

OWNER'S & OPERATOR'S GUIDE: 777-200/-300



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777-200 & -300 specifications

The 777-200/-300 family is powered by three main engine types. There are several weight, fuel capacity and range specification variants of the two series.

The 777 family is used mainly for long-haul operations, although operators in the Asia Pacific also use it for medium-haul services. The 777 family is based on two basic variants: the -200 series and larger -300 series. Within each series there are a number of variants, with longer range capability achieved through higher maximum take-off weight (MTOW), matched with higher engine thrust.

The first variant of the shorter -200 series entered service in June 1995 with United Airlines, and has an MTOW of 545,000lbs (247,200kg). The -200's standard three-class seat capacity is 305 passengers. The first variant of the longer -300 series entered service in May 1998 with Cathay Pacific and has an MTOW of 660,000lbs (299,370kg). The -300 series can carry an additional 50 extra passengers in a tri-class configuration.

Boeing has also launched ultra-long-range versions of the -200 and -300. The extended range -200ER can fly 7,700nm (14,260km), which gives it an additional range of about 2,500nm on the standard -200. This model was originally designated the -200IGW, for Increased Gross Weight. It had an increased MTOW, to take account of its additional fuel capacity, which was 656,000lbs (297,550kg).

Boeing has introduced two ultra-long-range passenger variants: the -200LR and the -300ER. These have additional range and MTOWs.

The 777-200LR has the -200's fuselage, a standard passenger configuration of 301 seats, an MTOW of 766,000lbs and 9,380nm range. It is powered by the GE90-110B, rated at 110,000lbs thrust (see table, page 7).

The 777-300ER has the same passenger capacity as the -300, a range of 7,930nm and an MTOW of 775,000lbs (see table, page 7).

The last quarter of 2008 will see the entry into service of the first 777F freighter. This is based on the 777-200LR, and has the same MTOW as the -200LR. It has a structural payload of 226,700lbs and range of 4,885nm.

Engine options

GE90 series

The GE90 engine is the only engine to be offered on all 777 models. There are six GE90 variants across the 777 fleet. These start with the GE90-76B, rated at 77,000lbs thrust for the 777-200, and continue to the GE90-115B, rated at 115,000lbs thrust for the -300ER (see table, page 7). Only the GE90-94B and the GE90-115B are in production.

The GE90-94B is rated at 94,000lbs thrust, and has had its performance improved by a three-dimensional aerodynamic high pressure compressor (HPC) and other new technologies. The -94B's 10-stage HPC is driven by a two-stage high pressure turbine (HPT). The three-stage low pressure compressor (LPC) is driven by a six-stage low pressure turbine (LPT). The engine is the heaviest and longest 777 engine option, at over 16,500lbs and 287 inches.

GE is now offering a Performance Improvement Package (PIP) which can upgrade an operator's current GE90 engine to a standard similar to that of the GE90-94B. The advantages consist of a 1.6% fuel burn improvement and about a 20°C increase in Exhaust Gas Temperature (EGT) margin, thereby providing an improvement in operating costs.

The GE90-115B is the only engine type available on the 777-300ER. This form of the GE90 has one less HPC stage, but one more LPC than the -94B.

For the 777-200LR and -200F, the GE90-115B is derated to 110,000lbs of thrust and designated the GE90-110B. The GE90-110B has a flat rated temperature of 92°F, while all other GE90s (including the -115B) are flat rated at 86°F.

The fan diameter for the standard GE90 is 123 inches, and has a bypass ratio of 8.7.

The -110B and -115B have a larger fan diameter of 128 inches, and a bypass ratio of 7.2.

PW4000-112 series

The PW4000-112 has a fan diameter of 112 inches. This engine is operated on the 777-200, -300 and -200ER, and has become the most popular option on the -200. There are five variants of the PW4000-112, ranging from 74,000lbs to 98,000lbs of thrust (see table, page 7).

All five engine models have a single stage fan, a two-stage HPT driving the 11-stage HPC and a six-stage LPC driven by a seven-stage LPT. All have a bypass ratio of 6.4 and a flat rating temperature of 86°F/30°C. This engine series is one of the heaviest available for commercial aircraft, second only to the GE90.

The first PW4000-112 engine was an industry first, with 180-minute ETOPS (extended-range twin-engine operations) qualified before it entered service in 1995. The PW4084 went on to be the first engine approved for 207-minute ETOPS.

The PW4084 was the third engine in the series. It has a thrust rating of 84,600lbs, and is operated on the -200 and -200ER. The PW4090 is rated at 91,790lbs, and is operated on the -200, -200ER and -300. The PW4098 is only operated on the 777-300, and has a thrust rating of 98,000lbs.

Trent 800 series

There are five basic variants of the Trent 800 which power the 777-200, -200ER and -300. These have thrust ratings between 75,000lbs and 95,000lbs (see table, page 7). The Trent 800 is the most popular engine selection on the 777 models it powers.

