The 777 has now been in operation for more than 10 years, and about 200 aircraft will have completed their first base check cycles. Analysis of the aircraft's maintenance requirements and inputs for its first base check cycle indicate it has low maintenance costs for an aircraft of its size.

Evaluating the 777's base check costs

The oldest 777s are now more than 11 years old. There are more than 590 aircraft in operation, of which about 180 are more than eight years old, or were delivered prior to 1999. The aircraft's maintenance planning document (MPD) is similar to the 737NG's. This gives intervals for maintenance tasks that are arranged in multiples of a base Phase 1 interval, but allows operators to group tasks into maintenance checks. This differs from the traditional system whereby groups of tasks are predefined as checks by the MPD. Under this system, operators' base maintenance cycles are completed after about eight years by some airlines, but in less time by others. This means that at least 200 aircraft will have completed their first base maintenance cycles.

Although the 777 is one of the larger widebody types, the maintenance steering group (MSG) 3 philosophy used for its maintenance programme, the incorporation of corrosion prevention and control programme (CPCP) tasks into structural inspections, the aircraft's maintenance-friendly design, and airlines being allowed to group tasks into their own checks, have resulted in a low expenditure of man-hours (MH), and therefore low maintenance costs. The total consumption of MH, materials and parts for a complete base maintenance cycle is therefore low compared to other similar-sized aircraft. This is the case for older and current generation widebody types.

777 in operation

The first 777-200 was delivered to United Airlines in May 1995. The airlines with the oldest fleets and most operational experience are United, All Nippon Airways (ANA), British Airways (BA), Japan Airlines (JAL), Cathay Pacific, Air China, Thai International, Malaysian Airlines, and Korean Air.

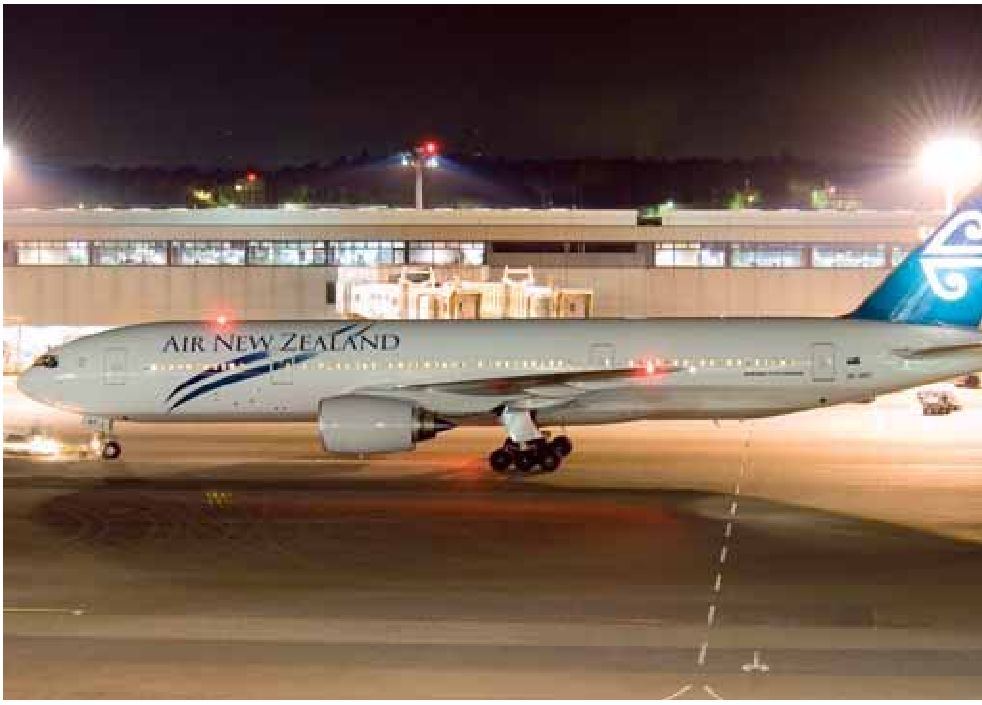
Aircraft are operated in several roles, reflecting the 777's design and multiple maximum take-off weight (MTOW) and fuel capacity variants. The 777-200's MTOWs vary from 506,000lbs for the lowest weight -200 to 766,800lbs for the -200LR.

