The oldest 747-400s have been through four full base check cycles, and some aircraft are approaching their fifth D check. The routine MPD tasks, ageing programmes, major ADs and additional cosmetic base maintenance requirements over five successive base checks are examined.

Assessing the 747-400's ageing maintenance

There are 648 747-400s in civil use, comprising 592 active aircraft, and 56 parked ones. The first aircraft were delivered in 1989, making them 23 years old. The D check interval has been extended to from five to eight years since 1989, so large numbers of the fleet have been through their fourth D check, and some will be approaching their fifth in the next few years.

The 747-400's C and D check intervals are determined in calendar intervals. A small number of tasks are specified in flight hour (FH) intervals. These are at such a level that most are grouped into base checks. The fleet can therefore be grouped by age in years, which will give an approximate indication of the number of base check cycles they have completed.

The routine inspections and the ratio of non-routine defects and findings for the 747-400 generally rise with age and successive base check cycles, so the overall maintenance burden increases. This may explain why about 100 aircraft have been retired from passenger service since 2002 by major airlines *(see Ultra large aircraft: fleet planning strategies & economics, Aircraft Commerce, December 2011/January 2012, page 15)*. Many have been converted to freighters.

Base maintenance costs account for a large portion of total maintenance costs, so they are considered over five base check cycles and an age of up to 25 years.

Fleet profile

There are 406 passenger- and combi-configured aircraft, with the fleet split between 365 active and 41 parked aircraft. The active fleet is divided between 325 passenger aircraft and 40 Combis.

The age of this fleet of 325 aircraft ranges from seven to 23 years old. This means that the very youngest of these aircraft will not have been through their first D check, since the interval for the first and second D checks was increased to eight years in 2009.

Most aircraft built up to 1991 or 1992 will have been through their fourth D check, and will be approaching their fifth if the original interval had not been extended by the airline. The workscope of this check may represent a retirement watershed for some operators.

The youngest aircraft in the fleet, which were built from January 2005 to April 2009, will have not been through their first D checks. These will come due between late 2012 and late 2015.

Freighters are prominent in the 747-400 fleet. There have been 75 aircraft converted to freighters from passenger models, and four of these are parked.

Converted freighters are 13-23 years old. The youngest aircraft may be coming due their second D checks, although these are likely to have been performed together with the freighter modification.

There are also 167 factory-built freighters. This includes some of the youngest 747-400s in operation, with aircraft as young as three years old and up to 19 years. The oldest aircraft will have been through three D checks and will be approaching their fourth D check. The youngest aircraft, the last 747-400s built, will be due their first D checks in four to five years.

Aircraft utilisation

Analysis of the fleet reveals that typical annual rates of utilisation are 4,500-4,900 FH and 600-650 flight cycles (FC) for the passenger- and combi-configured fleets. Average FC lengths of most operators are 7-8FH.

Converted freighters operate at 3,600-4,000FH and 600FC per year. Average FC length is 6.0FH.

Factory-built freighters operate at similar rates of utilisation to the passenger fleet: 4,400-5,000FH per year. Average FC lengths are shorter, however, and aircraft generally operate at about 6.0FH per FC.

MPD development

The 747-400's maintenance planning document (MPD) has a range of different task intervals. The majority are specified in calendar time, and a smaller number in FH. Only a small number of task groups have a secondary interval criterion of FC in addition to the primary interval criterion.

The 747-400's MPD is revised about once every 120 days, and so about three times a year. Up to 70 revisions will have been issued since the type entered service in 1989.

"The 747-400's MPD was first operated on maintenance steering group two (MSG-2) principles for the structure, and a new structure MSG-3 was analysed. The system and zonal programme were already MSG-3 analysed in 1989, but this was changed to complete MSG-3 principles in 2002," says Rainer Winter, project manager of 747/MD-11 maintenance programs at Lufthansa Technik.

Boeing started to update the maintenance programme for all 747 models in 1999 to a MSG-3 philosophy, which took about three years. The overall aim was to: help reduce maintenance costs through lengthened check intervals; eliminate redundant and inefficient tasks; create more efficient packaging of tasks and inspections; and generate alternative methods of corrosion prevention compliance, by incorporating the corrosion prevention control programme (CPCP) into the maintenance programme.

"With the MSG-2 system, the 747-400 had a separate CPCP to the MPD. The CPCP was issued in 1990, but it was incorporated into the main body of the MPD in May 2002 during a major revision when the aircraft was changed to a MSG-3 system," says Joorgen Hoogendoorn, manager of planning department for widebody maintenance at AFI KLM E&M.

Tasks in the MPD can be sub-divided according to type. The three main groups are system tasks, structural tasks and zonal tasks. Only the system group has tasks with intervals that relate to line maintenance, A checks, and base checks. The structural and zonal groups of tasks have intervals that relate only to base checks.

The intervals of line maintenance tasks are: daily; 48 hours; 72 hours; tasks with a range of FH intervals from 130FH to 1,000FH; and tasks with FC intervals below 150FC. Many of these FH and FC tasks are inspections related to engine accessories, and items such as oil levels and the integrated drive generator.

The intervals for basic 1A and 1C tasks when the 747-400 entered service were 400FH, 4,000FH and 15 months, whichever came first (WCF). The initial D check interval was 25,000FH or 60 months, WCF. There are several groups of A and C check tasks with multiples of the basic interval. These are 2A, 3A, 4A and 5A tasks.

The C check multiple task groups are the 2C, 3C and 4C tasks.

The 1C group has a total of 238 tasks, comprising 149 system, six structural and 83 zonal tasks *(see table, page 47)*. The 2C group has a total of 164 tasks, with 88 system, 24 structural and 52 zonal tasks. The 3C and 4C groups are relatively small, with just nine and 10 tasks respectively *(see table, page 47)*.

There is just one D check task group: the 1D tasks, but a large number of calendar tasks are included in D check packages.

The A and C task groups can be arranged into checks as suits each operator. A block check arrangement would mean differing size checks and numbers of tasks in each check. In the case of A checks, an A1 check would have just the 1A tasks; the A2 check the 1A and 2A tasks; the A3 check the 1A, 2A and 3A tasks; the A4 check the 1A, 2A and 4A tasks; while the 5A check would have the 1A and 5A tasks.

The five different multiples mean that all five task groups would rarely be in phase and performed in the same check. The A check cycle is therefore considered to be completed every five checks.

Similarly, the C checks would vary in size, with the 1C tasks being performed at every check, while the C4 check, every fourth C check, would have the 1C, 2C and 4C tasks. All four C check task groups would not come in phase until the twelfth C check. The C check cycle can probably be considered to be completed every four checks by most operators.

Check escalations

These basic intervals have been extended on several occasions since the aircraft entered service. The initial A check interval of 400FH meant the 5A check, with the 1A and 5A tasks, would have had an interval of 2,000FH when the aircraft first entered service; a little more than half a year of operation.

The A check interval had been escalated to 500FH by 1992, to 600FH by 2001, and is currently 1,000FH after further escalations. This gives the 5A check a current interval of 5,000FH; equivalent to 12-14 months of service by most operators.

"The C check interval started at 4,000FH and 15 months, but was first escalated to 5,000FH and 15 months in 1992, and then to 6,000FH and 18 months in June 2002," says Hoogendoorn. "It was increased again to 7,500FH and 18 months, and then escalated further to the current interval 10,000FH and 24 months in July 2009."

The 1D task group has just a single task, but this is combined with a large number of other tasks that have the same or similar intervals to form D check packages. "The D check interval in the MPD started at 25,000FH and five years for all D checks when the aircraft entered service in 1989," says Hoogendoorn. "While the C and D check task groups were completely different and independent of each other, the D check interval was close to the fourth C check. KLM, however, already had a lot of experience with the 747 Classics, so its initial D check interval for the -400 was six years."

