Despite the perception that the 747-200/-300 has lost favour as a passenger aircraft, its airframe and component maintenance costs are low and stable enough for it to remain economic operating networks with routes of up to 10 hours.

747-200/-300 holds its own with stable maintenance costs

The majority of 747-200s and -300s still operate as passenger and combi aircraft, but the fleet is evolving fast and about half will be freighters within a few years. With fleets now dispersing from first-tier operators to new carriers, this article analyses airframe and component maintenance costs of the 747-200/-300.

The 747-200/-300 fleet operates in a similar way for most operators. Aircraft still flying as passenger or combi variants fly average flight cycles (FCs) of about 7.0 flight hours (FHs), generating about 4,200FH and 600FCs per year.

Maintenance items

Analysing the 747's airframe and component maintenance costs per FH first requires the subdivision of all tasks. The periodicity of maintenance or time between overhaul (TBO), as relevant, of each element is then accounted for. The manhour (MH) and material input or cost for each element will then allow the full airframe and component cost per FH to be determined.

The 747-200/-300's airframe maintenance can be divided into line maintenance, airframe checks and ageing modifications.

Line maintenance concerns both airframe and component maintenance. Line replaceable unit (LRU) rotables are removed continuously for repair. Line checks are performed routinely according to the operator's maintenance schedule.

Airframe checks are also performed regularly, while the 747 has had some major ageing aircraft modifications. The Section 41 inspection and wing pylon modification both require terminatory work. Wing pylon modifications have been completed on all affected aircraft, while there are still an estimated 200 aircraft that have not had the Section 41 inspection completed.

The regular airframe checks include routine inspections and non-routine corrective actions, component repairs, interior refurbishment, implementation of service bulletins (SBs) and minor modifications, and strip and paint. They will also include the corrosion prevention and control programme (CPCP) and the structural sampling inspection programme (SSI).

Rotable components can be divided into three groups: LRUs, heavy components maintained on their own programmes, and rotables removed for repair during airframe checks.

LRUs include extinguishers and safety bottles, electronics and avionics, cabin pressure and cabin LRU items, batteries and power controls.

Heavy components maintained on their own programmes are thrust reversers, landing gear, wheels, brakes and auxiliary power unit (APU).

Components removed for repair during heavier airframe checks are evacuation equipment, hydraulic components, parts related to mechanical and pneumatic systems and cabin accessories.

The remaining components not analysed in this article are engine accessories. These are repaired during engine overhaul.

Maintenance schedule

Generically, the 747-200/-300 both have a maintenance schedule of A, C and D checks. Each airline has now modified and adapted its own schedule. In some cases the D checks, CPCP and sampling programme have been equalised into the C checks.

The variation in schedules between operators means manhour (MH) consumption for one schedule do not provide a comparison with other carriers.

"One thing you need to be aware of is deferred items," explains Sebastien Weber, 747/767 department manager at Air France Industries. "Deferred items are tolerance items. The portion of them in heavy checks is small, but larger in line and A checks. These increase MH, but each airline has a policy of how long it defers them. Deferring for too long affects aircraft reliability, causes variation in A and C check MH and can increase downtime".

KLM's schedule is a system of A checks performed every 700FH, having been escalated from a maintenance planning document (MPD) interval of 500FH.

The C check is performed every 18 months, having been escalated from 15months.

The D check, which is performed with the fourth C check, has an interval of 60 months. The second D check must also not exceed an interval of 25,000FH.

"Our major objective is to achieve the lowest possible downtime," explains Wim Rosendaal, project engineer 747 at KLM Engineering & Maintenance. "The

Most 747-200/-300 operators still operate a maintenance programme with A, C and D checks. D checks can vary in workscope. The standard items, however, will be routine inspections, non-routine rectifications, CPCP work, interior refurbishment, technical cleaning, incorporation of SDs, strip and paint, and repair of rotables. This consumes about 50,000 manhours and the total cost is about $4 million.

C check only takes about six days and the D check can be completed in about five weeks".

Garuda has a similar schedule. "Our programme basically consists of an A check at 500FH, a C check at 5,300FH or 15 months, whichever is first, and a D check at the earlier of five years or 26,000FH," explains Jemsly Hutabarat, director business development at Garuda Maintenance Facility. "We perform four C checks every D check cycle".

