767 family maintenance analysis & budget

The 767 has acceptable mature maintenance costs. This will enable to remain popular for many years to come.

The 767 has become the most successful widebody, twin-engined aircraft, due mainly to its combination of medium size and long-range capability. It remains a dominant type in many medium- and long-haul markets, and will continue to occupy this position for several more years to come. Although its replacement, the 787-8/-9, is selling well, it will not exist in significant numbers for another six years, which means that the 767's future as a major passenger aircraft is secure for another 10 years. The 767 is also well placed to become a major freight aircraft over the next 10-15 years. The 767 therefore still has a good future.

There are five main groups of 767s, of which the -200ER, -300 and -300ER are the three most important types.

Aircraft in operation

Of the 745 active passenger aircraft, 632 are the extended range models, and are therefore mainly utilised on operations of 4.0 to 8.0 flight hours (FH). Annual utilisations vary between 3,500 and 4,500FH, and 450-1,100 flight cycles (FC). Few aircraft are now operated on medium-haul services, although the 767 is still prominent on US domestic services.

The average flight cycle (FC) time on which 767s are used affects maintenance planning, since base maintenance tasks have FH and FC intervals. Many heavy components also have removal and repair intervals that are FC-related.

Line maintenance programme

Like the 757 and other aircraft types of the same generation, the 767 has a system of line and ramp checks that include a pre-flight (PF) check, a transit (TR) check, and a daily check. Some operators also include a weekly check.

Terminology between airlines varies, but the PF check is performed prior to the first flight of each day's operations, and the TR check is performed prior to all other flights made during the day. PF and TR checks have a similar content and both comprise a walkround visual inspection. This was traditionally done by the flight engineer on three-man aircraft, but later became a task for ground technicians on two-man types like the 767. Flightcrew have been given this task more recently, in order to save costs relating to line mechanics. The PF and TR checks only have about 30 minutes of maintenance planning document (MPD) items, which include a check on the oil quantity indicators on the engines. The PF check also includes items relating to extended-range twin-engine operations (Etops), such as checking oils, fluids and redundant items that relate to avionics and fire extinguishers. "There are some maintenance tasks to be completed in addition to PF and TR checks, as was the case with most operators in the past," says Karel Bockstael, vice president of base maintenance at KLM Engineering & Maintenance. "For this reason, our PF checks are carried out by line mechanics."

Daily checks are completed once every 24 hours, with a maximum limit of 48 hours. If possible operators will do this check overnight.

Operators of aircraft that are used on long-haul operations will not necessarily be able to do this check overnight, so they will have to schedule this check with the operating programme. An aircraft will usually have a daily check performed when it returns to operating base. This may be each day, but the interval may be longer if the aircraft is operating on the longest distance routes.

A 767 that is therefore completing about 4,500FH per year, and has an average FC time of 7.0FH will complete about 640FC annually. Over the course of the year, the aircraft will have almost 365 daily checks and a total of 640 PF and TR checks.

The next largest line and ramp check in some airlines' maintenance programmes is the weekly check. This has a maximum interval of eight days, and is similar in content to the daily check, but has just a few more items. The weekly check can be regarded as the sixth or seventh daily check in succession.

A check programme

The next highest interval in the 767's maintenance schedule is the A check. The A check tasks are grouped into system and structural tasks. The MPD intervals for the basic A (1A) check system tasks

The routine content of the 767's base maintenance checks has several elements, and these increase with age. The rise in MH used for subsequent base check cycles and the resulting reserves are not excessive, however.

767 C CHECK COMPOSITION

C check	System tasks	Structural tasks	CPCP tasks	Interval FH/FC/Months
C1	1C	S1C		6,000/3,000/18
C2	1C +2C	S1C + S2C		12,000/6,000/36
C3	1C + 3C	S1C + S3C		18,000/9,000/54
C4	1C+ 2C + 4C	S1C + S2C +S4C	S4C	24,000/12,000/72
C5	1C	S1C	S1C	30,000/15,000/90
C6	1C + 2C + 3C	S1C + S2C + S3C	S1C + S2C	36,000/18,000/108
C7	1C	S1C	S1C	42,000/21,000/126
C8	1C + 2C + 4C	S1C + S2C +S4C +S8C	S1C +S2C +S4C +S8C	48,000/24,000/144
C9	1C + 3C	S1C + S3C	S1C	54,000/27,000/162
C10	1C + 2C	S1C + S2C	S1C + S2C	60,000/30,000/180
C11	1C	S1C	S1C	66,000/33,000/198
C12	1C + 2C + 3C + 4C	S1C + S2C +S3C +S4C	S1C +S2C +S4C +S12C	72,000/36,000/216

are 500FH, although these have been extended by many operators. VARIG, for example, has an interval of 600FH, while KLM Engineering & Maintenance has succeeded in getting its interval extended to 770FH with its experience.

The MPD has four groups of system tasks with multiple intervals of this basic interval. These are the 2A, 3A, 4A and 6A tasks, with corresponding multiple intervals of the 1A interval.

The 1A items are performed each A check, the 2A items every second A check, and the other tasks according to their interval. These five groups of tasks would therefore all be in phase when the A12 check is reached, which will be at an interval of 6,000FH for an operator with an MPD maintenance programme. The interval will be higher at 7,200FH for an airline with a basic interval of 600FH.