All Trent 800 models have a fan diameter of 110 inches and a flat rate temperature of 86°F/30°C, except the Trent 895 which has 77°F. Bypass ratios for each model vary, with the ratio decreasing as the thrust rating increases.

The Trent 875 has a thrust of 75,000lbs with a bypass ratio of 6.2 and only operates on the -200. The Trent 877, also only operated on the -200, is rated at 77,000lbs thrust and has a 6.1 bypass ratio. The Trent 884 has a thrust of over 84,000lbs and a bypass ratio of 5.9. The family's two most powerful engines are the Trent 892 and Trent 895 with 92,000lbs and 95,000lbs thrust respectively and a smaller bypass ratio of 5.8.

All five models have the same engine composition: the fan driven by a five-stage LPT; a single-stage HPT driving the six-stage HPC; and a single intermediate pressure turbine (IPT) driving an eight-stage intermediate pressure compressor (IPC).

The Trent 800 follows the standard build of the Trent family with next generation wide-chord fans and three-shaft architecture, so the additional IPT

777-200/-300 SPECIFICATIONS TABLE

Aircraft variant	Engine type	Engine take-off thrust lbs	MTOW lbs	MLW lbs	MZFW lbs	OEW lbs	Max payload lbs	Fuel capacity USG	Seats 3-class	Range nm	Belly freight cu ft
777-200	GE90-76B	77,200	506,000/ 545,000	445,000	420,000	310,100	109,900	31,000	305	5,235	5,330
	GE90-85B	84,700	580,000	460,000	430,000	316,600	113,400	45,220	305	5,795	5,330
	PW4074	74,500	506,000	445,000	420,000	306,200	113,800	31,000	305	4,015	5,330
	PW4077	77,200	545,000	445,000	420,000	306,500	113,500	31,000	305	5,140	5,330
	PW4084	84,760									
	PW4090	90,500									
	Trent 875	73,500	506,000	445,000	420,000	302,100	117,900	31,000	305	4,100	5,330
Trent 877	76,000	545,000	445,000	420,000	302,400	117,600	31,000	305	5,210	5,330	
777-200ER	GE90-90B	90,000	580,000/ 656,000	460,000	430,000			45,220	305	7,700	5,330
	GE90-94B	93,700	656,000	460,000	430,000	317,000	113,000	45,220	305	7,770	5,330
	PW4084	84,600	580,000	460,000	430,000	312,700	117,300	45,220	305	5,845	5,330
	PW4090	90,200	656,000	460,000	430,000	314,400	115,600	45,220	305	7,650	5,330
	Trent 884	83,600	580,000	460,000	430,000	308,600	121,400	45,220	305	5,910	5,330
	Trent 892	92,000		460,000	430,000			45,220	305	7,665	5,330
	Trent 895	93,400	656,000	460,000	430,000	309,000	121,000	45,220	305	7,740	5,330
777-200LR	GE90-110B	110,100	766,000	492,000	461,000	320,000	141,000	47,890	301	9,380	5,330
777-300	GE90-94B	93,700	660,000					45,220	368	6,015	7,120
	PW4090	90,000	660,000	524,000	495,000	348,400	146,600	45,220	368	6,015	7,120
	PW4098	98,000	660,000	524,000	495,000	349,400	145,600	45,220	368	5,645	7,120
	Trent 892	91,600	660,000	524,000	495,000	342,900	152,100	45,220	368	5,955	7,120
777-300ER	GE90-115B	115,000	775,000	554,000	524,000	370,000	154,000	47,890	368	7,930	7,120
777-200F	GE90-110B	110,100	766,000	575,000	547,000	318,300	226,000	47,890		4,885	23,051

and IPC. This design means that the Trent 800 is the lightest engine for the 777.

Fuel capacities

The original 777-200 has a fuel capacity of 31,000 US Gallons (USG) (*see table, this page*). The 777-200 derivatives, the -200ER and -200LR (and -200LRF) have additional fuel capacity of 45,220USG and 47,890USG. The 777-300 has the same fuel capacity as the -200ER, while the -300ER has the same capacity as the -200LR.

Accommodation & interior

The 777-200 model series has 305 seats in a standard tri-class layout, 375 in a two-class layout, and 418 in all-economy.

Of the two-class operators, none have as many as 375 seats. Emirates has the highest number, with 346 seats on its -200. Other operators, which had a high number of seats in a two-class configuration, were mostly based in the Asia Pacific area, including Thai and Cathay Pacific. Delta has the least with 268 on the -200ER.

In three-class layouts on the -200ER, Air New Zealand has the largest number of seats with 313 in business, premium-economy and economy cabins. Nine-abreast configurations are used in the

economy and premium-economy cabins.

Most other operators use fewer than the standard 305 seats. All Nippon Airways (ANA) has 223 seats in the tri-class layout, but has a large 70-seat business class.

