The 787's sales success is largely explained by its unique use of carbon fibre and electric design. These features have several benefits, not least the expected reduction in maintenance costs over current generation aircraft. How this may affect the 787's maintenance costs is examined.

The 787's maintenance costs: an initial assessment

Boeing has expanded the lifecycle design of the 787 by reducing maintenance cost and increasing aircraft availability, which relates to utilisation, schedule reliability and maintenance downtime. An aircraft's design will significantly affect the cost of maintaining its systems over their lifetime.

The expanded use of carbon fibre composites, especially in the highly tension-loaded environment of the fuselage, reduces structural maintenance compared to an aluminium structure. The 787 also uses more titanium than previous Boeing types: 14%. Titanium is a low-maintenance design solution where loading is high in certain parts of the structure. It withstands loads better than aluminium, has minimal fatigue concerns, and, like carbon fibre, is highly resistant to corrosion.

The 787 is therefore expected to have a low non-routine ratio, which will increase at a lower rate throughout its life compared to current aircraft types. This will be a main factor in keeping the 787's maintenance costs low.

MPD status

Boeing plans to deliver a scheduled maintenance programme approved by the Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) prior to flight testing. The 787 programme has set target maintenance intervals for service entry which, across the board, will be double those of the 767's maintenance programme. Despite references to A and C checks, the 787's check programme is not based on letters, and the terms are only used generically.

The target intervals for the main maintenance checks are a line maintenance check or A check interval of 1,000 flight hours (FH) (every 500FH for the 767); a base check interval of 36 months (18 months for the 767); and first heavy structural inspection at 12 years (six years for the 767). Boeing estimates the 787 will have a cumulative reduction for maintenance downtime equal to 113 revenue flights over the 12-year maintenance cycle compared to the 767.

The maintenance planning document (MPD) covers four different task groups with intervals that are multiples of 1,000FH. These are generically referred to as A check tasks, the highest of which has an interval of 6,000FH. The base maintenance part of the programme has four different task groups with intervals that are multiples of 36 months and 6,000FC. The highest task group has an interval of 144 months and 24,000FC.

A maintenance steering group (MSG) 3 based maintenance programme will be adopted from the outset. "The 787's maintenance programme is flexible and may be different for each operator, even to the extent where some operators may choose not to have any C checks. Instead they could phase their maintenance completely through overnight visits," says Justin Hale, Boeing's 787 deputy chief mechanic. This means base check tasks could be split into smaller packages that can be completed in a short downtime.

In practice, airlines may choose to package the tasks into their own 'virtual' letter checks for planning purposes, probably referred to as C and D checks. However, as with the systems tasks outlined above, there will be groups of structural tasks which logically fall into intervals based on either calendar time or flight cycles (FC), and are performed at whichever interval is reached first.

As well as longer intervals between scheduled maintenance checks, Boeing claims that operators of the 787 could see a 20% reduction in man-hours (MH) for base checks compared to a similar-sized type like the 767. Moreover, total routine MH for maintenance inspections could be reduced by 60% over the aircraft's life.

Other expectations are that the MPD will save the 787 44% lower cumulative MH for its A checks compared to the 767 over a life of 25 years. The reduction would be as much as 65% for C checks, and 63% for D checks and heavy maintenance visits.

Not only will each check consume fewer MH, but there will be fewer checks overall. Over a 12-year base maintenance cycle the aircraft will have 20 fewer line checks, three fewer base checks, and one fewer structural check than the 767. Overall, Boeing estimates that the 787 will have 30% lower airframe and systems maintenance costs than the 767.

"The MPD on the 787 is 90-95% complete," says Hale. "The intervals are established for the tasks defined, but the MPD still has to go back to the FAA and EASA for final approval by the first quarter of 2008. It would be unprecedented for the FAA and EASA to change the intervals we have specified."

Lighter check tasks

The 787's MPD has no pre-flight, transit or daily checks for line and ramp maintenance. The lowest actual interval is three days. The main tasks which are included are a tyre condition and pressure check, which Boeing expects to be carried out by one person within 30 minutes.

The next task group takes place every 200FH, so the check will occur once a fortnight for an aircraft completing about 5,000FH per year. An example of an item in this group is a brake wear inspection and a press-to-test requirement. Hale expects that these will take two people 1MH to complete. This check will have other tasks scheduled, including non-routine rectifications, out-of-phase (OOP) tasks, and some interior cleaning and other items to be added for the whole workscope of the check.

