The MD-11F, 777-200LRF & 747-400F provide cargo capacity in the 175,000lbs to 240,000lbs class. Aircraft will be selected on the basis of performance over a route network and operating costs. Maintenance is an important element of cost, and is analysed here for the three types.

Maintenance costs of MD-11F, 777F & 747-400F

Most freight carriers considering large types for long-range operations will look at the MD-11F, 777-200F and 747-400F. These aircraft will be selected on the basis of their payload and range characteristics, and their operating costs. Maintenance costs, which are a key element of total operating costs, are analysed here. All elements of maintenance costs are included. These are the line and A checks, base checks, heavy components, rotable components, and engines. These elements are all analysed in terms of a $ cost per FH, based on the aircraft's typical rate of annual utilisation.

Freighters in operation

The MD-11F, 777-200F and 747-400F have gross structural payloads from 202,000lbs for the lighter weight MD-11F variant, up to more than 271,000lbs for some of the higher specification converted 747-400 models. When using containers for freight carriage, these translate into net structural payloads of 175,000lbs to 242,000lbs. The payload characteristics of the various freighter models are summarised *(see first table, page 56)*.

The MD-11F, 777-200F and 747-400F are operated by some of the world's major freight carriers.

Most MD-11s have been converted to freighter. The global fleet of 152 aircraft is operated by Aeroflot, Centurion Air Cargo, China Cargo, EVA Air, FedEx, Lufthansa Cargo, Martinair, UPS and World Airways. Many airlines operate their aircraft at flight cycle (FC) times of 4.0-6.5FH. Annual utilisations are 3,500-4,500FH.

The 777-200LRF entered service in 2009 and is operated by German carrier Aerologic, Air France Cargo, China Southern, Emirates, FedEx and LAN Cargo. The aircraft are mainly operated on long-range missions with an average FH:FC ratio of about 7:1, while the annual rates of utilisation are 4,000-4,500FH.

The 747-400 freighter fleet is sub-divided into three variants: the factory-built -400F; the Bedek Aviation-converted -400BDSF; and the Boeing-converted -400BCF.

The -400F is operated by a large number of major freight operators, which include: Atlas Air, Cargolux, China Airlines, Korean Air, Nippon Cargo Airlines, Polar Air Cargo, Singapore Airlines and UPS. Most operations are at FC times of about 5.5-7.5FH, while the annual rates of utilisation are 4,000-5,000FH.

The -400BCF and -400BDSF fleets are operated by some of the same carriers, plus others including Air Cargo Germany, Kalitta Air and Yangtze River Express. Most operations are at similar FC times and rates of utilisation to the -400F.

The three aircraft types have different payload-range characteristics, so they are used on different mission lengths and rates of utilisation. The maintenance costs of the three aircraft are therefore analysed based on their typical styles of operation, rather than being compared at the same pattern of operation and rates of utilisation.

The MD-11F is analysed at 750FC and 4,100FH per year, and an average FC time of 5.5FH. The 777-200LRF is examined at 650FC and 4,250FH per year; at an average FC time of 6.5FH. The 747-400F is examined at 700FC and 4,500FH; at an average FC time of 6.5FH.

Maintenance programmes

The maintenance programmes for airframe checks are split into two categories: line and light maintenance, and base maintenance.

The MD-11's line and light maintenance programme starts with pre-flight and transit checks prior to each flight, and a daily check that has an interval of up to 48 hours. The A check programme has an interval of 700FH for the basic 1A tasks. There are also 2A, 3A, 4A and 6A tasks with respective multiples of the basic interval. The 6A tasks have an interval of 4,200FH. The A check multiple task packages do not get in phase until the A12 check, which has an interval of 8,400FH.

The base check programme consists of a cycle of four checks: the C1, C2, C3 and C4 checks. The basic 1C tasks have an interval of 7,500FH and 18 months, with the check being carried out when one these intervals is reached. In some cases the interval is 6,000FH and 15 months.

There are other C check tasks with multiples of the basic interval, of which the 4C tasks are the heaviest at 30,000FH and 72 months. This also coincides with the D check tasks at the same interval. The C1, C2 and C3 are relatively light checks, followed by C4/D checks. The base check cycle therefore has a maximum interval of five or six years, depending on the maintenance programme.