This number is unsurpassed by any other 777 business cabin except on some ANA and JAL -300ERs, although Air France comes close with 67 business seats on its -300s.

United Airlines and British Airways are the only airlines to have a four-class configuration on their 777-200s, with 255-269 seats and 229 seats respectively.

The 777-300 series has a standard tri-class layout of 368 seats, 451 seats in a two-class layout, and up to 550 in an all-economy charter layout. Air France comes close to this with 472 seats in one configuration of the -300.


Most three-class -300s have 300-380 seats, while JAL and Singapore Airlines have less on theirs. Emirates and KLM have 425 seats in a two-class layout on their -300s, but most operators only get 350-400.

Qatar Airways' also configures its -300ER with two classes, but it only holds 335 passengers due to the generous pitch and width of its business and economy seats. The four-class layout is equally popular on the -300, and ANA and JAL configure their -300ERs to hold 246-272 passengers.

Freight capacities

The five passenger variants have belly freight capacity. The -200 series can carry six 96-inch X 125-inch pallets or 18 LD-3 containers in the forward cargo compartment (each with 158 cubic feet capacity). The aft cargo compartment can hold 14 LD-3 containers or four pallets. The bulk cargo compartment at the rear has a capacity of 600 cubic feet. If the three optional fuel tanks are added to the -200LR, the aft cargo compartment capacity drops to eight LD-3 containers, reducing the total from 32 LD-3s to 26.

The -300 series can hold up to eight pallets or 24 LD-3 containers in the forward hold, 20 LD-3 containers or six pallets in the aft hold, and 600 cubic feet of bulk cargo. If the optional lower hold toilet facilities are fitted to the -300ER, the aft hold capacity falls to four pallets.

The 777F has the same lower deck cargo capacity as the -200LR passenger aircraft, with a large maindeck cargo door accommodating 96-inch X 125-inch pallets. The maindeck capacity is 27 pallets, making the total capacity 37 pallets plus 600 cubic feet of additional bulk cargo. Live animal carriage is possible on the 777 freighter. 

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777 fuel burn performance

The fuel burn performance of the 777's most numerous variants with different engine selections are analysed.

The fuel burn and operating performance of four of the five passenger variants of the 777 aircraft are analysed and assessed. All three engine families powering these aircraft are represented in this analysis.

Aircraft variants

The 777-200 has three different variants: the -200, -200ER and the -200LR. All three have analysed here, as well as the -300ER.

All three engine manufacturers are represented for the -200 and -200ER. The -200LR and -300ER are powered exclusively by the GE90-110B/-115B.

The engines selected for the analysis of the 777-200 all have a thrust rating of about 77,000lbs, making a fair comparison between the airframe-engine combinations possible. The three engine variants chosen are the GE90-76B, PW4077 and Trent 877, because they are the most popular thrust rating and variants for the -200, particularly the PW4077 engine.

The maximum take off weight (MTOW) for the aircraft is 545,000lbs.

The same basis of comparison has been used for the 777-200ER, but using four engine options. The two most common thrust ratings powering the -200ER are 90,000lbs and 94,000-95,000lbs. The lower thrust is covered by the GE90-90B and PW4090 powering aircraft with an MTOW of 656,000lbs. The higher thrust of 93,700lbs is represented by the GE90-94B and Trent 895, also powering aircraft with an MTOW of 656,000lbs.

The 777-200LR has an MTOW of 766,000lbs and is the longest-range 777 variant. It has been assessed using the only engine currently available, which is the GE90-110B with a thrust rating of 110,000lbs.

The 777-300ER is now the only -300 series variant available from Boeing and is offered with the highest-rated engine, the GE90-115B. The engine being assessed therefore has a rating of 115,000lbs thrust, and the aircraft has an MTOW of 775,000lbs.

There are many thrust and MTOW variations used by different airlines. The basic specifications, as stated by the manufacturers, have been used for these calculations.

Flight profiles

Aircraft performance has been analysed both in-bound and out-bound for each route in order to illustrate the effects of wind speed and its direction on the actual distance flown, otherwise known as equivalent still air distance (ESAD). Average historical winds and temperatures for the month of October have been used in the flight plans produced by Jeppesen. The flight profiles in each case are based on International Flight Rules, which include standard assumptions on fuel reserves, diversion fuel, plus contingency fuel. A taxi time of 25 minutes has been factored into the fuel burns and added to the flight times to get block times. Long-range cruise (LRC) speed has been used. This is slower than other cruise speeds, but it consumes less fuel per nautical mile, thereby allowing the aircraft to fly further. Economy cruise is more likely for shorter flights. This provides an economical and operational compromise between fuel consumption and flight time. The LRC speed is different for each airframe-engine combination, as designated by the manufacturer. The speeds and the effects on the block times are shown. There are some large variations given the lengths of the routes.

