MD-11 maintenance analysis & budget

Given its size and ability as a high capacity long-haul freighter, the MD-11 has competitive and steady maintenance costs. The aircraft is likely to continue operating for 15-20 years.

Only 200 MD-11s were ever built, but with 195 remaining in operation, the aircraft has become established as an important freighter type. It is also relatively young, ranging in age from six to 16 years old. The MD-11F is also in a class of its own in terms of the payload capacity it offers to freight carriers. There are no direct alternatives, since the 777 factory freighter has a higher payload but also a disproportionately higher financing cost. The MD-11 is therefore a sought-after aircraft, whose popularity is expected to continue for the next 15-20 years.

Only 34 MD-11s remain in passenger configuration, eight of which have already been purchased for conversion to freighter. The remaining 26 are likely to be retired by their operators within the next 10 years, and subsequently converted to freighter. In 1999 UPS stated its original intention to acquire 35 MD-11s for conversion to freighter, and has now acquired 37. This reduces the number of passenger-configured aircraft available to 26 units, which are in high demand.

The MD-11's full maintenance costs are analysed here, including: line and ramp maintenance; base check maintenance; engine repair and overhaul; rotable repair and management; and heavy component repair and overhauls.

MD-11 in operation

The MD-11 is used as a medium- and long-haul aircraft in both passenger and freight operations. The freighter's range with a maximum payload is 3,700nm, equal to a flight time of eight hours. The route networks of many freight carriers mean that their average flight cycle (FC) times are in the region of five or six flight hours (FH). Freighter aircraft experience high annual rates of utilisation, which in many cases reach 4,500-5,000FH per year. This means that many aircraft accumulate 800-900FC annually. Lufthansa Cargo, for example, has a large global route network and an average FC time of 5.7FH. Its aircraft accumulate about 4,800FH and 830FC per year.

Finnair has a fleet of seven passenger-configured aircraft. These are operated on its long-haul network from Helsinki, which includes New York and various points in the Asia Pacific. The aircraft have an average utilisation of about 5,000FH per year, an average cycle time of about 7.0FH, and generate about 700FC annually.

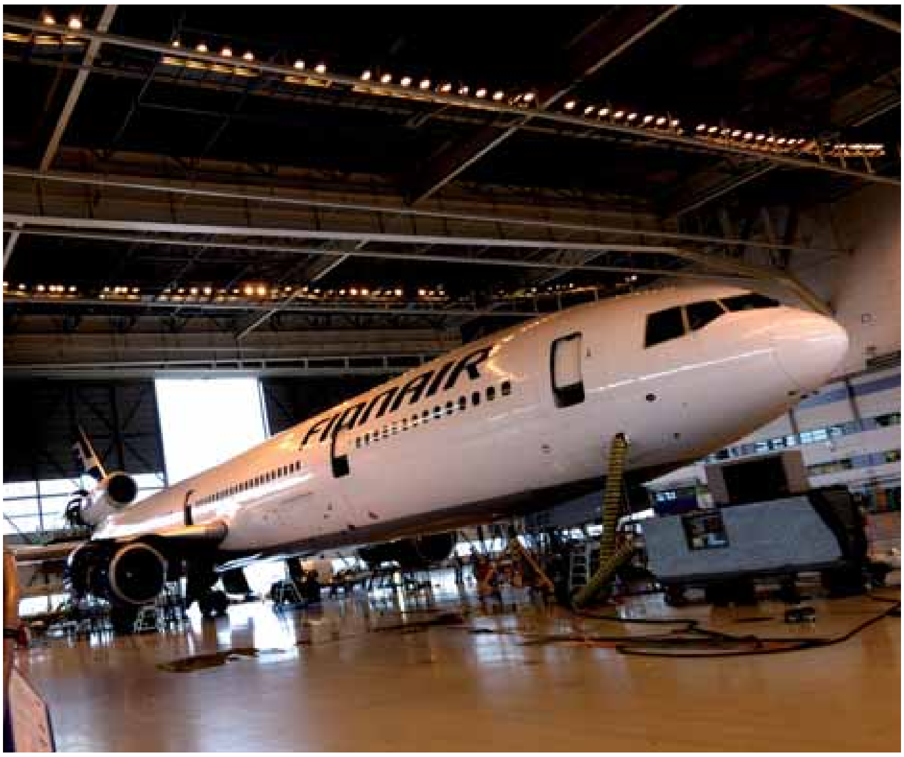
The MD-11's full maintenance costs are examined for a passenger aircraft completing 5,000FH and 700FC per year, at an average FC time of 7.0FH, and for a freighter aircraft completing 4,500FH and 820FC per year, at an average FC time of 5.7FH.

