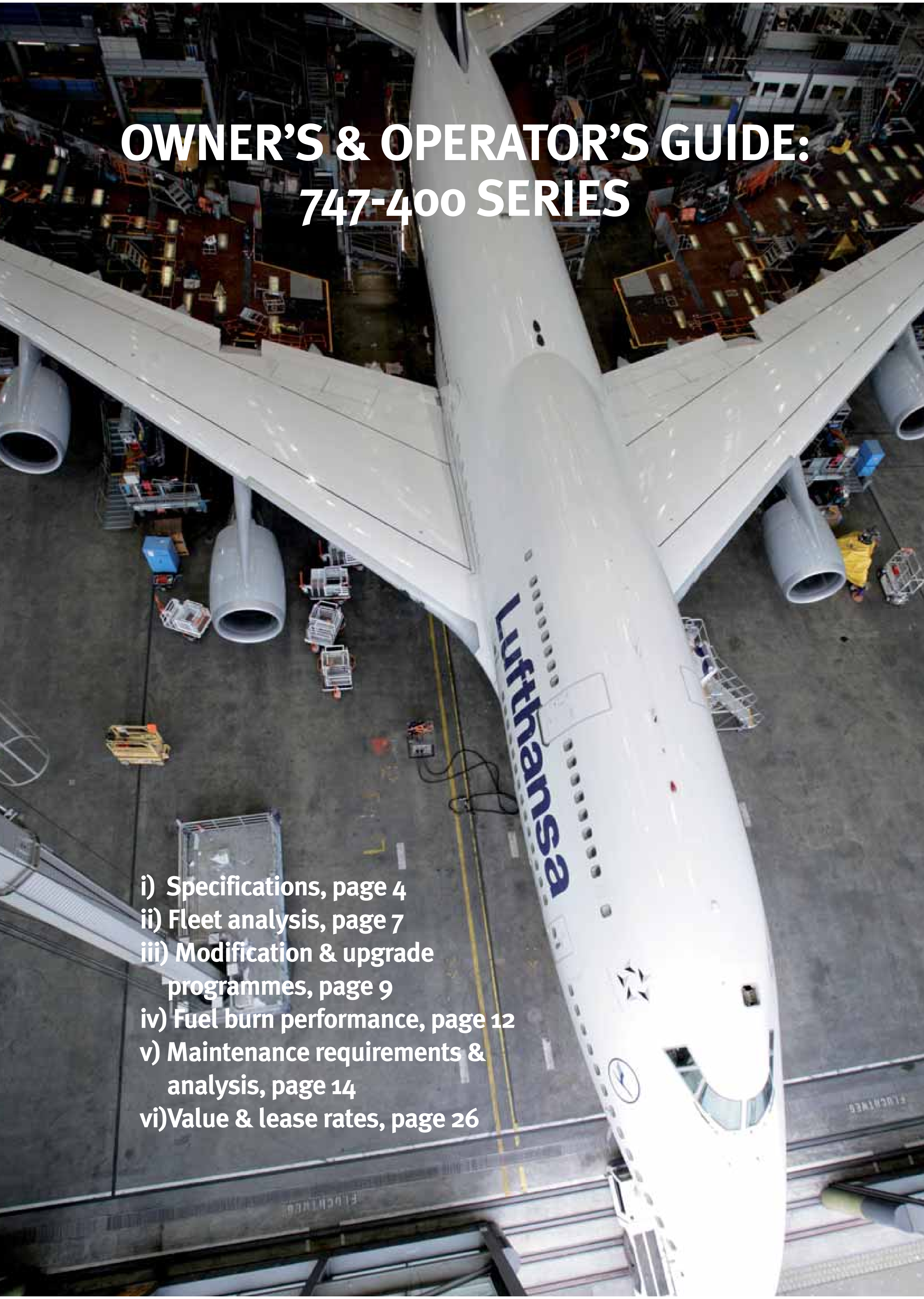
# OWNER'S & OPERATOR'S GUIDE: 747-400 SERIES



# 747-400 series specifications

## The 747-400 series is divided into four main groups of passenger, domestic passenger, combi and freighter aircraft.

The 747-400 was originally proposed as a longer-range, two-flightcrew and advanced version of the 747-300, with 1,000nm more range up to 7,260nm, along with lower fuel burn and operating costs. The 747-400's main features include the same fuselage dimensions as the -300 series, an increased maximum take-off weight (MTOW), a six-foot wingspan extension and a six-foot-high winglet on each wing. The -400 also features a horizontal stabiliser fuel tank, new carbon brakes, a new auxiliary power unit (APU), and various aerodynamic improvements over the earlier models.

Importantly, the -400 introduced a new two-man digital electronic flight instrument system (EFIS) flightdeck, as well as some new materials.

It should also be noted that the Section 41 decompression issue on the earlier 'classics' was resolved on the -400 by strengthening the upper-deck floor structure.

Structural carbon brakes are standard on the 747-400's 16 main landing gear wheels. They provide improved energy absorption characteristics and wear resistance, as well as an estimated weight saving of 1,800lbs over steel brakes. The 747-400 achieved additional weight savings by using higher strength aluminium alloys with improved fatigue life.

### Powerplant options

There are three engine options for the 747-400: the CF6-80C2B1F rated at 56,700lbs thrust; the PW4056 rated at 56,000lbs thrust; and the RB211-524G/H and -524G/H-T rated at 58,000lbs and 60,600lbs thrust respectively.

The CF6-80C2 and PW4056 had new nacelles and pylons that were common with the 767, while the RB211-524 required a modified pylon and nacelle. The two US engines have full authority digital electronic control (FADEC). The CF6-80C2B5F rated at 62,600lbs thrust is also certified as an option, but only powers the -400ER and the -400ERF variants.

Regarding the RB211 engines, Rolls-Royce also offers a 'hybrid' version of its powerplant, designated the RB211-524G-T or -524H-T. The modified engine is designed to eliminate the performance and reliability shortfalls that some operators experienced with the standard -524H. The -T upgrade integrates the high-pressure core '04 Module' of the Trent 700 with an otherwise standard -524G or -524H. This delivers a 2.5% reduction in fuel consumption. A number of aircraft have been retrofitted.

According to Ascend, a division of Airclaims, the 747-400 is equipped with a Pratt & Whitney Canada PW901A APU as standard, which is located in the tailcone. This new unit for the Series 400 has 40% lower fuel burn compared to the previous unit.

### Cockpit design

A two-man flightdeck featuring six EFIS screens is standard on the 747-400. In front of each pilot are two duplicated eight-inch-square cathode ray tubes (CRTs). These screens replace all electromechanical gauges of earlier generation 747s. Most importantly, they reduce the number of flightcrew from three to two. This system also has higher reliability.

The flightdeck also features a central maintenance computer (CMC), which is effectively a form of built-in test equipment (BITE) that records any faults with systems and major components for display to mechanics on the ground, or for response from the crew.

The Honeywell/Sperry flight management system (FMS) features autothrottle management, new radio-tuning and a worldwide navigation database.

The aircraft also features two observer seats and two rest bunks, since it will often be used on missions where one or two supernumerary crew are required.

### 747-400

The -400 features the highest specification weights of all 747 variants. The standard MTOW started at 870,000lbs. In late 1993 Boeing introduced a number of improvements, which included an MTOW increase to 875,000lbs. A retrofit kit is also available, Qantas became the first 747-400 operator to move up to the new weight in early 1994. Lower weights are available and British Airways has taken delivery of some 747-400 'Lites' which are certified at 840,000lbs, and do not

*About two-thirds of the 747-400s built are passenger- and combi-configured aircraft. The aircraft is also popular as a freighter.*

feature the crew rest facilities that are standard on other -400s. These aircraft are therefore restricted to a maximum flight time of 11 hours.

The aircraft's maximum landing weight (MLW) options are 574,000lbs, 585,000lb and 630,000lbs. The maximum zero fuel weight (MZFW) options are 535,000lbs, 540,000lbs and 565,000lbs. Typical operating empty weights (OEW) range from 380,000lbs to 407,107lbs.

The total usable fuel capacity, with horizontal stabiliser tank, is up to 57,065 US gallons (USG) compared with 48,070-52,410 USG for the 747-300. The -400 has six wing fuel tanks and a new 3,300 USG fuel tank in the horizontal stabiliser. This tail fuel is required for MTOWs in excess of 850,000lb and provides about 350nm extra range.

The 747-400's standard tri-class seating configuration is 412 passengers, with 34 first class, 62 business class, and 316 economy seats. This configuration will have 10 galleys and 14 vacuum toilets.

A high-density, two-class seating arrangement can accommodate 509 passengers. This is with 30 first and 479 economy class seats. Actual seating configurations and numbers vary between operators.

An optional feature on the aircraft is a rest area for the cabin crew, incorporating four bunks and four seats, which is situated in the upper rear fuselage above the rear passenger door.

The -400's total belly freight capacity is 6,025 cubic feet with 30 LD-1 containers. This reduces to 5,332 cubic feet with five pallets, 14 LD-1 containers and one 'bulk' pallet.

## 747-400 Combi

The 747-400 Combi has a 120-inch by 134-inch main deck cargo door on the port, rear side of the fuselage. The rear zones of the aircraft have a strengthened floor with a cargo handling system.

Typical three-class layouts include: 290 passengers plus six pallets; 266 passengers with seven pallets; or 220 passengers and twelve pallets.

The -400 Combi's maximum range is 7,214nm, while its maximum cargo capacity is 10,422 cubic feet, assuming that seven maindeck pallets, 14 LD-1 belly containers and five lower-hold pallets are used. Fuel capacity is the same as the 747-400.

## 747-400F

The 747-400F freighter is structurally identical to the all-passenger aircraft, and uses the same 120-inch by 134-inch side cargo door and 136-inch by 98-inch nose door as the -200F. The -400 also shares the same two-man flightdeck, wing extensions, winglets and increased capacity of the -400.

The -400F's total cargo volume is 27,467 cubic feet. It retains the shorter upper-deck of the earlier 747-200F, and benefits from the -400's MTOW of 875,000lbs and higher MZFW of 610,000lbs. This higher MZFW therefore increases the -400F's payload by up to 44,000lbs, to a maximum structural limit of 248,300lbs over a range of 4,445nm.

The -400F's freight capacity has a maximum usable volume on the maindeck of 21,347 cubic feet, with 30 pallets measuring 96 inches by 125 inches. The usable volume on the lower deck is 5,600 cubic feet using 32 LD-1 containers, while the volume of the additional bulk cargo is 520 cubic feet. The total cargo volume of the -400F is therefore 27,467 cubic feet.

Compared with the 747-200SF, the maindeck floor was revised on the -400F to make room for two additional 10-feet-high pallets on the main deck. This was done by reducing the number of positions available for 8-feet-high pallets. Boeing also created an additional pallet position in the nose area. These changes added 774 cubic feet more cargo space to the -400F's maindeck than on the 747-200F. Moreover, two additional LD-1 or LD-3 containers also fit into the aft lower hold, and, depending on the pallet and container mix, two additional containers can fit into the forward lower hold, thereby adding up to 700 cubic feet of additional containerised cargo volume in the lower hold.

The 248,300lbs of structural payload revenue capacity published by Boeing is a function of the following specifications: an MZFW of 610,000lbs; an OEW of 349,690lbs with no pallets or containers; and a total pallet and container tare weight of 12,010lbs for both decks. The payload capacity also assumes that a large number of pallets rather than unit load device (ULD) containers are loaded on the maindeck. If 125-inch by 96-inch ULD containers are loaded on the maindeck instead (such as the M1 and M1H ULDs, each of which have a tare weight considerably greater than a 125-inch by 96-inch footprint pallet), then the total structural revenue payload will decrease accordingly.

For example, one 125-inch by 96-inch pallet has a tare weight of 265lbs. This compares to one 125-inch by 96-inch contoured M1H ULD that uses the same floor area, but weighs 816lbs. Furthermore, if an operator loads a 747-400F with the nominal 30 LD-9 pallets on the maindeck, the total corresponding tare weight for the maindeck will be only 7,950lbs. If 23 118-inch high contoured M1H ULDs and seven 96-inch high M1 ULDs (contoured in the nose section) are used, then the total tare weight on the maindeck will be about 24,000lbs. This represents a tare weight difference of about 16,000lbs on the maindeck, with a proportionate reduction in payload capacity.