The 767 also has two groups of structural A check tasks. The S1A has an MPD interval of 300FC and the 5SA an interval of 1,500FC. These can be performed separately to the system tasks, but most operators group the S1A with the 1A tasks, and the 5SA in every fifth A check to simplify maintenance planning. The average FC time of most operators means that only a small portion of the FC interval of these tasks is used.

Base maintenance programme

The base check part of the MPD comprises a series of four C checks in a cycle, covering system, and structural and corrosion prevention and control programme (CPCP) tasks. There are also zonal tasks, which can be grouped with either system or structural tasks as necessary.

The system tasks have job cards with intervals based on FH and calendar time, while structural and CPCP tasks have intervals based on FC and calendar time.

The basic interval for the system tasks, the 1C items, in the MPD is 6,000FH and 18 months, whichever is reached first. An aircraft with an annual utilisation of 4,000FH will reach both limits at the same time. Aircraft with higher rates of FH utilisation will require checks more frequently than 18 months, while aircraft with lower rates of utilisation will accumulate fewer than 6,000FH in the 18-month limit.

The MPD also has base check system tasks with multiples of this basic interval. These are the 2C, 3C and 4C items with intervals of 12,000FH/36 months, 18,000FH/54 months and 24,000FH/72 months *(see table, this page)*. The fourth check in the cycle therefore has an interval of 24,000FH and six years. Actual utilisation of check intervals means that most operators will complete this cycle every five years, or every 20,000-22,000FH.

The 3C group of tasks is relatively small, while the 4C comprises a large group of inspections. All four groups of multiples will not actually be in phase until the C12 check, which is the fourth check at the end of the third base maintenance cycle. The base checks in the first three base maintenance cycles in which these four groups of system tasks are included, are summarised *(see table, this page)*. These three base maintenance cycles will be completed at an age of 15-16 years for most aircraft.

The basic interval for the structural tasks, the S1C tasks, is 3,000FC and 18 months, whichever is reached first *(see table, this page)*. Most aircraft operate at rates of less than 2,000FC per year, and so will reach the 18-month interval first. Structural tasks can be completed separately from system tasks, but this increases aircraft downtime.

The MPD also has structural tasks with multiples of these intervals. These are the S2C at 6,000FC and 36 months, S3C at 9,000FC and 54 months, and the S4C at 12,000FC and 72 months *(see table, this page)*.

In addition to annual rates of FH and FC utilisation, the 1C and S1C tasks both have an 18-month calendar interval. Similarly, the 2C and S2C have a 36-month interval, the 3C and S3C have a 54-month interval, and the 4C and S4C have a 72-month interval. It is therefore convenient for airlines to combine the 1C with the S1C, the 2C with the S2C, the 3C with the S3C and the 4C with the S4C, despite only a small portion of the FC intervals of structural tasks being utilised.

The structural tasks are repeated every base maintenance cycle in the same way that the system tasks are repeated. There is also a group of structural tasks referred to as the 8SC tasks. These have an interval of 24,000FC and 144 months. These are therefore first performed at the C8 check, then at the second C4 check *(see table, this page)*, and are repeated every eighth C check.

The CPCP tasks have a more complicated programme and sequence than the system and structural tasks. There are eight groups of tasks, which can be sub-divided into two groups.

The first group comprises those tasks that are performed once: the S4C, S8C and S12C CPCP tasks, which are carried out during the C4, C8 and C12 checks.

The second group of tasks are those with initial intervals and then repeat intervals. There are the S4C tasks which are repeated every S1C check, and a second group of S4C tasks that are repeated every second C check.

The S8C tasks are repeated every fourth C check, while another group of S8C tasks is also repeated every fifth C check. Finally the S12C tasks are repeated every eighth C check.

The arrangement of system, structural and initial and repeat CPCP tasks in each C check of the first three base maintenance cycles is summarised *(see table, this page)*. The table clearly shows how the workscope of the C checks varies throughout each of the four base check cycles, but also how the workscopes generally increase in size as the aircraft ages. The table shows the content in terms of MPD tasks up to an age of 18 years, and more likely 15-16 years. The earliest built 767s still in active service are 24 years old, but most aircraft range in age from six to 20 years old and so are in their second, third or fourth base maintenance cycle.

New maintenance programme

The organisation of base checks described has been superseded by a revised base maintenance programme, which was issued in 2005. Only a few 767 operators have begun to change their aircraft on to the new programme, and most are still utilising the original one.

The organisation of systems checks in the new programme has changed little from the original. The main change has been to incorporate the CPCP tasks into a new structural inspection and the zonal tasks.

The programme of structures tasks has now become more complex, with tasks having initial thresholds during the second and third base check cycles and repeat intervals. This has been done with the objective of simplifying the structural and CPCP tasks.

The revised maintenance programme is supposed to have reduced the number of tasks, since only structural tasks are left. Nevertheless, combining structural and CPCP tasks may not have reduced the man hours (MH) consumed to carry out the checks by the 40% projected by Boeing. Some maintenance providers predict that the MH used for routine inspections and non-routine rectifications relating to structural items will probably fall by only about 20%.

