CRJ family maintenance analysis & budget

The CRJ has a complex maintenance programme, with several groups of tasks with different interval parameters. The maintenance costs of the CRJ-100, -200, -700 & -900 are examined.

The Bombardier CRJ family is the most successful regional jet (RJ) family to date. There are more than 1,500 aircraft in operation, with the first CRJ-100 entering service in 1992. There are also 108 outstanding firm orders for the CRJ-700, CRJ-900 and CRJ-1000. The CRJ fleet can be sub-divided into two fleets: the CRJ-100 and -200 which are powered by the CF34-3A/-3B engine; and the CRJ-700, -900 and -1000 which are powered by the -8C series engine. The five main variants are the CRJ-100, -200, 700, -900 and -1000.

There are three different maintenance programmes:; one for the CRJ-100/-200; one for the CRJ-700; and one for the CRJ-900.

The maintenance programme for the CRJ-100/-200 is at its 21st revision, which was issued in May 2009. The maintenance requirements manual is at its eighth revision for the CRJ-700/-900.

CRJ in operation

There are nearly 1,200 CRJ aircraft in operation in North America, which has a small number of large fleets. Europe is the second largest operator with 239 aircraft. Few are operated elsewhere in the world.

Of these, the smaller 50-seat CRJ-100/-200 dominate, with 1,100 in operation, when the CRJ-440 is included. There are 214 CRJ-100s, which are dominated by the higher gross weight and higher performing CRJ-200/-440, which entered service in 1995. The last CRJ-100s entered service in 2001.

Almost 800 -100s and -200s are in North America, and more than 700 operate regional feeder services on spokes serving the US majors' hubs. These are operated by Comair (94), Jazz Air (24), Mesa (43), Skywest (138), Air Wisconsin (70), ASA (1120, Chautauqua (12), Mesaba (56), Pinnacle Airlines (124), and PSA (35). The CRJ-440 has the same fuselage as the -100 and -200, but is configured with 44 seats, and is used to comply with pilot union scope clauses.

All aircraft have similar operations and annual rates of utilisation: 1,900 flight hours (FH) and 1,650 flight cycles (FC) for the CRJ-100 fleet; and 2,300FH and 2,100FC for the CRJ-200s and -440s. These fleets all have an average FC time of 1.11-1.17FH.

There are several carriers in the Asia Pacific, including China Eastern, Huaxia Airlines, Ibex Airlines, J-Air, JetLite, Shandong Airline and Shanghai Airlines.

The CRJ-100 and -200 are also operated in Europe. The largest fleets are with Adria Airways (7), Brit Air (15), Cimber Air (13), Eurowings (18), Lufthansa Cityline (22), Air Nostrum (35), Austrian Arrows (13) and West Air Sweden (2). These carriers operate the aircraft at similar rates of utilisation to North American operators.

The CRJ-700 first entered service in 2001. The pilot union scope clauses of most US majors allow specified numbers of 70-seat RJs to be operated by their regional affiliates, so the CRJ-700 is operated most by regional carriers for feeder services. These include American Eagle (25), ASA (39), Comair (15), GoJet (21), Horizon Air (18), Jazz Air (16), Mesa (20), PSA (14) and Skywest (69).

The pattern of operation by many of these fleets is similar to the CRJ-100/-200, although aircraft are operated on longer average FC times of 1.40FH. Average rates of utilisation are 2,600FH and 1,900FH per year. The exceptions are Jazz Air and SkyWest Airlines which operate their aircraft on longer average cycles of 1.70-1.82FH, and consequently have higher annual utilisations of 2,750-2,900FH.

The CRJ-700 is also operated by three CRJ-100/-200 operators: Brit Air, Eurowings and Lufthansa Cityline. Air India and South African Express also have the CRJ-700.

The CRJ-900 has similar fleet distribution. Large numbers are operated by US feeder carriers, including ASA (10), Comair (13), Mesa Airlines (38), Mesaba (41), Pinnacle Airlines (16), and Skywest (21). These have FC times of 1.30-1.76FH, which are longer than North American operations for the CRJ-100/-200 and -700, and therefore have higher rates of utilisation at 2,350-2,800FH per year.

Some European carriers and other operators also have longer FC times of up to 1.25FH and higher rates of annual utilisation, but many still operate the CRJ-900 at 0.90-1.15FH per FC.

While there is some variation in rates of utilisation between operators, the maintenance costs of the aircraft are analysed here for aircraft operating at 2,300-2,400FH and 2,100FC per year, equal to an average FC time of 1.15FH.

Maintenance programme

The CRJ's three maintenance programmes are relatively complex compared to other jetliners. The programmes comprised A checks and base checks. A checks consist of three groups of tasks, and base checks consist of three other groups of tasks.

The CRJs do not have a maintenance planning document (MPD). Instead there are the maintenance requirements manual (MRM) and a maintenance planning manual (MPM). The MRM has two parts. The first relates to systems, structures, zonal inspections and the corrosion prevention and control programme (CPCP). The second part relates to airworthiness requirements, powerplants and fuel systems.

The MPM lists all the inspection tasks. There have been 21 revisions to the CRJ-100/-200's maintenance programme to date.

Airframe maintenance falls into three categories of line and light maintenance, A checks and base checks. Base checks will include interior refurbishment and stripping and repainting in addition to the tasks specified in the MPM.

Line checks

There are no actual line check tasks specified in the MPM, but many operators have written tasks for their own line maintenance programmes. "We have a pre-flight check and a recommendation to perform a service check every night on our CRJ-200 and -900 fleets, but only if this is possible at the homebase," explains Robert Rozman, engineering manager at Adria Airways. "The service check has a maximum interval of three days, but will be carried out more frequently than this. There is also a line check in the MPM known as the routine check. This has an interval of 100FH, but we added an additional eight-day limit and treat it as a weekly check. There are two sets of task cards

CRJ-100/-200 A CHECK ROUTINE INSPECTION TASKS

Inspection task group	Interval FH	MH for routine inspection
1A	500	50
2A	1,000	80
3A	1,500	50
4A	2,000	95
5A	2,500	80
APU1	300	2
APU2	700	2
APU3	1,200	2
APU4	1,500	2
APU5	1,800	2
APU6	3,000	2
Out-of-phase tasks	400	3

CRJ-100/-200 BASE CHECK ROUTINE INSPECTION TASKS

Inspection task group	Interval	MH for routine inspection
1C	5,000FH	210
2C	10,000FH	280
3C	15,000FH	60
4C	20,000FH	26
5C	25,000FH	3
Gp1 OOP	3,000FH	1
Gp2 OOP	4,000FH	70
Gp3 OOP	8,000FH	40
Gp4 OOP	12,000FH	2
Gp5 OOP	16,000FH	50
Gp6 OOP	24,000FH	80
12-month calendar	12 months	20
18-month calendar	18 months	1
24-month calendar	24 months	40
36-month calendar	36 months	7
48-month calendar	48 months	240
60-month calendar	60 months	10
72-month calendar	72 months	890
96-month calendar	96 months	780
120-month calendar	120 months	64
144-month calendar	144 months	2
180-month	180 months	5

created by Bombardier which combine all the tasks with intervals of 72 hours and 100FH. These are called the Service check and Routine check. "The Service and Routine checks do not exist on the CRJ-900," adds Rozman. "Every maintenance requirement in the two parts of the MRM has its own job card, and it is up to each operator to package task cards into checks, or perform them separately, as required. Based on MRM requirements and our own experience, we have created separate Service and Routine task cards."