The passenger airframe and engine combinations analysed have been assumed to have full three-class passenger payloads. The seat configurations used are Boeing's standard layouts of 305 seats for the 777-200 and 368 seats for the 777-300.

An alternative cabin layout on the longer-range 777-200LR and -300ER includes a crew rest area above the cabin. This reduces the passenger seat counts to 301 and 365 respectively.

For the purposes of this analysis, the passenger complement has been left the same for simplicity. The standard weight for each passenger and their luggage is assumed to be 220lbs with no additional cargo. The payload carried is therefore 61,000lbs for the 777-200s and 73,600lbs for the -300.

Routes analysis

Most of the big airlines in each of the global areas operate 777s. The majority operate the aircraft on long-haul routes, but some operators in the Asia Pacific use



The 777-300ER has the lowest fuel burn per seat of all 777 variants and models. This is mainly due to it having 17% more seats but burning only a little more fuel than the -200ER.

FUEL BURN PERFORMANCE OF 777

City-pair variant	Aircraft	Engine model	MTOW lbs	TOW lbs	Fuel burn USG	Block time mins	Passenger payload lbs	ESAD nm	Fuel per seat	Wind speed
LHR-IAH	777-200	GE90-76B	545,000	529,297	23,324	690	67,100	4,654	76.5	-29
	777-200	PW4077	545,000	528,901	23,183	718	67,100	4,642	76.0	-30
	777-200	Trent 877	545,000	534,032	24,174	680	65,000	4,649	79.3	-29
IAH-LHR	777-200	GE90-76B	545,000	511,375	20,240	599	67,100	3,928	66.4	37
	777-200	PW4077	545,000	515,483	20,551	583	67,100	3,940	67.4	37
	777-200	Trent 877	545,000	517,870	21,001	589	67,100	3,938	68.9	37
LHR-NRT	777-200ER	GE90-90B	656,000	546,619	25,062	718	67,100	5,210	82.2	15
	777-200ER	GE90-94B	656,000	546,076	25,010	720	67,100	5,200	82.0	15
	777-200ER	PW4090	656,000	537,979	23,728	678	67,100	5,196	77.8	16
	777-200ER	Trent 895	656,000	550,409	25,517	716	67,100	5,202	83.7	15
	777-300ER	GE90-115B	775,000	616,029	26,901	711	80,960	5,200	73.1	15
NRT-LHR	777-200ER	GE90-90B	656,000	563,708	27,544	776	67,100	5,473	90.3	-11
	777-200ER	GE90-94B	656,000	563,155	27,453	779	67,100	5,473	90.0	-11
	777-200ER	PW4090	656,000	454,054	25,022	713	67,100	5,474	82.0	-12
	777-200ER	Trent 895	656,000	569,547	28,254	773	67,100	5,475	92.6	-11
	777-300ER	GE90-115B	775,000	633,908	29,468	766	80,960	5,471	80.1	-11
YYZ-HKG	777-200LR	GE90-110B	766,000	670,123	37,127	957	67,100	7,190	121.7	11
HKG-YYZ	777-200LR	GE90-110B	766,000	669,322	36,624	940	67,100	6,837	120.1	32

Source: Jeppesen

it on high-density, short- to medium-haul routes.

The first route to be analysed is London Heathrow (LHR) to Houston (IAH) using the 777-200 and three engine options. This reflects many of the intercontinental routes on which the 777-200 is used, by airlines such as Continental and Emirates. Ellington Field Airport (EFD) is used as the alternate for IAH. London Stansted (STN) is used as the alternate on the return sector to LHR.

The first sector of LHR-IAH has block times of 680-718 minutes, and has a tracked distance of 4,349nm. This sector is hampered by a head wind of 29-30kts and an ESAD of 4,642-4,654nm. The return sector to LHR has a tracked distance of 4,269nm, and experiences a tailwind of 37kts. This results in shorter block times of 583-599 minutes and an ESAD of 3,928-3,940nm.

The second route to be analysed is London Heathrow to Tokyo Narita (NRT) for the 777-200ER and the -300ER. This is a longer route typical of those on which the -200ER and -300ER are used by large airlines such as JAL and ANA.

The alternate airport on the route to NRT is Nagoya (NGO), while STN is the alternate for the operation to LHR. The LHR-NRT sector has a tracked distance of 5,365nm, with a tail wind of 15-16kts. Block times were 678-720 minutes and the ESAD is about 5,200nm.

The return sector of NRT-LHR has a

headwind of 11kts, which increases the flight time by an hour, even though the tracked distance is shorter at 5,342nm. ESAD is 5,473nm. The -300ER completes both sectors about 10 minutes faster than the -200ER.

The final route of Toronto (YYZ) to Hong Kong (HKG) is used for the 777-200LR. This city-pair is an Air Canada route. The diversion airports used here are Ottawa (YOW) on the route to YYZ, and Macau (MFM) on the route to HKG. Both sectors are similar, having block times of 940-957 minutes. The average tracked distance of 7,286nm, and the route tail winds in both directions are 11 knots to HKG, and 32 knots to YYZ.

