737-200 maintenance analysis

An examination of the 737-200's maintenance requirements & guide to direct maintenance costs

The 737-200's maintenance requirements can be sub-divided into line maintenance, hangar checks, the ageing aircraft programme, heavy components, line replaceable components and engine repair.

Maintenance schedule

The 737-100/-200 were some of the last types to have a maintenance programme based on maintenance steering group 2 (MSG2) concepts. The MSG2 concept is one of maintenance inspection tasks having fixed intervals and being grouped into pre-defined checks.

A MSG3 maintenance concept is one of inspections being preventative and performed on an 'on-condition' basis, and where checks can be split into smaller packages or 'equalised'.

Although it is technically possible to change the 737-200 to a MSG3 programme, the bridging process would incur too many man-hours (MH) and expense for it to be economic.

The 737-200's maintenance programme comprises A, B, C and structural/D checks. The intervals for these have been extended from the original published in 1967. The initial D check interval of 6,000 flight hours (FH), and has been extended to 20,000FH. Several operators have extended their own check intervals further after gaining operational experience.

The recommended intervals for operators of late production aircraft are 125FH for A checks, 750FH for B checks, 3,000FH for C checks and 20,000FH for structural/D checks. Individual operators' intervals for these checks higher.

The A check is standardised in most cases. You can have A1 to A6 checks. There are two main groups of B check tasks; the 1B with the largest number of tasks and an interval of 750FH and the smaller 2B group with an interval of 1,500FH. B checks can thus have the 2B items equalised.

There are five different groups of C check tasks. These are the 1C items with a basic interval of 3,000FH. This interval is conveniently four times the B check interval. The 2C items have an interval of 6,000FH, the 3C items 9,000FH, the 4C items 12,000FH and the 7C items an interval of 21,000FH.

These packages are then grouped to form block C checks, so that the C1 check will have just 1C items. The C2 check will have 1C and 2C items, while the C3 check will have 1C and 3C items. The fourth check in the cycle, the C4 check, will have 1C, 2C and 4C tasks. While the 3C items appear again in the C6 check, all groups would be in phase at the C12 check. "The C check cycle, however, can be terminated at the C7 check, if all 1C, 2C, 3C, 4C and 7C tasks are performed together," explains Dominique Vargioni, engineering department at TAT Industries. "The operator has the other option of performing just the 1C and 7C tasks at the C7 check, while the 1C, 2C and 4C tasks would be grouped at the C8 check. This way different tasks would continue to be performed when they came due without ever zeroing the C check cycle.

"The structural and D check items have an interval of 20,000FH. Most operators combine these with the C7 check for simplicity," continues Vargioni. "This is why many operators take the opportunity to zero the C check cycle at this check. Performing the structural inspections requires the removal of many components so it is worth accomplishing all C items at this check. The cycle can be zeroed at any time, however, if there is a change in owner or operator."

These intervals have to be considered in relation to typical rates of aircraft utilisation and probable interval utilisation.

Most operators only achieve about 75% of the A check interval. Assuming 150FH as an average interval, the actual interval achieved would be about 110FH.

Most operators would aim to perform every fourth B check with each C check, and in turn perform the D check at the C7 check when terminating the C check cycle. The actual C check interval achieved may be in the region of 2,600FH. Since this is similar to annual rates of utilisation, the C check would be an annual event. The C6 check would be performed at about 15,500FH and about every six years. The C7 and D check could thus be performed one year later after another 2,600FH were accumulated, since the D check's 20,000FH interval would not be exceeded.

In the case of lower rates of utilisation, the C check may be an annual event. An analysis of direct maintenance costs for a 737-200 is made here, assuming a rate of utilisation of 2,600FH and 2,500FC. This is equal to an average FC time of 1.05FH. This rate of utilisation is representative for aircraft used in passenger operations, but some carriers will operate a smaller number of FC per year. Aircraft used in freighter operations will have utilisations of less than 1,000FC per year.