MD-11s are 11 to 20 years old, so the youngest aircraft will have completed their second base maintenance cycle, while the oldest will already be in their fourth.

The 777's airframe maintenance programme has been conceived to allow

MD-11F, 777-200F & 747-400F PAYLOAD SPECIFICATIONS

Aircraft type	MD-11F	777-200F	747 -400BDSF	747 -400BCF	747 -400F
MTOWlbs	630,500	766,800	870,000	870,000	875,000
MZFWlbs	451,300/ 461,300	547,000	610,000	610,000	635,000
OEWlbs	248,567	318,300	356,800	359,650	363,954
Gross structural payload lbs	202,733/ 212,733	228,700	253,200	250,350	271,046
Container tare weight lbs	27,420	28,200	27,972	27,962	28,350
Net structural payload lbs	175,493/ 185,493	200,500	225,238	222,388	242,696

MD-11F, 777-200F & 747-400 MAINTENANCE PROGRAMMES

Aircraft type	MD-11F	777-200LRF	747-400F/ -400BDSF/-400BCF
Line maintenance programme			
Transit/Pre-flight	Every FC	Every FC	Every FC
Daily	Up to 48 hours	Up to 48 hours	Up to 48 hours
Weekly		Up to 8 days	Up to 8 days
1A tasks	700FH	500FH	600FH
2A tasks	1,400FH		1,200FH
3A tasks	2,100FH		1,800FH
4A tasks	2,800FH		2,400FH
6A tasks	4,200FH		3,600FH
12A tasks		6,000FH	
Base checks			
1st base check	7,500FH	7,500FH	7,500FH
2nd base check	15,000FH	15,000FH	15,000FH
3rd base check	22,500FH	22,500FH	22,500FH
4th base check	30,000FH	30,000FH	30,000FH

operators to organise tasks into checks that suit their operation. There are about 2,000 tasks in the maintenance programme. Task intervals are specified in FH, FC and calendar intervals, with a combination of two or even three interval parameters.

A typical line maintenance programme for the 777 comprises transit or pre-flight checks prior to each departure, daily checks with intervals of up to 48 hours, a weekly check with an interval of seven or eight days, and a monthly check.

Most operators have a basic A check interval of 500FH, with 1A tasks at 500FH, and a secondary interval of about 100FC. The 12A tasks have the highest A check multiple with an interval of 6,000FH.

The biggest variation between operators is with base check programmes. One system involves having an annual base check in a cycle of eight checks. Even-numbered checks have structural tasks, so they are heavier than odd-numbered checks.

A second system has a base check with an interval of 7,500FH and 500 days. The C6 and C8 checks are the heaviest, with their intervals coinciding with the largest group of structural inspections.

A third system has an interval of 7,500FH and 750 days, close to two years. The largest structural inspections under this system come due at about the same interval as the fourth base check in succession.

The 747-400 has a traditional line maintenance programme, similar to the MD-11's. This includes transit and pre-flight checks prior to every check, a daily check that has a maximum interval of 48 hours, and a weekly check that has a maximum interval of eight days.

The basic interval for 1A tasks is 600FH, and there are 2A, 3A, 4A and 6A multiples with respective intervals of up to 3,600FH. All five groups of tasks come into phase at the A12 check, which has an interval of 7,200FH.

The base check programme is a cycle of four checks. The basic interval for the 1C tasks is 7,500FH and 18 months. The fourth check, the C4 or D check, has an interval of 30,000FH and 72 months.

The maintenance programmes for the MD-11F, 777-200F and 747-400F are summarised *(see second table, this page)*. What is apparent is how similar their maintenance programmes actually are in terms of check cycle structures and intervals.

Line & A check inputs

As with the maintenance programmes, the three types have similar inputs for line and A checks.

The overall costs for line maintenance per FH are based on each aircraft completing the number of FH and FC per year as described.

In the case of the MD-11, the pre-flight or transit check consumes about 2 man-hours (MH) of labour and $20 in materials and consumables. Although these routine checks are carried out by flightcrew, and therefore require no labour input from mechanics, non-routines and defects arising during operation do require attention from mechanics. These inputs are a conservative allowance.