### 747-400 FAMILY SPECIFICATIONS

| Variant | 747-400 | 747-400ER |
|---|---|---|
| MTOW lbs | 800,000/875,000 | 910,000 |
| MZFW lbs | 535,000/542,500 | 555,000 |
| OEW lbs (no tare) | 394,088 | 406,900 |
| Gross structural payload lbs | 140,912/148,412 | 148,100 |
| Fuel capacity USG | 53,765/57,065 | 63,240 |
| Seats (3 class) | 400 | 400 |
| Range nm | 7,260 | 7,670 |
| Belly freight cu ft | 6,025 | 5,599 |

| Variant | 747-400F | 747-400ERF |
|---|---|---|
| MTOW lbs | 800,000/875,000 | 910,000 |
| MZFW lbs | 610,000/635,000 | 611,000 |
| OEW lbs (no tare) | 349,690 | 350,390 |
| Gross structural payload lbs (incl tare) | 260,130/285,310 | 260,610 |
| Fuel capacity USG | 53,765/57,065 | 53,765 |
| Maindeck freight | | |
| Container volume cu ft | 21,347 | 21,347 |
| Belly freight | | |
| Container volume cu ft | 6,120 | 6,120 |
| Total volume cu ft | 27,467 | 27,467 |
| Volumetric payload lbs @ 7lbs/cu ft | 192,269 | 192,269 |


*A large number of 747-400Fs have been built, but Boeing has taken the last orders for these. Passenger-to-freighter modifications are now available from Boeing and IAI-Bedek.*

The generic OEWs quoted in marketing brochures, which incorporate bare minimum tare weights of the lightest pallets, do not represent a likely payload capacity for operators. A more useful starting point is the basic operating weight (BOW). The BOW is the OEW without any pallets or containers. In the case of the 747-400F, the BOW would therefore be 349,690lbs. Moreover, the MZFW minus the BOW is the gross structural payload capacity available to the operator, from which the tare weight of the pallets and containers it uses should be deducted. The operator can then 'mix-and-match' their own pallet and ULD combinations.

Besides the factory-built -400F, there are two passenger-to-freighter modifications for the 747-400. These are offered by Boeing and IAI-Bedek Aviation. Details of the payload specifications of the aircraft are given *(See 747-400 modification programmes, page 9)*.

## 747-400ER

The 747-400ER is an increased gross weight derivative of the 747-400 that allows it to carry additional fuel for longer ranges. This variant can be equipped with up to two 3,060 USG fuel tanks in the forward lower cargo compartment, and has a higher take-off weight of 910,000lbs, which is an increase of 35,000lbs over existing 747-400s. This gives the aircraft a range of 7,670nm, an increase of 410nm over the -400. The -400ER has the same MZFW as the -400.

It should be taken into consideration that a maximum belly cargo capacity of 5,599 cubic feet is possible with 28 LD-1 containers and bulk freight. According to Boeing's specifications, this capacity falls to 5,332 cubic feet with four pallets, 14 LD-1 containers and bulk freight. These volumes are smaller than for the 747-400, due to the presence of the auxiliary fuel tank in the forward lower cargo hold. The total maximum usable fuel capacity with these two auxiliary fuel tanks is 63,240 USG. With just one auxiliary tank the capacity reduces to 60,495 USG.

The -400ER also features some aerodynamic changes and a strengthened landing gear. Boeing also fitted the -400ER with a 777-style cabin.

## 747-400ERF

The 747-400ERF has many of the -400F's features, and an increased MTOW capability, which allows it to trade range for payload. The -400ERF has a 57,065 USG usable fuel capacity with the tail tank, since it is not fitted with the -400ER's auxiliary fuel tanks.

The 910,000lbs take-off weight allows the -400ERF to fly 525nm more than the -400F, or to carry an additional 22,000lbs payload on long-range flights. As the -400ERF's MZFW is only 1,000lbs greater than the -400F's, the -400ERF's maximum structural payload is 248,600lbs, which is almost the same as the -400F's. This payload is the difference between the MZFW and the OEW. This OEW includes tare container weight of about 12,000lbs, which is based on lighter pallets, rather than heavier ULDs. The -400ERF's BOW is 350,390lbs, making it only 700lbs greater than the 747-400F.

Looking at the original equipment manufacturer's (OEM's) payload-range curve, at one extreme, the -400ERF's range can be increased by 530nm to 4,970nm for the same amount of payload. At the other end, and within the maximum structural payload limitations, an additional 22,000lbs of payload can be carried on longer-range flights of between 4,970nm and 6,300nm when operating at MTOW.

The -400ERF's cargo capacity is the same as the -400F's. The maximum usable volume on the maindeck is 21,347 cubic feet, with 30 pallets. The lower deck usable volume is 5,600 cubic feet using 32 LD-1 containers. The total cargo volume is 27,467 cubic feet.

## 747-400D

The -400D has MTOWs of 600,000lbs and 609,700lbs. According to Ascend, a division of Airclaims, structural provision for an MTOW of 870,000lbs for long ranges is incorporated in all -400Ds. The -400D's other features include strengthening of the aircraft's structure to help cope with its high cycle operations, and the use of de-rated engines. The horizontal tail fuel tank is not activated and usable fuel capacity is reduced to 53,765 USG. The aircraft has a maximum design range of 2,500-3,000nm. The specification high-density configuration is 566 passengers, although JAL has adopted a 568-seat layout. The maximum payload is 246,000lbs, and the total cargo volume is 24,815 cubic feet, which comprises a lower deck volume of 6,095 cu ft, plus a maindeck volume of 18,720 cu ft.

The -400D can be converted to the regular -400 variant for long-range operations, which is a process that takes about four weeks. This includes the activation of the horizontal tail fuel tank, the installation of a wingtip extension and winglets, changes to wheels and tyres, the re-rating of the aircraft's engines and a paper recertification of the aircraft to an MTOW of 870,000lbs. AC

# 747-400 fleet analysis

## The 747-400 fleet is sub-divided between passenger, combi and freighter aircraft; and three engines types.

Of the 656 747-400 family members delivered, all but a handful are in active service. Most of these aircraft are with the original tier-one operators and major cargo carriers. Out of the active fleet of 642, 305 aircraft are powered by the CF6-80C2, 216 by the Pratt & Whitney (PW) PW4000-94, and 121 by the Rolls-Royce RB211-524H/-524H-T engines.

The 747-400 family includes six basic production versions: the 747-400 passenger-configured model; the 747-400D designed for high-frequency domestic operations; the 747-400M 'Combi'; the 747-400F freighter; the 747-400ER extended range passenger model; and the 747-400ERF extended range freighter model.

The 747-400 programme was launched on 22 October 1985, and the first aircraft, line number 696, powered with PW4056 engines, went into service with Northwest in February 1989.

### 747-400 passenger version

The basic 747-400 passenger version (excluding the 'Combi' variant), accounts for 413 active aircraft, equivalent to 65% of the 747-400 family fleet in operation. Maximum take-off weights (MTOWs) vary from 800,000lbs to 875,000lbs. Within the baseline -400 passenger aircraft fleet, there is greater powerplant standardisation and less physical variation than with its predecessor, the -200. The engines powering the 747-400 are fairly standard, with only minor respective variations from the three engine manufacturers. These engines are the GE CF6-80C2B1F, PW4056, and RB211-524G/H. The PW4000 powers 154 passenger-configured 747-400s, with 156 equipped with the CF6-80C2B1F, and 103 powered by the RB11-524.

The majority, about 290, of 747-400 passenger models are owned by their operators. The remainder are on operating leases and finance leases.

The last fleet data shows an average annual utilisation of 4,135 flight hours (FH), and 562 flight cycles (FC). This gives an average FC time of 7.4FH. The fleet leaders are a Lufthansa aircraft, with a total time of 89,912FH, and an All Nippon Airways aircraft with 19,470FC. The fleet averages are 51,529FH and 7,385FC.

As an example of aircraft age and accumulated utilisation, British Airways (BA), an original customer for RB211-powered aircraft, has a fleet of 57 747-400s with cumulative utilisation of 32,250-76,921FH and 3,663-10,588FC. These aircraft were delivered between 1989 and 1999, so BA is unlikely to start replacing its oldest 747-400s for another five to 10 years, by which time it may have ordered a successor such as the A380 or the 747-8.

There has been very little movement of 747-400s between operators, with most of the fleet still flying with their original operators and owners. The 747-400 is used for high capacity routes, and it is hard for many operators to fill. Airlines have therefore made a long-term investment in the aircraft, and amortised them over a large number of years.

Four airlines, Canadian Airlines, Malaysia, Singapore Airlines (SIA), and United, have all sold a significant proportion of their fleets for different reasons.

Canadian and United sold aircraft as part of their financial restructuring, and because of declines in passenger numbers and yields on routes to and from the North American continent following 9/11.

SIA's strategy has been to keep its fleet as young as possible, so it usually sells aircraft before they reach 10 years of age. Of the 59 aircraft delivered to SIA, 22 are now operated by other carriers. SIA has a large fleet of A380s on order, which will replace some of its 747-400s in operation.

Of the aircraft sold by SIA, at least five have since been acquired for freighter conversion, via the Boeing Converted Freighter (BCF) programme, and are in operation with Martinair Holland, Cathay Pacific, Air Atlanta Icelandic and Dragonair.

Meanwhile, Asiana, Japan Airlines and Korean Air have all taken aircraft from their own passenger fleets and then converted them for use as freighters. This suggests that many 747-400s could be converted to freighters and operated in the Asia-Pacific region.

There are 413 -400s in service. Another 11 aircraft are stored, one with GE engines and eight with PW engines *(see table, this page)*.

### 747-400 combi

There are 58 747-400M Combis in operation, which are identical to the -400 variant except for a 120-inch X 134-inch maindeck cargo door on the port side of the fuselage. The two rear zones of the aircraft have a strengthened floor with a cargo handling system. In addition to the aircraft delivered, another two 747-400 passenger aircraft operated by EVA Air have been converted to Combi configuration. A total of 61 Combis were delivered, 57 of which are still in service. Three Combis have been converted by IAI-Bedek Aviation. The majority of Combis are powered by CF6-80C2s, and KLM is the largest 747-400 Combi operator with 17. Other large customers of the type include Air France, Air China,

**747-400 FLEET SUMMARY**

| | PW4000 | CF6-80C2 | RB211-524 | Total |
|---|---|---|---|---|
| 747-400/-400D | 154 | 156 | 103 | 413 |
| 747-400D | 0 | 18 | 0 | 18 |
| 747-400ER | 0 | 6 | 0 | 6 |
| 747-400M | 10 | 47 | 0 | 57 |
| 747-400F | 33 | 60 | 15 | 108 |
| 747-400ERF | 8 | 14 | 0 | 22 |
| 747-400BCF | 8 | 3 | 3 | 14 |
| 747-400BDSF | 3 | 1 | | 4 |
| **Total** | **216** | **305** | **121** | **642** |

*Almost half the 642 747-400s in operation are powered by CF6-80C2B1F engines. One-third of the fleet is equipped with PW4056s, and 121 have RB211-524 engines.*

Asiana, Eva Air and Lufthansa.

Average annual utilisation of the 747-400 Combi is 4,366FH and 629FC, which gives an FC time of 6.9FH. The fleet leaders are a KLM aircraft with 87,977FH and a Korean Air aircraft with 12,487FC. The fleet averages are 61,511FH and 9,045FC.

## 747-400F

The next largest group comprises factory-built 747-400Fs, with 107 in operation. These are split between 60 CF6-powered aircraft, 33 PW4000-powered aircraft, and 15 RR-powered aircraft *(see table, page 7)*. Lead customers include China Airlines (20), Cargolux (15), SIA Cargo (14), Atlas Air (11), and Korean Air (10). A further 17 -400Fs are on order.

Air France was the launch customer for five aircraft. The first -400F went into service with Cargolux in November 1993.

Production ends in 2009, when the -400F will be replaced by the 747-8F. Nevertheless, the -400F will remain in service for at least another 20 years.

## 747-400D

The -400D is a special short-range domestic version developed for All Nippon Airways (10) and JAL (8). All the -400Ds are owned outright by their respective operators and all are powered by CF6-80C2s *(see table, page 7)*.

As with the earlier 747-100SR version, JAL and All Nippon Airways were the only customers. The first was delivered to JAL in October 1991.

The 747-400D does not have the wingtip extensions and winglets of the -400. These features were deemed unnecessary for the short sectors the aircraft was designed to operate.

In line with its short-range operational flight profile, the variant exhibits a low average FC time of 1.45FH. Aircraft therefore generate a high number of cycles, with the fleet leader having accumulated 26,500FC. ANA's lead aircraft has accumulated 43,021FH.