Ageing aircraft programme

There are three other major inputs into base maintenance in addition to the original items in the maintenance programme. These are the supplemental structural inspection document (SSID), ageing aircraft programme and corrosion prevention and control programme (CPCP).

"The SSID was devised to ensure that any possible structural damage to the aircraft was detected early enough. This was mandated by AD 91-14-20 in the case of the 737-200. This has now been superseded by AD 98-11-04," explains Vargioni. "The SSID requires that aircraft which have accumulated more than 37,500FC are selected for the SSID, which is basically a group of structural inspections on the aircraft's primary structure. These inspections are performed in addition to base check tasks during C or D checks. Moreover, SSID inspections are coordinated with relevant CPCP and maintenance task cards to ease maintenance planning.

"The group of SSID inspections may also be spread over several aircraft, rather than it being performed on every aircraft in their fleet. Aircraft stay in the SSID programme until they are withdrawn from service," continues Vargioni.

The CPCP was devised after concerns over the structural integrity of aircraft that had been in service for a long period. It was mandated as an inclusion into the aircraft's maintenance programme, and affects all aircraft. The CPCP is basically a group of inspections that have been added to the original maintenance programme. These inspections have their own initial and repeat intervals, which vary between two and 12 years. Some of these are calendar intervals and the initial interval is relatively high, while repeat intervals are about half the initial interval. CPCP inspections are added to C or D checks and require the removal of interiors in the aircraft.

Vargioni explains that the ageing aircraft programme is the largest addition to the 737-200's maintenance

The 737-200's heavy maintenance cycle is completed by most operators at the C7 check. Cost of maintenance are increasing as non-routine ratios increase with age.

programme. "This is a group of structural inspections and modifications totalling about 74 service bulletins (SBs). Each of these have an initial inspection, repeat inspection and termination interval," says Vargioni. "Terminations involve a modification, which consumes a varying number of MH and requires the purchase of a kit of parts. The initial and repeat inspections also consume MH, but these are small relative to the number required for modification."

These SBs can be split into four groups, based on the interval for termination by modification.

The first group has a termination interval of 20 years, and numbers eight SBs. Each one has a group of line numbers it applied to, and only three apply to aircraft with high line numbers. That is, built after 1980. These will have already been terminated for most 737-200s, except those built after 1985.

The second group is four SBs which have termination calendar intervals of 1992, 1994 and 1996. These will have all been terminated.

The third group totals seven SBs and all have termination thresholds of 8,000-37,500FC, and so will have been completed for most aircraft in service.

The fourth and largest group have to be terminated by 75,000FC. There are 56 of these SBs, and each one applies to a range of line numbers. Only 27 of these affect aircraft line number higher than 634. That is, aircraft built from 1980 onwards. Aircraft built from 1980 onwards are the most attractive for possible acquisition *(see 737-200 values & aftermarket, page 18)* because of their age and weight specifications. The relatively low number of ageing aircraft SBs that affects these aircraft is an additional factor that makes them attractive acquisition candidates.

The 75,000FC threshold is relatively high for all 737-200s, and operators are likely to retire the aircraft when they reach this number of FC, rather than bear the cost of terminating these modifications.

Line maintenance

Like other aircraft, the 737-200 will have transit, pre-flight and line checks in its line maintenance programme.

These checks have to be considered in relation to the aircraft's utilisation. Transit checks are performed before the first flight of each day, and pre-flight checks before all other flights in the day. Daily checks are usually done overnight every 24 hours. Assuming an annual utilisation of 2,600FH and 2,500FC per year, the aircraft will operate an average of seven flights per day. Excluding grounded time for maintenance, the aircraft will have about 350 daily checks, 350 transit checks and 2,150 pre-flight checks each year.

Transit and pre-flight checks only consume about one MH and $15 in materials and consumables, while daily checks can use six to 10MH and $50 in materials and consumables. These line checks therefore use an annual total of about 5,500MH and $550,000 in materials and consumables. Labour for line maintenance charged at a rate of $70 per MH will take the annual charge to $935,000. This equates to a cost of $360 per FH *(see table, page 17)*.

