The 737 is in regular use in commercial fleets worldwide. This aircraft's success lies not only in its ease of use, but also in its ease of maintenance. The components and costs of each package are detailed here.

The 737-200 and -300/-400/-500 series: a guide to maintenance costs

The 737 is the most widely used aircraft in air transport. Virtually all jet operators have used a 737 at one time or another. The aircraft is simple to use, it has widespread support, and is a known quantity.

Every examination of the 737's regular maintenance costs is comprehensive, and contains many elements. All components of the aircraft's on-going maintenance requirements except for engine overhaul are examined here for the -200 and -300/-400/-500 series.

Maintenance elements

There are six elements of regular maintenance: airframe checks, interiors, stripping and painting, the corrosion prevention and control programme (CPCP), modifications and components.

The steps for assessing maintenance costs are: analysis of the organisation of maintenance elements, the frequency and variability of frequency of the maintenance tasks, the manhour and material inputs for these tasks and the resulting cost of each element per fixed calendar period, flight hour or flight cycle.

737-200 check intervals

The 737-200 and /-300/-400/-500 series have similar maintenance schedules, each based on Boeing's maintenance planning document (MPD).

The 737-200's schedule works on the basis of standard A checks and equalised B and C checks.

The standard A check package has a MPD interval of 125 flight hours (FH). This interval has been extended to about 200FH by most operators. The standard A check is carried out up to five times before the B check becomes due.

There are two B check packages – B1 and B2 – but the B1 check includes most of the B check items. The B1 check has an MPD interval of 750FH. The different B2 items include a few job cards, and these are performed every 1,500FH.

The C1 check has an interval of 3,000FH and so coincides with the fourth B check, as well as the 24th A check.

The C checks are equalised from C1, C2, C3, C4 and C7 packages. Although the basic C check has an interval of 3,000FH, the C7 interval is 20,000FH. The C7 is performed with the C1. Most operators also elect to perform the C2, C3 and C4 checks at the same time to terminate their interval cycles. This group of checks is also performed with the structural items (SIs) to combine what is generically known as the D check. The same system for C checks is used on the -300/-400/-500 series. Based on an annual utilisation of 2,500FH, a D check is performed every eight years.

The -200 series also has transit and daily checks, with intervals of one flight cycle and 24 hours for line maintenance. "The 737-200 MPD does not have a weekly check, but if operators add one then the daily check becomes light," explains Donal James, technical services manager at Heavylift Engineering.

737-300/-400/-500 intervals

The MPD for the 737-300/-400/-500 series is based on a system of equalised A and C checks. There are four A check packages of 1A, 2A, 4A and 8A checks. The 1A package has an interval of 200FH and the 2A, 4A and 8A packages have corresponding multiple intervals of 400FH, 800FH and 1,600FH.

The 737-300/-400/-500's equalised C check pattern is similar to the -200's. The first 737-300s are coming due their second C7/D check.

There are 16 equalised A checks, the 16th having an interval of no more than 3,200FH. The composition of each multiple depends on the FH interval. For example, the 6A check multiple at 1,200FH combines a 1A and 2A package.

The 16th A multiple coincides with the 1C check. The equalised C check is based on five C check packages. The 1C package has an interval of 3,200FH. There are also 2C, 3C, 4C and 7C packages, again with corresponding multiple intervals.

The 1C check, with an MPD interval of 3,200FH, is performed along with the A16 check. The latter checks are thus performed with every equalised C check.

"If an operator performs the C check before accumulating 32,000FH it would still be required to perform all outstanding A checks," explains Martin Leslie, planning engineer at FLS Aerospace.

As with the -200 series, there are seven C check multiples. The D check consists of the same items as the 737-200 D check. This 7C has a MPD interval of 22,400FH. An annual utilisation of 3,000FH would require a D check every seven to eight years.

Schedule optimisation

In addition to airframe checks, the -300/-400/-500 series also has a transit, or between-flight check, as well as daily checks for line maintenance.

Although operators with experience of a large number of aircraft can get extensions for these intervals, the global fleet average for check intervals is close to the MPD intervals.

The MPD and maintenance schedule for the -300/-400/-500 series is based on an average cycle time close to 1.4FH, almost 3,000FH and 2,150 flight cycles (FC) per year, a total achieved by most operators. Of course, some operators have longer and shorter average cycle times and so can tailor maintenance schedules to suit their requirements.