The 787's base check tasks have intervals of 36 months; twice the interval of the 767's structural inspections. The 787's system-related checks will have intervals in multiples of 1,000FH, which will effectively combine to form generic 'A' checks that have intervals twice that of the 767's A checks.

The next items are the 'A check' tasks, or those with intervals in multiples of 1,000FH. Hale refers to a group of propulsion-related tasks, as an example of 1A tasks, which are likely to take two technicians about 90 minutes to complete on the 787. There are many other tasks, but the MPD is not yet approved.

The next group of 2A tasks has an interval of 2,000FH, and will take two people 4MH to complete, for systems checks and servicing. This may include some filter replacement, lubrication tasks, and fluid level checks.

Boeing estimates that the next group of tasks, the 4A items, with a 4,000FH interval, will require four mechanics for a two hour period, using 8MH.

"Wherever possible, these tasks are intended to be completed in an overnight visit," says Hale. "At the 4,000FH event we are assuming that four mechanics will work simultaneously because we want operators to complete this entirely overnight. The aircraft will have a couple of hours of downtime for the job."

The next systems grouping of 6A tasks has an interval of 6,000FH. This includes a flight controls lubrication task, which Hale calculates will consume 20MH. Six personnel are allocated for this task, since there are several panels that have to be removed from several locations on the wing and tail.

The entire A check workscope will include other routine inspections, non-routine rectifications, some engineering orders (EOs), OOP tasks, and some interior work.

While operators are free to perform the different tasks within the prescribed intervals, the routine items of A checks are more likely to depend on the arrangement of A check task multiples. There are 1A, 2A, 4A and 6A tasks with their respective multiples of 1,000FH intervals. The sequence of the first A checks will therefore be the A1, A2, A3, A4, A5 and A6 check every 1,000FH. The A1 and A3 checks will thus have just the 1A tasks, the A2 check will have the 1A and 2A tasks, and the A4 check will have the 1A, 2A and 4A tasks. The A6 check will have the 1A, 2A, 4A and 6A items. Not all task multiples will be in phase until the A12 check, which will include the 1A, 2A, 4A and 6A tasks.

Base check tasks

The MPD has four groups of structural task multiples, which are the equivalent of C check tasks, and have intervals that are multiples of 36 months or 6,000FC. Operators are likely to combine the A check multiple tasks with these base check tasks to form 'C' checks.

There are four groups of base check tasks multiples: the 1C, 2C, 3C and 4C tasks, with intervals of 36, 72, 108 and 144 months. The cycle of base checks will therefore be the C1, C2, C3 and C4 checks. The tasks are likely to be scheduled so that the C1 check will have just the 1C tasks, the C2 check will have the 1C and 2C tasks, and the C3 check will have the 1C and 3C tasks. The C4 check will be the largest check, comprising the 1C, 2C and 4C tasks.

Besides these base check multiple tasks, operators are also likely to schedule any A check task multiples that come due at the same time. Base checks will also include non-routine rectifications arising out of the routine inspections, EOs, OOP items, interior cleaning and refurbishment, and miscellaneous items. Airlines will also have to consider stripping and repainting at some point.

"We estimate that the 1C tasks in the 787's MPD will use less than 370MH, and will require a downtime of only two or three days," explains Hale.

The second group of 2C base check tasks with an interval of 72 months and 12,000FC, involves some structural work that includes external visual inspections. "There is only a very limited internal visual inspection for this second group of tasks," says Hale. "For example, it will not be necessary to remove any part of the interior to inspect the structure, so it is pretty light from that standpoint.

"The first inspection of any internal structure on the 787 comes at the 3C tasks, which have a nine-year and 18,000FC interval," adds Hale. "This will involve a structural inspection of the engine pylon."

The 787's airframe maintenance cycle will culminate in the C4 check. This will be the first time the 4C tasks come due at an interval of 12 years and 24,000FC. Many of these tasks are structural inspections. This C4 check will include all 1,000FH multiple tasks that come due at this point, as well as the 1C, 2C and 4C tasks. The 3C tasks will have been performed at the previous check. All base check task multiples will not be in phase until the twelfth base check: the C12 check, which has an interval of 36 years.