Operations for freight aircraft with a smaller number of FC per year will result in fewer pre-flight checks but a similar number of transit and daily checks being performed. The result will therefore be a higher cost per FC and FH.

Airframe checks

This analysis assumes that the C check cycle is terminated at the C7 check, which is combined with the D check.

A checks vary in size, but consume an average of about 90 MH and use about $1,500 of materials and consumables. This is low compared to modern aircraft which have MSG3 programmes.

B1 checks will use a total of 250-300MH, while B2 checks use 300-350MH. An allowance of $5,000 should be made for materials and consumables.

The assumed A check interval utilisation is about 110FH, with a B check being performed every sixth A check at 660FH. The B2 check cycle is therefore completed every 1,300FH. Total MH consumed in this cycle will be about 1,700, while material and consumable consumption will be about $28,000. A labour rate of $70 per FH for line maintenance will take total labour cost to about $120,000.

About two of these cycles will be completed each year, within the annual utilisation of about 2,600FH, at a total cost of about $300,000. This is equal to a rate of about $115 per FH *(see table, page 17)*.

The average consumption for the C1 to C6 checks is 3,500MH and $50,000 in materials and consumables. This includes an allowance for work clearance of deferred defects, work on interiors, removal and installation of components, repair of rotables and MH used for various ageing aircraft inspections.

The C7/D check for mature 737-200s will include routine inspections, clearance of non-routine defects, interior cleaning and refurbishment, removal and installation of components, and various inspections in the ageing aircraft programme and CPCP.

An estimate for total MH used for mature aircraft is 16,000-22,000MH. This can be higher, however, if there is a high non-routine ratio and degree of corrosion in the aircraft's structure.

The total cost of materials, consumables, repair of rotables and expenditure on items in the aircraft interior is $550,000-600,000.

This takes total consumption for the C check cycle to about 41,000MH and

Some elements of the 737-200's maintenance costs have reduced in recent years, but high-cost items such as LRU component support are becoming more expensive.

$850,000 for materials, consumables and rotable repairs. Labour for hangar maintenance charged at a rate of $50 per MH takes total cost for these checks to about $2.9 million. This is equal to a rate of $161 per FH when amortised over an interval of about 18,000FH *(see table, page 17)*.

Heavy components

There are basically four types of heavy components; the landing gear, wheels and brakes, auxiliary power unit (APU) and thrust reversers.

Landing gears are typically removed once every eight to 10 years for overhaul. While many operators elect to do a landing gear exchange, the surplus of material on the market will provide airlines with an opportunity to acquire time-continued gears at an economic rate.

The surplus of used 737-200 components on the market also means exchange fees have come under pressure. Exchange fees have the cost elements for overhaul and ownership. Typical market rates for landing gear exchange fees are $130,000. This is lower compared to five or more years ago.

The total FH accumulated during this eight to 10 year removal interval at the assumed rate of utilisation will be 20,000-25,000FH, and so the reserve rate for the landing gear exchange will be about $5-6 per FH *(see table, page 17)*.

The cost of wheels and brakes includes tyre remoulding, tyre replacement after two or three remoulds, wheel inspection, brake repair and overhaul, and brake replacement.

The number of FC between remoulds varies with operator, but is in the region of 200FC. Tyre replacements are thus made about every 800FC. Tyre remoulds cost about $300, and so each of the aircraft's six tyres may be assumed to have a remould cost of $750 for each replacement cycle. New nosewheel tyres cost about $500 and mainwheel tyres cost about $800. Total cost of a new shipset of tyres for the aircraft will be about $4,200. The total cost of remoulding and replacing tyres over each replacement cycle is thus about $9,000, equal to a rate of $11.25 per FC *(see table, page 17)*.

Wheel inspections are made at every removal, and so every 200FC, and have an average cost of $600. This equals $12 per FC for the aircraft *(see table, page 17)*. Brakes on the 737-200 are carbon units. Inspection intervals are dependent on rate of brake wear, and so depend on operation by the airline. The average interval will be in the region of 900FC, while the repair cost for a steel unit on the 737-200 is in the region of $10,000. The amortised cost per FC for the four brake units are thus in the region of $45 per FC *(see table, page 17)*.