In addition to tasks specified in the MPM, operators can add their own cabin cleaning items and tasks.

A checks

The next higher level of checks are the A checks. In the case of the CRJ-100/200, the basic interval for a group of 1A tasks is 500FH. At an annual utilisation of 2,300FH, this is equal to 11 weeks of operation.

There are five groups of tasks with multiples of these, so there are also 2A tasks with an interval of 1,000FH, 3A tasks with an interval of 1,500FH, 4A tasks with an interval of 2,000FH and 5A tasks with an interval of 2,500FH. The 5A tasks therefore come due once every 12-14 months.

These tasks can be formed into similar-sized 'equalised' checks or into 'block' checks as tasks come due. The A1 check will therefore comprise just the 1A tasks, the 2A check will comprise the 1A and 2A tasks, the 3A check just the 1A tasks, and the A4 check the 1A, 2A and 4A tasks. The five different intervals and task groups do not actually come into phase with each other until the A60 check at 30,000FH, so no A check gets finished. Task groups are continually carried out, and the A60 check comes due after 25-30 years' operation.

The 1A and 3A routine tasks each require50 man-hours (MH) to complete. The 2A and 5A tasks each use 80MH, and the 4A tasks are the largest group, using 95MH *(see first table, this page)*.

If grouped as block checks, the A1 check will therefore have 1A tasks and require 50MH for routine inspections. The A2 and A5 check routine tasks will use 130MH, while the A3 check routine tasks will consume 100MH. The larger checks will be the A4, with 1A, 2A and 4A tasks, and require about 225MH. The A6 check is also relatively large, including the 1A, 2A and 3A tasks. These will consume 180MH for routine inspections.

In the case of the CRJ-700 and -900 the basic 1A interval is 400FH, but this will be escalated to 600FH in the near future. This means the A5 check comes due at 2,000FH, but will be extended to 3,000FH.

The five task groups have routine MH consumption of 15-55MH, with the 1A group of tasks being the largest. If grouped into block checks, the A4 check is the largest, requiring 135MH for routine inspections. The smallest is the A1 check, with just 1A tasks, which will use 55MH for routine inspections.

There are, however, two more groups of tasks that are included in A checks by most operators. The first of these are inspections of the auxiliary power unit (APU). There are several groups of tasks with different intervals, which are based on APU hours (APUH) and FH. These intervals are unique to each operator.

One example is for tasks at 300FH, 700FH, 1,200FH, 1,500FH, 1,800FH and 3,000FH. Unlike most other tasks, these groups are not multiples of the basic interval of the first group of tasks.

"In the case of the CRJ-700 and -900 the APU tasks are at 500APUH, 2,000APUH and 3,000APUH," says Rozman.

Many of these are small tasks related to inspecting oil levels and detectors. There is also a fixed interval at 3,500APUH for removal and replacement of the APU.

The third group of tasks included in the A checks is the out-of-phase (OOP) tasks. These do not have intervals that match those of the main groups of A check tasks, and have odd intervals such as 400FH, 800FH and 1,200FH in the case of the CRJ-100/-200. These have to be planned into the A checks or Routine checks as appropriate for the aircraft's operation and utilisation.

"There are OOP tasks at 500FH and

30 days on the CRJ-700/-900," says Rozman.

The MH required to complete the routine inspections for each small group of OOP tasks is in the region of 2-5MH, and so their impact on additional work for Routine and A checks is small.

Base checks

The C checks or Base checks have inspections that are grouped into three lots of tasks by most. "In fact there are six groups of tasks," explains Rozman. "These relate to systems, powerplants, structures, zonal, corrosion and electrical wiring interconnection." These are grouped into the three types of tasks used by most operators in their planning.

The first of the three groups is the main inspections. In the case of the CRJ-100/-200, the basic interval for 1C tasks is 5,000FH. There are another four groups of tasks with multiples of this basic interval: the 2C tasks at 10,000FH; the 3C tasks at 15,000FH; the 4C tasks at 20,000FH; and the 5C tasks at 25,000FH.

In the case of the CRJ-700/-900 the basic interval for the 1C tasks is 4,000FH, so the 5C tasks come due at 20,000FH. "The basic interval will soon be escalated to 6,000FH, so the 5C tasks will come due at 30,000FH," explains Rozman.

In the case of the CRJ-100/-200, the 1C tasks consume 210MH for routine inspections. The 2C tasks use 280MH for routine inspections, and the 3C tasks consume 60MH *(see second table, page 20)*. Unlike many aircraft, the 4C tasks are a small group and use 26MH. The 5C tasks are also a small group, and use 3MH.

In the case of the CRJ-700/-900, the MH distribution among the five C check tasks groups is similar to that of the CRJ-100/-200. The 1C tasks use 280MH, the 2C tasks 350MH, and the 3C tasks use 80MH. The two smaller groups are the 4C and 5C which use 5MH and 35MH.

The second group of base check tasks are OOP items. These are grouped and treated differently by operators.

One example for the CRJ-100/-200 is for tasks to be expressed in FH. They vary in routine MH requirements. There are six groups with different intervals between 3,000FH and 24,000FH *(see second table, page 20)*. The first is due at 3,000FH and uses only 1MH, so it can easily be combined with a line or base check as it comes due. The second group is due at 4,000FH and uses about 70MH for routine inspections *(see second table, page 20)*. The third group has an interval of 8,000FH and consumes about 40MH for routine inspections. The fourth group has an interval of 12,000FH. It is also small and used only about 2MH. The fifth and sixth groups of tasks have intervals of 16,000FH and 24,000FH, and use 50MH and 80MH for routine inspections.

CRJ-700/-900 A CHECK ROUTINE INSPECTION TASKS

Inspection task group	Interval	MH for routine inspection
1A	400FH	55
2A	800FH	45
3A	1,200FH	15
4A	1,600FH	35
5A	2,000FH	45
APU1	500APUH	2
APU2	2,000APUH	2
APU3	3,000APUH	2
Out-of-phase tasks	500FH	2
Out-of-phase tasks	30 days	5

CRJ-700/-900 BASE CHECK ROUTINE INSPECTION TASKS

Inspection task group	Interval	MH for routine inspection
1C	4,000FH	280
2C	8,000FH	350
3C	12,000FH	80
4C	16,000FH	5
5C	20,000FH	35
Gp1 OOP	3,000FH	5
Gp3 OOP	4,400FH	5
Gp4 OOP	4,500FH	5
Gp5 OOP	5,000FH	15
Gp6 OOP	5,500FH	10
Gp7 OOP	6,500FH	2
Gp8 OOP	10,000FH	15
Gp 10 OOP	25,000FH	15
Gp 11 OOP	30,000FH	3
6-month calendar	6 months	5
12-month calendar	12 months	4
18-month calendar	18 months	2
24-month calendar	24 months	30
36-month calendar	36 months	12
48-month calendar	48 months	320
96-/48-month calendar	96 & 48 months	160
96-/72-month calendar	96 & 72 months	580

Rozman explains that the CRJ-700/-900's maintenance programme results in different groupings of OOP tasks. "The APU is removed at 3,000APUH, and other APU-related tasks are carried out every 1,000APUH thereafter, with some engine-related tasks at 3,000 engine flight hours (EFH) and every 2,000EFH thereafter," says Rozman. "In addition there are nine groups of tasks with FH intervals: 3,000FH, 4,400FH, 4,500FH, 5,000FH, 5,500FH, 6,500FH, 10,000FH, 25,000FH and 30,000FH *(see second table, this page)*.

