777 family maintenance analysis & budget

The 777-200/-300 have the lowest maintenance costs in their size class. The twin-engine design and maintenance programme contribute to low costs.

The 777 family has been a successful programme, becoming a long-haul workhorse for many operators, and displacing the 747 from this role in the process. The first 777 entered service in 1997, and there are now 729 aircraft in operation and another 357 on firm order.

The maximum take-off weights (MTOWs) and range capabilities of the -200 and -300 series have been steadily extended since 1997. The majority of aircraft are used on long- or ultra-long-haul missions. Earlier-built -200s and -300s are used on regional and medium-range services, particularly in the Asia Pacific. All aircraft on firm order are long-range models.

The most notable feature of the 777 is its maintenance programme, which comprises about 2,000 tasks with a range of different intervals and interval criteria. Operators are free to group tasks into checks that suit their operating schedules and maintenance planning.

777-200/-300 in operation

The 777-200 can broadly be divided into low, medium and high gross weight aircraft. There is also the specialist ultra-high gross weight -200LR powered by the GE90-110B *(see 777 family specifications, page 6)*.

The long-range group comprises the most aircraft, with 375 in service. The low gross weight category is the second largest with 58 aircraft, while there are 42 medium-weight aircraft. There are also 21 -200LRs in operation, while another 28 are on firm order.

The low gross weight aircraft comprise: 41 PW4074/77-powered aircraft operated by Air China, All Nippon Airways (ANA), and Japan Airlines (JAL); four GE90-85B-powered aircraft operated by China Southern; and 13 Trent-875/77/90-powered aircraft operated by Cathay Pacific and Thai International. These aircraft are all operated by carriers in the Asia Pacific and are used on short-haul, high-density missions. The aircraft operated by China Southern, Cathay, Thai International and Air China are used on medium-haul services with flight cycle (FC) times of 2.3-3.2FH and annual utilisations of 2,800-3,900FH. The ANA and JAL aircraft are used on domestic Japanese services of about 1.2FH per FC and annual utilisations of 2,000-2,200FH.

Most medium gross weight aircraft are mainly used on long-haul missions. United, Korean, Transaero, British Airways (BA) and Continental Airlines all use their aircraft on FC times of more than 5.0FH, and Continental actually has an average of 10FH. Emirates, Kenya Airways, and JAL have accumulated 3,600-3,800FH at FC times of 3.2-5.1FH.

The majority of high gross weight aircraft are used on long-haul missions. The exception is Saudia, which requires high gross weight performance because of the high ambient temperatures it experiences for its domestic operations.

Most high gross weight aircraft achieve 4,500-5,000FH per year at FC times of 5-10FH. Aeromexico, Air France, Alitalia, Austrian Airlines, Continental Airlines and Delta have the highest average FC times of 9.0FH per FC and higher.

The -200LR fleet is still small. Delta operates its aircraft in cycles of up to 13FH and has utilisations of about 5,600FH per year.

The -300 fleet is relatively small, with 56 aircraft. The aircraft was acquired mainly by operators in the Asia Pacific to replace 747s on high-density regional operations. Cathay, Singapore Airlines (SIA), Thai International and Korean Air all have FC times of 2.4-3.6FH, and have annual utilisations of 2,700-4,500FH.

The ultra-high gross weight -300ER is more popular than the -200LR. There are 160 -300ERs in operation with the GE90-115B engine, with Air Canada, Air France, Air India, ANA, Emirates, EVA Air, Jet Airways, and SIA. Most fleets accumulate at least 5,000FH per year and have FC times of at least 8.0FH.

All 777-200s and -300s so far delivered are in operation as passenger-configured aircraft, and their maintenance costs are analysed here for aircraft completing about 3,000FH and 1,000FC per year at an FC time of 3.0FH on medium-haul missions, and about 4,750FH and 650FC per year at an average FC time of 7.5FH on long-haul missions.

Maintenance programme

The 777's maintenance programme has up to 2,000 tasks with varying intervals. Operators are free to group these into maintenance checks that suit their operations. The tasks are listed in the maintenance planning document (MPD). Each task is listed with its respective interval, which is specified in FH, FC or calendar time. Some tasks combine two of these interval criteria.

In addition there are specific pre-departure, transit and daily checks. George Sifnaios, maintenance program manager for the 757/777 at Delta Tech Ops, says that there are 125 interval combinations.

There are also a few other tasks with specified intervals. These are inspection tasks that need to be carried out upon a component's removal, such as a zonal inspection of the auxiliary power unit (APU) compartment, or engine mount inspection during an engine change.

"The MPD includes all 1,700 maintenance tasks for each model and configuration," explains Nestor Koch, market & sales vice president at VEM Maintenance & Engineering. "The first section of the MPD contains the system maintenance programme for all system tasks, which total about 600. The second section is the structural maintenance programme for the external and internal structural inspections, corrosion prevention and control tasks, and fatigue-related inspections which total about 800 tasks. The third section is the zonal inspection programme, which includes general visual inspections in a particular zone of the aircraft to ensure that components, parts, wiring and tubing are securely attached, and inspections of the general condition of any system or structural items within a specific zone on the aircraft. There are about 300 of these tasks for each aircraft model and configuration."

Sifnaios says that section 9 of the MPD covers airworthiness limitations (AWLs) and certification maintenance requirements (CMRs). "The supplemental structural inspections are listed in Section 9 'Airworthiness Limitations' of the MPD, and concern those Structural Significant Items (SSIs) that do not receive adequate fatigue damage detection from the initial baseline structural programme and therefore require supplemental inspections," says Sifnaios. "These will begin after a defined

The majority of 777s are used on long-haul and ultra long-haul operations, generating annual utilisations that average about 4,750FH per year. The aircraft's twin-engine design and maintenance programme allow it to achieve lower maintenance costs than the A340-200/-300.

threshold (of 30,000FC) in the MPD is reached, with repeat intervals to be determined using the damage tolerance rating (DTR) form. The DTR system defines a required DTR (a numerical value) that must be achieved for each SSI.

