

# 737NG maintenance analysis & budget

**The 737NG has a flexible maintenance programme that allows airlines to package tasks into checks that suits their operation. This results in lean maintenance requirements and low reserves for base maintenance.**

There are 3,200 737NGs in service making it the most popular commercial aircraft. It offers superior range, cruise speed and cabin comfort, and lower cash operating costs than the older -300/-400/-500 Classics. The 737NG's maintenance planning document (MPD) lists individual maintenance tasks and their intervals in order to give operators full flexibility in planning maintenance and grouping checks. "This delivers lower airframe-related maintenance that uses one-third fewer man-hours (MH) than the 737 Classics," says Erdogan Firtinoglu, planning director at MyTechnic. The longer on-wing intervals of the CFM56-7B, the sole engine powering the 737NG family, also give it an economic advantage over its predecessor, the CFM56-3 series. These two key elements of total aircraft maintenance costs are analysed here, together with component-related costs.

## 737NG in operation

There are four main 737NG variants: the -600, -700, -800 and -900. The -700 and -800 dominate the fleet with 1,014 and 1,864 aircraft respectively. The 737NG has more than 240 operators in all continents, with fleet sizes varying from just a few aircraft to more than 200-300 aircraft in some cases.

There are just 63 737-600s in operation, with the biggest operators being SAS and Westjet. Average annual utilisations are 2,600 flight hours (FH) and 1,900 flight cycles (FC), with an average FC time of 1.4FH.

The 737-700 fleet is the second largest, with 1,014 aircraft. Major operators include Aeromexico, Air Berlin, AirTran, Alaska Airlines, China Eastern, China Southern, Continental Airlines, GOL, Southwest, Virgin Blue and Westjet. Southwest's fleet of 343 -700s is far the largest fleet. Westjet operates 64 737-700s.

Annual rates of utilisation average

3,300FH and 1,840FC, with an average FC time of 1.80FH.

The 737-800 fleet is the largest of all -800 models, with 1,864 aircraft in operation. Of the many operators those with the largest fleets include: Air Berlin, Air China (67 aircraft), Air Europa, Alaska Airlines (52), American Airlines (119), China Southern, Continental (117), Delta Airlines (71), GOL (61), Hainan, Jet Airways, Qantas, Ryanair (235), THY (48), Virgin Blue and Xiamen.

Annual rates of utilisation average 3,300FH and 1,650FC, putting average FC time at 2.14FH.

The 737-900 fleet is small at 123 aircraft, which are operated by only four airlines: Alaska, Continental, Korean Air, and Lion Airlines. Average annual rates of utilisation are 3,100FH and 1,700FC, making the average FC time 2.1FH.

The first aircraft delivered was a -700 in 1997, and is operated by Southwest Airlines. The fleet leaders have accumulated 45,400FH and 30,300FC.

The maintenance costs of the 737NG are analysed here for aircraft achieving an annual utilisation of 3,300FH and 1,700FC, with an average FC time of 1.95FH.

## MPD

The 737NG's MPD simply lists all maintenance inspections and, unlike the 737-300/-400/-500's MPD, does not group them into pre-defined airframe checks such as 'A', 'C' or 'D' checks.

"The tasks in the 737NG MPD fall into three categories: systems and powerplant tasks, as specified in section 1 of the MPD; the structural maintenance programme, as specified in section 2; and the airworthiness limitation limits (AWLs) and certification maintenance requirements (CMRs)," explains Firtinoglu.

The tasks have intervals specified in one or two of three parameters: flight hours (FH), flight cycles (FC) and

calendar time, varying from 50FH to 30,000FH, 50FC to 75,000FC, and 2 days to 180 months. Operators are free to group these tasks into maintenance events or check packages, by combining the tasks with different but similar intervals, and those that come due at a similar time. Inevitably this means that not all task intervals will be fully utilised. Tasks with intervals of 1,200FH, 1,250FH, 1,600FH and 1,800FH, for example, will not use as much of their interval as a group of tasks with an interval of 1,000FH if they are grouped into the same check package with a 1,000FH interval.

"The system tasks have intervals specified in all three interval parameters, and are included in all types of checks," says Farid Abu-Taleb, director technical planning engineering at Joramco. "The structural and corrosion tasks also use all three interval parameters, but are only included in the heavier base checks with the higher intervals."

Duncan Rae, production support manager at KLM UK Engineering, comments that most structural and zonal tasks are usually aligned to 'C' or base checks, although higher frequency structural and zonal tasks are often aligned to A checks.

Task intervals are extended or shortened according to the findings and defects that arise from the routine inspections made by all operators. "The MPD is revised about once every four to six months," says Abu-Taleb, "so the MPD has been revised up to 30 times. Unlike older aircraft types, the revisions are not numbered. The most recent revisions were in February 2010 and mid-June 2010."

Many operators generate 3,000FH per year with their aircraft, and use an 'A' check every 500FH or 600FH, and a 'C' or base check every 6,000FH and 24 months. Tasks with intervals lower than the chosen A check interval may be included in line checks.

While most system tasks have intervals specified in FH, some have other interval parameters.

"The MPD released in June 2010 has 1,111 tasks," explains Elvin Coskun, aeronautical engineer at Turkish Technic. "There are 355 tasks with FH intervals, starting with 50FH. There are nine different intervals and 12 tasks up to 500FH. There are another 13 intervals up to 5,500FH, and 106 task cards."

There are a further 237 tasks for intervals from 6,000FH and 30,000FH, making them suitable for inclusion in base checks. The intervals of 6,000FH, 7,500FH, 8000FH, 12,000FH and 25,000FH have a large number of tasks, between 14 and 91. The 7,500FH interval has the largest number of tasks with 91. There are 22 intervals between



the two extremes, and each interval comprises one to 11 tasks. The number of tasks generally indicates the amount of work at each interval, although an individual complex task can use five times the man-hours (MH) that several tasks at the same interval may require, for example. The number of tasks at each interval also changes at each revision of the MPD.

“The latest revision of the MPD in June 2010 saw a large number of tasks at the 6,000FH interval move to 7,500FH,” says Coskun, “so we will also be escalating our base check interval to 7,500FH.”

There are 84 tasks with FC intervals, ranging from 50FC to 75,000FC, and there are 18 different intervals. The intervals with the largest number of tasks are 1,600FC and 4,000FC. Seven tasks have intervals up to 300FC. Another 28 tasks have intervals between 450FC and 2,000FC, and the remaining 49 tasks have higher intervals up to 75,000FC.

There are an even larger number of tasks, 408 in total, with dual interval parameters of FC and calendar time, ranging from 560FC/90 days to 36,000FC/12 years. There are 33 different task intervals, and in every case the calendar interval would be reached first by an aircraft operating at 1,700FC per year. In all, there are 44 tasks with intervals of 560FC/90 days to 4,000FC/18 months.

There are 11 intervals that have a large number of tasks. The largest is the 5,500FC and 30-month interval, which has 74 tasks. The 5,500FC and 24-month interval has another 30 tasks. In all, 156 tasks come due at 24 or 30 months, and so would probably be combined and all grouped into a bi-annual base check.

