747-200/-300 maintenance analysis & budget

The 747-200/-300 has high maintenance costs, although operators can minimise these as aircraft approach retirement.

The 747-200/-300s that remain in service are between 15 and 34 years old *(see 747-200/-300 fleet analysis, page 8)*. This means that virtually all aircraft in operation have had three D checks, while the oldest will have been through five. Many 747-200s and -300s operate as freighters or converted freighters, while no more passenger-configured aircraft are being modified to freighter. Most aircraft will continue in operation until they reach their fifth D check or up to a maximum age of 30 years.

Most aircraft now accumulate about 3,500 flight hours (FH) per year and have an average flight cycle (FC) time of 5.0FH, thereby generating about 700FC annually.

Maintenance programme

The 747-200/-300's line maintenance programme is standard for most types. The aircraft has transit and pre-flight checks prior to each flight, and daily checks. While daily checks on short-haul aircraft are performed at night when the aircraft are grounded, 747 operators still have to do daily checks when the aircraft return to home base, or occasionally at outstations. Many operators are permitted interval extensions of 48 hours for daily checks. Ameco Beijing, which manages the maintenance for Air China's 747-200F fleet, has a system with an AF check every 24 to 48 hours, as well as a daily check performed every five elapsed days of operation.

There are five A check multiples: the 1A, 2A, 3A, 4A and 6A items. The A check cycle will therefore be completed at the A12 check when all task groups are in phase. The basic interval for 1A items varies. Ameco Beijing has an interval of 300FH. "The A check cycle has an interval of 3,600FH, which coincides with our basic C check interval," says Michael Keller, manager of production engineering & planning department at Ameco Beijing.

Maintenance schedules for A checks are similar for most airlines, although some operators choose to equalise the A check packages. Air New Zealand had a block check system, but had a basic 1A interval of 450FH which was later escalated to 550FH.

El Al operates a unique ramp and A check system. "Until now we have used a system of transit checks prior to each flight, a daily check every 24 hours performed at Tel Aviv, and E800 and L800 checks to deal with engine-related and lubrication items from the A check instead of having a full A check. These two have an interval of 800FH," explains Moti Sonsino, director of aircraft overhaul and logistics at El Al Engineering. "We then have a larger B check every 1,600FH. Our fleet of five aircraft is now between 24 and 27 years old, and we are going to change to a system of having an A check every 400FH to replace the E800, L800 and B checks. This is because the number of defects is gradually increasing and more frequent line checks are needed to manage it."

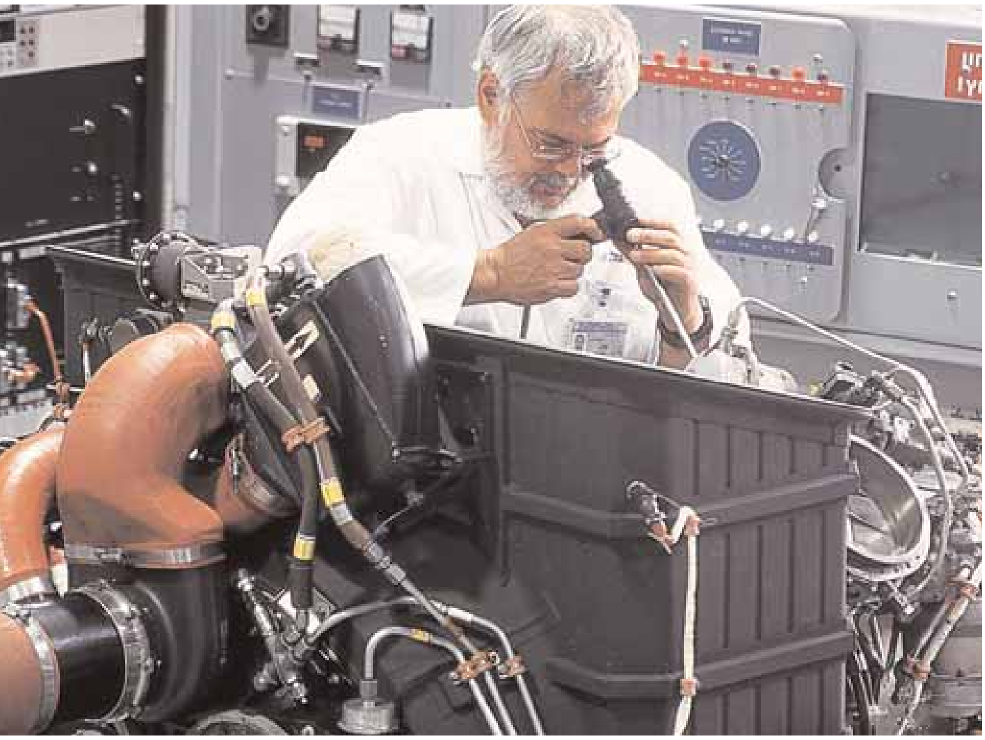
The 747-200/-300 originally had an MSG-2 maintenance programme. Most operators have remained with it.