Routine MH for these nine groups of tasks are small for the first and fourth groups of OOP tasks, at only a few MH. The four other groups use 10-15MH *(see second table, this page)*.

The third main group of base check inspections are tasks with calendar intervals. These are mainly related to structures and corrosion. As with OOP tasks, calendar inspections are treated differently by operators.

One example for the CRJ-100/-200 is for up to 11 groups with intervals of 12, 18, 24, 36, 48, 60, 72, 96, 120, 144 and 180 months *(see second table, page 20)*. All, except the 18-month tasks, occur at convenient annual intervals up to 15 years. In terms of MH consumption for routine inspections, the 24-, 48-, 72-, 96- and 120-month tasks are the largest, using 40-900MH *(see second table, page 20)*. The other tasks use only relatively few MH for routine inspections.

"In the case of the CRJ-700/-900, there are eight different groups of tasks," continues Rozman. "The intervals are six,

CRJ-100/-200 BASE CHECK TASK GROUPING

Base check	Interval	C check tasks	OOP base check tasks	Calendar tasks	Routine MH
C1	4,800FH	1C	Gp1, Gp2 & Gp3	12 mth, 18mth, 24mth & 36mth	390
C2	9,600FH	1C + 2C	Gp1, Gp2 & Gp3	12mth, 18mth, 24mth, 36mth, 48mth & 60mth	920
C3	14,400FH	1C + 3C	Gp1, GP2, Gp3 & Gp5	12mth, 18mth, 24mth, 36mth & 72mth	1,390
C4	19,200FH	1C, 2C & 4C	Gp1, Gp2 & Gp3	12mth, 18mth, 24mth, 36mth, 48mth, 60mth, & 96mth	1,725
C5	24,000FH	1C & 5C	Gp1, Gp2, Gp3, Gp4 & Gp6	12mth, 18mth, 24mth, 36mth & 120mth	538
C6	28,800FH	1C, 2C & 3C	Gp1, Gp2, Gp3 & Gp5	12mth, 18mth, 24mth, 36mth, 48mth, 60mth, 72mth & 144mth	1,921
C7	33,600	1C	Gp1, Gp2 & Gp3	12mth, 18mth, 24mth, & 36mth	389
C8	38,400	1C, 2C & 4C	Gp1, Gp2 & Gp3	12mth, 18mth, 24mth, 36mth, 48mth, 60mth & 96mth	1,725
C9	43,200	1C & 3C	Gp1, Gp2, Gp3 & GP5	12mth, 18mth, 24mth, 36mth & 72mth	1,389
C10	48,000	1C, 2C & 5C	Gp1, Gp2, Gp3 Gp4 & Gp6	12mth, 18mth, 24mth, 36mth, 48mth, 60mth, 120mth & 144mth	1,070

CRJ-700/-900 BASE CHECK TASK GROUPING

Base check	Interval	C check tasks	OOP base check tasks	Calendar tasks	Routine MH
C1	3,600FH	1C	Gp2, Gp3 & Gp4	18mth	307
C2	7,200FH	1C + 2C	Gp1, Gp2, Gp3 & Gp4	12mth, 18mth, 36mth & 48mth	1,000
C3	10,800FH	1C + 3C	Gp2, Gp3, Gp4 Gp6	18mth	387
C4	14,400FH	1C, 2C & 4C	Gp1, Gp2, Gp3, Gp4 & Gp5	12mth, 18mth, 24mth, 36mth & 48mth	723
C5	18,000FH	1C & 5C	Gp2, Gp3, Gp4, Gp6 & Gp 7	18mth, 96/48mth & 96/72mth	1,100
C6	21,600FH	1C, 2C & 3C	Gp1, Gp2, Gp3, Gp4 & Gp8	12mth, 18mth, 36mth & 48mth	1,093
C7	25,200	1C	Gp2, Gp3 & Gp4	18mth & 96/48mth	467
C8	28,800	1C, 2C & 4C	Gp1, Gp2, G3, Gp4, Gp5, Gp6 & Gp9	12mth, 18mth, 24mth, 30mth, 36mth & 48mth	1,048
C9	32,400	1C & 3C	Gp2, Gp3 & Gp4	18mth, 96/48mth & 96/72mth	1,127
C10	36,000	1C, 2C & 5C	Gp1, Gp2, Gp3, Gp4 & Gp7	12mth, 18mth,24mth, 36mth & 48mth	1,078

12, 18, 24, 36 and 48 months, 96/48 and 96/72 months. The routine MH required for these tasks are small for the first five groups up to a 36-month interval. The 48-month and both 96-month groups consume large numbers of routine MH."

Check planning

Grouping the three sets of inspection tasks for the A and base checks into check packages is complicated by the large number of OOP and calendar tasks with intervals that are not in phase with the FH inspections. How tasks are grouped and formed into checks depends on rates of aircraft utilisation. This analysis assumes aircraft operating at 2,300-2,400FH and 2,100FC per year.

The first consideration of check planning is base checks. The large number of tasks means that if each group was performed as they come due then the aircraft would have to be grounded frequently at irregular intervals for maintenance. To generate a regular stream of base checks with regular frequencies means bringing forward some tasks and performing them early by combining them with others. This inevitably means the utilisation of intervals on some tasks is poor, but fewer checks are made on the aircraft.

In the case of some OOP and calendar tasks the number of inspections and MH required are small, and these can actually be grouped into A checks or even Routine checks if convenient.

CRJ-200/-200

The annual utilisation of 2,400FH means that 4,800FH are completed every 24 months. This is convenient in the case of the CRJ-100/-200, which have the large groups of FH-related inspections in multiples of 5,000FH. The CRJ-100/-200 also have the five largest groups of calendar-based tasks at two-, four-, six-, eight- and 10-year intervals. The most efficient way of planning base checks would therefore be to have a C check every two years *(see first table, this page)*. Other smaller groups of inspections would have to be planned into these checks by performing them early, or by being included in other smaller checks.

C checks every two years for the CRJ-100/-200 means a check every 4,700-4,800FH. Some of the OOP and calendar-based tasks inevitably drop out.

There are six groups of OOP tasks. The first two groups have intervals of 3,000FH and 4,000FH. For simplicity in maintenance planning it is easiest to perform these annually, every 2,400FH, so that the second group is performed 1,600FH early in relation to its interval. This means that these two groups of tasks, which use 70MH for routine

In terms of maintenance planning, the CRJ family should be considered in the two groups of the CRJ-100/-200 and the CRJ-700/-900. The maintenance programmes of both have large numbers of tasks that are not in phase with each other, and consequently complicate check planning.

inspections, are not included in a base check when the aircraft is one year old and then every two years thereafter. On these occasions they would drop out and be included in A checks. On even numbered years they would be included in the C checks *(see first table, page 22)*.