The programmes operated by KLM and Garuda are similar for other operators that have not equalised D checks into C check packages. "Air China has an A check interval of 300FH and the 12 A checks are performed every C check cycle," explains Rudolf Benk, director aircraft maintenance & overhaul at Ameco Beijing. "There are A check tasks cards that have multiple A check intervals up to 12A. These are not equalised.

"The 12 A checks means the C check could theoretically occur at its interval of 3,600FH and 15 months. Typical utilisation of 4,200FH per year means the A and C checks will get performed about once every three or four weeks and 10 to 11 months".

Ameco does seven unequalised C checks every D check cycle. The first D check interval is 25,000FH, equal to almost seven times the C check interval. The interval reduces to 22,000FH and 20,000FH for the second and third D check. The C and D check cycles are independent, but the C check cycle is terminated with the D check.

Virgin Atlantic has adopted a system of equalised checks. It operates 'line' checks every 530FH, which are equivalent to A checks. There are then hangar 1 and hangar 2 checks, similar to B checks. These have a 1,060FH interval. Our C check packages are equalised C and D checks and are performed every 15 months. These are not working well, because the CPCP causes out-of-phase tasks which are difficult to synchronise with the C checks. Virgin is now working with Boeing on the MPD to separate C and D checks with the CPCP integrated. This will leave it with a schedule of A, C and D checks. The SSI has been superseded by the CPCP. It is possible to marry the CPCP and SSI, but most of the SSI is done when the CPCP is performed.

Check composition

The maintenance programmes operated by KLM Engineering & Maintenance, Garuda, Ameco Beijing and Air France, indicate that an 'average' schedule, where D checks are not equalised, would have approximate intervals of 450FH, 5,000FH and 22,000FH for A, C and D checks. About 10 or 11 A checks would be performed every C check cycle, and four or five C checks every D check cycle.

The composition of A and C checks will be similar between carriers operating this type of maintenance programme.

Like most aircraft types, airlines will include routine inspections and non-routine rectifications arising thereof, minor SBs, technical and cabin cleaning and any component or engine changes that can be scheduled.

A few airlines will additionally include heavier cabin refurbishment if their marketing requirements demand it. CPCP and SSI may also be added, depending on their maintenance programme.

D check composition can vary widely. The standard package or workscope in most airlines' cases will be routine inspections and related non-routine rectifications and CPCP work. Interior refurbishment of galleys and lavatories will be added for passenger and combi aircraft; technical cleaning, strip and paint will be done; SBs, repair of flight control surfaces and the repair of rotables scheduled for repair during heavy checks will be carried out. Many airlines have now adopted the policy of exchanging items with freshly repaired units to reduce downtime and simplify maintenance. An advantage for 747-200/-300 operators is the surplus of 747 material on the aftermarket at reduced rates.

"Parts and materials can generally be divided into three classes," explains Jemsly. "The first is rotables. This category can be subdivided into the three groups of LRUs, units which get repaired during checks, and other heavy components repaired on their own schedules.

"The second class is repairables, which get removed for work during heavy checks. These are mainly flight control surfaces. The third is consumables items, such as rivets, brackets and clips, which are only used once," explains Jemsly.

Several large additions can be made to D checks, some of which are included in almost every heavy maintenance inspection. This list of additions includes Section 41 modification, engine pylon modification, flightdeck and maximum take-off weight upgrade and installation of in-flight entertainment equipment (IFE). Airworthiness directives (ADs) are also issued, and these have included re-wiring modifications in relation to the fuel tanks and thrust reverser locks.

IFE installation can occur once every 10 years or two D checks, but may be more frequent as technology improves. The MH for this task are larger, but often considered as a marketing expense, rather than regular maintenance.

It is estimated about 200 aircraft still require termination on Section 41. This has to be completed before 20,000FC are accumulated. Considering normal levels of utilisation, aircraft can reach an age of more than 20 years before completion is required. The modification adds about 20,000MH to a D check, but is likely to be done when aircraft are sold and converted to freighter.

Flightdeck and maximum take-off weight (MTOW) upgrades are also likely to be completed during conversion to freighter.