The 747-200-300 has a block C check programme, with five multiples. "The basic C check interval is 3,600FH and 15 months, whichever comes first," explains Keller. "The five multiples are 1C, 2C, 3C, 4C and 6C groups of tasks. These can be equalised, but we group multiples accordingly to perform block checks, with the C4 check having the 1C, 2C and 4C items. The C6 check has the 1C, 2C and 3C items. This has an interval of 21,600FH, and the C7 check has an interval of 25,000FH. There are also a few items at 20,000FH, which are de-escalated to the C5 check.

"The D check is independent of the C check, and the D check interval varies according to which one has been performed," continues Keller. "The D1 has an interval of 25,000FH, the D2 an interval of 22,000FH, and the D3, D4 and D5 all have a 20,000FH interval. This 20,000FH interval coincides with the probable timing of the C6 check, at which point the C check cycle is terminated."

Other operators have longer C check intervals. "We had an interval of 5,000FH, and then escalated this to 6,000FH and 15 months," says Graham Wallace, project leader engineering services at Air New Zealand Engineering Services (ANZES). "Our D check interval was 25,000FH and was then extended to

The 747-200's/-300's ageing aircraft programme adds a large number of MH to base checks. Full workpackages for D checks can be 90,000-100,000MH for aircraft at their D4 or D5 checks.



Rotables can be paid for via a flight hour agreement. The implosion of the 747-200/-300 fleet, however, means many airlines can reduce their cost of rotables by acquiring items at low rates on the used market.

30,000FH. We originally phased our maintenance programme by performing 1/8 of 1C items, 1/16 of 2C items, and 1/32 of 4C items in each check, which was performed about every eight weeks. We then changed to a block system, with a C check about every 13 months."

El Al equalises its D check over six C checks. The C check has a basic interval of 4,800FH and 24 months, whichever comes first," explains Sonsino. "We use about 90% of the full cycle interval of 28,800FH, and so complete it at about 24,000FH."

Ageing programme

In addition to base maintenance checks in the MSG-2 maintenance programme, operators have to consider additional maintenance requirements connected to the aircraft's ageing aircraft programme. "There are four main parts to the 747-200/-300's ageing aircraft programme," explains Sven Pawliska, team leader system engineering at Lufthansa Technik. "The first of these is the corrosion prevention and control programme (CPCP). This is a set of about 30 inspection tasks to check for corrosion, which have initial thresholds of between four and 30 years. These also have repeat inspection intervals. These inspection intervals are not in the same phase as the C and D checks in the MSG-2 maintenance schedule. The addition of the CPCP to the C and D checks means they vary in workscope content and MH requirement.

"The second main part of the ageing aircraft programme is the supplemental structural inspection document (SSID). This is sometimes referred to as the SSIP," continues Pawliska. "This is independent of the MSG-2 maintenance programme, and the SSID should not be confused with the significant structural items (SSI), which is a part of the MSG-2 maintenance programme related to the aircraft structure. The SSID is also a set of structural inspections which add to the workscope of the C and D checks.