On this basis, the first 747-400s built would have come due for their first D checks, D1 checks, during 1993 and 1994. D2 checks for these aircraft would have come due about four-and-a-half years later in 1998 and 1999.

"The D check interval was first escalated to an initial D check interval of six years in 2002. It was later escalated to an initial interval of eight years and subsequent interval of six years. This was at the same time the C check interval was escalated to 18 months," continues Hoogendoorn. "A further escalation in the D check interval was made in the July 2009 revision. This saw the second D check interval rise to eight years."

The implications of this latest escalation are that the first two D checks will coincide with the fourth C check in the case of young aircraft, but then with every third C check from the D3 check.

The escalation of the first and second D checks to eight years in 2009 would only noticeably benefit aircraft delivered after 1996, since aircraft built prior to this date would have been through their second D check by 2007 or 2008 before the second D check interval was escalated to eight years. About half the fleet were delivered after this date, so they will have fully benefited from the escalated intervals of both the first two D checks.

Base check OOP tasks

Besides the main A, C and D check task groups, there are another 28 groups of tasks with intervals that make them appropriate for including with A, C or D checks. These are often referred to as out-of-phase (OOP) tasks.

The line maintenance OOP tasks with intervals of 130FH to 1,200FH are appropriate for combining either with line checks or A checks. The tasks with higher intervals would be grouped into A checks. The current A check interval of 1,000FH means line tasks with intervals of up to 1,000FH and 1,200FH are most likely to be combined with A checks.

The OOP tasks that have intervals close to C check intervals are FH and calendar tasks.

7,500FH & 18-month tasks

There are 42 tasks with a combined 7,500FH and 18-month interval *(see table, page 47)*; the C check interval prior

747-400 BASE CHECK TASK GROUPS

Task gp interval	*Aircraft Commerce* name	No. of system tasks	No. of structural tasks	No. of zonal tasks	Total No. of tasks	Total No. of structural tasks	Total No. of deep tasks
Intervals lower than C check							
7,500FH/18 mths		41	1		42	1	1
18 mths/1,800FC		45			45		
Included every C check							
1C		149	6	83	238	88	21
24 mths/2,000FC		47	2		49	2	
30 mths		1			1		
36 mths/3,000FC		9			9		
9,000FH		1			1		
12,000FH/12,500FH		6			6		
15,000FH/3 years		25			25		1
Included every 2nd C check							
2C		88	24	52	164	81	73
48 mths		7			7		1
2,300FC/2,500FC		4			4		1
Included every 3rd C check							
3C		9			9		1
72 mths		26	9	3	38	10	14
22,500FH/24,000FH		3			3		
Included every 4th C check							
4C		10			10		2
Included in D checks							
1D		1			1	1	1
8 years/6 years	A		6	7	13	13	12
8 years/2C	B		3		3	3	2
8 years	C	40			40		12
8 years/5,000FC	D	4			4		
8 years/8 years/Rpt 6 years	E	75	37	27	139	88	91
16 years/6 years	F		1		1	1	1
16 years/8 years	G		1		1	1	1
16 years/12 years	H	38	5	17	60	26	39
16 years/12 years/8 years	I		2		2	2	2
16 years/16 years/8 years	J		1		1	1	1
Out-of-phase tasks							
45,000FH, Rpt 3C check		2			2		
48,000FH		2			2		
50,000FH		3			3		
9 years		1			1		
10 years			8		8	8	
12 years		4			4		1
NOTE, LIFE LIMIT & VEN REC tasks							
NOTE		22	3		25	3	6
LIFE LIMIT		10			10		
VEN REC		26			26		
Total base check tasks		**699**	**109**	**189**	**997**	**329**	**284**

to the last escalation. These 42 tasks are mainly system tasks and their interval was not escalated with the main block of C check tasks. Since most operators use 85-90% of their base check interval, C checks will now be performed once every 21-22 months. These 7,500FH and 18-month tasks will therefore probably have to be combined into higher A checks, but may come due at the same time as a base check once every three or four C checks.

The same applies to a second group of 45 tasks with an interval of 18 months *(see table, this page)*.

24- to 72-month tasks

There are 104 OOP tasks with 24-, 30-, 36-, 48- and 72-month intervals. The 24-, 30- and 36-month tasks are likely to be combined with the 1C tasks by most planners *(see table, this page)*.

The 30- and 36-month tasks will have to be brought forward or de-escalated and performed early every 21-22 months with the 1C tasks. Few operators are likely to perform these separately to C

The 747-400's D check interval was five years when it entered service in 1989. It has since been escalated to six years and then eight years. Despite these escalations, the aircraft's maintenance programme is complicated by a large number of different task groups.

checks. The 36-month tasks are operational or functional checks, and so are naturally performed in a C check. They could also be planned into A checks, however.

With a higher interval, there are seven 48-month tasks *(see table, page 47)*. These are mainly functional and operational checks, most likely to be grouped with the 2C tasks.

There are also four tasks with an interval of 2,300FC or 2,500FC. These are all system tasks, and are either functional or general visual inspection (GVI) tasks. Given typical rates of aircraft utilisation they are most likely to be grouped together with 2C tasks.

There are 38 72-month tasks, 26 of which are system tasks and nine are structural tasks *(see table, page 47)*. Their interval matches the 3C tasks, so these two groups should be combined.

9,000FH to 15,000FH tasks

There are 32 tasks with intervals of 9,000FH, 12,000FH and 15,000FH *(see table, page 47)*. These are all system tasks. Their interval means it is probably easiest for check planners to de-escalate these tasks and include them with the 1C group of tasks.

8- to 16-year tasks

There are 10 different groups of calendar tasks with high intervals or initial intervals of eight to 16 years. These have a total of 264 tasks, comprising 157 system, 56 structural and 51 zonal tasks. To make identification of these 10 groups simple, *Aircraft Commerce* has named these groups A to J *(see table, page 47)*. The initial and repeat intervals of these groups means they should therefore all be combined with the 1D tasks to form various D check packages.

The intervals are eight years; an initial and repeat interval of eight and six years; the same initial interval of eight years for the first two checks and then a repeat interval of six years (8-year/8-year/repeat 6-year) as the 1D task; and three groups with an initial 16-year interval and three different repeat intervals of six, eight and 12 years. There are also a few tasks with initial intervals of 16 years and 16 years, followed by a repeat interval of eight years *(see table, page 47)*.

The largest group is E, which is the 8-year/8-year/repeat 6-year tasks. This matches exactly the intervals of the first, second and subsequent D checks. The group has 139 tasks, comprising 75 system, 37 structural and 27 zonal tasks.

These 10 task groups should therefore first be included in the first or second D checks, and then every D or second D check thereafter.

9-, 10- and 12-year tasks

There are also 13 tasks with 9-, 10- and 12-year intervals; and are mainly structural and zonal tasks *(see table, page 47)*. The 10-year tasks are all related to inspections of the landing gear, and the interval is the same as the landing gear overhaul interval. While the landing gear removal could be performed during an A or C check, the 9- and 12-year tasks could be included in D check packages.

45,000FH to 50,000FH tasks

There are also a small number of FH-related tasks with high intervals of 45,000FH, 48,000FH and 50,000FH. These are all system tasks, and are related to functional checks of the cargo heating system and thermal duct switches in various compartments.

Base check task details

The different tasks in each base check task group have several differences in terms of the type of inspections they involve, and what degree of access they require.

The MPD classifies tasks according to inspection type. The system tasks in the MPD have nine inspection categories. Six of them (operational checks, functional checks, visual checks, service checks, lubrication tasks, and discard of component tasks) all generally involve relatively easy access, and so use few additional man-hours (MH) to make the inspection. The other three classes of tasks are detailed (DET) inspections, general visual inspections (GVI), and restoration (RST) inspections. These inspections can require both relatively little or relatively deep access.

