757 maintenance analysis & budget

The 757 has reasonable total maintenance costs for its age. One of the largest and most variable elements of maintenance costs are engine reserves.

Most 757s are mature aircraft in maintenance terms, and only about 140 will still be in their first base check cycle. The oldest aircraft will have passed their fourth base check cycle and will now be in the ageing phase of their life. Although production of the 757 has ceased, the aircraft is in a class of its own and is therefore likely to remain popular, ensuring that the number of 757s in operation will not change significantly from the current number of about 1,000 for the next five to 10 years.

One major change in the 757 fleet could be the conversion of a large number to freighters. The 757 is in a size class that is forecast by many to experience a high rate of growth, and several hundred may be modified to freighter. The 757 will have a range capability of up to about 2,500nm with a full payload, and can therefore offer itself as a versatile freighter. The aircraft could thus operate in a variety of roles, with low and medium rates of utilisation being experienced across short- and medium-haul operations.

757 in operation

Most 757s operate medium-haul passenger services on sectors with average flight times of 2.7 flight hours (FH), and operate about 1,050 flight cycles (FC) per year. Aircraft therefore accumulate about 2,700FH and about 3,000 block hours (BH) per year.

This pattern of utilisation is relatively efficient for narrowbody aircraft, since most other types are operated on shorter average FC times, which have the effect of raising costs per FH. The 757's long average FC time will reduce maintenance costs per FH for items such as landing gears, thrust reversers, wheels and brakes, some elements of engine reserves and base checks, and line and ramp checks.

Most aircraft that will be converted to freighter are likely to operate shorter average FC times, with the effect of increasing many of the aircraft's FH maintenance costs. One particular issue of concern for future freighter operations is the effect on maintenance costs of RB211-535E4 and PW2000 engines changing to shorter average cycle times and lower rates of annual utilisation.

Maintenance programme

The 757's maintenance programme was developed in parallel with the 767's maintenance schedule under a maintenance steering group 3 (MSG3) programme. Ageing aircraft tasks are thus built into the maintenance programme. The initial thresholds for these are relatively high, and appear in the second or third base check cycles.

Separate maintenance programmes were developed for structural- and system-related tasks. System tasks were grouped into checks with FH intervals, while structural inspections were grouped into checks with FC intervals. These two groups of checks could then be performed together or separately at the operator's discretion.

The maintenance planning document (MPD) has an interval of 500FH for system-related A check items. There are also system-related tasks with multiples of this interval: the 2A, 3A, 4A and 6A tasks (the latter having an interval of 3,000FH).

The structural-related system 1SA tasks have an interval of 350FC. There are also 5SA tasks with an interval of 1,500FC.

The different groups of tasks will not be in phase until the A12 check, so the A check cycle terminates at this check, which has an interval of 6,000FH.

Downtime for maintenance is minimised if the structural tasks are combined with a multiple of the system tasks. That is, the 1SA could be combined in one check with the 1A, 2A or 3A tasks, depending on the average FH:FC ratio achieved during operation. An aircraft with an FH:FC ratio of 1.4:1 or less would combine the 1SA with the 1A tasks in order to utilise a high proportion of both check intervals.

An aircraft with an average FH:FC ratio of 1.4-2.8:1 would combine the 2A items with the 1SA tasks, while an aircraft with an FC time of more than 2.8FH would combine the 3A tasks with the 1SA tasks to best utilise check

Most 757s operate on average FC times of 2.0-2.7FH and achieve annual utilisations of 2,500-3,250FH. This has the beneficial effect of lowering the costs per FH of the many elements of maintenance that have cycle-related costs.

intervals. The majority of operators, however, combine 1A and 1SA tasks, irrespective of their FH:FC ratio, to simplify maintenance planning, which means most of the 1SA check interval is not utilised.

This also affects C check planning. The 1C system check tasks have an interval of 6,000FH and 18 months. There are 2C, 3C and 4C multiples, with intervals of 12,000FH/36 months, 18,000FH/54 months and 24,000FH/72 months.

The 1SC structural tasks have an interval of 3,000FC and 18 months. There are 2SC tasks with an interval of 6,000FC and 36 months, 3SC tasks with an interval of 9,000FC and 54 months, and 4SC tasks with an interval of 12,000FC and 72 months. Like A check items, most airlines combine 1C tasks with 1SC tasks to simplify maintenance planning.

Most operators arrange C checks into block checks. The C4 check therefore includes the 1C, 1SC, 2C, 2SC, 4C and 4SC tasks, forming the largest check in the cycle, and also terminating the cycle of C check items.

