rotable components, clearing defects that have occurred during operation, and some OOP tasks. This again will vary according to each airline's maintenance programme and philosophy. This portion of the check requires 200-300MH.

Interior work can be divided between regular cleaning and refurbishment. A budget of 150MH for regular cleaning in these checks should be used.

Total labour consumption for the three lighter checks is 2,000-2,750MH. Consumption for the Bas-4 check can be 11,000-11,500MH. Total labour for the four checks in the cycle will be 17,500-18,500MH. Charged at a labour rate of $50 per MH, this is equal to $875,000-925,000.

The consumption of materials and consumables varies from $15 to $50 per MH for different elements of the check. Overall material consumption is $55,000-75,000 for the first three checks, and up to $300,000 for the Bas-4 check, taking total consumption over the cycle to $530,000.

The total cost of labour and materials for the four checks in the first cycle is therefore estimated to be $1.5 million with the labour rates used here. Actual check intervals are assumed to be 24 months for ease of maintenance planning as described. This means that the interval between checks is about 4,600FH, compared to the 6,000FH MPD interval. The fourth check will therefore be completed at about 18,400FH, so the reserve for these four checks will be about $79 per FH *(see table, page 22)*.

Refurbishment & painting

Interior refurbishment is treated as an on-condition task by most airlines, although several have established soft times for refurbishing different parts of the interior. The interior includes seat covers, seat cushions, carpets, sidewall and ceiling panels, overhead bins, passenger service units (PSUs), galleys, toilets, and servicing areas.

"We usually dry clean our seat covers once every three or four months. After three cleans they lose their inflammable properties, so we usually have to replace them once a year," says Koskentalo. Similarly, Egyptair replaces its seat covers at every C check, up to every two years.

Removing, reinstalling and dry cleaning a shipset of seat covers will cost about $700. Replacing the shipset will cost about $20,000. On the basis of three cleans and one annual replacement, the amortised cost is equal to about $10 per FH.

Seat cushions will also have to be replaced, and can be done about once every five years. This will cost about $25,000, equal to about $2 per FH.

Carpets will also experience a high rate of wear, although this will vary between operators. Finnair finds that aisle carpets require frequent replacement due to the effects of winter weather. "We replace aisle carpet about once every three months, and other carpet about once a year," says Koskentalo.

Carpet removal and replacement uses about 30MH, and a shipset of new carpet material costs about $2,000. Amortising the two parts over the relevant intervals is equal to $2.00 per FH.

The remaining interior items are maintained by most airlines on an on-condition basis. "We examine the condition of these every base check, and refurbish them to a level so that they last until the next base check," says Koskentalo. "We then plan to do a major refurbishment on these items at the Bas-4 and Bas-8 checks."

The restoration of the panels, bulkheads, bins and PSUs may use 100-200MH at the Bas-4 check. Refurbishment at the Bas-8 check may use about 800MH and $4,000. Refurbishment of galleys, toilets and servicing areas at the Bas-8 check may use about 400MH and $5,000. The total cost of this, amortised over the Bas-8 check interval, will be equal to a reserve of about $2 per FH.

The final element of refurbishment is aircraft stripping and repainting. This will use about 1,200MH and $10,000-15,000 for paint, taking the total cost to $70,000. If aircraft are repainted once every six years, the reserve will be $5 per FH.

The total reserve for interior refurbishment and stripping and repainting will be $21 per FH *(see table, page 22)*. About $12 per FH of this cost is related to the refurbishment and replacement of seat covers and cushions.

Heavy components

Heavy components comprise the landing gear, wheels and brakes, and the auxiliary power unit (APU).