The daily check uses about 6MH and $200 in materials and consumables.

The MD-11 will require about 350 daily checks each year, so it will also have a further 400 pre-flight/transit checks. Using $70 per MH as a standard labour rate, the total annual cost for the MD-11's line checks is about $281,000, equal to a rate of $74 per FH.

The 777-200LRF uses 2.0-2.5MH and $20 in materials and consumables for the pre-flight/transit check. The daily check will use 4-5MH, and a budget of $200 should be made for materials and consumables. The aircraft will have about 350 daily checks and 300 pre-flight or transit checks each year. Total costs for these line checks will be $251,000, equal to $60 per FH.

A budget for transit and pre-flight checks for the 747-400F is 2-3MH of labour and $20 of materials and consumables. The daily check uses about 8MH and $200 in materials and consumables, while the larger weekly check will use 12MH, and should have an allowance of $300 for materials and consumables.

The aircraft will require about 350

The MD-11F is the smallest of the large widebody freighters. Despite its age, it has stable airframe-related maintenance costs and competitive engine-related costs. Its overall maintenance costs are lower than the 777-200LRF's, and the MD-11F remains in a class of its own.

daily checks each year, and so have a similar number of pre-flight/transit checks. It will also have about 50 weekly checks. The total costs for these checks will be $403,500, equal to about $90 per FH.

A checks

Inputs for A checks for freighters differ to those for passenger-configured aircraft. Freighters will require a smaller labour input due to the absence of a cargo loading system, but repairs to the cargo-handling system often involve relatively high input for materials and consumables.

In the case of all three aircraft, A checks are based on blocks of tasks and so vary in size. The input for the average A check on the MD-11 is about 440MH in labour and $11,000 in materials and consumables. The inputs for average-sized A checks on the 777 and 747-400 are 500MH and $25,000 materials and consumables, and 550MH and $30,000 materials and consumables.

The intervals for A checks are 700FH for the MD-11, 500FH for the 777, and 600FH for the 747-400. Actual intervals at which checks are performed are about 80% of these intervals. Reserves are therefore $80 per FH for the MD-11, $150 per FH for the 777-200LRF, and $140 per for the 747-400.

Base checks

The labour and material inputs for base checks for freighters are generally smaller than those for their passenger-configured counterparts, and mainly comprise: routine inspections; non-routine rectifications; the removal and installation of rotable components; service bulletins (SBs) and airworthiness directives (ADs); and interior work. "The largest differences between passenger and freighter aircraft are with routine inspections and interior refurbishment," says Janne Tarvainen, assistant vice president of aircraft maintenance at Finnair Technical Services. "The cabin in a passenger aircraft requires a lot of labour and materials in order to keep it up to a high standard for premium customers. Freighter aircraft can therefore use noticeably lower labour and material inputs for the same checks."

The MD-11's base check interval of 7,500FH means that checks would actually be performed about once every 6,500FH and the cycle of four checks would be completed in about 26,000FH.

The three lighter C1/2/3 checks will use routine inputs of 2,300MH, and corresponding non-routine rectifications will use about 1,900MH. An allowance of 400MH should be made for engineering orders (EOs), SBs and ADs.

The total for these lighter C checks will therefore be about 4,600MH. The cost of associated materials and consumables will be about $70,000.

The C4/D check will use about 13,000MH for routine inspections, while corresponding non-routine rectifications will use about 9,000MH. An allowance of 2,500MH can be used for EOs, SBs and ADs.

The total for the D check will therefore be about 25,000MH, while associated materials and consumables will cost about $500,000.

Stripping and repainting once every base check cycle will use about 2,500MH and $50,000 in materials.

The total inputs for the four checks of the base check cycle will therefore be 41,000-42,000MH in labour and $760,000 in materials and consumables. Using a standard labour rate of $50 per MH for base maintenance, the total cost is $2.9 million. Amortised over the interval of 26,000FH, this results in a reserve of $111 per FH *(see table, page 60)*.

In the case of the 777, one maintenance programme that could be used is a series of six base checks. Each has an interval of 500 days and 7,500FH. The C6 check would be the heavy check in the cycle, while the C3 check would be an intermediate check.