"The other two parts of the ageing aircraft programme are the repair assessment programme (RAP) and widespread fatigue damage (WFD) programme. The RAP requires an inspection of a structural repair 15,000FC after it has been performed, while the WFD requires inspections if fatigue damage is found in several places on an aircraft or on several aircraft in a fleet," explains Pawliska.

Boeing made an MSG-3 analysis for the 747-200/-300 and issued the maintenance programme in 2002. A few operators have converted their aircraft from an MSG-2 to an MSG-3 programme, although it is only considered to be beneficial if aircraft remain operational for an extended period. "Changing to an MSG-3 programme escalated a lot of inspection and C and D check intervals and incorporated the ageing aircraft inspections into the MPD. Overall it resulted in fewer total MH being consumed in C and D checks," says Pawliska. "As an example, the C check interval was extended from 3,600FH and 15 months to 6,000FH and 18 months. The D check interval was changed to a six-year interval, with no FH limitation. Changing to an MSG-3 programme obviously requires a bridging check, which is best done during a D check."

Heavy modifications

The 747-200/-300 has had several highly publicised, major structural modification programmes. The first of these is the Section 41 modification, which affects the front section of the fuselage. The pear-shaped profile of this section was found to cause cracks in the fuselage rings as early as an accumulation of 6,500FC. This was dealt with under airworthiness directive (AD) 86-03-51, which was later superseded by AD 86-23-06. This AD affected all 747s up to line number 603. This was an aircraft built in 1984 for Singapore Airlines. The AD was later revised and extended to line number 685, a -200B built in late 1987 for the US Air Force. The extension brought some -300s into the group of aircraft affected by the AD.

The AD requires a series of repetitive inspections to some of the structural parts in Section 41. The threshold for these inspections is 8,000FC, and the amount of Section 41 that is affected is initially small, but increases up to 19,000FC when the whole of Section 41 must be inspected. After this threshold is reached inspections have to be performed every 1,500FC or 3,000FC. The need to perform these inspections can be terminated by replacing part of the original structure. The 1,500FC repeat interval after 19,000FC effectively means the modification has to be performed by a total time of 20,000FC.

This modification was incorporated on the production line for aircraft with line number 686 and higher, so that these aircraft are not affected by the AD. This includes all -400 series aircraft.

The modification can be carried out in stages, since it concerns several zones of the Section 41 structure. The modification can also be completed in a single step, and is combined with a D check. The full cost is estimated to be up to about $2.0 million, which includes a labour input of up to 40,000MH. The modification kits are supplied free by Boeing.

Many, mostly older, 747s have completed their Section 41 modifications. The majority of the 281 aircraft still in operation have accumulated less than 20,000FC and so are unlikely to have had the full modification performed. This will be required for continued operation after 20,000FC. The age and market for used 747-200s/-300s has to be considered when assessing whether the Section 41 modification should be completed. No more 747-200s/-300s are likely to be converted to freighter, since the younger -400 is at an age and market value where modification to freighter is economic. The -400 has a larger payload capacity, longer range and lower operating costs than a -200 or -300. The implications therefore are that remaining 747-200s/-300s will continue in service until they reach the 20,000FC threshold for Section 41 modification, at which point the cost of the modification will be economically prohibitive and the aircraft will be retired. Many aircraft have accumulated between 10,000FC and 15,000FC, and so could remain operationally viable for up to another 15 more years.

The second major structural modification for the 747 was the engine pylons. This was initiated by separation of the engines from the wing during flight on three aircraft, resulting in total loss. This led to an AD 95-13-05 being issued in 1995 which required the modification of engine pylons on all 747s up to line number 1,046. This affects all 747-200s and -300s built, as well as some of the earlier production -400 series aircraft.

The modification requires the four original engine mountings to be strengthened with the installation of stainless steel bolts and the addition of two new mountings. The deadline for completing this modification was three to five years from the issuance of the AD in 1994, and so all affected aircraft will have been modified.

Line maintenance

On the basis of an annual utilisation of 3,600FH and 700FC per year, an aircraft will operate for up to about 330 days per annum. This implies that about 65 daily checks, 260 AF checks, about 375 transit checks and 325 pre-flight checks will be performed annually. This is a total of about 1,025 ramp checks per year.