Another 79 tasks come due every six years, 73 come due every eight years, 30 come due every 10 years, and 20 come due every 12 years.

The MPD also has 151 calendar tasks with intervals of 48 hours to 12 years. Four of these come due every two and 15 days. Another 21 tasks have intervals of 70 days to 18 months. The remaining 126 tasks are multiples of two years, with 58 due every two or three years, and the others due every four to 12 years. These can be grouped into bi-annual base checks.

There are also 11 tasks for the auxiliary power unit (APU), and 102 others, related mainly to component removals, life limited parts (LLPs), and NOTE and VEN REC (vendor recommended) tasks.

The 1,111 tasks can be broadly grouped according to their interval so that they are likely to be included in line, ‘A’, and ‘C’ or base checks. There are 23 tasks with intervals, or the equivalent, of up to 550FH, which means they are likely to be included in line checks. There are 199 tasks with intervals, or the equivalent, of 600FH to 5,500FH, so they are likely to be grouped into ‘A’ or intermediate checks, but they could also be grouped into line checks as they come due.

There are 772 tasks with intervals of 6,000FH or two years, or higher. Most have intervals that are multiples of two years. Others can be brought forward to two-year intervals. All these tasks are therefore most likely to be grouped into bi-annual base checks.

There are also 11 APU-related tasks with intervals of 1,000-10,000 APU hours. These are likely to be scheduled into A and base checks.

*The 737NG's maintenance programme is based on usage parameters, and operators are free to group tasks into check packages that suits their operations. Despite this freedom, many airlines still package tasks into checks that are generically referred to as 'A' and 'C' checks.*

There are 102 extra tasks for APU and engine changes, replacement of LLPs (mainly safety equipment), and VEN REC tasks.

## Check planning

“The problem with check planning is that it is difficult to group the many task intervals,” says Dobrica Vincic, engineering manager at JAT Tehnika.

Each aircraft's accumulated FH and FC can be monitored as it operates, and compared with the task intervals, either manually, or with an IT system. The objective of any operator is to package tasks in order to maximise interval utilisation and minimise downtime for maintenance. “KLM uses the Swiss Aviation Software AMOS system,” says Rae.

## A checks

Most operators still use a system of ‘A’ checks with intervals every 400-700FH, and ‘C’ or base checks with intervals every 4,000-6,000FH and 18 or 24 months. Tasks with the shortest intervals will be included in line checks, while those tasks with odd intervals that do not coincide with any of the line checks or A or base check intervals will be grouped by operators into checks as they come due.

The MPD line check tasks are specified in the usual pre-flight, daily, overnight and weekly intervals. Most of these tasks come from the flight operations manual, and a few from the MPD. Aircraft operating at 3,300FH per year are accumulating 65FH per week, so weekly checks therefore provide an opportunity to include tasks that have intervals between 60FH and the operator's chosen interval for ‘A’ checks.

Rae explains that the KLM line maintenance programme consists of a pre-flight check prior to every flight, for a maximum ground time of four hours; an overnight check, which is valid for 28 hours; and a daily check every day, which is valid for 48 hours. “Some drop-out tasks get planned into overnight and daily checks,” says Rae.

The logical choice for A checks is the interval which divides exactly into the majority of task intervals. That is, 500FH should be used if most tasks are a

**POSSIBLE TASK GROUPING OF 737NG BASE CHECK TASKS**

Interval parameter	FH	FC	FC/time	Time	TOTAL
Task group					
1C	157	1	156	58	372
2C	45	28	6	12	91
3C	3		79	18	100
4C	23	4	73	7	107
5C	8	1	30	20	59
6C		5	20	11	36
7C					
8C		7			7
<b>Total</b>	<b>235</b>	<b>46</b>	<b>364</b>	<b>126</b>	<b>772</b>

1C interval = 6,000FH, 3,000FC & 24 months

**POSSIBLE 737NG BASE CHECK TASK GROUPING**

Base check number	C1	C2	C3	C4	C5	C6	C7	C8
Task group								
1C	372							
2C		91						
3C			100					
4C				107				
5C					59			
6C						36		
8C								7
<b>TOTAL</b>	<b>372</b>	<b>463</b>	<b>472</b>	<b>570</b>	<b>431</b>	<b>599</b>	<b>372</b>	<b>577</b>

multiple of 500FH. These would be 1,000FH, 1,500FH, 2,000FH and so on up to the base check interval.

Operators may term the group of tasks that have an interval equal to the basic A check interval the '1A' tasks, and call the first A check the 'A1' check. Other tasks with a higher interval that are brought forward and performed early at the A check are also referred to as the 1A tasks. Tasks with an interval that is twice the basic A check interval can be referred to as the '2A' tasks. While there will be a sequence of A checks (A1, A2, A3, A4 and so on), unlike previous aircraft types there will be no clear cycle of A checks where all tasks are in phase at the last check of the cycle. Instead, there is a continuous stream of A checks. Some operators, however, consider the highest A check to be the one that is performed just before the base check interval.

KLM has an A check interval of 675FH and 400FC, but Turkish Airlines' check interval is 150FH. "We have an equalised system for A checks," says Coskun. "There are a large number of tasks between the weekly check interval and up to our 7,500FH and 24-month interval for the C check. We used to have

an interval of 600FH, but we now divide this into quarters. An equalised system means that the first three checks are light, and can be carried out at outstations. Only the fourth check is relatively heavy, which means that this has to be performed at our base."

While most tasks are packaged into A or C checks, a problem is created by tasks that fall at odd intervals between the operator's chosen A and C check intervals.

A C check interval of 6,000FH and 24 months means that the large number of tasks with intervals between the A check interval and up to 5,500FH will have to be performed in a particular A check as they come due. The odd intervals of many tasks mean that some airlines have had to develop a relatively small intermediate check with an interval midway between the A checks, which consists only of these drop-out tasks.

**Base checks**

Tasks with intervals higher than 6,000FH and up to 11,500FH can either be performed early and grouped together at every 6,000FH interval and included in the base checks, or as they come due and

are included in a particular A check.

Whether tasks with these odd intervals are included in A checks or base checks will be partly dependent on how much access is required. Light tasks are usually included in A checks, while those needing deeper access will go into base checks.

As with A checks, there is no clear cycle of C or base checks. The first base check may be referred to as the C1 check, and will be followed by the C2, C3, C4 checks and so on. Tasks with an interval equal to the C1 check might be referred to as 1C tasks, and those with intervals equal to higher C checks could be referred to as 2C, 3C, 4C tasks.

How tasks might be arranged into block checks is shown by using 6,000FH, 3,000FC and 24 months as a base check interval.

For tasks with FH intervals, those with intervals of 6,000-11,500FH might be grouped as 1C tasks, while those with intervals of 12,000-17,500FH might be grouped as 2C tasks and so on. If this system is used, the largest groups of tasks with FH intervals are those with intervals at or close to 6,000FH. These are the 1C tasks, totalling 157 tasks (see table, this page). There are also 45 2C tasks with FH intervals at, or just above, 12,000FH. There is another group of 23 4C FH tasks at 24,000FH, and eight FH 8C tasks at 48,000FH (see table, this page).