Deep access tasks require a large number of MH in addition to performing the inspection. Some inspections will involve the removal of the aircraft's interior, for example, so several hundred MH are required to remove and reinstall all the affected items. Most maintenance planners therefore prefer to include most or all deep access inspection tasks in D checks. D checks not only ensure sufficient downtime is available to remove and reinstall all the items required to allow access for the particular inspections to be made, but also allow tasks with the same access requirements to be grouped together. This avoids the repeat use of access MH if deep access tasks are planned into two different checks.

The structural groups of tasks only have GVI and DET inspections, while the zonal group of tasks has only internal or external GVI inspections.

In addition to deep access tasks, maintenance planners also need to be aware which tasks are structural inspections. MPD task numbers have a two-digit prefix to indicate the air transport association (ATA) chapter, and therefore the zone of the aircraft, to which the inspection relates. The three-

The calendar tasks with initial 8-year and 16-year intervals account for the majority of D check tasks. A large number of deep structural MPD tasks are included in D check packages.

digit task sub-number indicates the type of task. "Sub-numbers that are -400, -500, -600 or -700 are structural tasks, while those with -800 are internal zonal tasks," says Hoogendoorn. "The -800 tasks can be distinguished from -900 tasks, which are external zonal tasks. The structural and -800 tasks generally require deep access, or are heavy tasks.

"These -400 to -800 tasks are also the most critical, since there is a large impact in terms of additional MH and extended downtime if there are findings as a result of routine inspections," continues Hoogendoorn. "For example, cracks or corrosion are most likely to be found in the bulkheads, engine pylons, keel beams, flap tracks, and wing structures, such as chords, ribs and spars.

"Another issue with structural tasks is that they might require special jacking and repair procedures, so it makes sense to combine them all in the same check," adds Hoogendoorn. "It may mean that the wings cannot move when performing a repair as a result of a finding made during a routine inspection. Such repairs might need special jacking procedures. Heavy findings in structures can cause extended downtimes of up to three weeks."

Heavy inspection tasks

Analysis of the MPD reveals that a high portion of structural and zonal tasks are structural inspections, and also require deep access. A large number of structural tasks, which therefore require deep access, are also present in the system tasks. The number of detailed, structural and deep access tasks can be analysed.

Of the 699 system tasks in the base check task groups described, 227 are DET tasks *(see table, page 47)*. Some of these will require deep access and/or are structural tasks. In the system task groups, 112 require deep access and 71 of these are structural tasks. The largest portion of these deep access tasks are in the 10 calendar task groups included in the D checks, although the 1C and 2C task groups also have some structural tasks. The 10 groups of calendar tasks that are included in the D check also account for 66 of the deep access tasks.

The structural and zonal task groups have a higher portion of deep access and structural tasks.

There are 109 structural tasks in the base check task groups, all of them structural inspections. Of these 109, 72 require deep access *(see table, page 47)*. The largest number of structural tasks are in the D check calendar groups, with 56 inspections; and in the 2C group, with 24 inspections.

There are 189 zonal tasks in the base check task groups. These include 149 structural inspections and 100 deep access tasks *(see table, page 47)*. Moreover, 126 of the 189 zonal tasks now incorporate CPCP tasks that were originally in the MSG-2 maintenance programme as separate tasks. The majority of zonal tasks are in the 1C, 2C and D check task groups.

For the whole MPD, there are 284 detailed tasks, 329 structural tasks and 284 deep access tasks out of the 997 base check tasks in the MPD *(see table, page 47)*.

Heavy task details

Of the heavy inspection tasks, 139 of the structural tasks and 162 of the deep access tasks are in the D check calendar task groups. The remainder are in the C check packages. "A lot of -400 to -800 sub-number tasks in the 8- and 16-year calendar task packages get included in the D check packages," says Hoogendoorn. "Many of them have high access requirements. We try to include all of these tasks in a D check. This means a lot of access is achieved in the same check. Further efficiencies are achieved if many engineering orders (EOs) and modifications are also included in the same checks."

There are several examples of tasks that require deep access, and many of them are those with high calendar intervals that would be included in D checks. There are four 2C tasks that require inspection of the engine pylon fuse assembly, and which require deep access.

The 8-year/8-year/repeat 6-year task group, group E, has one of the highest number of tasks that require deep access. One of these is the inspection of the keel beam assembly, which will require the removal of the floor panels in the cargo compartment. Another is inspection of all passenger door cut-outs, which will require removal of many of the sidewall panels and other related items to gain full access.

There are five inspections of the internal fuselage structure in the zonal programme. Although the MPD estimates that only 18MH are needed to perform the inspections this is misleading. The necessary removal, and then replacement, of the insulation blankets and floor panels to gain access mean that several hundred MH are actually required.

The same interval group also has three tasks that are internal fuselage inspections. While the MPD provides an estimate of just 14MH for the inspections, removal and reinstallation of a large quantity of the aircraft's interior furnishings are required for access. This can add a large number of MH.

The 8-year/6-year task group, group A, has seven tasks in the zonal programme that require inspection of different sections of the lower deck cargo compartment. These require removal and reinstallation of the cargo floor.

The 10-year group of tasks has two large tasks related to inspections of various components and structures of the

Tasks requiring the deepest access are those that require the removal and reinstallation of interior furnishings. These tasks include inspection of seat tracks, both in dry and wet areas of the aircraft.

wing and body main landing gears. The MPD provides an estimate of 100MH for each of these tasks; the highest number of MPD MH of any tasks in the MPD.

The 16-year/12-year task group, group H, has several tasks with high access requirements. In the system programme there are three tasks related to inspections of the in-tank tubing, and fuel quantity indication system in the fuel tanks. These three tasks have a combined MPD estimate of 48MH for the inspections, but also require deep access.

There are another five inspections in the zonal programme with this interval that are fuel tank inspections.

This task group also has a task for the interior fuselage inspection. While the MPD estimate for inspection is just 12MH, it requires the removal and reinstallation of a lot of the interior furnishings and equipment.

The 16-year/12-year/8-year tasks, group I, has a task for the inspection of the internal fuselage structure above the main deck. While the MPD estimate for this is 96MH, one of the largest tasks in the MPD, it requires a lot of the interior to be removed and reinstalled. This will use several hundred MH to gain access.

The same task group also has an inspection for the cabin window forgings on the upper and main decks. This requires the same level of access.

Tasks that require the largest amount of interior furnishings to be removed are zonal inspections that require inspections of the seat tracks and cargo racks.

"In addition to DET tasks being mainly heavy maintenance and deep access tasks, some RST tasks also can be related to heavy maintenance," adds Hoogendoorn. "This is because a lot of access is required to restore bundles of electrical wiring. A lot of cleaning can also be involved, so many additional MH are used."

A third issue for check planners to consider are the tasks from the MSG-2 CPCP programme that have been incorporated into the zonal group of tasks in the new MSG-3 maintenance programme.

The CPCP requirements were mandated by AD 90-25-05. All the CPCP tasks were incorporated into the structure and zonal maintenance programme of the MPD, and are now summarised in Appendix G of the MPD. This gives a brief description of each task, and the CPCP item number that has been incorporated into the structure and zonal task number.

A total of 126 zonal task group inspections have had CPCP tasks incorporated into them. Most of these are in the 1C task group (46 tasks), the 2C task group (39), and the D check calendar task groups (40). Many of these CPCP tasks also require deep access.

"The zonal tasks with CPCP tasks incorporated into them mainly affect the landing gear, flaps, galleys and lavatories, cargo bays, wheel wells, upper crown, horizontal stabiliser and centre section, upper wing skin, the wing-body centre section under the main deck floor," explains David Peretz, aircraft MRO program manager at Bedek Aviation. "As part of these inspections, we have had some requests from customers to do non-destructive testing (NDT) inspections on lap joint fasteners. Also, some of the zonal tasks, now incorporating CPCP tasks, have a requirement to remove the galleys and lavatories to make underfloor inspections."