Line maintenance programme

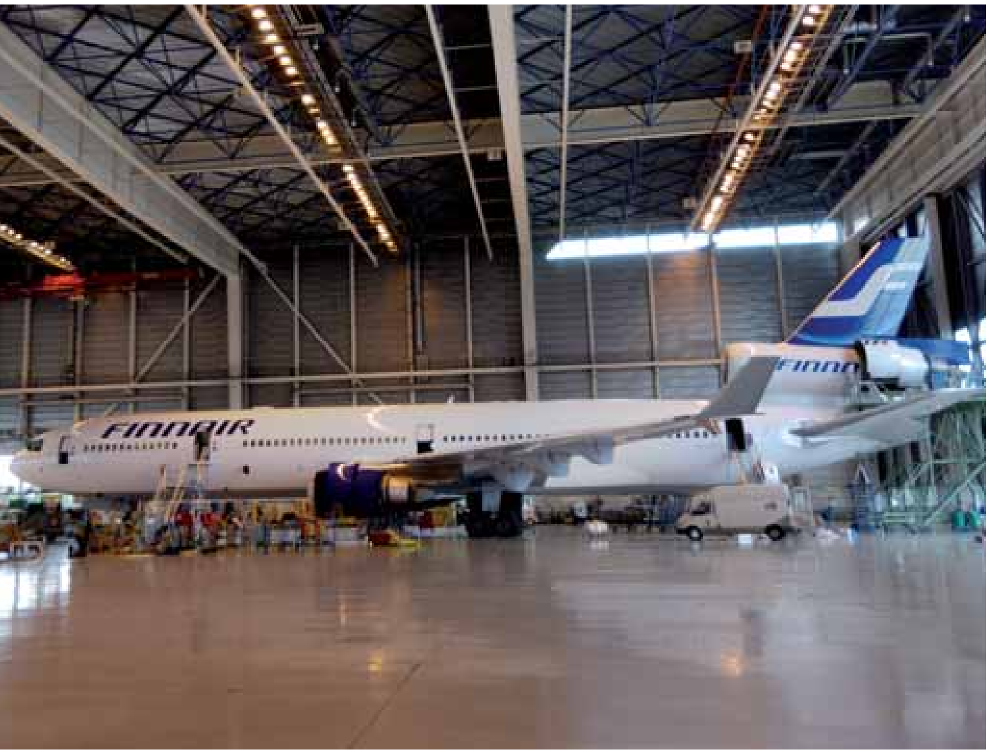
Like all aircraft types, the MD-11 has pre-flight (PF) checks made before the first flight of each day's operations, a transit (TR) check prior to all other flights during the day, and a daily check. Under maintenance steering group 3 (MSG3) philosophy, a daily check can now be performed up to every 48 hours. Daily checks are usually performed when the aircraft is present for a sufficiently long downtime at its homebase. In the case of long-haul aircraft, like the MD-11, this can be more than once every 24 hours.

After the daily check, the A check is the next highest check in the MD-11's maintenance programme. "The MD-11's original 1A tasks interval in the maintenance review board (MRB) in 1990 was 350FH," explains Tapio Leskinen, manager MD-11 fleet engineering at Finnair Technical Services. "We have been able to escalate this interval several times since 1990 and our current interval for the 1A tasks is 700FH. There are also multiples of A check tasks: 2A tasks with an interval of 1,400FH; 3A tasks at 2,100FH; 4A tasks with a 2,800FH interval; and 6A items with a 4,200FH interval. The full cycle of A check tasks is therefore completed at the A12 check, which has a maximum interval of 8,400FH."

The MD-11's maintenance planning document (MPD) now has an interval of 600FH for the basic 1A check items. There are also tasks that have multiples of this interval: the 2A, 3A, 4A and 6A tasks. The 6A tasks therefore have an MPD interval of 3,600FH. The A12 check and the A check cycle would have an interval of 7,200FH.



The MD-11 is operated as a long-haul aircraft both in passenger and freight operations. The aircraft is capable of intensive use, achieving annual utilisations of up to 5,000FH per year.



The MD-11's base maintenance programme is simple, with a series of four checks culminating in a heavy check. The C4 check is used to refurbish the aircraft interior and overall usually is a large workscope. The aircraft has so far demonstrated a low non-routine ratio.

Other experienced operators have a longer basic 1A interval. "We operate a fleet of 19 aircraft. Some of these are factory-built freighters, while other older aircraft are converted passenger aircraft," explains Thomas Streyczek, manager of MD-11 system engineering at Lufthansa Technik. "We have escalated our 1A interval to 720FH during the course of our operation." This means that the maximum possible interval for the A check cycle is 8,640FH, although in all operators' cases the actual interval achieved between A checks is 80-85% of the MPD interval. Most MD-11 operators have an A check interval of 600FH, so they would be performing an A check every 450FH, and completing the A check cycle after 5,400FH.

Base maintenance programme

The MD-11's MPD is based on MSG3 philosophy. The ageing aircraft programme items that were added on to the DC-10's maintenance programme are therefore an integral part of the MD-11's programme.

Leskinen says that the MD-11's MRB initially had an interval of 4,200FH and 15 months, whichever is reached first, when it began operations in 1990. This meant that the aircraft would be limited to an annual utilisation of 3,360FH if both intervals were to be fully utilised.

Leskinen explains that Finnair, which is one of the first and most experienced MD-11 operators, has managed to have its own C check intervals extended up to 7,500FH and 18 months.

The MD-11's MPD has a C check interval of 6,000FH and 15 months, which allows a maximum of 4,800FH per year if both intervals are to be reached at the same time. There are multiple tasks, the heaviest of which are the 4C items, and the base check cycle culminates with the C4 check. The base check cycle therefore comprises the C1, C2, C3 and C4 checks.

The C4 check, which is sometimes referred to as the D check, is the last and heaviest check in the base maintenance cycle. This has an interval of 24,000FH and 60 months. The base maintenance cycle is therefore completed every five years, or about every four years considering most operators' utilisations of check intervals.

"Our C4 check interval is one of the longest in the global fleet: 30,000FH and 72 months," says Leskinen. "This means that our full base check cycle now has an interval of up to six years, but the shorter intervals that the aircraft originally had mean that the first C4 checks were performed at an age of about five years. Our oldest aircraft will have their third C4/C12 check in the next year."

Lufthansa Cargo has a 1C task interval of 6,000FH and 15 months, which allows up to 4,800FH per year if both intervals are to be completely utilised. The airline's 4C check interval is 24,000FH and 60 months.

The length of the base check cycle, and probable check interval utilisation, mean that the oldest MD-11s will now have been through, or will just be approaching, their third C4 check. The youngest and last MD-11s were built in 1999 and 2000. These aircraft will have been through their first C4 check, and will be approaching their second in two to three years' time. Most of the MD-11 fleet is therefore mature.

Base check contents

C checks include several elements that are present in base checks for all aircraft. The first of these comprises routine inspections for corrosion and other items that were treated as separate ageing aircraft items. These routine inspections are accompanied by non-routine rectifications and defects that arise out of the routine inspections.