The third group of OOP tasks, with an interval of 8,000FH and which use about 40MH for routine inspections, could be performed early, and grouped with every C check and performed at 4,800FH intervals.

The fourth group of OOP tasks only uses 2MH and has an interval of 12,000FH. These can then be performed at their interval, every five years, and then alternate between heavy A checks at five and 15 years, and every fifth C check every 10 and 20 years *(see first table, page 22)*.

The fifth and sixth groups, which use about 50MH and 80MH for routine inspections, can conveniently be included in every third and fifth C check according to their intervals *(see first table, page 20)*.

The largest groups for the calendar-based tasks are the 24-, 48-, 72-, 96-, 120- and 144-month inspections. These all conveniently have intervals that are multiples of 24 months, and so are combined with the relevant C checks as they come due *(see first table, page 22)*.

The other six groups only use a small number of MH.

For ease of planning, the 12- and 18-month tasks can be performed annually. On odd-numbered years they drop out into large A checks with the first and second group of OOP tasks. On even-numbered years they come due with C checks.

It is simplest to perform the 36-month tasks at 24-month intervals, so they are always combined with C checks.

The 180-month checks use only a few MH, and so are can be grouped into a large A check when they come due.

Overall, the first and second group of OOP and 12- and 18-month calendar-based tasks drop out on odd-numbered years and are grouped into large A checks. The fourth group of OOP tasks and 180-month calendar inspections also drop out as they come due, and are grouped into large A checks.

This raises the issue of how A checks are planned. While the Routine and A check intervals are 100FH and 500FH, it is likely that they will be performed at roughly 80FH and 400FH intervals.

The APU tasks can then be grouped into the A checks as close as possible to their intervals. In some cases they will not coincide with A checks, but will then be included with Routine checks.

One large check will therefore be the A3 check. It will have two A check task groups and four APU task groups. The A6 check will also be large.

The 400FH interval for OOP tasks will conveniently come due at the likely interval for the A check. The OOP tasks can otherwise be grouped into Routine checks.

The OOP and calendar-based tasks that drop out of C checks can be included in the A6 check package, which is due every 2,400FH.

CRJ-700/-900

The case of the CRJ-700/-900 is different. These currently have five groups of FH-related tasks with intervals that are multiples of 4,000FH, with a fifth multiple at 20,000FH. An annual utilisation of 2,400FH means the 4,000FH interval is reached every 19-20 months.

There are also OOP tasks with intervals from 3,000FH to 30,000FH, although most are up to 10,000FH. The intervals of these are awkward in relation to C checks at 3,600FH intervals. Those with intervals of 4,400-5,000FH are best scheduled with each C check. Others have to be scheduled at other intervals to make best use of their intervals, and so drop out and have to be included in heavy A checks, or occasionally be scheduled into C check packages *(see second table, page 22)*.

The calendar-based tasks are between six months and eight years. The six-month tasks could be combined with the A checks.

There are another seven groups of tasks that have intervals of 12-96 months, and that are also multiples of six months. Two sets have initial intervals of 96 months, but different repeat intervals. The 12-month tasks are scheduled annually, and so are often not included in a C check package. The same applies to other tasks, and most groups on most occasions drop out from C check packages *(see second table, page 22)*.

The escalated C check interval of 6,000FH for the FH-related tasks means the base checks of C1 up to C5 would be performed once every 30 months.

OOP and calendar-based tasks would therefore be scheduled differently. On most occasions they would not be included in C check packages, but would instead be packaged into heavy A checks at six- or 12-month intervals between C checks.

Line check inputs

There are are no line checks in the CRJ's MPM, and the smallest specified check is the Service check at 100FH.

Many operators include 'pre-flight', 'transit' and daily checks in their line maintenance programmes to maintain operational reliability.

The pre-flight and transit checks are performed prior to each flight, often by flightcrew, but line mechanics will be required to rectify technical defaults. A conservative allowance of 0.5MH per check will cover all required maintenance throughout an operation. One check per FC means 2,100 pre-flight and transit checks will be made each year. An

The CRJ-100/-200 have C check tasks with an interval at multiples of 5,000FH. It is simplest to have base checks every two years. Most out-of-phase & calendar tasks can be planned into base checks, even though their full intervals sometimes do not get fully utilised.

additional allowance of $10 for materials and consumables should also be made.

Service checks are daily, but some maintenance programmes allow an interval of up to 72 hours. An average of 275 checks will be consumed in a year. A budget for labour and material consumption is 1.5MH and $150.

Routine checks have an interval of 100FH, but some operators add a second interval parameter of seven or eight days, meaning about 50 service checks are made each year. Labour and material inputs are about 3.0MH and $200.

A final element of line checks will be APU tasks with OOP intervals. During one year's operation 12 groups of APU tasks will be completed, using 40MH.

Total consumption during the year will be 1,600MH in labour, and $75,000 in materials and consumables. Using a generic labour rate of $75 per MH, total inputs for a year's operation equal about $200,000, or $85 per FH when amortised over the year's annual FH utilisation *(see first table, page 32).*

A check inputs

The A check task grouping described for the CRJ-100/-200 results in routine labour inputs of 55-265MH. In addition to routine tasks there are also non-routine rectifications, additional OOP tasks that have dropped out of base checks, the clearing of defects, and interior work.

The non-routine ratio for aircraft in their first 10 years of operation is 50%. A budget of 25MH for clearing defects and 10MH for interior cleaning should be allowed. Base check OOP tasks total 20MH, and are included in one A check per year.

This results in total labour inputs of 120-460MH. Costs of consumables and materials for these checks are $5,000-21,000. Using a standard labour rate of $70, total cost for the six checks in a year's operation is $190,000. Amortised over the annual utilisation of 2,400FH, the reserves for A checks are $78 per FH *(see table, page 32).*

In the case of the CRJ-700/-900, task grouping results in routine MH requirements of 60-140MH, once OOP and APU tasks have been added. Base check inspection tasks that have dropped out of C checks can be included in annual or semi-annual A checks.

It is assumed here that actual A check intervals average 320MH, so that seven or eight checks are performed each year.

Using the same 50% non-routine ratio and budgets for clearing defects and interior cleaning takes total annual MH consumption to 1,300MH. The cost of associated materials and consumables for each check is $5,000-11,000. Using the same standard labour rate, the total annual cost for A checks is $140,000. In addition, there are 30-day OOP tasks, which can be completed with every fourth weekly check. These consume 5MH each time, and so about 65MH per year at an additional cost of $4,500. Reserves for all these costs are equal to $61 per FH *(see table, page 32).*

Base check inputs

CRJ-100/-200

The content of the base checks will first include the routine inspections as described. The large number of different task groups means that the labour used in these routine inspections in the first five C checks varies from 400MH to 1,725MH, with the C4 check being the largest.

The other elements of the base check include non-routine rectifications, the clearing of defects, engineering orders (EOs) and serviced bulletins (SBs), changing hard-timed components, and interior cleaning.

The non-routine ratio in the first base checks is in the region of 50%, but this then rises to about 80% by the fourth or fifth base check. The MH used for non-routine rectifications therefore increase during the first check cycle from 200MH at the C1 up to 1,400MH for the C4 check. The sub-total for routine inspections and non-routine rectifications is 8,500-9,000MH for the first five checks.