"A CMR," continues Sifnaios, "is a required periodic task, and is established during the design certification of the aircraft as an operating limitation of the type certificate. An example of a CMR inspection is the operational check of the ram air turbine (RAT) and RAT auto and manual deployment systems, which has an interval of 6,000FH.

"Also, the fuel system AWLs, better known in the industry as SFAR88, are covered in Section 9," explains Sifnaios. "These are mandatory maintenance actions required to ensure that unsafe conditions identified by the SFAR 88 safety review do not occur or are not introduced into the fuel tank system during the operational life of the aircraft. The AWLs may only be revised with the approval of the Seattle Federal Aviation Administration (FAA) aircraft certification office."

Task intervals

"Most of the system tasks have FH intervals, but some have FC/calendar intervals, FH/calendar and FC intervals," says Koch. "Most structural tasks have FC/calendar intervals, and there are some AWL tasks that have threshold and repeat intervals in FC.

"Zonal tasks have mainly FC/calendar intervals, although a few have FH intervals," continues Koch. "Overall there are about 370 tasks that only have FH intervals, ranging from 100FH to 30,000FH. There are eight tasks with FH/calendar intervals, and 40 tasks with FC intervals. FC intervals range from 100FC to 32,000FC.

"There are also about 330 tasks for which the threshold and repeat intervals have yet to be decided. These are from the AWL, and their intervals will be in FC. Most AWL structural tasks have a threshold interval of 30,000FC, so they will not be performed until the aircraft reaches old age, and may never actually be performed by an airline utilising the aircraft purely for long-haul operations," explains Koch.

Only carriers like JAL and ANA that accumulate about 2,500FC per year will have to start performing these tasks when their aircraft reach 12 years of age. The repeat intervals of some of these tasks have yet to be published in the MPD. There are 37 tasks, for example, with an initial interval of 32,000FC and 6,000 days, but their repeat interval has not been determined. Another 17 tasks have initial intervals of 28,000FC and 5,250 days. Others have initial intervals of 24,000FC/4,500 days, 16,000FC/3,000 days, and 10,000FC/3,000 days.

"There are also about 800 tasks with FC/calendar intervals, and about 150 with calendar intervals. Calendar intervals range from 30 days to 6,000 days," continues Koch.

However, the actual intervals for each task vary between operators. More experienced operators with longer experience of utilising larger fleets will have been able to get extensions for task intervals from their local airworthiness authorities.

Operators are free to group these tasks with different intervals into maintenance checks according to their different interval criteria. The two most important factors that influence how operators group tasks are the FH:FC ratio and the rate of annual utilisation. One example is item 12-008-00, which involves lubrication of the leading-edge slat torque tube couplings, supports and gearbox couplings. This item has an interval of 6,000FC and 1,125 days, whichever is reached first. Only aircraft that are completing more than 5FC per day will reach the 6,000FC limit first. Most aircraft operating on long-haul missions will reach the calendar limit long before reaching the 6,000FC limit.

Another example is item 72-206-01, which is a detailed borescope inspection of the first and second stage high pressure turbine (HPT) blades on the GE90 on the left engine. This has intervals of 2,000FH and 600FC, whichever is reached first. This depends on the aircraft's FH:FC ratio.

Taking United Airlines' programme as an example, there are a total of at least 1,400 tasks, comprising: 320 with FH intervals of 48-24,000FH; 68 FC tasks, with initial thresholds of 30-32,000FC; 134 calendar tasks, with initial thresholds of 75-6,000 days; 143 tasks with FH and calendar intervals; and 728 tasks with FC and calendar intervals.

The 777, like the 737NG, does not have pre-defined A and C checks. The aircraft does have some specific tasks grouped into defined pre-flight, transit and daily checks for a line maintenance programme. Most operators do, however, group tasks with larger intervals into generic 'A', 'B', 'C' and structural checks. These can differ in content and interval between different carriers, but there are also similarities between different operators.

Line maintenance programme

Some line maintenance tasks have to be performed in specific line checks. These are defined by each operator to ensure the execution of MPD tasks with small intervals such as transit, daily, 48 hours and 125FH. The operator can create 'transit', 'daily', 'weekly' and 'monthly' checks to address these tasks.

The line maintenance programme that most operators actually follow has the standard line checks that are used for all aircraft types. "The first of these is a daily

The 777's maintenance programme has about 2,000 tasks and 125 different task intervals. Operators are free to group tasks into checks according to their operation, rate of utilisation and FH:FC ratio. This makes maintenance planning more efficient and results in lower MH requirements than older generation aircraft.

check which has to be performed at an interval not exceeding 48 hours," explains Matko Dadic, sales manager at Europe Aviation.

Aircraft that are utilised on short- or medium-haul services can have the daily check performed each day at their homebase, usually as an overnight check. Aircraft used on long-haul operations are often unable to return to homebase once every 24 hours so, if permitted, a 48-hour interval can allow the daily check to be performed at the homebase when the aircraft returns, according to its operating schedule. These checks have to be performed by mechanics.

"However, the transit and pre-flight checks can be carried out by flightcrew members after completion of a training programme authorised by the operator's local authority," says Dadic. "The transit check is performed at every transit and following a daily check, while the pre-flight checks are performed prior to each departure.

"An extended-range, twin-engined operations (Etops) service check also has to be done prior to an Etops flight," continues Dadic. "These tasks cannot be done by flightcrew, due to the specific Etops tasks included in the Etops service check". To obtain Etops approval operators must perform some special MPD tasks. Examples of daily tasks for an Etops include: reading the status messages, existing faults and fault history and taking appropriate actions; checking engines and the APU for oil consumption; and checking the cargo compartment linings for damage.