The MSG-3 maintenance philosophy differs from MSG-2, which involved a lot systems testing. "As the aircraft accumulated years in service, the reliability of systems improved and so the need to test them diminished," explains Hoogendoorn. "There were, however, a lot of findings in general areas of the aircraft. An example is in the landing gear trunnion. A lot of moisture also accumulates in the wing and keel beam areas, and the general structure and surrounding area. There was no such thing as a zonal inspection programme in the old MSG-2 MPD. The findings of corrosion and damage therefore led to the creation of the zonal task groups, as well as the incorporation of the CPCP tasks into them. The zonal inspection programme therefore means that whole areas of the aircraft, such as a landing-gear bay, get inspected, rather than just individual components.

Ageing maintenance tasks

In addition to the main MPD tasks, there are several additional groups of tasks that planners have to consider as the aircraft gets older.

"The first of these additional groups is the repair assessment programme (RAP)," says Hoogendoorn. "This consists of various types of inspections for physical repairs that have been made to the aircraft. The findings from the inspections are such that some repairs may have to be re-done. The alternative option for operators is to have repetitive inspections of the same repairs at varying intervals; the length of which will depend on the criticality of the repair.

"The RAP was issued to KLM in 2007," continues Hoogendoorn. "It only affects the 747s."

The second group of additional inspections is the supplemental structural inspection document (SSID). "There are two parts to the SSID," says Hoogendoorn. "The first relates to inspections in the wings, and the second relates to inspections in the fuselage. The inspections check for fatigue, cracks or corrosion of particular structures in the wings and fuselage.

"The threshold interval for initial inspections to the wings was 100,000FH and 20,000FC, but this was recently increased to 115,000FH and 20,000FC," continues Hoogendoorn. "Some of the oldest aircraft in the fleet have accumulated just over 115,000FH, and several others had reached or were close to reaching 100,000FH before the threshold was escalated. This means that some aircraft will have had the initial inspections for the wing. The 20,000FC threshold interval for the fuselage inspections only really affects the aircraft with higher FC operations, such as those used on domestic services in Japan."

There are repeat inspections following the initial inspections, and the interval and severity of these are complex. "Prior to the initial threshold being escalated from 100,000FH, we had aircraft that had accumulated about 85,000FH by the time they had reached their third D checks, D3 checks," says Winter. "Given that our aircraft operate at an annual utilisation of about 5,200FH, and that D check intervals were six and five years for the oldest aircraft in the fleet, some would have accumulated close to 85,000FH by their D3 checks. With continued operation at 5,200FH per year following these checks they would have reached the 100,000FH threshold before they reached their D4 checks five years later. They would therefore have needed the initial SSID inspections included in the D3 check to avoid an additional layover to make the inspections between the D3 and D4 checks."

The SSID programme of initial inspections for the wings has 119 inspection tasks, except centre wing items. "Most of these are NDT tests, and some require deep access since they are in the wing's internal structure," says Winter. "It is appropriate for the tasks to be included in a D check. Operators then have the option of either repeating the tasks during subsequent C checks or in the next D checks. If the airline chooses to do them in every subsequent C check, at a more frequent interval, then they are just GVI or DET tasks. If the airline chooses to do them less frequently every second or fourth C check or every D check then the inspections have to be NDT again. Either way, the maintenance burden increases significantly once the initial inspections come due.

"The deep access nature of many of the inspections adds significant routine inspection requirements to the aircraft from either the D3 or D4 check," continues Winter. "The base checks from the D3 check will be heavier than those prior to the D3 check."

A third group of ageing aircraft routine inspections will be the widespread fatigue damage (WFD) programme. "This is still under development, and is being devised to test for local fatigue damage," says Hoogendoorn. "The aim is to test for fatigue damage to the surrounding area of the aircraft that has been damaged and/or been repaired. The issue is that there could be weaknesses to the fuselage structure where the aircraft has experienced cracks, damage or weaknesses. The WFD is likely to include inspections with high initial intervals. Once issued, this will add further structural inspections to the aircraft's routine base maintenance requirements."

Major ADs & SBs

Several airworthiness directives (ADs) and service bulletins (SBs) affect the 747-400. The largest of these was the engine pylon modification, and was issued in 1995.

In more recent years there have been ADs issued in relation to tension ties in the upper deck structure of Section 41 o the fuselage, scribe line inspections, and inspection of the vertical stabiliser seal.

These major ADs are reviewed *(see table, page 54)*.

Check task grouping

Several task groups have to be grouped or planned into C and D checks. This has to achieve the best compromise of task interval utilisation.

The first main groups of C and D check tasks can be arranged in a block check format *(see table, page 55)*. This table illustrates how the MPD C and D check task groups would be grouped into checks, but many operators have escalated and de-escalated certain tasks from the MPD intervals to shorter or

MAJOR AIRWORTHINESS DIRECTIVES AFFECTING THE 747-400

AD 2012-15-13

AD 2007-23-18 relates to tension ties in the area of the forward fuselage upper deck structure. This has recently been superseded by AD 2012-15-13.

The AD requires detailed NDT inspections to be made following reports of cracks and severed tension ties, broken fasteners and cracks in the frames in the area of the upper deck related to tension ties between body stations 1120 and 1220. The AD requires NDT inspections to be made to detect cracks that could result in decompression. These inspections are made at two stages.

Intervals for the Stage 1 inspections are before the aircraft has accumulated a total of 10,000FC, or within 250FC being flown of November 2007; whichever comes later. These are heavy inspections, because they require a lot of deep access that involves the removal of interior furnishings. Holes have to be drilled and fasteners removed to make some of the NDT inspections.

These initial inspections are estimated to use 600-700MH for the routine inspections, and the access required means it makes sense to include them in a D check. "Several thousand MH could be required if there are findings from these inspections," says Jorgen Hoogendoorn, manager of planning department for widebody maintenance at KLM Engineering & Maintenance.

Repeat inspections then have to be made every 250FC after; which is equal to once every five months of operation. They are visual, and require their own dedicated maintenance check. They no longer have to be performed once the Stage 2 inspections are performed.

Stage 2 inspections are high frequency eddy current (HFEC) inspections in the same area of the aircraft. The limits for performing these inspections are 16,000FC or within 1,000FC being flown of November 2007; whichever comes later. There are also some additional inspections. An example is an open HFEC inspection at BS 1140 at specific tension ties.

Stage 2 inspections cannot be done at the same time as Stage 1 inspections, although Stage 2 inspections can be done to avoid doing Stage 1 inspections. David Peretz, aircraft MRO program manager at Bedek Aviation estimates that Stage 2 inspections use about 160MH, during C checks. This includes 40MH for access.

There are then repeat inspections after Stage 2, which are visual and NDT inspections. The AD is terminated by open hole inspections.

While some of the fleet will have not reached the limits for performing Stage 1 inspections, other aircraft will have been through Stage 1 and Stage 2 inspections.

AD 2012-04-09

A second major AD is AD 2009-04-09, and relates to scribe line inspections along the fuselage skin panels and lap joints. The AD was issued in response to scratches found on fuselage skin panels as a result of knives being used to remove paint and sealant between skin panels," says Hoogendoorn. "These scratches can propagate and lead to cracks forming. The AD requires visual and x-ray inspections to be made of the skin and skin joints. The limit for performing the x-ray inspections is 15,000FC.

The AD becomes complex to implement, however, after the initial inspections have been made. "Repeat inspections have to be made at intervals that vary from 100FC to 1,000FC," says Rainer Winter, project manager of 747/MD-11 maintenance programs at Lufthansa Technik. "Repeat intervals are not being known until the initial inspections have been made. To date, only two aircraft worldwide have been through their initial inspections."

The AD is not terminated. Repeat inspections are required every C check if there are findings. Peretz estimates that about 650MH are required in area 1 and 2 of the aircraft for the initial inspections. The NDT and visual inspections require paint to be removed. Repeat inspections are done using lasers.