The landing gear overhaul life varies across the E-170/-190 variants, ranging from 30,000 cycles/12 years for the E-170/-175, to 20,000 cycles/eight years for the E-190/-195. Given the average utilisation of 1,800FC per year the majority of landing gear overhauls will take place when the calendar limits are reached. The estimated overhaul cost for the E-170/-175 gear is $207,000. A typical overhaul reserve is therefore $10 per FC *(see table, page 22)*, equal to $8 per FH. The estimated overhaul cost for the E-190/-195 gear is $259,000. A typical overhaul reserve is therefore $18 per FC *(see table, page 22)*, equal to $14 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 wheels, brakes and tyres is $50 per FC for the E-170/-175, equal to $39 per FH and $70 per FC for the E-190/-195, equal to $55 per FH *(see table, page 22)*.

The APU is a Hamilton Sundstrand Model APS 2300 and overhaul is on-condition. A typical overhaul is estimated to cost $147,500 and the average time before overhaul (TBO) to be 6,700 APU hours (APUH). This gives a reserve of $22 per APUH *(see table, page 22)*. Assuming an APU utilisation of 0.8APUH per FH this is equal to $18 per FH.

Rotable components

Considering the relatively small size of the E-170/-190 fleet it, is surprising that no fewer than three companies are offering rotable overhaul programmes for it. They are all fundamentally similar, covering most of the rotable parts with the exception of the larger items, the landing gear and APU. Failed or hard-time components are removed from the aircraft by the operator and exchanged for fresh components provided by the service provider. The latter then arranges for the repair, testing, and return of serviceable parts to the inventory. As well benefiting from having predictable costs, the operator avoids the burden of managing warranty administration, and having arguments with a large number of vendors.

Unsurprisingly, the most established of these providers is Embraer itself. The company's Parts Pool Program, which was developed for the earlier ERJ-145 family, has been extended to the E-170/-190 and has been selected by a large number of operators.

In November 2008 Lufthansa Technik became the second player in this market when it announced that National Air Services, of Saudi Arabia, would be the launch customer for its Total Component Support (TCS) service for the E-190. Lufthansa Technik offers TCS across the whole range of Airbus and Boeing products, as well as the Bombardier CRJ series and the Q400. This builds on Lufthansa Technik's earlier co-operation with LOT Polish Airlines on the Embraer 145 and E-Jet. The two companies signed a co-operation agreement in 2004, whereby Lufthansa Technik is responsible for component repair, and LOT Polish Airlines provides the logistic support. In addition to these two fleets, Lufthansa Technik will undoubtedly support the 30 E-190/-195s that have been ordered by Lufthansa itself.

The most recent entrant is US-based Barfield, a part of the Sabena Technics Group. In June 2009 the company announced that it had been selected by TACA of El Salvador to provide full repair and overhaul support for the rotable components on its fleet of 11 E-190s.

The actual costs for these three

DIRECT MAINTENANCE COSTS FOR E-170/-175 & E-190/-195

Maintenance Item	E-170/ -175	E-190/ -195
Line & ramp checks	65	65
A check	38	38
Base checks	79	79
Interior refurbishment & stripping/repainting	21	21
Landing gear	8	14
Wheels & brakes	39	55
APU	18	18
LRU component support	209	209
Total airframe & component maintenance	**477**	**499**
Engine maintenance:		
2 X $153-180 per EFH	306-360	
2 X $136-156 per EFH		272-312
Total direct maintenance costs:	**783-837**	**771-811**

Annual utilisation:
2,300FH
1,800FC
FH:FC ratio of 1.28:1

competing programmes depend on fleet size, utilisation, route network and style of operation among other criteria. Typical budgets for new aircraft are estimated to be $115/FH for the FH fee covering repair and overhaul, and $15,000 per aircraft per month for the pool-access fee covering the financing of the pool stock, insurance and administration (equating to $78/FH).

A fleet of five E-170/-190 family aircraft operating 2,300FH per year is estimated to require an on-site stock inventory with a value of $1 million. The monthly lease cost for this stock would be about $15,000 shared between the five aircraft. This would be equal to about $16 per FH.

The total for the three elements is therefore $209 per FH *(see table, this page)*.