Hale estimates that MPD routine MH for the 4C tasks will be 760MH, pointing out, however, that this represents an MH reduction of as much as 60% in MPD MH compared to the 767's MPD MH. Moreover, the total hangar downtime for these tasks is only 15 days, compared to the minimum of 20 days required for the MPD tasks to be completed on the 767.

To put the predicted differences between the 767 and 787 into context, maintenance planning engineers expect routine tasks for the heavy check on a mature 767 to use 6,500MH *(see 767 family maintenance analysis & budget, Aircraft Commerce, June/July 2006, page 23).*

Check planning

The MH outlined above are all the manufacturer's estimates for the routine MPD inspection tasks. Operators are aware that the MH quoted in aircraft MPDs must be multiplied by a factor of at least three to arrive at the minimum number of routine MH that will be required by the check. This is a basic, but risky, factor that can be used for reaching an approximate number of routine MH for large checks.

The MH quoted for individual tasks in the MPD only estimate the MH required to do the inspection, and do not take into account any MH required to gain access, or for preparation. For example, a large number of MH are used to perform an inspection on a structural task underneath a major installation such as a galley or toilet. While the inspection may only use 5-20MH, gaining access can use 100-150MH. Another example is an inspection of the flight controls under the main cabin floor, which would require the removal of a large number of seats, carpets and flooring. This would also greatly increase the total MH required.

The MH quoted for the 787's routine inspections are therefore a fraction of the total routine MH actually required to perform the check.

The first 787 will enter service in the second half of 2008, and will not have its first heavy check until 2020, so it is too early to get an accurate estimate of actual routine MH. Nevertheless, the 787 has features in its design to aid the reduction of MH used for routine inspections.

Flight controls are one example. Lubrication of flight control cables on the 787 is expected to consume no MH. "In general, we have achieved a reduction of 40% in Maintenance Review Board (MRB) tasks for all the systems-related Air Transport Association (ATA) chapters in the 787 compared to the 777," notes Hale. "This is because there is a lack of mechanical complexity. There are fewer moving parts, which reduces the number of items requiring intrusive inspection."

The 777 has 243 structural inspection tasks, 77 of which relate to corrosion. As the 787 does not have any dedicated corrosion tasks, its structures-related tasks fall to 125. The 787 has fewer items requiring inspection.

Hale points out that some of this is due to simplified structure. "The wing uses single-piece stiffeners from the wing root all the way out to the wingtip attachment. If those joints are eliminated, the inspection requirements are also eliminated. Moreover, the lap joints have gone from the fuselage with the one-piece barrel, so that is another area of inspection which we can eliminate."

Non-routine

Besides the factor required for translating the manufacturer's estimated labour spend into actual routine MH, non-routine labour used for rectifications that arise out of the routine inspections also accounts for a large portion of the total MH used in a check.

The MH used for non-routine rectifications can be estimated for a complete base check by using approximate ratios. Non-routine rectifications occur due to deterioration or corrosion of the aircraft's systems and structure. The non-routine ratio for current generation aircraft is known to steadily increase with age, and is often analysed according to which base maintenance cycle the aircraft is in. Routine MH also increase with age in current generation aircraft. In the case of the 767, for example, there are routine tasks which first come due in the second or third base maintenance cycles, and are generally related to corrosion inspections.

Non-routine MH are a significant portion of the total MH used for a check, so as both the routine inspections and non-routine ratio rise with age, total maintenance costs will increase at a rate that eventually makes the aircraft uneconomic to operate.

An example of the rise in routine MH used for base checks is the 767's C8 check (the aircraft's second heavy check), which uses 6,700MH for routine tasks, rising to 8,000MH for the C12 check (the third heavy check) *(see 767 family maintenance analysis & budget, Aircraft Commerce, June/July 2006, page 23).*

The 787's use of carbon fibre not only allows structural inspections to be made at twice the interval of current generation aircraft, it will also result in a lower non-routine ratio and a slower rate of increase in the non-routine ratio over the aircraft's life compared to current generation aircraft.

The non-routine ratio for all routine inspections across the four checks in the 767's base maintenance programme also increases with each cycle. The non-routine ratio in the first cycle is estimated to be 50%, rising to 75% in the second, and to 80-100% in the third. The total routine and non-routine MH for the third base check cycle will therefore be at least 60% higher than the MH used for the first.