Clearing defects will be shared between A checks and base checks. The labour used will depend on operation and maintenance policy, but a budget of 100MH for a base check should be used.

There is then labour for completing airworthiness directives (ADs), SBs and EOs. This is variable, and depends on the ADs and SBs that are used, which aircraft they are applicable to, and airline policy with respect to upgrading aircraft. A budget of 50-300MH should be used, depending on the size of the check workscope and downtime.

A budget of 50MH should be used for component changes, and another 100MH allowed for interior cleaning.

For the first five base checks the total labour varies from about 900MH for the C1 up to 3,700MH for the C4. The total for the four checks is 10,500-11,000MH. At a generic labour rate of $50 per MH this is equal to $530,000.

In addition to labour there will be the cost of parts and materials. This varies from about $17,000 for the C1 check to about $68,000 for the C4 check, and the total reaching about $200,000 for the five checks. The total cost of about $750,000 for the first five checks amortised over the interval of 12,000FH is equal to a reserve of about $30 per FH.

The labour and material inputs for the five checks in the second base check cycle will be higher. Routine MH will increase to 6,900MH, due to the arrangement of inspection task packages.

The non-routine ratio will also continue to increase, starting at about 90% for the C6 check and rising to more than 100% by the C8 or C9 check. The

CF34-3A1/-3B1 LIFE LIMITED PARTS

Life limited part	Catalogue price-$	EFC life limit
Fan disk	111,200	6,000-24,300
Fan forward shaft	49,300	15,000-25,000
Fan drive shaft	66,620	22,000-25,000
Compressor forward shaft	24,820	25,000-30,000
Blisk-stage 1 compressor rotor	81,950	15,000-25,000
Stage 2 HPC disk	19,080	22,000-25,000
Stage 3-8 HPC spool	71,950	22,000-27,000
Stage 9 HPC disk	28,310	23,000-25,000
Stage 10-14 HPC spool	61,980	22,000-25,000
Compressor rear shaft	54,270	23,000-25,000
CDP seal	5,419	22,000-30,000
HPT shaft	55,990	30,000
OBP seal	20,030	15,000-18,000
Stage 1 forward CP	11,000	30,000
Stage 1 HPT disk	62,210	15,000-18,000
Stage 1 aft CP	23,400	15,000-18,000
Outer torque coupling	27,830	30,000
Stage 2 forward CP	9,940	15,000-30,000
Stage 2 HPT disk	62,680	15,000-18,000
Stage 2 aft CP	10,160	30,000
Stage 3 disk	50,020	22,000-25,000
Stage 3/4 seal	7,600	15,000-23,000
Stage 4 disk	59,160	22,000-25,000
Stage 4/5 seal	7,342	15,000-25,000
Stage 5 disk	55,100	15,000-25,000
Stage 5/6 seal	6,766	15,000-25,000
Stage 6 disk	38,910	22,000-25,000
Turbine cone drive	27,440	22,000-25,000
Turbine rear shaft	37,040	22,000-25,000
Total	**1,147,517**	

total labour for non-routine rectifications will therefore total 6,600-7,000MH for these five checks.

Assuming that similar inputs are required for clearing defects, incorporating SBs and EOs, changing hard-timed components, and interior cleaning, the total labour for the five checks will be about 16,000MH. The associated cost of parts and materials will increase to about $300,000 over the five checks, taking total labour and material cost to about $1.1 million. Amortised over the same 12,000FH interval, the reserve for these checks will be $45 per FH *(see table, page 32)*.

CRJ-700/-900

With the tasks arranged into checks, the routine MH requirements in the first 10 C checks vary from 310MH in the C1 to 1,100MH each for the C2, C5, C6, C8, C9 and C10.

Assuming that the CRJ-700/-900 have similar non-routine ratios to the CRJ-100/-200 over the first 10-15 years of operation, the total MH used for routine inspections and non-routine rectifications will be about 16,000MH. Inputs for other elements of defects, EOs and SBs, and interior cleaning take the total to 20,500MH. With materials and consumables charged in similar proportion to the CRJ-100/-200, the total cost for the first 10 C checks, at a 4,000FH interval, will be $1.4 million. This is equal to a reserve of $40 per FH *(see table, page 32)*.

Interior refurbishment

Interior work must also be taken into consideration. This concerns items such as: carpet cleaning and replacement; seat cover cleaning and replacement; seat cushion replacement; cleaning, refurbishing and servicing panels, overhead bins, and bulkheads; and servicing and refurbishing toilets and galleys.

Most regional aircraft do not have extensive interior refurbishment programmes, but some interior refurbishment is done to keep the aircraft in a clean and acceptable condition for passenger operations. Seat cover cleaning and servicing of panels and overhead bins will usually be done every C check. Replacing seat covers and refurbishing these items will usually be done every three or four C checks. Taking these intervals, typical cost of materials and MH inputs into consideration; the overall cost for interior refurbishment will be in the region of $15 per FH *(see table, page 32)*.

The final element will be stripping and repainting. This will cost in the region of $100,000, and will be performed on average once every five C checks, resulting in a reserve of $5 per FH *(see table, page 32)*.

Heavy components

Heavy components comprise: wheels, tyres and brakes; landing gear; thrust reversers; and the APU.

Tyres are not remoulded by most operators on the CRJ, and are instead replaced at every removal. Removal intervals are 250-300FC, while new nose tyres are $300-350, and new main tyres are $1,300-1,400. The cost of replacing worn tyres is therefore $19 per FC for the CRJ-100/-200, and $22/FC for the CRJ-700/-900.

Wheels are inspected at tyre removal, and then have an overhaul about every fifth removal. Taking into account the typical costs of wheel inspections and overhauls, the cost of wheel repairs is $8 per FC for the CRJ-100/-200, and $13 per FC for the CRJ-700/-900.

Brakes are steel, and have a shop visit about every 2,000FC for the CRJ-100/-200 and every 1,600FC for the CRJ-700/-900. Taking typical third-party shop visit costs into account, the cost of brake repairs is $30 per FC for the CRJ-100/-200, and $50 per FC for the CRJ-700/-900.

The total cost for wheels and brakes is $57 per FC for the CRJ-100/-200, equal to $50 per FH. The total for the CRJ-700/-900 is $85 per FC, equal to $74 per FH *(see table, page 32)*.

Landing gear shop visit intervals take place every 10 years and 20,000FC. Using a heavy annual A or base check as the appropriate time to change landing gears, the interval for the CRJ-100/-200 and CRJ-700/-900 is 19,000FC. Typical landing gear exchange and overhaul fees are $180,000 for the CRJ-100/-200, and $260,000 for the CRJ-700/-900. Reserves are equal to $9 per FC for the CRJ-100/-200, and $14 per FC for the CRJ-700/-900. These are equal to $8 and $12 per FH for the two types.

Thrust reversers are maintained on-condition, and intervals are variable. Taking 15,000FC as an expected average for a reverser shipset of the appropriate size, the cost per FC is $20 for the CRJ-100/-200 and $23 for the CRJ-700/-900. These are equal to $17 and $20 per FH *(see table, page 32)*.