The MD-11 also has some structural sampling tasks that are required on a percentage of an operator's fleet.

As with all types of aircraft, there are also out-of-phase tasks. These are items that have fixed or hard-time maintenance intervals that do not coincide with A or C check intervals, but are normally scheduled into one of these checks to avoid additional maintenance downtime to take care of these issues. Janne Tarvainen, assistant vice president component department at Finnair Technical Services, explains that of the MD-11's 1,300 rotable components, about 10% are hard-time components. These are safety items, batteries and items such as the integrated drive generator and the radio cooling fan.

The C4 or D check is the check during which most operators will carry out the larger items of interior refurbishment. This can include the refurbishment of galleys and toilets, overhead bins and passenger service units, sidewall panels and carpets, and seats. Seats and carpeting may also be refurbished on an on-condition basis and taken care of during the lighter C checks.

"Freighter aircraft will use up to 10,000MH fewer for a full C4 check package, because freighter aircraft have almost no interior refurbishment requirements," explains Leskinen. "Passenger aircraft have many additional items that consume a lot of MH for refurbishment."

The C4 check has a downtime of about four weeks, which also presents an opportunity to strip and repaint the aircraft. Leskinen explains that this consumes 2,500MH and $50,000 in materials.

Service bulletins (SBs), modifications and airworthiness directives (ADs), must also be considered. These can account for several hundred or thousand MH of a complete C or C4 check workpackage.

"We have made several upgrades and modifications to our MD-11s over recent years, which include a flight management computer (FMC) 921 upgrade, an enhanced ground proximity warning system (EGPWS) installation, a predictive windshear installation and various other avionic modifications. We also get SBs issued by Boeing, some of which are individual structural inspections. There are also several system and avionic upgrades," says Leskinen.

"The MD-11 has also had three major ADs issued against it, which have all been dealt with across the fleet, but which have added a large number of MH to complete the modification," continues Leskinen. "The first of these was the engine pylon upper spar modification, which used about 900MH per engine pylon. The second was AD 2000-11-02, relating to the installation of a new cabin insulation blanket to provide better protection against fire. This has been completed on all MD-11s, but used about 10,000MH per aircraft to complete. The third major AD involved inspection and treatment of the horizontal stabiliser barrel nuts, which used about 1,500MH per aircraft. This has now been recently completed on all MD-11s."

Brian O'Meagher, components monitoring centre manager VEM Maintenance & Engineering, explains that typical SBs used in C checks are the torque shaft bearing inspections on the passenger doors, while SB MD11-53-066 requires an inspection on the left and right main landing gear doors that takes about 40MH to complete.

Line maintenance inputs

TR and PF checks were originally carried out by flight engineers, but were handed over to line mechanics with the advent of aircraft with two-man flightdecks. Many airlines now have these checks performed by the flightcrew, which in most cases require less than 1MH to complete and use just a few dollars of materials and consumables.

A conservative budget would be for 2MH used in each TR and PF check, together with about $20 for materials and consumables. A line maintenance labour rate of $70 per FH would take the cost for each check to about $160.

Finnair Technical Services estimates that daily checks use an average of 6MH and $80 in materials and consumables. A labour rate of $70 per MH would take the total cost of a daily check to $500.

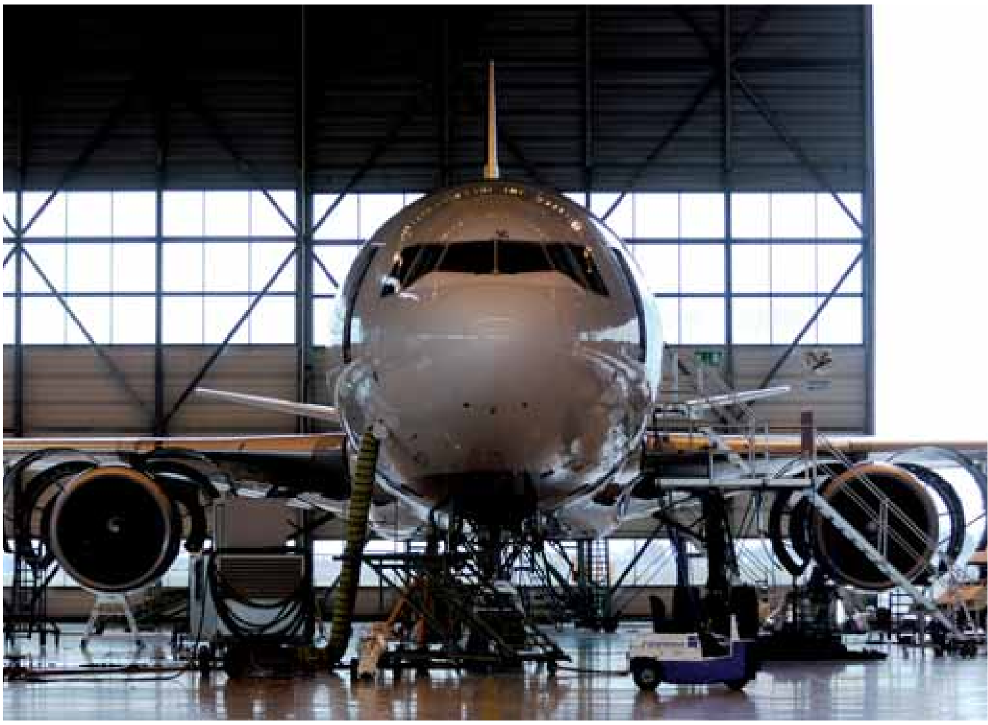
The rate per FH for line and light checks can be analysed in terms of total costs for all these checks performed during the course of a year. The number of daily checks depends on the style of operation. In the case of aircraft operating one return flight per day, as with Finnair, a daily check would be performed on most days, or every second flight when the aircraft was at the homebase. This would total about 350 daily checks. The pattern of operation between different freight carriers varies between short-, medium- and long-haul. Either way, most aircraft will require a similar number of daily checks in the year, which will also be close to about 350. The average cost of $500 for each daily check will take the annual cost to $175,000.