The completion of the A check cycle will depend on the operator's A check interval and how much of it is actually utilised. Intervals vary between 300FH and 500FH, and utilisation rates are 60-80%. The A check cycle will thus be completed every 2,700-4,000FH, equal to between nine and 13 months of operation.

The total consumption of MH and materials for line, ramp and A checks will depend on various factors: the A check cycle completion interval; the number of ramp checks performed during this interval; the number of MH used in each check; the operator's policy for managing deferred defects; and labour efficiency. The policy of managing and clearing deferred defects will affect the non-routine portion of the checks.

Completion of the A check cycle every 2,700FH and nine months will result in about 525 pre-flight and transit checks, 195 AF checks and 50 daily checks being completed during the same period. This is a total of 775 ramp checks.

Keller estimates that pre-flight and transit checks each consume an average of seven MH and $500 in consumables and expendables. AF checks require 22 MH on average and use about $1,000 in consumables and expendables, while daily checks use about nine MH and a similar amount for materials. The inputs for these ramp checks over one A check cycle total about 8,500MH and about $600,000 in consumables and expendables. Line maintenance labour charged at an industry average rate of $70 per MH takes this to a total cost of about $1.2 million. This equals a cost of about $446 per FH when amortised over the 2,700FH interval.

Longer A check intervals of up to 600FH might allow actual A check intervals of 350FH, and the completion of the A check cycle every 4,200FH.

Total maintenance costs for the 747-200/-300 can be close to $3,000 per FH. Airlines can make reductions on this cost by managing engines to avoid LLP replacement, acquiring cheap rotables on the used market, minimising base check work packages, and even dispensing with reserves for a D check if its known the aircraft will be retired.

More line and ramp checks would be completed in this period, and their total cost would be $1.87 million. The overall cost per FH of performing these checks would still be about $445 per FH *(see table, page 22)*.

The routine MH input for A checks varies by check because of the block system. In addition to routine inspections, MH will be required for rectification and clearance of deferred defects. The A4, A8 and A12 checks will have the largest labour inputs and will use in excess of 1,000MH. An average consumption of 600MH should be used for a conservative budget for aircraft beyond their third D3 cycle. This is equal to $42,000 for labour charged at $70 per MH. Expenditure on materials and consumables will be $6,000, taking total cost for the check to $48,000. Performance of an A check every 350FH is equal to $138 per FH *(see table, page 22)*.

Base maintenance

Operators have a variety of choices for organising their base maintenance schedules. The most common is the standard MSG-2 system of block C checks and a D check performed at the C6 or C7 check, terminating the C check cycle.

Workscopes of C and D checks have several additions to the routine inspections of the MSG-2 task cards. The ageing aircraft programme will add inspections for the CPCP and SSID programmes. These and the routine task cards will result in findings and non-routine rectifications.

Another addition to this basic package of work will be engineering orders, Service Bulletins (SBs), Engineering Orders (EOs) and ADs. These vary in total quantity for each check, and according to the operator's policy for incorporating modifications. A further possible addition will be major modifications, such as Section 41 inspection. The third major addition to a base check work package will be interior work. This can involve cleaning and small rectifications, as well as major refurbishment of the galleys, toilets, overhead bins, sidewall panels, carpeting, seats, and in-flight entertainment (IFE) systems. In the case of freighter aircraft, many of these interior items will not be included, although the freight handling system will require inspections and rectifications. This is despite on-going repairs being made to the freight handling system during operation.

The last major item that can be added to the work package of a C or D check is stripping and repainting, which adds a significant number of MH and cost for paint.

The number of MH for routine inspections will be influenced by the timing of the specific ageing programme tasks included in each workscope, how well planned each check is, and the efficiency of labour. The non-routine labour requirement and ratio will also be affected by planning and labour efficiency.

"The amount of MH used for MSG-2 and ageing aircraft routine inspections varies by a small amount for the actual C check," explains Ralf Riemann, manager service engineering VIP & Government jet maintenance at Lufthansa Technik. "This can typically be 7,000-8,000MH if the check is planned and performed efficiently, but can rise to up to 12,000MH for a less efficient check.