One of the 787's main advantages will be its expected low incidence of non-routine rectifications. This will result in a low non-routine ratio in its first base maintenance cycle, but more importantly the non-routine ratio will increase more slowly than on current types like the 767.

Non-routine MHs for rectifications are high compared to MPD MH estimates. An MPD estimate of 2MH for a particular inspection, for example, may result in 4MH for rectification work. This increase is put in perspective when the MH for the routine task are increased by a factor of three or four, thereby taking routine labour to 6-8MH. The non-routine ratio then becomes 30-50%.

"The 787 is expected to have a low non-routine labour requirement," says Hale. "It will not have as many corrosion and fatigue issues, which have traditionally driven a lot of non-routine work in structural inspections of aluminium aircraft."

Hale highlights a problem where many operators do not track non-routine ratios. "Boeing surveyed 777 operators to examine typical non-routine ratios, for composite structures in particular. We asked them how much non-routine work is required for the composite floorbeams and empennage, and used these ratios to extrapolate the expected ratios for the 787, and establish a baseline." The result showed a large advantage for the 787.

"We managed to verify that the 777s do not require any non-routine MH for their composite structures," says Hale. "While this bodes well for the 787, we still expect some non-routine labour in the overall structure given that it still uses 20% aluminium. We would be surprised if there was no corrosion and fatigue. We expect non-routine labour to be at least half that required by the 767, particularly after the 12-year base check." This will be when the 787 becomes 'mature' in maintenance terms.

Besides using carbon fibre, the 787 has several design features that should keep its non-routine ratio low, including bolted repairs. "Bolted repairs have been performed on composite structures on the 777. They have comparable repair times and can be permanent and damage-tolerant, just as they can be on a metal structure," says Hale.

"Airlines can perform bonded composite repairs, which offer an improved aerodynamic and aesthetic finish," continues Hale. "These repairs are permanent, damage-tolerant, and do not require an autoclave. Boeing has exploited the properties of composites to develop a temporary repair capability that can be applied in less than an hour to get an aircraft flying again quickly."

Other check items

Besides routine and non-routine items, base checks will also include service bulletins (SBs), airworthiness directives (ADs), OOP tasks, and cabin cleaning and interior refurbishment. The MH used for most of these items will not differ from those used for similar-sized current generation aircraft.

The 787's design, however, is intended to reduce the costs relating to interior refurbishment. A large number of MH are used to remove and reinstall interior items such as galleys, toilets and overhead bins to gain access for inspections. The 787's interior has been designed to reduce these MHs, as part of the commitment to assemble the 787 in just three days. Boeing has therefore also had to change the way it installed the aircraft's interior. "I believe it takes about three days just to install an interior into an existing Boeing aircraft," says Hale, "but the 787's interior will be installed in 10% of the time required by a 777 or 767 interior.

"This is an advantage that will be passed on to the operators," continues Hale. "Considerable adaptability will be built into the aircraft, so that when things need to be changed, no secondary structural changes are required to the aircraft itself because both structures and systems are pre-provisioned. Removing and reinstalling interior components, say to inspect an area behind an interior, is now dramatically shortened in the same way as for the factory in production."

Hale points out that there will be a significant amount of 'tool-free' installation in the cabin area to facilitate rapid access to ceiling and sidewall panels and monuments which all come in and out very quickly. "In the past, monuments could often not be removed from the aircraft without being significantly disassembled, or in some cases even cut in half. Now all of our monuments are made to come apart."

Comparisons to 767

While it is hard to estimate the 787's base check labour requirements, an examination of the 767's base checks is a starting point to see where the 787 could experience reductions.

The 767's second heavy check, the C8, at 12 years of age can consume up to 19,000MH if a full interior refurbishment and complete strip and repaint are included.

The 767's C8 check will use 6,700 routine MH and, with a non-routine ratio of 75%, will use another 5,000MH. This sub-total of 11,700MH will be added to by other items. EOs could add another 1,000MH, although the actual number

The 787's interior has been designed with a modular concept. This allows removal and installation in a fraction of the time of the interior fittings of current generation aircraft. This saving in labour will make a major contribution to reducing the costs of base maintenance.

used varies widely. One-off heavy modifications will increase this number. Another 300MHs can be added by OOP tasks. The labour requirement for these two elements would not be expected to differ much between the 767 and 787.

