**The 737NG has a flexible maintenance programme that allows operators to optimise maintenance checks in line with their operations. Maintenance costs per FH are low as a consequence, particularly for base checks. The 737NG's airframe and component maintenance costs are examined.**

# Budgeting for 737NG airfame & component maintenance costs

The 737NG family has become one of the most ubiquitous of all aircraft types. With the first examples delivered in late 1997, there are now more than 2,500 aircraft in operation and a firm order backlog in excess of 2,200. The 737NG will clearly be operated in a global fleet of more than 5,000 units, and will remain in service for another 20-40 years.

More than 2,200 of the 737NGs in operation are -700s and -800s. Unlike older aircraft types, the 737NG does not have a maintenance programme of pre-defined checks, and has no defined base check cycle of C and D checks. The 737NG's maintenance programme consists of 1,000 light and base check tasks, with intervals specified in flight hours (FH), flight cycles (FC), or calendar time, or in a combination of two or even three of these criteria. Operators are free to group tasks into checks according to their maintenance philosophy, and rates of aircraft utilisation and FH:FC ratios.

The relative size of base checks depends on how tasks are grouped, so checks can be small and frequent, or larger and less frequent. Individual tasks can either be included in larger base checks, or scheduled in smaller checks that are similar to the A checks of older types. Base check workscopes therefore vary between operators' fleets, and also between individual aircraft within a fleet. In many cases, the heavier base checks are between the fifth and eighth in sequence. Moreover, base check intervals are 4,000-6,000FH for most operators.

Most of the 960 aircraft that are six years or older have been through heavier checks, which means that operators have gained sufficient experience to fully assess the aircraft's airframe maintenance costs.

In addition to airframe maintenance, the frequency and repair costs of the aircraft's various rotable components are also examined and analysed. The total costs of the aircraft's airframe and component maintenance are summarised *(see table, page 52)*.

## 737NG in operation

The 737NG family is operated in large numbers on all continents. Fleet sizes vary, with some comprising the largest fleets of any aircraft type in service. The 737NG is particularly popular in North America and Europe, but several hundred are also operated in China and in Central and South America.

Southwest has the largest fleet, with 312 -700s in service. Other large fleets are operated by Continental (157), Delta Airlines (98), American Airlines (77), WestJet (59), and Ryanair (173).

Rates of utilisation are 2,500-3,500FH per year; high relative to the 737 Classic models because of the NG's longer-range capability. The 737NG is used on a mixture of short- and medium-haul routes by its operators.

Turkish Airlines, for example, uses the 737-800 on its European network and on routes to destinations in the former Soviet Union from Istanbul. The aircraft has an average FC time of 1.9FH and an annual utilisation of 3,800FH, the highest of all 737NG operators. This is equal to more than five flight cycles (FC) and 10.4FH per day.

Average utilisation among the largest operators is 3,200FH per year, and the average FH:FC ratio is 1.9. Southwest averages 3,775FH per year and has an FH:FC ratio of 1.76, while Ryanair averages 3,600FH per year and a FH:FC ratio of 1.55. Continental, Delta, and American have FH:FC ratios over 2.0.

## Maintenance tasks

The 737NG's maintenance programme comprises 1,000 light and base check maintenance tasks. These have intervals expressed in FH, FC and calendar time. Some task intervals are a combination of FC and calendar time. The frequency at which some of these tasks are done relative to others therefore depends on the aircraft's rate of utilisation, and its FH:FC ratio.

The frequency of repair and overhaul of many heavy components is also related to FC intervals, and governed by the FH:FC ratio.

The aircraft's overall airframe and component maintenance costs are therefore affected by rate of utilisation and FH:FC ratio. The aircraft here are analysed with an annual utilisation of 3,000FH and an FH:FC ratio of 1.9FH, which is representative of the average utilisation for the -700 and -800 fleet. The aircraft therefore complete in the region of 1,580FC per year.

Some operators may have been able to extend the intervals of individual tasks because they have demonstrated sufficient reliability through extensive experience.

Task intervals are reviewed when the maintenance planning document (MPD) is revised, which is every four months. The last revision was in February 2008, and the next is due in late June 2008.