"Next is the service check, which has to be performed every eight days, or no more than every 216 hours," explains Dadic. "This is often called the weekly check by many operators.

"The pre-flight check mainly comprises visual inspections," says Dadic. "Although routine checks can be performed by flightcrew, any defects that they find have to be rectified by mechanics. A defect can be deferred if it is a minimum equipment list (MEL) item. The length of the deferral is listed in the MEL. Items not listed in the MEL are no-go items, which means that they have to be rectified before the aircraft can fly again. The aircraft's technical log should also be examined to observe the listed outstanding defects."

Transit checks are almost the same as pre-flight checks. "The routine visual inspections of these two checks include pitot tubes, lights, bay doors and access panels, slats and flaps, engine inlets, and wheels and landing gears," continues Dadic. "Interior inspections include items such as radios, fire detectors, flightdeck oxygen and other emergency equipment. Other tasks include inspection of the radome latches, ram air inlet and outlet doors, left and right integrated-drive generator oil levels, and a fuel drain from all fuel tanks."

The Etops service check includes an inspection to see that the engine oil filler cap seal is in good condition and that the cap is correctly fitted.

Daily checks are slightly larger in content than transit and pre-flight checks. The routine tasks are the same as those for transit and pre-flight checks, but also include additional tasks for line mechanics, such as the manual checking of tyre pressures, brake disc wear, and shock absorbers. Engine oil levels should also be checked, as should the APU bay. "The daily check also includes ensuring that the toilets and the potable water system are serviced, and that the passenger cabin is checked for general condition and cleanliness. The aircraft's maintenance log and cabin discrepancy log are also reviewed," says Dadic.

Weekly checks have the same content as the daily checks plus a few additional tasks. "These include examining the magnetic chip detectors and landing gear shock absorbers, draining and refilling water, and checking emergency gas bottles and cargo compartment doors," explains Dadic.

As well as the MPD tasks with transit or daily intervals, operators can choose to include additional tasks in the line checks according to their own experience.

"In addition to the pre-flight and transit checks, which are valid up to four hours prior to the flight's departure, there is an after-landing check," says Walid Elkhafif, aircraft system senior engineer at Egyptair Maintenance & Engineering Company. "This is required after each arrival at base for stops that are four hours or more."

Koch gives an example of a line maintenance programme of pre-flight and transit checks, a daily check at 48 hours, and a monthly check every 30 days.

An example of a line maintenance programme is given by Fabrice Defrance, aircraft maintenance and engineering vice president at Air France Industries. "We have the usual pre-flight, and then daily and weekly checks. The content of the daily and weekly checks is similar, with the weekly having just a few more tasks. We also have an 'M' check, which has an interval of 850FH. This is the first significant check over the line maintenance programme, and has an interval similar to many operators' 'A' checks. This has a downtime of about eight hours and takes 20-30 man-hours (MH) to complete. Our 'A' check interval is 1,200FH, and we hope to escalate the check to 1,500FH in 2009. This check is a hangar check."

A checks & base maintenance

Most operators group tasks with intervals from about 500FH, 200FC and 60 days into generic A checks or higher base checks.

Delta's programme for the 777 is one example. "We used to have an A check every 500FH, 100FC and 50 days,

777 OPERATOR'S HANGAR CHECKS & INTERVALS

Airline operator	Air France	Delta Airlines/ Tech Ops	Egyptair	El Al	United Airlines	VEM
Lower check	'M'check 850FH					
A check	1,200FH	250FH 50FC 25 days	500FH	600FH	300FH X 24 = 7,200FH	500FH X 12= 6,000FH
C check	7,800FH 960FC 18 months	7,500FH 1,250FC 500 days	7,500FH 750 days	7,500FH 24 months	18 months	10,000FH 4,000FC 750 days
Heavy/structural check	4,000FC 66 months 8,000FC 108 months		36,000FH 3,000 days			

whichever interval was reached first," says Sifnaios. "We recently divided this into intervals of 250FH, 50FC and 25 days to help us achieve our operational goals *(see table, this page)*. This has effectively made the checks into half A checks.

"The next highest checks are our 'C' checks. We used to have a system of a base check every 12 months. Every second check was a heavy check because many of the structural tasks were grouped into two-year intervals," continues Sifnaios. "The base check cycle was effectively completed every eight checks because the highest intervals of most tasks coincided with the eighth check. Later checks would, however, have more tasks because some have higher initial thresholds. We have recently changed our base check system to a 'C' check with intervals of 7,500FH, 1,250FC and 500 days, whichever is reached first *(see table, this page)*. At our utilisation of about 5,250FH and 480FC per year, this check comes due every 16 or 17 months. This C check captures system, structural and zonal tasks. There is in fact no particular cycle of checks, and tasks are continuously added as the aircraft ages. There are, for example, tasks with intervals of 4,500 days or 30,000FC. The 777 has a continuous, rather than cyclical, maintenance programme, which consists of 52 C checks. Every sixth check (C6, C12, C18 etc) is the heavy check because it has 1C, 2C, 3C and 6C tasks. The C7 check, by comparison, has 1C and 7C tasks."

The A check in VEM's case has an interval of 500FH, as well as intervals in FC and days. Koch explains that there are 1A, 2A, 3A 4A, 6A and 12A tasks with intervals that are corresponding multiples of 500FH. The A check cycle is therefore completed at the A12 check at 6,000FH.

Koch explains that, like all operators' base maintenance programmes, VEM's is based on grouping tasks. "Most structural tasks are those with intervals of 4,000FC or higher, and many operators put these tasks into SC or heavy maintenance checks that have higher intervals than generic C checks, which have mainly system-related tasks. We, however, had an operator with a different approach. Most of the system tasks were in the A check multiples. The 1C check had an interval of 10,000FH, 4,000FC and 750 days, whichever was reached first *(see table, this page)*. Most tasks in the 1C check were structural and zonal, and so had mainly FC and calendar time intervals."