Maintenance planning

As described, most operators combine 1A and 1SA tasks and relevant multiples in the A checks, and combine 1C items with 1SC tasks and relevant C check multiples in the C checks for the ease of planning. This results in a low rate of utilisation for structural-related A and C task intervals.

Aircraft converted to freighter will still combine system and structural tasks in this way, and will use a high proportion of the structural check intervals because they are more likely to operate with shorter average cycle times.

Most operators also perform block checks. There are 1A, 2A, 3A, 4A and 6A tasks. The 1A tasks are performed every check, the 2A tasks every second check, the 3A tasks every third, the 4A tasks every fourth, and the 6A tasks every sixth. The tasks are therefore all in phase at the A12 check, at an interval of 6,000FH.

C checks are arranged in the same way, and block checks are formed with the C4 check being the largest, grouping the 1C, 1SC, 2C, 2SC, 4C and 4SC tasks together. In theory all task cycles will be in phase until the C12 check, because the 3C and 3SC tasks will have to be performed every third check. The cycle is completed by most operators, however, at the C4 check. The 3C and 3SC tasks comprise only a few items.

In addition to systems and structural tasks, operators and maintenance planners also include tasks that have intervals that are out of phase with the main tasks, including: cabin cleaning; cabin and interior refurbishment; performance of ageing aircraft tasks as they come due in later checks; performance of airworthiness directives (ADs) and service bulletins (SBs); removal and reinstallation of components and rotables; and strip and repaint when required. These tasks increase the content of checks, and can almost double the number of man-hours (MH) required to complete some of the heavier checks.

Check interval utilisation is an important issue. Airlines typically only utilise about 70% of their A check intervals, and so the 757 would have an A check about every 350FH. The A check would thus get completed about every 4,200FH or every 18 months when compared against typical annual utilisation.

Airlines utilise higher proportions of base check intervals, typically 85%. On this basis, a 757 would have a C check about every 5,100FH. The C check also has an 18-month calendar limit, which is unlikely to be fully utilised. A 15- or 16-month interval between checks is more likely. About 3,375-3,600FH will thus be accumulated between each C check, utilising only about 60% of the FH interval. The C4 check and base check

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The 757's base maintenance programme has a cycle of four C checks and a C check interval of 18 months. The implication of this is to limit the cycle time to a maximum of six years, limiting the number of FH that can be accumulated in this time.

cycle, will therefore be completed about every 14,400FH and 62 months. Most 757s will therefore complete a base check cycle about every five years, and so the oldest aircraft will be in their fifth base check cycle.

Line & ramp checks

The line and ramp checks for 757 passenger operations are the pre-flight check prior to the first flight of each day, a transit check prior to all subsequent flights of an operating day, and a daily check performed overnight every 24 hours.

The content, MH and material inputs used, and the number of these checks performed every year or each A check cycle can account for a high proportion of maintenance costs. There will be a large number of pre-flight and transit checks in a given period for aircraft that have high cycle rates of utilisation.

The three line and ramp checks can be analysed over an A check cycle, and their inputs compared to the aircraft's annual utilisation. Taking into consideration downtime for base checks, the aircraft is likely to operate for 345-350 days per year. This means the same number of pre-flight and daily checks will be performed each year. The number of transit checks will therefore be about 700.

The actual interval between A checks will be in the region of 400FH, so the A check will be completed about every 4,800FH, which is equal to 21 months of operation. During this period the aircraft will go through about 600 pre-flight checks, 1,200 transit checks and 600 daily checks.

The MH used for each type of check vary widely between operators, and also depend on how the aircraft's technical defects are managed. Pre-flight checks consume about 5MH and $60 should be allowed for materials and consumables. Transit checks use about 1MH, and can sometimes be carried out by flightcrew. An allowance of $10 should be made for materials and consumables. A daily or overnight check, which will be used to clear most of the technical defects that arise during operation, will require a total input of up to 15MH from more than one mechanic, and a budget of $150 should be made for materials and consumables.

Over the duration of an A check cycle, a total of 13,000-14,000MH and $106,000 in materials and consumables will be consumed for these line and ramp checks. A labour rate of $70 per MH will take this to a total cost of about $1.05 million, which is equal to a rate of $220 per FH when amortised over the interval of 4,800FH *(see table, page 26)*.

Lighter A checks consume about 250MH, and two heavier checks in the A check cycle consume about 400MH each. Average material and consumable consumption is about $6,000 per check, taking total costs for the 12 checks in the cycle to about $300,000, and equal to a reserve of about $65 per FH *(see table, page 26)*.