Fuel burn performance

The fuel burn performance of each airframe-engine combination is shown (see table, this page) for all routes along with the associated fuel burn per passenger and per passenger-mile.

On the first route, LHR-IAH and IAH-LHR, the GE90-76B comes out with the best fuel burn per passenger of 66.4 USG on the return sector, but it has the slowest flight time, although only by about 10 minutes. The PW4077 is close in fuel burn performance to the GE90. The Trent-877-equipped aircraft did not perform as well on fuel burn as the other two engines on this route. The seemingly fast block time on the first sector is due to the reduced payload, which is necessary in order for this combination to complete

the flight.

The 777-200ER variants have burns of 77.8-83.7USG per passenger on the second route of LHR-NRT, with the PW4090 being the best performer. On the NRT-LHR route, fuel burns are 82.0-92.6USG per passenger.

The larger 777-300ER has lower burns of 73.1USG per passenger on LHR-NRT, and 80.1USG per passenger on NRT-LHR (see table, this page). This is because 17% more passengers are carried, resulting in only a 5-12% higher fuel burn compared to the -200ER.

On the third route of YYZ-HKG, the 777-200LR has a burn of 121.7USG, and a block time of 957 minutes. It follows a tracked distance of 7,350nm and has an ESAD of 7,190nm. Burn per passenger is almost the same, with an ESAD of 6,837nm and block time of 940 minutes (see table, this page).

If all flights had been flown at the same speeds, then the results again would have been that the PW4090 had both the fastest times and lowest fuel burn on the LHR-NRT sector.

Once fuel burn per passenger-mile is analysed then there is little variation with route length. The largest factor having an impact on burn per passenger-mile is aircraft size and seat count, which is illustrated by the -300ER's 12-14% lower burn. **AC**

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777-200/-300 modification programmes

The major modification & upgrade programmes for the 777 include a performance improvement programme, a drag reduction modification, engine upgrades and avionic enhancements.

There have been a number of modifications and upgrades that have taken place on the 777.

The majority have been Airworthiness Directives (ADs) and Service Bulletins (SBs). There have also been optional improvements. One option, which is regularly taken up by most passenger airlines, is the reconfiguration and improvement of their cabin environments and interior layouts. Another option has been the improvement of certain aspects of the 777's operational costs. This particular improvement is offered by Boeing as the Performance Improvement Package (PIP).

Performance improvement

The 777-200LR has enhancements in its design that were not in place for previous models. These improvements in weight, drag, and therefore fuel burn, have provided operators with cost savings. These enhancements were then included on all new 777-300ER aircraft

delivered after November 2005, with Air France taking delivery of the first aircraft with the improvements. The developments on the 777-200LR and freighter, which trickled down to the all-new -300ER, will shortly be available as a PIP for older 777s. This includes the earlier built -300ERs.

Older 777-300ERs had already shown an improvement of up to 2% in fuel burn by operators with aircraft in revenue service, compared to what had been expected prior to delivery. The new -300ERs have an overall efficiency improvement of 1.4% due to the PIP, in addition to the initial 2% improvement.

The -300ER package involves modifying the vortex generators and the air induction systems for the environmental control systems in order to reduce the amount of drag caused by the aircraft's shape. In addition, the aircraft's weight has been reduced by the utilisation of lighter materials for internal structures such as the maindeck floor panels. The 1.4% improvement in fuel efficiency,

according to Boeing, equates to an annual fuel saving of at least 200,000 US Gallons (USG). For a fuel price of \$2 per USG, an annual saving of \$400,000-500,000 per aircraft can be made.

These improvements form the basis of the PIP, which will provide each aircraft 1% more efficiency, thereby enabling older models to perform more like younger ones.

Boeing began offering the PIP at the start of 2008, and it is expected to be certified by the Federal Aviation Authority (FAA) and to be in operation by April 2009. It has been taken up by at least 13 airlines, including many of the larger 777 operators. British Airways (BA) is one of the latest operators to order the PIP modification for all its older 777s. BA and Boeing believe that the PIP will provide an annual fuel saving of at least \$200,000 per aircraft (assuming a crude oil price of \$70-100 per barrel), which represents a potential saving of over \$8 million per year across the whole 777 fleet.

Boeing has stated that the changes will reduce carbon dioxide emissions by 3 million lbs per aircraft per year. The potential reduction in both fuel consumption and carbon dioxide emissions has gone a long way to encouraging operators to order the PIP.

The PIP includes low-profile vortex generators, an enhanced ram air system and drooped ailerons. Boeing has said that it is still looking at further modifications to add to the PIP. Dan da Silva, vice president of sales at Boeing Commercial Aviation Services, has stated that "the 777 is among the most efficient, environmentally progressive airplanes in operation, but we must continue to pursue these performance gains". If fitted to all 777-200, 200ER and -300 aircraft,



The 777-300ER had a 2% better fuel burn performance than predicted when it first entered service, and the performance improvement programme realises a further 1.4% reduction in fuel consumption.