AD 2009-14-02

A third major AD is AD 2009-14-02. This relates to an inspection of a seal between the base of the vertical stabiliser and the skin of the upper fuselage. "The wear of this seal has warranted inspections at the base of the vertical stabiliser. It is best to include the inspections in a D check," advises Hoogendoorn. "Inspection thresholds are 10,000FC or by June 2013."

Peretz estimates that about 50MH are required to remove inspection panels. If there are findings, such as corrosion, the seal has to be removed and the area cleaned prior to HFEC NDT inspections. The AD can be terminated with a repair detailed in the structural repair manual.

SFAR 88

SFAR 88 relates to the TWA 747 incident in 1996, in which ignition of fuel vapours was caused by electrical arcing in empty fuel tanks. This requires a lot of inspections of wiring looms and bundles to check for chafing. SFAR 88 has been re-named Enhanced Zonal Analysis Procedure (EZAP). There is also the electrical wiring interconnection system (EWIS), which requires the splitting of wiring bundles into smaller groups and the proper clamping of bundles. "Inspections also check all pumps and valves in the wiring system," continues Hoogendoorn. "These are a large number of tasks that are incorporated into the MPD."

AD 2010-14-08

AD 2010-14-08 is one of two smaller but significant ADs affecting the 747-400. This AD involves a modification of the fuel jettison pump. This requires entry into the fuel tank, and so clearly can only be done when the aircraft is on for a C or D check. A lot of access is required.

AD 2007-21-13

This AD relates to the electrical earthing of the fuel boost pump. This again requires entry into the fuel tank during a base check, and a modification to ensure the correct electrical binding between the fuel boost pump and the aircraft structure.

Older ADs

There are several older major ADs affecting the 747-400.

The first of these was AD 95-13-05, and relates to the modification of engine pylons. This followed the loss of an El Al 747 freighter following the failure of two engine pylons.

The AD required the strengthening of the engine pylons. This affected 747-400s from line number 705, the first 747-400 off the production line; to line number 1,033, which entered service in May 1994. Later-built aircraft had the AD incorporated on the production line.

The AD had a calendar compliance limit, and so would have been complied with from 1995 to 1998, and been included in a C or D check. Peretz estimates that the modification used 8,000-8,500MH. Repeat inspections are still required, because pylons are prone to corrosion.

A second example is AD 2000-02-10, which required an inspection for cracks around the frame of door three on the main passenger deck. This AD has been complied with.

A third AD is AD 2005-19-09, and is a modification to the brace in the engine pylons, and specifically the fuse pins. Peretz estimates that about 950MH were used for this modification, including the removal and reinstallation of the engines.

Two other major ADs that affected the 747-400 were the requirement to remove the heat exchanger from the fuel tank, and to modify locks in the engine thrust reverser units. One was AD 2004-10-06, SB 29A2104. This affected all 747 variants, including -400s, up to line number 1,271. This had to be complied with as soon as possible, and is estimated to have used about 55MH.

747-400 BASE CHECK TASK GROUPS

Base check	C& D check task groups	OOP FH task groups	OOP mth task groups	OOP annual task groups	Total MPD tasks	Total MPD MH
C1	1C	9KFH, 12KFH, 15KFH	24/30/36 mth		329	451
C2	1C, 2C	9KFH, 12KFH, 15KFH	24/30/36/48 mth		500	699
C3	1C, 3C	9KFH, 12KFH, 15KFH, 24KFH	24/30/36/72 mth		379	590
C4/D1	1C, 2C, 4C, 1D	9KFH, 12KFH, 15KFH, 45KFH, 48KFH, 50KFH	24/30/36/48 mth	A, B, C, D, E	712	1,088
C5	1C	9KFH, 12KFH, 15KFH	24/30/36 mth		329	451
C6	1C, 2C, 3C	9KFH, 12KFH, 15KFH, 24KFH	24/30/36/48/72 mth	B	553	845
C7	1C	9KFH, 12KFH, 15KFH	24/30/36 mth		329	451
C8/D2	1C, 2C, 4C, 1D	9KFH, 12KFH, 15KFH, 45KFH, 48KFH, 50KFH	24/30/36/48 mth	A, B, C, D, E, F, G, H, I, J	775	1,332
C9	1C, 3C	9KFH, 12KFH, 15KFH, 24KFH	24/30/36/72 mth		379	590
C10	1C, 2C	9KFH, 12KFH, 15KFH	24/30/36/48 mth	B	503	706
C11/D3	1C, 1D	9KFH, 12KFH, 15KFH, 45KFH, 48KFH, 50KFH	24/30/36 mth	A, C, D, E, F, G	528	831
C12	1C, 2C, 3C, 4C	9KFH, 12KFH, 15KFH, 24KFH	24/30/36/48/72 mth	B	563	850
C13	1C	9KFH, 12KFH, 15KFH	24/30/36 mth		329	451
C14/D4	1C, 2C, 1D	9KFH, 12KFH, 15KFH, 45KFH, 48KFH, 50KFH	24/30/36/48 mth	A, B, C, D, E, F, G, H, I, J	765	1,327
C15	1C, 3C	9KFH, 12KFH, 15KFH, 24KFH	24/30/36/72 mth		379	590
C16	1C, 2C, 4C	9KFH, 12KFH, 15KFH	24/30/36/48 mth	B	513	711
C17/D5	1C, 1D	9KFH, 12KFH, 15KFH, 45KFH, 48KFH, 50KFH	24/30/36 mth	A, C, D, E, F, G, I, J	531	936

longer intervals, and in the process have created other C check task multiples.

"We do not have a 3C or 4C multiples in our maintenance programme, because tasks in these two groups have either been escalated to the D check interval, or de-escalated to the 2C interval," says Winter.

Although the C and D check task groups are completely independent of each other, the C and D check intervals through the early stages of the 747-400's operation meant that D checks would best be grouped together with every fourth C check.

This changed in 2009 when the C check interval was escalated to 24 months. This meant the D check would then be performed together with every third C check. By this date, the oldest 747-400s would have been 20 years old, and have been going through or due their fourth D checks. They would therefore not perform the D check with the third C check until reaching the D5 check.

Younger aircraft would start grouping the D check with every third C check at the D4 or D3 check.

The initial C check intervals of 15 months, and the typical 85% utilisation of base check intervals by operators, means that C checks would be performed once every 12-13 months, and so C4/D checks every 50-52 months.

After C check interval escalation to 18 months and D check interval to six years, C checks would be performed once every 15-16 months, and C4/D checks every 60-64 months.

With the further escalation of the first and then the second D checks to eight years and C checks to 24 months, actual check intervals would be 21-22 months, with the D check done at seven-year intervals. Third and subsequent D checks, with every third C check, would be every five years.

The number of MPD tasks in each check varies from as low as 238 for checks with just the 1C items, to 402 for C2 checks that also have the 2C tasks, and up to 413 tasks for the C4/D checks.

The number of system, structural and zonal tasks in the MPD reduced when it evolved from an MSG-2 to an MSG-3 programme. The total number of MPD tasks for the C and D checks *(see table, this page)* will differ from the number that would have been included in the 747-400's early years of operation. This is because of the change in the number of tasks in each task group, which in many cases would have been higher in the MSG-2 programme.

The current intervals of other OOP calendar and FH task groups have all been escalated from their original intervals since the aircraft entered service in 1989. It is assumed in this analysis that the intervals of all these task groups have been escalated in step with the C and D task groups. The checks they would be best included in now have therefore not changed since the aircraft entered service in 1989.

The second main group of tasks is the OOP FH tasks with lower intervals. There are four main groups: the 9,000FH, 12,000FH, 15,000FH and 24,000FH. The first three would have to be included in every check *(see table, this page)*, although it may be possible to plan the 15,000FH items into every second C check. The 24,000FH tasks could probably be performed every third base check.

These four groups only have 35 tasks, and the MPD has an allowance of 57MH for their performance.