Tasks in the other three groups with intervals specified in FC, FC and calendar time or just calendar time could be grouped according to how their intervals convert to an equivalent FH interval. Using the FH:FC ratio of 1.95:1, the big groups of tasks with FC intervals are the 2C items with 28 tasks, the 4C items with four, the 6C tasks with five, and the 8C tasks with seven tasks (see table, this page).

Other large groups of tasks are those with dual FC and calendar intervals. With an interval of 3,000FC for most base checks, the large groups of tasks are 156 1C tasks, six 2C tasks, 79 3C tasks, 73 4C tasks, 30 5C tasks, and 20 6C tasks (see table, this page).

Calendar tasks also have large groups. Using a 24-month base interval, there are 58 1C tasks, 12 2C tasks, 18 3C tasks, seven 4C tasks, 20 5C tasks and 11 6C tasks (see table, this page).

There will be 772 tasks with intervals above the 6,000FH level: 372 1C tasks, 91 2C tasks, 100 3C tasks, 107 4C tasks, 59 5C tasks, 36 6C tasks, and seven 8C tasks (see table, this page).

If they are grouped into block checks, the smallest checks will be the C1 and C7 with 372 tasks (see table, this page). Checks with the largest number of tasks will be the C4, C6 and C8, with the C6 being the largest with 599 (see table, this page). The C8 check would have 577

tasks, almost the same number as the C6. The C2, C3 and C5 checks will have 16-25% more tasks than the C1/7 check, showing the relative differences in MH likely to be used for routine inspections during these checks.

"There is a group of 30 tasks with a dual interval of 10 years and 30,000/36,000FC, and another large group of 20 tasks with a dual interval of 12 years and 36,000FC. The 10- and 12-year intervals are likely to be reached before the 36,000FC interval, so some of the largest checks take place when these tasks come due. The base check cycle is considered complete when these higher tasks have been performed," explains Abu-Taleb.

An example of a base check interval is 6,000FH, 4,000FC and 24 months for KLM's fleet of 32 737-700/-800/-900s. This compares with annual rates of utilisation of 2,800FH and 1,620FC. "KLM's base check interval has three parameters of 6,000FH, 4,000FC and 24 months," says Rae. "The FC intervals are for structures and zonal tasks, while the calendar intervals are for both structures and system tasks. The C6 check, or the sixth check, is one of the largest checks on the 737NG, because it has a lot of 12-year structures tasks."

Turkish Airline's C check interval started at 5,000FH when its first 737NGs started operation. "This interval was escalated to 6,000FH, and then again to 7,000FH and 24 months in October 2007," says Coskun. "We will escalate the interval once more to 7,500FH and 24 months. The oldest aircraft was delivered in 1998, and has been through its C7 check."

Vincic says that some operators have a maintenance programme with an annual base check, so that tasks with 24-month intervals, plus FH and FC intervals falling due once every two years, can be split into left-hand and right-hand side tasks and performed on alternate checks. Tasks with odd intervals can also be planned into the base checks, rather than grouped into A checks.

In the past, airlines would adapt their own maintenance programmes and request permission from their local authorities to extend the intervals of task and checks over the MPD interval. "A more recent trend has been for airlines to follow the MPD as closely as possible, since a larger number of aircraft are acquired through operating leases. This is because lessors require aircraft to be maintained and returned after lease, based on the MPD," explains Vincic.

## Line check inputs

The line maintenance programme adopted by most carriers for the 737NG is the standard for most aircraft types.

The pre-flight and transit checks are a walkaround visual inspection that is performed by flightcrew in a little over 30 minutes. Some airlines may still use mechanics for this, who will also be required to fix any defects that have arisen during operation. This can use several MH of mechanics' labour, and the line maintenance budget must allow for this.

The overnight and daily checks include visual inspections, and 2-3MH for some minor routine maintenance tasks, including: measuring brake pad thickness; inspecting and testing emergency systems and equipment; testing systems like the hydraulics; checking fluid levels; and reviewing messages on the on-board maintenance computer. Once an allowance for non-routine labour has been added, total labour will be 4MH. A budget of \$30 should also be allowed for materials and consumables.

At the rates of utilisation used for this analysis, an operator will perform 1,600 pre-flight and transit checks and 350

daily checks per year.

The weekly check has a similar routine content to the daily checks, but includes a few additional tasks. The check has a routine labour requirement of 4MH, and an allowance for non-routine should take the total to 6MH. An allowance of \$60 should be made for materials and consumables. An operator will perform about 50 weekly checks each year.

The allowance for non-routine labour to clear defects as they arise during operation should be 50% of routine labour for line checks. The total annual consumption of routine labour is 2,200MH, so additional non-routine labour is 1,100MH. A further 120MH per month should be added for cleaning. This takes total annual labour to 4,800MH. Charged at a standard labour rate of \$70 per MH, this totals \$335,000. The additional cost of materials and consumables will be \$10,000-15,000. The total cost of \$350,000 is equivalent to a rate of \$110 per FH (see table, page 30).

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## A check inputs

Operators can choose a variety of intervals for A checks, and package tasks in many different ways when using the same interval.

With a 600FH interval to analyse the 737NG's maintenance costs, the tasks between the weekly and A checks are taken into consideration. Some operators bring certain tasks, such as lubricating items like the landing gear and flap and slat mechanisms, forward into weekly checks, while others use intermediate checks. Turkish Airlines has recently changed to an equalised system of checks at 150FH intervals in order to address this issue.

A check tasks include those in the weekly check, some functionality tests, checks on emergency and safety equipment, control surfaces and mechanisms, and some non-destructive tests on a few parts.

Using a 600FH interval for the A check and 6,000FH interval for the 'C' or base check means the ninth or tenth A check will be combined with the base check, depending on check interval utilisation. These two interval parameters, and the absence of an intermediate check have been used to illustrate MH consumed in A and base checks.

The workscope of A checks will start with routine inspections. The A6 and A10 checks at 3,600FH and 6,000FH have a larger group of routine tasks, and so will be the larger checks. There will be 40-75MH used for the eight lighter checks, while the A6 check will use 145MH, and the A10 check will use 205MH.

Airworthiness directives (ADs),

service bulletins (SBs), and engineering orders (EOs) will be added. The labour used will vary, and will depend on the ADs and SBs that are included in the check.

Some component changes, drop-out tasks and the operator's own additional requirements will also be required.

Another element is interior cleaning. This will include basic cleaning, and usually the changing of seat covers.

A conservative budget of 70-80MH could be allowed for these three elements.

The sub-total for all four elements will therefore be 110-145MH for the lighter A checks, 215MH for the A6 check, and 275MH for the A10 check.

The labour used for non-routine work will include rectifications arising from routine inspections and clearing defects accumulated during operation. "The non-routine ratio will be 30% for young aircraft, but 40-50% for mature aircraft," explains Abu-Taleb.

The non-routine ratio used here is 35-40% for the eight lighter checks, and 50% for heavier checks, taking the total labour input for the lighter checks to 150-205MH, 320MH for the A6 check to 320MH, and 415MH for the A10 check. Total labour for all 10 checks in the cycle is 2,100MH. At a labour rate of \$70 per MH, the total cost is \$147,000.