MH inputs

MH for checks will vary, partly because of deferred items, but also because of quality. "The labour rate charged for third-party contracts is a big driver," says Weber. "Labour rates are highest in west European airlines, at about $60-70/MH. Higher labour rates generally result in lower MH consumptions — and vice versa. Low MH consumptions can be quoted by facilities, but if work is not done thoroughly reliability will be poor and defects can follow".

Routine MH for the A check in a standard A/C/D check schedule are about 400 for a check with a lot of task cards, with additional items taking total routine consumption to about 600MH. The A check usually has no SBs and other items are deferred to the C check. Non-routine ratio is low at about 0.8, and so total MH expenditure is about 1,000 for heavier A checks. The expenditure for an average A check will be 600-800MH.

The C check, in a standard type of programme with a D check, consumes about 2,000-2,500MH for routine inspections when SBs, technical cleaning and other standard items are included. Routine to non-routine ratio is about 1:1 for most aircraft. The total MH, depending on workscope, for the check is 4,000-5,000.

Older aircraft will experience increases in the ratio of non-routine MH, as will those operating in a harsh environment or that have had excessive deferred maintenance. "This is particularly true with freighters," explains Weber. "Although freighters have no cabin interior, which consumes MH for cleaning, they do have a cargo loading system that takes a lot of punishment. Compared to passenger aircraft, freighters also have a higher non-routine ratio because of the cargoes they carry. The MH they save in no cabin work is made up for by higher non-routine ratio compared to a passenger aircraft. C check MH for both variants are similar".

A D check with standard items and a typical quantity of additional items for SBs and ADs will consume 25,000-30,000 routine MH.

The ratio of routine to non-routine will be about 1:1.2 for well-maintained middle-aged and younger passenger -200/-300s. This will rise to as much as 1:2 for older and poorly maintained aircraft, in particular freighters.

"Total MH is about 50,000-55,000 for the first and second standard D check packages for a passenger aircraft," says Weber. "Most 747-200/-300s are now beyond their second D check. Freight aircraft will save MH because cabin work is not required, but will have a higher non-routine ratio. The difference between passenger and freight aircraft is 2,000-4,000MH. Total MH for a standard D check package will be about 55,000-60,000 for a passenger variant".

Downtime for a standard D check is normally up to seven weeks. "Delays can

While freighters do not require the cabin refurbishment that passenger aircraft do in a D check, freighters save about only 3,000 manhours and a total D check cost of about $400,000.

easily add two or three weeks," explains Weber. "These are caused by critical path items not being properly organised, or an operator adding them after the D check has begun. This will include modifications or refurbishments that require heavy repairs or lead time for preparation. Downtime can be minimised by replacing items rather than repairing them, but this is expensive".

MH totals can escalate to extremely high levels when heavy additional items are included. "We have completed checks with 100,000MH," says Rosendaal, "but this includes most things and pylon modifications".

Materials and consumables

The MH quoted for the A, C and D checks are for standard checks. They do not account for heavy or once-in-a-lifetime modifications.

The additional charges commensurate with these MH are cost of materials and consumables and repair or exchange of rotables removed during a D check.

Materials are items used by mechanics, while consumables are non-repairable aircraft parts. These total about $10,000 for the A check and $100,000 for the C check. Expenditure for the C check can be as low as $75,000, but this is if less attention is given to the interior.

The D check has a heavy materials and consumables consumption and will use up to about $600,000. This is made up of approximately $350,000 for regular materials and consumables and another $250,000 for interior items and furnishings. Freighters will obviously incur a lower materials cost.

Rotable repairs

The MH, materials and consumables cost for repair of flight surface controls, or repairables, is already accounted for.

Repair or exchange of rotables is a mixture of MH, material and consumable costs, third-party repair charges and exchange fees.

Airline and third-party facilities have different mixtures of repair capabilities for all types of rotables. Ameco Beijing is one facility, for example, that has an in-house capability for repairing all 747 rotables removed during a D check.

These items include evacuation equipment, hydraulic components, parts related to mechanical and pneumatic systems and cabin accessories. Deep access is required to take out many of these, making removal during D check convenient. Some airlines, however, can elect to have these components removed and repaired on an 'on-condition' basis.

Third-party repairs means airlines will still need to maintain an inventory of spare items, especially if the units put back on an aircraft are different from the ones being repaired.

The cost of repairing all these components on a third-party basis will be about $350,000. Exchange programmes are an alternative, but do not require an inventory to be kept.