Elkhafif explains that Egyptair has organised the 777's maintenance programme into phases of 500FH, and the equivalent FC and day intervals according to its pattern of operation, rate of utilisation and task intervals. Tasks are grouped into a multiple of 500FH according to their interval. The interval for Egyptair's generic 'A' check is 500FH, and the FC and day equivalents. "The first A check is performed at the first phase of 500FH. The first base or 'C' check is performed at the 14th phase, which is 7,500FH and 750 days, and the FC equivalent *(see table, this page)*. C check multiples are therefore performed at multiples of these intervals. The heavy check interval is at phase 72, which is 36,000FH and 3,000 days, and the FC equivalent," explains Elkhafif. "There are also structural tasks, which are grouped for combining with the heavy check. The initial interval for this is 6,000FC and 1,125 days. Repeat intervals thereafter are 4,000FC and 750 days."

Air France Industries has a programme of M checks every 850FH, and A checks every 1,200FH *(see table, this page)*. The A checks include several system tasks that some operators might include in A check multiples or base checks. "Our base maintenance programme is based on calendar and FC intervals," explains Defrance. "We have a C check every 18 months, 7,800FH and 960FC, whichever is reached first *(see table, this page)*. These checks alternate between a C1 and a C2 check. This compares with the earlier interval of 12 months for the C1 and 24 months for the C2 checks.

"The lighter C1 check has mainly system tasks, and the C2 check is the C1 plus some additional (zonal) tasks, and has a downtime of about five days," continues Defrance. "We also have SC checks for performing structural tasks. The SC1 has an interval of 66 months and 4,000FC, whichever is reached first, while the SC2 check has intervals of 108 months and 8,000FC. The SC check has also been escalated from its original interval of 48 months.

"It makes most sense for us to combine the SC checks with a multiple of the C check so as to reduce downtime. This means, for example, performing the C2 slightly early at 66 months, rather than at 72," continues Defrance. "The SC2 is the heaviest maintenance visit, because it includes a C1 or C2 check, the SC1 and SC2 structural inspections, interior refurbishment, and airworthiness directives (ADs) and service bulletins (SBs) with more significant MH."

United, like Delta, has divided its original A check package with an interval of 500FH into two 300FH checks for the purposes of Etops. This is an escalation from an earlier interval of 250FH. It has 24 A check segments, with the A24 check having an interval of 7,200FH. The base maintenance programme is a sequence of four checks, each of which includes

The 777's base check MH inputs are low relative to older types like the 747. Although the number of routine tasks will increase as the aircraft ages, MH will still be relatively low.

system, structural and zonal tasks. The current interval is 18 months. This is an escalation from the original interval of 12 months.

Line & A check inputs

Pre-flight and transit checks use small amounts of labour and materials. Dadic says that during a usual turnaround the 777 uses up to 2.5MH for these checks. Even though some of this labour can be provided by flightcrew, a conservative estimate of maintenance costs assumes that all labour is provided by mechanics. A generic labour rate of $70 per MH equals a labour cost of $175.

The materials and consumables used during these checks include oil, shock absorber cleaner, lightbulbs, and any items related to non-routine occurrences. A budget of $50 should be allowed for these checks.

A daily check will use a little additional labour because of the larger workscope, and Dadic estimates that 4-5MH will be needed. This equals up to $350. One mechanic is usually sufficient to complete the job. The actual labour amount will depend on any findings and non-routine work that arise from the routine tasks. There are also items such as reflating tyres and changing lightbulbs. A budget of $200 should be allowed for materials and consumables.

A weekly check has a larger scope than the daily check, but is often used to clear the smaller accumulated deferred defects that have arisen since the last weekly check. Dadic suggests that a budget of 6-8MH be used for labour, equal to $420-560, and up to an additional $500 should be allowed for materials and consumables.

A check inputs vary by operator as a consequence of differing maintenance programmes and styles of operation. A budget of 500MH and $25,000 for materials can be used to reflect inputs for a generic maintenance programme. This is equal to a total cost of $60,000.

Aircraft on annual medium-haul operations of 3,000FH and 1,000FC will require 1,000 pre-flight and transit checks, and 355 daily and 50 weekly checks per year. The total annual cost for these checks will be $470,000, so reserves for these will be $147 per FH *(see first table, page 23)*.

While the generic A check interval is 500FH, the actual interval between A checks is likely to be 350-450FH, which means that the aircraft will also have seven to nine A checks. Reserves for these will be $135-170 per FH *(see first table, page 23)*.

Aircraft on long-haul operations at 4,750FH and 650FC will require about 650 pre-flight and transit checks, and 355 daily and 50 weekly checks each year. The total annual cost for these will be $390,000, so the reserve will be $82 per FH. Reserves for A checks will be similar to those for aircraft on medium-haul operations *(see second table, page 23)*.

Base check contents

The content of the base checks will be more than just routine task card inspections and the non-routine rectifications that arise as a result. The downtime, tooling and gantry in the hangar provided by base checks mean that there is scope for several other elements to be added.

The first of these usually includes clearing all accumulated technical defects that are recorded in the aircraft's technical log. Other items are interior cleaning and varying levels of interior refurbishment, depending on which check is being performed. Modifications and upgrades are also usually included, as are ADs and SBs. Routine inspections can often reveal faults with system rotables, and some hard-time components that have to be removed. The aircraft's downtime will also be exploited at some stage so that the aircraft can be stripped and repainted.

As operators are free to plan their own maintenance programmes, these can vary considerably. A generic programme of a base check every 18 months is used here to illustrate the inputs for the base maintenance cycle up to the first heavy check, which will include a large number of structural tasks, removal and installation of a large number of rotable components, and interior refurbishment. The heavy check is the C6 check, and the C3 check is a medium-sized check. The C6 check has the 3,000-day/100-month tasks, and the C3 check the 1,500-day/50-month tasks.