## 747-400ER

As orders for the baseline -400 and -400F tailed off in the late 1990s, Boeing decided to introduce upgraded versions: the -400ER and -400ERF, with MTOW increased from 875,000lbs to 910,000lbs. This resulted in a wave of orders. Six -400ERs are in operation with Qantas *(see table, page 7)*.

The 416-seat 747-400ER has a 435nm longer range of 7,435nm. The average annual utilisation is 4,964FH and 417FC, giving the aircraft an average FC time of 11.9FH. The fleet leader has accumulated 18,692FH and 1,692FC. Fleet averages are 17,478FH and 1,524FC.

The -400ER uses the stronger wing of the earlier 747-400F and has a 6,360USG higher fuel capacity provided by removable auxiliary tanks in the forward cargo hold. The aircraft is powered by engines rated at 61,000-62,000lbs thrust. The 61,100lbs thrust CF6-80-C2B5F was selected by Qantas. The PW4062 and RB211-524H-T are also available, although neither has been selected.

## 747-400ERF

The 747-400ERF was launched by International Lease Finance Corporation (ILFC) for five aircraft. A total of 40 747-400ERFs have been ordered, making it more popular than the -400ER. There is an order backlog of 18 aircraft, and 22 are in service with Air France (6), China Cargo Airlines (1), Jade Cargo (3), KLM (3), Korean Air (8), and TNT Airways (1). Eight of the 22 are powered by the PW4000 and 14 by the CF6-80C2 *(see table, page 7)*.

Average annual utilisation is 4,074FH and 558FC, giving the aircraft an average FC time of 7.3FH. The fleet leaders are an Air France aircraft with 21,259FH, and a Korean Air aircraft with 2,823FC. The fleet averages are 10,946FH and 1,408FC.

## Freighter conversions

At the time of writing, 18 747-400 passenger and Combi aircraft have been converted to freighters, 14 with Boeing's BCF programme, and another four under the Bedek Special Freighter (BDSF) programme.

There are 14 -BCFs in service with Cathay Pacific (5), Korean Air (2), Japan Airlines (3), Martinair (2) and Dragonair.

There are 33 outstanding orders for the -400BCF from Cathay Pacific (3), Korean Air (6), JAL (5), Guggenheim (4), SIA (6), Air France (3), Air Atlanta Icelandic (4) and UPS (2).

During 2006 IAI Bedek undertook its first two -400BDSF conversions, on a Combi aircraft and a passenger aircraft. There are four aircraft modified by Bedek Aviation. Two, owned by Guggenheim Aviation partners, are now flying for Air China. Another, owned by Rabobank, is flying with Air Atlanta Icelandic (for Cargolux). One more aircraft has been converted for Asiana, and will be followed by a fifth that will go to Eva Air. Other aircraft are currently being converted. IAI operates three conversion slots, and is in the process of adding two more slots in Israel, plus another two overseas.

Five 747-400Ms in Asiana's fleet are earmarked for conversion by IAI. One is a parked aircraft and the other four are active. AC

# 747-400 modification programmes

**The modification programmes for the 747-400 series fall into the categories of freighter modifications, engine upgrades, weight upgrades and avionic installations and improvements.**

Modifications and upgrades for the 747-400 family fall into different groups. The first comprises service bulletins (SBs) and airworthiness directives (ADs), all of which are listed on the Federal Aviation Administration's (FAA's) website, together with their compliance date. Other groups include passenger-to-freighter conversions, and avionics upgrades, such as electronic flight bags (EFBs) and FMS memory enhancements.

All aircraft types have been affected by, and have had to comply with, a variety of avionics upgrades, including: traffic avoidance collision system (TCAS); enhanced ground proximity warning system (EGPWS) and terrain awareness warning system (TAWS); reduced vertical separation minima (RVSM); 8.33kHz VHF communication frequency spacing for Europe; Mode-S transponders; FANS-1; basic area navigation (B-RNAV) in Europe; and precision area navigation (P-RNAV).

Many 747-400 operators plan to carry out major upgrades to the interiors and in-flight entertainment (IFE) systems on board their aircraft. These will generally be highly customised projects configured on a case-by-case basis.

## Freighter conversions

The 747-400F and -400ERF are popular among blue-chip operators. The 747-400 production line will close in 2009, so older passenger and Combi aircraft are increasingly attractive for conversion into freighter configuration.

There are two major programmes under way: the original equipment manufacturer's (OEM's) Boeing Converted Freighter (-BCF); and IAI-Bedek's Bedek Special Freighter (BDSF) conversion. The specification for both Boeing- and IAI-converted aircraft is similar. Both have a fuel capacity of 53,765 US gallons (USG), and total cargo volumes of 24,962 cubic feet with 30 pallets on the maindeck. They also have gross structural payload limits that are within 1,000lbs of each other.

Launched in January 2005, Boeing's own 747-400BCF programme is aimed as a replacement for the 747-200F, with the advantage of more fuel-efficient engines and a two-man flightdeck. The conversion adds a side cargo door, and modifies the layout so that it is almost identical in freight volume to the 747-400F. The converted aircraft also have 1,000nm longer range than the 747-200F. Unlike the -400F, converted aircraft retain the stretched upper passenger deck, albeit with internal modifications, and do not have the -400F's upward-hinging nose door.

Other changes include removing part of the upper-deck floor to accommodate full-height containers, and installing a fully powered cargo handling system.

The first 747-400BCF (ex-South African Airways) was completed in December 2005 and delivered to Cathay Pacific. TAECO in China performs the conversions of the Boeing modification, and Boeing also sells kits to airlines (and third parties) that wish to perform the conversion themselves.

The Boeing conversion allows a maximum take-off weight (MTOW) of 870,000lbs, and a payload including container tare weight of approximately 251,000lbs. This is derived from a maximum zero fuel weight (MZFW) of 610,000lbs minus a basic operating empty weight (OEW) of 359,000lbs. The aircraft has a maximum design range of about 4,076nm.

At the time of writing there are 14 -BCFs in service with Cathay Pacific (4), Japan Airlines (3), Korean Air Cargo (2), SIA (with two that are operated by Dragonair), and Guggenheim (with two leased to Martinair and a third leased to Great Wall). Outstanding orders for the Boeing conversion comprise 35 firm orders and 19 options.

The IAI-Bedek -400BDSF modification programme is the second option. IAI-Bedek received supplemental type certificates (STCs) for both the 747-400 and 747-400 Combi modifications in


*The first Boeing-converted 747-400s have been delivered to end-users. While factory-built freighters can no longer be ordered, market values of passenger aircraft are too high to make conversion economic.*


*The -T upgrade for the RB211-524 incorporates the high pressure module from the Trent 700 primarily to improve reliability. There is an added bonus of a small reduction in fuel burn.*

2006. In 2003, the company teamed with Eolia Ltd to create a joint venture company based in Cyprus, called PSF Conversions LLP, which owns the STCs. PSF Conversions allocates conversion slots to customers, and says it will carry out seven simultaneous conversions in Israel and abroad. Customers include Guggenheim, Rabobank, GECAS, Atlas Air, Eva Air and Asiana.

The converted aircraft carries 30 positions in the main deck, and part of the upper-deck floor is modified to enable more 10-feet-high unit load device (ULD) positions.

According to IAI, the modified aircraft's specification weights are an MTOW of 870,000 lbs, an MZFW of 610,000lbs to 635,000 lbs, and a maximum landing weight (MLW) of 652,000lbs. Total containerised volume is 20,820 cubic feet.

The maximum load of all cargo including container tare weight is 251,400lbs. This is calculated from an MZFW of 610,000lbs less the basic OEW of 358,600lbs.

A basic price for the -BDSF conversion of a passenger aircraft is $20 million, and the basic price for a Combi aircraft is $15.5 million. These prices exclude the Ancra-supplied cargo loading system, or any of the weight upgrades or maintenance.

## RB211-524-G/H core upgrade

Investors should consider the engine model when evaluating candidate aircraft for conversion to freighter. The factors to consider are: engine weight; fuel consumption; engine maintenance costs; aircraft market and purchase value; and the popularity of the engine type. In terms of weight, a 747-400 equipped with RB211-524s will have an OEW of 3,000lbs more than a similar aircraft powered by CF6-80C2s. While this may seem a weak point, it only penalises RB211-powered aircraft if they are loaded with their maximum structural payload. This only occurs if all the available cargo volume is filled at the maximum possible cargo loading density. This is an unlikely scenario, however.

If these aircraft are loaded at their maximum volumetric payload, packed at a typical density of 7lbs or 8lbs per cubic foot, the 3,000lbs higher OEW will not affect the payload carried. In terms of weight, the PW4056 sits between the RB211 and CF6-80C2.

It should be noted that RB211s are slightly more fuel efficient than CF6-80C2s and PW4056s. This superior fuel efficiency can, for some mission profiles, offset the engines' higher weight. The PW4056 powers most of the cargo-converted 747-400s to date, which are the ex-Korean and ex-SIA aircraft. As for Cathay Pacific, its entire 747 fleet has historically been powered by RB211s, so it is likely to prefer RB211-powered aircraft to maintain commonality across its 747 fleet.

In the 1990s Rolls-Royce introduced significant turbomachinery variation by offering a mid-life retrofit for the RB211-524G (58,000lb thrust) and RB211-524H (60,600lb thrust) with the core '04 module', the complete high-pressure section, from the Trent 700. This reduced fuel consumption and increased exhaust gas temperature (EGT) margin. The resulting model with the retrofit was designated with a '-T' suffix. Subsequent new-build RB211s, such as those ordered by Cargolux for its new 747-400Fs, had the modification already incorporated.

## Interiors

According to Craig Larson, Boeing's director of marketing services, interiors are where most of the activity is on the 747-400. "The predominant focus of our interior work is certifying the installation of new seats and integrating new IFE equipment. The latter usually requires an upgrade to the IFE cooling system to provide higher capacity airflows. The other issue is that lie-flat seats are heavier, with more actuators, than earlier premium seats, so we often have to make enhancements to the floor structure to accommodate the heavier weights."

"Installing new seats can require installation of additional decompression vents, so as not to overload the floor structure," adds Larson.

## MTOW upgrades

While there is a maximum structural weight which the aircraft was built to take, airlines will often order the aircraft at a lower MTOW to reduce landing fees. As the airline's mission requirements change, or the aircraft is sold to a new operator, Boeing will often certify changes to the MTOW and/or MLW, to accommodate the new customer's route structure. This does not result in a physical change to the aircraft. The only exception is on the 747-400D, which is built for short-range operations in Japan. This requires different tyres and brakes to be fitted.

"These may have to be updated, depending on what weights the aircraft goes to," says Larson. "Besides this, structural weight aspects are generally paper changes to meet airline requirements, and go up to 870,000lbs if they have the tail fuel tank activated. The aircraft is either delivered with provision for tail fuel, or it has tail fuel activated."

## Class-3 electronic flight bag

A major change to the flightdeck is the Boeing Class-3 EFB, which is integrated into the avionics on the flightdeck. "The side console is modified and the display unit is installed in the sidewall, while electronics units are


*Boeing is planning to offer a retrofit of the 747-8's flight management computer into the -400 series.*

installed in the electronics bay to integrate with various systems such as the flight management computer (FMC), flightdeck printer, aircraft communication and reporting system (ACARS), and the flightdeck entry video surveillance equipment," says Larson.

The purchase price of the EFB itself is about $200,000. This covers a kit of parts including the two display units, two electronics units, the sidewall console, wiring, fibre optics, and the installation instructions. The price does not include labour to retrofit the unit.

## Flight management computer

Boeing is defining an FMC memory increase. "We are a couple of years out on that, but as the air traffic control (ATC) system has evolved, operators need to be able to load more routes and waypoints into the FMC," says Larson. "Our current plan is to use the upgraded FMC, which we have designed for the 747-8, and retrofit it onto the 747-400. This should be a 'plug and play', such that we only need to remove one box and replace it with a new one. The wiring will therefore not have to be changed. We would issue an SB for the installation, and the customer would buy the FMC directly from the supplier."

## 747-400 EGPWS/RAAS

Honeywell offers an improved EGPWS, which can include a runway awareness and advisory system (RAAS). This system facilitates aural warnings on the ground and in the air during the final approach phase. The system has been installed by Lufthansa Technik (LHT) on Lufthansa's 747-400s since 2005. Following a successful trial phase, it is now permanently activated. LHT say that installation only requires three man hours (MH), and is carried out primarily via a simple software upload for the 747-400.