Base checks

As previously described, the majority of 757s are now mature since they are in the second, third or fourth base check cycles. The 18-month calendar limit on C checks and typical levels of utilisation of check intervals means the four-check cycle gets completed about every five years. This is equal to about 13,500FH.

The majority of aircraft are in their second and third base check cycles, and the important issue is by how much the number of MH used to complete these checks increases with each base check cycle.

The content of base checks will include: routine inspections; corrosion prevention and control programme (CPCP) and sampling inspections; non-routine labour arising from routine inspections; cabin cleaning; ADs and other modifications; interior refurbishment; and stripping and re-painting. The total number of MH used for each of these checks will vary. First, the efficiency of maintenance planning will affect the number of MH required for routine inspections and, second, the initial thresholds of CPCP tasks occur late in the first base check cycle, and increase thereafter. The routine portion of base checks is therefore not only variable, but also increases with age.

The non-routine portion is determined by the age of the aircraft, its operating environment and how well the defects that arise during operation are managed. It is generally held that the non-routine ratio is relatively low during the 757's first base check cycle, and that it does not increase rapidly as the aircraft ages.

The content of the C1, C2 and C3 checks is relatively small, since they only include one or two groups of inspection tasks. The workscope for interior work and modifications is also relatively small. Routine and non-routine inspections therefore account for a high percentage of the total MH used in these checks.

The non-routine ratio for these first three checks is typically 40-50%. Routine MH for the C1 check are 1,500-1,650, and so the total routine and non-routine MH are 2,100-2,600.

MH used for modifications, ADs, SBs and engineering orders will vary between 300 and 550 according to how the operator manages its aircraft and what modifications are issued at the time. Interior cleaning consumes another 400-500MH, taking the total MH consumed for the check to 3,100-3,500.

The C3 check in the first cycle consumes a similar quantity of MH to the C1 check. The number of MH for routine inspections are marginally higher, while the non-routine ratio and MH used for modifications and cabin cleaning are about the same as the C1 check. This takes the total MH for the C3 check to 3,300-4,000.

The quantity of materials and consumables used for these two checks is is in the region of $65,000 for each visit.

The C2 check is a larger check, with the 2C and 2SC tasks being larger than the 3C and 3SC inspection items. Routine tasks consume 2,100-2,400MH, and the non-routine ratio can also be higher at 50-60%. This takes the labour used for non-routine tasks to 1,100-1,450MH and the sub-total for routine and non-routine inspections to 3,300-3,800MH. On average, a similar number of MH will be used for modifications and interior cleaning as consumed in the C1 and C3 checks, taking the total labour used in the check to 4,100-4,700MH. The cost of materials and consumables used in this check is about $80,000, but will vary according to modifications and defects found during routine inspections.

The C4 check, sometimes referred to as a 'D' check, has the largest workscope, because the initial CPCP items are included in the first C4/D check. The group of routine tasks is also about three times the size of the C1, C2 and C3 checks, while the non-routine ratio can also be 50-60%. Operators also normally have a higher inclusion of modifications, ADs and SBs. Most airlines also perform interior refurbishment during this check, which involves the refurbishment of galleys, toilets, overhead storage bins, sidewall panels, and seats and carpeting.

Routine inspections in the first C4/D check consume 5,000-6,000MH, and a non-routine ratio of 50-60%, take the sub-total for routine and non-routine to 7,500-9,500MH. A few operators experience higher non-routine ratios.

About 1,000-1,200MH can be used for modifications, ADs, SBs and EOs. Cleaning and a full interior refurbishment will consume up to 3,000MH. Stripping and painting will add another 2,000MH to the check's total. The overall total for the check will therefore reach 13,500-15,500MH, although it can be as high as 19,000MH where high non-routine ratios are experienced.

The cost of materials and consumables for this check will be $250,000-350,000, depending on the level of interior refurbishment and number of modifications included in the check.

The complete first base check cycle therefore consumes about 25,000MH and $460,000-560,000 in materials and consumables. A labour MH rate of $50 would take this to a total cost of $1.7-1.8 million. Amortised over an interval of 13,500FH, this would be equal to a cost of $125-135 per FH. Total MH expenditure can be as low as 19,000-20,000MH, however, if MH used for routine inspections are marginally lower, a non-routine ratio of about 40% is experienced and less MH are required for modifications, and cleaning and interior refurbishment. This would lower the reserve for by about $20 per FH.