The first aircraft delivered were low gross weight -200s. These are operated on US and Japanese domestic routes with flight times as short as 60 or 90 minutes, or for intra-Asian operations with flight times of three to four flight hours (FH). Most -200s were delivered prior to 1998.

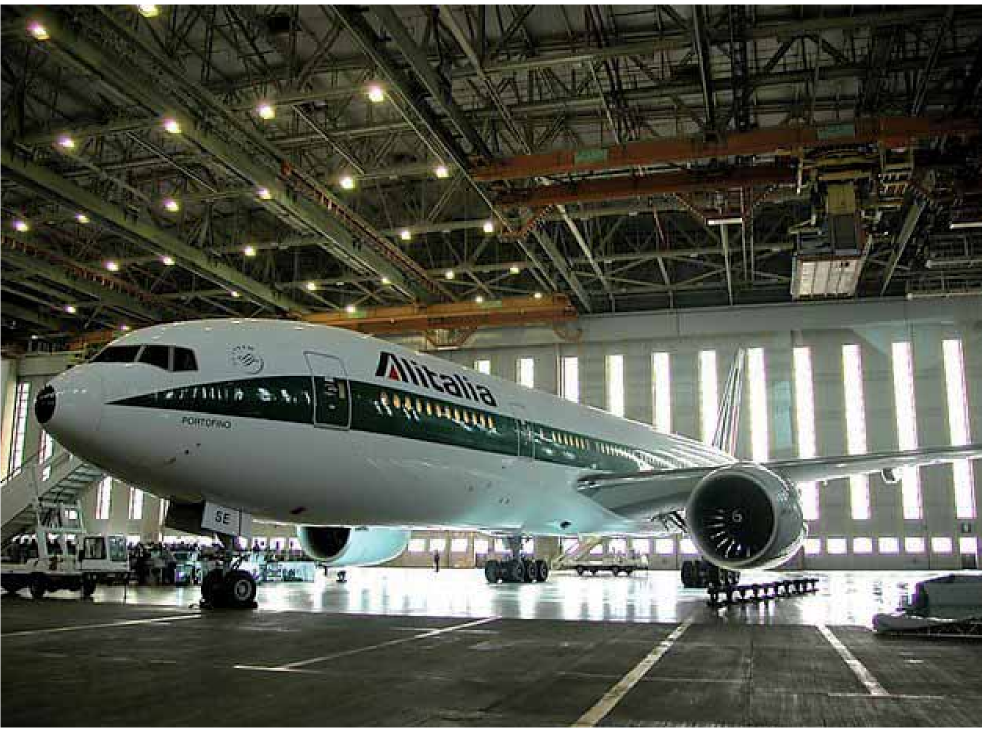
There are more than 380 777-200ERs in operation. The majority were delivered from 1997 to 2002, and are used as a long-haul workhorse by most operators. The aircraft is typically used on cycle times of 6.0-9.0FH. Many are now operated on longer routes.

There are 60 -300s in operation. The majority of aircraft were delivered from 1998 to 2003. The -300's biggest operators are Cathay Pacific, JAL, Thai International, ANA, Singapore Airlines and Korean Air, which use the -300 for high-density, intra-Asian operations on average flight cycle (FC) times of 3.0-4.0FH.

There are also 57 -300ERs in operation, which were delivered between 2004 and 2006. The -300ER is used in similar ways to the 777-200ER with



The 777-200ER accounts for the majority of 777s in operation, and are used as long-haul aircraft on cycle times of 8.0 to 10.0FH. Many airlines are now using the aircraft for ultra long-haul operations.



777s that are used for long-haul operations generate 4,500-5,000FH per year in most cases. Most operators' maintenance programmes are a system of either annual or bi-annual base checks, with a heavy check being completed at an eight-year interval.

similar average flight times.

The 777 fleet is therefore used on a wide-ranging selection of average flight times, ranging from 2.5FH to more than 10.0FH. This has an influence on maintenance programmes and maintenance planning.