Line maintenance inputs

The number of different line and ramp checks performed on an aircraft depends on its pattern of utilisation and operation. This analysis examines an aircraft operating at an average FC time of 7.0, and completing 4,500FH and 640FC per year. Under this operation aircraft complete less than two flights per day. About 340 PF and TR checks and 350 daily checks will be completed each year.

The MH and material inputs vary with each operator. PF, TR and daily checks consume about 2MH. Operators have different maintenance programmes, and some include weekly checks. Different programmes have a different spread of MH for the individual line and ramp checks. In many cases, for example, PF and TR checks consume less than 1MH.

A conservative budget is for the PF and TR checks to each use 45 minutes and up to $20 in materials and consumables. Daily checks utilise 10MH and up to $100 in materials and consumables. A standard labour rate of $70 per MH for line and ramp maintenance takes the cost to about $75 for each PF and TR check, although the use of flightcrew to do these inspections will minimise this cost. These checks usually, in fact, require no material expenditure. Labour and materials are only required on those occasions that defects are found. The total cost for each daily check is $800.

The total cost for all these checks over the course of a year's operation is about $326,000, which is equal to $75 per FH *(see table, page 35)*.

A checks

The A check interval is assumed to be 500FH, and the actual interval is given as 400FH. This means that the full cycle of 12 checks will be completed about every 5,000FH. Some operators have longer intervals with the benefits of lower costs per FH.

A checks consume 300-400MH and $11,000 in materials and consumables. Some operators record MH consumption of up to 600MH, although the actual amount depends on non-routine rectifications and clearing technical defects.

A conservative average of 500MH and $11,000 can be used for budgeting purposes. A standard labour rate of $70 would take the total check cost to $46,000, which would equal a cost of $110-115 per FH when amortised over the 400-500FH interval *(see table, page 35)*.

Base check contents

The workscopes of base checks vary widely. This maintenance analysis mainly concerns aircraft in their second and third base check cycles. These are aircraft ranging in age from five to 16 years old.

The first main components of C checks are routine inspection tasks relating to system, structural, CPCP and zonal inspections. These inspections raise non-routine defect rectifications, and the non-routine ratio increases with age.

In addition to the routine inspections there are also sampling tasks, which are inspections in areas of the aircraft that are prone to cracks and corrosion, such as engine pylons and landing gear attachments. The fleet size determines how many aircraft actually require sampling tasks, which usually only affect 5-10% of the fleet.

The 767 also has out-of-phase (OOP) tasks for maintenance planners to take into consideration. These are inspections whose intervals do not match the other MPD tasks. To avoid increased aircraft downtime, OOP tasks will be scheduled with base checks. Many OOP tasks involve work on hard-timed components, such as the replacement of a battery or borescoping engines.

Another element of C checks is the removal of rotable components with hard time repair intervals. The 767 has about 2,200 rotable items accounted for by about 2,000 different part numbers. About 95% of these are maintained on an on-condition basis, but about 110 items are removed at fixed intervals to coincide with A and C checks.

These are life limited parts (LLPs), comprising mainly safety items such as gas bottles and evacuation slides. These are both open- and closed-loop items.

Besides these MPD inspections, there are several other elements of base checks that are more variable. Only some are not mandatory.

The first group of additional items comprises airworthiness directives (ADs), service bulletins (SBs), modifications and engineering orders (EOs).

Examples of SBs incorporated into 767 C checks in recent years include: wire bundle inspections; fire blocking insulations; fire extinguisher inspections in the cargo hold; lubrication of flight controls; and adjustments to flight control actuators. Cooper explains that the lighter of these SBs can consume 4-5MH, while larger ones can use up to 100MH.

A major AD affecting the 767 is the engine pylon improvement programme. This is covered by six ADs: two for each engine type. ADs 2001-02-07 and 2004-16-12 concern PW engines, ADs 2001-06-12 and 2004-16-12 for GE engines, and ADs 2000-19-09 and 2001-16-12 for Rolls-Royce engines.

These basically require structural strengthening on engine pylons, and are due prior to the aircraft reaching a total FC time of 37,500 or 20 years of age - whichever is reached first.

Cooper explains that this modification is heavy, and involves the removal of the engine, followed by the removal of the engine pylon from the wing. It therefore makes sense to combine this removal with a C12 check, which has a maximum interval of 18 years. The MPD also calls for a structural zonal inspection of engine pylons. Different groups of aircraft are affected differently, and Cooper estimates that up to 4,000MH will be required to comply with these ADs.

C checks will also be used to clear deferred defects that have accumulated, as well as to repair physical damage to the aircraft sustained during operation.

The other main items included in C checks will be interior refurbishment and cleaning.

Interior refurbishment concerns seats, carpets, sidewall and ceiling panels, overhead bins, passenger service units, in-flight entertainment equipment, toilets and galleys. As the refurbishment of these items is mainly a cosmetic consideration, it is therefore not mandatory.

Areas to be cleaned include seat covers, carpets and flooring material, toilets, galleys and the overall aircraft appearance.