The number of PF and TR checks will be equal to the number of annual FC, less the number of daily checks. In the case of passenger aircraft used on long-haul missions this will be close to 350. This will take the annual cost of TR and PF checks to about $56,000.

Freighter aircraft operating at a shorter average FC time and generating about 850FC per year, will require 500 TR and PF checks each year, and will have an annual cost of $80,000.

Passenger aircraft will consume a total of $230,000 per year for TR, PF and daily checks. Amortised over a utilisation of 5,000FH, this will be equal to $46 per FH *(see table, page 30)*.

Freighter aircraft will consume a total of about $255,000 per year for line and



The C4 check for passenger-configured MD-11s consumes about 43,000MH, while its freighter counterpart will consume about 10,000MH less. This is one main factor that makes the MD-11F/CF competitive against the ageing 747-200SF, which will consume 90,000-100,000MH in its D check.

light checks. Amortised over a utilisation of 4,500FH, this will be equal to a rate of $57 per FH *(see table, page 30)*.

A check inputs

A checks are performed in block checks by most operators, and consequently vary in size. "We use an average of 440MH for our A checks," explains Streyczek. "This is for the whole A check package, and includes 120MH used for routine tasks. The package will also include rectifications arising from the routine tasks, clearing of deferred defects, engineering orders (EOs) and modifications, cleaning and some out-of-phase tasks."

Finnair uses a block check system, and aims to clear all defects during the A check to maintain a reliable operation. "We basically use each of our aircraft on one return flight per day, and we do not stock an inventory of rotables at outstations. We therefore like to clear technical defects not long after they occur," explains Erkki Lehtonen, assistant vice president aircraft heavy maintenance at Finnair Technical Services. "We get about one defect for each flight. Some of these can be dealt with between flights, and others have to be dealt with at stops because they are no-go items. Deferred items can be cleared during the daily and A checks. The auxiliary power unit (APU) and in-flight entertainment (IFE) system present the most regular problems.

"The A check therefore varies in size and content," continues Lehtonen. "We use 400-500MH for an A check, since they vary in size and content. The main factor causing variation in size is the clearing of technical defects."

The consumables and materials used vary, and mainly include oils, lubricants and small items. The average for an A check will be in the region of $11,000. A labour rate of $70 per MH would take the total A check cost to about $46,000. This would be equal to a rate of $105 per FH *(see table, page 30)*, if the average interval between A checks is 450MH.

Base check inputs

The elements that comprise the C check packages have been described. The lower C checks (the C1, C2 and C3 checks) have a downtime of about five days, and may include some interior work on the seat covers and carpets. "The C6 checks and the C3 check in the second base check cycle actually have some structural inspections with an initial threshold of 90 months and a repeat interval of 60 months," explains Streyczek. "This means that they are repeated every fourth C check in most cases. They are therefore repeated at each third C check in the base maintenance cycle, and so will occur again at the C10, C14 and C18 check, and every fourth C check thereafter. This means that the routine content of the C checks rises during the second base check cycle.

"We had subcontracted all lighter C checks, but started on the C1/C2/C3/C5/C7 checks at our Frankfurt base earlier in 2006," continues Streyczek. "The routine inspections, rectifications and allowance for findings of these lighter C checks consume about 2,700MH, while another 600MH are used for EOs, SBs, modifications and clearing deferred items. This is a sub-total of about 3,300MH. An A check is also included in the C check, as are major modifications and major component changes. This will take the total for these lighter C checks to 4,000-4,500MH for freighter aircraft."

Leskinen at Finnair says its MD-11s use an average of 8,300MH for lighter C checks, depending on the workpackage. This includes about 3,200MH for routine inspections, 2,300MH for non-routine rectifications, 2,200MH for EOs and modifications and another 600MH for additional work. These aircraft are passenger-configured and will require a higher MH input because of interior-related items. The accompanying consumption of materials and consumables totals in the region of $167,000, and 10% of this is for interior work.

The C4 check is used by most operators to complete interior refurbishment and stripping and repainting, and will comprise a large workpackage when all items are considered. Leskinen says that these checks take about four weeks to complete, although they will take longer when items such as the insulation blanket modification is being performed. "The C4 checks on passenger-configured aircraft consume an average of about 43,000MH for the full package, which includes interior refurbishment and stripping and repainting," says Leskinen.

The full package includes about 15,400MH for routine inspections, 13,300MH for non-routine rectifications, another 10,500MH for EOs and modifications and about 3,500MH for additional work. The total includes about 2,500MH for stripping and repainting, as well as about 6,500MH for interior refurbishment. Overall, freighter aircraft use about 10,000MH less for a check of about the same workpackage; the difference being explained by the lack of interior-related work.

"This number of MH is for a C8 check, which is the second heavy check at 10 to 11 years of age. This does not include a large modification, such as changing the insulation blankets on the aircraft. The associated cost of materials and consumables for the whole workpackage is in the region of $1.18 million, including all items for interior refurbishment," continues Leskinen.