Maintenance planning

The 777's maintenance programme was designed to provide operators with flexibility in maintenance planning. Like the 737NG's MPD, the 777's MPD has several thousand task cards which can be grouped into maintenance checks in any way the operator wants. "The 777's task cards have intervals expressed in FH, FC or calendar time, and these have to be considered when grouping certain task cards into maintenance checks," explains Nan Jiang, head of engineering at Ameco Beijing. "Ameco manages the maintenance of Air China's 10 777-200s. Ameco prepares the maintenance task operating plan (MTOP), which involves packaging the separate tasks into maintenance checks. Like the 737NG, the 777's task cards have a basic Phase 1 interval of 500FH, and all other FH intervals are multiples of this phase interval. The Phase 1 also has a secondary limit of 75 days, so all tasks must be performed at whichever limit is reached first. The MPD conveniently puts all items as multiples of the basic Phase 1 interval of 500FH and 75 days. The items that are performed at the Phase 1 interval are generically referred to as an 'A' check. The tasks grouped into a check at the Phase 10 interval of 5,000FH are generically referred to as a 'C' check. These limits were based on the aircraft completing 2,500FH per year. Air China's aircraft only complete about 7.0FH per day, and so reach the 5,000FH and 750 day limits at similar times.

"The FH and calendar limits must be considered in relation to aircraft utilisation," continues Jiang. "An aircraft on long-haul operations that completes 5,000FH per year will reach the 5,000FH limit in 365 days, half the maximum calendar interval. An aircraft that operates medium-haul sectors averaging 3.0FH will reach the 5,000FH limit in 600 days. Ameco actually extended this basic Phase 1 interval to 600FH in October 2006. The aircraft are now being used on longer flights to Sydney, Tokyo, Seoul, Moscow and Frankfurt. The full base check cycle that Ameco has for Air China's 777-200s comprises four checks: the Phase 10, Phase 20, Phase 30 and Phase 40. The Phase 40 check now has a maximum limit of 24,000FH and 3,000 days, or just over eight years. Aircraft operating 3,000FH per year reach the 24,000FH limit in eight years, while aircraft operating on long-haul missions and at a higher rate of utilisation equal to 5,000FH will reach the Phase 40 check in less than five years. A base or 'C' check will be performed every 14 months.

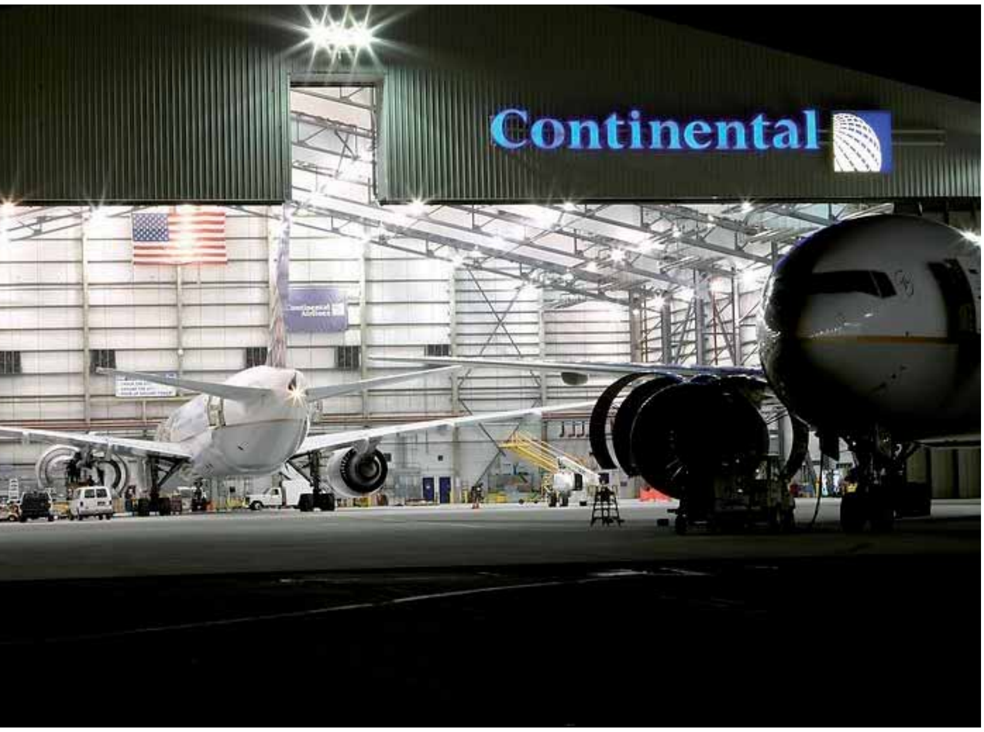
"The Phase 10 check has system- and structural-related tasks," continues Jiang. "The Phase 20, 30 and 40 checks also have structural tasks, with the Phase 40, or C4 check, having the most. Air China's first three 777-200s were delivered in October and November 1998, so the oldest aircraft has recently had its C4 check."