The budget allowed for materials and consumables should be \$800-1,500 for the eight lighter checks, \$3,000 for A6 checks, and \$7,000 for A10 checks. Total materials for the 10 A checks will be \$15,000-18,000.

Total cost for the 10 checks will therefore be \$165,000. The utilised interval is likely to be 85%, or 5,100FH. The reserve for A checks should therefore be \$32 per FH (see table, page 30).

The intervals used by 737NG operators for 'A' checks are close to 600FH, while intervals used for 'C' or base checks are close to 6,000FH and 24 months.

Reserves can be higher, particularly if an interval of 500FH is used for the A check.

## Base check inputs

Using the 6,000FH, 3000FC and 24-month interval for this analysis, tasks can be grouped into block checks, so that the peaks in the number of tasks would occur with the C4, C6 and C8 checks. There is no particular cycle of checks, and the number of tasks for each check varies. The C12 would have the largest number, with 1C, 2C, 3C, 4C and 6C all coming due at the same time, totalling 706 tasks.

These tasks form the routine inspections for each check. Despite the number of tasks being grouped as described, operators will not use the full interval of each check. Actual rates of interval utilisation are typically 85%. At this rate, base checks would be performed every 20 months and 5,600FH and 2,900FC. With this actual interval, maintenance planners would group tasks into checks so that the aircraft was free of all major tasks for up to 24 months. Moreover, the first aircraft delivered in the late 1990s would have had base check intervals close to 5,000FH and 18 months, so the number of tasks would not be as described.

The C5 check would therefore come due at eight-and-a-half to nine years, while the C6 check would come due after 10-and-a-half to 11 years. The large group of structural tasks with a 10-year interval would therefore have to be performed at the C5 check, making it a heavy check. The C7 check would come due at 12 years. The C6 check would then have a relatively low number of tasks, while the C7 check would have a large number of tasks, including the 30 or so tasks that have an interval of 12 years, making it a heavy check.

The inputs for routine tasks and inspections for these first seven checks would be 1,000MH for the C1 check, rising steadily for each check up to the C5 check to 2,500MH. The C6 would be smaller, using 2,000MH, and the C7 would be larger again using 2,400MH. The total labour input for these checks over a period of 12 years and interval of 67,000FH is 13,000MH.

The extra items included in the base checks are: AD inspections and SB modifications; non-routine rectifications; component changes; interior cleaning;



clearing defects that have accumulated during operation; and additional customer items.

The amount of non-routine labour will depend on the non-routine ratio. This will start at a low rate for the early checks in the cycle. Turkish Technic has recorded ratios of 0.30 for C1 checks, rising to 0.60 for C2 checks, and 0.70 and 0.80 for C3 and C4 checks. The heavier checks will have a higher non-routine ratio, and reach 1.0 for the C5 check. The ratio observed by Turkish Technic dipped again at the lighter C6 check, but climbed to a high level of 1.40 for recently performed C7 checks.

These ratios would therefore generate MH inputs for non-routine rectifications of 320 for the lightest C1 check, to about 2,500MH and 3,400MH for the heaviest C5 and C7 checks. The total non-routine labour for these seven checks would be 11,500MH.

The labour inputs for ADs and SBs are highly variable, and depend on: the applicability of each AD and SB to the aircraft line number; which ADs and SBs have been issued and have to be complied with; when the aircraft is going into the check; and which SBs the airline wants to use. Examples of MH inputs for ADs and SBs are 150MH for the lightest checks to as much as 1,200MH for heavier checks, or where a large number of ADs have to be complied with, and a large number of SBs have to be incorporated on the aircraft.

Fortunately, the 737NG has had few major ADs and SBs. The few it has had cover the enhanced rudder power control unit, and the slat actuator modification.

Abu-Taleb recommends allowing 120MH for component changes at each check, 150MH for interior cleaning and

general cabin work, 100MH for clearing defects, and 200-300MH for additional customer items.

The total for the C1 check would therefore reach 2,000MH. The total would climb to 3,000MH and 3,700MH for the C2 and C3 checks, 5,000MH for the larger C4 check, and 6,800MH and 7,300MH for the largest C5 and C7 checks. The total labour input for all seven checks would be 33,000-34,000MH. Using a generic labour rate of \$50 per MH for base maintenance for illustrative purposes, the labour cost for these inputs is \$1.65-1.70 million.

The cost of materials and parts for the seven checks will vary from \$25,000 for the lightest C1 check up to \$250,000 for the heaviest C7 check. The total for the seven checks will be \$800,000.

This takes the labour and material inputs for these seven checks to \$2.5 million. Amortised over the interval of 39,000FH for these seven checks, the reserve would be \$65-70 per FH (see table, page 30).

The final elements of base checks will be interior refurbishment and stripping and repainting, the timing and quantity of which depend on airline policy. Turkish Technic, for example, strips and repaints its aircraft every five years. If this was done every third C check, it would be about once every 60 months. A typical input would be 1,200MH and \$25,000 for materials. Using the same labour rate of \$50 per MH, this would cost \$85,000, and equal a reserve of \$5 per FH (see table, page 30).

The refurbishment of interior items consists of: replacing worn carpet; cleaning and replacing seat covers; replacing seat cushions; overhauling seat frames; and refurbishing large items such

The 737NG's maintenance programme results in low reserves per FH for the aircraft. Tasks can be grouped into base checks, or those with awkward intervals can be included in A checks. There are a large number of tasks that come due every six, eight, 10 and 12 years.

as sidewall panels, overhead bins, passenger service units, dado panels, galleys and toilets.

Carpets, seat covers and seat cushions are cleaned or replaced, and the seat frames overhauled, on an on-condition basis by most airlines. The different intervals vary between every two A checks to every five years on a type like the 737NG. The regular refurbishment of large items can be carried out every five years.

The worksopes and costs for aircraft the size of the 737NG and A320 are detailed (see *Costs of narrowbody interior refurbishment, Aircraft Commerce, February/March 2010, page 26*). The reserve for refurbishing all these interior items is \$28 per FH (see table, page 30).

The total reserve for base check inputs, regular stripping and repainting and interior refurbishment is therefore \$100-105 per FH.

## Components

The 737NG has 2,500-3,000 rotatable components, depending on configuration and aircraft specification. These include landing gear and safety equipment. About 6%, 150-200, of these are maintained on a hard-time basis.

The remaining 2,300-2,800 rotatables are maintained either on-condition (550-700) or are condition-monitored (1,800-2,100).

Rotable components can be subdivided into heavy components and all other rotatables.

## Heavy components

There are four main heavy components of wheels and brakes, thrust reversers, the APU, and the landing gear.

Wheels and brakes require the maintenance of tyres, wheel rims and brake units. Tyre wear and brake pad thickness are checked during transit and pre-flight checks.

Wheels are removed when tyres become worn. In the case of nosewheels, this is typically up to 200FC, and at a slightly shorter interval for mainwheel tyres.

At this stage tyres are remoulded. Mainwheel tyres can be remoulded five or six times, while nosewheel tyres can be remoulded 10 or 12 times. It costs \$200-



300 to remould a nosewheel tyre, and \$450-600 to remould a mainwheel tyre.