Stripping and repainting the aircraft is a final item to consider, and may also have to be scheduled separately from C checks because of environmental considerations. Operators typically repaint aircraft every five to eight years, depending on aircraft utilisation and marketing requirements.

Base check inputs

The elements that make up base checks have been described. The routine content gradually increases as the aircraft progress through each base check cycle.

The MH required for routine inspections in the first and third base checks in the cycle, the C5 and C7 or C9 and C11, are relatively light. "The C5 and C7 only require about 1,650MH for routine inspections," says Peter Cooper, senior planning engineer at Shannon Aerospace. "This increases a little to 1,700-1,720 in the second cycle for the C9 and C11 checks. The C6 and C10 checks, the second check, require in the region of 3,300MH. There is little change in the routine MH between these checks because the system, structural and CPCP tasks are similar. The content of the C12 check is heavier than the C8, however, because of an increase in CPCP tasks. The C8 requires about 6,700MH for routine items, while the C12 needs about 8,000MH." This takes the total routine MH to about 13,350 for the C5 to C8 checks, and to about 14,600MH for the C9 to C12 checks.

These inputs will be added to by non-routine defects arising out of the inspections, and the amount of work generally increases with each base check cycle. "The non-routine ratio varies between aircraft and checks, but generally increases with age on a linear basis," explains Cooper. "The ratio in the second cycle is in the region of 75%. It increases to 80-100% in the third cycle, and will be at its highest at the C12 check."

This results in a total of 10,000 non-routine MH for the C5 to C8 checks, and 12,300MH for the C9 to C12 checks. The routine inspections and non-routine defects for the four checks in the second base cycle total 23,000-24,500MH, and increase to 27,000-28,500MH in the third base cycle.

This group of tasks and defect rectifications accounts for the majority of MH that have to be spent for base checks. "The other MPD items consume relatively little," explains Cooper. "An average for sampling tasks will be about 145 MH in the heavy check: the C8 and C12. MH used for ADs, SBs and modifications naturally vary, but excluding heavy modifications, averages have been 250-400MH for the first three checks and 500-1,000MH for the fourth heavy check. The OOP tasks require an average of 300MH per base check to complete, and about the same number of MH are required for routine hard-time component changes and clearing of defects. Finally, interior cleaning for items such as the carpets and the sidewall panels, and other cosmetic issues will utilise an average of about 200MH in each check.

"These four groups of tasks consume about 1,100MH for the first and third checks in the cycle, 1,200-1,300MH for the second check and 1,400-1,900MH for the fourth check," estimates Cooper. "The total for the four checks comes to 5,000-6,000MH, which brings MH used for the four checks to 28,000-30,500MH for the second base check, and to 32,000-33,500MH for the third base check."

The timing and scope for interior refurbishment depends on the operator, but this is usually performed once every base check cycle, and would be combined with the C4/8/12 check. Interior refurbishment will normally include painting or recovering wall and ceiling panels, refurbishing and covering overhead bins, and repairing bulkheads.

767 FAMILY HEAVY COMPONENT MAINTENANCE COSTS

4,500FH & 640FC per year
Average FC time of 7.0FH

Number of main wheels	8
Tyre retread interval-FC	200
Tyre retread cost-$	450
Number of retreads	3
New main & nose tyres-$	1,250/1,000
$/FC retread & replace tyres	**32**
Wheel inspection interval-FC	200
Main & nose wheel inspection cost-$	1,500/1,000
$/FC wheel inspection	**70**
Number of brakes	8
Brake repair interval-FC	1,700
Brake repair cost-$	50,000
$/FC brake repair cost	**235**
Landing gear interval-FC	5,000
Landing gear exchange & repair fee-$	500,000
$/FC landing gear overhaul	**100**
Thrust reverser repair interval-FC	6,000
Exchange & repair fee-$/unit	250,000
$/FC thrust reverser overhaul	**85**
APU hours shop visit interval	3,000
APU hours per aircraft FC	2.5
APU shop visit cost-$	260,000
$/FC APU shop visit	**87**
Total-$/FC	**609**
Total-$/FH	**87**

Galleys and toilets are also removed from their installations and refurbished, while seats will also refurbished and even re-covered. This process will consume 4,500-5,500MH, and about $200,000 in materials and parts.

The final item that must be taken into consideration is stripping the paint from the aircraft and repainting it. "This normally coincides with the heavy check, and so it is done every five years or so," says Haytham Nasir, assistant manager production planning at GAMCO. "Stripping and repainting are also often combined with refurbishing the aircraft interior and the heavy check, and such a workscope can have a downtime of up to five weeks. This can be shortened if the items that are replaced during the interior refurbishment are ready to be installed at the start of the check. Stripping and painting the aircraft utilise about 2,500MH and paint is about $30,000."

This additional 2,500MH for stripping and painting takes the total MH consumption for the four base checks to the region of 36,000MH for the second base check cycle, and up to about 40,000MH for the third base check cycle.

These totals comprise about 4,000 for the C5 and C7 checks, 7,000MH for the C6 and up to 21,000-22,000 for the C8 check. The total for the C8 will increase by up to another 4,000MH if the engine pylon improvement programme is included. This is more likely in the C12 check, however.