The main cause of maintenance cost escalation during the second and third base check cycles is the increase in routine inspections and non-routine ratio. An increase in non-routine ratio by about 10 percentage points across all four checks in the cycle, and an increase in routine inspections raises the total MH consumed by about 5,000. The C4/D check in this case will consume about 18,000MH. The cost of materials and consumables also rises, and total cost for the four checks of the cycle rises to about $2.1 million, an increase of $300,000-400,000 that takes the amortised rate up to $155 per FH *(see table, page 26)*.

A similar rate of increase is experienced for the third base check cycle. Experience of the fleet shows that the increase in non-routine ratio has been about another 10 percentage points, while MH used for routine inspections also increase slightly. Total MH for the four checks of the cycle are in the region of 33,000, of which the C4/D check uses

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about 19,000. Total material and consumable cost also increases to about $700,000, and total cost for the four checks is in the region of $2.35 million. This equals a rate of $175 per FH when amortised over the 13,500FH interval *(see table, page 26)*.

This demonstrates that the rise in base check maintenance costs is in the region of about $20 per FH for each base check.

These base check costs also have to be considered for aircraft that are modified to freighter configuration. These are likely to have a lower rate of annual utilisation than passenger aircraft, which is likely to be in the region of 1,500-2,000FH per year, even when carrying general freight on medium-haul. Utilisations will be lower than this for aircraft that are used for carrying express packages and in many cases may not exceed 1,000FH per year. These lower rates of utilisation will have the effect of reducing the number of FH achieved between C checks and for the whole base check cycle compared to passenger aircraft, because of the 18-month interval for C checks. The interval between subsequent C4/D checks is thus likely to be 7,500-10,000FH.

The MH and materials consumed for all checks will be less than the equivalent checks for passenger aircraft, however. First, there will be fewer routine inspections because of the removal of some cabin items relating to passenger configuration. Non-routine MH will also decrease, although deterioration of freight handling systems will counter some of this reduction to a degree.

The aircraft will also require fewer MH for interior cleaning, and most freight operators perform fewer modifications on their aircraft than passenger airlines. One of the largest reductions will be MH used for interior refurbishment, since most items will be absent in freighter aircraft. Some MH will be required for maintenance of a crew toilet and sidewall panels on the main deck, however. MH used for stripping and painting can also be minimised, and repainting is likely to be done less frequently than for passenger aircraft.

It is therefore possible that a converted aircraft in its third base check cycle could consume about 26,000MH compared to about 33,000MH used by a passenger aircraft. This would result in a reserve of about $190-220 per FH over the expected interval.

Heavy components

Heavy components of wheels and tyres, brakes, landing gear, thrust reversers and auxiliary power unit (APU) collectively account for 10-15% of total maintenance costs. These components all have cycle-driven maintenance costs, so aircraft operating on long average cycle times will benefit with lower rates per FH.

Main and nose wheel tyres have average removal intervals in the region of 300-400FC. Retreads are made at an average cost of $300-400 per tyre, and three or four retreads are possible before tyres have to be replaced. New main wheel tyres cost about $1,100, and nose wheel tyres about $900. These factors equate to an overall cost for tyre remould and replacement of about $16 per FC.

Wheel inspections are made at the same time as tyre remoulds, and repairs can cost $900-1,250 for each wheel. This combines to a total cost of $27 per FC.

Brake repair intervals depend on the severity of landing and braking action by pilots, but an interval of 2,500FC is representative. An average repair costs about $35,000 per unit, and the overall cost per FC for all eight brake units is $112.

These three elements total $155-165 per FC, which will be $57-61 per FH for an aircraft with an average cycle time of 2.7FH.

Landing gear overhauls have a hard time interval, and an eight-year removal is normal. At a utilisation rate of about 2,700FH and 1,000FC per year, the landing gear will be overhauled about every 22,000FH and 8,500FC. Market

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rates for landing gear exchange and repairs are in the region of $400,000, equalling a rate of $18 per FH and $49 per FC.

Thrust reversers are also repaired on an on-condition basis, but an interval of 5,000-6,000FC is representative of the 757 fleet. An average shop visit cost and exchange fee is $250,000-275,000 for an engine shipset, and so the total cost for both shipsets amortised over the interval equals a reserve of $90-105 per FC. This equals $35-40 per FH for a FC time of 2.7FH.

The GTCP 331-200 used on the 757 has an average interval between shop visits of about 3,500 APU hours. How this relates to an aircraft FH interval depends on how long the APU is used between between flights. If it is used for one hour between flights it will have a removal interval of about 3,500FC and about 9,000FH. An average shop visit cost of $300,000 will equal a reserve of about $86 per FC and about $35 per FH.

Combined, these four component groups have a total cost of about $390 per FC and $155 per FH *(see table, page 26)*.