"Maintenance tasks can be split into three groups: system tasks, structural tasks, and zonal tasks. Structural and zonal tasks are mainly confined to base checks, although a few are included in line and A checks. System tasks are included in line, A and base checks," explains Dominique Vargioni, head of methods engineering & documentation at Sabena Technics. "With older aircraft

*The 737NG is now operated in large numbers across the world. Annual utilisations range between 2,500FH and 3,500FH, and FC times are 1.0-3.0FH.*

types, zonal tasks mainly had FC intervals, since these are related to the fatigue that comes from aircraft operations. Corrosion tasks had calendar intervals, since corrosion accumulates over time. The zonal and corrosion tasks are combined in the 737NG. Most zonal tasks have both FC and calendar intervals, and the corrosion tasks are included in the zonal tasks. Many corrosion tasks have just calendar limits. Other tasks with just FC limits are mainly structural inspections."

About 130 tasks have short intervals which are included in the aircraft's line and light checks. This includes about 60 tasks with intervals shorter than 4,000FH. There are 15 tasks with intervals from 50FC to 1,600FC, and about 50 tasks with calendar intervals ranging from 15 days to 18 months.

Base checks typically consist of tasks with higher intervals. "Base check system tasks generally have FH intervals. There are a total of 340 tasks with FH intervals," continues Vargioni. "These vary from 4,000FH to 30,000FH."

There are 19 different FH intervals, and the largest groups are at 4,000FH (56 tasks), 6,000FH (147 tasks), 8,000FH (26 tasks), and 25,000FH (25 tasks).

In several cases there is only a single task for many FH intervals. There are also several other intervals which each have just two tasks. Many other intervals have up to 10 or 11 tasks.

Up to 400 check tasks have FC intervals. About 340 of these also have calendar limits. The FC intervals vary from 1,250FC, which are regular inspections of the landing gear at 50FC, to 36,000FC. Moreover, this group also includes some tasks which have threshold and repeat intervals. The calendar threshold intervals vary from eight to 12 years, while repeat intervals are from six to 10 years.

The largest groups of FC tasks are those with intervals of 4,800FC, 5,500FC, 18,000FC, 21,600FC and 36,000FC.

There are several calendar limits for each FC limit, and vice versa. Most of these tasks usually reach their calendar limits first, unless the aircraft are used intensively on high-cycle, short-route operations.

There are also about 105 base check tasks with just calendar intervals that range from six months to 10 and 15 years. The largest groups are 24 months, six years, 10 years and 12 years. All the calendar limits included in base checks are a multiple of six months.

Although the majority of aircraft that are older than six years will have been through relatively heavy base checks, only 150-200 will have accumulated more than 30,000FH, and so have had all FH-related tasks performed on them. Moreover, no aircraft will have reached the 36,000FC thresholds of the highest FC-related tasks. In fact, the aircraft that has accumulated the highest number of FCs, 29,000, was built in 1997. No aircraft have therefore had all FC-related tasks performed on them.

Only 70-100 aircraft are more than 120 months old, and have had all calendar-related tasks performed on them.

## Check packages

The grouping of tasks into packages that form the checks is at the discretion of the operator.

The tasks scheduled into line and A checks have FH intervals that vary from 24FH to, in some cases, 5,000FH. Although base check intervals are typically 4,000-7,000FH, tasks with intervals as high as 5,000FH can sometimes be scheduled into A checks by maintenance planners because they are light or do not require deep access. The range of the FH-related A and base check tasks are mainly multiples of 500FH. There are some tasks with FH intervals that are also multiples of 200FH, 400FH, and 800FH. Some operators have half A checks known as intermediate checks.

Line and A checks also have tasks with intervals ranging from 50FC up to 3,000FC. There are also calendar tasks which have intervals of just a few days, a week or multiples of a week, and from three to 30 months.

A system of smaller 'A' checks runs parallel to larger base checks. A checks can be performed at 500FH or 600FH intervals. The first check at 500FH might be generically referred to as the A1 check, with the A2 check at 1,000FH and the A3 check at 1,500FH. This process would continue for the lifetime of the aircraft.

Larger groups of tasks are at the 4,000FH, 6,000FH and 8,000FH intervals. An operator may, for example, choose to have a base check every 4,000FH. The base 7 check, or 'C7' check, would therefore be at 28,000FH, comprising all FH-related tasks, with the eight tasks at the highest 30,000FH interval being brought forward to 28,000FH.