A complete interior refurbishment in this single check could use up to 4,500MH. Some operators would extend this out over all checks in the base check cycle. Finally, stripping and repainting the aircraft would add 2,000-2,500MH, taking the total for the check to 19,000-20,000MH. The associated cost of materials and consumables for this check, including items relating to the interior, would be $400,000-500,000.

The three largest elements of this check are the routine inspections, non-routine rectifications and the interior refurbishment. A lower routine inspection requirement for the 787 might require 4,000-5,000MH. A lower non-routine ratio would result in 2,500 non-routine MH, taking the sub-total for the two elements to 7,500MH, a potentially large reduction over the 767. Removing and reinstalling the interior more easily might save another 1,000-1,500MH.

While only speculative, this indicates where the 787 could realise the biggest savings in its base check MH requirements. A lower MH requirement would lead to a lower expenditure in materials and consumables. Moreover, the 787 has base checks at twice the interval of the 767, which is where the 787 would realise some of its largest reductions in maintenance expenditure.

The 767's costs for line, ramp, A and base checks are equal to $350 per FH *(see 767 family maintenance analysis & budget, Aircraft Commerce, June/July 2006, page 23)*. This accounts for 35% of the aircraft's total maintenance costs.

Rotable components

The 787 also has design features that will reduce the cost of owning and maintaining its rotable components.

First, Boeing hopes that the move to electrical systems will reduce schedule interruptions affected by its no-bleed and electrical architecture by about a third compared with the 767.

Other benefits of the 787 include improved health monitoring, greater fault tolerance, and the potential for future improvements in systems technology, including: wing ice protection; the engine start; auxiliary power unit (APU) start; cabin pressurisation; and hydraulic pumps.

Boeing believes that the 787's no-bleed architecture offers maintenance cost and reliability advantages. By eliminating pneumatic systems, the 787 will realise a reduction in the mechanical complexity of aircraft systems. Some of the components that will be eliminated by this design are pneumatic engine and APU start motors, APU load compressor, pre-coolers, and various ducts and valves.

Rotable maintenance costs can also be reduced with avionics. "The 787 is the first Boeing airliner to use integrated modular avionics. Historically there have been separate black boxes throughout the aircraft, which we have consolidated into two redundant computing cabinets. These house hundreds of aircraft functions, instead of having separate line replaceable units (LRUs) all over the aircraft. We will see huge maintenance cost reductions in this area, compared to aircraft in service today."

The 787 features expanded and improved systems monitoring capability, and an advanced on-board maintenance computing system. Combined with real-time ground-based monitoring, this capability should result in rapid and accurate troubleshooting of the 787. Aircraft systems information will help maintenance and engineering organisations isolate failed components and reduce return-to-service times. Boeing expects the 787 to reduce no-fault-found (NFF) removals to 58% compared with the 767. Not only will this reduce costs relating to rotable components, it will also help to reduce line maintenance labour requirements.

These design factors will contribute to lowering the total costs of maintaining the 787's rotable components, which include the cost of acquiring, maintaining and managing inventories of rotable parts. The cost of this is $220 per FH for the 767 *(see 767 family maintenance analysis & budget, Aircraft Commerce, June/July 2006, page 23)*, and accounts for 20% of its total maintenance costs.

The expected higher reliability of the 787's components and systems will reduce failure and removal rates, and lower repair costs. It will also reduce the inventories of spare items that need to be held. The lower count of avionic LRUs will also contribute to lowering costs of inventory and repair.

Summary

The two main ways the 787's design and maintenance programme can deliver efficiencies in its maintenance costs are clear. It is too early to assess how much lower its costs might be over similar-sized types like the 767-300ER or A330-200.

The costs of the 767's airframe maintenance and rotable ownership and maintenance are close to $600 per FH when it is operating long-haul missions of 6.0FH. The potential reduction in this figure will be attractive to 787 operators, especially given the lower frequency of its airframe checks. Even if it consumes the same MH and materials in a base check cycle as the 767, the 787's reserves per FH will be half the 767's because the 787's check intervals are double those of the 767. AC