Streyczek points out that freighter aircraft do, however, have a cargo

MD-11 FAMILY HEAVY COMPONENT MAINTENANCE COSTS

FH & FC per year	
Average FC time of FH	
Number of main & nose wheels	10 + 2
Tyre retread interval-FC	180/230
Tyre retread cost-$	500/400
Number of retreads	4
New main & nose tyres-$	1,950/1,200
$/FC retread & replace tyres	**42**
Wheel inspection interval-FC	1,400
Main & nose wheel inspection cost-$	2,600
$/FC wheel inspection	**19**
Number of brakes	10
Brake repair interval-FC	1,400
Brake repair cost-$	70,000
$/FC brake repair cost	**500**
Landing gear interval-FC	4,500-5,500
Landing gear exchange & repair fee-$	750,000
$/FC landing gear overhaul	**140-167**
Thrust reverser repair interval-FC	3,500
Exchange & repair fee-$/unit	200,000
$/FC thrust reverser overhaul	**175**
APU hours shop visit interval	2,500
APU hours per aircraft FC	2.0
APU shop visit cost-$	300,000
$/FC APU shop visit	**240**
Total-$/FC	**1,116/1,145**
Total-$/FH passenger aircraft @ 7.0FH per FC	**160**
Total-$/FH passenger aircraft @ 5.5FH per FC	**210**

loading system that has to be examined as it is subject to damage during operation. This therefore requires some refurbishment work. "We remove and refurbish the cargo loading system every C check," says Streyczek. "The power drive units are particularly important."

Summary base checks

Mature passenger-configured aircraft consume a total of 68,000MH and $1.68 million of materials and consumables in a full base check cycle of four checks. At a labour rate of $50 per MH this will be a total cost of $5.1 million.

In many cases this will be over a maximum interval of 60 months, although typical levels of check interval utilisation mean that the actual full interval is more likely to be 50-53 months. An aircraft operating at an annual utilisation rate of 5,000FH per year will accumulate 21,000-22,000FH between checks. The reserve for these C checks will therefore be in the region of $230-245 per FH *(see table, page 30)*. This might be reduced to about $215 per FH for operators that have extended check intervals. These rates are for mature aircraft going up to their second C4 check, however, and MH and material expenditure are likely to rise as the aircraft pass through their third and fourth base check cycles.

Freighter aircraft will consume a total of about 48,000MH for the full base check, and in the region of $1.15 million in materials and consumables. A labour rate of $50 per MH would take this to a total of $3.55 million.

This will be amortised over the same calendar interval as the passenger aircraft: 50-53 months in most cases considering usual rates of check interval utilisation. On the basis that freighter aircraft accumulate about 4,500FH per year, the reserve for base checks over an interval of 19,000FH would be $180-190 per FH *(see table, page 30)*.

Rotable components

Rotable components and heavy rotable components must be considered separately. Heavy components include landing gear, thrust reversers, wheels and brakes, and the APU. These are considered separately from all other rotables.

Besides these four types of heavy components, up to 1,800 different rotable components are installed on the MD-11. The number can be as low as 1,300, but will vary considerably according to aircraft configuration. "There are, actually, rotable and repairable components, and so the number of total components on the aircraft depends on the definition used," explains Tarvainen at Finnair Technical Services. "We track about 650 rotable components with a computerised system for the purpose of monitoring aircraft configuration, maintenance planning, and managing inventory.

"The MD-11 is a relatively modern aircraft and about 90% of its rotable components are maintained on an on-condition basis, while the rest have hard-time maintenance intervals," continues Tarvainen. This implies that only about 120 rotables are maintained on a hard-time basis. Tarvainen explains that these are items which have life limited parts (LLPs), and so their lives and utilisations need to be monitored. The other components with hard-time maintenance intervals are safety-related components such as gas bottles, escape slides, and the standby horizon on the flightdeck. Other hard-time components include batteries, the integrated drive generator (IDG) and radio cooling fan. The number of hard-time rotables is far smaller than on older generation aircraft, such as the DC-10. "The higher percentage of components that are maintained on an on-condition basis is partly explained by the increased reliability of the components," explains Tarvainen. "The reliability of on-condition components, such as the engine control unit, has been monitored and soft times for recommended removal have been established. Soft times can of course be exceeded when reliability is good."

Finnair Technical Services is one supplier of rotable support packages to MD-11 operators. "These packages are considered separately to heavy components,"says Tarvainen. "The package includes the management of the parts such as logistics, repairing and tracking the components. We subcontract the repair of many of the parts, since we do not have repair capability for all 1,300 or so rotables on the aircraft. We repair about 70% of the volume in-house.

"There are three elements to this type of rotable support package," continues Tarvainen. "First, the airline is supplied with a homebase stock to which it has immediate access. These are components that are critical to the operation of the aircraft, and also have a high failure rate. The second part of the package involves providing the airline with access to a pool of the remaining rotables at our own stock. These often form the majority of rotables an airline will use. The third part of the package is providing logistics services relating to both groups of components. This includes transporting failed and serviceable units, testing and repairing removed components, and providing all relevant airworthiness and serviceable documents."

The size of the homebase stock is affected by several factors, including: aircraft operation and utilisation; fleet size; age and condition of the aircraft; the component configuration of the aircraft; whether the aircraft is in passenger or freighter configuration; and the insurance level required by the operator. Tarvainen estimates that the list price of homebase stock for a fleet of five aircraft is $4.5-6.0 million, while another $2.5 million of stock is required for a fleet of 10 aircraft. The associated lease rate for these components is $35,000-45,000 per month for a fleet of five aircraft, and $65,000-75,000 per month for 10 aircraft. This comes to $85,000-110,000 per aircraft per year, equating to $17-22 per FH for an aircraft accumulating 5,000FH annually. The rate is reduced to $16-18 per FH for a larger fleet of 10 aircraft.

Fees for the access pool are $30,000-35,000 per month for a fleet of five aircraft, and $50,000 per month for 10 aircraft. This translates to a rate of $12-15 per FH per aircraft, depending on fleet size.

"The third element for repair and management is about $190-260 per FH for passenger aircraft, and about $160 per FH for freighter aircraft," says Tarvainen.

These three elements total $220-300 per FH for passenger aircraft, and $190-210 per FH for freighter aircraft *(see table, page 30)*.

Heavy components

As described, these comprise four main component types: wheels and brakes, landing gear, thrust reversers and the APU.