Rotables

There are many ways an airline can access rotable components. Large operators have their own repair shops and own their inventories. These have many direct and indirect cost elements and make it impossible to identify costs relating to a particular fleet.

Third party support contracts provide visibility in the cost of rotable inventory, repair and management. Airlines will lease a home-base stock, and pay a power-by-the-hour (PBH) fee for access to the remaining inventory, and a pay another PBH fee for the repair and management of all components.

The capital cost for a fleet of 10 757s will be $8-10 million, depending on which part numbers are included or excluded. A lease rate for this might be $100,000 per year for each aircraft, and so about $35 per FH. The fee for access to remaining parts kept in a pool by the component provider will be $65-80 per FH. The third element of a repair and management fee will be $160-180 per FH.

These three elements total in the region of $260-300 per FH *(see table, page 26)*, depending on inclusions and contract terms.

Engine maintenance

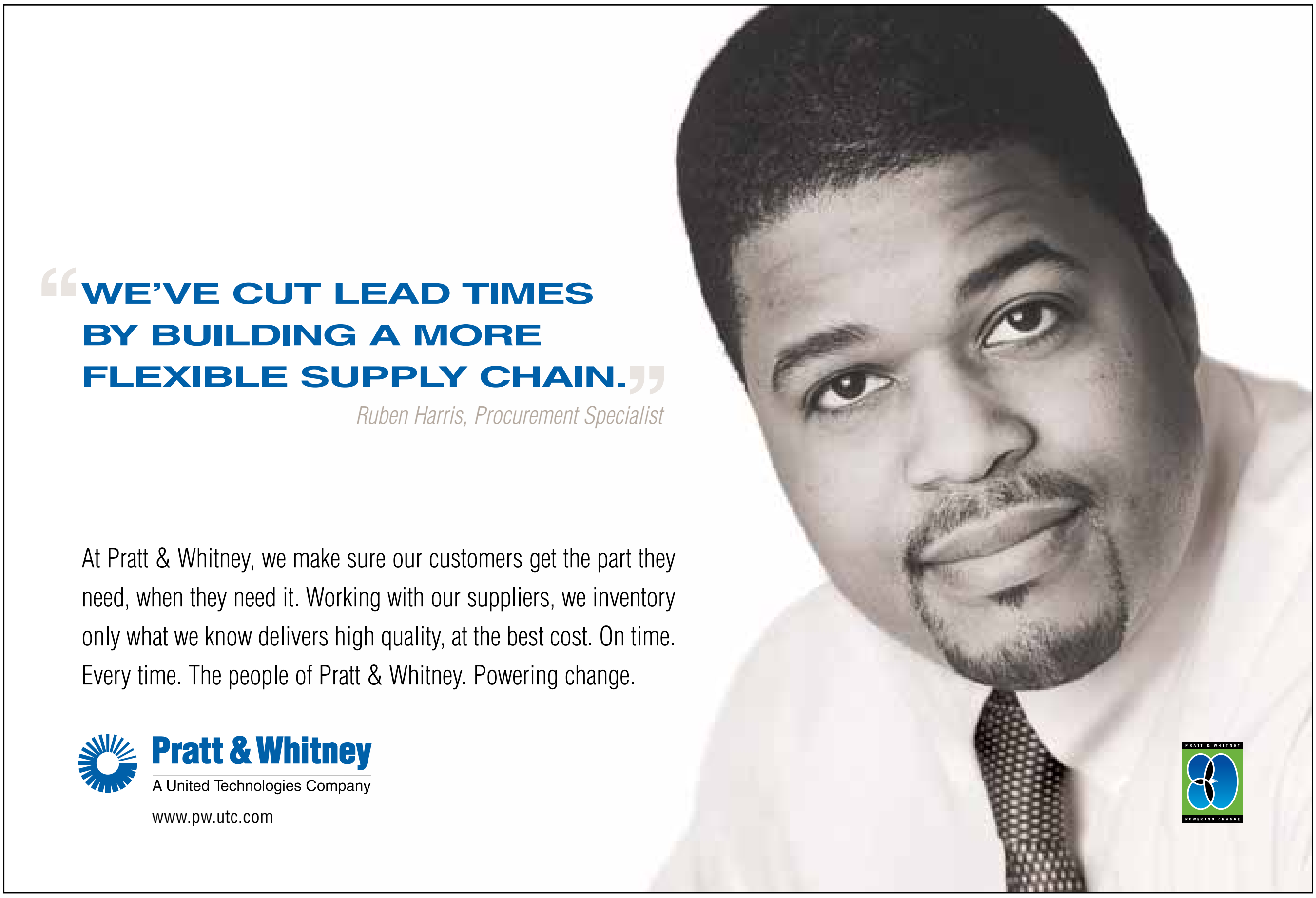
The distinction between the two engine types on the 757 is clear. The PW2000 powers a smaller number of aircraft for a few carriers. The engine suffered negative publicity during its initial operation because of poor on-wing reliability, which it has since overcome to achieve competitive reliability.