Total check costs

The total cost of the A, C and D checks will be for the MH, materials and consumables and rotable repairs.

Burdened labour rates for heavy maintenance are in the region of $50 per MH in the Asia Pacific and north America, but may be closer to $65 per MH for west European facilities.

Labour rates will be slightly higher for A checks, at $60-65/MH, and $65-70/MH for line checks.

At $60 per MH, the total cost for an A check will be about $58,000. Performed once every 450FH, this results in a cost per FH of about $130 *(see table, page 32)*.

A $55 labour rate gives a C check cost of about $375,000 for passenger aircraft and $325,000 for freighters. Once every 5,000 this is equal to $65-75 per FH.

The labour, materials and rotable repairs portion for a passenger aircraft consuming 60,000MH in a D check totals $3.95 million. A freighter aircraft of a similar age routine to non-routine ratio will have a cost of $3.55 million. This will equal about $180 per FH for passenger variants and $162 for freighters *(see table, page 32)*.

Line maintenance

These major checks are preceded by line maintenance checks. These generally include pre-flight, transit and daily checks and checks with longer intervals of 3-7 days.

The pre-flight check generally refers to an inspection of an aircraft every day before it leaves its home base, or when it stops overnight at an outstation. Transit checks are done each time the aircraft stops en-route. An aircraft, for example, may leave its home base and operate two sectors and have an overnight stop at the end of the second, before returning home. It will therefore have a pre-flight check at the home base before departing and at the second outstation, before returning. Transit checks will be done at the first outstation on the outbound and inbound legs.

Daily checks are performed each day at the home base overnight. They are the heaviest line checks and normally have a lot of deferred items. The interval in most

PASSENGER 747-200/-300 FLIGHT HOUR (FH) AIRFRAME AND COMPONENT MAINTENANCE COSTS

Maintenance Item	Maintenance interval	MH used	MH cost ($)	Materials cost ($)	Total cost ($)	Cost per FH ($) 7.0FC
Transit	Every FC	5				
Daily & pre-flight	24-48 hours	30				
Total		250/week	16,250	7,000	23,250	290
A check	450FH	800	48,000	10,000	58,000	129
C check-passenger	5,000FH	5,000	275,000	100,000	375,000	75
C check-freighter	5,000FH	5,000	275,000	50,000	325,000	65
D check-passenger	22,000FH	60,000	3,000,000	950,000	3,950,000	180
D check-freighter	22,000FH	57,000	2,850,000	700,000	3,550,000	161
Landing gear change						
Engine change						
Heavy components						
Tyre remould	280FC x 6				25,000	2
Tyre replace	2,000FC				19,000	1
Wheel rim inspection	280FC x 3				18,000	2
Wheel rim overhaul	1,120FC				8,000	1
Brake repair	840 x 2				160,000	14
Brake overhaul	1,680				190,000	16
Landing gear exchange & repair					600,000	18
Thrust reverser repair	5,500FC				650,000	17
APU shop visit	4,000FH					56
LRUs/Rotables						
Lease rate						140
Fixed FH repair cost						400
Tot al cost per FH-passenger						**1,341**
Tot al cost per FH-freighter						**1,312**

operators' cases is 24 hours, but can be extended to 48 hours so that it can be done when the aircraft returns home. The daily check is generally bigger than the pre-flight check, and whenever possible the two are performed when the aircraft is at its home base.

While the daily check interval can be extended, the pre-flight check must be performed every day.

The inputs used for line checks are labour, materials, a few consumables and exchange of LRUs on a continuous basis.

The removal and exchange of LRUs with serviceable items is related to inventory management. The ownership, repair and inventory cost of these components is dealt with later *(see page 32)*.

Considering average levels of utilisation, an operator can expect to perform one return flight per day from its operating base. One transit, one pre-flight and one daily check will be done each day.

MH for a combined daily and pre-flight check is about 30, and about 5MH for a transit check.

This takes total MH consumption per week to about 250MH, or 10,000-13,000MH per year.

Cost of materials and consumables used are hard to estimate, because they consist of grease, oil and small items.

A budget of about $7,000 per week should be made for an aircraft the size of the 747-200/-300. This will take total MH and materials cost to about $290 per FH.