While the 777 has had various ADs and SBs issued, it has not yet had any major ADs issued that incur high costs or are serious safety-related issues.

that would amount to over 500 aircraft. This excludes the older -300ERs.

Airframe modifications

Reduction in drag of any aircraft is important and on the 777 this has been improved, in part through the PIP, by modifying the aircraft's vortex generators. Vortex generators are small extensions that maintain steady air flow over the wing surface. Changing their size or location can seriously help or hinder an aircraft's aerodynamics.

Another change to come from the PIP is on the environmental control systems. The air induction systems are modified to reduce drag. By drooping the outboard ailerons even more when flaps are extended, drag is again reduced. Although ailerons control an aircraft's banking movements, they also affect the lift on take-off and landing.

A major aspect of any aircraft design is reducing its overall weight while increasing its power and payload ability. Since the 777 first entered service, lighter parts have been developed to further reduce the weight of the 777. The predominant aspect has been the increased use of composite materials such as aluminium alloys and titanium. The maindeck floor panels can now be replaced with much lighter panels without losing strength, and the ducts of the environmental control system are now made from lighter materials too.

Engine modifications

While developing the GE90-94B, and with the GE-115B in mind, General Electric (GE) developed a PIP for the GE90-90B. This package was offered at GE's facility in South Wales and could be integrated during normal maintenance. The advanced 3-D aerodynamic components of the -115B were included in the package along with new seals and turbine technology to improve the engine's performance and the thrust in particular. This all came together to produce a 1.6% fuel burn improvement and an additional exhaust temperature margin of more than 20 degrees Celsius. Other improvements included longer on-wing times, increased payloads and reduced maintenance costs.



GE developed the GE90-115 for the 777-300ER and de-rated the engine design for the -200LR and 777F. Developments included aspects that improve fuel efficiency, thrust and the noise levels of the engines. The improved combustor means that the engine is producing no more than 50% of the carbon dioxide levels currently allowed by international standards.

Two major Service Bulletins (SBs) were issued with regard to the thrust reverser V-blade. The first, SB777-78-0061, required the inspection and change, if necessary, of the outer V-blade. The second, SB777-53-0042, refers to the splice plate assembly change of floor panels.

Avionics

The first major avionics upgrade since 1995 involved the introduction of an improved Airplane Information Management System (AIMS) called Aims-2. This upgrade promises to be smaller, faster, less expensive and easier to use than the original system.

There have been six major SBs issued affecting the Electronic Flight Bag (EFB) and associated flight deck technology.

SB777-78A requested the installation of a class 3 EFB dual display system.

SB777-46-0015 requested the installation of an on-board network server, software and terminal wireless LAN unit.

SB777-46-0018 then dealt with the installation of hardware, such as Ethernet ports and personal computer (PC) power outlets. As passenger airlines have had to tighten up security, on-board security has also been increased, with items such as

cockpit door surveillance systems. SB777-23-0231 involved the de-modification of the system. The communications systems have been upgraded by the installation of a single HSD Satcom transceiver and 3-channel Satcom system as referred to in SB777-23-0257.

SB777-34-0132 dealt with back-up and requested the installation of an integrated standby flight display system.

Airworthiness Directives

The 777 has had ADs issued against four main areas since it entered service.

The first one is SB777-27A-0073, which involved modifications to the flight controls, trailing edge flaps and outboard flap support gimbals plate change.

The second AD is SB777-27A-0071, which related to the flap pin.

Modifications were made to the trailing edge flap support pin, ball set and bushing replacement.

The third AD, SB777-57-0054, related to the torque tube. Modifications were made on the wing, trailing edge and trailing edge devices. The inboard flap and inboard support were replaced.

The fourth area involved the thrust reverser and incorporated SB777-78A-0065 and SB777-53A-0044. Both of these involved inspections, the first covering the inner-wall thermal insulation blanket and its associated panel. The second inspection, for corrosion, was of the fuselage skin panels on Section 43 and section 46. Preventative measures were to be undertaken if necessary. [AC](#)

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777 family maintenance analysis & budget

The 777-200/-300 have the lowest maintenance costs in their size class. The twin-engine design and maintenance programme contribute to low costs.

The 777 family has been a successful programme, becoming a long-haul workhorse for many operators, and displacing the 747 from this role in the process. The first 777 entered service in 1997, and there are now 729 aircraft in operation and another 357 on firm order.

The maximum take-off weights (MTOWs) and range capabilities of the -200 and -300 series have been steadily extended since 1997. The majority of aircraft are used on long- or ultra-long-haul missions. Earlier-built -200s and -300s are used on regional and medium-range services, particularly in the Asia Pacific. All aircraft on firm order are long-range models.