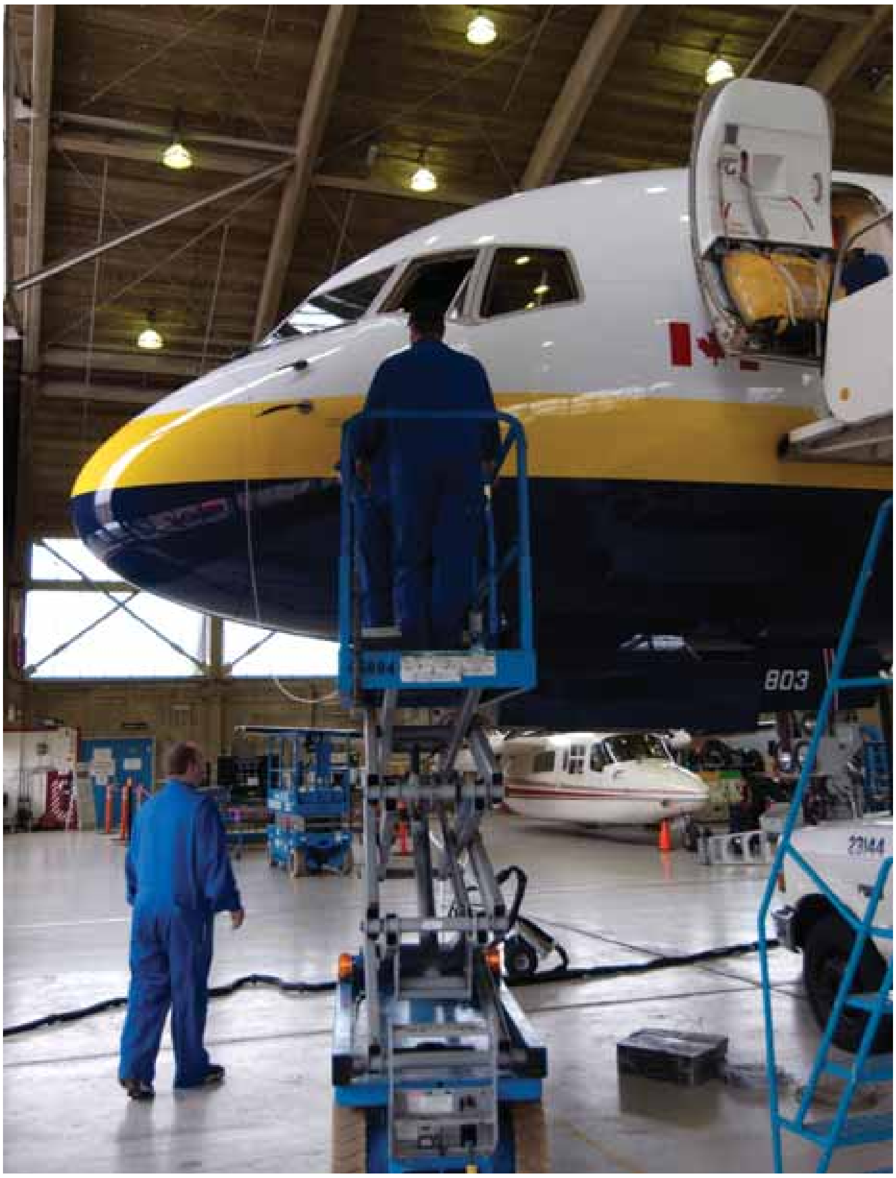
The RB211-535E4 gained a large number of customers at the expense of the PW2000's reputation for poor reliability. Rolls-Royce-owned and joint venture shops dominate the repair and overhaul market. Iberia and Ameco Beijing are independent shops that also overhaul the engine. The RB211-535E4, is reliable, but has gained a reputation for being expensive to overhaul.

The RB211-535E4 on average achieves intervals between planned removals that are 15,000-20,000 engine flight hours (EFH) in many cases. LTU, which operates at an average FC time of 3.0 hours, has an average interval of about 14,000EFH. The main causes of engine removal are hot section distress, rather than erosion of exhaust gas temperature (EGT) margin.