One example is Braathens, the domestic Norwegian carrier. "Braathens operates in a harsh environment with a lot of turbulence, freezing weather and salty atmosphere at many airports," explains Egil Askeli, senior engineer airframe engineering at the carrier. "We also have very short cycles of 32 to 45 minutes, which is half the global fleet average. This means we are able to spot weaknesses with aircraft at an early age. This includes parts of the aircraft vulnerable to corrosion.

"We have customised maintenance for our aircraft and do preventative work on the doors and re-condition the flaps at every C check as examples. We know it is necessary to do some D check items every C check," says Askeli.

Sophisticated computer systems are evolving to plan checks and monitor their consumption of routine and defect manhours and materials.

Braathens' average cycle time means that items which have cycle limits will become due before FH related items. The opposite would be true in an operation with a cycle time closer to average. Its maintenance schedule has to be tailored. Braathens has a C check interval of 18 months and a four-month 'float' period. The maximum interval of 22 months has no FH limit and there are six C check multiples, with the C6 or D check being performed every nine years. The four-month float period gives the airline planning flexibility. Braathens also manages and performs heavy maintenance for other operators.

Manhour consumption

Manhour consumption for line maintenance and A and C checks can be estimated on the basis of several parameters.

The first of these is that the airframe check packages are based on job cards derived from the MPD. All maintenance providers escalate these cards when estimating the inputs for a check because the manufacturer's estimates are based on ideal conditions. "Most providers work on an escalation factor of 1.6 to 1.7," says Askeli. "This provides an accurate estimate of routine manhours."

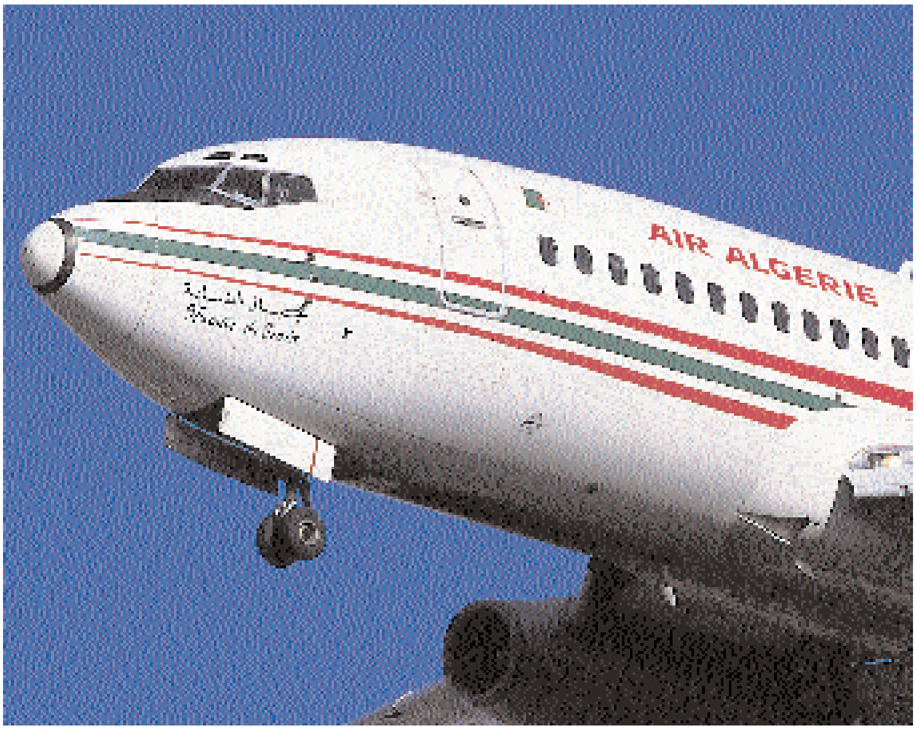
The MPD manhours for most checks are close to the total of each check package added together. A C1 check for a 737-300/-400/-500 will therefore be the 1A, 2A, 4A, 8A and 1C combined, which totals about 453 manhours (including 110 for the 16A and 343 for the 1C).

Routine inspections then incur non-routine rectification. "The actual ratio between routine and non-routine depends on the check being performed, the age of the aircraft and the number of check cycles the aircraft has already been through and average cycle time of the aircraft," says Askeli. "The ratio varies from less than 0.5 to more than 1.5."