While the 777's MPD allows operators to develop their own unique maintenance programmes, airlines tend to have similar maintenance programmes. The maintenance tasks initially have the same MPD intervals and there is a limited number of ways in which tasks can be grouped together. Checks can be more frequent and small, with relatively few tasks. Small checks can be performed overnight, however, which can be managed for aircraft operating domestic and short-haul route networks with shorter cycle times. Aircraft with low rates of utilisation can have maintenance programmes with base checks about once a year. Structural tasks are usually performed every second check.

Aircraft used on long-haul operations are more suited to programmes with less frequent, larger checks. Maintenance programmes have base checks every 12-16 months, and each one includes structural tasks.

Long-haul aircraft

Delta operates a fleet of eight Rolls-Royce Trent 800-powered aircraft, which it uses to London and Tokyo from various points in the US. "The aircraft have increased their rates of utilisation, and now accumulate about 15FH and 1.3FC per day. The average FC time is about 11.5FH. We have now recently started a service between New York and Bombay, which will increase the average FC time," explains George Sifnaios, maintenance programme manager 757/777 at Delta TechOps. "The MPD has more than 1,000 separate tasks. There are FH, FC and calendar intervals, and each task is either constrained by an FH or FC interval. It may also possibly have a calendar interval. Most system tasks have FH intervals, but some have



The 777's maintenance programme results in the MH used for routine inspections being similar in number to that used by older generation narrowbodies.

both FH and calendar intervals. Structural and zonal tasks have FC and calendar intervals. There are 89 combinations of FH, FC and calendar intervals for the 1,000 or so maintenance tasks. This inevitably means that some tasks will get performed at or near their full limit, while others will not utilise their full limit. There are, for example, 99 items with a limit of 7,500FH, 10 with a 12,000FH limit, and 24 with a limit of 24,000FH. Our base check programme is a system of a PSV check every 12 months. These alternate between light and heavy checks because many of the structural tasks have limits of two years, and so can be performed every second check, which is the heavier check in the cycle. The base maintenance cycle is completed at the PSV8 check, the fourth heavy check, after an interval of eight years.

"We are now about to adopt a new maintenance programme where the PSV check will be called the C check," continues Sifanios. "This will have limits of 7,500FH, 1,250FC and 500 days. This will allow the check to be done every 16 months for our aircraft that are now completing more than 5,000FH per year. This new programme has been developed because our aircraft have increased their utilisation, and the task intervals have been escalated in the MPD. The cycle has changed to one of six checks, ending with the 6C check, after a similar interval of about eight years. The oldest aircraft in our fleet will have its PSV8 check in November 2006, making it the first to complete its base check cycle. We will use this check to bridge the aircraft on to the new programme."

El Al has a fleet of four -200ERs, and uses the aircraft on long-haul routes with an average FC time of 8.5-9.0FH. "We complete about 4,500FH and 500-540FC per year with the aircraft," explains Amnon Hammer, director of engineering at El Al Engineering. "Our base maintenance programme has a base check interval of 7,500FH and 24 months, with the check being performed at whichever limit is reached first. Our annual utilisation means we are reaching the 7,500FH limit in about 20 months. We want to extend the FH limit on the C check so we can perform it every 24 months. Our aircraft are about six years old, and so far we have done the C3 checks on the fleet. The C4 checks are due in 2008, and will comprise the structural inspections and heavy check, thereby finishing a cycle of checks."