The third group of OOP tasks are those with 45,000FH, 48,000FH and 50,000FH intervals. It may be simplest to perform these tasks at every D check.

The fourth main group of tasks are the OOP calendar tasks with intervals of 24 to 72 months. The first three groups of 59 tasks would have to be included in every base check *(see table, this page)*, and have an MPD allowance of 38MH. The 48-month tasks would be included in every second base check, and would add a smaller number of tasks and MH. The 72-month tasks would be performed every third base check. These have the largest MPD labour requirement of 130MH.

The fifth main group are the OOP calendar tasks with longer intervals of six to 16 years *(see table, this page)*. The intervals of groups A, C and D are the same as the D check intervals. These four groups have 196 MPD tasks, and a MPD labour estimation of 376MH.

Group B's repeat interval is 2C, and so has to be performed every second C check after the first D check.

Groups F to J all have an initial interval of the second D check. These have 65 tasks, but some have the highest MH requirement in the MPD. They have a MPD labour estimation of 243MH.

The F and G tasks have to be included in all D checks from the D3 check, but are small inspections.

The H tasks, which include some internal fuselage structure inspection tasks with a high access requirement, only have to be performed once again during the D4 check.

The I and J tasks have to be performed again at the D4 and D5 checks. The I group has just two tasks, both of which are the internal fuselage structure inspections. Their high access requirements, they add several hundred MH to the routine portion of the check.

The grouping of these five main groups of tasks into base checks is summarised for the five base check cycles. *(see table, page 55)*. This is based on an aircraft performing the D check with every third C check from the D3 check onwards. These five main task groups result in the number of MPD tasks varying from 329 tasks for the smallest check with just the 1C tasks, up to 775 tasks for the D2 check, with almost all task groups included. The MPD labour allowance for the routine inspections is about 450MH for the smallest check package, increasing to 700-850MH for checks with the 2C tasks included, and 950-1,350MH for the D check packages *(see table, page 55)*.

In addition to these five main groups there are also the various ageing programme tasks that include the SSID, RAP and WFD.

Base check inputs

The total labour MH and costs of materials, consumables and life-limited rotables can be examined for five successive D check cycles *(see table, page 60)*. This will be based on the grouping of tasks into base checks, as described and listed *(see table, page 60)*.

The analysis is made for an earlier-built 747-400, entering into service during 1989-1992. This aircraft will have been through its fourth D check; the D4 check, during 2008-2010, and will be due its D5 check in 2013-2016.

The D check would be performed with every fourth C check for the first two base check cycles. The D check would then have come due every third D check thereafter due to interval escalations *(see table, page 60)*.

The MH and costs for materials and consumables are therefore based on actual inputs. The inputs for the fifth base check cycle up to the D5 check are based on expected inputs.

The analysis will illustrate how the base maintenance requirements increase with successive base check cycles. Increases are due to growing routine inspections and ageing programmes, steadily increasing non-routine ratios, and major ADs.

Besides the routine MPD inspections, as previously described, many additional elements of a base check that have to be performed. The routine inspections of each check will also include lesser line and A checks, some OOP tasks, customer-specific items, and outstanding deferred defects. Most customer-specific items will be tasks related to interior cleaning and refurbishment. MPD tasks are also often re-authored and have customer additions. The result is that a large number of tasks can be added to the MPD items due in a check.

Winter illustrates the point with the 1,102 tasks that Lufthansa Technik has in its approved maintenance plan. It has another 369 of its own tasks in addition to these. The majority are base check and OOP tasks.

Routine inspections

Routine inspections in the MPD have MH estimates, although maintenance planners are aware that these do not reflect the MH actually used to perform the tasks. MPD estimates have to be multiplied by an escalation factor to take into consideration aircraft preparation and docking, supervision, hands-on labour efficiency, and access. Gaining access in particular accounts for a large portion of the escalation factor, because some of the inspections require the removal and reinstallation of a large amount of the aircraft's interior equipment and furnishings. Many of the inspections in the larger check packages, in particular D checks, are ones that require deep access. The escalation factor for routine inspections is therefore higher in heavier checks.

Peretz estimates the MH for routine inspections is low at about 2,200 for the

Section 41 of the 747-400 is affected by a major AD that requires inspections to be made in relation to tension ties between the upper deck and main deck.

lightest C checks; the C1 and C5 checks. These have just the 1C tasks, plus some OOP tasks *(see table, page 60)*.

The routine MH requirement increases as the C check packages get larger. The C7 and C13 checks have just 1C tasks, but a larger number of OOP tasks. Peretz estimates these typically use 2,700-3,100MH.

The C3, C9, and C15 checks have the 1C and 3C tasks, plus varying amounts of OOP tasks. These use 2,900-4,400MH for routine inspections.

Checks with 1C and 2C task groups include the C2 and C10 checks; plus OOP tasks *(see table, page 60)*. These use 4,300-5,000MH.

The next largest packages are the C6 and C16 checks. These have the 1C, 2C and either 3C or 4C tasks *(see table, page 60)*. Peretz suggests a budget of about 4,300MH for routine inspections.

The largest C check, without D check task groups, is the C12 check. This has all C check task groups, plus some OOP tasks. Peretz estimates the possible labour requirement to be 5,500MH.

The routine inspections in D check workscopes generally increase with each successive base check cycle. The increase in MH requirements is not steady, however, since the number of C check, D check and OOP tasks coming due fluctuates. The tasks and routine labour requirement vary with each check, but Peretz estimates that 13,000MH is required in each case *(see table, page 60)*.

Defects & non-routine

The number of defects and findings, and therefore the non-routine ratio, generally increases with age and successive base check cycles for all aircraft types. A typical pattern is to see the non-routine ratio (number of MH used for defects as a portion of routine MH) steadily increase with successive C checks. The non-routine ratio is highest with the final D check; one reason is that the deep access tasks reveal defects.

Many defects are also related to dilapidation of cabin interior equipment and furnishings. Hoogendoorn warns that a lot of defects are related to sheet metal work and delamination of metal surfaces in structures that have to be repaired. Moreover, a lot of these structures are driven by SBs. Another issue is corrosion in the seat tracks. Most are rectified during the D check.

The non-routine ratio for the first C check in the successive base check cycle is therefore lower, since many defects have been rectified in the preceding D check. The non-routine ratio will rise steadily again, and can be expected to be higher for this D check compared to the previous D check.

The non-routine ratio for the C1 check has been 0.50-0.60. This has increased steadily over the next three checks to 0.80-0.90 for the C4/D1 check. This will generate a requirement of about 11,000MH for the C8/D1 check, and a total of 17,000-18,000MH for the first base check cycle *(see table, page 60)*.

"The non-routine ratio typically increases by about 25% between the D1 and D2 checks," says Hoogendoorn. "This is partly because the number of findings increases, but also because more routine tasks come due at the D2 check.

The non-routine ratio can be up to 1.10 by the C8/D2 check. MH for non-routine could therefore be 14,000-15,000 for the C8/D2 check, and total 24,000MH for the four checks in the cycle *(see table, page 60)*.

"Another increase can be expected between the D2 and D3 check," continues Hoogendoorn. "This is larger at about 50%. In this case there is not much of an increase in the number of routine task cards. There is then a further increase in findings and non-routine MH from the D3 to D4 check. The MH used for non-routines and defects increase at even higher rate than the number of non-routine task cards. The non-routine task cards are mainly structural repairs, such as cracks and corrosion."

The non-routine ratio can reach 1.20-1.40 by the D3 and D4 checks. The D3 and D4 checks could therefore use 15,000MH and 19,000MH for non-routine findings and defects.

No 747-400s have been through their D5 checks so far, but it is estimated that the non-routine ratio could be as high as 1.60. This could generate a need for up to 20,000MH *(see table, page 60)*. The non-routine ratio climbs relatively steadily for passenger-configured aircraft, but climbs faster for freighters.