This system raises the issue of what to do with a large number of tasks whose intervals fall between the 4,000FH and 8,000FH interval. Smaller groups of tasks with these intervals, or ones which require little deep access of the aircraft structure and systems, could be scheduled into lighter checks. These could drop out into the appropriate A check number. The 10 tasks at 5,000FH, for example, could therefore be included in the A10 check.

With this system, the large group of 118 tasks with a 6,000FH interval, and other large groups of tasks that do not have intervals that are a multiple of 4,000FH, would have to be brought forward and performed every 4,000FH. The system would mean that the cycle of FH tasks would be completed once every 28,000FH, at the seventh check.

An alternative system would be to


*The 737NG's maintenance programme consists of about 1,000 tasks. These have intervals specified in FH, FC, calendar time, or a combination of two of these criteria. Operators are free to group these tasks into checks in accordance with their annual utilisations and FH:FC ratio.*

have a base check once every 6,000FH, meaning that the tasks at 30,000FH can be performed every fifth base check, or at the 'C5' check. There are still, however, large numbers of tasks that have intervals between the multiples of 6,000FH intervals, which would either have to be brought forward into earlier checks or dropped into lighter checks.

The FC-related tasks have intervals between 50FC and 75,000FC, and these are treated as out-of-phase (OOP) with FH-related tasks. The FC-related tasks have to be planned into particular checks with an FH interval according to aircraft utilisation, FH:FC ratio and the FH interval that corresponds to the tasks' FC interval. When the FC intervals are converted into FH intervals for an aircraft operating at an average FC time of 1.9FH, the FC tasks have intervals ranging from 95FH to 142,500FH. The actual FH:FC ratio constantly changes so these tasks have to be monitored. "The utilisation and accumulated FH and FC of aircraft have to be constantly monitored, and planning engineers plan these tasks into the appropriate A or base checks," explains Graham Stevens, team leader reliability & maintainability at SR Technics. "The FC tasks with lower intervals usually get included in regular A checks or even line checks. The higher tasks get included in base checks as they come due. Some of these also have calendar intervals. There are some, for example, that have a 10- or 12-year and 36,000FC interval. At 1.9FH per FC this is 68,000FH. The 10-year interval is clearly reached before 68,000FH or 36,000FC."

The third group of tasks with calendar-related intervals is also treated as OOP items, and so have to be converted to FH intervals and planned into checks by planning engineers. At an annual utilisation of 3,000FH the 24- to 144-month task intervals are equal to between 6,000FH and 30,000FH. Many of them conveniently have intervals that are multiples of 6,000FH, a common base check interval used by a large number of operators.

## Maintenance programmes

Turkish Airlines' line maintenance programme starts with a transit check before each flight, which can often be performed by flightcrew. It also has a daily check with a maximum interval of 36 hours. There is also a ramp check once every five days and a line check every 300FH and every month. Both intervals are reached at similar times.

Turkish Airlines had a system of A checks every 500FH and C checks every 6,000FH. "We escalated the C check interval to 7,000FH in October 2007, and our aviation authority required us to add a calendar interval of 24 months," explains Erhan Ozcan, manager of production planning and control at Turkish Technic. "We also increased the A check interval to 600FH, and added a calendar interval of two months."

Turkish Airlines has now been operating the 737-800 since 1998, and Turkish Technic has put seven aircraft through their sixth base check or 'C6' check. "We had a system of an A check once every 500FH and C or base check every 6,000FH," says Ozcan. "We then escalated these intervals to 600FH for the A checks and to 7,000FH for the base checks. Some of the FH tasks in the base checks did not get escalated, and so have dropped out into the A checks.

"We have basically grouped all base check tasks into packages in multiples of the basic 7,000FH interval, to form block checks. There are therefore 1C tasks with a 7,000FH interval, 2C tasks at 14,000FH, 3C tasks at 21,000FH, 4C at 28,000FH, 5C at 35,000FH, 7C at 49,000FH and some 8C tasks at 56,000FH. The 7C and 8C tasks are relatively small, and include some with FC and calendar intervals that have been converted to FH intervals, taking our FH:FC ratio into consideration," continues Ozcan. "The C4 check therefore comprises the 1C, 2C and 4C tasks. The two largest checks are the C6 and C8. The C6 has the 1C, 2C and 3C tasks, while the C8 has the same as the C4, plus the 8C tasks. The C6 is actually bigger and uses more man-hours (MH) than the C8."