"The non-routine ratio for aircraft that have accumulated a total time of about 60,000FH can be in the region of 50%, and so the number of non-routine MH arising from these inspections will be 3,000-4,000," continues Riemann. "This would take MH for routine and non-routine work to about 13,000MH."

A higher non-routine ratio of 100% is not uncommon in some aircraft, and so can be in the region of 8,000-12,000MH for some aircraft that are in their D3 or D4 check cycles. This could take the total for just the MSG-2 and ageing aircraft inspections up to 24,000MH.

"While modifications incorporated during C checks vary, only certain modifications can be made because of the restrictions imposed by downtime for the check and the requirement that power be switched off," explains Riemann. "Modifications, EOs, SBs and ADs can typically add 2,000MH to a C check. A further 800-1,000MH can then be added for the cleaning of the aircraft interior and maintenance of IFE equipment. Freighter aircraft will of course not require some of the work on interiors that passenger aircraft do, but the cargo handling system can still use 500-1,000MH for repairs. Therefore, even when the MH for MSG-2 and ageing aircraft inspections total about 13,000MH, the total labour consumption for the check would be in the region of

16,000MH. A higher non-routine ratio could see that total rise to more than 20,000MH for some aircraft. Downtime for this size of check will be five to eight days. The cost of consumables and expendables commensurate with this size of check will be in the region of $100,000."

Wallace at ANZES confirms that workscopes and inputs for C checks of 747-200s/-300s can be high. "Our 747-200s consumed in the region of 8,000MH when we first switched the aircraft to a block base system. The MH consumption had already climbed to 12,000-14,000 by the late 1990s just before we retired the aircraft," says Wallace. "The C check workscope includes: routine task cards and consequential rectifications; CPCP and ageing programme inspections and rectifications; EOs and ADs; and cabin work. The CPCP and ageing programme portion itself could consume up to 10,000MH, and the total for a C check would now be in the region of 20,000MH."

The D check will terminate the C check cycle. Routine task cards will therefore include various C check items. "Routine tasks and inspections for the MSG-2 items and ageing programme inspections can be as high as 40,000-50,000MH in a D3 or D4 check. An aircraft will have accumulated a total time of about 65,000FH at a D3 check and about 82,000FH at a D4 check," says Riemann. "The non-routine ratio for an aircraft of this age may only be as low as 25%, and so only 12,000-13,000MH are generated from these routine inspections. The total MH is thus 52,000-63,000. A higher non-routine ratio of up to 75% is seen in many aircraft, with 30,000-40,000MH being required. A total of 70,000-80,000MH is therefore used for this portion of the work package. Besides major modifications, the amount of labour required for EOs, SBs and modifications is in the range of 6,000MH to 8,000MH for most D checks. A similar amount of labour is required for interior refurbishment where seats, sidewall panels, and toilets and galleys are refurbished. Only 2,000-3,000MH would be required for interior-related work for freighter aircraft. Stripping and painting will use about 3,000MH."

This will take the total labour consumption to 67,000-83,000MH for a passenger-configured aircraft with a low non-routine ratio, but up to 95,000MH for an aircraft with a high non-routine ratio. Freighter aircraft will require marginally less MH. Downtime for a smaller work package will be about 50 days, climbing to 75 days for a heavy package. Riemann estimates the labour requirement for a D5 check can easily reach 100,000MH, since there is a higher requirement from the SSID programme. One example is the need for removal and non-destructive testing of the wing bolts.

Riemann estimates the cost of consumables and expendables associated with this check to be in the region of $700,000, which could easily climb to $900,000-1,000,000 for a check with a higher MH consumption, higher level of modifications and extensive IFE installation.

A full D check cycle might be completed about every 20,000FH, including five C checks. Consumption of 18,000MH and $100,000 in materials for each C check, and 90,000-100,000MH and $700,000-1,000,000 in materials for the D check would result in a total cost of $10.2-11.0 million for the D check cycle. Over the 20,000FH interval, this would be equal to $510-550 per FH *(see table, page 22)*.