Routine & non-routine

The sub-total for routine inspections and non-routine defects could therefore total 40,000MH for the first base check cycle. This would climb to 47,000MH for the second cycle, and 45,000MH in the third cycle; despite one check fewer. It would continue climbing in the fourth and fifth base check cycles *(see table, page 60)*. The number of MH depends heavily on the non-routine ratio.

Interior cleaning

Interior cleaning is always required. Some cleaning tasks will be defined by cards authored by the operator, while others will be issued by a general instruction. Cleaning requirements vary by operator and check, but a general budget can be made.

Peretz at Bedek Aviation suggests that 750MH should be allowed for the first and third check in the base check cycle (the C1 and C3 checks), 1,100MH for the C2 check, and 1,500MH for the C4/D check. This allowance changes little during the life of the aircraft.

Interior refurbishment

Interior refurbishment is a customer-specific and cosmetic item.

Aisle carpets are usually replaced and seat covers cleaned during C checks. These two items will use another 550MH and cost $6,600 for materials *(see The costs of large widebody interior refurbishment, Aircraft Commerce, October/November 2011, page 28).*

The requirement to gain deep access to several parts of the aircraft's structure mainly comes from tasks in the D check. These tasks require a lot of interior items and furnishings to be removed during this check, which provides an opportunity to refurbish many of the aircraft's interior items at the same time.

Interior refurbishment in a D check often includes: the replacement of seat area carpets; replacement of seat covers and seat cushions; maintenance of seat frames; the refurbishment of panels, overhead bins and passenger service units; installation of new floor material in servicing areas; and refurbishment of galleys and lavatories. These items can use up to 12,000MH and $100,000-250,000 in materials, consumables and replacement parts *(see The costs of large widebody interior refurbishment, Aircraft Commerce, October/November 2011, page 28).*

Ageing programmes

The thresholds of the SSID, RAP and WFD programmes mean that no labour would have been used until at least the D3 check.

Peretz estimates that labour required for these three programmes would use 1,400-1,500MH in the C11/D3 check. "The MH required for the SSID and RAP are not too high, despite the complexity of the programmes," says Hoogendoorn. "The WFD is covered by AD 2010-05-03, and requires HFEC tests prior to reaching 135,000FH. This is a big task, and uses about 1,500MH. In many cases this will come due at the D4 check."

The MH used for the three ageing aircraft programmes will rise during the fourth base check *(see table, page 60).*

ADs, SBs & EOs

The labour used for ADs, SBs and EOs has to be considered in two parts. The first is the labour used for smaller items that are issued on a regular basis. The second is the larger ADs and SBs that use large amounts of labour and/or have a high material cost.

Hoogendoorn makes the point that SBs not included in the MPD items can drive a large amount of MH due to findings resulting from the inspections.

An allowance of 1,700-2,000MH should be made for lighter C checks in earlier base check cycles, and 2,700-3,000MH for C2 checks.

Heavier C4/D checks have used an increasing amount of labour in successive D checks. This starts at 3,000MH for the D1 check, but Hoogendoorn recommends budgeting for a consumption of 8,000MH in the D4 and D5 checks *(see table, page 60).* This accounts for the possibility of findings in the scribe line inspections and the tension tie modification.

Major ADs

The major ADs affecting the 747-400 have been described. The timing of these ADs will depend on the aircraft's build date in relation to the AD's issue date.

All the major ADs described will have affected the earlier-built aircraft. These, in particular, include AD 95-13-05 for engine pylon modification. This will have been included in a check in the second base check cycle for an aircraft built in 1989-1992, and is likely to have used 8,000-8,500MH *(see table, page 60).*

Heavy component changes

Heavy component changes include engines and landing gear. The landing gear has a 10-year overhaul interval. Removing and installing a landing gear uses about 700MH. Removal of an engine and installing a replacement uses about 50MH. Other heavy components include the auxiliary power unit (APU) change, and some life-limited rotables.

An allowance of 300-400MH should be made for the light checks and about 750MH for the D check in the first base check cycle *(see table, page 60)*. The removal of engines and installing replacements will be scheduled either with A or C checks, and some of the allowance for these checks will include this.

The allowance for light checks will remain similar for the C checks during the second base cycle. The labour used can double in the second D check to about 1,400MH *(see table, page 60)*, since the first landing gear removal is likely to occur at this stage. If not, it will be at the previous C check.

The labour used for C checks in later base cycles can rise, and the allowance for D checks should be up to 1,900MH for the D5 check.

An allowance should be made of $8,000 for the cost of changed parts in the lighter C checks, $12,000-16,000 for the heavier C2 checks, and $20,000-28,000 for D checks.

Stripping & repainting

As with interior refurbishment, stripping and repainting is often performed at the D check. It can also be scheduled separately, although aircraft are stripped and repainted at intervals similar to D check intervals.

An allowance of 4,500-6,000MH should be made for this process, plus a budget of about $270,000 for the paint.

Total labour inputs

Total labour used will climb steadily with each base check cycle. This is mainly due to an increasing non-routine ratio, ageing programmes, and major ADs.

Besides the routine inspections and non-routine defects, additional items will add up to 7,000MH to C checks and up to 32,000MH to D checks.

Light C checks will use 7,000-8,700MH in the first two base check cycles, and then rise to 11,000MH in later cycles.

C2 checks will initially use about 12,000MH, and then climb to 14,000-15,000MH in the second base check cycle *(see table, page 60)*. This will continue to rise up to 20,000MH by the time the aircraft is in its fifth base check cycle.

The first D checks will have used about 45,000MH. With the engine pylon modification included, the D2 check will have used about 63,000MH.

The labour used in subsequent D checks will continue to climb, reaching 60,000-65,000MH in the D4 check. The actual labour used can be up to 10,000MH higher in facilities with poorer labour efficiency.

"Although no D5 checks have been performed on the 747-400, it is likely to require 5,000-8,000MH more than the D4 check," says Hoogendoorn. The big unknown with the D5 check is how much the non-routine ratio could climb, and what non-routine defects will be driven by AD inspections.

The total labour used for the four successive base check cycles will start at about 73,000MH for the first cycle to the D1 check *(see table page 60)*. Of this, 45,000MH is used for the D1 check.

This increases to about 93,000MH for the second base check cycle. This is split between about 31,000MH for the three C checks and 63,000MH for the D2 check. The D2 check therefore uses about 18,000MH more than the D1 check. Taking away the effect of the engine pylon modification that the earlier-built aircraft would had to comply with, the D2 check still uses about 55,000MH; about 10,000MH more than the D1 check. The three main contributors of this increase are a higher non-routine ratio, a heavier interior refurbishment workscope, and a larger requirement for ADs and SBs.

The aircraft's requirements will rise during subsequent base check cycles, but this will have been partially offset by the escalation of C check intervals that will have allowed the D check to be combined

THIRD PARTY TECHNICAL SUPPORT FOR 747-400S

Many 747-400s are likely to continue in operation in their later years with smaller operators. This is particularly the case with aircraft that have been converted to freighters. Airlines that are in the position of operating small fleets will want to source technical, engineering and maintenance support from specialist providers.

SIA Engineering Company (SIAEC) has 22 years experience of supporting the 747-400, and has conducted more than 800 C and D checks. It has also performed several other large projects, such as interior reconfiguration and major structural work.

One of SIAEC's services is its Fleet Management Programme (FMP). This provides all engineering and inventory management functions for airlines that choose to outsource these tasks. SIAEC provides its FMP for over 200 aircraft, which includes the 747-400. With FMP, SIAEC takes over an airline's engineering operations, including recommending a suitable maintenance programme for the operator. This involves defining maintenance intervals and getting approval to escalate them and planning of maintenance visits.

FMP comprises Fleet Technical Management (FTM) and Inventory Technical Management (ITM); where ITM relates to managing an inventory of rotable components, as well as the repair and overhaul of components. ITM is aimed at reducing the operator's spares provisioning and to allow them to enjoy synergies of SIAEC's spares support and logistics network.