Checks will be a similar size in the third base check cycle, except the C12 will use 22,000-24,000MH, plus up to another 4,000MH to comply with the engine pylon improvement programme.

Materials and consumables

The use of materials and consumables falls into several categories. The first of these comprises routine inspections and defect rectifications. Cooper says that material expenditure commensurate with the MH used for both routine and non-routine items totals about $55,000 for the C5, C7, C9 and C11 checks. The expenditure is higher at an average of $75,000-80,000 for the second checks in the cycle, the C6 and C10 checks. The heavy checks, the C8 and C12, require $210,000-250,000.

The second category includes materials and consumables consumed for the sampling tasks, modifications and ADs, OOP items, routine component changes and clearing of defects, and cosmetic cleaning. These amount to $17,000-29,000, depending on the size of the check.

Materials for a full interior refurbishment will cost up to $200,000. Total materials, parts and consumables for the interior refurbishment and stripping and repainting for all items in the four checks of the full base check cycle is $700,000-750,000.

Summary base checks

Using an industry representative labour rate of $50 per MH, the total utilisation of 34,000MH in the four C checks of the second base check cycle has a cost in the region of $1.7 million for the first cycle. When combined with the cost of materials and consumables, these four checks have a total cost of $2.4-2.6 million.

An operation completing about 4,000FH per year will have a C check interval of about 5,000FH, and will complete a base check cycle about every 20,000FH. The total cost for the second cycle of base checks will be equal to a reserve of $120-130 per FH *(see table, page 35)*.

The labour used in the third cycle will have a cost equal to about $2.0 million, and when materials and consumables are added, the total cost of $2.75 million is equal to a reserve of $140 per FH *(see table, page 35)*. An additional reserve of $15 per FH should be budgeted for the engine pylon improvement programme.

Rotables

As described, there are about 2,200 rotable components installed on the 767, which are accounted for by about 2,000 part numbers.

Taking the heavy rotable items, such as landing gear, wheels and brakes, thrust reversers and the auxiliary power unit (APU) into consideration separately, the majority of these rotable components on the 767 are maintained on an on-condition or condition-monitored basis.

The random removals of these components require an inventory to be kept, and the logistics of transporting, testing, repairing, record keeping and storing them have to be organised or provided. This service can be provided by many suppliers. Excluding the heavy components, Christopher Whiteside, managing director at AJ Walter, estimates that a fleet of 10 767s accumulating about 4,500FH per year each would need to lease a homebase stock of hard-time, on-condition and condition-monitored rotables that have a value of about $10 million. A monthly lease rate factor of 1.5% means that the lease rental for this equipment would be about $150,000 per month, and equal to $1.8 million per year. This would result in an FH rate of $45 per aircraft. Whiteside explains that the remaining rotables could be supplied in an all-inclusive package by A.J.Walter, which would include all logistics services and the repair and management of all parts. The rate per FH for this element of the service would be $175, taking the total cost for the supply of rotables to $220 per FH *(see table, page 35)*.

Heavy rotables

This leaves the four heavy components of landing gear, wheels and brakes, thrust reversers and the auxiliary power unit (APU) to be considered. The cost of these components is related to FC maintenance intervals. Apart from the landing gear, these components are maintained on an on-condition basis. Their removal intervals, repair costs and related costs per FC are summarised *(see table, page 30)*.

Engine maintenance

Engine-related maintenance costs for the 767 family ultimately involve five major engine types, up to 10 thrust ratings and consideration for a wide range of operating conditions, average flight cycle times and levels of engine de-rate.

Since the majority of 767s operating are -200ER and -300ER variants, this analysis of engine maintenance costs focuses on the PW4000 and CF6-80C2.

The PW4000, with a 94-inch diameter fan, has four different thrust ratings for the 767 family: 52,000lbs, 56,000lbs and 60,000lbs thrust for the -200ER; and the same three ratings plus 62,000lbs thrust for the -300ER. The engine rated at 56,000lbs thrust is by far the most numerous on the 767-200ER, and the engine rated at 60,000lbs thrust is the most numerous on the -300ER.

The CF6-80C2 has five thrust ratings for the 767. The -80C2B2 rated at 52,500lbs and the -80C2B4 rated at 57,900lbs are the two main types powering the 767-200ER, while the -80C2B6 rated at 60,800lbs and the -80C2B7 rated at 61,500lbs are the two main types powering the -300ER.

Many operators fly these aircraft on routes averaging five to seven FH, but there are also extremes where aircraft are used on sectors of just one or two hours, or as long as eight or nine hours. The longer the average FC time, the higher the aircraft take-off weight and the lower the engine de-rate, which increases the exhaust gas temperature (EGT) of the engine, and can affect on-wing life. Engines used on long average cycle times tend to have removal intervals more related to engine flight hours (EFH). Conversely, engines used on intensive networks of short cycles tend to have removal intervals more related to engine flight cycles (EFC).