FLS Aerospace's Leslie notes: "The highest defect ratio would be about 2.5:1.0 for an old aircraft. An A check ratio is normally between 0.25 and 0.50:1.0 for a 737-300/-400/-500 and 1.0 to 1.75:1.0 for a C check. A ratio of 1.75:1.0 is for an aircraft which has not been maintained well by its operator on the lesser checks."

A defect ratio as high as 1.5:1.0 should be used for a 737-200 A check. A lower ratio of 1.0 is about the level for B checks and 1.5 for C checks.

Further to routine and non-routine manhours, an additional amount of time should be added for handling, docking



The second C7/D check for the 737-200 can consume between 21,500 and 35,000 manhours.

and supervisory work. "We use an assumption of 15% of the sub-total of estimated routine and non-routine manhours," says Leslie.

The A check for the 737-200 takes up about 60 manhours. A further 30 should be added for regular cleaning and interior work, taking the total to 90 manhours.

The B1 check, which includes the A check, uses about 200 manhours and the larger B2 check about 235. Another 50 manhours should be budgeted to cover interior and cleaning work, taking the total to 245–285 manhours.

The aircraft consumes about one manhour in each transit check and six or seven manhours in the daily check.

Manhours for the C1 to C6 checks for the -200 series vary between 3,000 and 4,000 manhours. This includes interior work or manhours taken up when carrying out modifications. C checks allow little downtime for interior refurbishment, but interior work uses about another 200 manhours. The average C check will thus consume 3,500 manhours.

The -300/-400/-500 series uses a similar number of manhours for transit and daily checks. The equalised pattern of A checks means that between 25 and 325 manhours are used on A check multiples for MPD work. Average consumption for A check multiples is about 90 manhours, to which an additional 30 should be budgeted to cover routine interior work and cleaning.

C check manhour usage varies between 2,500 and 3,500 manhours for pure MPD work and another 200 for routine interior work and cleaning. This takes the average total to 3,200.

CPCP and D check

The ageing aircraft programme for the -200 and -300/-400/-500 series is complex.

The programme for the -200 series has three elements: the CPCP, the supplemental structural inspection document (SSID) and structural modification bulletins.

"The SSID came out in April 1983 and was applied to aircraft which at the time had accumulated more than 37,000 FC," explains Askeli. "Originally this only affected a certain group of -100s and -200s. The programme was to determine how age had damaged aircraft and define an aircraft's life limit".

Of the other two elements, structural modifications are performed once only and are not a cost of regular maintenance, whereas the CPCP is a continuous process which adds manhours to maintenance requirements.

"There is overlap with the CPCP and SIs and corrosion prevention (P) items, which are MPD items superseded by the CPCP. The SIs and P items are covered in the MPD for the -300/-400/-500," says Serge Vrancken, head of airframe heavy maintenance at Sabena Technics. "If an operator does all the SIs in the D check then it covers 75% of the full CPCP in the process. This is because the two involve the same or similar inspections. If all the P items are done as well then 90% of the full CPCP is done. P items are not mandatory on all aircraft and SIs can be sampled across a large fleet. They will therefore not all get done on all aircraft. The CPCP items are mandatory, however, and so all the items do eventually get covered. The fleet size and operators attitude towards maintenance determines what additional manhours are required by the CPCP."

The CPCPs for each aircraft are complicated by the fact that there are many different inspections. Each has its own initial inspection and repeat inspection thresholds.

The initial inspection thresholds do not mean the task has to be carried out by this age, but rather that it has to be done for the first time between the initial threshold and first repeat interval.

The fact that initial inspection thresholds for most CPCP items are more than seven or eight years means the first D check and preceding C checks will be relatively light of CPCP items. The C checks following the first D check and subsequent D checks will have a much higher CPCP content.

"Because CPCP work requires access and similar inspection work to the items in the D check, performing CPCP tasks with a D check means not many additional manhours would be added to the D check total for CPCP items that are already required," explains Paddy Ryan, production planning manager at Shannon Aerospace.

"On its own a full CPCP programme would consume about 10,000 to 11,000 manhours for inspections and defects. This is because 5,000 would be used just to get access. The first D check on a 737-300/-400/-500, which would have very little CPCP work, would use about 12,000 manhours for the MPD inspections and consequent defects.