At a utilisation rate of 4,250FH per year, the 500-day interval would be reached first and the actual check interval would be about 440 days, equal to about 5,200FH. The total interval for the six checks in the cycle would therefore be 31,200FH.

The lighter C1, C2, C4 and C5 checks would have routine inputs of 750-800MH. Non-routine inputs would be similar in quantity for an aircraft in its first or second base-check cycle. An allowance of 400MH for SBs and ADs should be made. The total for these checks will be 2,000-2,400MH, and the corresponding costs of materials and consumables will be in the region of $100,000. Total inputs for the intermediate C3 check will be about 3,500MH and $175,000 for materials and consumables.

The heavy C6 check could use about 2,600MH for routine inspections, and 3,500MH for rectifications. A further 2,000MH would be used in the removal and installation of rotables, up to 2,500MH for EOs, SBs and ADS, and 3,000MH for interior work. While the 777F will not need any work on passenger equipment and furnishings, it will require some work on the cargo loading system. The total labour input for the check would therefore be about 13,500MH. The associated cost of materials and consumables will be about $450,000.

Stripping and repainting, about once every seven to eight years, will use 2,500-3,000MH and $50,000.

Total inputs for the six checks in the cycle and stripping and repainting will therefore be 29,000MH, and $1.05 million of materials and consumables. Using a standard labour rate of $50 per

The 777-200LRF has only been in operation for just over a year. It is consequently only possible to assess airframe-related costs by extrapolating those costs for passenger-configured aircraft less labour for items that are not present on freighter-configured aircraft.

MH for base maintenance, the total cost is therefore about $2.5 million. Amortised over the interval of 31,200FH, the reserve for these checks will be $80 per FH *(see table, page 60)*.

The 747-400's base check intervals of 7,500FH mean that actual intervals are likely to be about 6,500FH. The cycle of four checks will be completed in about 26,000FH at the D check.

As with the other two types, the labour and material inputs will be smaller than for passenger-configured aircraft, particularly for routine inspections and interior refurbishment.

In the case of light C checks, routine inspections will have inputs of about 2,200MH, while corresponding non-routine rectifications will use about 1,600MH. A budget of 400MH should be made for SBs and ADs, with a small allowance of 200MH for interior work and additional items. The aircraft will need some work on the cargo loading system, and an allowance of about 400MH should be made. This will bring the total for C1/2/3 checks to 4,500MH. The corresponding cost of materials and consumables will therefore be about $100,000.

The C4/D check will use about 18,000MH for routine inspections, in contrast to more than 20,000MH for a passenger-configured aircraft. Non-routine rectifications will use a similar number of MH for a converted aircraft, which will be in at least its third base-check cycle. An allowance of up to 2,000MH should be made for EOs, SBs and ADs. The cargo loading system will also require some work, so an allowance of about 3,000MH should be made. The total for the check will therefore come to about 43,000MH. The associated cost of materials and consumables will be about $750,000.

In addition, the aircraft will be stripped and repainted every seven or eight years, using 3,000MH and $75,000 in materials.

Total labour for the four checks and periodic repainting will be about 62,000MH. Charged at a standard labour rate of $50 per MH this will equal $3.1 million. Adding the cost of materials and consumables takes the total cost of all inputs to $4.25 million. Amortised over the interval of 26,000FH, the reserve for base maintenance is $160 per FH *(see table, page 60)*.

Heavy components

Aircraft components are sub-divided into heavy components, and the remaining group of rotable components.

The small group of heavy components includes: wheels, tyres and brakes; landing gear; auxiliary power unit (APU); and thrust reversers. Most are removed on an on-condition basis, although the landing gear has a fixed removal interval based on calendar time and FCs.

Maintenance costs are therefore a function of repair or shop-visit cost, and FC removal interval. Typical intervals and repair costs are analysed for each type.