PW4000-94

There are two classes of PW4000 engines: those that have had the Phase III modification; and those that have not had the modification, which are known as Phase I engines. The Phase III modification kit was introduced in the mid-1990s and involved the installation of new engine hardware that had the effect of reducing fuel consumption and EGT, thereby increasing EGT margin. "Phase III engines tend to have EGT margins about 15 degrees centigrade higher than Phase I engines," explains Domenic Janutin, product management at SR Technics. "Phase III engines rated at 56,000lbs have test cell EGT margins of about 53 degrees C corrected for an outside air temperature (OAT) of 15 degrees C and standard day conditions. The on-wing readings when the engine is installed are higher by 5-10 degrees C. A Phase III PW4056 would therefore have an EGT margin of about 60 degrees following a shop visit, and a Phase I engine an installed margin of about 45 degrees. The test cell margin of a Phase III PW4060 or PW4062 is 38-40 degrees, and so about 50 degrees when installed."

All PW4000 engines have full authority digital engine control (FADEC) systems, which have been used to improve on-wing life.

German charter carrier Condor operates 767-300ERs with Phase III PW4062 engines. "These have test cell EGT margins of 30-40 degrees C after a shop visit," says Andreas Linke-Diesinger, propulsion systems engineer for the PW4000 at Lufthansa Technik.

These EGT margins can influence intervals between shop visits, but EGT margin erosion has to be considered. "The initial rate of EGT margin erosion is about 13 degrees C in the first 1,000EFC after a full refurbishment," says Janutin. "The blade tips and knife edge seals in the engines are worn down, but the EGT margin erosion rate then reduces to a rate of somewhere between 5-10 degrees C in the second 1,000EFC, and gradually declines to a low level after this."

This implies that the engines will lose 20-23 degrees C of their EGT margin in the first 2,000EFC. This will be equal to 8,000-14,000EFH for engines operated at an average EFC time of 4.0-7.0EFH. This will leave PW4056 engines with 35-39 degrees C, and a PW4060 with 35-30 degrees C at this stage. "The rate of EGT margin loss per 1,000EFC flattens to about only one or two degrees shortly after this, and PW4000-94 engines are rarely removed to EGT margin loss. The EGT margin still available and the rate of loss allows engines to stay on wing for several thousand more EFH, and engines tend to be removed because of deterioration of their hardware," explains Janutin.

The rate of EGT margin loss also depends on whether or not engines have had the ring case modification. "This modification concerns a design change in the inner case area of the latter part of the high pressure compressor (HPC), just in front of the combustion chamber. The old design had instability problems because of thermal expansion of the case with larger HPC blade tip clearances after acceleration to high power. This contributed to high power surges," explains Linke-Diesinger. "The HPC cases have been modified from the segmented case design to the ring case design. There is now one ring for each compressor stage from stage 8 to stage 15. This maintains a better blade tip clearance behaviour during thermal expansion of the case structure. Due to the better performance figures of the ring case, a reduced rate of EGT margin loss is expected. This modification was covered by AD 2003-19-15. The thresholds for the AD were that half of all engines on an operator's 767 fleet had to be modified by 31st May 2006. With half having been modified by now, the remainder will have to be modified by 30th June 2009. Unmodified engines lose EGT margin at a rate of about 2.0 degrees per 1,000EFH, while modified engines should have a lower rate of loss of about 1.5 degrees per 1,000EFH.

"Removal intervals until today are not much driven by EGT margin loss, however," continues Linke-Diesinger. "The removals are mainly driven by the ring case modification requirements and the stage II high pressure turbine (HPT) blades. The stage II HPT blades had a limit of around 2,500EFC because of a corrosion problem, which is equal to 17,500EFH at our EFC time of 7.0EFH. We now use better blades, and removal intervals can get up to 20,000-22,000EFH."

"PW4060 engines tend to remain on wing for 14,000-17,000EFH, while PW4056 engines typically have removal intervals of 17,000-20,000EFH," says Janutin. "Although there are various operating factors, PW4000-94 engines will stay on wing for up to 16,000EFH or 4,000EFC, whichever is reached first. They seldom stay on-wing for longer than 20,000EFH or 5,000EFC." Given that most engines operate on average EFC times of 4.0-7.0EFH, removal intervals will be more closely related to accumulated EFH.

Like all other PW engines, the PW4000 mainly conforms to a simple shop visit pattern of alternating performance restorations and overhauls. The intervals of 15,000-16,500EFH for PW4060 engines are equal to 2,000-3,750EFC, and the intervals for PW4056 engines are equal to 2,250-4,000EFC. These have to be considered in relation to shop visit patterns, workscopes and the need to replace LLPs.

The PW4000 has 24 to 26 disks and shafts. They have lives of 20,000EFC for PW4052/4056 engines, and 15,000EFC for PW4060/62 engines. A set of LLPs for the PW4000-94 has a list price of $3.4 million. Engine managers will aim to replace LLPs at an overhaul when full engine disassembly is already required.

The aim to achieve the lowest rate for LLP reserves would be for PW4052/4056 engines operating at a ratio of 4.0EFH:EFC and achieving about 4,000EFC between removals to have their LLPs replaced at the fourth shop visit, thereby leaving a stub life of about 4,000EFC, at a total time of 16,000EFC. Engines operating longer cycles of 6.0-8.0EFC and achieving 2,250-3,000EFC on-wing, would aim to have their LLPs replaced every sixth or eighth shop visit after 17,000-18,000EFC and to leave a stub life of 2,000-3,000EFC.