"The D check would require about 800 manhours for thorough cleaning, 2,500 for the removal and re-installation of the interior, another 2,500 to take out and re-fit the flight controls and horizontal stabiliser, 1,200 to open the wings and to take off the engines for pylon inspections, 700 for work on the landing gear and hydraulics, 2,200 for sheet metal repair and 1,800 for the removal, testing and re-installation of avionics. This takes the total to just less than 12,000. This does not include any repairs of rotables or components in the shops," says Ryan.

He adds: "About another 500 hours should be added for flaps and movable flight controls and 350 for composites. The total manhour consumption for the basic D check will total approximately 13,000. The lowest for a first D check is about 10,500 to 11,000."

Operators should budget about 13,500 manhours for a first D check on the -300/-400/-500 series. "About another 1,400 should be added for painting," says Ryan.

The second and subsequent D checks are more difficult to estimate with respect

737-200 FLIGHT HOUR (FH) MAINTENANCE RESERVES

Maintenance Item	Interval	Manhours consumed	Manhours cost ($)	Materials used ($)	Rotables/ interiors ($)	Total cost ($)	Cost per flight hour ($)
Pre-flight check	Per cycle	1	50			50	40
Daily check	24 hours	6	300			300	42
A-check	125–200 FH	90	4,500	1,500		6,000	30–48
B-check	750–900 FH	265	13,250	5,000		18,250	21–24
C-check	3,000 FH	3,600	180,000	45,000		225,000	75
D-check	20,000 FH	16,500–35,500	825,000–1,775,000	270,000	250,000	1,345,000–2,295,000	67–115
Landing gear exchange	D-check					150,000	8
APU repair	6,000FH					90,000	15
Brake repair	700FC					35,000	26
Tyre remould/ replacement	200 FC/ 800 FC					3,200	11
Wheel replace	16,00FC					32,000	16
LRU PBH rate							190
Total cost per flight hour							**541–610**

This table is based on an annual utilisation of 2,500FH, 2,000FC and an average flight time of 1 hour and 15 minutes.

to manhours. This is because there will be a higher defect ratio and a larger amount of CPCP work.

"Preventative maintenance reduces the defect ratio," explains Askeli. "Preventative maintenance means you accept lower tolerances on condition-monitored components and systems. This means you repair them when they have reached a low state of degradation. This will be earlier than if not doing preventative maintenance. This philosophy for maintenance improves technical despatch reliability (TDR). Although this practice means more frequent inspections it results in a lower level of non-routine work. It also means D check packages will be smaller since components will have had repairs at an earlier date."

A conservative estimate for a second D check would be about 16,000 manhours. This could be as high as 30,000 manhours, however, if maintenance and repairs are poor on the previous D check and subsequent C checks. This number of manhours is quite often required on a second D check for a -200. Only the first -300s are now becoming due for their second D check.

Additions to checks

While these manhours have been escalated considerably since the MPD estimates, there are still other manhours to add for regular maintenance items. Checks also include component overhaul, cabin refurbishment work, modifications and changes of heavy components.

While these components are maintained according to their own schedule, they are removed and replaced during airframe checks and the manhours required have to be added.

"An engine change uses about 250 manhours," says Ray Kazmierczak, head of engineering & planning at Shannon Aerospace. Engine changes can occur during any check, but are determined by their condition.

"Landing gear changes consume about 350 manhours," says Kazmierczak. The landing gear on the -200 series has a removal interval of 20,000FH and 10 years. In this case it would be aligned with the D check, which would occur about every eight years. The -300/-400/-500 gear has a removal interval of 22,400FH, 16,000 cycles and eight years. At a utilisation of 3,000FH per year the D check and landing gear removal would occur every seven to eight years. The overhaul of components and cabin interior refurbishment are both normally confined to D check. This generates additional manhours which are generally included in the cost of rotable repairs.

The number of manhours used for incorporating modifications covered by service bulletins (SBs) are hard to predict. A large operator will modify its fleet with the same SBs and will incorporate them over a contract period. A lessee with an aircraft on short-term lease will keep SBs down to a minimum.

As a guide, an average of 100 manhours could be spent on SB incorporation during C checks and about 1,500 during a D check.