Engine maintenance

The E-170/-190 family is powered exclusively by engines from the General Electric (GE) CF34 family. The E-170-175 are powered by variants of the CF34-8E, while the E-190/-195 are powered by variants of the higher-rated CF34-10E.

It is not widely appreciated that, although they are both members of the CF34 family, there is no commonality between the CF34-8 and CF34-10. The CF34-8 was a derivative of the CF34-3 which powered the Canadair CRJ200. It retained the same architecture but incorporated a larger fan and a new ten-stage compressor derived from the F414 military engine.

For the even greater thrust required by the CF34-10, General Electric used the architecture of the CFM56 rather than the CF34. The compressor is based on the CFM56-7B. The retention of the CF34 designation was more to do with branding than engineering.

CF34-8E5

There are two engine variants available for the E-170 and E-175: the CF34-8E5 and the CF34-8E5A1. They are physically identical and differ only in the normal take-off thrust rating and the maximum allowable take-off temperature *(see table, this page)*.

All these engines are maintained on-condition, but a typical interval for the first shop visit of a CF34-8E5 is about 11,500 engine flight hours (EFH). Subsequent shop-visit intervals will be lower at 7,500EFH. The first and second shop visits are estimated to cost $700,000, but the third will be more expensive at an estimated $1,000,000. Over the three shop visits the cost per EFH will be $91/EFH.

The CF34-8E has 23 different life limited parts (LLPs), and all the current-production parts have a projected ultimate life of 25,000EFC. However the current life limits vary from 11,500EFC up to 25,000EFC (only 13 of the 23 LLPs having so far reached the projected ultimate life). GE, however, has guaranteed to meet the 25,000EFC limit. In the event that the LLP is removed, because the limit has not been extended, then GE will compensate the operator the difference. The list price of the current production-standard parts is approximately $1.65 million. Dividing each individual part cost by its ultimate cycle life puts the LLP reserve at $66/EFC.

Reserves for LLP replacement, however, depend on the stub life that can be left at replacement. Based on the projected ultimate component lives, and assuming an annual utilisation of 2,300FH/1,800FC, LLP replacement will not be a factor until the third shop visit. Assuming that the third shop visit takes place at 26,500EFH/20,740 cycles, then the stub life left in the LLPs at replacement is likely to be in excess of 15%, so a more realistic LLP reserve would therefore be $80/EFC.

CF34-8E5A1

The equivalent shop-visit intervals for the higher-rated -8E5A1 will be about 9,500EFH and 6,500EFH. Therefore although the shop visits are estimated to cost the same as those for the -8E5, the reserve per EFH will increase from $91/EFH for the CF34-8E5 to $107/EFH for the -8E5A1.

The CF34-8E5A1 has the same LLPs as the -8E5 and, with the exception of the components in the high pressure turbine (HPT), all the current production parts have a projected ultimate life of 25,000EFC. The seven HPT LLPs have a projected ultimate life of only 20,000EFC. The current life limits of the components in the HPT, however, are only 6,000EFC. Dividing each individual part cost by its ultimate cycle life puts reserves at about $70/EFC, but again this fails to take into account the stub life that will be left at replacement.

Based on the projected ultimate component lives, and assuming an annual utilisation of 2,300FH/1,800FC, LLP replacement will not be a factor until the third shop visit. Assuming that the third shop visit takes place at 22,500EFH/17,600 cycles, the stub life left in the LLPs at replacement is going to be about 9% for the LLPs in the HPT, but almost 30% for the remaining LLPs. A more realistic LLP reserve would therefore be $94/EFC. It is clear that the lower 20,000-cycle life of the LLPs in the HPT will have a significantly negative impact on the operating cost of this engine.

There is little difference in overall maintenance costs between the E-170/-175 and E-190/-195. The larger aircraft have higher heavy component costs, but this is offset by slightly lower engine maintenance costs.