The actual interval achieved between checks is likely to be 15-16 months. Medium-haul aircraft will achieve 3,900-4,000FH between checks, and long-haul aircraft 5,900-6,300FH between checks. The C6 check will be completed at about 90 months, equal to seven and a half years, and equal to 22,500-23,500FH for medium-haul aircraft, and 35,000FH for long-haul aircraft.

Routine inspections

The routine inspections in the base checks will be a combination of system, structural and zonal tasks. The ability of operators to plan their own maintenance programmes and checks means that these tasks are now dealt with more efficiently than on previous generation aircraft.

Routine inspections use 800-900MH for the lighter C1, C2, C4 and C5 checks. These MH include removing and installing a small number of rotable components, as well as a little interior work.

Further MH are required to clear defects that have arisen during operation and for non-routine rectifications that arise as a result of the routine task cards. With the clearing of defects included, the non-routine ratio will be more than

Heavy component maintenance costs account for 10-12% of total maintenance costs. About half of heavy component costs are related to brake repairs.

100%. The MH used for the C1, C2, C4 and C5 checks will be 1,000-1,400.

The C3 check will use 2,150MH and, like lighter C checks, will include removal and installation of rotable components and some lighter interior work.

The C6 check is the heavy maintenance visit and will use 3,000MH. Another 2,000MH could be used to remove and install rotable components. A major interior refurbishment will be included in this check, but the inputs for this are treated separately.

Engineering orders

Engineering orders (EOs) cover all modifications, upgrades, SBs and ADs. The 777 has so far been relatively free from major ADs or SBs. A few have arisen since the aircraft entered service, however.

One example of an SB included in base checks is AD 2007-11-23, which incorporates SB 777-27A0071 and relates to trailing edge flaps, the flap support pin, ball set and bushing replacement.

Another example is SB 777-27-0072, which relates to flight controls that affect the aileron and flaperon control, and requires a wire routeing revision.

One SB requires the replacement of the passenger door seal, while another modifies or replaces the ram air door.

An example of an AD that is included in the 777's base checks is AD 2007-17-12, which is the horizontal stabiliser trim actuator ballscrew lubrication and inspection.

AD 2007-15-05 is a functional check on the elevator surface freeplay.

These ADs and SBs do not require large inputs of MH, but they do affect the aircraft because they have a relatively high frequency of inspection.

Major ADs affecting the 777 involve the inspection and repair of the station 246 floorbeam, and the replacement of the wing torque tube and the gimbal support. These ADs and AD 2007-11-23 are large enough to require a special visit separate from a base maintenance visit, or to be included in a large check. Estimates by United Airlines are that it can take 3,500-7,000MH to complete.

An allowance of 500MH for the input of ADs and SBs will be made for lighter C1, C2, C4 and C5 checks, while 800MH should be budgeted for the C3, and a large input of 4,000MH should be used for the C6 check.

Rotable components

Base checks will involve the removal of some hard-timed components. In the case of closed-loop components the removed rotables are tested and repaired and then reinstalled on the same aircraft. Some components are replaced with new items. In the case of open-loop components the removed items cannot be repaired in the time allowed by the check's downtime, and serviceable items are installed on the aircraft.

Most of the rotable components on the 777 are maintained on an on-condition basis. There are 2,300 rotable components installed on the 777, although the number varies depending on the variant and exact configuration. Of these, about 1,700 are maintained on an on-condition basis, and the remaining 600 are maintained on a hard-time basis. Hard-time components include safety-related items, such as emergency escape slides, oxygen bottles, life rafts and batteries.

The remaining components that are maintained on an on-condition basis are removed during line checks in the event of malfunction or failure. They are then replaced during these line checks with serviceable units from an inventory of components. System checks during A and base checks may reveal component malfunction or failure, however. In this case replacement rotable items will be required.

Interior work

The items that have to be refurbished at varying intervals are seat covers, carpets, sidewall and ceiling panels, overhead bins, passenger service units (PSUs), galleys and toilets. The intervals for refurbishing some of these items relate more to appearance and marketing considerations than airworthiness.

United uses a cabin maintenance module (CMM) to refurbish seat covers and carpets at intervals of 400FH or more. Delta inspects and cleans seat covers once every 10 days, but replaces them every two to four years in most cases. Similar intervals apply to carpet replacement.

Sidewall and ceiling panels have similar refurbishment intervals to overhead bins and PSUs. Air France, for example, refurbishes these items at every SC check, which has an interval of 66 months. Similarly, Egyptair refurbishes these items at every fourth C check, which takes place every six to seven years. VEM refurbishes these items at even longer intervals of up to 10 years, while Delta does this at every sixth C check, which is every eight or nine years.

Most operators refurbish galleys and toilets at similar intervals to panels, overhead bins and PSUs, with a heavy check affording the opportunity and downtime for the size of the workscope.

In the analysis used here, the major interior refurbishment is made at the C6 check. This includes the items described above, and consumes 5,500MH for an aircraft operated on medium-haul operations after seven to eight years, but 6,500MH for an aircraft that has accumulated a larger number of FH over a similar period. The cost of materials for this element of the base check would be $200,000-250,000.