The portion of MH and materials used at outstations during transit checks, and some LRUs, will be charged at third-party rates.

Heavy components

The category of rotables can be divided into three sub-categories. The first two of these are rotables repaired or exchanged during heavy checks and LRUs.

The third group is heavy components and consists of wheels, brakes, landing gear, APU and thrust reversers.

Many airlines now have some or all of their heavy components repaired by third-party agencies and are supplied on power-by-the-hour or fixed-rate contracts.

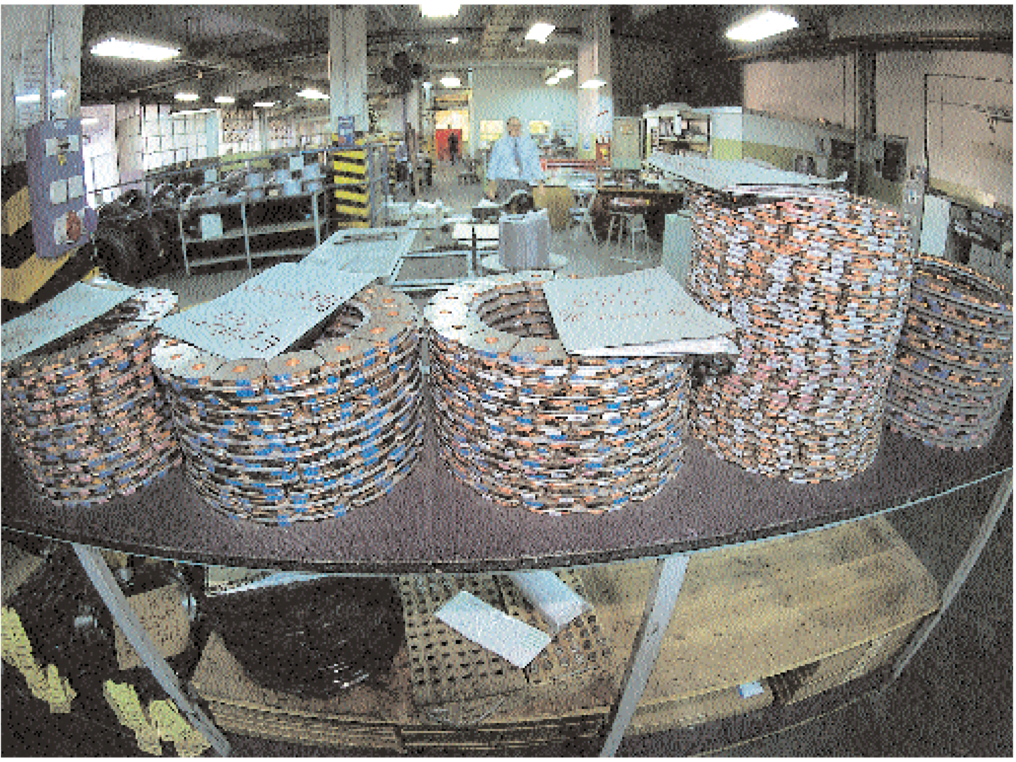
Wheels concern both tyres and wheel rims. Wheels and brakes are inspected between flights and brake disc thickness measured with callipers during line checks.

As Wang Xue Min, senior engineer sub-division component overhaul, at Ameco Beijing, explains, "Removal intervals for wheels are determined by tyre wear, and vary according to landing severity. They average, however, about 280FC. On removal, tyres are taken off for remould and wheel rims are inspected using non-destructive testing (NDT)".

Tyres can be remoulded about six times before replacement. Wheel rims are inspected on average three times before being overhauled. Wheel rims can last 20-25 years if handled and maintained well. Few are therefore likely to require replacing in the 747-200/-300 fleet.

Tyre remould cost is about $180 for a nose tyre and $235 for a main tyre. Replacement costs are about $600 for a nose and $1,100 for a main.

Tyres therefore go through a six remould and replacement cycle about once every 2,000FC. Total cost for all tyre remoulds and replacements is about



Even some airlines with medium- and large-sized fleets have the repair of their heavy components supplied on a fixed cost per FH basis. This makes costs predictable and dispenses with the need to manage parts.

$45,000 and costs about $22 per FC, or $3 per FH.