Another example of a maintenance programme is the one implemented by SR Technics, which manages easyJet's fleet of 737-700s.

"For larger checks we had a system where initially all tasks were arranged in phases of 500FH. The 500FH basic interval was used for the 1A tasks, and A checks were repeated every 500FH. The base check interval was every 10 phases, so 5,000FH. We then escalated the basic phase interval to 600FH. A or phase checks actually get performed every 550FH, which meant the base check was coming due every 5,500FH and losing 500FH of its interval. We therefore separated the A and base check streams. We have six multiples of base check tasks, with the highest tasks at 36,000FH. The FC and calendar tasks are treated as OOP items and scheduled into base checks according to FH:FC ratio and rate of utilisation."

## Line check inputs

Line maintenance programmes for the 737NG typically have a transit or pre-flight check prior to each flight. "The check is mainly an external visual inspection, and has few tasks that require a lone mechanic," explains Johan Meganck, commercial director at Stella Aviation. "Most airlines have the check performed by the flightcrew. The check is a walkaround inspection to check for physical damage. Line mechanics are only really required in the event of technical faults occurring. Some faults can be deferred, but line mechanics are required

*Most 737NG operators have maintenance programmes based around 'A' checks with intervals of 500FH and base checks with intervals of 6,000FH. There is not a set cycle of checks, but the heavier base checks are between the fifth and eighth, which will be performed after eight to 11 years in service.*

if the failed item is on the minimum equipment list. In some cases the flightcrew is allowed to perform a few tasks, but they require particular training.

"Only 30 minutes of the flightcrew's time is needed for the routine portion of the check," continues Meganck. "Several MH of line mechanic labour can be required if technical faults occur."

A daily check will be carried out every 24 and 48 hours, depending on each operator's maintenance schedule. The daily check again includes a walkaround visual inspection, but also includes some minor maintenance tasks. "These include measuring brake disc thickness with callipers, inspecting and testing the emergency system and equipment, some inspections and tests on some of the critical systems, such as hydraulics, and a read-out of data from the on-board maintenance computer to analyse the technical errors and error messages that have occurred during operation," says Meganck. "The fluid levels of all systems must also be checked. These checks need 2MH for the routine portion of the check, plus additional labour for the non-routine part."

The weekly check has an interval of seven to nine days, and is similar in workscope and content to the daily check. "All fluid levels have to be checked, checks for technical errors and defaults have to be made, and engine cowlings are opened," says Meganck.

A weekly check has a routine labour requirement of 4-5MH. Technical defects will lead to some non-routine labour input being required, although this will depend on aircraft age.

The non-routine ratio for these checks will be 20%, and so add some additional labour requirement. The daily check will therefore total 2-3MH. At a standard labour rate of $70 per MH for line maintenance this costs $140-210. An additional $15-20 can be budgeted for the cost of materials and consumables.

Weekly checks may use a total of about 6MH, equal to $420 for labour. An allowance of $55-60 should be made for materials and consumables.

Meganck estimates the non-routine labour for these checks at 1MH per day for a young aircraft, and 50-80% of routine labour for mature aircraft.

An aircraft completing 3,000FH and 1,600FC per year will require 350 daily checks and 1,600 pre-flight or transit checks, and about 50 weekly checks. On this basis the routine labour requirement for these three levels of check will be 2,200MH. Non-routine labour will therefore be 1,100-1,750MH, taking the total to 3,300-4,000MH. This will incur a cost of $230,000-280,000 when charged at a standard labour rate of $70 per MH.

The additional cost of materials and consumables for these checks will be $10,000-15,000.

A further 2-4MH per day or 120MH per month should be expected for cleaning, which will add another $100,000 to the line maintenance budget.

The total for annual line maintenance inputs will be $340,000-400,000, equal to $110-135 per FH *(see table, page 52)*.