The APU on the CRJ is a Garrett APU. APU intervals and APU utilisation vary. A typical interval is 3,500APUH, and a typical rate for some operators is 0.65 APUH per FH. Shop visit costs of $100,000-150,000 result in reserves of $18 per FH for the CRJ-100/-200, and $27 per FH for the CRJ-700/-900 *(see table, page 32)*.

Rotable components

Rotable components are assumed to be supplied, repaired and managed under an all-in total support package. This is structured with three main elements: a homebase stock which is leased, a pool stock of remaining components which the operator has access to; and a fixed rate per FH fee to cover the repair, transportation and management of all components.

Typical rates for the lease of homebase stock are equal to $15 per FH for the CRJ-100/-200, and $15-20 per FH for the CRJ-700/-900. The fixed fee per FH for pool access and stock financing is about $50 per FH for the CRJ-100/-200, and $75-80 per FH for the CRJ-700/-900.

The third element of repair and management costs is in the region of $120 per FH for the CRJ-100/-200 and $130 for the CRJ-700/-900.

The total costs for the three elements are $190 per FH in the case of the CRJ-100/-200, and $210-230 per FH in the case of the CRJ-700/-900 *(see table, page 32)*.

Engine maintenance

The CRJ family is powered by the General Electric CF34-3A1/-3B1, -8C1 and -8C5 series.

-3A1/-3B1 series

The CF34-3A1 was the first variant, and powers the CRJ-100. This engine has an installed thrust rating of 8,729lbs thrust. It has a fan diameter of 49.6 inches and a bypass ratio of 6.2:1 *(see table, this page)*.

Besides a single-stage fan, the engine has a 14-stage high pressure compressor (HPC), a two-stage high pressure turbine (HPT) and a four-stage low pressure turbine (LPT).

There are three life limited parts (LLPs) in the fan module, eight LLPs in the HPC, nine parts in the HPT and nine LLPs in the LPT *(see table, this page)*. Earlier production -3A1s had 10 LLPs in the HPT, but this was reduced to nine following the issue of SB 72-34.

During the production of the -3A1 and other CF34 variants, several part numbers have been issued for each LLP. In most cases successive part numbers have longer life limits. Operators may therefore have LLPs with varying life limits in new engines. These will be replaced when modules get fully disassembled, and then replaced with later part numbers compared to the original parts in the engine. Engines therefore generally tend to have LLPs with longer lives as they progress through their productive life.

The three fan module LLPs have life limits that are as low as 6,000 engine flight cycles (EFC) for the earliest part numbers, and up to 25,000EFC *(see table, this page)*. The current list price for these parts is $227,120.

The eight LLPs in the HPC have lives at 15,000EFC and as low as 6,000EFC in the case of some earlier part numbers, and up to 25,000EFC for later part numbers. Two parts in the -3B1 have a life of 30,000EFC. The list price for these parts is $348,000.

The earlier part numbers in the HPT module had lives as short as 15,000EFC, and, in the -3B1, these have been increased to 18,000EFC with later part numbers. The earliest -3A1s had LLPs with lives of 6,000EFC, which have now been increased to 15,000EFC. Other parts have lives of 30,000EFC. The list price for these parts is $283,000 *(see table, this page)*.

Most part numbers for LLPs in the LPT module have lives of at least 22,000EFC in the -3A1, and up to 25,000EFC in the -3B1. There are a few earlier part numbers with lives as low as 15,000EFC, however. These parts have a list price of $289,500.

Overall, LLP lives in the -3A1 are shorter than those used in the -3B1.

The -3A1 is flat rated at 21 degrees centigrade, meaning that its thrust rating remains constant up to this outside temperature. The aircraft's performance will therefore not be limited by reduced engine thrust in most operating conditions.

The -3A1 had some hot section problems, so the -3B1 was introduced to partly overcome these. The -3B1 powers the heavier CRJ-200. This has the same thrust rating, but is flat rated at 30 degrees centigrade, the same fan diameter, bypass ratio and configuration as the -3A1. The -3B1, however, has a blisk in the first stage of its HPC and uses a different HPT design to the -3A1.

The -3B1 powers the CRJ-200 and CRJ-440, and was introduced in 1996. A CRJ-100 becomes a -200 if powered by two CF34-3B1s.

-8C1 series

The larger -8C1 series was developed to power the CRJ-700, which entered service in 2001. The -8C1 series is a larger engine, with a 52-inch diameter fan, but with a 10-stage HPC, two-stage HPT and four-stage LPT. It has an installed thrust of 12,670lbs, a bypass

CF34-8C SERIES LIFE LIMITED PARTS

Life limited part	-8C1 EFC life	-8C5B1 EFC life	-8C5A1/2/3 EFC life
Fan disk	25,000	25,000	15,000
Fan drive shaft	20,000	25,000	25,000
Blisk compressor rotor, stage 1 & 2	9,000	20,000	20,000
Shaft, HP compressor forward	19,000	25,000	25,000
Blisk, compressor rotor stage 3	14,000	24,000	23,000/24,000
Spoiler, HP compressor rotor	N/A	25,000	25,000
Spool, compressor rotor aft shaft	17,000	23,000	23,000
CDP seal	15,000	25,000	25,000
HPT shaft	10,000	N/A	N/A
Cooling plate, stage 1 aft	15,000	N/A	N/A
Cooling plate, stage 2 forward	15,000	N/A	N/A
Air seal, inner balance	N/A	24,800	24,800/18,100
Air seal, HPT outer balance	N/A	18,300	18,300/14,500
Cooling plate, stage 1 HP turbine forward	15,000	17,500	17,500/13,200
Disk, stage 1 turbine rotor	9,000	17,300	17,300/15,200
Coupling, HP turbine outer torque	15,000	14,700	14,700/13,400
Disk, stage 2 turbine rotor	10,000	17,700	17,700/13,200
Cooling plate, stage 2 HP turbine aft	15,000	25,000	25,000/20,000
Stage 3 disk	26,000	25,000	25,000
Stage 3/4 seal	26,000	25,000	25,000
Stage 4 disk	26,000	25,000	25,000
Stage 4/5 seal	26,000	25,000	25,000
Stage 5 disk	26,000	25,000	25,000
Stage 5/6 seal	26,000	25,000	25,000
Stage 6 disk	26,000	25,000	25,000
Turbine rear shaft	26,000	25,000	25,000

The current basic interval for the CRJ-700/-900 is 4,000FH. Base check tasks and reserves are similar to the CRJ-100/-200. The basic interval for the CRJ-700/-900 will be extended to 6,000FH, and should have the effect of reducing base check reserves.

ratio of 5.0:1, and is flat rated at 30 degrees centigrade.

LLPs in the fan module have lives of 20,000-25,000EFC, LLPs in the HPC and HPT modules have lives of 9,000-17,000EFC, and LLPs in the LPT have lives of 26,000EFC *(see table, page 27)*. A shipset of parts has a list price of $1.94 million. The fan and LPT module LLPs account for $814,300 of this, while the HPC and HPT account for the remaining $1.13 million.

The -8C1 had a problem with retaining exhaust gas temperature (EGT) margin, so it had poor on-wing performance.