The most notable feature of the 777 is its maintenance programme, which comprises about 2,000 tasks with a range of different intervals and interval criteria. Operators are free to group tasks into checks that suit their operating schedules and maintenance planning.

777-200/-300 in operation

The 777-200 can broadly be divided into low, medium and high gross weight aircraft. There is also the specialist ultra-high gross weight -200LR powered by the GE90-110B (see 777 family specifications, page 6).

The long-range group comprises the most aircraft, with 375 in service. The low gross weight category is the second largest with 58 aircraft, while there are 42 medium-weight aircraft. There are also 21 -200LRs in operation, while another 28 are on firm order.

The low gross weight aircraft comprise: 41 PW4074/77-powered aircraft operated by Air China, All Nippon Airways (ANA), and Japan Airlines (JAL); four GE90-85B-powered aircraft operated by China Southern; and 13 Trent-875/77/90-powered aircraft operated by Cathay Pacific and Thai International. These aircraft are all operated by carriers in the Asia Pacific and are used on short-haul, high-density missions. The aircraft operated by China

Southern, Cathay, Thai International and Air China are used on medium-haul services with flight cycle (FC) times of 2.3-3.2FH and annual utilisations of 2,800-3,900FH. The ANA and JAL aircraft are used on domestic Japanese services of about 1.2FH per FC and annual utilisations of 2,000-2,200FH.

Most medium gross weight aircraft are mainly used on long-haul missions. United, Korean, Transaero, British Airways (BA) and Continental Airlines all use their aircraft on FC times of more than 5.0FH, and Continental actually has an average of 10FH. Emirates, Kenya Airways, and JAL have accumulated 3,600-3,800FH at FC times of 3.2-5.1FH.

The majority of high gross weight aircraft are used on long-haul missions. The exception is Saudia, which requires high gross weight performance because of the high ambient temperatures it experiences for its domestic operations.

Most high gross weight aircraft achieve 4,500-5,000FH per year at FC times of 5-10FH. Aeromexico, Air France, Alitalia, Austrian Airlines, Continental Airlines and Delta have the highest average FC times of 9.0FH per FC and higher.

The -200LR fleet is still small. Delta operates its aircraft in cycles of up to 13FH and has utilisations of about 5,600FH per year.

The -300 fleet is relatively small, with 56 aircraft. The aircraft was acquired mainly by operators in the Asia Pacific to replace 747s on high-density regional operations. Cathay, Singapore Airlines (SIA), Thai International and Korean Air all have FC times of 2.4-3.6FH, and have annual utilisations of 2,700-4,500FH.

The ultra-high gross weight -300ER is more popular than the -200LR. There are 160 -300ERs in operation with the GE90-115B engine, with Air Canada, Air France, Air India, ANA, Emirates, EVA Air, Jet Airways, and SIA. Most fleets accumulate at least 5,000FH per year and have FC times of at least 8.0FH.

All 777-200s and -300s so far delivered are in operation as passenger-configured aircraft, and their

maintenance costs are analysed here for aircraft completing about 3,000FH and 1,000FC per year at an FC time of 3.0FH on medium-haul missions, and about 4,750FH and 650FC per year at an average FC time of 7.5FH on long-haul missions.

Maintenance programme

The 777's maintenance programme has up to 2,000 tasks with varying intervals. Operators are free to group these into maintenance checks that suit their operations. The tasks are listed in the maintenance planning document (MPD). Each task is listed with its respective interval, which is specified in FH, FC or calendar time. Some tasks combine two of these interval criteria.

In addition there are specific pre-departure, transit and daily checks. George Sifnaios, maintenance program manager for the 757/777 at Delta Tech Ops, says that there are 125 interval combinations.

There are also a few other tasks with specified intervals. These are inspection tasks that need to be carried out upon a component's removal, such as a zonal inspection of the auxiliary power unit (APU) compartment, or engine mount inspection during an engine change.

"The MPD includes all 1,700 maintenance tasks for each model and configuration," explains Nestor Koch, market & sales vice president at VEM Maintenance & Engineering. "The first section of the MPD contains the system maintenance programme for all system tasks, which total about 600. The second section is the structural maintenance programme for the external and internal structural inspections, corrosion prevention and control tasks, and fatigue-related inspections which total about 800 tasks. The third section is the zonal inspection programme, which includes general visual inspections in a particular zone of the aircraft to ensure that components, parts, wiring and tubing are securely attached, and inspections of the general condition of any system or structural items within a specific zone on the aircraft. There are about 300 of these tasks for each aircraft model and configuration."