CF34-10E5 in operation

There are no fewer than five engine variants available for the E-190 and E-195: the CF34-10E5, E5A1, E6, E6A1 and the E7. They are physically identical, and the difference between them is in the take-off thrust rating, flat-rating temperature and the maximum allowable take-off temperature *(see table, page 22)*.

All these engines are maintained on-condition, but a typical interval for the first shop visit of a CF34-10E5 is about 18,000EFH. Second and third shop-visit intervals will be lower at about 12,000EFH and 10,000EFH respectively. The first shop visit is estimated to cost in the region of $850,000, but the second and third will be more expensive at $1.4 million and $1.3 million respectively. Over the three shop visits the cost per EFH will be $89/EFH.

On all the CF34-10E variants the LLPs have a projected ultimate life of 25,000EFC. The list price of the current production-standard parts is approximately $1.4 million. Dividing each individual part cost by its ultimate cycle life puts the LLP reserve at about $56/EFC. Again, reserves for LLP replacement depend on the stub life that can be left at replacement.

Based on the projected ultimate component lives and assuming an annual utilisation of 2,300FH/1,800FC, LLP replacement will not be a factor until the second shop visit. Assuming that the second shop visit takes place at 30,000EFH/23,480 cycles, then the stub life left in the LLPs at replacement is likely to be approximately 6%, and a more realistic LLP reserve would therefore be $60/EFC.

CF34-10E6

The equivalent shop-visit intervals for the higher-rated -10E6 will be about 17,000EFH, 10,500EFH and 9,000EFH. The first shop visit is estimated to cost in the region of $850,000, but the second and third will be more expensive at $1.35 million and $1.25 million respectively. Over the three shop visits, the cost per EFH will be $95/EFH.

Based on the projected ultimate component lives, and assuming an annual utilisation of 2,300FH/1,800FC, LLP replacement will not be a factor until the second shop visit. Assuming that the second shop visit takes place at 27,500EFH/21,520EFC, then the stub life left in the LLPs at replacement is going to be about 14%, and a more realistic LLP reserve would therefore be $65/EFC.

CF34-10E7

The equivalent shop-visit intervals for the higher-rated -10E7 will be about 13,000EFH, 7,000EFH and 6,000EFH. The first shop visit is estimated to cost in the region of $700,000, but the second and third will be more expensive at an estimated $1.0 million and $950,000 respectively. Over the three shop visits the cost per EFH will be $102/EFH.

Based on the projected ultimate component lives, and assuming an annual utilisation of 2,800FH/2,200FC, LLP replacement will not be a factor until the third shop visit. Assuming that the third shop visit takes place at 26,000EFH/20,350 cycles, then the stub life left in the LLPs at replacement is going to be approximately 18%, and a more realistic LLP reserve would therefore be $69/EFC.

Maintenance cost summary

Perhaps surprisingly, there is not a great difference between the total maintenance costs for the E-170/-175 and the larger E-190/-195. This is mainly because the E-190/-195 has slightly lower engine maintenance costs than the E-170/-175.

Despite the greater thrust and the higher cost of overhaul of the CF34-10, its longer shop-visit intervals result in an overhaul cost per EFH comparable with the CF34-8E5. Moreover, the list price for the LLPs on the CF34-10 is actually less than the CF34-8 at $1.4 million compared to $1.65 million. As a result, the higher-rated CF34-8E5A1 suffers the highest cost of all, because it has the shorter shop-visit intervals, the most expensive LLPs and the lowest LLP life.

The total maintenance cost for the two smaller members of the family is $783-837 per FH for the E-170/-175, and $771-811 per FH for the E-175 *(see table, page 22)*. The difference is mainly due to the increased cost of maintaining the higher-rated engines. The E-190/-195 have higher heavy-component-related costs, which offset their lower engine maintenance costs.

The total costs are particularly low for the E-190/-95 considering their size. This is one major element that makes the aircraft appealing compared to the smallest jetliners, whose maintenance costs are about $300 per FH higher. Although the maintenance costs are relatively high for the E-170/0175, the aircraft nevertheless remain economically attractive. AC