FTM includes all other engineering management functions that an airline will usually have to perform for itself. These functions include: publication and documentation library management; fleet reliability management; management and evaluation of ADs and SBs; maintenance control; aircraft configuration control; and technical records management.

Besides major interior refurbishment and reconfiguration projects, SIAEC has worked on installing in-flight entertainment (IFE) equipment, installing aircraft connectivity modifications and ensuring the timely issuance of Supplemental Type Certificates (STCs).

SIAEC's maintenance capabilities for the 747-400 include line and light maintenance, base maintenance, inventory and rotable component management, on-wing engine maintenance and heavy component repair. Engine maintenance is provided through its OEM joint ventures with Pratt & Whitney, Eagle Services Asia (ESA); and Rolls-Royce, Singapore Aero Engine Services (SAESL). ESA and SAESL are Centres of Excellence for engine overhaul in the Asia-Pacific region.

These elements of maintenance production include all levels of maintenance production an aircraft will require at some stage in its life. Base maintenance capabilities include Section 41 modifications, composite repairs, cabin interior refurbishment, painting, and passenger-to-freighter conversion; besides C and heavy checks.

SIAEC has its base maintenance hangars, component repair shops and engineering management centre based at Changi Airport Singapore. It also provides a Quick Action Team (QAT), supported by a global cluster of line maintenance stations at more than 30 airports, for emergency line maintenance and aircraft-on-ground (AOG) situations around the world.

SUMMARY OF MH & MATERIAL INPUTS FOR FIVE BASE CHECK CYCLES - PASSENGER-CONFIGURED 747-400

Check	Total Routine MH	Defect ratio	Non-routine MH	Sub-total routine, non-routine & other MH	Interior clean MH	Interior refurb MH	Ageing SSID, RAP, WFD MH	EOs, SBs, ADs MH	Major ADs MH	Engine & heavy comp change MH	Strip/ Paint MH	Total MH	Total materials cost- $
C1	2,204	0.60	1,322	3,526	750	550		1,700		340		6,866	124,729
C2	4,295	0.70	3,007	7,302	1,100	550		2,800		340		12,092	217,556
C3	2,950	0.75	2,213	5,163	750	550		1,700		340		8,503	152,543
C4/D1	13,028	0.85	11,074	24,102	1,500	10,000		3,000		750	6,000	45,352	1,210,981
Total for cycle	**22,477**		**17,615**	**40,092**	**4,100**	**11,650**	**0**	**9,200**	**0**	**1,770**	**6,000**	**72,812**	**1,705,807**
C5	2,204	0.90	1,984	4,188	750	550		1,900		340		7,728	139,569
C6	5,025	0.95	4,774	9,799	1,100	550		2,700		340		14,489	258,309
C7	2,655	1.00	2,655	5,310	750	550		1,700		340		8,650	155,050
C8/D2	13,192	1.10	14,511	27,703	1,500	12,000		6,000	8,000	1,400	6,000	62,603	2,078,254
Total for cycle	**23,076**		**23,924**	**47,000**	**4,100**	**13,650**	**0**	**12,300**	**8,000**	**2,420**	**6,000**	**93,470**	**2,631,182**
C9	3,350	1.15	3,853	7,203	750	550		1,900		340		10,743	191,023
C10	5,036	1.20	6,043	11,079	1,100	550		2,700		340		15,769	280,076
C11/D3	12,186	1.20	14,623	26,809	1,500	12,000	1,450	7,000		1,600	6,000	56,359	1,503,106
Total for cycle	**20,572**		**24,519**	**45,091**	**3,350**	**13,100**	**1,450**	**11,600**	**0**	**2,280**	**6,000**	**82,871**	**1,974,205**
C12	5,475	1.30	7,118	12,593	750	550	450	2,800		650		17,793	318,473
C13	3,106	1.20	3,727	6,833	1,100	550	600	1,700		340		11,123	197,094
C14/D4	13,662	1.40	19,127	32,789	1,500	12,000	3,000	8,000		1,800	6,000	65,089	1,652,510
Total for cycle	**22,243**		**29,972**	**52,215**	**3,350**	**13,100**	**4,050**	**12,500**	**0**	**2,790**	**6,000**	**94,005**	**2,168,077**
C15	4,340	1.50	6,510	10.850	750	550	550	2,200		340		15,240	267,580
C16	5,066	1.50	7,599	12,665	1,100	550	900	3,500		650		19,365	339,205
C17/D5	12,516	1.60	20,026	32,542	1,500	12,000	1,650	8,000		1,900	6,000	63,592	1,629,057
Total for cycle	**21,922**		**34,135**	**56,057**	**3,350**	**13,100**	**3,100**	**13,700**	**0**	**2,890**	**6,000**	**98,197**	**2,235,842**

with the third C check in the cycle. The labour for the first two C checks are higher than in previous cycles, however. The D3 check will have consumed 56,000-60,000MH in many cases. Total labour for the three checks in the cycle will be about 83,000MH.

D4 checks have been higher at 60,000-65,000MH, where the aircraft has been maintained at facilities with some of the higher labour efficiencies in the world. With lower labour efficiencies the MH used can be 5,000-10,000 higher.

The fifth base check cycle is more of an unknown. Passenger-configured aircraft are being operated following their D4 check. Most elements of the D5 check will require more MH than the D4 check.

There are three elements where a labour saving may be realised.

The first is the number of MPD tasks. Only 1C tasks are likely to come due compared to 1C, and 2C tasks in the D4 check. The 2C and 4C tasks will have actually come due in the preceding C16 check *(see table, this page)*. The D5 check will also have fewer heavy OOP tasks than the D4 check. The routine labour requirement will therefore be smaller than a D4 check. The preceding C16 check will have been a large workscope.

The second is the ageing programmes. This may use less labour than in the D4 check, because the main inspections have already been performed.

The third is that airlines may be able to economise on the interior refurbishment, depending on how long the aircraft will be operated for after going through the D5 check.

The labour used on the D5 check will be similar to the D4 check. The C16 check will use about 8,000MH more than the C13 check, however.

Consideration has to be given to the labour used by freighter-configured aircraft. A few MPD items will not have to be included for freighters. A smaller number of MH will be used for some of the heavy tasks in D checks because less interior equipment and fewer furnishings will have to be removed and reinstalled.

The biggest saving freighters will have is having a small need for interior refurbishment. There will be some interior equipment, but freighters will save several hundred MH per C check and up to about 11,000MH per D check.

Peretz warns, however, that these savings are usually offset by freighters having higher non-routine ratios. This will be not only for MPD routine inspections, but also for damage to the interior and cargo loading system during operation, and relating to the inspections made in ADs and SBs. As Hoogendoorn explains, a lot of non-routine defects are found in the delamination of skins and metal panels. The level of damage is likely to be higher in freighter aircraft.

Materials & parts

An allowance of materials and consumables used during the checks for the routine inspections, non-routine defects, and ADs and SBs should be made. Lighter C checks will use $120,000-150,000, and this will climb up to about $200,000. Heavier C checks will use $200,000-330,000 as the aircraft progresses through its base check cycles.

Allowances for D checks start at $800,000-900,000, and increase up to $1.1 million for the D4 and D5 checks.

The cost of all materials, rotables, consumables, interior refurbishment components, and new paint totals about $1.7 million for the first base check cycle. It is highest in the second base check cycle at $2.6 million because of the engine pylon modification, but continues to climb to $2 million for the fourth base check cycle *(see table, this page)*.

Summary

The 747-400 has a complex maintenance programme. There are a large number of OOP tasks, including mainly groups of calendar tasks with long intervals. The aircraft is also affected by several ageing programmes and major ADs. These all combine to escalate the 747-400's maintenance requirements over successive base check cycles.

The increase in labour to perform heavy base checks has been partially offset by escalations to the aircraft's C and D check intervals. The 747-400's maintenance requirements have nevertheless risen with age. AC