## Mode-S transponder

SB 747-34-2815 requires that to fulfil the European ATC requirements, Mode-S 'enhanced surveillance' functionality should be implemented with effect from 31 March 2007 for Instrument Flight Rules (IFR) flights as general air traffic (GAT).

The modification enables the transmission to the ground of elementary surveillance (ELS) parameters. These comprise the Mode-S address, flight number, altitude report, flight/ground status, transponder capacity, RA report, Surveillance Identifier (SI) code. The modification also enables the transmission of enhanced surveillance (EHS) parameters: magnetic heading, indicated airspeed, vertical speed, roll angle, track angle rate, ground speed, and selected altitude. About 140 MH are required for the modification.

## Trim air diffuser

In trim air diffuser ducts (TADDs) hot bleed air is mixed with the conditioned air from the packs. On the 747-400, the TADDs are located between the wing centre section and the main deck floor. Several operators have reported heat damage to the TADDs. This can lead to a disconnection of the TADDs from the titanium trim air ducts, which results in the release of hot air onto the surrounding structure, an inability to control the cabin temperature, and hot floor and sidewalls.

According to LHT, an AD (AD2007-07-03, dated 28 March 2007) has been issued to prevent fuel or vapours leaking into areas where ignition sources may be present. The AD mandates repetitive inspections every 1,200FH for hot air leaking from the TADDs, and a general visual inspection for damage to, or discrepancies with, the TADDs every 12,000FH. Assuming a daily utilisation of 15FH, the first inspection must be completed by 20 July 2007. If any leaks are found during the inspection, a general visual inspection must be performed before further operations.

The hot air leak inspection uses 13MH, and aircraft downtime is about seven hours. The general visual inspection uses about 90 MH, and overall downtime is 32 hours, according to LHT.

## Hydraulic heat exchanger

SB 747-29A2104 R/I 02 and AD 2004-10-06 specify the elimination of arcing or sparking between the hydraulic heat exchanger penetration fittings and the rear spars, due to inadequate electrical bonding at the interface between the fitting and the spar during a lightning strike event. Therefore, to eliminate the potential for arcing or sparking, the application of an alodine protective coating (according to the SB) is required. According to LHT 36MH are required to carry out this modification, and work should be completed during a heavy maintenance visit, prior to 21 June 2009.

## Nose landing gear

To ensure the safety of maintenance staff from the uncontrolled closing of the 747-400's nose landing gear doors, several bearings of the ground door release mechanism must be replaced. This will eliminate the problem of seized bearings, which cause the mechanism to move back into the normal (closed) position while the handle is in the open position. Boeing is also expected to offer an additional locking feature as a solution to this problem. The modification will require 38MH per aircraft. AC

# 747-400 fuel burn performance

## The fuel burn & operating performance of passenger- and freighter-configured aircraft are analysed on ultra long-haul missions.

The fuel burn and operating performance of the passenger and freighter variants of the 747-400 are analysed. Each of these two main groups has aircraft powered by CF6-80C2, PW4000 and RB211-524 engines.

The performance of three maximum take-off weights (MTOW) variants of the 747-400 passenger aircraft powered by the CF6-80C2 have been examined. Passenger-configured aircraft powered by PW4056 and RB211-524 engines with an MTOW of 870,000lbs have also been examined. Their performance has been examined at Mach 0.84.

Only GE- and P&W-powered freighter aircraft have been analysed. The performance has been examined at Mach 0.84.

### Passenger routes

The performance of passenger-configured aircraft has been examined on a typical ultra-long-haul route: Hong Kong (HKG) -Vancouver (YVR). This has a great circle distance of about 5,500NM.

Performance of the aircraft has been analysed in both directions to illustrate the effects of wind speed and direction on the actual distance flown and the aircraft's performance. Headwinds and tailwinds increase or reduce the equivalent still-air-distance (ESAD), compared with the tracked distance.

The HKG-YVR route has a flight time of 11-12 hours, depending on the direction and wind speed, and is close to the edge of the 747-400's payload-range performance. The fuel the aircraft are legally required to carry to operate the route in either direction is influenced by the choice of suitable diversion and alternate airports. These are Calgary (YYC) when operating to YVR, and Macau (MFM) when operating to HKG.

The flight plans, performed by Jeppesen/Boeing, have used 50% reliability winds and 50% reliability temperatures for the month of June.

The aircraft have been assumed to carry a full passenger payload of 400 passengers in three classes. The standard weight for each passenger plus baggage is 220lbs. No additional underfloor cargo is carried. Each aircraft therefore carries a payload of 88,000lbs.

The flight profiles in each case are based on domestic FAR flight rules, which include standard assumptions on fuel reserves, standard diversion fuel (for the alternate airports mentioned above), plus contingency fuel.

In an easterly direction to YVR, the aircraft is assisted by a 45-knot tailwind. This results in a flight time of 681 minutes and a shorter ESAD of 5,503nm compared with a tracked distance of 5,971nm.

Meanwhile, for the YVR-HKG route, where there is a headwind component of 18 knots, the 5,768nm tracked distance compares with an increased ESAD of 5,990nm. This route has a flight time of 738 minutes.

### Freighter route

The freighter aircraft are examined on a shorter route: Seattle (SEA) - Shanghai (PVG). The aircraft performance has been analysed in both directions to illustrate the effects of wind speed and direction on the ESAD and aircraft performance. The chosen city-pair is typical of many 747-400 long-range freight operations, since it has a block time of 10-11 hours depending on the direction of travel. The diversion and alternate airports chosen are Fuzhou (FOC) when operating to PVG, and Portland (PDX) when operating to SEA. Again, 50% reliability winds and 50% reliability temperatures for the month of June have been used.

The aircraft have been analysed carrying the maximum possible freight payload in both directions on this route. The freight payloads are 173,797-203,000lbs for the respective sectors. The flight plans have therefore calculated the payload that can be carried without the aircraft exceeding its MTOW, and carrying all the legally required trip, contingency, diversion and taxi fuel.

When operating in a westerly direction to PVG, the aircraft encounter a headwind component of 3 knots which results in an ESAD of 5,356nm compared with a tracked distance of 5,322nm. This route has a flight time of 655 minutes.

The aircraft experience a tailwind component of 51-53 knots when operating in an easterly direction operating to SEA. This results in an ESAD of 4,825nm compared with a tracked distance of 5,310nm. This route has a flight time of 591 minutes.

*Aircraft powered by CF6-80C2B1F engines have lower rates of fuel burn per passenger and per ton-mile than aircraft equipped by PW4056 and RB211-524 engines. These differences are only in the order of 1-3%.*

**FUEL BURN PERFORMANCE OF PASSENGER-CONFIGURED 747-400**

| City-pair variant | Aircraft | Engine model | MTOW lbs | TOW lbs | Fuel capacity USG | Fuel burn USG | Flight time mins | Passenger payload | ESAD nm | Fuel per seat | Wind speed |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HKG-YVR | 747-400 | CF6-80C2B1F | 850,000 | 788,132 | 53,757 | 38,222 | 680 | 400 | 5,503 | 96 | 45 |
| HKG-YVR | 747-400 | CF6-80C2B1F | 870,000 | 788,782 | 57,057 | 38,290 | 680 | 400 | 5,503 | 96 | 45 |
| HKG-YVR | 747-400 | CF6-80C2B1F | 875,000 | 788,782 | 57,057 | 38,290 | 680 | 400 | 5,503 | 96 | 45 |
| HKG-YVR | 747-400 | PW4056 | 870,000 | 792,960 | 57,277 | 38,731 | 681 | 400 | 5,503 | 97 | 45 |
| HKG-YVR | 747-400 | RB211-524G/H | 870,000 | 803,981 | 57,277 | 39,783 | 681 | 400 | 5,503 | 99 | 45 |
| YVR-HKG | 747-400 | CF6-80C2B1F | 850,000 | 798,767 | 53,757 | 41,703 | 738 | 400 | 5,990 | 104 | -18 |
| YVR-HKG | 747-400 | CF6-80C2B1F | 870,000 | 798,752 | 57,057 | 41,701 | 738 | 400 | 5,990 | 104 | -18 |
| YVR-HKG | 747-400 | CF6-80C2B1F | 875,000 | 798,753 | 57,057 | 41,701 | 738 | 400 | 5,990 | 104 | -18 |
| YVR-HKG | 747-400 | PW4056 | 870,000 | 802,493 | 57,277 | 42,090 | 739 | 400 | 5,990 | 105 | -18 |
| YVR-HKG | 747-400 | RB211-524G/H | 870,000 | 811,222 | 57,277 | 42,664 | 739 | 400 | 5,990 | 106 | -18 |

**FUEL BURN PERFORMANCE OF FREIGHTER-CONFIGURED 747-400**

| City-pair variant | Aircraft | Engine model | MTOW lbs | TOW lbs | Fuel capacity USG | Fuel burn USG | Flight time mins | Freight payload lbs | ESAD nm | Fuel per ton-mile | Wind speed |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SEA-PVG | 747-400 | CF6-80C2B1F | 870,000 | 865,164 | 57,057 | 40,638 | 655 | 175,219 | 5,356 | 0.098 | -3 |
| SEA-PVG | 747-400 | PW4056 | 870,000 | 868,971 | 57,277 | 41,130 | 655 | 173,797 | 5,356 | 0.100 | -3 |
| PVG-SEA | 747-400 | CF6-80C2B1F | 870,000 | 832,564 | 57,057 | 35,856 | 590 | 189,024 | 4,825 | 0.080 | 51 |
| PVG-SEA | 747-400 | PW4056 | 870,000 | 860,203 | 57,277 | 37,558 | 591 | 203,000 | 4,825 | 0.078 | 51 |

Source: Jeppesen

## Fuel burn performance

The fuel burn for each aircraft-engine combination and the consequent burn per passenger or ton-mile of freight are summarised *(see table, this page)*.

The first comparison is between three different MTOW versions (850,000lbs, 870,000lbs and 875,000lbs), all with CF6-80C2B1F engines, and a cruise speed of Mach 0.84 for consistency.

The data shows that for the respective models, the fuel burn per passenger increases in relation to actual take-off weights, regardless of the aircraft's MTOW capability *(see table, this page)*. This is because the MTOW capabilities of the aircraft are not actually reached, and the actual take-off weights of the three aircraft analysed are almost identical. The aircraft with MTOWs of 870,000lbs and 875,000lbs have exactly the same take-off weights, and are required to carry (and burn) exactly the same amount of fuel. The lighter aircraft with an MTOW of 850,000lbs has just a 650lbs lighter take-off weight and burns 68USG less fuel during the trip.

The differences between the fuel burns of the three CF6-80C2-powered 747-400 examples are thus small. The requirement for aircraft with a higher MTOW is that they are able to carry higher payloads on longer routes than aircraft with a lower MTOW capability.

A single variant of PW4056-powered aircraft with an MTOW of 870,000lbs has been analysed. This has a higher fuel burn compared with the CF6-80C2-powered aircraft. The PW4056-powered aircraft burns 442USG more fuel than its counterpart when operating to YVR, and 389USG more when operating to HKG.

This is a more significant difference than the above example, and is mainly a result of the PW4056-powered aircraft having a 4,178lbs higher actual take-off weight and a 572lbs higher operating empty weight (OEW). The higher OEW is due to the PW4056s being heavier than the CF6-80C2B1F engines.

The difference in fuel burn between aircraft powered with RB211-524G/HT and CF6-80C2B1F engines is larger, at 1,493 USG *(see table, this page)*. There are several reasons for this. The OEW of the RR-powered aircraft is 2,196lbs greater. The actual take-off weights show a larger difference, with the RR-powered aircraft being 15,284lbs heavier for the same mission to YVR sector.

The ESAD differs by 487nm for the two missions. This is matched by a difference of 58 minutes in flight time between the two directions of travel, which results in differences in fuel burns. Aircraft with PW4056 engines burn 3,359USG more fuel in a westerly direction to HKG compared to operating in an easterly direction to YVR. The aircraft burns 3,350-3,400USG per hour in the cruise.

## Freighter fuel burn

The SEA-PVG and PVG-SEA missions are close to the 747-400F's payload-range performance. The easterly operation to PVG has a 519nm longer ESAD than the westerly leg to SEA, so the aircraft carries 13,805lbs less payload when operating to PVG for it to carry enough fuel to operate the 519nm longer ESAD.

Moreover, the aircraft's actual take-off weight is at 865,000-868,000lbs; just 2,000-5,000lbs less than the MTOW of 870,000lbs when operating to PVG *(see table, this page)*.