The final major element for a D check usually involves refurbishment of the interior. "There is very little in the MPD with respect to the interior," says Kazmierczak, "but operators always know, for example, that there will be defects on the doors. The same is true for the interior. A full refurbishment will consume about 2,500 manhours. This would include overhauling the galleys and lavatories, recovering sidewall panels, putting in a new carpet and seat covers, overhauling the seats and re-spraying all the passenger service units. This would effectively make the interior look new."

Total manhours

These additional items then increase manhour consumptions for the -200 as follows: one for the transit checks, six for the daily check, 90 for the A check, an average of 265 for the B check and about 3,600 for the C check. The second D check should start at about 21,500 and could be as high as 35,500 for the second and subsequent D checks.

With the -300/-400/-500 series manhour expenditure includes one for the transit check, six for the daily check, 120 for the A check and about 3,300 for the C check. The first D check should consume about 19,000 manhours and would rise to about 21,500 manhours in the second and subsequent D checks if the aircraft is well maintained after the first heavy maintenance visit.

Maersk Data has developed a computerised system for maintenance job card production, tracking manhour and

737-300/400/-500 FLIGHT HOUR (FH) MAINTENANCE RESERVES

Maintenance Item	Interval	Manhours consumed	Manhours cost ($)	Materials used ($)	Rotables/ interior ($)	Total cost ($)	Cost per flight hour ($)
Pre-flight check	Per cycle	1	50			50	36
Daily check	24 hours	6	300			300	35
A-check	200 FH	120	6,000	1,500		7,500	37
C-check	3,000 FH	3,300	165,000	45,000		210,000	70
D-check	22,000 FH	19,000–21,500	950,000–1,075,000	270,000	250,000	1,470,000–1,595,000	57–72
Landing gear exchange	D-check					150,000–170,000	7–8
APU repair	6,000FH					90,000	15
Brake repair	700FC					35,000	23
Tyre re-mould/ replacement	200 FC 800 FC					3,200	10
Wheel replace	16,00FC					32,000	23
LRU PBH rate							130
Total cost per flight hour							**453–459**

This table is based on an annual utilisation of 3,000FH, 2,150FC and an average flight time of 1 hour and 24 minutes.

material consumption and defect ratio occurrence on maintenance jobs. Maersk Data has developed the system for launch customer the system for launch customer Maersk Air.

The System has two parts. The first (Tech IT) is the production of maintenance jobcards. This system was implemented using SGML (ATA spec 2100-compliant) data from Boeing. The system accumulates data from the MPD, task intervals and instructions from the maintenance manual. These sources are the usual way of generating jobcards, but Maersk Air says the system reduces the time to perform this task by over 90%.

A huge overhead and labour cost is deleted in the process, while most maintenance facilities generate these jobcards manually. The elimination of all manual labour means labour efficiency is also improved. Another advantage is that human errors generated by inputting correct data are avoided.

The system generates further advantages. Manufacturers revise maintenance manuals for each aircraft type about three times a year. This process is normally performed manually and requires engineers to search for jobcards affected by the revision, which is a massive job.

This process normally takes three or four weeks per revision per aircraft type, but is reduced to a matter of minutes by Maersk Data's system. It is this process which generates the 90% timesaving. Maersk is currently supporting the system with the 737, 777 and Fokker 50. The system can also pull out tasks not specifically required for an aircraft, which includes items such as SBs.

Materials and rotables

Aircraft materials consist of consumable parts and items used to assist the airframe check. A budget for material costs is $1,500 for an A check and $5,000 for a B check. A ratio of about $15 to $20 per manhour spent is used for C checks, thus $45,000 would be spent on a C check consuming 3,000 manhours. Similarly, a D check using 18,000 manhours would use $270,000 of materials.

D checks also involve the overhaul and repair of rotable items. A budget of $150,000 for these tasks is a good average, although the cost can occasionally be less than $100,000 or more than $300,000. Interior refurbishment should also be added. A working average for this during a D check is about $100,000 for materials and parts.

These materials, parts and rotable repair costs and labour expenditure subsequently determine the cost to perform airframe checks.

Components

This element of maintenance includes line replaceable units, landing gears, wheels, brakes, tyres and the auxiliary power unit.