Removals of wheels and brakes are first triggered by tyre wear and a need for remoulding. There are 10 main wheels. Finnair reports an average interval of 230FC for remoulds, and 180FC for nose tyre remoulds. Main tyres have a life limit of 1,200FC and so are remoulded up to four times before being replaced at the fifth removal, while nose tyres have a limit of 800FC and are remoulded up to three times.

Remoulds cost about $500 for main tyres and $400 for nose tyres. New main tyres cost $1,950 each and new nose tyres $1,200 each. The life cycle remoulding and replacement cost for a complete shipset of 12 tyres is about $22,000, which is equal to a reserve of $42 per FC *(see table, page 24)*.

Leskinen at Finnair explains that wheel rim inspections are made every sixth tyre change, and cost $2,600 per wheel. This has a shipset cost of $26,000, which, amortised over an interval of 1,400FC has a reserve of $19 per FC *(see table, page 24)*.

The MD-11 has carbon brakes and Leskinen explains that these have an average repair interval of 1,400FC, and associated average repair cost of $70,000, including the cost of a new heat pack. This is equal to a reserve rate of $500 per FC for all 10 brake units *(see table, page 24)*.

The landing gear has a hard-time removal interval of eight years and 7,500FC, whichever is reached first. Most aircraft accumulate in the region of 700FC per year, and so about 5,500FC over an eight-year removal interval.

Most airlines choose to have an exchange that includes an element for the capital cost of the landing gear, the repair and overhaul cost, and any additional costs that may be incurred. A market rate for a complete exchange fee is $750,000. This is equal to a reserve of $140 per FC *(see table, page 24)*.

Thrust reversers are generally removed on an on-condition basis, although most operators have established soft times for overhauls. The MD-11 is one of the new generation of aircraft that benefits from relatively long intervals, which are in the range of 2,800-4,300FC.

An intermediate shop visit has a cost in the region of $200,000, and so the cost for all three reversers will be $600,000. With an average interval of 3,500FC, the reserve for thrust reverser repair and maintenance will be $175 per FC *(see table, page 24)*.

The MD-11's APU is the Honeywell TSCP 700-4E. Lehtonen comments that it provides some of the MD-11's highest reliability problems, adding that the APU is basically underpowered for the aircraft. The APU has an average removal interval of 2,500 hours. The unit is used on average for one hour for every 3.5FH of aircraft utilisation. The APU has a removal interval equal to about 8,000FH.

A typical shop visit cost of $300,000 will result in a reserve of $240 per FC *(see table, page 24)*.

The total for all these heavy components is in the region of $1,100 per FC. This is equal to $160 per FH for a passenger aircraft with an average FC time of 7.0FH, and equal to $203 per FH for a freighter aircraft with an average FC time of 5.5FH *(see tables, pages 24 & 30)*.

Engine maintenance

The engine choices on the MD-11 are simple compared to other aircraft types. The two main types are the General Electric CF6-80C2 and the Pratt & Whitney PW4000-94. There is only one variant of the CF6-80C2: the -80C2D1F rated at 61,500lbs thrust, which has full authority digital engine control (FADEC). The two variants of the PW4000 are the PW4460 rated at 60,000lbs thrust, and the PW4462 rated at 62,000lbs thrust. Both of these engines have FADEC controls as standard.

Most MD-11s are operated on relatively long average FC times of 4.0-7.0FH. The consequence of this generally is that engine removal intervals are more related to engine flight hour (EFH) intervals rather than engine flight cycle (EFC) intervals.

These three engine variants all have high thrust ratings compared to other variants in the same engine families. These high thrust ratings mean that exhaust gas temperature (EGT) margin for the variants is relatively low and that loss of performance and EGT margin is a major removal driver for shop visit maintenance.

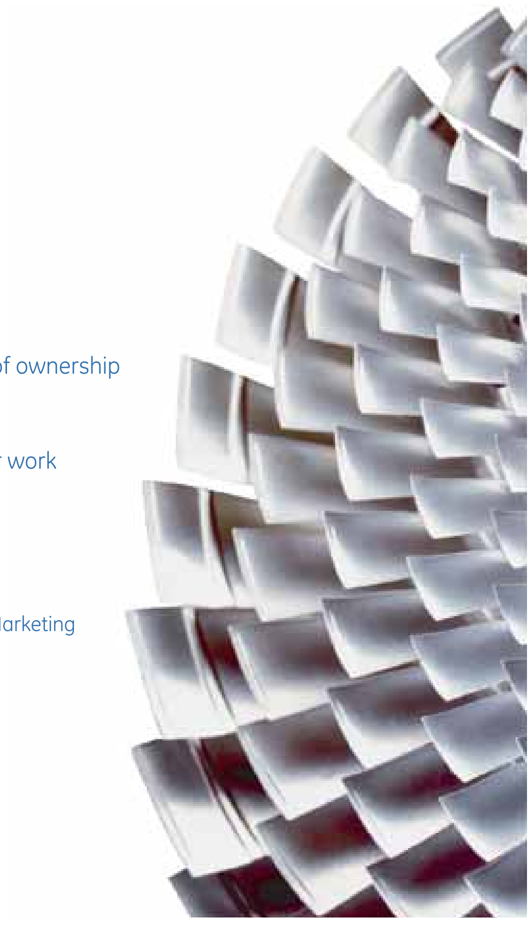
PW4000

The PW4460/62, with the Phase 3 modification, has an EGT margin of 26-30 degrees centigrade in the test cell after a shop visit. Domenic Janutin, product management at SR Technics, explains that on-wing margins are 5-10 degrees higher. The engines would thus have on-wing EGT margins of 31-40 degrees centigrade.