The tailwind in the reverse direction to SEA reduces the ESAD to 4,825nm, and the aircraft have to take off at 832,564lbs and 860,203lbs *(see table, this page)*. These lower take-off weights and lighter fuel loads allow the aircraft to carry more payload.

It is worth noting the differences in the engine-related fuel burns between the PW- and GE-powered 747-400F. As previously evidenced with the passenger version, the CF6-80C2-powered freighter is slightly more fuel efficient than the PW-powered aircraft *(see table, this page)*. The installed engine weight difference is certainly a factor, and the two engines also differ in propulsive efficiency. AC

# 747-400 maintenance analysis & budget

**The 747-400 clearly has lower maintenance costs than its older -200 and -300 series counterparts. Combined with lower fuel burn, the 747-400 will displace the older Classic models.**

The 747-400 is the most successful series of the 747 model, having won 694 of the 1,500 total orders for the aircraft family. The 747's size means that it has always been operated by a small number of the largest airline, the majority of which are flag carriers. The first -400s went into operation in early 1989 with Northwest Airlines, with 660 having now been delivered, and about 35 still on order. The last orders for the -400 series have now been placed, selling in small numbers because the market is now focusing on the new -8 series.

The 747-400 replaced most 747-100s, -200s and -300s in mainline passenger operation. The 747-400 has no direct competitors, although the 777-300/-300ER are the closest in seat capacity and range capability. The 747-400 freighter also has a unique payload capacity, and is, like the passenger variant, in a class of its own. These factors could see 747-400s remaining in operation until they are 25-30 years old, which means that the majority of these aircraft are less than halfway through their lives, with about 500 having been delivered since 1992.

The 747-400's full maintenance costs are analysed here, including: line and ramp maintenance; base check maintenance; engine repair and overhaul; heavy component maintenance; and rotable repair and management.

## 747-400 in operation

Of the 700 -400 series that have been ordered, 465 are passenger variants and another 61 are configured as Combis. Another 166 aircraft are freighters, which is a high percentage of the fleet compared to other types *(see 747-400 fleet analysis, page 7)*. The 747-400's popularity as a freighter is explained by its payload-range performance, which allows it to carry a near full payload across the Pacific, albeit with a technical stop at a midway refuelling point like Anchorage, Alaska.

The 747-400's size makes it a high-risk aircraft to operate. Like the -100 and -200 'Classic' series before it, the -400 is operated by airlines that are regularly able to fill its large capacity. This requires both a large operating base and a well developed route network with routes and traffic rights to a large number of major airports. The -400's largest operators are British Airways (BA) (57 aircraft), Cathay Pacific (23), China Airlines (15), Japan Airlines (40), Korean Air (25), Singapore Airlines (SIA) (23) and United Airlines (30). Other operators include Air China, Air France, Air India, EVA Air, KLM, All Nippon Airways, Lufthansa, Northwest, Thai International and Qantas.

The -400 is clearly a long-haul workhorse, and accumulates up to 5,000 flight hours (FH) per year in most operations. It is used to operate on some of the world's longest and busiest routes, such as London-Singapore and -Hong Kong, Sydney-Singapore, Auckland-Los Angeles. The average flight cycle (FC) time in passenger operations is 7.5FH. The longer-range -400ER is exclusively used on ultra-long-distance routes, and has longer average FC times of 11.5FH.

The 747-400 is also a major freighter. Virtually all orders for 747-400s in recent years have been for freighter variants. There are 131 aircraft in operation, with the fleet split between 109 -400Fs and 22 -400ERFs. The largest fleets are operated by China Airlines (20), Cargolux (14), Atlas Air (15), Korean Air (10) and SIA (18). The largest number of -400ERFs in operation are a fleet of eight with Korean Air, and smaller fleets of two or three aircraft operated by KLM and Jade Cargo of China. All 35 outstanding orders for the 747-400 are for -400F and -400ERF models.

Freighter aircraft operate shorter average routes than passenger aircraft, because the range performance of the freighter models is shorter than that of passenger aircraft. The majority of -400Fs and -400ERFs have been acquired to operate routes serving markets in the Asia Pacific and China. Aircraft often require technical stops to refuel when carrying full payloads, so their average FC time is 6.0FH as a result. Freighter aircraft accumulate 4,800FH per year.

The 747-400 has clearly not yet entered the arena of used aircraft, although a small number of the oldest examples have been converted to freighter and have been returned to service in the cargo divisions of their original operators.

A large number of 747-400s are expected to be converted to freighter as aircraft now come due for retirement


*The 747-400 is used as a long-haul workhorse, with aircraft achieving annual rates of utilisation of 4,500-5,000FH per at average FC times of 8.0-11.0FH.*


*The 747-400's MPD has an A check interval of 600FH, C check interval of 7,500FH and 18 months, and D check interval of 72 months. Some operators have managed to extend A check intervals to 850FH and C check intervals to 24 months.*

from passenger service. Few aircraft are likely to be operated by secondary passenger airlines, however, because of the difficulty in filling them profitably.

The 747-400's full maintenance costs are examined here for a passenger aircraft completing 5,000FH and 625FC per year, at an average FC time of 8.0FH, and for a freighter completing 4,500FH and 750FC per year, at an average FC time of 6.0FH.

## Maintenance programme

The 747-400 has a maintenance steering group 3 (MSG3) programme, which is similar to the programme for the 747-200's/-300, from which it is derived.

The 747-400's line and ramp maintenance programme has pre-flight checks prior to the first flight of each working day, a transit check prior to all other flights of the day, a daily check up to every 48 hours and a weekly check with a maximum interval of eight days.

Daily checks will often be performed at the operator's homebase, and airlines are often allowed an interval of up to 48 hours. Daily checks sometimes have to be performed at outstations by sub-contractors.

The basic A check interval in the original maintenance planning document (MPD) was 500FH, but it has been revised to 600FH. The 500FH interval is still used by some operators, but it will be extended to 600FH for several carriers. Some of the more experienced operators are trying to escalate the A check interval to a higher number of FH. "The 747-8 is expected to have an MPD interval of 800FH at service entry, so we are trying to extend it for the -400s," says Wilfred van Duuren, director of widebody base maintenance at KLM Engineering & Maintenance. "Our own MPD interval has already been extended to 850FH and 150FC, whichever is reached first. The 150FC limit is for engine-related items, including engine borescopes. Our customers also benefit from this extended interval, which includes a major Chinese freight operator and two important European 747-400 operators. KLM Engineering & Maintenance manages the engineering for these airlines, so they have the same check intervals as us."

Besides the 1A items, there are five groups of A check task multiples, the highest of which are the 6A items with an interval of 3,600FH. The other tasks are 2A, 3A, 4A and 6A tasks with intervals of their respective multiple of 600FH.

The full A check cycle is therefore theoretically reached when all these multiples are in phase, which will not be until the 12th check in succession, the A12 check. This will have a full interval of 7,200FH. The actual amount of this interval that an operator is able to utilise will be influenced by their ability to schedule and plan maintenance in accordance with the aircraft's operation. A typical rate of A check utilisation is 75-80%. Airlines will therefore be performing checks every 400-500FH.

The 747-400's base maintenance programme comprises two independent cycles of C and D checks. The 747-400's basic C check interval for 1C tasks is 7,500FH and 18 months, although this has been extended from a shorter interval in an earlier revision of the MPD. These two intervals mean that an aircraft can operate for 5,000FH per year and reach both limits at the same time. This is similar to the annual rate of utilisation achieved by most operators.

Freight aircraft operating at lower levels of utilisation will not be able to fully utilise the 7,500FH limit in the 18-month interval.

Most operators' C check intervals are the same as, or close to, the MPD interval. United Airlines, for example, has an interval of 18 months with no FH limit.

"Our C check intervals are longer than the MPD intervals," says van Duuren. "The C check interval is 24 months for aircraft up to 14 years of age under our programme, and is reduced to 18 months for aircraft older than 14 years. Operational constraints mean that we are not quite able to fully utilise these intervals. We are trying to escalate the interval to 24 months for aircraft older than 14 years. The other main benefit is that our C check intervals do not have an FH limit."

The 747-400's MPD comprises another three groups of C check tasks: the 2C, 3C and 4C items with respective intervals that are multiples of the base 1C interval. There are relatively few 3C items, while the 4C is a large group of tasks. These tasks have an interval of 30,000FH and 72 months, equal to six years.

The 747-400's D check MPD interval has similarly been extended with operational experience accumulated by the aircraft. The original MPD interval of 25,000FH and 60 months has been extended to 72 months. This interval is used by United and Ameco Beijing. The D check interval is therefore equal to the 4C interval, so the two are performed together, although the C and D check tasks run as two independent groups of inspections.

KLM's D check interval is longer than the MPD interval. "The interval for the first D check in our programme is 96 months," says van Duuren. "This is equal to four times the basic C check interval for aircraft of this age. All subsequent D checks have an interval of 72 months."

## Line, ramp & A check inputs

A passenger aircraft, operating at 5,000FH and 625FC per year, will complete about 350 pre-flight checks annually, and another 275 transit checks


*The 747-400 completes a base check about once every five years. This is long compared to younger generation aircraft. The 747-8 is expected to have a D check interval of eight years.*

for the remaining number of FCs completed over the course of the year. It will also undergo about 325 daily checks and 50 weekly checks every year.

A freighter aircraft operating at 4,500FH and 700FC per year will have the same number of pre-flight, daily and weekly checks per year, but about 400 transit checks.

Budgets for inputs for these checks will be three man-hours (MH) and $20 of materials for a pre-flight check, 1.5MH and $10 of materials for transit checks, 25MH and $80 of materials for daily checks, and 30MH and $100 of materials for weekly checks.

Passenger aircraft will use 11,000MH and $41,000 in materials and consumables a year. Labour for line and ramp maintenance charged at $70 per MH will take the total annual cost to $820,000, equal to $165 per MH *(see tables, page 24)*.

Freighter aircraft will use 11,500MH and $42,000 in materials and consumables, taking the cost for line and ramp checks to $190 per FH *(see tables, page 24)*.

Inputs for A checks vary with the tasks included, since lighter checks include the 1A and 3A tasks, while heavier checks also include the 2A, 4A and 6A tasks. These make the A4, A6, A8 and A12 checks the largest. "The average labour requirement for A checks is 550MH," says van Duuren. "This is the total package that includes routine inspections, rectifications, modifications and interior work. The A check has a downtime of 24 hours and requires 90-100 mechanics. About $17,000-18,000 should be budgeted for materials and consumables for passenger aircraft, but $43,000-44,000 for Combis which have the freight loading system."

An aircraft will therefore consume 6,500MH every A check cycle, with an average interval of 450FH and $175,000 of materials and consumables. The cycle will be completed about once every 5,400FH. Labour charged at the rate of $70 per FH will take the total cost for the inputs to $680,000, equal to a cost of $125 per FH *(see tables, page 24)*.

## Base check contents

### Inspections

The full C and D check workpackages on the 747-400 comprise several elements. The first of these is naturally the routine inspections and job cards, as previously described. The earlier 747 'Classic' models, the -100, -200 and -300 series, had separate ageing aircraft inspections added to their initial maintenance programmes, comprising four elements: the corrosion prevention and control programme (CPCP); the supplemental structural inspection document (SSID); the repair assessment programme; and the widespread fatigue damage programme. The SSID can often be confused with the significant structural inspection (SSI) items, which form part of the original maintenance programme.

The 747-400's MSG3 maintenance programme has incorporated these ageing aircraft inspections into the MPD, thereby simplifying maintenance.

These routine inspections result in non-routine rectifications. Operators will also use the C and D checks to clear all outstanding defects that have arisen during operation and that have not been cleared during the lighter A checks.

Base checks will also include out-of-phase (OOP) items, such as the inspection and removal, for repair and overhaul, of hard-timed rotable components like batteries and safety equipment.

### Engineering orders

Another major element of base checks is inspections relating to service bulletins (SBs) and airworthiness directives (ADs), and associated terminating actions. The 747-400 is fortunate not to be affected by the major ADs that applied to the 'Classic' series, in particular the Section 41 inspection and modification programme. Cracks in the forward fuselage Section 41 on the 747 Classics were discovered in the mid-1980s, as a result of which an AD was issued to force inspections and terminating action. This only affected 747s up to line number 685, and all -400 models are exempt.

A second major modification, which did affect a small number of -400 series aircraft, concerned engine pylons. In-flight separation of engines from three aircraft resulted in AD 95-13-05 being issued in 1995. This affected 747s up to line number 1,046, and so included 321 -400 series aircraft.