In the majority of cases, the landing gears on both the 737-200 and -300/-400/-500 series would be removed for overhaul at the D check stage. This would occur at about every 20,000FH for the -200 series and at about every 22,400FH for the -300/-400/-500 series. The -300 and -500 have the same landing gears, while the -400 has a heavier set. The -200 has a unique set of landing gears.

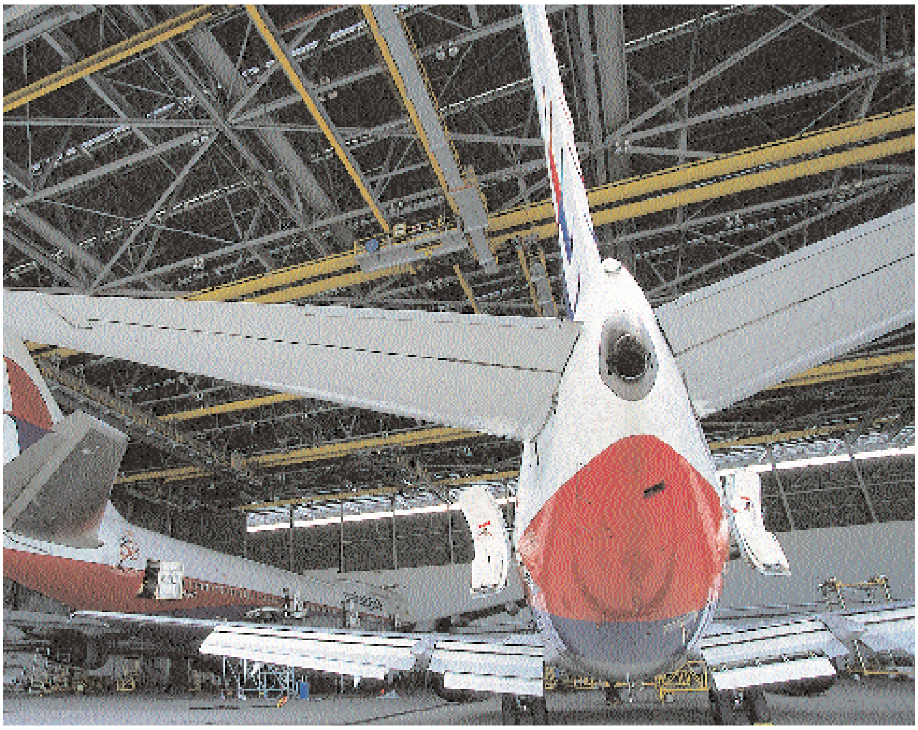
Many airlines now elect to do a landing gear exchange rather than perform overhaul in house. This type of arrangement has a fixed cost, which covers overhaul, and an element for ownership of spare inventory.

Exchange fees for landing gears will increase with age as life-limited parts have to be scrapped. A guide price for a 737 landing gear exchange is about $150,000, including exchange fee and repair costs for -200,-300 and -500 aircraft. The cost rises to about $170,000 for the heavier gear supporting the -400.

Considering this task is usually carried out at D checks, the interval between removals will be 20,000FH for a -200 series aircraft and 22,000FH for -300/-400/-500 series aircraft. This makes the reserve rate for landing gears $7.50 per FH for the -200, $6.80 per FH for the -300 and -500 and $7.80 for the -400.

Tyres are remoulded three or four times before being replaced. Removals occur about every 150 to 250 landings and replacements every 800 landings. This usually results in about eight remoulds and two or three tyre replacements a year for a -200 accumulating 2,000FC. The -300/-400/-500 aircraft that achieve about 2,200FC per year will experience about nine remoulds and three replacements in that time.

A remould for a full set of tyres costs between $1,750 and $2,150, and replacement costs $4,000–$6,000. Taking into account the number of remoulds and intervals, costs average out at about $14.00 per FC. This equates to $11.20 per FH for the -200 and $10.00 per FH for the -300/-400/-500 series.



With an operation of 3,000 FH and 2,150 FC per year the 737-300/-400/-500 could be expected to have airframe and component maintenance costs of about $460 per FH.

Wheels are repaired on-condition and are inspected every seven or eight tyre changes. Non-destructive testing for corrosion is also performed and once wheels crack they are thrown away. As with landing gears, the wheels for the -300 and -500 are the same, while the wheels for the -400 and -200 are different.