Heavy components

This group includes four types of component, each of which has either its independent maintenance programme or 'on-condition' maintenance: wheels and brakes; landing gear; auxiliary power unit (APU); and thrust reversers.

The maintenance and repair of these components is mainly FC-related, and so the final cost per FH is dependent on the FH:FC ratio. This analysis assumes an average FC time of 5.0FH, although each operator's actual FC time will vary.

The overall cost per FC for the repair of wheels and brakes is a combination of the cost per FC of tyre remoulds and replacements and wheel inspections and repairs. There are 16 main wheels and brakes and two nose wheels. Average tyre remould intervals for main wheels are 280FC. Tyres might be remoulded four times at an average cost of $500 and then replaced at a typical cost of $1,800. Overall cost per FC for 16 main tyres is $43.

Nose wheels are remoulded about every 350FC at an average cost of $400, and are replaced for about $1,000. Overall cost per FC for two nose tyres is $3. The total for main and nose wheel tyre remoulds and replacement is $46 per FC *(see table, page 22)*.

Wheel inspections are made at tyre remoulds, with costs of $650 for main wheels and $600 for nose wheels, resulting in a cost per FC of $40 *(see table, page 22)*.

Each main brake unit is repaired about every third wheel removal, at about 850FC, and at a cost of about $13,000. Overall cost per FC for main brake repairs is $245 *(see table, page 22)*.

Landing gears can be removed every eight to 10 years, equal to every second D check. The most common method is an exchange of a landing gear shipset, which in the current market costs about $575,000. This is equal to $85-105 per FC, depending on actual removal interval, and $17-21 per FH *(see table, page 22)*.

Thrust reversers are removed for maintenance on an on-condition basis. Shipsets are removed every 6,000-8,000FC for the JT9D and CF5-50 engines. An average cost for a thrust reverser shipset shop visit is about $170,000. For the four shipsets, this is equal to about $115 per FC, or $24 per FH *(see table, page 22)*.

The 747-200/-300's APU is the GTCP 660. This has an average shop visit interval of about 3,000 APU hours. On the basis that an operator will use the APU for an average of two hours every flight, it will have an annual utilisation of about 1,400 hours. It will therefore have a shop visit about every two years. An average shop visit cost of $180,000 results in a cost per aircraft FC of $120, equal to $24 per FH *(see table, page 22)*.

The total for all heavy components is about $668 per FC, equal to $134 per FH *(see table, page 22)*.

Rotables

Remaining rotable components can be maintained according to the maintenance programme, on an on-condition basis or using soft times derived from the history services of these components to provide a preventative maintenance programme.

These rotables include: avionics; emergency equipment; galley and interior items; flap mechanisms; flight controls; hydraulic system items; pneumatic system items; fuel system items; electrical system items; and a large number of other components.

Collectively these rotables can be paid for using a flight hour agreement with a large 747-200/-300 maintenance provider or component specialist.

Rates will depend on exclusions, which are the items not covered in the flight hour agreement. These can vary. In some cases wheels and brakes are included in the agreement for rotables, while other heavy components are not included. Flight hour agreements often exclude cabin and IFE items.

When the heavy components previously described are excluded and all other rotables are included, a typical flight hour agreement will be in the region of $150 per FH for the lease of the components and an additional $400-450 per FH for the repair and management of the rotables. This would take the total cost for rotables to $550-600 per FH *(see table, page 22)*. There is now a high supply of many rotables on the aftermarket, which may allow lower costs.

Engine maintenance

The 280 747-200s/-300s still in operation are powered by a combination of JT9D, CF6-50 and RB211-524 engines. Potential and current operators are interested in the highest gross weight aircraft with the largest payload and longest range capability.

The majority of the lower gross weight aircraft are powered by the -7A and -7F variants of the JT9D. There are few of these left in operation. The highest maximum take-off weight for the 747-200 and -300 is 833,000lbs. These aircraft are powered by the JT9D-7Q, JT9D-7R4G2, CF6-50 and RB211. About 240 of the aircraft left in operation are equipped with these engines.