The modification required the use of stainless steel engine mounting bolts and the fitting of new engine mountings in the engine pylon. The deadline for completing this modification was 1998, so all affected aircraft have been modified.

The 747-400 is affected by a few moderate ADs and SBs. "The first of these is the AD relating to the dual side brace modification which affects the mounting on the pylons. The AD number is 2005-19-09," says van Duuren.

The AD requires inspections of the dual side braces and mid-spar fittings that attach the engine pylon to the wing. These items are repaired and modified as mandated by the AD. "Carrying this out on each aircraft takes 800MH and $13,000 in materials, and is included in the D check," explains Robert Henry, manager of line maintenance and event & capacity planning at United Services. "The AD also requires the purchase of three sets of special project tooling at a cost of $570,000.

"There is another AD that requires the removal of the heat exchanger from

*Base check contents will include routine inspections, non-routine rectifications, EOs, out-of-phase tasks and clearing deferred defects. D checks can often also include refurbishment of the interior and stripping and repainting.*


inside the fuel tank, and modifications to prevent electrical arcing in the event of a lightning strike," continues Henry. "This takes 180MH per aircraft to complete."

A third major AD to complete on the 747-400 involves a modification to thrust reverser locks to prevent in-flight deployment. Van Duuren estimates that carrying this out requires about 870MH, and it is performed during a D check.

A fourth major upgrade affecting the 747-400 is a modification to the fuel harness, and is performed during a D check. "This is still only an SB at the moment," explains van Duuren, "and requires 400MH and a kit of $70,000 to complete."

An example of an SB with a smaller impact that can be included in 747-400 base checks is the replacement of the trim air diffuser duct (TADD). "This is because ducts and joints deteriorate over time due to high air temperatures. This SB requires about 65MH and $26,000 of materials per aircraft to complete," says Henry. "Another SB is the replacement of the electrical equipment centre drip shield, which requires the removal of associated electrical equipment to gain access to, and replace, cracked and damaged drip shields. This SB requires 100MH and $4,000 in materials to complete per aircraft."

Van Duuren explains that the list of SBs and ADs worked on during base checks will be unique to each check, since airlines will plan them into checks as they are issued and according to which SBs they want. The MH used for SBs and ADs during base checks therefore vary between checks, but an amount of MH has to be budgeted.

## Rotable components

C and D checks will also include the removal of some rotable components for repair and overhaul. These will be scheduled during these base checks either because they are large items that require the downtime of base checks to remove them, or because they involve deep access to the aircraft.

Removed items will have to be reinstalled once repaired if they are closed-loop components, or have repaired components installed in their place if they are open-loop components.

Examples of large items are the landing gear, which requires 1,000MH for removal and installation of a shipset. Other examples are thrust reversers and the auxiliary power unit (APU).

Examples of smaller components are batteries, evacuation slides and oxygen bottles.

## Interior work

Interior work is another major element of C and D check workpackages. The list of interior items is extensive on a passenger aircraft, and includes: seats; carpets; curtains; sidewall and ceiling panels; the bulkhead; toilets; galleys; overhead bins; passenger service units; in-flight entertainment (IFE) equipment; lighting; and air conditioning ducts. The interior was traditionally repaired and cleaned on an on-condition basis during A and C checks, and refurbished during D checks. "The extended maintenance intervals, especially of heavy checks, has led to some airlines adopting a more on-condition approach to interior refurbishment and maintenance," says van Duuren.

"The interior of the 747 is usually refurbished every D check," says van Duuren, "although the timing for refurbishment is determined by the downtime allowed by the check as well as the condition of the cabin."

United performs a complete interior refurbishment at the D check, since this provides about five weeks of downtime plus the access provided by deep inspections that require removal of galleys, toilets and panels. "We use the A and C checks to maintain the interior for functionality and appearance as part of a find-and-fix programme," says Henry. "The D check involves the refurbishment and replacement of most interior items. About 85% of the interior items are refurbished, while 15% have to be replaced."

Other operators choose to refurbish the interior in portions at different base checks. "We remove major interior items in conjunction with the CPCP inspections," explains Shaul Peri, maintenance specification manager, at El Al Engineering. "This means that we remove and overhaul different items when CPCP inspections dictate their removal, so we refurbish parts of the interior at each C check. The seats are overhauled every 5-6 years."

Interior cleaning and refurbishment account for a large percentage of the total MH used during C and D checks in passenger aircraft. Freighter aircraft use fewer MH for interior work. While all passenger-related items are absent, freighter aircraft do have cargo loading systems which suffer punishment from loading and off-loading pallets and containers. Freighters therefore require some MH for interior-related items.

## Stripping & repainting

Stripping and repainting are another item that is treated on an on-condition basis by many airlines, although completion of a strip and repaint on a 747-400 takes 12-16 days. This is done under the D check that is performed every five to six years. Some airlines schedule this at either end of a D check, while others strip and repaint their aircraft at longer intervals of seven years.

Lufthansa Technik strips and repaints its 747-400s every six to eight years, and estimates that this requires 2,600-3,000MH and $70,000 for the paint.

*The MH and material cost inputs a 747-400 uses in a complete base check cycle is 40-45% less than that required by the 747-200/-300 in a full base check cycle.*

## Base check inputs

The 747-400 certainly has lower total inputs for labour and materials and consumables over its base check cycle than the 747-200/-300.

The labour input for the first three C checks, the D check that includes the fourth C check, complete interior refurbishment, and stripping and repainting, totals 80,000-85,000MH. This labour input is used for mature passenger-configured aircraft in their second or third base check cycle, which will have an interval of about 26,000FH when probable utilisations of check intervals are considered.

This compares to a total labour input of 135,000-170,000MH for the three C checks, D check, interior refurbishment, and stripping and repainting used for a 747-200/-300 in its fourth or fifth base check cycle with an interval of 20,000FH *(see 747-200/-300 maintenance analysis & budget, Aircraft Commerce, June/July 2005, page 13).*

The actual contents of base checks vary, and some operators choose to schedule the majority of engineering orders and interior work in the D check, thereby resulting in relatively small C checks. Others have larger C check workscopes and smaller D checks.

Henry estimates that C checks consume an average of 10,000MH and another $175,000-225,000 in materials and consumables. Checks vary in size and content, however, and the lighter C1 and C3 checks can consume in the region of 9,000MH, while heavier C2 checks will use 5,000MH.

The following D check will use 48,000-50,000MH. The associated cost of materials and consumables for this check will be $600,000-750,000. The additional task of stripping and painting, which is done about once every base check cycle, will use 3,000MH. The cost of paint and other materials used is $75,000-100,000.

This system of organising base maintenance results in relatively large C checks, with some of the cabin refurbishment tasks being scheduled in these checks. Operators may also choose to include some major modifications in these checks, which will result in relatively light D checks.

The inputs for these base checks will take the total labour consumed to 84,000-86,000MH, and total materials and consumables to $1.2-1.4 million. A labour cost of $50 per MH will take the total cost for this base check cycle to $5.4-5.7 million. This is equal to a reserve of $208-220 per FH *(see table, page 24).*

An alternative way to organise base check workscopes is to schedule all major tasks in the D check, and have just routine inspections, non-routine rectifications, some cabin cleaning and a relatively small package of SBs and ADs in the C checks. This will leave all major items for the D check, making it relatively large. A cabin refurbishment programme can be added to a C check if necessary. "We feel it is better to use the D check, because there are several items which result in a long check downtime, and so should be done in the D check," says Andreas Drosdowski, leader of maintenance planning services and Lufthansa Technik. "These items include refurbishment of the interior, major modifications, installation of new IFE equipment, and overhaul of major rotables like the flap carriages. We feel that it is best to put all these items in the D check. There are also some findings arising from inspections in the C check that can be deferred to the D check. The result of following this philosophy is that the C checks are relatively small and the D checks large.

"The C checks use about 2,500MH for routine inspections and an average of 1,500MH are required for non-routine rectifications, resulting in a sub-total of about 4,000MH," continues Drosdowski. "Another 1,000MH are used for cabin cleaning and some light refurbishment. Unless there is a major modification to be performed, 300-500MH will be used for engineering orders (EOs). This results in a total of 4,000-5,000MH. While there are some differences in the size of different C checks due to different inspection packages, the total MH used for the checks only varies by 5-10%. The cost of associated materials and consumables is in the region of $85,000.

"The D check uses about 22,000MH for routine inspections. This is about the same for the D1, D2 and D3 checks," continues Drosdowski. "The labour required for non-routine has increased from about 22,000MH for D1 checks to 28,000MH for D3 checks, resulting in a sub-total of about 50,000MH for routine and non-routine labour. The amount of non-routine labour has increased with aircraft age because of structural damage and corrosion found in the galley lift and stairs connecting the main and upper passenger decks. A further 5,000MH will be used for interior refurbishment, which accounts for virtually all the interior and cabin refurbishment made over the base check cycle. Another 3,500-5,000MH will be used for EOs and modifications, and 800-1,000MH can be used for changing heavy components such as landing gears. This reaches a total of about 60,000MH for a D3 check, and compares to 54,000-55,000MH for a D1 check. Another 3,000MH can be added to the check total if stripping and painting are included at this time. These are productive MH. Another 5,000MH can be used for management issues that include check planning, task card preparation, controlling, administration and material management. A third-party

*Freighter aircraft use only about 3,000MH fewer MH for a D check than a passenger aircraft. While a freighter will use about 5,000MH less because it has no interior to refurbish, it will use about 2,000MH to repair its cargo loading system.*

maintenance provider can either charge for the additional management MH, or include them as an element of the labour rate charged for the productive MH.

"The associated cost of materials and consumables for a check of this size will be about $1.25 million," continues Drosdowski.

Using the *Aircraft Commerce* standard labour rate of $50 per MH for base maintenance checks, the 63,000 productive MH for a D3 check, including stripping and painting, on a passenger-configured aircraft will take the total cost to about $4.4 million. It is generally observed that there is only about a 5% variation in the number of MH used for the same check on different aircraft in the fleet.

The total labour for the third or fourth base check cycle for a passenger aircraft is therefore expected to be 77,000-80,000MH. The total cost, including materials and consumables, is $5.3-5.5 million, which is equal to a reserve of $205-212 per FH *(see table, page 24)*.

There are also large numbers of 747-400 freighters in operation, so base check inputs also have to be considered for these aircraft. "While all 5,000MH used for the interior refurbishment during the D check will not be used for a freighter, there will be a further 2,000MH used for defects on the cargo loading system, so there will only be a net reduction of about 3,000MH compared to the D check for a passenger aircraft," says Drosdowski. "A D3 or D4 check on a 747-400 freighter will therefore use about 60,000 productive MH." The cost of materials will be lighter for a freighter, because of the absence of interior items, so this will be in the region of $0.8 million, thereby taking the total cost to about $3.8 million.

The total inputs for the full base check cycle for a mature freighter will therefore be about 72,000MH and $1.1 million in materials and consumables, taking the total cost to $4.7 million. At an annual utilisation of 4,500FH, freighters would be able to complete a base check cycle in about 25,000FH, so reserves would therefore be about $190 per FH *(see table, page 24)*. Many freighter operators, however, achieve higher rates of utilisation in excess of 5,500FH per year, so they would have longer intervals and lower reserves over the full base check cycle.

## Rotable components

The majority of rotable components on the 747-400 are maintained on an on-condition basis, or are condition monitored. Few components are maintained on a hard-time basis.

Northeast Aero is a rotable repair shop in New York state. "We specialise in repairing several hundred rotable part numbers for several aircraft types, including the 747-400. These fall into the categories of pneumatics, hydraulics, fluid and air driven components, and electromechanical components," says Vic Calabrese, vice president of operations and quality control at Northeast Aero Inc. "Our core business is components like air cycle machines, and associated components like valves and actuators. An example of a pneumatic component is the leading edge flap drive on the 747-400. Most of these components are now maintained on an on-condition basis, which is done as an attempt to drive down maintenance costs. The repair and management of these components can therefore be included as part of an all-inclusive rotable support packages that are offered to airlines from specialist rotable suppliers. One such company that is a customer of ours is AAR. We also deal directly with airlines. Our airline 747-400 customers include UPS, Air France, China Airlines and EVA Air."

Andre Fischer, section manager of product sales aircraft component services at Lufthansa Technik, estimates that there are 800-1,000 rotable part numbers installed on the 747-400, with the actual number depending on the configuration and modification status of the aircraft. The total number of rotable components installed is 2,500-2,700, with the actual number again dependent on the aircraft's configuration. Only 30-50 of these rotables are hard-timed, and these include safety items such as oxygen bottles and escape slides. The cost of maintaining these components is included in base check costs.