## A check inputs

A weekly check will be performed once every 55-70FH, depending on utilisation. Because there are tasks which have intervals of 50FH to 500FH, operators can choose either to perform these early in the weekly check, or to have an intermediate check at an interval half-way through the A check interval. The workscopes of these intermediate checks will be similar to A checks. Some of these involve lubrication of various moving parts, such as flap and slat mechanisms and landing gears.

Meganck explains that A check workscopes comprise the tasks included in weekly checks: functionality tests for flight controls; visual inspection of life vests; checking the expiry dates for emergency equipment; checking flap mechanisms and control surface delamination; lubrication tasks, and some non-destructive testing (NDT) inspections of a few specific parts.

A check workscopes vary in size, but an example of a maintenance programme would be a check interval of 500FH and cycle of eight checks. The fourth check would be a heavy visit, but the eighth would be the heaviest. The other six checks would be relatively light.

Routine labour requirements of the six light checks vary from 25MH to 55MH for most of the checks, but are up to 200MH for the fourth check. They can be as much as 465MH for the eighth check.

The non-routine ratio for these checks will be 20%, and will add 5-12MH for the smaller checks, 35-40MH for a large check, and 95-100MH for the largest check in the cycle.

A checks are also used by operators to perform smaller engineering orders (EOs), so a further 80MH should be allowed for these. Some hard-timed rotable components have to be changed during these checks, so an allowance of 20MH should be made for this. Interior cleaning and changes of seat covers can use another 20MH. The total for the six light checks will be 150-190MH, equal to $10,500-13,500 at the standard labour rate. An allowance of $850-1,200 should be made for materials and consumables, taking the total for the check to $11,500-15,000.

The fourth check would use 330-350MH of labour, and require $2,500-3,000 for materials and consumables. The total cost for the check would be $28,000-30,000.

The eighth heavy check would use 700MH and $7,000 in consumables and materials, taking the total for the check to $55,000-57,000.

The total cost for the eight checks over the cycle would be $165,000-

*Base check workscopes include all the items the base checks of previous generation aircraft had. Unlike older generation aircraft, refurbishment of the interior is often treated as an on-condition item, rather than being performed during a heavy check.*

170,000. While the interval is 500FH, the actual interval achieved will typically be 420FH. The eight-check cycle would therefore be completed once every 3,500FH, and the reserve would be $50 per FH *(see table, page 52)*.

## Base check workscopes

The base check workscopes start with routine inspections, which give rise to non-routine rectifications. There will also be several other items included in the base check workscopes. Some routine system tasks will involve testing components that are maintained on an on-condition basis. The testing may reveal problems, and so require the component to be replaced with a serviceable unit. This is an example of a non-routine rectification.

"We first analyse the workscope of the base check, and start with routine tasks," explains Radoslav Ilic, principal engineer at JAT Tehnika. "This includes system, structural/zonal, corrosion and supplemental structural inspection tasks. We assess the MH required for these routine tasks, as well as for access."

Base check workscopes also comprise other items, including: airworthiness directives (ADs) and service bulletins (SBs), collectively referred to as EOs; the removal and installation of components maintained on a hard-time basis; additional customer tasks; clearing deferred technical defects that have arisen out of operation; and general cleaning and interior work.

On a less frequent basis base checks will also include interior refurbishment, and stripping and repainting.

The 737NG has had relatively few major ADs and SBs, but one major AD is AD 2007-03-07, which relates to the enhanced rudder power control unit. The inspections are detailed in SB 737-27-1247. "The AD requires 280MH to complete, plus the cost of the kit," explains Ilic.

The other major EOs affecting the 737NG are slat actuator modification, and what is known as the P5 panel modification.

"After assessing MH requirements for routine inspections, we then assess MH needed for inspections relating ADs and SBs," says Ilic. "The third main element of the routine part of the check is miscellaneous items that include washing, an external damage check, and the acceptance check. The sub-total of inspections, ADs and SBs, and miscellaneous items forms the routine part of the check. It requires a predictable amount of MH, and materials and consumables."

While routine tasks include testing rotable components that are maintained on an on-condition basis, components maintained on a hard-time basis will also be removed for repair. The 737NG family has 2,500-3,000 rotable components installed on the aircraft, 2,100-2,500 of which are maintained on an on-condition basis. The remaining 500 or so items are hard-timed units, which will have to be removed during base or A checks. This adds to the workscope content.