Andrew Gainsbury, programme manager at Total Engine Support (TES) says that the RB211-535's EGT margin is generally not an issue with on-wing reliability. "Most removals are not driven due to performance deterioration," he explains. Intervals for mature engines are usually 5,000-8,000EFC. An average interval of 15,000-20,000EFH might thus be expected by an operator with a 2.5:1 ratio.

Common removal causes include thermal deterioration of the high pressure (HP) turbine blades or combustion chamber and expired life limited parts (LLPs).





The 757 achieves total maintenance costs in the region of $1,200-1,450 per FH. The engine type on the aircraft has the largest effect of total costs. Despite negative publicity about poor reliability in the early years of operation, PW2000 engines have lower costs per FH as a result of their shop visit costs being lower than the RB211-535's.

Gainsbury explains that RR has four levels of engine shop visit workscope which can be applied at engine or modular level. "Engines will typically go through a level 3 workscope after 15,000-20,000EFH. Every second major shop visit is usually a level 4 workscope," explains Gainsbury. "Shop visits thus alternate between level 3 and level 4 workscopes. The engine comprises seven modules and a level 3 workscope requires work on each module, so a level 4 workscope involves more in-depth work and often a higher replacement rate of parts.

"The cost of a level 3 workscope will be in the region of $3.0 million," continues Gainsbury. "Materials are expensive, for example, and a new set of HP turbine blades costs around $600,000." Experience has shown that investing in more thorough shop visits gives a good on-wing life and in the longer term tends to work out cheaper per flying hour than more frequent, cheaper 'Check-and-Repair' shop visits.

Level 4 shop visits can cost in the region of $3.5 million, and so reserves for shop visits will typically be in the region of $200-215 per EFH. The rate would be higher for engines operating at a shorter FC time of 1.0-1.5EFH.

The RB211-535 LLPs vary in life limit between 14,000EFC and 27,000EFC throughout the engine. A shipset of LLPs (including uniquely in this engine, fan blades and annulus fillers) has a list price of about $2.65 million, and so a reserve of about $150 per EFC will cover their replacement. This is equal to a reserve of $55 per EFH at an average EFC time of 2.7EFH.

This takes total reserves for the RB211-535E4 to the region of $220-270 per EFH *(see table, page 26)*.

The PW2000 fleet can be divided into two sub-fleets. Pratt & Whitney (PW) introduced a reduced temperature configuration (RTC) modification on engines built from 1994. This production modification supercharged the lower pressure compressor (LPC) to increase airflow through the engine core. The CET-kit (modification of engines in service) could also be used to modify the low-speed rotor system of earlier-built engines by installing it during a shop visit. "About 50% of the fleet of engines built prior to 1994 have been modified," says Kurt Gschwind, PW2000 programme manager at PW. "It is most cost-efficient to install the RTC kit when the LLPs in the LPC are due to expire, and the kit costs about $1.1 million per engine.

"In addition to the RTC, we also introduced another modification known as the combustion exit temperature (CET) modification," continues Gschwind. "This increases core flow and turbine cooling air to reduce the EGT and so prolong the life of the hot section. The overall effect of these two modifications is that it improves EGT margin by about 25 degrees centigrade over an unmodified engine."

A RTC-modified PW2037 has an EGT margin of about 46 degrees centigrade, while the higher thrust-rated modified PW2040 has a margin of about 40 degrees centigrade. "EGT margin for unmodified engines is 28-35 degrees," says Leo Koppers, senior vice president of marketing and sales at MTU Maintenance. "RTC-modified engines have EGT margins that are 15-20 degrees higher. The RTC modification certainly has a large impact, but it is an expensive modification."

Koppers puts average rate of EGT margin deterioration at 7-8 degrees per 1,000EFC for an engine with an average EFC time of 2.0EFH. This implies unmodified engines might be expected to have a removal due to performance deterioration after about 4,000-5,000EFC, while modified engines would have intervals of 5,500-7,000EFC. These would equate to 11,000-13,500EFH for unmodified engines and 15,000-19,000EFH for modified engines when operating at an EFC time of 2.7EFH. The main cause of removals is loss of engine performance. Some airlines that operate in a hot environment stick to a soft time of about 8,000EFH, but most engines operate in large fleets with US carriers.

"EGT margin loss is not an issue for modified engines," says Gschwind. "The main causes of removal have been HPC blade failures, HPC stator failures and LLP expiry. Most engines, like other PW types, conform to a pattern of alternating hot section inspection and overhaul shop visits."