"The EGT margin on the PW4000 tends to deteriorate by about 13 degrees C in the first 1,000EFC after a full refurbishment, but it stabilises at a much lower rate of 5-10 degrees C in the second 1,000EFC," explains Janutin. The engine will have lost 18-23 degrees C after 2,000EFC following a shop visit. An engine with an average EFC time of 4.0-7.0EFH will have accumulated 8,000-14,000EFH. An interval of 2,000EFC/14,000EFH can be close to the full interval an engine is able to achieve.

The engine will be left with an EGT margin of 10-22 degrees C at this stage. The rate of EGT margin loss reduces to about two degrees per 1,000EFC after this.

Janutin explains that because the MD-11 is generally operated at high



average cycle times, and the PW4460/62 engines are operated at a relatively high thrust level, they rarely achieve on-wing intervals between two refurbishments of more than 16,000EFH. If engines are managed well, they will rarely be removed due to LLP expiry. This will be equal to 2,300-4,000EFC for engines operating on average cycle times of 4.0-7.0EFH.

The LLPs in the engine have lives of 15,000EFC, with the exception of the turbine coupling and low pressure turbine (LPT) shaft, which have lives of 30,000EFC. The removal intervals mean that most LLPs will have to be replaced every four to six shop visits. Engines that achieve up to 4,000EFC/16,000EFH on-wing will experience LLP expiry that will force an early fourth removal after about 3,000EFC. In most cases, however, it will be possible to use most of the LLPs' lives. The LLPs in the PW4000-94 have a list price of $3.4 million, and full utilisation will have an impact on engine maintenance reserves.

The PW4000 generally follows a shop visit pattern of alternating performance restorations and overhauls. These workscopes must be considered in relation to LLP replacement; the ideal timing for this to be when the engine requires an overhaul. Average removal and shop visit intervals of about 1,800EFC, 2,500EFC or 3,600EFC would allow LLPs to be replaced when the engine is removed for an overhaul, and full LLP lives to be used. They are correspondingly replaced at the eighth, sixth or fourth shop visit. The target for engines operating with an average EFC time of 7.0EFH would be for intervals of about 2,300EFC and 16,000EFH, and the replacement of LLPs at the sixth shop visit after about 14,000EFC.

This would be equal to 17-20 years of operation, however, and many operators and owners may consider only replacing LLPs once, since the aircraft are likely to be retired by the time the second LLP replacement comes due. LLP replacement at 14,000EFC would leave a stub life of just 1,000EFC. The resulting reserve for LLPs would be $245 per EFC, although the list price of LLPs will increase each year.

The target for engines operating at an average EFC time of 5.5EFH would be for intervals of 3,000-3,500EFC and 16,500-19,000EFH, although the shorter intervals are more likely to be realised. In this case LLPs would be replaced at the fourth shop visit after a total time of about 12,000EFC or 15,000EFC, if LLP replacement at a performance restoration was acceptable. The resulting reserve would be $230-285 per EFC.

Performance restoration shop visits consume in the region of 4,500MH for the complete workscope, $850,000 in parts and materials and $120,000 for sub-contract repairs. A labour rate of $70 per MH would take the total shop visit cost to $1.35 million, although the variation in parts, materials and sub-contract repairs could take this up to $1.5 million.

A higher labour rate of $100 per MH would take the total shop visit cost up to about $1.7 million.

An overhaul will involve work on the low pressure modules: the LPT, fan and low pressure compressor (LPC). An overhaul will use about 5,500MH, $1.0 million in parts and materials and $120,000-150,000. The total cost would consequently reach at least $1.5 million, although it could rise to $1.8 million.

A higher labour rate of $100 per MH would take the total up to $1.9-2.0 million.

The total of these two shop visits would be $3.2-3.3 million for engines operating at an EFC time of 7.0EFH, when using a labour rate of $70 per MH, and $2.9 million for an engine operating at 5.7EFH.

The cost of two shop visits, for engines operating at a cycle time of 7.0EFH, would be amortised over an interval of about 31,000-32,000EFH and result in a maintenance reserve of $105-110 per EFH. Engines operating at 5.5EFH per EFC would have lower shop visit costs but also shorter removal intervals. They would also have similar shop visit reserves of $105-110 per EFH.

These reserves would increase by $10

per EFH if a higher labour rate of $100 per MH were used.

The reserves for LLPs would have to be adjusted for average cycle time. Engines operating at 7.0EFH per EFC would have an additional reserve of $35 per EFH, while engines operating at 5.5EFH would have an additional reserve of $42-52 per EFH.

Where a labour rate of $70 per MH is used, total reserves would be $150-155 per EFH for engines operating at 7.0EFH, and $150-165 per EFH for engines operating at 5.5EFH *(see table, page 30)*.

CF6-80C2D1F

The CF6-80C2D1F, used exclusively to power the MD-11, has a test cell EGT margin of 36 degrees centigrade following a shop visit. Paul Lueck, propulsion systems engineering at Lufthansa Technik, explains that the on-wing EGT margin is similar to this.

The -80C2D1F has a high rating compared to other -80C2 variants, and so has a high rate of EGT margin erosion. "This makes EGT margin erosion and performance loss a main removal driver for the CF6-80C2 on the MD-11," says Lueck. "So far we have experienced a large number of second removals for the engines powering our MD-11 factory freighters, and we set an average on-wing life target of 12,000EFH. We recently exceeded this, and have now set a new target of 13,000EFH. This on-wing interval was for the second scheduled removal, which was of course shorter than the first. We do expect, however, the third and fourth intervals to be similar to the second intervals, which is why we are targeting 13,000EFH. This can be achieved by improving the build standard of the engines in the shop."

This interval of 12,000EFH is for an operation with an average EFC time of 5.7EFH, typical of the ratio for freighter aircraft. This interval is therefore equal to about 2,100EFC.

Passenger aircraft operating at longer average cycle times of about 7.0EFH are likely to have on-wing intervals in the region of 16,000EFH/2,300EFC, similar to the performance achieved by the PW4460/62.