The MD-11 has carbon main wheel brakes, which have a shop-visit interval of about 1,250FC. "Brake wear is detected by a wear pin, but wheels are removed when tyre treads are worn. At this stage wheel rims are also inspected," explains Manu Skytta, manager of the component department at Finnair Technical Services. "Tyres can be remoulded three or four times before being replaced. Main wheels are removed about every 200FC, while nose wheels are removed every 150FC. Wheel rims are given an eddy current inspection, although they are occasionally overhauled. Each wheel rim inspection will use 10-15MH in labour, and total cost will be a few hundred dollars. Reserves for wheel inspections and overhauls will be about $53 per FC.

Tyre remoulds cost $1,000-1,500, while new main wheel tyres cost about $2,000 each and nose wheel tyres cost about $1,300 each. A full shipset will therefore cost about $23,000. Reserves for tyre remoulds and replacement will be $75 per FC.

"Brake unit repairs use in the region of 24MH, but replacing the heat stack accounts for most of the cost," continues Skytta. "A heat stack will cost about $60,000 per brake unit, and the total shop-visit repair cost will be $80,000." This is equal to a rate of $64 per FC per brake unit, and $640 per FC for all 10 units.

The landing gear has an overhaul interval of eight years and 7,500FC. An annual utilisation of 750FC per year means that the calendar interval is reached first. A typical market rate for the exchange fee and overhaul cost is $650,000. The reserve for landing gear overhaul is therefore $108 per FC.

"Thrust reversers are maintained on an on-condition basis, and can last a long time," says Skytta. "Checks are performed on the reversers during base checks, and they are removed if there are findings. The overhaul interval is therefore debatable, but is probably in the region of 5,000FC. Half-way through this interval we do a mid-check. The exchange and overhaul fee for a reverser half is about $250,000, and so $500,000 for a shipset." This is therefore equal to $100 per FC per reverser, and so $300 per FC for all three units.

The MD-11's APU is the Honeywell TSCP 700. "It has had some reliability issues, but its average shop-visit interval is about 3,000 APU hours. The cost per aircraft FH or FC is dependent on the ratio of APU use, but it is about 0.3APU hours per aircraft FH in our case," says Skytta. "A shop visit costs $250,000-300,000." Reserves are therefore about $30 per FH.

The total reserve for the wheels, tyres, brakes, landing gear and thrust reversers

The 747-400F/-400BDSF/-400BCF has the highest maintenance costs of the three large widebody freighters. Moreover, they are not proportionately higher in relation to the aircraft's larger size, and consequently the type has the lowest maintenance cost per unit of available payload.

is $1,177 per FC. This is equal to $215 per FH at an average FC time of 5.50FH. Added to this is the APU reserve, taking the total reserve for all four components to $245 per FH *(see table, page 60)*.

The removal intervals and shop-visit costs of the 777's and 747's components are similar to the MD-11's. In the case of the 777, the reserves for tyre remoulds and replacement are $60 per FC, while reserves for wheel inspections are $39 per FC. Brake repairs and overhauls have a reserve of $720 per FC, while the reserve for the landing gear is $123 per FC, and $200 per FC for the aircraft's two thrust reversers. The total of these five reserves is therefore $1,142 per FC; $175 per FH at the FH:FC described.

This should be added to the reserve for the GTCP 331-500 APU, which is $17 per FH. This takes the total reserve for all heavy components to $192 per FH *(see table, page 60)*. This low rate partly illustrates the benefits of a twin-engined aircraft over a tri-jet or quad configuration.

Remoulding and replacing the tyres on the 747-400 has a reserve of $76 per FC, while the reserve for the wheel inspections and overhauls is $54 per FC.

Repairs and overhauls for the 16 main wheel brakes have a reserve of $800 per FC. The reserve for the landing gear overhaul performed every eight years will be $134 per FC, and the reserve for the aircraft's four thrust reversers about $400 per FC. These five elements total about $1,464 FH, equal to $228 per FC at the FH:FC ratio of 6.50 FH.

The PW901 APU has a removal interval of 9,000APU hours, and therefore a reserve of $15 per FH. This takes the total reserve for all heavy components to $243 per FH *(see table, page 60)*.