Stripping and painting was traditionally performed before and after the D check, which was 5-6 years in the

777-200/-300 HEAVY COMPONENT MAINTENANCE COSTS

Operation	Medium-haul	Long-haul
FH:FC	3.0	7.5
FH per year	3,000	4,750
FC per year	1,000	650
FH:FC	3.0	7.5
Number of main & nose wheels	12 + 2	12 + 2
main/nose tyre retread interval-FC	360/250	360/250
Tyre retread cost-$	1,050/670	1,050/670
Number of retreads	3/2	3/2
New main & nose tyres-$	1,550/1,050	1,550/1,050
$/FC retread & replace tyres	**45**	**45**
Main/nose wheel repair interval-FC	1,440/1,000	1,440/1,000
Main & nose wheel inspection cost-$	2,650/1,800	2,650/1,800
$/FC wheel inspection	**26**	**26**
Number of brakes	12	12
Brake repair interval-FC	1,800	1,800
Brake repair cost-$	60,000	60,000
$/FC brake repair cost	**400**	**400**
Landing gear interval-FC	10,000	6,500
Landing gear exchange & repair fee-$	1,250,000	1,250,000
$/FC landing gear overhaul	**125**	**192**
Thrust reverser repair interval-FC	12,000	6,000
Exchange & repair fee-$/unit	400,000	400,000
$/FC thrust reverser overhaul	**67**	**133**
APU hours shop visit interval	7,500-8,500	7,500-8,500
APU hours per aircraft FC	3,400-5,500	3,400-5,500
APU shop visit cost-$	400,000-500,000	400,000-500,000
$/FC APU shop visit	**75-156**	**75-156**
Total-$/FC	**738-819**	**872-953**
Total-$/FH	**246-273**	**116-127**

case of most aircraft types. This is treated on an on-condition basis by most operators, and intervals have been extended to six to eight years in most cases.

Stripping and repainting will use 2,500-3,000MH and $20,000 for paint and other materials. Using a standard labour rate of $50 per MH, the cost for stripping and repainting is $160,000-180,000.

Base check reserves

The total number of MH required for routine and non-routine rectifications, removal and installation of rotable components, incorporation of ADs and SBs, and clearing of defects and interior work will be 2,400-2,800MH for the C1, C2, C4 and C5 checks.

The corresponding cost of materials and consumables for each of these checks will be $150,000-175,000.

The total will be 5,500-6,000MH for the intermediate C3 checks, and materials and consumables will cost $250,000.

Inputs for the heavy C6 check will be 17,000-18,000MH and $700,000-800,000 for materials, consumables and interior refurbishment parts.

Total inputs over the six checks will be 33,000-35,000MH and $1.6-1.7 million in materials, consumables and parts. Using a standard labour rate of $50 per MH, and including a strip and repaint, the total cost for the base maintenance will be $3.4-3.6 million.

When amortised over a total interval of 23,000FH, reserves for medium-haul aircraft are $148 per FH. The interval of 35,000FH for long-haul aircraft results in a lower reserve of $97-103 per FH *(see second table, page 23)*.

Heavy components

Heavy components comprise four main categories: the landing gear, wheels and brakes, thrust reversers, and the APU.

The 777's landing gears comprise two main legs, each with six wheels, and a nose leg with two wheels. The 12 wheels on the main landing gear have carbon brakes.

Wheels are removed when tyre treads are worn. Tyres are removed for remoulding, which also gives the opportunity to inspect the wheel rims. The rate at which tyre treads wear depends on the harshness of braking action during landing, and the weight of the aircraft. Removal intervals vary, but averages can be established. Nose wheels have shorter intervals, and Elkhafif says that the average remould intervals for nose wheel tyres are about 250FC.

Main wheels have longer intervals. Elkhafif records an average of 360FC. Sifnaios says that main wheel tyres can last up to one year for an operation with a long average cycle time. In Delta's case this is 330-350FC.

Tyres can be remoulded several times before being replaced. The number of remoulds depends on airline policy and tyre manufacturer. "We have used radial Michelin tyres, and remoulded these three times before replacing them," says Koch.

Elkhafif says that at Egyptair nose wheel tyres are usually remoulded twice, while main wheel tyres are remoulded three or four times before being replaced. United remoulds tyres up to six times, however.

Koch puts the cost of remoulding at about $670 for a nose wheel tyre, and $1,050 for a mainwheel tyre. New tyres cost about $1,050 for a nose wheel and $1,550 for a mainwheel.

The overall reserve for remoulding and replacing the complete shipset of tyres over their useful life is about $45 per FC *(see table, this page)*.

The removal of tyres for worn treads provides the opportunity for wheel inspections. This is an on-condition maintenance process, so it can occur at different intervals to tyre remoulds. An inspection is only visual, so it does not involve any disassembly but it will reveal whether a repair or overhaul is needed. An overhaul is more detailed than a repair. "The cost of a nose wheel inspection is about $110, and rises to $1,650 for a repair and to $2,000 for an overhaul. In the case of a main wheel, repairs cost about $2,500 and overhauls $2,900," says Koch. "Repairs occur about every fourth removal, and overhauls about every fifth removal."

The reserve for wheel repairs and overhauls is about $26 per FC *(see table, this page)*.

The 777 has carbon brakes, which are lighter and have longer removal intervals than steel units. Maintenance on brake units is on an on-condition basis, and depends on the wear and thickness of brake discs. Brake discs are checked on a regular basis during daily checks. Like tyre treads, the wear of brake discs will depend on the harshness of landing and the aircraft weight at landing. Intervals between brake overhauls vary from operator to operator: United has an average interval of 1,500FC; Egyptair an interval of 1,700-1,800FC; and VEM an interval of 2,400FC.

The cost of a shop visit for a brake unit is $55,000-65,000. Taking an average interval of 1,800FC for a shop visit, a reserve of $400 per FC accounts for all 12 main wheel brake units *(see table, page 20)*.

Landing gear overhaul intervals are calendar-time- and FC-based. Actual intervals vary between operators. "The initial maintenance programme interval was 10 years or 16,000FC, whichever was reached first," explains Elkhafif. "Subsequent intervals could then be established depending on inspection results at the first shop visit."

Koch gives the interval as 10 years or 18,000FC, whichever is reached first.