Base check contents

A true picture of the 777's maintenance costs is given by considering all elements of the base checks. The routine inspections and task cards form a large portion of the aircraft's base checks. These will lead to non-routine rectifications. These two portions will account for most of the aircraft's workscope, but additional elements will add to the total.

The first of these is out-of-phase items. These are tasks whose maintenance interval is not a multiple of the Phase 1 interval, and so have to be scheduled with a lighter or base check.

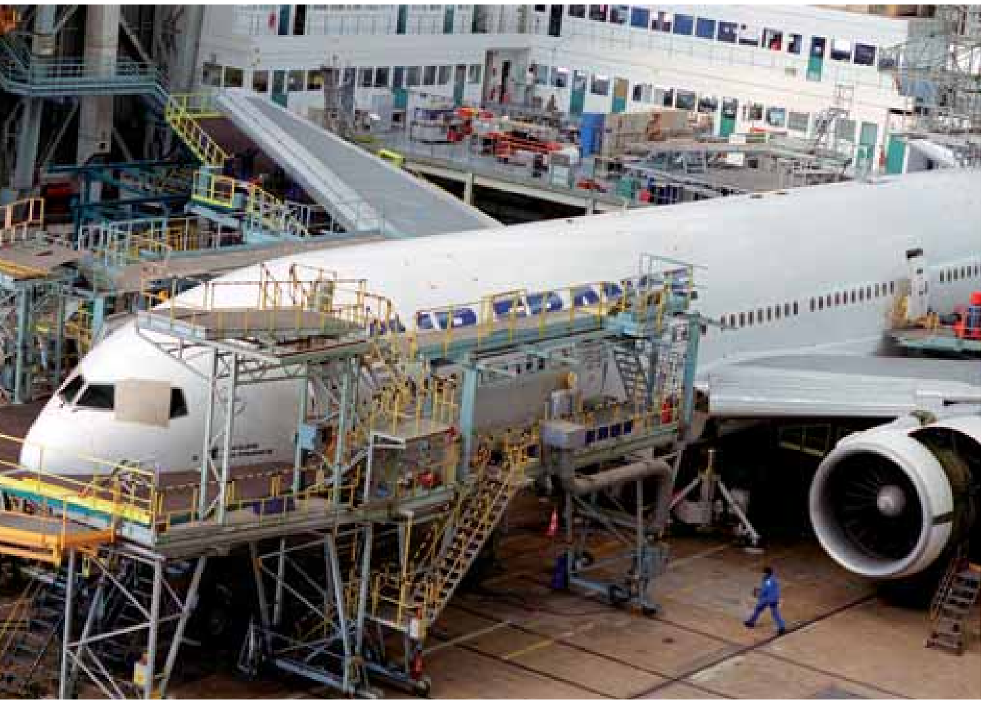
Another group of additional tasks is the removal and installation of hard-time or life-limited rotable components. "We follow and trace about 1,200 rotable components on the 777. Between 800 and 900 of these are maintained on an on-condition basis," says Jiang. "The remaining 300-400 are hard-time rotables."

Many of the hard-time rotable components are safety-related items, such as oxygen bottles, escape slides and rafts and batteries. Overall, the 777's MSG3 design philosophy has led to most rotables being maintained on an on-condition basis, so the removal and installation of rotables will lead to a small number of MH being used.

Northeast Aero is a specialised rotable repair agency in New York state. "Our prime business is the repair of pneumatic system components," says Vic Calabrese, vice president of operations and quality control at Northeast Aero Inc. "We repair pneumatic system components for the 777, including the air cycle machine. We also repair hydraulic and fuel system components, as well as linear and rotary actuators, whether the parts are hard-time or on-condition components that have been sent by airlines. The 777 is now getting to the point where rotables are past their warranty age limits, and we are consequently getting more rotable repair work for the aircraft. We can offer time and material, power-by-the-hour or flat-rate pricing contracts to customers. We also offer parts on an exchange basis to help airlines minimise check downtimes."