The slightly shorter EFC shop visit

The 767 has so far had few ageing aircraft issues or problems with major ADs. Operators should be aware of the engine pylon improvement programme AD, which has to be terminated by 20 years of age. This can add up to 4,000MH to a heavy C check.

intervals of PW4060 engines have to be considered in relation to their LLP lives of 15,000EFC. Engines operated on shorter average EFC times of 4.0EFH will have removal intervals close to 3,750EFC, and LLPs can then be removed at the fourth shop visit close to LLP expiry. Engines operated on longer cycles of 6.0-8.0EFC will have intervals of 2,000-2,750EFC, and so LLPs can be replaced at the fourth or sixth shop visit after a total time of about 15,000EFC, leaving little or no stub life.

This management and pattern of engine removals must be considered with shop visit workscopes. "Performance restorations on the PW4000-94 have used up to about 4,500MH, and $850,000 in parts and materials, and a maximum of $120,000 in sub-contract repairs," says Linke-Diesinger. "We have a high in-house repair capability, which keeps the cost of sub-contract repairs low."

A typical industry labour rate of $70 per MH would take the total shop visit cost to about $1.35 million. Costs could reach $1.5 million where the portion of sub-contract repairs was higher.

Overhauls usually include the low pressure turbine (LPT) and the fan and booster section. "For an overhaul we would use in the region of 5,500MH in labour, about $1.0 million in parts and materials, and a maximum of $120,000 for sub-contract repairs," says Linke-Diesinger. This would take the total to $1.5 million with a standard labour rate of $70 per MH. Many overhauls would have a higher material consumption, and may also use a higher rate of sub-contract repairs, in which case the total cost could reach $1.7-1.8 million.

When these two shop visits are amortised over two successive intervals, the resulting shop visit reserves are $90-100 per EFH for the PW4056 engines and $106-115 per EFH for the PW4060 engines.

LLP reserves have to be adjusted for EFC time, and are $24-53 per EFH for the PW4056 when operated on cycles between 4.0 and 8.0 EFH, and are $35-57 per EFH for the PW4060 when operated on cycles between 4.0 and 8.0 EFH. This takes total reserves for the PW4056 up to $115-155 per EFH for average EFC times of 4.0 to 8.0 EFH, and up to $142-170 per EFH for the PW4060 for average EFC times of 4.0 to 8.0 EFH *(see table, page 35)*. Unscheduled shop visits should also be considered. These occur on average at longer intervals than scheduled visits, and also have lower costs. An additional $25 per EFH should be budgeted.

CF6-80C2

In addition to the different thrust ratings of the CF6-80C2 family, the engine type is divided between those that have FADEC controls and those with power management controls (PMC). The main difference between FADEC and PMC engines lies in the compressor stators and the engine management controls. About equal numbers of CF6-80C2 engines powering the 767 have FADEC and PMC controls.

Most CF6-80C2 engines powering the 767-200ER and -300ER are the -80C2B4, -80C2B6 and -80C2B7 variants. Their EGT margin will depend on whether the engine is FADEC controlled or has PMC controls. Frank Herr, customer programme manager CF6 projects at MTU Maintenance, explains that FADEC engines have higher EGT margins. Herr says that mature engines with FADEC controls have test cell EGT margins of 35-45 degrees C corrected for a hot day temperature of 25 degrees C after a shop visit restoration, while a mature engine with PMC controls has a lower margin of 25-35 degrees on the same basis.

These test cell EGT margins can often decrease by about five degrees C when installed on the aircraft, although EGT margin does actually increase on a few occasions.

Engines operating on typical cycle times of 7.0EFH and a 10% take-off de-rate will lose 15-20 degrees C of EGT margin in the first 1,000EFC or 2-3 degrees C per 1,000EFH following a shop visit. Herr explains that PMC engines generally deteriorate fast and so have shorter on-wing intervals.

Vassil Vassilev, senior sales executive engine services at GAMCO, explains that EGT margin erosion is influenced by several factors, in addition to EFH:EFC ratio. Engines with an average EFC time of 7.0EFH lose about 2.7 degrees C of EGT margin per 1,000EFH. Vassilev explains that this increases to about 3.05 degrees per 1,000EFH for an engine operating at 3.0EFH per EFC, and rises further to 6.3 degrees C per 1,000EFH for an engine on a 2.0EFH average EFC time.

Despite these rates of EGT margin loss, Vassilev explains that on-wing removal intervals are more related to deterioration of first-stage HPT blades than loss of EGT margin. Vassilev further explains that hardware deterioration rather than loss of performance retention is the main driving factor in CF6-80C2s. GAMCO's experience is that CF6-80C2B4 engines, rated at 57,900lbs thrust, are capable of remaining on wing for up to about 3,500EFC in the sandy conditions in which Gulf Air operates, at an average EFC time of about 2.8EFH, if the engines have new HPT blades. This is equal to about 9,000EFH. This time is reduced if the engines' HPT blades have been repaired.

FADEC -80C2B6 engines operating at average EFC times of 7.0-8.0EFH can remain for about 2,400EFC or

16,500EFH, while engines operated on shorter average EFC times of 4.0EFH can have intervals in the region of 14,500EFH or 3,600EFC.