About 55 747-200s have the JT9D-7Q, while the majority of the 52 aircraft with the JT9D-7R4G2 are 747-300s. The most popular of all 747-200s/-300s are those with the CF6-50E2 engine. Atlas Air, for example, acquired all its 747-200s with CF6-50 engines. There are 86 of these aircraft still in operation.

Less important and less popular are the 40 aircraft with RB211-524 engines, the majority of which are the -524D4.

Aircraft with the JT9D-7Q/-7R4G2 and CF6-50 engines will remain the most important types in the future.

Like most Pratt & Whitney engines, the JT9D is usually managed so that it follows an alternating pattern of a performance restoration followed by an overhaul. The engines are now mature, and only have EGT margins of 20-50 degrees centigrade following an overhaul. These margins deteriorate at about 8-12 degrees per 1,000 engine flight cycles (EFC), and so could potentially remain on-wing for 2,500-4,000EFC. Actual average removal intervals between shop visits for an operation with an average EFC time of 5.0EFH are in the region of 6,000-7,000 engine flight hours (EFH) for the JT9D-7J and 7,000-8,000EFH for the -7R4G2. Removals to the first shop visit are longer than to the second removal.

The workscope for performance restoration shop visits for these two variants consumes about 4,500MH, $800,000 in materials and another $450,000 for sub-contract repairs. An average labour cost of $70 per MH results in a total shop visit cost of $1.6 million.

Overhauls use about 5,500MH, up to $1.5 million for materials and $550,000 for sub-contract repairs. This would take total cost to about $2.5 million.

These two shop visits amortised over the combined removal intervals of 14,000FH for the JT9D-7Q and 16,000FH for the JT9D-7R4G2 generate reserves of about $295 per EFH for the JT9D-7Q and $255 for the JT9D-7R4G2 *(see table, page 22)*. These rates would be lower for aircraft operating with longer average cycle times, since removal intervals are closely related to EFCs and shop visit inputs would be similar to those described. Some operators are also able to achieve removal intervals up to 2,000EFH longer than those described, which would also result in lower reserves per EFH.

The replacement of LLPs has to be considered in addition. All LLPs have lives of 15,000EFC for both variants, and a full set has a list price of about $1.7 million. Given that in this scenario -7Q engines will accumulate about 2,600EFC between overhauls and -7R4G2 engines about 2,800EFC between overhauls, LLP replacement would be most efficient at every fourth or possibly fifth overhaul. This interval, however, is equal to about 20 years of operation. Given that the youngest aircraft are 15 years old and the oldest aircraft with -7Q engines are 25-26 years old, and that most aircraft are only likely to be operated up to a maximum age of 30 years, airlines may be able to avoid the cost of replacing LLPs in most of their engines. This is because LLPs will have already been replaced one and are unlikely to require replacing a second time in their operational life.

Time-continued engines are often available on the market, as are LLPs, and values are likely to steadily decline over the long term. Airlines will thus only need to replace LLPs in some of their engines at a fraction of the cost of replacing all of them with complete new sets.

DIRECT MAINTENANCE COSTS FOR 747-200/-300

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Ramp checks	1,870,000	4,200FH		445
A check	576,000	4,200FH		137
C & D checks	10,200,000-11,000,00	20,000FH		510-550
Heavy components:				
Landing gear	575,000	5,600FC	103	21
Tyre remould & replacement	66,000	1,400/1,750FC	46	10
Wheel inspections	11,600	280/350FC	40	8
Brake inspections	208,000	850FC	245	50
Thrust reverser overhauls	680,000	6,000FC	113	23
APU	180,000	1,500FC	120	24
Total heavy components			668	134
LRU component support				550-600
Total airframe & component maintenance				**$1,775-1,865/FH**
Engine maintenance:				
4 X JT9D-7Q				$1,180/FH
4X JT9D-7R4G2				$1,020/FH
4X CF6-50E2				$1,040/FH
Total direct maintenance costs:				
Aircraft equipped with JT9D-7Q:				$2,955-3,045/FH
Aircraft equipped with JT9D-7R4G2:				$2,795-2,885/FH
Aircraft equipped with CF6-50E2:				$2,815-$2,905/FH

Annual utilisation:
3,500FH
700FC
FH:FC ratio of 5.0:1.0

The CF6-50 will achieve average removal intervals of 1,300-1,500EFC at an average EFC time of 5.0EFH, equal to about 6,500-7,500EFH in most 747-200/-300 operations, although some airlines can achieve up to another 1,000EFH on-wing.