To harmonise the CF34-8 family and solve the CF34-8C1 issues, General Electric introduced an upgrade modification to upgrade the -8C1 to a -8C5B1. This is best installed during the engine's first shop visit when the LLPs in the HPC and HPT expire after 9,000EFC. The upgrade involves the replacement of the HPC stage 3-5 vanes, HPC rotor assembly, HP drive shaft, first stage nozzle assembly, the HPT module, the combustor, the LPT shaft, and the LPT third-stage blades and shrouds. This is introduced to improve EGT margin retention.

The LLPs in the HPC and HPT are also exchanged for parts with longer lives. The LLP lives in the HPC are 20,000-25,000EFC, and those in the HPT are 14,700-25,000EFC *(see table, page 27)*. These two groups have a list price of $1.09 million.

The upgrade is encompassed in several SBs issued by GE, and there are several kits of parts to complete the modification. The kits vary with each engine, but they cost in the region of $1.3 million, including the LLPs.

Already about 70% of -8C1 engines have been upgraded to -8C5B1 standard.

-8C5 series

The CF34-8C5 was introduced in late 2002 on the CRJ-900, but also on the CRJ-700 in 2005 following problems with the -8C1. The -8C5 was later introduced on the CRJ-700 in 2005. This engine has longer life LLPs in the HPC and HPT, an improved design, and overall better EGT margin retention.

There are four sub-variants: the -8C5B1, -8C5A1, -8C5A2 and -8C5A3. The -8C5B1 has an installed rating of 12,500lbs thrust, the -8C5 has an installed rating of 13,130lbs thrust, the -8C5A1 has an installed rating of 13,400lbs thrust, the -8C5A2 an installed rating of 13,800lbs thrust, and the -8C5A3 an installed rating of 14,260lbs thrust. Bypass ratio is 5.0:1, and all variants are flat rated to 15 degrees centigrade. The engine has the same configuration as the -8C1.

Current LLP lives in the -8C5 series are 15,000EFC and 25,000EFC in the fan, 20,000-25,000EFC in the HPC, and 25,000EFC in the LPT *(see table, page 27)*. These three groups have list prices totalling $1.45 million.

LLP lives are more variable in the HPT. These are 14,700-25,000EFC in the -8C5B1, and -8C5A1, and 13,200-20,000EFC in the -8C5A2 and -8C5A3. These parts have a list price of $447,100, thereby taking the total cost of LLPs for the whole engine to $1.9 million.

GE, however, has stated that it will extend the lives of all LLPs in all modules to a uniform life of 25,000EFC. The exception is the HPT LLPs in the -8C5A2 and -8C5A3, which will have a uniform life of 20,000EFC. GE has said that this extension will be made before the engines reach their first shop visit. Some of the earlier-built engines are reaching their first shop visit now. This extension will simplify shop visit planning and engine management.

CF34-3 & -8C in service

As described, most CRJ-100/-200 operations are at an average FC time of 1.15FH, and so the average EFC time for the -3 series is the same; about 1.15 engine flight hours (EFH).

The -8C on the CRJ-700 and -900 operates on longer average EFC times of 1.30-1.50EFH. These can have an impact on LLP life consumption and removal intervals.

CF34-3A1/-3B1

"The EGT margin of new CF34-3B1 engines is 55-60 degrees centigrade in most cases," says Guillermo Pablo, CF34 production support engineer at Iberia Maintenance.

EGT margin erosion and loss of EGT margin is a typical cause of engine removal for engines operated on short cycle times. "The rate of EGT margin erosion on the CF34 family is low, especially in new engines," says Donald Stricklin, manager engine product lines at Delta TechOps. "We see rates of 1.5-2.5 degrees centigrade per 1,000EFC."

The -3A1 initially had hot section and EGT margin retention problems, so it had short removal intervals in the early years of operation. "These were related to cracks in the combustor liner and deterioration in the stage 1 HPT nozzles," explains Stricklin.

"One main benefit of the CF34's military heritage is that it has been designed so that the HPT and LPT modules can be removed and replaced while the rest of the engine remains on-wing. The shaft LP remains in the engine, while the HP shaft is removed with the HP rotor," explains Pablo. "The HPT can be removed and replaced and then the LPT can be put back on without having to remove the whole of the engine. While this means that an airline will have to hold spare HPT modules in its inventory, it simplifies maintenance planning. The HPT has LLPs with the shortest lives, and

GE has stated that it will extend the lives of all LLPs in all modules of the -8C5 series to 25,000EFC, and do this before the engines reach their first shop visit. The exceptions will be HPT LLPs in the -8C5A2/A3 engines, which will have lives of 20,000EFC.

also may require performance restoration maintenance prior to LLP expiry. The remaining modules are able to remain on-wing until they reach their LLP limits."

The ability to remove just the HPT therefore makes maintenance planning more flexible. There is also the possibility of doing a top case inspection, where the casing of the HPC can be removed in the event of foreign object damage (FOD). HPC blades can be removed and replaced this way, thereby avoiding some unscheduled removals.

It is therefore possible for the engine to remain on-wing until the life limits of LLPs in the fan, HPC and LPT modules are reached. A removal and full overhaul is carried out at this stage, when HPC LLP lives expire and need replacing. Fan and LPT module LLPs can be replaced on-wing if necessary, although they would clearly be replaced during this overhaul.

-3A1

"The -3A1 engine has LLPs in the HPC and HPT that are both at 15,000EFC. Because they expire at the same time the whole engine has to come off," says Stricklin. "The workscope at the first shop visit would include the HPC, combustor and HPT. This would restore the hot section and replace the expired LLPs."

This workscope would consume about 1,500MH, $460,000 in parts and materials, and $430,000 for sub-contract repairs. Using a standard labour rate of $70 per MH, the total cost for the shop visit would reach about $1.0 million. This does not include the cost of LLP replacement. Another $20,000 should be added for HPT removal and installation.

"Following the first shop visit the engine can achieve a second removal interval of 12,000-15,000EFC, and the total time from new would be limited to 22,000EFC by LLPs in the LPT. All engine modules would then have a full workscope, and have their LLPs replaced."

The following overhaul at a total time of 21,000-22,000EFC would come to about 2,000MH in labour, about $500,000 in parts and materials, and another $500,000 in sub-contract repairs. A further $20,000 for engine test takes the total to about $1.2 million, not including LLP replacement.

The total of these two shop visits amortised over the interval of 22,000EFC is equal to a reserve of $100 per EFC.

The list price of the the six LLPs replaced in the first shop visit is about $240,000, and the remaining parts have a list price of about $910,000. Amortising these over the respective replacement intervals equals a reserve of $57 per EFC. Total reserves are $157 per EFC. This is equal to $136 per EFH *(see table, page 32).*

-3B1

"In the case of the -3B1 we follow the practice of removing the HPT off-wing at Delta TechOps," continues Stricklin. "We first do a mid-life HPT removal at the first shop visit after 10,000-12,000EFC on-wing. We do minor work with the first stage HPT nozzles and combustor liners at this stage, as well as some minor stuff on the HPC.

"The engine can then remain on-wing to a total time of 18,000EFC when the LLP life is expired in the HPT," continues Stricklin. "The HPT and combustor have a full workscope at this stage, with HPT LLPs replaced. Little work is done on the fan and HPC, and the LPT needs no work at all until its LLP limit of 25,000EFC, when a third removal and shop visit are carried out and all modules are overhauled and have their LLPs replaced.