Deferred technical defects occur constantly, and will be items that are too large to clear during A checks, or items deferred since the last A check. Dealing with these is also regarded as a routine part of the workscope.

Base checks will also include general cleaning of the cabin. The actual amount of work performed on the interior will depend on the operator's policy. Turkish Airlines, for example, has leather seats and these, together with carpets and panels, are cleaned at every base check.

"The non-routine element of a base check will be non-routine rectifications as a result of routine inspections, materials and consumables associated with non-routine rectifications, performing modifications, and specialist repairs," explains Ilic. "There is also the procurement and fitting of on-condition rotables that have failed tests."

Each airline will have its own policy on the level of interior and general cleaning work to be done during A and base checks. Airlines that want to maintain a high level of cleanliness and interior standards may follow a policy similar to Turkish Airlines'. Low-cost airlines may decide to spend less on general interior work at each base check.

Interior refurbishment was traditionally done during D checks on older aircraft types because the downtime allowed all major items like overhead bins, passenger service units (PSUs), toilets and galleys to be removed. This is not necessarily followed by airlines with current generation aircraft. "When we have a check downtime of longer than two weeks we remove all interior items for inspection and cleaning," says Ozcan. "We replace seat covers and carpets, and also disassemble galleys and toilets. The floor panels are lifted during the C6 check."

Full refurbishments may be conducted once every third or fourth C check, depending on utilisation.

Some operators refurbish a third of the interior at every C check, so that a complete interior refurbishment is carried out once every three C checks.

Repainting the aircraft depends on airline policy, but a typical interval is once every four to six years. This can be included with a heavy C check, or performed separately.

## Base check inputs

Base check programmes do not follow any particular cycle, so inputs and reserves per FH can only be analysed on the basis of the checks so far performed on the oldest aircraft. As described, base check intervals are 6,000FH in many cases, but 7,000FH in some. The largest checks in many cases are between the fifth and seventh in the series. An aircraft that accumulates 3,000FH per year and

**737NG AIRFRAME & COMPONENT MAINTENANCE COSTS**

| Maintenance Item | Cycle cost $ | Cycle interval | Cost per FC-$ | Cost per FH-$ |
|---|---|---|---|---|
| Line & ramp checks | 340,000-400,000 | Annual | | 110-135 |
| A check | 170,000 | A check- 3,400FH | | 50 |
| Base checks | 2.0-2.55 million | 30,000-33,000FH | | 67-77 |
| Interior refurbishment | 420,000-500,000 | 30,000-33,000FH | | 15-17 |
| Stripping & painting | 72,000 | 15,000-16,500FH | | 5-6 |
| Heavy components | | | 160 | 84 |
| LRU component support | | | | 180-230 |
| **Total airframe & component maintenance** | | | | **510-600** |

*Annual utilisation:*
*3,000FH*
*1,580FC*
*FH:FC ratio of 1.9:1*

has a base check interval of 6,000FH will therefore have a base check interval of two years. Actual interval utilisation of 85% means that the check will be performed once every 5,100-5,500FH and 20-22 months. The sixth check in the series will therefore be performed when the aircraft reaches between 10 and 11 years of age, and after it has accumulated 30,000-33,000FH.

Routine MH for each of these checks clearly depend on the operator's maintenance programme and how tasks have been grouped, and the operator's FH:FC ratio and rate of aircraft utilisation. These affect the MH required for the routine portion of the check, and the MH for all other elements and the total labour requirement. Two examples of maintenance programmes and labour and material inputs are analysed here.

Actual routine MH are generally three to four times the amount stated in the MPD. In the first example, the first two checks can have routine labour requirements of 1,200-1,300MH. This rises to 2,000MH in the third, 1,700MH in the fourth, and 2,500MH in the fifth. The sixth check requires about 4,200MH. The total for the six checks is 12,800MH.

In the second example, the routine requirements are similar for the first two checks, but are overall lower for the six checks, totalling 10,500MH. There are, of course, variations in labour efficiency between maintenance providers.