Tyres are replaced after the maximum number of remoulds. New nosewheel tyres cost \$350-400 each, and new mainwheel tyres cost \$1,400-1,600 each.

At the same time that wheels are removed for tyres to be remoulded, wheel rims are inspected using a simple workscope. This costs \$300 for a nosewheel and \$500 for a mainwheel.

The combined cost for tyre remoulding and replacement and wheel rim inspection is therefore \$34 per FC.

Main wheels have brake units, which are typically repaired every third wheel removal, which is equal to 560FC. The 737NG has steel brakes, and the cost of repairing and overhauling each one of its four brake units is \$11,000, while the cost per FC for repair and overhaul of all four is \$79 per FC.

The landing gear has an overhaul interval of 18,000FC or 10 years, whichever is reached first. Aircraft operating at 1,600-1,700FC per year would reach the 10-year interval first. Most airlines now use third-party landing gear overhaul shops. Major landing gear shops for the 737NG are AAR Component Services, Ameco Beijing, Bedek Aviation, Goodrich, Hawker Pacific, Messier Services, Revima, SR Technics, ST Aerospace and Turkish Technic.

Most operators agree an exchange fee for landing gear overhauls. This includes the cost of overhaul and repair, and ownership or inventory of the gear set. There may also be an additional fee charged for the replacement of scrap parts, which is less predictable than the other costs.

The current market exchange fee for a

737NG landing gear shipset is \$300,000. Amortised over the 10-year interval, which is equal to 16,000-17,000FC, the reserve for landing gear maintenance is equal to \$18 per FC.

Thrust reversers are maintained on an on-condition basis. Intervals for the units on the CFM56-7B series are longer than those on older engine types, due to the extensive use of composites. Typical intervals vary by operator, but average intervals are expected to be 12,000FC, equivalent to seven or eight years of service.

Most operators sub-contract thrust reverser repair and overhaul to independent shops. Main providers include Goodrich Prestwick, Nordam, Middle River Aircraft Systems, Spirit Aerosystems, and Triumph Airborne Structures. The market rate for thrust reverser repair and overhaul is \$200,000 per shipset. The reserve for both shipsets is therefore equal to \$33 per FC.

The 737NG is equipped with the GTCP 131-9B APU, which has an average removal interval of 8,000-9,000 APU hours. The equivalent interval in aircraft FH depends on the operator's policy for APU use. Some will leave it running during turnaround between flights, while others will switch to ground power. If used during the complete turnaround time, which will be 45-70 minutes for most operators, the ratio of APU hours to aircraft FC will be 0.75-1.10:1. The APU removal interval is therefore equal to 8,000-12,000FC.

An APU shop visit costs \$200,000, not including LLPs, so the APU maintenance reserve is \$22 per FC.

The total cost for these four groups of heavy components is therefore \$254 per FC, equal to \$130 per FH for aircraft

*The CFM56-7B has some of the longest removal intervals achieved by narrowbody engines. Despite this, reserves per EFC and EFH are still relatively high on account of high shop visit costs.*

operated at 1.95FH per FC (see table, page 30).

## Rotables

Besides the heavy components, all other remaining rotatable components can be treated as one group. A minority are maintained on a hard-time basis, so most will be removed during A and C checks. The remainder are on-condition and condition-monitored components, and so will be removed at random intervals, usually during line checks.

Large operators will own and maintain most or all of their inventories. Operators are increasingly interested in total support rotatable packages, which are provided by AJ Walter, AvTrade, KG Aircraft Rotables, P3 Aviation, AAR, Lufthansa Technik, and SR Technics.

These packages provide airlines with a homebase stock of rotatable parts with the highest failure rates, which are critical to the aircraft's operation, with the remaining parts supplied through a pool stock. Operators pay for the logistics and management of all parts, and the repair and overhaul of the inventory in an all-inclusive cost per FH contract.

Airlines will typically lease the homebase stock. The amount of stock and its value will be about \$2 million for a single aircraft, and about \$10 million for a fleet of 10, with a larger fleet benefiting from economies of scale. A lease rental of 1.5% per month would therefore be equal to \$150,000 per month, and \$55 per FH. The other two elements of main pool access and repair and management would be \$30-40 and \$150-160 per FH. The total for the whole support package would therefore be \$235-255 per FH (see table, page 30).

## Engine maintenance

The CFM56-7B family has six main variants, each with a thrust rating ranging from 19,500lbs to 27,300lbs (see *CFM56-7B Owner's & Operator's Guide, Aircraft Commerce, June/July 2008, page 9*). The engine variants for each variant of the 737NG are summarised (see *737NG family & CFM56-7B specifications, fleet & developments, page 4*).

Several modifications have been made

since the base engines were introduced into service in 1997. The most notable is the Tech56 modification, which entered service in 2007. It was available for previously built engines and has also been standard on all engines built from this date. The Tech56 modification costs \$1.5 million, although not all the kit has to be installed, as it is possible to install different parts of the kit at less than full cost.

The modification includes a 3-D aero compressor blade design, an enhanced single-annular combustor, and improved designs for the high pressure turbine (HPT) blade and low pressure turbine (LPT) nozzle. This increases the engine's exhaust gas temperature (EGT) by 10 degrees centigrade, and reduces fuel burn by 1%. It also lowers NOx emissions.

Most 737-700s are powered by the -7B22 and -7B24 variants rated at 22,000lbs thrust and 24,000lbs thrust. The majority of the 737-800 fleet is powered by the -7B26 and -7B27 rated at 26,000lbs thrust and 27,000lbs thrust.

The small -900 fleet is powered by -7B24, -7B26 and -7B27 variants.

Few aircraft are powered by the -7B18, so the -7B20 is the only other significant variant. The smaller -600s are powered by -7B20 and -7B22 variants.

The most notable feature about the CFM56-7B is that all variants have high initial EGT margins when delivered new. "For non-Tech56 engines, these are: 125-130 degrees centigrade for the lowest-rated -7B18 and -7B20; 100-105 degrees for the medium-rated -7B22 and -7B24; 80 degrees for the -7B26; and 50-55 degrees for the -7B27," says Claus Bullenkamp, senior manager engineering & planning at MTU Maintenance.

Operators have to consider removal causes and likely removal intervals when optimising engine management. The engine has 18 LLPs. The shipset has a list price of \$2.11 million, up from the 2008 list price of \$1.77 million.

There are three LLPs in the fan and low pressure compressor (LPC), nine in the high pressure compressor (HPC) and HPT, and six in the LPT. CFMI has target lives of 30,000 engine flight cycles (EFCs) for the three parts in the fan/LPC, 20,000EFC in the HPC/HPT module, and 25,000EFC in the LPT. The three parts in the fan/LPC have a list price of \$424,000, up from the 2008 price of \$360,000. The nine HP parts have a list price of \$1.09 million, up from the 2008 price of \$921,000. The six LPT parts have a list price of \$594,000, up from the 2008 list price of \$500,000.