The third additional element for base check contents comprises engineering orders (EOs), service bulletins (SBs), airworthiness directives (ADs) and modifications. "The 777 will require modifications to be completed during base checks in the same way all other aircraft do, but the 777 has had no major ADs issued against it," says Sifnaios. "There is one that relates to the replacement of the leading-edge flap outboard gimbal plate. This is covered by AD 2006-NM-080-AD. This is quite extensive, since it necessitates the removal of the flap system, and has to be completed within 24 months of the AD being released. We will cover this AD in the PSV8 check on our aircraft.

"There are also a few ADs that are related to structural inspections which have initial thresholds of 30,000EFC. The repeat intervals have not yet been released," continues Sifnaios. "Some aircraft are completing 1,000EFC or more per year, and the oldest 777s may



When the 777's base check inputs are analysed over an eight-year cycle of four or eight checks, the reserves that account the cost of labour and materials are less than similar-sized widebodies.

reach this threshold in another 15 years. Our aircraft are accumulating only about 500FC per year, and so are not likely to reach this interval while we operate the aircraft."

Interior refurbishment

Final major elements of base checks include interior refurbishment and stripping and repainting. Neither item is included in the MPD, but both still consume a large number of MH and materials.

Sifnaios makes the point that the cosmetic appearance of the aircraft cabin is important to operators. The frequency and depth of work done depends on the aircraft's operation. "We use daily, weekly and monthly inspections to perform on-condition maintenance on seat covers, carpets and overhead bins. We change seat covers on an on-condition basis. We will, however, refurbish the aircraft's interior at the PSV8 check. This is because the check will have a downtime of about 17 days, which will give us time to refurbish the seats, overhead bins, toilets and galleys."

Hammer at El Al Engineering explains that major interior items such as overhead bins, toilets and galleys in different parts of the aircraft have to be removed at different base checks in accordance with the zonal checks of the MPD. "It makes sense to refurbish these removed items when they are removed, so the refurbishment of major interior items will be conducted over a series of base checks."

Some interior work that can be completed in a short downtime will be carried out during the lighter checks. This will include work on repairing and cleaning seat covers, carpets, bins and other simple items such as toilets and galley walls.

Heavier interior refurbishment will include the removal of wall and ceiling panels, overhead bins, carpets, toilets and galleys. These items first have to be removed to provide access for deep inspections, so their removal and the check's extended downtime allow for their refurbishment.

A refurbishment workscope will increase as the aircraft ages. While all major interior items are removed, the carpet is the only major item likely to be replaced. All others will be refurbished, which will mainly require the cleaning and replacement of coatings, linings and surfaces to improve appearance. Few major items will be replaced in the galleys and toilets at the first refurbishment while the aircraft is young. The level of replacement will escalate as the aircraft ages, so the number of MH, materials and parts used to complete an interior refurbishment will rise as a result.

Stripping and repainting have traditionally been performed with the aircraft's D check, every five or six years. The absence of an extended heavy check means many operators perform stripping and repainting at separate times, and on an on-condition basis. This may result in an interval of five to eight years, and so will be done at least once every base check cycle.

Base check inputs

Like the 737NG, the 777 has so far demonstrated a relatively low consumption of MH during base checks for an aircraft of its size. As described, the main elements of base checks include routine inspections, non-routine rectifications, the removal and reinstallation of a few rotable components, EOs and modifications, clearing of defects and interior work.

An eight-check base maintenance programme with annual checks is typical for many operators of long-haul aircraft. This can be used to illustrate typical MH and material inputs for a first base check cycle. This maintenance programme has a Phase 1 interval of 500FH, a base check at the Phase 10 interval of 5,000FH, and assumes that the check is performed about every 4,500FH.

The fourth, sixth and eighth checks in the cycle will be the heaviest and have the largest workscopes. The other five checks are lighter in content and total MH, and will utilise fewer materials than the heavy checks.

The 'C1', or first base check in the cycle, will use 820MH for routine inspections. This will include the removal and reinstallation of hard-timed rotable components and the lighter interior work of cleaning seat covers.

Non-routine MH will include work for clearing outstanding technical defects, and will total about 1,000MH in the first base check. This will take the sub-total for these two major elements to 1,850-1,900MH for this first check.