A new main wheel costs $6,500 and a nose costs $3,000. Assuming a complete replacement every eighth tyre change, or at 16,000FC, the cost per FH is $16 for the -200 and $23 per FH for the -300/-400/-500.

Brakes have to be overhauled about every 600 to 800 landings and are repaired until the repair cost becomes higher than the cost of new ones. The average cost for repairing an aircraft's four sets of main wheel brakes is about $16,000. A new set of brakes costs about $44,000. On the basis of a new set being required after three repairs, the cost for brakes will be about $33 per FC, $26 per FH for the -200 and $23 per FH for the -300/-400/-500 series.

There are several auxiliary power units (APUs) on the 737. The -200 series has the Allied Signal GTCP 85-129, and the -300/-400/-500 series have the GTCP 85-129E/H/J/K, GTCP 36-280 and APS 2000, respectively. "The APU on the -200 tends to have a more consistent, or hard, time between hot section inspections (HSIs) and overhauls than the APUs on the -300/-400/-500 series," says Dirk Werquin, general manager, component workshops at Sabena Technics. "It is hard to give an exact figure for on-aircraft times between HSIs and overhauls because it depends on the operational time of the APU and not flight hours or cycles. The current-generation APUs achieve about 4,000 hours between overhauls."

Some operators have worked on a hard time of 5,000FH between HSIs and overhauls. An on-condition programme can be used and this results in longer intervals of about 5,000FH for the -200 and 6,000FH for the -300/-400/-500.

The average third-party shop visit cost for a HSI and overhaul can be conservatively taken at $90,000. This results in a cost of $15 per FH.

One final crucial element of components are the supply of line replaceable units (LRUs). Budgeting for this, however, remains an impossible task. The rate at which LRUs must be removed and repaired is unpredictable, and the number of replacements needed is complicated by the amount of operating bases and sectors an aircraft fleet serves.

For this reason many smaller carriers have arranged a PBH agreement with larger airlines and major spares suppliers to supply sufficient LRUs and the relevant support to provide enough inventory to keep the fleet operational.

Airline Rotables is an example of just such a supplier of LRUs. The company charges an airline on a flying hour basis. The rate depends on several factors, including the number and age of the aircraft, the type and utilisation of operation and the coverage the airline wishes to have. Airline Rotables also sets up consignment stocks at outstations. These generally include no-go items and parts with high failure rates.

An airline will use its own line engineers and subcontract the use of others to perform line work, including the removal and replacement of LRUs. For budgeting purposes a LRU PBH package will cost in the region of $170 to $200 per FH for -200s and $110 to $150 per FH for the -300/-400/-500s. This cost does not include the supply of heavier rotables, such as wheels, brakes and tyres, which are all covered separately.

Maintenance budget

If we amalgamate the costs for all the elements examined here, we can calculate an estimate of cost per flight hour covering all regular maintenance with the exception of engine shop visits.

Third-party providers must estimate manhours for a check before accessing the aircraft. Grady Mixon, program manager at Pemco, points out: "When we bid for a job we take routine manhours, budget for non-routine and estimate the customer's additional requirements. We can then monitor the progress of the check each day. We have a computer system which uses barcodes on jobcards to monitor how many hours are being spent on each job."

The second part of Maersk Data's system (Plan IT), currently under final development, will allow airframe checks to be planned to achieve optimal efficiency. The planning of several thousand items for each check is a huge task. New maintenance standards mean new-generation 737s and the 777 are not controlled by traditional letter checks, but rather allow operators to amalgamate jobcards and determine their own checks.

The system creates checks by combining jobcards according to intervals. Letter checks are controlled by the lowest common denominator of all tasks; by controlling tasks on the item level the system creates checks that maximise task interval and downtime efficiency.

With barcoded job cards, the system then monitors manhours required for defects and records descriptions of defects put in by the mechanics. The system also monitors the progress of each check with respect to manhours and downtime consumed. Statistics are created for used manhours and materials to support future maintenance planning.

Total costs per FH are summarised *(see tables, pages 32 and 34)*. The cost per FH of the airframe checks are based on the estimated manhour and consumption and material cost divided over the standard flight hour limit of each check. In reality not all checks have these intervals. For example, not all 16A check multiples are terminated when the C check is reached, nevertheless they must still be terminated.

The resulting cost per FH for both families is close to industry standards for these aircraft, though there will be variables. AC