Rotable components

Rotable components can be owned, managed and repaired by an airline's own maintenance & engineering department. In the case of small fleets of freighters, however, airlines are more likely to use complete support power-by-the-hour (PBH) rotable support packages. These contracts lease a core of homebase stock to airlines, provide remaining items via a pooling arrangement, and repair and manage all parts at an agreed fixed rate per FH. Each of these elements has a cost per FH. It is assumed here that a fleet of five aircraft is operated for each type.

In the case of the MD-11, the value of the homebase stock for five aircraft is about $5.5 million. "This can be supplied as homebase stock, or in two parts as a homebase stock and flyaway kits carried on the aircraft," says Skytta. At a lease rate of 1.2% per month, total lease rentals for the year are about $800,000, equal to $39 per FH. "The two additional elements of pool access and repair and management come to about $70 per FH and $210 per FH," adds Skytta. This takes the total cost to $340 per FH *(see table, page 60)*.

The value of the homebase stock to support a fleet of five 777s is in the region of $6 million. Leased at 1.2% per month, this results in lease rentals that are equal to about $41 per FH. Other costs are $40 per FH for the pool access for the remaining stock, and $220 per FH for the repair and management of all stock. This totals about $300 for complete rotable support *(see table, page 60)*.

The value of homebase stock required to support a fleet of five 747-400s is about $8 million. Leased at 1.2% per month, this results in lease rentals that are equal to $48-52 per FH. Other costs are $65 per FH for pool access to the remaining stock, and $220 per FH for the repair and management of all stock. This totals about $335 per FH for all elements of rotable support for the 747-400 *(see table, page 60)*.

Engine maintenance

All MD-11s are powered by the General Electric (GE) CF6-80C2 or the Pratt & Whitney (PW) PW4000-94. The CF6-80C2 powering the MD-11 is the -D1F rated at 61,960lbs thrust, while the PW4000-94 variants powering the aircraft are the PW4460 and PW4462 rated at 60,000lbs and 62,000lbs thrust respectively.

The majority of 747-400 freighters, including virtually all converted aircraft, are powered by either the PW4056 rated at 56,000lbs thrust, or the CF6-80C2B1F rated at 58,090lbs thrust. A small number are powered by the PW4062.

Two fleets of factory-built freighters are powered by the Rolls-Royce RB211-525G/H-T.

All 777-200LRFs are powered by the GE90-110, rated at 110,000lbs thrust.

Analysis of engine maintenance costs is based on the PW4056 and CF6-80C2B1F powering the 747-400, the PW4060/62 and CF6-80C2D1F for the MD-11, and the GE90-110 for the 777.

The CF6-80C2D1F will have an average mature shop-visit removal interval of 2,200 engine flight cycles (EFC), equal to about 12,000EFH at the FH:FC ratio of 5.50:1. A mature engine will follow a varying shop-visit pattern. The first shop visit after a full engine overhaul will usually be a core restoration, followed by a heavier workscope on the core modules at the second shop visit, and then a full overhaul on all modules at the third shop visit. The total costs for these workscopes will be about $1.7 million, $1.9 million and $2.4 million respectively, coming to a total cost of $6.0-6.5 million. Amortised over the total interval of 36,000EFH, the shop-visit reserve is therefore $170-175 per EFH.

The engine has a stack of life limited parts (LLPs) of 21 units with a total list price of about $4.5 million. Most parts in the fan/low pressure compressor (LPC),

SUMMARY OF MD-11F, 777-200LRF & 747-400F/-400BDSF/-400BCF MAINTENANCE COSTS

Aircraft type	MD-11F	777-200LRF	747-400F/-400BDSF/-400BCF
FH per year	4,100	4,250	4,500
FC per year	750	650	700
FH:FC	5.50	6.50	6.50
	$/FH	**$/FH**	**$/FH**
Line checks	74	60	90
A checks	80	150	140
Base checks	111	80	160
Heavy components	245	192	243
Rotable components	340	300	335
Sub-total airframe & components	**850**	**782**	**968**
Engine maintenance			
CF6-80C2	651-666		684
PW4000-94	735-771		696-736
GE90-110B		836	
Total costs			
CF6-80C2	**1,501-1,516**		**1,652**
PW4000-94	**1,585-1,621**		**1,664-1,704**
GE90-110B		**1,618**	

high pressure compressor (HPC) and low pressure turbine (LPT) have lives of 20,000EFC. A few have shorter lives of 15,000EFC. Parts in the high pressure turbine (HPT) have lives of 9,000EFC and 15,000EFC. The average replacement life of these LLPs will be 17,500EFC, equal to about eight shop visits. The reserve for LLPs will therefore be about $257 per EFC, which is equal to $35 per EFH. Total reserves for the engine will therefore be in the region of $217-222 per EFH.