Wheel rims are inspected at an average total cost of $300 and overhauled on average every fourth removal at a cost of $400. This inspection and overhaul cycle is repeated about every 1,100FC. Total cost of inspecting and overhauling all wheels is about $26,000 and cost per FC averages $23, or $3 per FH.

Brakes on the 747-200/-300 are made of steel. These have shorter inspection and overhaul intervals than carbon units, but have lower costs.

Xue Min says inspection intervals are about once every three wheel removals, or 840FC. Brakes are overhauled every second inspection, at about 1,700FC.

Inspection and overhaul cost per unit is about $10,000 and $12,000. For all brakes, the cost per inspection and overhaul cycle is about $350,000, equal to $210 per FC, or $30 per FH.

Landing gears are now exchanged for freshly overhauled sets by most carriers. Overhaul shops charge airlines based on three cost elements. The first is an exchange fee, covering ownership and asset cost of the gear. The second is a repair and overhaul charge, which is based on a standard workscope and build configuration (see *The economics of landing gear maintenance, Aircraft Commerce, July/August 2000, page 29*). The third element is for additional costs, to account for corrosion or additional parts. A typical exchange fee for the 747-200/-300 will be about $600,000-650,000. This can rise, because of additional costs, if operators elect to remove their gears after extended intervals, which will lead to corrosion and a higher workscope.

It is recommended by most landing gear shops that gears are removed every eight years to achieve the lowest cost per FC. An eight-year removal will thus be equal to 4,800FC. Amortised cost will be $123 per FC, or $18 per FH.

Thrust reversers are removed on-condition, but average about 5,500FC between removals. Overhaul cost for each unit is about $160,000. The cost for all four units averages about $118 per FC, or $17 per FH.

The 747-200/-300's APU is the Allied Signal GTCP 660-4. On aircraft times are 3,000-5,000FH and shop visit costs are $150,000-300,000. This works out at a cost per FH of about $56.

LRUs

The final component cost is for LRUs. Major airlines have traditionally held their own inventories and operated their own repair shops. Inventory is determined by route structure, but airlines have mechanisms, such as the international airline technical pool, simple borrowing, flyaway kits and deferring to deal with LRU failures or shortages at outstations.

The simplest method of accessing and maintaining an LRU inventory is for an airline to lease it from a specialist provider. Such arrangements also involve a fixed cost per FH for repairs, thus simplifying the cost of LRUs.

A fleet of 5-10 aircraft will require an inventory of material at a cost of $2-3 million per aircraft. Leased at a monthly rate of 2% per month, this would give a cost equal to $140 per FH.

The additional repair cost for these components could probably be secured by the operator at $400 per FH.

Cost summary

For its size and age, the 747-200/-300 has steady airframe and maintenance costs. The largest elements are line checks, the D check and cost of LRUs.

Despite their magnitude, the costs are unlikely to be much lower for the younger 747-400 operating the same average FC of 7.0FH. Line checks will need similar MH and material inputs. The -400's first and second D checks will consume only about 5,000 less MH, equal to a saving of only $250,000, or about $11 per FH. The -400's LRUs should be more reliable and cheaper to maintain, but this could be outweighed by the fact that they are more expensive to purchase.

The -400 will, however, be able to dilute maintenance costs per FH by operating longer average FCs. The -200/-300's maintenance costs are still low and predictable enough to make the aircraft economic overall for operating shorter routes than the -400.

The biggest difference between the 747-200 and -400 comes with engine-related shop visit and overhaul costs. The JT9D-7J/Q has costs of about $260 per engine flight hour (EFH) (see *JT9D maintenance costs examination, Aircraft Commerce, November/December 1998, page 30*). The more durable -7R4G2 on the youngest -200s and -300s has costs of about $200 per EFH. This compares to the PW4000, which because it can consistently achieve on-wing times of 15,000-18,000EFH, has costs of $120-140 per EFH (see *PW4000-94 on-wing durability makes for economic reserves, Aircraft Commerce, March/April 2000, page 27*). This makes the -200's engine maintenance costs $300-500 per FH higher than the -400's.

Overall, the 747-200/-300 will have total airframe and component costs of $1,340 per FH. Engine-related costs will add $800-1,000 per FH to this, taking the total to $2,140-2,340.

In comparison, the 747-400 will have total costs in the region of about $1,600-$1,700 per FH.