There are several part numbers for each LLP, and the earlier part numbers have lower life limits than the target lives. Engines with the Tech56 modification have all LLPs at target lives. "All engine variants now have LLPs at their target

lives, except non-Tech56 -7B26 and -7B27 engines. These have four parts in the HPT with lives at 17,600EFC.

"The high EGT margins of the lower- and medium-rated -7B engines mean that these engines generally achieve first and some subsequent on-wing removal intervals that are limited by LLP lives," explains Bullenkamp. "High thrust variants are usually removed due to a combination of EGT margin erosion and mechanical deterioration."

The CFM56-7B has had three main types of mechanical deterioration. The first is wear of the variable stator vane bushings in the HPC, which led to contacts between the stators and rotors. CFMI initially managed the problem through an SB, but improved hardware has now fixed it.

A second problem involved the engine's fuel nozzles.

A third issue was deterioration of the

HPT blades in earlier engines due to cooling problems caused by poor casting. This led to removals being limited to 14,000EFC and 16,000EFC in some cases. "There is a programme initiated by CFMI to manage the HPT blades, which comes via SB72-0696," explains Paul Smith, engineering manager at Total Engine Support (TES). "This SB applies a soft time for removal to certain standard HPT blades, necessitated by HPT blade failures to certain build-standard blades. Some were removed as early as 12,500EFC and 16,000EFC, which forced early engine removals in lower-rated engines."

Operators have to take into account the potential first, second and third removal intervals of each variant due to available EGT margin and rate of EGT margin erosion, possible mechanical deterioration, and the lives of LLPs in each of the three main groups. Restored

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EGT margins are 75% of initial EGT margins. The potential removal intervals in terms of EGT margin and engine performance for second and subsequent removal intervals will therefore be 75% of first removal intervals. A compromise has to be reached between these two main factors when managing engines.

The Tech56 modification programme increases EGT margin by 10 degrees centigrade, making it attractive for medium- and higher-rated engines. "The rate of EGT margin erosion averages 4-6 degrees per 1,000EFC, but is higher in the first 2,000EFC on-wing and then slightly lower," explains Markus Kleinhans, propulsion systems engineer CFM56-7B at Lufthansa Technik.

The additional 10 degrees provided by the Tech56 modification would therefore allow engines to remain on-wing for another 2,000EFC. This makes little difference to lower-rated engines that can remain on-wing to LLP limits, but is a worthwhile gain for higher-rated ones.

There are three types of workscope defined for the engine and its modules: a level 1 workscope, involving no LLP replacement, when the engine has lost its EGT margin, or the HPT or fuel nozzles have deteriorated; a heavier level 2 workscope for the HP modules, involving full disassembly and, in most cases, LLP

replacement; and a level 3 workscope for a full overhaul of the whole engine, and replacement of all LLPs.

#### **-7B20/22**

These lower-rated engines are capable of first removal intervals of up to the first LLP limit, which is 20,000EFC for parts in the two HP modules. The EGT margin of these engines is in fact high enough for them to remain on-wing for up to 25,000EFC. These long intervals are equal to 39,000-49,000 engine flight hours (EFH) at the average FC time being used in this analysis. The engines are therefore likely to also experience mechanical deterioration and reliability problems at these long intervals.

Some older LLPs in the HP modules have lives lower than 20,000EFC, and so will limit the first removal intervals of these older engines. In most cases, these lower-rated engines should be able to achieve first on-wing intervals of up to 20,000EFC.

At this stage, shop-visit worksopes are considered. A heavy workscope will clearly be required on the HP modules, resulting in a restored EGT margin of 75-100 degrees. This will allow a second on-wing interval of 20,000EFC, subject to restrictions placed by mechanical deterioration. This will only be possible,

however, if all the engine's LLPs are replaced at the first shop visit. The fan/LPC module will have parts removed with remaining or 'stub' lives of at least 10,000EFC. Parts in the LPT will have stub lives of at least 5,000EFC. The fan/LPC parts could be used in higher-rated -7B variants, or sold on the aftermarket. Parts in the LPT are likely to be scrapped.

The -7B20/22 variants will therefore need heavy worksopes on all modules at the first shop visit, since all LLPs will have to be removed. This full overhaul will allow the engine to achieve a second on-wing interval of 38,000-40,000EFH, equal to 20,000EFC. This interval is likely to be limited only by mechanical deterioration.

The engine will therefore have to be fully overhauled again at its second shop visit to prevent stub life LLPs in the fan/LPC and LPT limiting the third on-wing interval. It could therefore have accumulated a total of up to 75,000EFH by its second shop visit, equal to more than 20 years' operation.

#### **-7B24**

The -7B24's lower initial EGT margin of 100 degrees will allow a first on-wing interval of 18,000EFC, when operating in temperate climates, equal to 34,000EFH,

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and 10 years' operation. HP module LLPs will have to be replaced at this stage.

Like the -7B20/22 variants, the main factor driving first removals for shop visits will be loss of EGT margin. Mechanical deterioration can also be an issue for engines with potentially long on-wing intervals. Remaining LLP lives, restored EGT margin and potential second on-wing interval also have to be considered when determining the first shop-visit workscope.

A probable restored EGT margin of 70-80 degrees would allow a second removal interval of 14,000-17,000EFC. The stub lives of 12,000EFC in the fan/LPC module mean it does not make economic sense to replace them at the first shop visit. Stub lives of 7,000EFC for LPT parts mean they should be replaced, however. The first workscope would therefore be a heavy visit for the HP and LPT modules to replace LLPs and restore EGT margin and performance.

The second on-wing interval would be limited to 12,000EFC, or rather the total of the first and second intervals would be limited to 30,000EFC, the life of fan/LPC LLPs.

When the second shop visit is due, the fan/LPC LLPs will be replaced and the new LLPs in the HP and LPT modules will have only accumulated 12,000EFC. The second shop visit should comprise a

performance restoration workscope on the HP modules and a full workscope on the fan/LPC to replace LLPs. The LPT would be left unless there were findings on visual inspection.

The restored EGT margin again means the engine could have a third on-wing interval of up to 17,000EFC. The HP module LLPs will have a stub life of 8,000EFC at this stage, however, which will restrict the third interval to this short limit. The third shop visit will have heavy workscope on the HP and LPT modules for LLP replacement.

The higher EGT margins of the -7B24 Tech56-modified engines would allow them to achieve the same first removal interval as the lower rated -7B20/22 engines. The Tech56 -7B24 therefore has to have a full overhaul at its first removal in order to prevent LLP lives limiting the second removal interval in the LP modules.

The Tech56-modified -7B24 should be capable of a second on-wing interval of 15,000EFC, or possibly 2,000-3,000EFC longer. It should also be capable of a similar interval for third and subsequent runs, with the available EGT margin, which has to be considered together with LLP lives. The best compromise is to plan for removals every 15,000EFC, or a total of 30,000EFC every two intervals, so that HP and LPT module LLPs are replaced

every shop visit, and fan/LPC parts are replaced every second shop visit. A longer interval of 18,000EFC for the first interval would make better use of HP and LPT LLP lives, while a shop visit at 15,000EFC would leave LPT LLPs with stub lives of 10,000EFC, making them attractive enough for the used market.