DIRECT MAINTENANCE COSTS FOR 757-200

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Ramp checks	$1,050,000	4,800FH		$220
A checks	$300,000	4,800FH		$65
Base checks (2nd cycle)	2,100,000	13,500FH		$155
Base checks (3rd cycle)	2,350,000	13,500FH		$175
Heavy components:				
Landing gear	$400,000	22,000FH	49	18
Wheel, tyre & brake inspections & repairs			155-165	57-61
Thrust reverser overhauls	$530,000-550,000		90-105	35-40
APU	$300,000	9,000FH	86	30
Total heavy components			390	$155
LRU/rotable component support				$260-300
Total airframe & component maintenance				**$855-915**
Engine maintenance:				
2 X RB211-535E4				$440-520
2 X PW2037/2040 (RTC)				$320-390
2 X PW2037/2040 (non-RTC)				$400-490
Total direct maintenance costs:				**1,175-1,435**

Annual utilisation:
2,700FH
1,050FC
FH:FC ratio of 2.7:1.0

The complete core is always worked on during the first shop visit, while all modules are overhauled during the second shop visit. Excluding replacement of LLPs, the lighter shop visits have a cost of $1.5-2.0 million. Overhauls have a higher cost of $2.0-2.5 million. Labour is a small portion of these costs, being just $300,000-400,000. The majority of costs are materials, parts and sub-contract repairs.

The amortised costs for unmodified engines over two removal intervals averaging 12,000EFH equals a reserve of $145-170 per EFH. The reserve for modified engines that achieve an average interval of 17,000EFH will be $105-120 per EFH. This saving of $35-60 per EFH that older engines will realise a payback on the investment for the RTC modification after about 20,000EFH. This is equal to about eight years of operation, although the modification will also enhance the aircraft's and engine's residual value.

Like most other PW engines, LLPs in the PW2000 have almost uniform lives. All parts, except two in the LPT, have lives of 20,000EFC. The on-wing intervals of 5,000-7,000EFC imply that LLPs will be replaced every third or fourth shop visit after a total accumulated time of 15,000-20,000EFC. A shipset of LLPs has a list price of $3.0 million, and so reserve for LLPs will be $150-200 per EFC. This equates to $55-75 per EFH for an average EFC time of 2.7EFH.

Total reserve for unmodified engines will therefore be $200-245 per EFH for unmodified engines and $160-195 per EFH for RTC-modified engines *(see table, this page)*.

Summary

In this analysis the 757 benefits from a long average FC time, which has the effect of diluting almost every element of the maintenance cost by: reducing the number of ramp checks in a given FH interval; diluting the FC-related costs for heavy components; reducing the PBH rate paid for rotable support; increasing FH on-wing intervals for engines; and diluting reserves for engine LLP replacement.

Total costs per FH shown *(see table, this page)* are for an aircraft in its second or third base check cycle, and so likely to be 5-15 years old. Engine reserves account for about one third of total costs. While the original PW2000 engine received negative publicity about its on-wing reliability, poor performance is offset by low shop visit costs, and the engine still has lower overall reserves than the RB211. RTC-modified PW2000s have even better overall economics, reducing total aircraft maintenance costs by $240-260 per FH compared to an RB211-powered aircraft. This difference in engine reserves is the major cause of variation in total maintenance costs shown.

The effects of MH and materials used in ramp and line checks should also be considered. Efficiency leading to fewer MH will have an impact on total maintenance costs.

Operators should also consider the effect of utilising the aircraft on shorter average cycle times. This will have the effect of raising the cost of per FH of most elements of maintenance. For a given number of FH more line and ramp checks will be performed, heavy components will have a higher cost per FH, and engines will have a higher reserve rate because of the impact on LLPs.

Future freighters

As already described, freighter aircraft are likely to operate at lower rates of utilisation. Average FC times of freighters in operation will be similar to those used here for general freight, but may be lower for many aircraft used in small package operations.

To offset the effect of lower rates of utilisation and shorter average FC times, freighter aircraft will have smaller workscopes for airframe checks, and so save some costs. Maintenance costs for heavy components and engine reserves will only be affected by average FC time. LRU components will have lower costs per FH because of the absence of passenger-related items. The constraint of an 18-month C check interval will reduce the base check cycle interval for aircraft operating at low rates of utilisation.

Freighter aircraft are thus likely to experience higher base check-related costs per FH, but slightly lower rotable-related costs for aircraft operating at a lower rates of utilisation but at similar average FC time to passenger aircraft. Costs per FH for other elements will be little affected.

Freighters operating at lower utilisations and on shorter cycles will experience higher costs for many elements of maintenance. The reserve for engine LLPs per FH, for example, would alone increase total maintenance costs by about $130 per FH if average FC time was halved to 1.35FH. AC