Iberia follows a pattern of two removals and shop visits for the -3B1. "Mid-life maintenance can be done on the HPT module at some point during the life limit of the LLP with the shortest life. This is 17,000-18,000EFC in the case of most engines," continues Pablo.

A workscope on the HPT will use about 300MH in labour, about $460,000 in parts, $50,000 for sub-contract repairs, and $20,000 for the HPT removal and replacement. This would have a total cost of $550,000.

The LLPs replaced at this stage would be the four HPT parts with lives of 18,000EFC, which have a list price of about $156,000.

The second removal interval depends on the remaining lives of LLPs in the replacement HPT, and the shortest life in the HPC. This is the blisk, which has a life of 22,200EFC for most currently operating engines. In 2008 a new post-SB 72-240 blisk part number was introduced to improve its life to 25,000EFC. A full overhaul of these modules was carried out at a total time of 22,000EFC or 25,000EFC. Usually, most LLPs in the fan, HPC and LPT would be replaced in the modules that have a full disassembly performed on them."

The second shop visit would be an overhaul, and have a similar cost to the -3A1 as described. The remaining LLPs in the engine would be replaced at this stage, and have a list price of $990,000.

The cost of the two shop visits would be amortised over 22,200EFC or 25,000EFC, depending on the HPC blisk part number fitted in the engine. The combined reserve would be $62-70 per EFC, depending on interval. Corresponding LLP reserves would be $49-54 per EFC. The total reserves for the -3B1 would therefore be $111-134 per EFC. This is equal to $96-116 per EFH *(see table, page 32).*

CF34-8C1 & -8C5

The two main variants of the -8C series are managed differently. The -8C1

DIRECT MAINTENANCE COSTS FOR CRJ FAMILY

Maintenance Item	CRJ-100/ -200	CRJ-700/ -900
Line & ramp checks	85	85
A check	78	61
Base checks	45	40
Interior refurbishment & stripping/repainting	20	20
Landing gear	8	12
Wheels & brakes	50	74
Thrust reversers	17	20
APU	18	27
LRU component support	190	210-230
Total airframe & component maintenance	**511**	**549-569**
Engine maintenance:		
2 X $136, or 2 X $96-116 per EFH	$192-232/$272	
2 X $144, 2 X $165, or 2 X $183-187 per EFH		$288/$230/$370
Total direct maintenance costs per FH:	**$703-743/783**	**$838/$800/$940**

Annual utilisation:
2,400FH
2,100FC
FH:FC ratio of 1.15:1

have limiting LLPs in the HPC and HPT of 9,000EFC. This therefore forces a removal at this stage, at which point the engine gets upgraded to a -8C5B1.

The upgrade includes an extension to the engine's LLP lives. LLPs in the HPC get increased to lives of 20,000-25,000EFC, while parts in the HPT get extended to 14,700-25,000EFC *(see table, page 27)*.

In the case of the -8C1, the first shop visit will involve some work on the HPC, combustor and HPT parts, although much of the material in these modules will be replaced at this stage with the upgrade kit. The cost of the upgrade kit is borne by the operator, and once labour, in-house and sub-contract repairs and scrap replacements are added, the shop visit cost is $600,000-700,000. The reserve for this shop visit would be $78 per EFC.

"The upgraded engine, now a -8C5B1, can then achieve a second removal interval of up to about 15,000EFC," says Josef Hoeltzenbein, CF34 manager sales support at MTU Maintenance Berlin-Brandenburg. "The total time at the second shop visit will be up to 24,000EFC, as allowed by LLPs in the fan and LPT. At this stage the workscope will include full overhaul and LLP replacement on the fan, LPT and HPT modules. The HPC may be fine, but work will have to be done if there are any findings."

The full overhaul for the converted -8C5B1 at the second shop visit at a total time of up to 24,000EFC will incur a similar cost to that of the -3B1: about $1.2 million (excluding LLPs). The reserve for this, over an interval of about 15,000EFC, would be $80 per EFC.

All LLPs in the fan, HPT and LPT modules would be replaced at this stage, and have a list price of $1.17 million. LLPs in the HPC would have 9,000-10,000EFC remaining, and could remain in the engine to the third removal. The reserve for all LLPs in the engine will be about $86 per EFC.

The reserve for both shop visits amortised over an interval of 24,000EFC would be $80 per EFC. Combined with reserves for LLPs, the total reserves for this engine would be $166 per EFC; equal to$144 per EFH *(see table, page 32)*.

-8C5A1/A2/A3

The later -8C5A1/A2/A3 engines have LLPs with the shortest lives: 14,700EFC for the -8C5A1; and 13,200EFC for the -8C5A2 and -8C5A3. These limit the first removal interval. "Most operators are removing the whole of the engine, and not just the HPT module at this stage," explains Hoeltzenbein. "The first removals will be at 10,000-13,000EFC. At this stage the workscope will involve the HPC, combustor and HPT, including HPT stage 1 blade replacement, repair of combustor liners and HPC damage. The overall aim is to restore HPT performance. For older serial numbers, a modification of the compressor stator is also required. GE aims to extend all LLP lives to at least 20,000EFC in the HPT of the -8C5A2 and -8C5A3 engines. All other LLPs will be 25,000EFC. This should be before the engines reach their first shop visit, and so no LLPs will require replacing.

The first shop visit for the -8C5 engines would include a workscope on the HPC, combustor and HPT, with an estimated cost of $0.8-1.0 million. No LLPs would be replaced at this stage.

"The second removal will be at a total time of 16,000EFC to 19,000EFC for the higher-rated -8C5A2 and -8C5A3, and a total time of 17,000-25,000EFC for the -8C5 and -8C5A1. The workscope as well as the LLP replacement depends on the engine condition, the flight profile, and other customer requirements. For the -8C5A3 at least the HPT LLPs will be replaced," continues Hoeltzenbein. "The new built -8C5B1 will have its second removal at 25,000EFC. The shop visit workscopes at this stage will have to be full overhauls on all modules to replace LLPs."

The second shop visit would be either another performance restoration, or a complete overhaul, which would incur a cost of $1.2-1.3 million.

The reserve for the two shop visits, with a total cost of $2.0-2.3 million, would be $110 per EFC for the -8C5A1, and $115 per EFC for the -8C5A2/A3.

The full shipset of LLPs could be replaced at this stage. The reserve for -A1 engines will be $76-80 per EFC, and $95-100 per EFC for the higher-rated -A2/-A3 engines.

The total reserves for the -8C5A1 will therefore be $186-190 per EFC or $162-165 per EFH, and $210-215 per EFC or $183-187 per EFH for the -8C5A2/A3 *(see table, page 32)*.

Summary

The differences between the CRJ-100/-200 and the CRJ-700/-900 are small compared to differences in their seat capacities. This is not surprising given that most costs are related to line checks and rotable provisioning and heavy component costs, which are the same or similar for the two types.

The main difference between the two types comes from engine-related maintenance costs. These differences are small, and the CRJ-700/-900 benefit from economies of scale and improvements made to their engines as a result of the operational experience gained with the 3A1 and -3B1. AC