Non-routine ratios will start low for young aircraft for their first three base checks. These will be 35-50% for the first check, 65-75% for the second check and 80-90% by the fourth check. The higher fifth and sixth checks will have non-routine ratios of 100% or more. On this basis, the labour required for non-routine work in the first example will be 13,500-14,000MH, which compares to the routine input of 12,800MH. If lower non-routine ratios are achieved then the labour required for non-routine work will be 95-105% of the routine work.

The sub-total for routine and non-routine work will total 21,000-25,000MH for the first six checks, making an average of 3,500-4,000MH per check.

Other elements of the base check workscopes have to be considered. The first of these are ADs and SBs. The labour required for these is variable, but will start relatively low for young aircraft, from 100MH to 500MH. This will rise as base checks progress, and can reach 3,600-5,000MH for the first six checks.

Labour is also required for changing hard-timed components. An allowance of 20MH per check should be made.

Some defects will inevitably occur during operations and be deferred. These will need to be cleared during base checks. An allowance of 100MH for the base check should be made for this.

The final element is interior cleaning and work. Excluding the refurbishment of major interior parts such as toilets, galleys and overhead bins, the labour needed for cleaning and replacing seat covers, and any necessary repairs or minor refurbishment work can range from 500MH to 1,000MH per check, totalling 6,000MH for the six checks. The requirements for interior refurbishment are considered separately.

The total labour consumption for these first six checks will be 2,800-3,500MH for the first base check. This will rise to 3,200-4,200MH for the second check, 4,000-5,500MH for the third check, 7,500-8,000MH for the fifth check, and 9,000-12,000MH for the sixth check. The total for these six checks will be 32,000-40,000MH. The main factors affecting the total are maintenance programme and aircraft utilisation, non-routine ratio, ADs and SBs, and policy on maintaining the aircraft's interior.

The cost of associated materials and consumables depends on the amount of non-routine labour as a percentage of total labour. The cost of materials is relatively low for the workscope elements of routine labour, ADs and SBs, and component changes, but higher for the non-routine labour portion of the check.

The cost of materials will average $12-16 per MH used in the checks. The first two or three checks will have a lower rate because of their lower non-routine ratios. On this basis, consumption of materials and consumables will be $20,000-30,000 for the first check, $30,000-40,000 for the second, and $120,000-190,000 for the fifth and sixth checks. Total consumption for the first six checks will be $400,000-530,000.

The total cost of labour and materials and consumables used over the 10-11 year period will be $2.0-2.55 million when using a standard labour rate of $50 per MH. This is equal to a reserve of $67-77 per FH *(see table, this page)*.

Although aircraft have traditionally had their interiors refurbished during D checks, 737NG operators do not have fixed schedules for this. Many will refurbish the interior as required, although galleys and toilets do have to be removed at heavier base checks because of the need to inspect floor beams. Most 737NGs are young and have not required much interior refurbishment to date. Ozcan explains that some interior refurbishment is performed on Turkish Airlines' aircraft during lighter base checks, requiring 150MH and $15,000 in materials and consumables at each check. More extensive interior refurbishment at the fifth and sixth checks requires 1,300MH and $100,000 in materials and consumables. The total over the six checks therefore comes to about 3,200MH and $260,000 in materials and consumables, resulting in a total cost of $420,000. Amortised over the interval of 30,000-33,000, this is equal to a reserve of $14-15 per FH *(see table, this page)*.

Stripping and repainting the aircraft will use an average of 1,200MH and $25,000 in materials. This will be done twice over the same interval as the six base checks. The cost for these two repaints will be about $170,000, and a reserve of $5-6 per FH should be budgeted for this *(see table, this page)*.

## Components

The 737NG has 2,500-3,000 rotable components installed, depending on configuration and specification. Of these, about 500 are maintained on a hard-time basis, and the remaining 2,000-2,500


*The 737NG's flexible maintenance programme means tasks are not performed before necessary with the result that costs per FH for base checks are low relative to similar-sized aircraft types.*

parts are maintained on an on-condition basis. Most of these rotable components can be provided, repaired and managed in a rotable provisioning package, although there are some heavy components for which maintenance, repair and management have to be arranged separately.

## Heavy components

The four groups of heavy components include: wheels and brakes; landing gear; thrust reversers; and the auxiliary power unit (APU).