Besides items such as wheels and brakes, most rotables are maintained on-condition, so they are removed after failure. These items can be supplied, maintained and managed in an all-inclusive support package for an operator. "We can provide a customer with a Total Component Support (TCS) package, where we are responsible for monitoring the reliability of components, managing the exchange of failed parts with serviceable units, managing all paperwork and documentation, and managing repairs and other items such as transport and storage," says Fischer.

The costs of this type of service comprise three elements. The operator will be supplied with an inventory of homebase stock, which are items that they will require at their homebase. These can be leased. The list price for this inventory of stock is $6-8 million for a fleet of five aircraft, and $9-11 million for a fleet of ten. Freighter aircraft will require smaller inventories than passenger aircraft because of the difference in cabin- and passenger-related items.

Monthly lease rates for these components are 1.2%,which is equal to about $29 per FH for a fleet of 10 passenger aircraft operating at 5,000FH per year. The rate for five freighters operating at 4,500FH per year is about $39 per FH.

The remaining parts can be accessed

### 747-400 HEAVY COMPONENT MAINTENANCE COSTS

| | |
|---|---|
| Number of main & nose wheels | 16 + 2 |
| Tyre retread interval-FC | 250/325 |
| Tyre retread cost-$ | 550/450 |
| Number of retreads | 4 |
| New main & nose tyres-$ | 2,000/1,100 |
| **$/FC retread & replace tyres** | **58** |
| Wheel inspection interval-FC | 250/325 |
| Main & nose wheel inspection cost-$ | 2,500 |
| **$/FC wheel inspection** | **175** |
| Number of brakes | 16 |
| Brake repair interval-FC | 2,000 |
| Brake repair cost-$ | 70,000 |
| **$/FC brake repair cost** | **560** |
| Landing gear interval-FC | 5,500-6,000 |
| Landing gear exchange & repair fee-$ | 700,000 |
| **$/FC landing gear overhaul** | **120-130** |
| Thrust reverser repair interval-FC | 5,000 |
| Exchange & repair fee-$/unit | 300,000 |
| **$/FC thrust reverser overhaul** | **200** |
| APU hours shop visit interval | 9,000 |
| APU hours per aircraft FC | 2.5 |
| APU shop visit cost-$ | 450,000 |
| **$/FC APU shop visit** | **125** |
| **Total-$/FC** | **1,235** |
| **Total-$/FH passenger aircraft @ 7.5FH per FC** | **165** |
| **Total-$/FH freighter aircraft @ 6.0FH per FC** | **205** |

by the operator from the supplier through a pooling agreement, whereby a pool of parts is held by the supplier for all its customers whenever they are required. Fischer estimates that the pool access fee will be about $55 per FH for an operator with a fleet of 10 passenger aircraft, but higher at about $65 per FH for a freight airline operating at lower rates of utilisation.

The third element will be a fee for managing and repairing all parts from the homebase stock and pool stock. This will be $200 per FH for passenger aircraft, but $220 per FH for freighters operating at lower rates of utilisation.

The total costs for passenger aircraft operating as described will be $284 per FH, and the costs for freighters will be $324 per FH *(see tables, page 24)*.

## Heavy components

Heavy components comprise four types of items: wheels, tyres and brakes; the thrust reverser; the landing gear and APU.

The 747 has 16 main wheels and two nose wheels. The 16 main wheels are equipped with carbon brakes as standard. Wheels are removed when tyre treads or brake disc thickness have worn down to a minimum accepted level. This means that removals are entirely on an on-condition basis, and intervals vary according to the heaviness of landings and harshness of braking by pilots. Wheels are most often removed for tyre tread wear. Tyres are then remoulded, and wheel rims undergo inspection with non-destructive testing (NDT) at the same time. Intervals that can be used for budgeting purposes are 250FC for main wheels and 325FC for nose wheels. Tyres are remoulded an average of four times before being replaced after the fifth removal. Tyre remoulds cost about $550 for main tyres, and $450 for nose tyres. New main tyres cost about $2,000, while nose tyres cost about $1,100. The total cost for the complete cycle of remoulding and replacing the shipset of tyres is about $75,000, and a reserve of $58 per FC is allowed for the cycle interval *(see table, this page)*.

Wheel inspections have an average cost of $2,500, and a resulting cost per FC of $165 *(see table, this page)*.

Average repair intervals for the carbon brakes are 2,000FC, and average repair costs for a unit are about $70,000, equalling a reserve of $560 per FC for the shipset of 16 brakes. The total cost for tyres, wheels and brakes is about $795 per FC *(see table, this page)*.

The landing gear intervals for the 747-400 are 10 calendar years and 6,000FC, whichever is reached first. An interval of 5,500-6,000FC is possible for aircraft operating at 625FC and 750FC per year. Exchange and overhaul fees for a shipset are in the region of $700,000, so they are equal to a reserve of $120-130 per FC *(see table, this page)*.

Thrust reversers are maintained on-condition, and the use of composite materials in the units on modern aircraft means that intervals can be longer than those for older aircraft. Reversers on the CF6-80C2 and PW4000 can remain on-wing for 5,000-6,000 landings (FC). An average shop visit cost of $300,000 per unit results in a reserve of $50 per FC, which is equal to $200 per FC for the whole aircraft *(see table, this page)*.

The PW901A is the exclusive APU on the 747-400. APUs are typically used for two to three hours per flight. They are sometimes switched on for the entire turnaround between flights, but more usually they are on after landing and again before departure.

Like engines, the APU is maintained on an on-condition basis. "The mean time between APU shop visits is about 9,500 APU hours," says Frank Schwaben, engineering product line PWC engines at Lufthansa Aero. "The maintenance guide to the PW901A has a maintenance 'soft' time of 10,000 hours, and can be used for planning. New APUs can meet this 10,000 hours, and several will exceed it. Mature PW901As can have an average closer to 5,000 hours. The only control the pilots have on the APU is the start button, as there is no throttle or other controls, and it is fully automatic. Mechanics only fix an APU when it fails to start, and if they cannot start it after troubleshooting it is removed for a shop visit. While it is possible to track temperature margins, no airlines actually do this."

Engines that reach a soft time on wing close to about 10,000 APU hours should have a complete disassembly and a full refurbishment. This workscope will typically cost about $450,000. A removal after about 9,000 APU hours will equal a reserve of $125 per FC for APUs operating at 2.5 APU hours per FC *(see table, this page)*.

The total cost per FC for these four groups of components is $1,235 per FC. This equals $165 per FH for aircraft operating at an FC time of 7.5FH, and $205 per FH for aircraft operating at an FC time of 6.0FH *(see tables, page 24)*.

## Engine maintenance

The three engine types powering the 747-400 fleet are the General Electric (GE) CF6-80C2B1F, Pratt & Whitney (PW) PW4000-94 and Rolls-Royce (RR) RB211-524G/H. The CF6-80C2 is the most dominant engine type on the 747-400, having been specified for 305 aircraft. The PW4000-94 has been specified for 216 aircraft, and the RB211 is used by only six operators.

The PW4000-94 and CF6-80C2B1F have similar fuel burn performance and a similar effect on the operating empty weight (OEW) of the aircraft. Their maintenance costs are also close. The RB211-524 gives the aircraft a higher OEW, thereby resulting in a smaller payload. The aircraft also has a higher fuel burn with these engines *(see 747-400 fuel burn performance, page 12)*.

In terms of maintenance costs, operators focus on removal intervals between shop visits, shop visit input costs, life limited part (LLP) lives and costs, and maintenance and aftermarket support. The engine type installed also has an effect on the aircraft's residual value. RR is known to control the maintenance and aftermarket support of RB211-524 engines, so operators of RB211-powered aircraft have no other choices for engine overhaul and technical support. RB211 engines have the reputation, however, of achieving longer removal intervals between shop visits than the CF6-80C2 and PW4000-94.

The maintenance costs of all three engine types have been analysed here for two operations: a passenger aircraft operating at an average FC time of 7.5FH; and a freight aircraft operating at an average FC time of 6.0FH.

### CF6-80C2B1F

The CF6-80C2B1F, rated at 58,000lbs thrust, has a mature exhaust gas temperature (EGT) margin of 35-55 degrees centigrade. There are three main production blocks of CF6-80C2 engines. The older block 1 and block 2 engines generally have a poorer build and material standard than the younger block 3 engines. Block 1 and 2 engines therefore have lower EGT margins of 35-40 degrees, while the block 3 engines have higher margins of 45-55 degrees.

The engines lose up to 10 degrees of EGT margin in the first 2,000 engine flight hours (EFH). The deterioration rate subsequently falls to 2.5-3.0 degrees per 1,000EFH. The CF6-80C2B1F has registered first removal intervals of up to 28,000EFH, but mature intervals for engines operating at an average EFC time of 7.5EFH are about 15,000EFH. This is equal to about 2,000EFC. EGT margin erosion is not a main removal driver, however, and mechanical deterioration of parts such as the variable stator vanes and cracking of the high pressure turbine blades (HPT) is the main cause.

Engines operating at an average EFC time of 6.0EFH achieve an average removal interval of 13,500EFH.

The two core modules generally follow a pattern of a heavy restoration that alternates with an overhaul, while the low pressure turbine (LPT) and fan/booster module usually only require a performance restoration or an overhaul every second shop visit.

A heavy core restoration uses about $1.3 million in materials, $300,000 in sub-contract repairs and 4,500MH in labour. Charged at a labour rate of $70 per MH, the total shop visit cost for this level of workscope is in the region of $1.95 million. A core overhaul will use more materials and require about 500MH more labour. Overall it will have a higher cost of about $2.1 million.

An LPT overhaul every second shop visit will use an average of $150,000 in materials, $40,000 in sub-contract repairs and 900MH in labour. The total cost for this module will therefore be about $255,000. A fan/booster overhaul will use about $125,000 in materials, $30,000 for sub-contract repairs and 650MH in labour, taking the total cost of the shop visit to about $200,000. A heavy second shop visit with a core, LPT and

### DIRECT MAINTENANCE COSTS FOR PASSENGER-CONFIGURED 747-400

| Maintenance Item | Cycle cost $ | Cycle interval | Cost per FC-$ | Cost per FH-$ |
|---|---|---|---|---|
| Line & ramp checks | 820,000 | 1 year | | 165 |
| A check | 630,000 | 5,400FH | | 125 |
| Base checks | 5,300,000-5,700,000 | 26,000FH | | 205-220 |
| Heavy components: | | | 1,235 | 165 |
| LRU component support | | | | 284 |
| **Total airframe & component maintenance** | | | | **934** |
| Engine maintenance: | | | | |
| 4 X PW4000: 4 X $210 per EFH | | | | 840 |
| 4 X CF6-80C2: 4 X $191 per EFH | | | | 764 |
| 4 X RB211-524G/H: 4 X $215 per EFH | | | | 860 |
| **Total direct maintenance costs:** | | | | |
| 4 X PW4000 | | | | **1,784** |
| 4X CF6-80C2 | | | | **1,708** |
| 4 X RB211-524G/H | | | | **1,804** |

***Annual utilisation:***
***5,000FH***
***625FC***
***FH:FC ratio of 7.5:1.0***

### DIRECT MAINTENANCE COSTS FOR FREIGHTER-CONFIGURED 747-400

| Maintenance Item | Cycle cost $ | Cycle interval | Cost per FC-$ | Cost per FH-$ |
|---|---|---|---|---|
| Line & ramp checks | 820,000 | 1 year | | 190 |
| A check | 630,000 | 5,400FH | | 125 |
| Base checks | 4,700,000 | 25,000FH | | 190 |
| Heavy components: | | | 1,235 | 205 |
| LRU component support | | | | 325 |
| **Total airframe & component maintenance** | | | | **1,035** |
| Engine maintenance: | | | | |
| 4 X PW4000: 4 X $231 per EFH | | | | 924 |
| 4 X CF6-80C2: 4 X $214 per EFH | | | | 856 |
| 4 X RB211-524G/H: 4 X $235 per EFH | | | | 940 |
| **Total direct maintenance costs:** | | | | |
| 4 X PW4000 | | | | **1,959** |
| 4X CF6-80C2 | | | | **1,891** |
| 4 X RB211-524G/H | | | | **1,975** |

***Annual utilisation:***
***4,500FH***
***750 FC***
***FH:FC ratio of 6.0:1.0***

fan/booster overhaul will therefore incur a total shop visit cost of $2.55 million.