The PW4460/62 powering the MD-11 has similar shop-visit removal intervals of 2,000-2,200EFC and 11,000-12,000EFH. The PW4000-94 follows an alternating pattern of core restoration and full overhaul shop visits. These two workscopes have total costs of about $1.9 million and $2.7 million. The overall reserve for shop visits is therefore $190-200 per EFH.

Management of the PW4000-94 is also made easier by the fact that the engine has uniform lives for its 24 LLPs. These have a list price of about $4.4 million. In the case of the PW4060/62, the LLPs have lives of 15,000EFC. The replacement interval can be close to the full life of the parts, so it can reach the seventh shop visit up to a total time of 14,000-14,500EFC. The reserve will therefore be $303-314 per EFC, equal to $55-57 per EFH. Total reserves for the engine will therefore be $245-257 per EFH.

In the case of the CF6-80C2B1F, which powers the 747-400, the engine has a mature interval of about 2,400EFC, with its lower rating allowing it to achieve longer on-wing intervals. This is equal to 15,500EFH at the FH:FC ratio of 6.5:1. The engine will follow a shop-visit pattern and have shop-visit workscopes similar to the D1F variant powering the MD-11. The total cost for the three shop visits will therefore be $5.8-6.2 million, resulting in a reserve of $130 per EFH.

The average LLP replacement interval will be about seven shop-visit intervals, which is equal to about 16,800EFC. The shipset of LLPs will therefore result in an LLP reserve of $271 per EFC; equal to $41 per EFH. The total reserve will therefore be $171 per EFH, and $684 per FH for all four engines *(see table, this page)*.

The PW4056 powering the 747-400 will be similar to the higher-powered variants installed on the MD-11. The PW4056 will have mature removal intervals of 2,500-2,750EFC, equal to about 16,250-18,000EFH. The engine will follow a similar alternating shop-visit pattern to the PW4460/62, and have shop-visit workscope costs of $4.5-5.3 million. Shop-visit reserves are consequently $136-147 per EFH.

LLPs in the PW4056 have a uniform life of 20,000EFC. They can therefore be replaced at the seventh shop visit, after accumulating about 18,000EFC. LLP reserves are therefore about $244 per EFC, equal to $37 per EFH, so total maintenance reserves come to $174-184 per EFH.

The GE90-110B powering the 777-200LRF will be a new engine, so its first removal intervals are in the region of 3,000EFC and 19,500EFH, at an average FC time of 6.50FH. At this stage the engine will undergo a heavy performance or core restoration. The second run will be shorter: about 2,000EFC and 13,000EFH. The workscope following this interval will then comprise a full overhaul.

The two workscopes will cost in the region of $9.5 million, resulting in a reserve of $292 per EFH.

The GE90-110B has 26 LLPs with lives ranging from 3,500EFC to 15,000EFC plus a set of fan blades, while the list price for a shipset is about $8.2 million. The average replacement age of 10,000EFC will result in a reserve of $820 per EFC, equal to $126 per EFH. Total maintenance reserves for the GE90-110B will therefore be $418 per EFH, and $836 for both engines *(see table, this page)*.

Summary

Despite the differences in size between the three types, there are only small variations in their maintenance costs. As is to be expected, the MD-11 has higher airframe and component maintenance costs than the 777. The 777, however, loses the advantage of its lower airframe-related costs because its GE90-110B engine has such high reserves. The MD-11F's costs are up to $110 per FH lower than the 777F's, even though the MD-11F has higher airframe- and component-related costs.

Despite being larger than the 777F and having higher airframe- and component-related costs, the 747-400 has similar costs overall to the 777F. This is because the 747-400 benefits from lower total engine maintenance, while the 777F is disadvantaged by the high reserves of its GE90-110Bs. AC