Only a few airlines have their own shops, so most landing gear overhauls are dealt with on an exchange basis. Operators pay a fee for the overhaul and shop visit, and another fee for being provided with a freshly overhauled gear shipset in exchange for the one removed from the aircraft. Market rates for overhaul and exchange fees are $800,000-1,000,000 and $350,000-380,000. The total will therefore be amortised over the removal interval to establish a reserve. The interval will be 10,000FC for the medium-haul and 6,500FC for the long-haul aircraft operations. Reserves will be $115-138 per FC for the medium-haul operation, and $177-212 per FC for the long-haul operation *(see table, page 20)*.

Thrust reversers are maintained on an on-condition basis. Unlike the thrust reverser units on older generation aircraft, the thrust reverser units on the 777 have long removal intervals. This is mainly due to a high level of composite materials in the structures. United, for example, has removed only a small number of the 100-plus units that it operates at an average interval of 4,400FC. Most thrust reverser maintenance occurs on-wing during base maintenance. Air France and KLM have devised soft removal intervals to prevent major damage being caused to the thrust reversers from keeping them on-wing for too long. Intervals for long-range aircraft are 6,000FC, and 12,000-16,000FC for short- or medium-haul aircraft.

The average shop visit cost for a thrust reverser shipset is about $400,000. The reserve for two reversers on long-haul aircraft is therefore $135 per FC, and $65-80 per FC on the short- and medium-haul aircraft *(see table, page 20)*.

The 777's APU is the Allied Signal 331-500. APU maintenance is performed on an on-condition basis. Average removal intervals are 7,600-8,500 APU hours. How this equates to aircraft FH and FC intervals depends on the utilisation of the APU during aircraft operation. This can be minimised by using the APU for an average of only up to 90 minutes per FC, and using it mainly for engine start and air conditioning prior to engine start, as well as for a few minutes while taxi-ing in after landing. Ground power is used for the majority of the turnaround between flights.

In other cases, the rate of APU use per FC can be higher - up to 150 minutes per FC. The removal interval will therefore be equal to 3,400-5,500FC.

Shop visit costs are $400,000-500,000, meaning that APU reserves are $84-141 per FC *(see table, page 20)*.

Total reserves for all heavy components are $738-819 per FC for the aircraft on medium-haul operations, and $872-953 per FC for the aircraft on long-haul operations *(see tables, page 23)*. These are equal to $246-273 per FH for the medium-haul operation, and $116-

There are differences in maintenance reserves between different engine types, but engine maintenance accounts for about half of total aircraft maintenance costs.

127 per FH for the long-haul operation *(see tables, page 23).*

Rotable components

There are about 2,300 rotable components installed on the 777, although the actual number will depend on configuration. About 600 of these are maintained on a hard-time basis, and the remainder on an on-condition basis.

Many airlines have complete or partial inventories, and in-house repair-and-test and warehousing facilities and logistical services for managing these parts, and ensuring that they are available when required during the fleet's operation. Several specialist providers offer turnkey rotable support packages for a range of aircraft types, including AAR, AJ Walter, Avtrade, Singapore Technologies and Lufthansa Technik.

The packages that are offered include: the supply of a homebase stock of high failure rate and no-go items that are held at the airline's main base; access to a pool stock of remaining rotables, which can be sent to the airline by the supplier when required; and a repair, management and logistics service for all components under the agreement. These last two elements can be paid for at a fixed rate per FH.

The homebase stock for a fleet of 10 777s will have a value of $5-8 million. Lease rentals will be equal to $20-30 per FH for long-haul aircraft, and $30-45 per FH for medium-haul operations.

The pool access, and repair and management fees will be $230-260 per FH for medium-haul and $200-220 for long-haul aircraft. This will take the total to $260-305 per FH for medium-haul aircraft, and $220-250 per FH for long-haul aircraft *(see tables, page 23).*

Engine maintenance

The 777 fleet can be subdivided into two categories: low gross weight -200s; and high gross weight -200s/-200ERs, -200LRs, -300s and -300LRs.

The 777-200s are mainly powered by the PW4074/77 and Trent 875/77/90 engines, and operate medium-haul cycles of 3.0FH. The 777-300s are mainly powered by the PW4090/98 and Trent 892, and also operate FC times of about 3.0FH. The 777-300s are powered mainly by the PW4090/98 and Trent 892, and also operate at about 3.0FH per FC.

The high gross weight -200s and -200ERs are mainly powered by the PW4084/90, GE90/94 and Trent 892/895, and operate on long-haul missions averaging 6.0-8.0FH per FC.

The -200LR and -300LR fleets are powered by the GE90-110/-115 and operate on missions of 8-11FH.

The use of different airframe-engine combinations at different FH:FC ratios influences engine removal intervals and maintenance reserves.

The PW4074/77 at 3.0 engine flight hours (EFH) per engine flight cycle (EFC) have first and second removal intervals that average 11,500EFH/3,800EFC and 8,500EFH and 2,800EFC. First and second shop visit costs are $3.2 and $4.3 million respectively. The total cost amortised over the first two shop visits averages a reserve of $375 per EFH.

Mature removal intervals are 8,250EFH and 2,750EFC. The PW4000's life limited parts (LLPs) have lives of 20,000EFC, and can be expected to be replaced after a total accumulated time of about 17,500EFC. The list price for a shipset is $7.0 million, so this will result in LLP reserves of $400 per EFC. Overall reserves for shop visit costs and LLPs will therefore be about $533 per EFH *(see first table, page 23).*

The Trent 892 on similar operations will have first and second removal intervals of 16,000EFH/5,300EFC and 14,000EFH/4,700EFC. First and second shop visit costs are $4.2 million and $5.2 million respectively. The reserve for these two shop visits is about $315 per EFH.

The mature interval is about 13,000EFH/4,250EFC. The engine's LLPs have lives of 15,000EFC, and can be expected to be replaced after about 14,000EFC. A shipset has a list price of about $6.0 million, so LLP reserves will be about $430 per EFC. Total reserves will therefore be about $460 per EFH *(see first table, page 23).*

For higher gross weight -200s and -200ERs, the GE90/94, PW4084/90 and Trent 892/895 should be considered.