These two levels of shop visit cost will result in a reserve of $150 per EFH for engines operated at an average time of 7.5EFH per EFC, and $167 per EFH for engines operated at an average EFC time of 6.0EFH.

A minority of the CF6-80C2's life limited parts (LLPs) have lives of 15,000EFC, while the majority have lives of 20,000EFC. The total list price for a full shipset is about $3.4 million. The average removal interval of 2,200-2,400EFC means that LLPs will be replaced every sixth to eighth shop visit, thereby resulting in a reserve of about $190 per EFC. This is equal to $26 per EFH for engines operated at 7.5EFH, and $32 per EFH for engines operated at 6.0EFH.

The third main element of engine maintenance costs is related to the quick engine change (QEC) kit. This has a reserve rate of about $15 per EFH.

These three elements total about $191 per EFH for engines operated at an EFC time of 7.5EFH, and $214 per EFH for engines operated at an EFC of 6.0EFH *(see tables, this page).*

#### PW4000-94

The PW4000-94 achieves similar performance and removal intervals to the CF6-80C2B1F, but the PW4000-94 has been affected by a few ADs in recent years.

The PW4056 is the most numerous PW4000 variant on the 747-400. "Mature engines have an EGT margin of 42-45 degrees centigrade following a shop visit, and the engines have a stabilised EGT margin degradation rate of about 1.0 degree per 1,000EFH after initial losses," says Wayne Pedranti, programme manager at Total Engine Support. "EGT margin loss only accounts for a minority of engine removals, while the majority of removals are due to mechanical deterioration. Examples are the burning of the second stage nozzle guide vane (NGV), and sulphidation of the first-stage HPT blades.

"The major AD that has affected the PW4000 in recent years is the 'ring case' modification, or RCC. The deadline for completing this on all engines is 2009. The AD states that out of four engines on the 747-400, one already has to be modified," continues Pedranti. "The rules for unmodified engines are that a stability test has to be done on the high pressure compressor (HPC) at 2,800EFC since overhaul. The engine has to be tested at take-off power in a test cell with the fuel supply cut, re-engaged and then surged to take-off power. Failing this test forces a removal, in which case the engine is split at the HPC and the modification has to be done. About half of the PW4000-94 fleet has been modified. The modification kit costs about $300,000 per engine, and this can be incorporated in a shop visit."

Mature engines often achieve 18,000EFH or more between planned removals when operating at average EFC times of 7.5EFH, but when unscheduled removals are taken into consideration the average works out to be about 15,000EFH. This is equal to about 2,000EFC. The PW4000 has already been

*The 747-400 will displace the 747-200 in the freight sector. The -400 series not only has superior payload-range performance, but also has about $1,000 per FH lower maintenance costs and $300-300 per FH lower fuel cost.*

through a modification programme known as Phase III, and engines with this upgrade have 12-15 degrees higher EGT margin, so they can last longer on wing, and also have better specific fuel consumption. Pratt & Whitney is also designing a second stage NGV to improve on-wing life.

"The PW4000 conforms to the usual pattern of alternating shop visits, with the first being a performance restoration, which is followed by an overhaul," says Pedranti. "The performance restoration requires work on the HPC, the diffuser case and combustor, the HPT, and the turbine nozzle. This will use 3,500-4,000MH of labour, about $1.1 million in materials and parts, and up to $0.8 million in sub-contract repairs. The PW4000 has a high percentage of parts that are repairable. A standard labour rate of $70 per MH will take the total cost of the shop visit input to about $2.1 million.

A full overhaul will use 4,500-5,000MH, about $1.7 million in materials and parts, and about $1.0 million in sub-contract repairs. This will have a total cost in the region of $3.0 million.

The total for the two shop visits can be amortised over 30,000EFH for two removals for engines operated at an average EFC time of 7.5EFH. Reserves will be equal to $170 per EFH. Engines operating at shorter cycle times of 6.0EFH will achieve about 13,500EFH between removals, and so have reserves of $185 per EFH.

All LLPs in the engine have lives of 20,000EFC, which simplifies engine management, although there are two parts that have lives of 30,000EFC: the LPT shaft and the LPT coupling. Given that engines accumulate only 600-700EFC per year, it is unlikely that these two parts will require replacement. Moreover, the LLPs with lives of 20,000EFC will have to be replaced after about 30 years. A full set of LLPs has a current list price of $3.3 million. Amortised over a used life of 18,000EFC, this results in a reserve of $183 per EFC. This is equal to $25 per EFH for engines operating at 7.5EFH per EFC, and $31 per EFH for engines operating at 6.0EFH.

The third element of engine maintenance is the reserve for the QEC kit, which is about $15 per EFH.

The total reserves for engines operating at 7.5EFH are therefore $210 per EFH, and $231 per EFH for engines operating at 6.0EFH *(see tables, page 24).*

**RB211-524H**

The RB211-524H and -524H-T engines are renowned for their durability and long removal intervals between shop visits. While the CF6-80C2B1F and PW4000-94 have average removal intervals of about 15,000EFH when operating on the 747-400 at cycle times of about 7.5EFH, the RB211-524H/-524H-T have average removal intervals of about 19,000EFH.

Although these longer intervals are welcomed by operators, the cost of shop visit inputs for the RB211-524H/-524H-T are also notoriously high, and the long intervals are not enough to offset the additional expense. The reserves for shop visits are in the region of $178 per EFH, making them about $13-18 per EFH higher than the CF6-80C2B1F and PW4000.

Reserves for LLPs are $24 per EFH, and a further $13 per EFH is required for the QEC kit. These three elements total $215 per EFH *(see tables, page 24).*

## Maintenance cost summary

The direct maintenance costs for passenger-and freighter-configured 747-400s are summarised *(see tables, page 24).* These costs are $950-1,100 per FH lower than for 747-200/-300s operating at a lower rate of utilisation of about 3,500FH per year *(see 747-200/-300 maintenance analysis & budget, Aircraft Commerce, June/July 2005, page 13).*

While the repair and overhaul costs of the 747-400's heavy components, and the costs relating to its rotable components are higher than those for the 747-200/-300, the 747-400 clearly benefits from lower airframe and engine maintenance.

The 747-400 uses about half the inputs for line and ramp checks that the 747-200/-300 do. This is one example of the lower maintenance costs of younger aircraft. The 747-400 also uses less labour and fewer materials for the A checks. The largest difference between the two types is reserves for base checks. This is due to both higher labour and material inputs for the C and D checks and shorter check intervals of the 747-200/-300. This gives the 747-400 an advantage of $300-330 per FH.

The 747-400 also has a smaller cost advantage over its older counterparts with its engine-related maintenance costs. These are $300-400 per FH lower for the -400's four engines. The 747-400 also gains from its lower fuel burn, consuming 150-200 fewer US Gallons per FH on long-distance missions. Considering current fuel prices of $2.05 per USG, this adds a further $300-400 per FH to the -400's cost advantage. These two points illustrate how the 747-400 is now likely to displace the 747-200/-300 in a freight role once enough passenger-configured -400s are retired to make their conversion economic.

Although the 747-400 benefits from a two-man flightcrew, airlines are required to carry supernumerary crew on many operations, which eliminates the cost advantage that a smaller crew would have given it over the -200/-300. AC

# 747-400 values & aftermarket activity

**Trading activity of used 747-400s relies mainly on passenger aircraft being acquired for freighter conversion. Availability of passenger aircraft is tight, which has seen their values rise and make freighter conversion uneconomic.**

The 747's size means that it is almost exclusively used by the world's largest carriers. It has always had few used market opportunities in the passenger role, and the only market where a demand exists for appreciable numbers of used aircraft is in conversion to freighter.

Conversion to freighter only makes economic sense, however, when the total investment of used aircraft purchase, conversion to freighter, installation of the cargo loading and handling system, and additional associated maintenance, are low enough for the investor or lessor to realise a return from investment from the prevailing market lease rates that they are likely to receive for the aircraft. Investors and lessors that convert passenger aircraft at 15-20 years old need to receive a lease rate equal to 1.3-1.5% per month of their total investment.

The cost of conversion is lower for Combi aircraft, making them preferable candidates for airlines, investors and lessors. The list prices for freighter conversion are $20 million for the IAI-Bedek modification, and up to $28 million for the Boeing conversion.

A cargo loading system will add $2 million, and additional equipment another $0.5 million.

The corresponding costs for converting Combis are $16 million for the IAI-Bedek conversion and $24 million for the Boeing option. The costs for the loading system and other items are similar to that for passenger aircraft.

The cost of required maintenance will depend on maintenance status, and can be as high as $4.5 million for a D check if required *(see 747-400 maintenance analysis & budget, page 14)*.

This can take total costs to $19-30 million when converting a Combi aircraft, and higher to $26-34 million when converting a passenger aircraft. This limits the maximum purchase price at which used aircraft can be acquired.

"The tight supply of large freighters means that many are expecting airlines will be prepared to lease converted aircraft for $750,000-800,000 per month," says Steve Rimmer, chief executive officer at Guggenheim Aviation Partners. "The limited supply of freighter aircraft is made worse by there being no Boeing conversion slots available until 2009 or 2010. This is because Boeing individually engineers each aircraft for conversion, and the company has a limited engineering capability. There is therefore a long lead time."

This probable lease rate of $750,000 per month limits the total investment in a converted aircraft at $50-55 million. Even when discounts on conversion programmes are considered, this means that the highest price at which used aircraft should be acquired is $36 million. The price falls to as low as $25 million in many cases. There is a trade-off between the purchase value and the cost of required maintenance, however. "Prices need to be $28-30 million to make conversion viable," estimates Rimmer.

This has to be considered in relation to the current market values of the oldest 747-400s being at $38-40 million. This takes the total investment up to $65 million, which is too high compared to the expected market lease rate. "Another issue is that the tight supply of widebodies generally means lessors can get lease rates of $550,000 per month for passenger aircraft of this age, so it is more attractive to keep them in their current configuration," continues Rimmer.

Current market values are in contrast to the lower values of the 2002-2004 period when a large number of 747-400s were available. In 2003, when there were about 30 aircraft available, values fell to $30-40 million. Aircraft were marketed by Air Canada, Malaysian Airlines, Singapore Airlines (SIA) and United Airlines. Some ex-United aircraft were acquired by Thai International and some ex-SIA aircraft were bought by Oasis Hong Kong, but several aircraft that came on the market were bought by Guggenheim Aviation Partners. "We bought nine aircraft from Air Canada, SIA and Malaysian in 2004 and 2005 and converted these to freighter," says Rimmer. "Several aircraft came onto the market because of surplus capacity after 9/11. The difficulty now is that supply has reduced so lease rates and values have strengthened again."

Values of used 747-400s will remain strong until the A380 and 747-800s start to be delivered in significant numbers. This will not occur until at least 2010 in the case of the A380, and 2014 in the case of the 747-8. At this stage major 747-400 operators will begin to retire the aircraft in appreciable numbers.

A few 747-400 operators are already getting ready to retire their aircraft. All Nippon Airways of Japan has already started retiring its fleet and will replace them with 777-300s. This could depress values slightly.

Avitas's value forecast puts the current market values of aircraft built between 1989 and 2004 at $34-110 million. It also forecasts future values given predicted prevailing market conditions. Values of the oldest aircraft, built in 1989 and 1990, are expected to fall to about $31 million by 2009 and to drop further to $24-28 million in 2011-2012. Conversion will therefore start to become economic again from about 2009 or 2010.

An examination of the aircraft that have already been converted from all-passenger or Combi-configuration, shows that they were all built between 1989 and 1993. They had accumulated 7,400-12,000 flight cycles (FC), which is an important factor in the value and remaining life of the aircraft. "The age of the aircraft has a lot to do with its valuation. When the cost of conversion and a heavy maintenance visit is added, the converted freighter should have a market value of $70-75million," according to Greg Peppes, manager of marketing for Boeing's freighter conversion programmes. "Customers need to look at the oldest passenger aircraft, which have the lowest residual value to minimise their investment into a freighter. We have seen aircraft as young as 13 years old being converted. In general therefore, candidate aircraft would need to be about 15 years or older."

"Cycles are important, with the 747-400's original design goal of 35,000FC," notes Peppes. "We are seeing 747-400s coming to the modification with about half of this number of accumulated FC. Given that freighter utilisation is typically less than passenger utilisation, conversion helps prolong the life of the aircraft. So they will be able to operate as freighters for another 10-15 years with no problem. Even the oldest aircraft that we built in 1989-1990 have plenty of cycles left, so really that element is not yet on the critical path." AC