### -7B26

The -7B26's EGT margin of 80 degrees allows a first removal interval of 14,000EFC. The restored EGT margin after the first shop visit of 45 degrees would only allow a second interval of 9,000EFC. It should be appreciated that this variant has HPT LLPs at 17,600EFC, which would limit the second interval.

A level 2 workscope on the HP modules is therefore required at the first shop visit.

The fan/LPC LLPs will have remaining lives of 11,000EFC, the maximum possible second removal interval. The second removal is only likely to be 9,000EFC, however, before EGT margin is eroded. Fan/LPC LLPs will only have 5,000-7,000EFC remaining. The workscope at the second shop visit will require full overhauls of the two LP modules to allow LLP replacement. The HP modules will only need a level 1 workscope, since they will



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have only accumulated 9,000-11,000EFC on-wing since LLP replacement.

The HP module will have LLPs limited at 17,600EFC, unless target lives of 20,000EFC are reached. This will be the limit of the second and third removal intervals. Each one will therefore average 8,800EFC, so the third shop visit will need a heavy workscope on the HP modules to allow LLP replacement.

-7B26 engines with the Tech56 modification will be capable of a longer first removal interval of 16,000EFC. Despite an improved EGT margin and HP module LLPs at 20,000EFC, the LLP lives in the LPT still limit the second removal interval to 9,000EFC. The higher EGT margin and HP module LLP lives will therefore mean that the third removal interval will be limited to 11,000EFC. The engine will therefore follow the same shop visit pattern as an unmodified engine.

### -7B27

Like the -7B26 non-Tech56 variant, the -7B27's initial EGT margin allows a first removal interval of only 11,000EFC.

The total of the first and second removal intervals will be limited to 17,600EFC. Restored EGT margin, of 39-44 degrees, will allow second and

subsequent removal intervals of up to 9,000EFC. The first interval is likely to be 10,000EFC, and the second 7,600EFC.

HP module LLP replacement is not required until the second shop visit. The 25,000EFC lives of LPT LLPs will limit the third interval to 7,400EFC. The fan/LPC LLPs will have remaining lives of 5,000EFC at this stage, which would limit the fourth removal interval. They would probably be replaced at this stage.

The workscope at the first shop visit will be a level 1 workscope for the HP modules. The workscope at the second shop visit will be a full overhaul for the core to allow for LLP replacement. The third shop visit will require level 2 worksopes to replace fan/LPC and LPT LLPs, plus a level 1 workscope on the HP modules to restore performance.

The Tech56-modified -7B27 engines are capable of slightly longer first removal intervals than unmodified engines, at 12,000EFC. This suggests that, despite a longer second removal interval being possible, it will be limited to 8,000EFC because of HP module LLPs. The restored EGT margin will actually allow a removal interval of 10,000EFC. The shop visit and removal pattern should therefore be aiming for full worksopes on the HP and LPT modules to allow LLP replacement at the

second shop visit. A full workscope, for LLP replacement, on the fan/LPC and a level 1 workscope on the HP modules would be made at the third shop visit.

### Workscope inputs

There are four types of workscope for which inputs and costs have to be considered. Shop-visit costs comprise routine and non-routine labour, parts and materials, and sub-contract repairs.

The cost of each item will depend on the percentage of parts that can be repaired, or scrapped and replaced with new parts. A higher rate of repair will use relatively large amounts of labour and have a high sub-contract repair cost. A high rate of replacement and a low rate of repair will utilise less labour but cost more in materials and parts.

Shop-visit costs also depend on the shop's in-house capability for hi-tech repairs. A small capability will see smaller labour and materials inputs, but greater expense for sub-contract repairs.

A core restoration will use up to 2,500MH for all labour inputs, up to 1,500,000 for materials, and \$250,000-400,000 for sub-contract repairs. The higher material cost will cover 100% HPT blade and nozzle guide vane (NGV) replacement. Using a generic labour rate



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## SHOP VISIT WORKSCOPES, INPUTS &amp; RESERVES FOR CFM56-7B FAMILY

Shop visit	Removal interval EFC	Shop visit workscope	LLP replacement	Shop visit cost-\$	LLP cost-\$	Reserve \$/EFC	Unsched visits \$/EFH	QEC \$/EFH	Total \$/EFH
<b>-7B20/22</b>									
1st	20,000	Full overhaul	All parts	2,200,000	2,110,000	216	31	10	152
2nd	20,000	Full overhaul	All parts	2,600,000	2,110,000	236	31	10	162
<b>-7B24</b>									
1st	18,000	Level 2 core & LPT	Core & LPT	2,250,000	1,684,000	241	31	10	165
2nd	12,000	level 1 core & level 2 fan/LPC	Fan/LPC	2,050,000	424,000	257	31	10	173
3rd	8,000	Level 2 core & LPT	Core & LPT	2,350,000	1,684,000	375	31	10	233
<b>-7B24-Tech56</b>									
1st	20,000	Full overhaul	All parts	2,200,000	2,110,000	216	31	10	152
2nd	15,000	Level 2 core & LPT	Core & LPT	2,350,000	1,684,000	269	31	10	179
3rd	15,000	level 2 core & fan/LPC	Full set	2,250,000	2,110,000	291	31	10	190
<b>-7B26</b>									
1st	14,000	Level 2 core	Core	1,800,000	1,090,000	251	31	10	170
2nd	8,800	level 1 core, level 2 fan, LPC & LPT	Fan, LPC & LPT	2,200,000	1,018,000	315	31	10	202
3rd	8,800	level 2 core	Core	2,000,000	1,090,000	352	31	10	221
<b>-7B26 Tech56</b>									
1st	16,000	Level 2 core	Core	1,800,000	1,090,000	237	31	10	162
2nd	9,000	Level 1 core, level 2 fan, LPC & LPT	Fan, LPC & LPT	2,200,000	1,018,000	297	31	10	193
3rd	11,000	Level 2 core	Core	2,000,000	1,090,000	301	31	10	195
<b>-7B27</b>									
1st	10,000	Level 1 core		1,600,000	0	303	31	10	196
2nd	7,600	Level 2 core & LPT	Core & LPT	2,350,000	1,684,000	406	31	10	249
3rd	7,400	Level 1 core, level 2 fan/LPC	Fan/LPC	1,850,000	424,000	359	31	10	225
<b>-7B27 Tech56</b>									
1st	12,000	Level 1 core		1,700,000	0	267	31	10	178
2nd	8,000	Level 2 core & LPT	Core & LPT	2,350,000	1,684,000	374	31	10	233
3rd	10,000	Level 1 core & level 2 fan/LPC	Fan/LPC	1,950,000	424,000	295	31	10	192

of \$70 per MH, the total cost for this shop visit will be up to \$2.0 million; the higher level is more likely for second and subsequent shop visits when a higher rate of expensive parts will be replaced.

A fan/LPC workscope will require 400-900MH for all labour inputs, \$80,000-100,000 for materials and parts, and up to \$50,000 for sub-contract repairs. This will take the total to \$180,000-230,000.