Non-FADEC engines will have shorter intervals, and those operating on long-haul cycles of 7.0-8.0EFH will remain on wing for about 12,000EFH and 1,700EFC. Engines operating on shorter cycles of 4.0EFH achieve about 10,500EFH and 2,600EFC.

Most CF6-80C2s in operation conform to an alternating pattern of performance restorations and overhauls. A core restoration is required at every shop visit, while an overhaul on the fan/booster and LPT modules is usually required every second shop visit, but workscopes are determined by the condition of the modules.

All LLPs in the engine have a life of 20,000EFC, except those in the HPT module, which have lives of 15,000EFC. The aim of engine management would be to maximise the life of LLPs and to replace them when the engine requires a overhaul workscope.

FADEC engines operating at average cycle times of 6.0-7.0EFH, and at removal intervals of 2,500EFC, could have their 20,000EFC LLPs replaced at every eighth shop visit, with little or no stub life remaining. Engines operating at shorter average cycle times of 4.0EFH, with longer removal intervals in the region of 3,250EFC, could have the same LLPs replaced at the fifth shop visit, and will have removals forced by LLP expiry, thereby maximising the use of LLP lives.

A shipset of LLPs for the CF6-80C2 has a list price of $3.2-3.4 million, and reserve rates would be $125-135 per EFC, depending on EFC time and timing of replacement.

Non-FADEC engines with average EFC times of 7.0EFH and shorter removal intervals can replace their LLPs after 10 shop visits, and have a stub life of about 2,000EFC. LLPs would be replaced every sixth or seventh shop visit for those engines operating on shorter average EFC times of about 4.0EFH, and have LLPs replaced after a similar time and leaving a similar stub life. LLP reserves would be similar for FADEC engines.

Lighter shop visits, which usually take the form of a performance restoration, will use 4,000-4,500MH. Charged at a labour rate of $70 per MH, lighter shop visits would be equal to a cost of $280,000-315,000.

Not including LLPs, the cost of materials can be in the region of $850,000-950,000. The actual amount depends on the workscope, the engine shop's in-house repair capability and the percentage of parts manufacturing approval (PMA) components used.

The cost of sub-contract repairs will be $250,000-300,000, although the amount can fall to only about half this if the shop has a high in-house repair capability.

These three elements bring the total cost for the workscope to $1.4-1.55 million. The cost of LLPs is considered separately as a reserve for the full shipset.

Engines operating in a harsher environment will have more expensive shop visit workscopes because a higher number of parts will have to be replaced. Engines operating in a sandy environment will have their HPC blades replaced more frequently than engines in a cool environment. This will therefore increase the cost of the shop visit workscope by several hundred thousand dollars.

A heavier workscope can vary widely in content, since in some cases only one of the fan/booster and LPT modules need be worked on, and in others both will have to be worked on.

The labour content for this level of workscope will be 5,000-5,500MH, equal to a cost of $350,000-385,000. The cost of materials will be $1.0-1.1 million, not including LLPs. Again, the actual cost will depend on in-house repair capability, workscope content, and what percentage of PMA parts are included.

The final element of sub-contract repairs will be $350,000-400,000 for a shop with an average in-house repair capability.

This will take the total cost for the shop visit to $1.70-1.90 million.

While the costs for shop visits are the same for FADEC and PMC engines, engines with FADEC controls will benefit from lower shop visit reserves on account of their longer removal intervals. FADEC engines will have reserves of $105-120 per EFH, depending on EFC time. When LLP reserves are added, taking into consideration the average EFC times, reserves will be increased to $130-160 per EFH.

PMC engines will have higher shop visit reserves of $145-165 per EFH. Reserves for LLPs will take this up to $170-205 per EFH, depending on the average EFC time *(see table, this page)*. An additional $20 per EFH should be budgeted for unscheduled shop visits.

DIRECT MAINTENANCE COSTS FOR 767-200ER/-300ER

Maintenance Item	Cycle cost $	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	326,000	1 year		75
A check	550,000	4,800FH		115
Base checks	2,400,000-2,750,00			120-155
Heavy components:			609	87
LRU component support				220
Total airframe & component maintenance				**620-655**
Engine maintenance:				
2 X PW4000				280-390
2X CF6-80C2				310-460
Total direct maintenance costs:				
2 X PW4000				900-1,045
2X CF6-80C2				930-1,115

Annual utilisation:
4,500FH
640FC
FH:FC ratio of 7.0:1.0

Summary

The 767 at a mature age has good maintenance costs for an aircraft of its size. The total airframe and component costs of $620-655 per FH would of course be higher for an aircraft operated on short- and medium-haul routes with shorter average FC times and lower rates of utilisation.

The 767 also benefits from not having any serious increase in airframe-related costs due to ageing aircraft issues. The engine pylon improvement programme only increases maintenance reserves by $15 per FH if amortised over the interval of a base check cycle.

The 767 will soon face competition from the 787, which will have more attractive maintenance costs. Many 767s are likely to be converted to freighter. The combination of the aircraft's size, fuel and maintenance costs and payload-range performance will make it attractive. AC