Lueck explains that after this amount of time on-wing most of the engine has to be disassembled. "We would like to work on the LPT every second removal if possible, and the second shop visit in succession is usually heavier than the first."

The CF6-80C2 has LLPs with lives of 20,000EFC, except those in the high pressure turbine (HPT) which have lives of 15,000EFC. As with the PW4000, it is preferable to replace LLPs during a heavier shop visit. The removal intervals of 2,100-2,500EFC mean that LLPs can last in the engine for six or seven shop visits. This would allow LLPs to be replaced after a total time of 13,500-14,500EFC, and leaving a stub life of 500-1,500EFC. As with the PW4000, LLPs may only be replaced once, since their replacement at the second expiry could be avoided because of aircraft age.

Lueck explains that there are two types of LLPs in the CF6-80C2. "There is a set for a higher standard of HPT LLPs, which have a list price of $3.7 million. The price for the LLPs with the poorer HPT has a list price of about $3.3 million." Reserves for the higher set of LLPs will be $255-275 per EFC.

Lighter shop visits or a performance restoration consume 4,000-4,500MH, and when charged at a labour rate of $70 per MH incur a cost of $280,000-315,000. This will rise to $400,000-450,000 if a higher labour rate of $100 per MH is incurred.

Materials, parts and consumables, excluding LLPs, cost $850,000-950,000, although this can be reduced by a high rate of in-house repair or by the use of parts manufacturing approval (PMA) components. The cost will also be higher if the condition of the engine is poor. The cost of sub-contract repairs will be $250,000-300,000 if the shop has low in-house repair capability.

The total cost of this level of shop visit will be $1.4-1.55 million if the labour rate is $70 per MH, but up to $1.55-1.7 million if the labour rate is $100 per MH.

DIRECT MAINTENANCE COSTS FOR PASSENGER-CONFIGURED MD-11

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	230,000	1 year		46
A check	46,000	450FH		105
Base checks	5,100,000	21,000-22,000FH		230-245
Heavy components:			1,116	160
LRU component support				220-300
Total airframe & component maintenance				**760-1,270**
Engine maintenance:				
3 X PW4000: 3 X $150-155 per EFH				450-465
3 X CF6-80C2: 3 X $140-150 per EFH				430-450
Total direct maintenance costs:				
3 X PW4000				**1,210-1,735**
3X CF6-80C2				**1,190-1,720**

Annual utilisation:
5,000FH
700 FC
FH:FC ratio of 7.0:1.0

DIRECT MAINTENANCE COSTS FOR FREIGHTER-CONFIGURED MD-11

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	255,000	1 year		57
A check	46,000	450FH		105
Base checks	3,550,000	19,000FH		180-190
Heavy components:			1,145	210
LRU component support				190-210
Total airframe & component maintenance				**740-775**
Engine maintenance:				
3 X PW4000: 3 X $150-165 per EFH				450-495
3 X CF6-80C2: 3 X $160-185 per EFH				480-555
Total direct maintenance costs:				
3 X PW4000				**1,190-1,270**
3X CF6-80C2				**1,220-1,330**

Annual utilisation:
4,500FH
820 FC
FH:FC ratio of 5.5:1.0

A heavier workscope will use 5,000-5,500 MH depending on the total content of the shop visit. A labour rate of $70 per MH will take the cost to $350,000-385,000. The cost of materials, parts and consumables will be $1.0-1.1 million, excluding LLPs, while sub-contract repairs will be $350,000-400,000. This will take the total to $1.7-1.9 million. A higher labour rate of $100 per MH would increase this to $1.8-2.05 million.

The total cost of two shop visits would be $2.9-3.4 million, if a labour rate of $70 per MH is used.

Engines operating at an EFC time of 5.7EFH are likely to have an interval of 30,000-32,000EFH for two consecutive removals, and would incur higher shop visit costs of $3.3 million. If this cost is equalised over the interval, it would have a reserve of $105-115 per EFH. This would be increased by $10 per EFH if a higher labour rate of $100 per MH were incurred.

LLP reserves would be equal to $35 per EFH when equalised over the the EFC time of 7.0EFH. Total reserve would be $140-150 per EFH, for a labour rate of $70 per MH *(see table, this page)*.

An engine operating at an average cycle time of 5.7EFH would have a total time on-wing for two consecutive shop visits of 24,000-25,000EFH. The lower shop visit inputs totalling about $2.9 million would have reserves of $115-120 per EFH. This would be increased by about $10 per EFH if a labour rate of $100 per MH were used.

The additional cost of LLPs of $250 per EFC would be equalised over 5.7EFH, taking the reserve to $45 per EFH. This would take the total reserve to $160-185 per EFH, when a labour rate of $70 per EFH is used *(see table, this page)*.

Summary

The MD-11's maintenance costs allow the aircraft to remain competitive, despite its age, level of technology and the fact that it has three engines. The total of $1,200-1,735 per FH for passenger aircraft and $1,200-1,330 per FH for freighter aircraft varies due to variations in component- and engine-related costs. The freighter aircraft's maintenance costs explain why it is popular with cargo operators. The total maintenance costs of its closest competitor, the 747-200SF, are $2,800-3,000 per FH *(see 747-200/-300 maintenance analysis and budget, Aircraft Commerce, June/July 2005, page 13)*.

Savings can be made from the MD-11's total costs for operators using the aircraft on long-haul operations. If engine LLPs have already been replaced once since new, they are unlikely to need replacement for about another12-15 years.

The tight supply of MD-11s and its popularity as a freighter, mean that it is likely to have the same strong ability to retain market value as the DC-8-70 series. Demand for good quality MD-11s will persist, since few freight carriers can justify the high financing charges of the 777F. For this reason, MD-11 operators and owners should ensure that their assets are maintained well. Freighter aircraft that are placed on the market will sell quickly. AC