The MH required for routine items in the second, third, fifth and seventh base checks will be similar to the first, rising to 900MH in the seventh check. The non-routine MH will rise in proportion, and reach about 1,400MH, including clearing of defects, in the seventh check. The sub-total of these two major portions of the base checks will vary from 1,800MH to 2,300MH for these lighter checks.

The fourth 'C' check can be expected

to consume about 2,200MH for routine inspections and interior items, and a further 1,500MH for non-routine defects and clearing outstanding defects. This will take the sub-total to 3,700MH for these two major items.

The sixth check will be slightly smaller than the fourth, using about 1,600MH for routine inspections and 1,750MH for the non-routine parts, taking the sub-total to 3,400MH.

The eighth and last check will include the most structural inspections and may also involve a major interior refurbishment. As described, interior work is carried out on an on-condition basis. While the eighth check in this type of programme provides a long downtime to allow for a full interior refurbishment programme, major interior refurbishment of some toilets and galleys will be performed in the fourth and sixth checks, splitting up the interior refurbishment task into several checks. This analysis assumes that most of the interior refurbishment work is performed during the largest check.

The routine inspections, including regular cleaning and component removals and reinstallations, will consume about 3,000MH. The corresponding non-routine portion and clearing of defects will use about 4,000MH. A large number of rotables will be removed and reinstalled during this check, and so this element will use about 2,000MH. These three groups will take the sub-total to 9,000MH.

Airlines which have performed several C checks in the first base check cycle have reported a relatively low non-routine ratio. “We have found that non-routine work has accounted for 30% of the work packages in the C1, C2 and C3 checks,” says Hammer. “It might be 30-40% in the C4 check, the heavy check, but we do not yet know what it will be in the second cycle, although we expect it to increase.”

A third major element of the base checks will be EOs, SBs, ADs and modifications. Besides ADs, the number of modifications performed on aircraft is at the discretion of each operator, so only an approximation of MH used for this purpose can be given. A reasonable budget for the first seven checks in the cycle is 500-600MH.

This will take the total workpackages for the fourth and sixth checks to about 4,000MH each.

The light first, second, third, fifth and seventh checks will use 2,300-2,800MH for the total check workpackage for the first base check cycle.

The heavy check, which involves the largest number of structural inspections and deep work, can use up to 4,000MH for SBs and modifications. This will take the total for this check, excluding interior refurbishment, to about 13,000MH.

The total labour requirement for the eight checks on the cycle will be about 33,000MH.

Labour charged at a rate of $60 per MH will take the cost of the labour portion of lighter checks to $140,000-170,000, and to about $240,000 for the fourth and sixth checks. The 13,000MH for the heavy check will cost about $780,000.

Associated materials and consumables for these checks will cost $150,000-175,000 for each of the five lighter checks, and $200,000-250,000 for the heavier fourth and sixth checks. The resulting cost of materials and consumables for the heavy check will be $450,000-500,000.

This will take the total cost for the five lighter checks to $290,000-370,000, and to $450,000-500,000 for the fourth and sixth checks. The heavy check will have a total cost in the region of $1.2-1.3 million. The total cost for the eight checks in the cycle will be $3.5-3.8 million.

The corresponding interval for this is 36,000FH. This is based on the basic Phase 1 interval of 500FH and the Phase 10 and base check interval of 5,000FH. It is assumed that not all the interval will be

777 BASE MAINTENANCE CHECK DATA

Base check item	Total MH	Materials Costs $	Total Cost $
C1/C2/C3/C5/C7 checks	12,500	775,000	1,525,000
C4 & C6 checks	7,900	400,000	875,000
C8 check	13,000	500,000	1,280,000
Interior refurbishment	5,500	550,000	880,000
Stripping & repainting	3,000	16,000-20,000	200,000
Total for base check cycle	41,000-43,000		4,500,000-4,800,000
Interval			36,000FH
Base maintenance reserve			$120-130 per FH

utilised, and the base check is actually performed every 4,500FH. The cycle of eight checks is therefore completed in about 36,000FH. The reserve for these inputs is thus $100-105 per FH, although this does not include inputs for interior refurbishment.