The combined cost of tyre remoulds and replacements, wheel inspections and brake overhauls is in the region of $80 per FC.

The thrust reverser units on the 737-200 are the clamshell type, and have an average removal interval of 8,000FC. Repair and overhaul is on an on-condition basis, but an average repair cost is $170,000 per unit, and so equal to about $42 per FC for both reverser units *(see table, page 17)*.

The 737-200 is equipped with the GTCP 85-129. These have a generally low reliability compared to younger models of APU. Average interval between shop visits is in the region of 4,000 APU hours. How this relates to aircraft utilisation depends on the length of time the APU is used during turnaround between flights. In most cases this will be less than one APU hour between flights, and be in the region of 30-45 minutes. This implies the APU could be removed for a shop visit about once every 5,500FC.

Shop visit costs vary, and a conservative cost is about $125,000. The reserve rate per FC is therefore about $23 per FC *(see table, page 17)*. Actual rates may be closer to $15-20 per FH when lower shop visit costs are incurred.

The 737-200's operation of 1.05FH per FC in most operators' cases, means the combined reserves of $133 per FC for wheels, brakes, thrust reversers and APU are equal to about $127 per FH *(see table, page 17)*. This is added to by the reserve for landing gear overhaul of about $6 per FH, taking the total to $151 per FH.

Line replaceable components

There are several ways an operator can acquire support for line replaceable unit component support. Inventory for 737-200s can now be acquired more cheaply from the aftermarket as more aircraft are broken for parts. This is a good source for acquiring the odd parts with low failure rates or high cost, but most airlines prefer to source their line replaceable rotables from third part suppliers, so avoiding high investment in components.

The number of specialist rotable supply, management and maintenance suppliers offering services for the 737-200 is reducing as the fleet diminishes. Rates quoted depend on fleet size, operation and number of part numbers that are covered in the contract. Rates which include the supply, management and repair of components for a high, but not complete, coverage of parts are $150-180 per FH *(see table, page 17)*.

Besides this cost, airlines also have to consider the management of aircraft in terms of dealing with aircraft-on-ground situations, acquiring parts that are not covered in line replaceable component contracts, and organising unscheduled repairs. Other engineering costs include the keeping of maintenance records and the overall technical management of the aircraft.

Engine maintenance

The 737-200 has the advantage of being powered by the JT8D, which is a simple and easy-to-maintain engine. The average removal interval for the engine varies according to thrust rating and engine flight hour (EFH) to engine flight cycle (EFC) ratio. In the case of the 737-200 this is 0.90-1.10EFH per EFC for most operations. The average for most operators is about 1.1EFH per EFC.

An annual utilisation of about 2,500FC compares to typical on-wing intervals of 4,500-5,500EFC, implying each engine is removed for a shop visit once every two to three years. Shop visit intervals have to be considered against shop visit workscopes and the management and replacement of LLPs.

Many JT8Ds are managed in an alternating pattern of light and heavy shop visit workscopes, sometimes referred to as engine shop visit one (ESV1) and engine shop visit two (ESV2).

The ESV1 workscope is generally a hot section inspection plus repair on one or two other modules, while the ESV2 workscope is an overhaul. If this pattern is maintained, then LLPs can be replaced every fourth shop visit and every second ESV2; allowing a high utilisation of all LLP lives. That is, a low average interval of 4,000EFC means LLPs will need replacing after about 16,000EFC, while longer average intervals will allow LLP replacement at 18,000-19,000EFC.

Shop visit intervals, workscopes and LLP replacement timings also have to be considered in relation to AD 2003-12-07. This AD supersedes AD 98-12-07, which required the inspection of steel HPC disks for corrosion. This particularly concerned engines operating in low utilisation operations.