The CF6-50 follows a shop visit pattern described by General Electric's workscope planning guide. This outlines the workscope at three levels for each of four modules based on the time since the last overhaul. The CF6-50 generally follows a shop visit pattern of alternating workscopes similar the JT9D.

A performance restoration shop visit will consume 4,000-5,000MH, about $600,000 for materials and $500,000 for sub-contract repairs. This will take total cost for the shop visit to $1.4-1.5 million.

An overhaul will consume about 5,500MH, $800,000-900,000 for materials and up to $800,000 for sub-contract repairs, taking total shop visit cost to $2.0-2.2 million.

The two shop visits will generate a reserve of about $260 per EFH. Like the JT9D, the life of LLPs in the CF6-50 is long compared to the probable remaining life of the aircraft. A full set of LLPs has a list price of more than $2 million, while the supply of time-continued engines and LLPs will be relatively high and so market values low. Like the JT9D, LLPs in the CF6-50E2 will have already been replaced once in most engines and will not need replacing a second time in their operational life. Airlines may be able to acquire time-continued LLPs at cheap rates on the used market for young engines that may require LLP replacement.

Maintenance cost summary

The costs for almost all direct maintenance for the 747-200/-300 are summarised *(see table, page 22)*. Absent costs are reserves for engine LLPs and spare engine provisioning. LLPs have been omitted because the age of the aircraft means that in many cases it will not be necessary to replace them again. Spare engine provisioning can now be variable and also less with a high supply of time-continued engines on the market.

The total maintenance costs for the aircraft are $2,800-3,050 per FH, depending on engine type, inputs required for airframe checks, and the negotiated terms for rotable support. This compares to a total maintenance cost of $1,500-1,600 per FH for the 747-400. The 747-200/-300 suffers partly because its assumed FH:FC ratio in this analysis is short compared to most -400 operations. This automatically increased engine- and component-related costs for the -200/-300. The 747-200/-300 is also at a disadvantage because of the high MH inputs into base checks and short removal intervals between shop visits.

There are also several limits to continued operation that operators must consider. The first of these is engine maintenance costs, which are increasing per FH because of reducing intervals. Engine LLP replacement is also high, at about $2 million per engine, which is equal to the current value of most some engines or about half the value of passenger-configured aircraft. The cost of four sets of engine LLPs exceeds the market value of most 747-200 and -300s.

Another issue is the high inputs required at the D5 check, which is likely to trigger retirement by most operators. There is also the issue of Section 41 termination. Most 747-200s/-300s in service have not reached the 20,000FC threshold for termination, and the cost of this is another cost barrier that is likely to trigger retirement, unless the modification has already been completed.

Operators can find ways to reduce maintenance inputs and costs. One consideration is to minimise the work performed on interiors, EOs, ADs and modifications during base checks. Time-continued engine modules and landing gear sets can sometimes be purchased on the aftermarket for less than the cost of a full shop visit.

Long-term considerations

Few of the aircraft that remain in operation are unlikely to go through their D5 check or pass the 20,000FC threshold for Section 41 modification. These both represent timings for probable retirement. The cost of completing both of these will exceed $7.5 million. The reserve for this, plus cost of C checks, engine LLP replacement and engine maintenance reserves make the maintenance costs of ageing 747-200/-300s excessive. This indicates that the remaining 280 aircraft in operation will retire at a high rate , with few left in operation in another 10 years. If Section 41 modification and engine LLP replacement can be avoided, the aircraft provides large capacity when its combined low capital cost and maintenance costs are considered. AC