A workscope on the LPT can use 800-1,500MH, depending on depth of scope and level of parts repair and replacement. Materials will cost \$150,000-250,000, and sub-contract repairs up to \$50,000. Total cost for the input will therefore be \$280,000-400,000.

A full overhaul will use 4,500-6,000MH, and cost \$300,000-400,000. The cost of materials and parts will be

\$1.4-1.7 million, depending on the level of parts replacement and repair. Earlier shop visits will have lower inputs, compared to later visits, which will have a higher cost of materials due to higher scrap rates. The cost of sub-contract repairs will be \$400,000-500,000. Total cost for the shop visit will therefore be \$2.2-2.6 million.

### Unscheduled shop visits

Unscheduled shop visits fall into two categories: engine- and non-engine related. Non-engine-related shop visits are mainly due to birdstrikes and foreign object damage, and result in high shop-visit costs.

Engine-related unscheduled shop visits are light or heavy events. Light events do not interrupt the pattern of

planned shop visits, and incur costs of \$200,000-350,000. If they occur at average intervals of 60,000-70,000, a reserve of \$5 per EFH should be used.

Heavy engine-related events include bearing failures. These and non-engine-related events usually incur large shop visit costs of \$2.0-2.5 million, occurring once every 35,000-40,000EFC. They interrupt the pattern of planned shop visits, so they replace one in every three or four planned events. A reserve of \$40-50 per EFC should be made for these events. The reserve for all unscheduled shop visits is \$26-31 per EFH.

### Engine reserves

The removal intervals, shop visit worksopes, LLP replacement, shop visit costs and reserves in \$ per EFC are

## DIRECT MAINTENANCE COSTS FOR 737NG FAMILY

Maintenance Item	Cycle cost-\$	Cycle interval	Cost per FC-\$	Cost per FH-\$
Line & ramp checks	350,000	Annual		110
A check	165,000	5,100FH		32
Base checks	25 million	39,000FH		65-70
Stripping & repainting	85,000	16,800		5
Interior refurbishment				28
Heavy components			254	130
LRU component support				235-255
<b>Total airframe &amp; component maintenance</b>				<b>605-630</b>
Engine maintenance:				
CFM56-7B20/22:	2 X \$152-162 per EFH			304-324
CFM56-7B24:	2 X \$165-233 per EFH			330-466
CFM56-7B24 Tech56:	2 X \$152-190 per EFH			304-380
CFM56-7B26:	2 X \$170-221 per EFH			340-442
CFM56-7B26 Tech56:	2 X \$162-195 per EFH			324-390
CFM56-7B27:	2 X \$196-249 per EFH			392-498
CFM56-7B27 Tech56:	2 X \$178-233 -per EFH			356-466
<b>Total direct maintenance costs per FH:</b>				<b>909-1,128</b>
<b>Annual utilisation:</b>				
3,300FH				
1,700FC				
FH:FC ratio of 1.95:1				

summarised for each engine variant (see table, page 28).

The reserves per EFC at each removal are not simply the cost of the shop visit and LLPs replaced at the time, divided by the most recent interval. The workscopes for modules must be taken into consideration, and LLPs must be replaced once every two or three shop visits. Reserves for these occurrences are spread across several shop visits, thereby making the calculation of reserves more difficult. The reserves listed (see table, page 28) relate to the shop-visit workscopes and LLPs replaced. These are at a cost per EFC.

There are additional reserves of \$31 per EFH for unscheduled shop visits, and \$10 for the repair and management of quick engine change (QEC) and accessory rotatable components.

The reserves for shop-visit inputs and LLP replacement are then converted from \$ per EFC to \$ per EFH, taking into consideration the FH:FC ratio of 1.95:1.

Total reserves per EFH are shown in the final column (see table, page 28). The reserves generally increase for each variant as the engine experiences shorter removal intervals after each successive on-wing run. Reserves are lower for lower-rated engines that have longer removal intervals. Reserves for engines operating in a harsh environment would be higher.

## Reducing shop visit costs

The cost of shop visits is dominated by the expense of materials and parts, which can be reduced through a higher rate of parts repair, or the use of parts manufacturer approval (PMA) parts.

The most expensive engine parts are the airfoils. Repairs to these can cut the cost of shop visits by several hundred thousand dollars. Chromalloy is one of the largest providers of designated engineering representative (DER) hi-tech parts repairs for blades and stators in the CFM56-7B. These are repairs that are not approved by the OEM, and so are not available in the engine's repair and shop visit manual. One example is the stage 1 HPT vanes. "This is a very advanced repair, since it requires the casting of new airfoils, but it eliminates almost all airfoil scrappage," says Rob Church, regional sales director for the Americas at Chromalloy. "The list price for a set of HPT vanes or NGVs in the -7B is \$700,000-800,000. There is usually a 20% scrappage rate at each shop visit, but the cost of a repair is half that of a new OEM part, thereby saving \$100,000 per shop visit."

Chromalloy also has a repair for the stage 1 LPT vane. Church says there is a 34% scrappage rate at each shop visit, and that the repair can save \$34,000 at

each shop visit. The list price for a shipset of LPT vanes is \$330,000.

Chromalloy also offers tip repairs to HPC blades, and an erosion coating with a tungsten-carbide cobalt. It will soon offer an HPC blade chord restoration.

Another expensive part is first stage HPT blades. A typical blade scrappage rate at the first shop visit is 6%, and is higher at the second shop visit. There are 80 blades in a set, and each blade has a list price of \$9,000-10,000. The potential savings are therefore significant.

Chromalloy also has repairs for HPC stators, HPT shrouds and airseals.

MTU Maintenance also provides some DER repairs for the CFM56-7B, including a split vane repair for the NGV. This costs \$14,000, versus the \$29,000 list price for a new unit. It also offers repairs for combustion chambers.

Pratt & Whitney Engine Services (PWES) also offers DER repairs for HPT first stage blades and NGVs.

Chromalloy offers several PMA parts for the engine, and is developing more. "We already offer HPC stator seals and LPT outer stationary airseals," says Church. "We are now developing PMA blades, vanes, shrouds and HPT blades. We expect to be able to offer HPT blades for \$6,000 each, which comes to \$240,000 less for a shipset. We already offer PMAs for the stage 1 HPT NGVs and stage 1 LPT NGVs, which provide big savings when scrapped parts have to be replaced when they are beyond repair. We offer PMA stage 1 HPT NGVs for \$15,000. With 42 in a set, the saving is substantial.

"The OEM first stage NGVs in the LPT have a list price of \$15,000, while we offer PMA parts at \$9,000 each, saving \$6,000 per unit," adds Church.

DER repairs and PMA parts can save as much as \$350,000 per shop visit.

## Summary

The 737NG's total maintenance costs are \$909-1,128 per FH, depending on aircraft variant and engine model, for aircraft in their first cycle of main base checks, up to their sixth or seventh base checks at an age of 12-14 years, and for aircraft with engines that are up to their third removal and shop visit, which can be as long as 50,000FC and 100,000FH, equal to more than 25 years' operation.

The varying total cost per FH is due mainly to the engine reserves, which gradually increase from the first to the third removal. The engines of most 737NGs are within their first or second engine removal cycles, so higher engine reserves apply to few operators. **AC**

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