Phil Seymour, managing director at the IBA Group gives an example of a base maintenance programme for aircraft that are used on long-haul operations. This is a system of a base check every 24 months, with the fourth check at 96 months being the heavy check. "Excluding interior refurbishment, the first three checks in the cycle will each consume 5,000-5,500MH and about $225,000 in materials and consumables. The fourth, heavy check will use 18,000-21,000MH and about $850,000 in materials and consumables," says Seymour. "The four checks in the cycle will therefore consume a total of 33,000-37,000MH and $1.5-1.6 million in materials and consumables. A labour rate of $60 per MH would take this to a total cost of $3.5-3.8 million."

This is similar to the programme of eight annual checks, and consequently has a similar reserve per FH.

Interior work

The final element of interior refurbishment must be considered for the eighth check. The labour required for the removal and reinstallation of the interior items will total about 2,000MH. The labour element for refurbishing the various interior elements for an aircraft in its first base check cycle is likely to be 3,500MH if all the work is done in house. The total of 5,500MH charged at a rate of $60 per MH will be equal to a cost of $330,000.

As described, the material cost will be low for a first base-check cycle interior refurbishment. The aircraft is young, so few items will require replacing, and the materials used will be required to re-cover panels, overhead bins and galley and toilet walls. The cost of consumables and materials is likely to be $200,000-250,000, therefore taking the total cost for interior refurbishment to $530,000-580,000.

Both MH and material costs will increase as the aircraft ages. The aircraft will require a higher level of parts replacement, and more intensive refurbishment work will also be required.

In addition to interior refurbishment, stripping and repainting will also be carried out. This was traditionally done at each heavy check, every five or six years, but some operators now treat this as an on-condition item, and it is performed at a similar interval. Other carriers may perform this task once or twice every base check cycle. Stripping and repainting a 777-200 will use 2,500-3,000MH and $16,000-20,000 in paint and materials, thereby incurring a total cost of about $200,000.

Summary

The total for the main check items, interior refurbishment and stripping and repainting for workpackages of the eight checks will be $4.5-4.6 million *(see table, this page)*. This will include a total of 41,000-43,000MH for this base check programme. The total MH and materials inputs will vary little between the 777-200 and -300 series aircraft. This is because many of the routine tasks for the two variants are system-related and identical. Most structural tasks will be the same, with the -300 having a few additional items. The -300 is likely to require more labour for interior refurbishment.

When amortised over the interval of 36,000FH, the reserve for these eight checks is therefore $120-130 per FH when interior refurbishment is included.

The 777 is relatively young, however, and only a minority of aircraft have completed their first base check cycles. A clearer picture of their maintenance requirements will emerge in due course. Moreover, these reserves are for long-haul aircraft, and reserves for medium-haul aircraft are likely to be higher.

Aircraft will naturally be expected to have a higher consumption of MH and materials for their base checks in subsequent cycles. The extension of the basic Phase 1 interval to 600FH, and of the base check interval to 6,000FH, means that the base check cycle is likely to be completed after 43,000FH. The total MH for an eight-check cycle will only increase by 3,000-5,000MH, representing an increase of up to $300,000. A total increase of $700,000 in base check costs would see little increase in reserves.

By comparison, a mature MD-11 has a full base check cycle of four C checks, which in the case of most operators has an interval of 24,000FH. The actual cycle is likely to be completed in 22,000FH, equal to four and a half years' of operations. The four checks for a mature aircraft will use 68,000-70,000MH and more than $1 million in consumables and materials *(see MD-11 maintenance analysis & budget, Aircraft Commerce, August/September 2006, page 19)*. At the same labour rate of $60 per MH, the aircraft's reserve will be $240 per FH.

The more advanced A340-300 completes a base check cycle in eight checks, which has an interval of 120 or 144 months, depending on the operator. The cycle is likely to be completed every 45,000-50,000FH, depending on the operator. The eight checks use a total of 84,000-90,000MH and $1.5-2.0 million in materials and consumables. This would have a total cost of $6.5-8.3 million at the same labour rate, and so a reserve of $150-165 per FH.

This illustrates how the 777 benefits from its maintenance-friendly design and maintenance programme. AC