AD 2003-12-07 requires inspection of all disks every eight years for most part numbers, irrespective of rates of utilisation. Overhauls or heavy shop visits are about every 9,500EFH/9,000EFC in the case of the 737-200 analysed here. Annual utilisations of 2,000-2,500EFC mean that these inspections can be made within the calendar limit without forcing early removals.

Typical inputs for an ESV1 are 2,000-2,500MH, up to $300,000 in parts and materials and $50,000 of sub-contracted repairs. The cost of materials, parts and sub-contracted repairs are low compared to modern types such as the CFM56 and V.2500. The cost of materials and parts for the JT8D has declined in the past three years because the large number of these engines that have been retired. This has thus reduced the average cost of shop visits. A labour rate of $70 per MH takes the cost for a large ESV1 up to about $525,000; although in the region of $400,000-450,000 in many cases.

DIRECT MAINTENANCE COSTS FOR 737-200

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line checks	$935,000	2,600FH		360
Hangar checks	$2,900,000	18,000FH		161
Heavy components:				
Landing gear	$130,000	20,000-25,000FH		6
Tyre remould & replacement	$9,000	800FC	11	
Wheel inspections	$2,400	200FC	12	
Brake inspections	$40,000	900FC	45	
Thrust reverser overhauls	$340,000	8,000FC	42	
APU	$125,000	5,500FC	23	
Total heavy components			133	127
LRU component support				150-180
Engine maintenance	$1,250,000	9,500FH		115-130
Spare engine coverage				10
Total				**1,100-1,150**

Based on an annual utilisation of 2,600FH and 2,500FC.

An ESV2 uses 2,500-3,000 MH, in the region of $550,000 in materials and parts and requires about another $100,000 in sub-contracted repairs. This takes the total cost to about $800,000-860,000.

The fan and low pressure compressor sections can often only require work at the third shop visit, so affecting the scope of the ESV2 and increasing the subsequent ESV1.

These two shop visits combined total in the region of $1.1-1.25 million, and amortised over an interval of about 9,500EFH equal a rate of $115-130 per EFH. The cost of LLPs has to be considered against this.

A full set of LLPs now has a list price of just $600,000, and may be amortised over a period of 19,000EFH/18,000EFC. This equates to a further reserve of $32 per EFH, taking total engine reserve to $147-162 per EFH *(see table, this page)*. This is comparable to modern generation engines, such as the CFM56-3 and V.2500. Although these engines have longer removals between shop visits, even when mature, they have higher costs for parts and LLPs have higher list prices.

The cost of supplying spare engines also has to be considered. Average removal intervals and rates of aircraft utilisation indicate that passenger operators can expect to have about one engine removal per aircraft per year. The total time each engine is away during transport and shop visit will be 75-90 days every year, and operators need spare engine coverage for this. Engines can be owned, leased long-term or leased for short periods. The total time an engine is removed for each aircraft indicates that, for the assumed rate of utilisation, one spare engine will have a high rate of utilisation for every three or four aircraft operated in the fleet. Owning a spare engine will be economic for an operation that is expected to continue for several more years, considering the low market value of good quality engines. This is $300,000-450,000 for refurbished JT8D-15/-17s. Amortising ownership of this engine between four aircraft over five years at an interest rate of 6% equals a cost of about $25,000 per aircraft per year, or $10 per FH.

Maintenance cost summary

The total of these elements is about $1,100-1,150 per FH for direct maintenance cost *(see table, this page)*. This is comprised of $360 per FH for line checks, $115 per FH for A and B checks, $161 per FH for hangar C and D checks, $133 per FH for repair of heavy components, $150-180 per FH for LRU component support and repair, $147-162 per FH for engine reserves and $10 per FH for spare engine coverage. This cost is relatively high for an aircraft of this size, and is likely to increase. Although the cost of engine shop visits might fall, the 737-200 will consume more MH and materials in its line and hangar checks as the aircraft age. Cost of LRU component support is also increasing. Total maintenance cost per FH would be more for aircraft operating at lower rates of utilisation, mainly because of the high number of line checks relative to aircraft utilisation. AC