The repair of tyres and wheels has to be considered together. Line check inspections check for tyre tread and brake disc thickness. Wheels are removed when tyre treads are worn. Mainwheel tyres can be remoulded five or six times, while nosewheel tyres can be remoulded 10 or 12 times. Remoulds for main tyres can cost $600, and $200 for nose tyres. New mainwheel tyres cost $1,600, and new nosewheel tyres $400. The total cost of remoulding the aircraft's four mainwheel tyres and replacing them is $6,500, and $1,600 for the nosewheel tyres. These have a rate per FC of about $12.

Wheels are inspected when tyres are remoulded, but they are overhauled at every sixth removal. Inspections cost about $700, and overhauls average about $1,100. The cost of inspecting and overhauling the aircraft's six wheel units over the cycle of six removals is about $28,000; equal to about $15 per FC.

The 737NG has steel brakes, which are repaired once every third wheel removal, or every 900FC. Brake repair costs average $15,000 per unit, and the cost per FC for the aircraft's four mainwheel units is $67 per FC.

The landing gear has an overhaul interval of 18,000FC or 10 years, whichever is reached first. Aircraft operating at 1,600FC would clearly reach the 10-year interval. Common practice is for airlines to have landing gear exchanges with landing gear overhaul specialists, such as Hawker Pacific. Marco Meijers, support manager at SGI Services Aviation, says that a current market rate for landing gear overhaul and exchange is $300,000-330,000. Amortised over the 10-year interval, this is equal to $19-21 per FC, and $10-11 per FH at the FH:FC ratio of 1.9FH.

Thrust reversers are maintained on an on-condition basis, and typical intervals are about 12,000FC, which is equal to about eight years of operation. Jan Pekstok, head of technical services at SGI Aviation Services, says that operators can expect to pay a shop visit cost of $200,000 for a thrust reverser shipset. The reserve for both shipsets would therefore be $35 per FC, equal to $18 per FH *(see table, page 52)*.

The 737NG's APU is the GTCP 131-9B. This has high reliability compared to older generation APUs. The mean time between removals (both scheduled and unscheduled) is about 8,700 hours. The cost per FC for APU maintenance depends partially on the rate of APU hours to aircraft FH and FC. Typical ratios for 737NG operations are 0.8 APU hours per FC. The interval between APU shop visits is therefore about 12,000FC. Meijers estimates that the average market shop visit for this model is $125,000-140,000. The cost per FC for APU maintenance is therefore about $12.

The total cost per FC for these four categories of heavy components is therefore $160 per FC, which is equal to $84 per FH *(see table, page 52)*.

## Rotables

There are 2,500-3,000 rotable components installed on the aircraft. A minority of these, about 500, are hard-timed components. These will be removed during airframe checks and replaced or repaired. The 2,000-2,500 on-condition components will either be removed after failure or after soft times. All rotable components can be provided for in a total support package. Airlines are typically provided with a homebase stock of more critical and high-failure-rate items. A lease rate is often paid for these. Operators are then given access to a pool of stock for remaining rotables, usually paid for on a per FH basis. Third, the repair and management of rotables from the two sources are paid for on a per FH basis. The total cost for these three elements in a typical rotable support package will be $180-230 per FH for a fleet of five to 10 aircraft operating at FC times and rates of utilisation similar to those described here *(see table, page 52)*.

## Summary

The total cost per FH for all airframe and component maintenance is $510-600 *(see table, page 52)*. Components account for the largest portion of this cost, while base maintenance, interior refurbishment and stripping and repainting account for the smallest portion at $87-100 per FH.

The costs per FH for line/light and base airframe maintenance are dependent on labour costs, however, since labour accounts for the majority of the inputs for this maintenance. Pekstok makes the point that MH rates for maintenance have a large influence on the final costs per FH. "Reserves for C and heavy base checks can be $105 per FH when the labour rate for base maintenance is $80 per MH. The world average MH rate is now in the region of $70 per MH," comments Pekstok. "Labour rates are $75-100 per MH in Europe, $60 per MH in North America, and $60-65 per MH in the Asia Pacific.

Reserves for base checks in this analysis would be $100-114 per FH if the labour rate were $80 per MH. AC