The GE90/94B operating at about 7.5EFH per EFC will have first and second removal intervals of 18,000EFH/2,250EFC and 15,500EFH/2,000EFC respectively. Removal intervals are limited to 4,000EFC by one of the GE90's LLPs; the HPT interstage seal. The first removal workscope is usually a performance restoration, and incurs a shop visit cost of $4.0 million. The second workscope, after a total time of 34,000EFH and 4,200EFC, will be a full overhaul, and cost $5.0 million. The reserve for these two shop visits will be $270 per EFH.

The majority of the GE90-90/94's LLPs have lives of 15,000-20,000EFC. Mature removal intervals will be about 2,000EFC, and so average accumulated time for LLP replacement will be about 10,000EFC. A full shipset has a list price of about $8.1 million, so reserves will be $810 per EFC. Total reserves will therefore be $370 per EFH *(see second table, page 23).*

The PW4084/90 at the same EFH:EFC ratio will have first and second removal intervals of 19,000EFH/2,300EFC and 16,000EFH/2,000EFC respectively. Pratt & Whitney engines generally follow a simple shop-visit pattern of alternating performance restorations and overhauls. The first shop visit will incur a cost of $3.9 million, while the following overhaul will cost $5.5 million. The reserve for these two, amortised over a total time of 35,000EFH and 4,700EFC, will be $270 per EFH.

The engines will have a mature interval of about 2,000EFC. LLPs in the PW4084/90 have uniform lives of 15,000EFC, and average LLP life at replacement will be about 13,500EFC. A shipset has a list price of $7.5 million, so LLP reserves will be about $560 per EFC. Total reserves will be about $340 per EFH *(see second table, this page)*.

The Trent 892/895 at the same EFH:EFC ratio will have first removal intervals of 23,000-25,000EFH and 3,100-3,300EFC. The first shop visit will incur a cost of about $4.8 million. The second removals will be about 20,000EFH and 2,500EFC, and the following shop visit will be $5.5-5.8 million. The reserve for the two shop visits will be amortised over a total interval of 42,000-45,000EFH, and will be $230-245 per EFH.

The Trent 892 and 895 have LLPs with lives of 15,000EFC and 10,000EFC. The list price for a shipset for both is $6.0 million. LLPs will be replaced after a total time of about 14,000EFC for the Trent 892, and about 8,500EFC for the Trent 895. LLP reserves for the Trent 892 will be about $430 per EFC, and for the Trent 895 about $700 per EFC.

Total reserves for the Trent 892 will be about $280 per EFH, and for the Trent 895 about $330 per EFH *(see second table, this page)*.

The GE90-110/-115 powering the 777-200LR/-300ER will be operated at an average EFH:EFC ratio of 10:1, but the actual ratio will depend on each airline. At this EFC time, the engine is expected to have first removal intervals of about 24,000EFH and 2,400EFC, and the first shop visit will incur a cost of about $4.3 million. The second removal interval is predicted to be 18,000EFH and 1,800EFC. The following overhaul will incur a cost of about $5.3 million. The cost for these two shop visits will be amortised over a total time of about 42,000EFH and 4,200EFC, with a reserve of $230 per EFH.

The GE90-110/-115 has 26 LLPs with lives of 15,000-20,000EFC, although a few parts are limited to shorter lives. The list price for a shipset is $8.1 million. Average accumulated time at replacement is 10,000EFC, resulting in a reserve of $810 per EFC.

Total reserves for the GE90-110/-115 will be about $310 per EFH.

Summary

There is a difference of $300-900 per FH between the aircraft used on medium- and long-haul operations, depending on the exact reserves allowed for some of the maintenance, and the engine type used on the aircraft.

The 777-200's total costs for medium-haul operations are higher than the A330-300's *(see A330-200/-300 maintenance analysis & budget, Aircraft Commerce, April/May 2008, page 20)*. This is mainly due to the 777's higher line and A checks, heavy components, and engine maintenance costs. This is not surprising, given that the 777's heavier design and larger engines gave it the capability to be developed into a long- and ultra-long-range aircraft.

The 777-200ER has $160-400 per FH lower maintenance costs than the A340-200/-300 *(see A340-300 maintenance analysis & budget, Aircraft Commerce, June/July 2007, page 17)*. This is mainly due to the A340's four-engine design. The 777 also has lower airframe and component maintenance costs. The 777 particularly benefits from lower base maintenance reserves. AC

DIRECT MAINTENANCE COSTS FOR 777-200/-300: MEDIUM-HAUL OPERATION

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	470,000	Annual		147
A check	60,000	350-450FH		135-170
Base checks	3.4-3.6 million	23,000FH		148
Heavy components:			738-819	246-273
LRU component support				260-305
Total airframe & component maintenance				**788-1,043**
Engine maintenance:				
2 X PW4074/77: 2 X $533 per EFH				1,066
2 X Trent 875/877/890: 2 X $460 per EFH				920
Total direct maintenance costs:				**1,710-2,100**

Annual utilisation:
3000FH
1,000FC
FH:FC ratio of 3.0:1

DIRECT MAINTENANCE COSTS FOR 777-200ER: LONG-HAUL OPERATION

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	390,000	Annual		82
A check	60,000	350-450FH		135-170
Base checks	3.4-3.6 million	35,000FH		97-103
Heavy components:			872-953	116-127
LRU component support				220-250
Total airframe & component maintenance				**650-732**
Engine maintenance:				
2 X PW4084/90: 2 X $ 340 per EFH				680
2 X GE90-90/-94: 2 X $ 370 per EFH				740
2 X Trent 892/895: 2 X $ 280/330 per EFH				560/660
Total direct maintenance costs:				**1,200-1,475**

Annual utilisation:
4,750FH
650FC
FH:FC ratio of 7.5:1