Sifnaios says that section 9 of the MPD covers airworthiness limitations (AWLs) and certification maintenance requirements (CMRs). "The supplemental structural inspections are listed in Section 9 'Airworthiness Limitations' of the MPD, and concern those Structural Significant Items (SSIs) that do not receive adequate fatigue damage detection from the initial baseline structural programme and therefore require supplemental inspections," says Sifnaios. "These will begin after a defined

The majority of 777s are used on long-haul and ultra long-haul operations, generating annual utilizations that average about 4,750FH per year. The aircraft's twin-engine design and maintenance programme allow it to achieve lower maintenance costs than the A340-200/300.

threshold (of 30,000FC) in the MPD is reached, with repeat intervals to be determined using the damage tolerance rating (DTR) form. The DTR system defines a required DTR (a numerical value) that must be achieved for each SSI.

"A CMR," continues Sifnaios, "is a required periodic task, and is established during the design certification of the aircraft as an operating limitation of the type certificate. An example of a CMR inspection is the operational check of the ram air turbine (RAT) and RAT auto and manual deployment systems, which has an interval of 6,000FH.

"Also, the fuel system AWLs, better known in the industry as SFAR88, are covered in Section 9," explains Sifnaios. "These are mandatory maintenance actions required to ensure that unsafe conditions identified by the SFAR 88 safety review do not occur or are not introduced into the fuel tank system during the operational life of the aircraft. The AWLs may only be revised with the approval of the Seattle Federal Aviation Administration (FAA) aircraft certification office."

Task intervals

"Most of the system tasks have FH intervals, but some have FC/calendar intervals, FH/calendar and FC intervals," says Koch. "Most structural tasks have FC/calendar intervals, and there are some AWL tasks that have threshold and repeat intervals in FC.

"Zonal tasks have mainly FC/calendar intervals, although a few have FH intervals," continues Koch. "Overall there are about 370 tasks that only have FH intervals, ranging from 100FH to 30,000FH. There are eight tasks with FH/calendar intervals, and 40 tasks with FC intervals. FC intervals range from 100FC to 32,000FC.

"There are also about 330 tasks for which the threshold and repeat intervals have yet to be decided. These are from the AWL, and their intervals will be in FC. Most AWL structural tasks have a threshold interval of 30,000FC, so they will not be performed until the aircraft reaches old age, and may never actually be performed by an airline utilising the aircraft purely for long-haul operations," explains Koch.

Only carriers like JAL and ANA that accumulate about 2,500FC per year will



have to start performing these tasks when their aircraft reach 12 years of age. The repeat intervals of some of these tasks have yet to be published in the MPD. There are 37 tasks, for example, with an initial interval of 32,000FC and 6,000 days, but their repeat interval has not been determined. Another 17 tasks have initial intervals of 28,000FC and 5,250 days. Others have initial intervals of 24,000FC/4,500 days, 16,000FC/3,000 days, and 10,000FC/3,000 days.

"There are also about 800 tasks with FC/calendar intervals, and about 150 with calendar intervals. Calendar intervals range from 30 days to 6,000 days," continues Koch.

However, the actual intervals for each task vary between operators. More experienced operators with longer experience of utilising larger fleets will have been able to get extensions for task intervals from their local airworthiness authorities.

Operators are free to group these tasks with different intervals into maintenance checks according to their different interval criteria. The two most important factors that influence how operators group tasks are the FH:FC ratio and the rate of annual utilisation. One example is item 12-008-00, which involves lubrication of the leading-edge slat torque tube couplings, supports and gearbox couplings. This item has an interval of 6,000FC and 1,125 days, whichever is reached first. Only aircraft that are completing more than 5FC per day will reach the 6,000FC limit first. Most aircraft operating on long-haul missions will reach the calendar limit long before reaching the 6,000FC limit.

Another example is item 72-206-01,

which is a detailed borescope inspection of the first and second stage high pressure turbine (HPT) blades on the GE90 on the left engine. This has intervals of 2,000FH and 600FC, whichever is reached first. This depends on the aircraft's FH:FC ratio.

Taking United Airlines' programme as an example, there are a total of at least 1,400 tasks, comprising: 320 with FH intervals of 48-24,000FH; 68 FC tasks, with initial thresholds of 30-32,000FC; 134 calendar tasks, with initial thresholds of 75-6,000 days; 143 tasks with FH and calendar intervals; and 728 tasks with FC and calendar intervals.

The 777, like the 737NG, does not have pre-defined A and C checks. The aircraft does have some specific tasks grouped into defined pre-flight, transit and daily checks for a line maintenance programme. Most operators do, however, group tasks with larger intervals into generic 'A', 'B', 'C' and structural checks. These can differ in content and interval between different carriers, but there are also similarities between different operators.

Line maintenance programme

Some line maintenance tasks have to be performed in specific line checks. These are defined by each operator to ensure the execution of MPD tasks with small intervals such as transit, daily, 48 hours and 125FH. The operator can create 'transit', 'daily', 'weekly' and 'monthly' checks to address these tasks.

The line maintenance programme that most operators actually follow has the standard line checks that are used for all aircraft types. "The first of these is a daily



check which has to be performed at an interval not exceeding 48 hours,” explains Matko Dadic, sales manager at Europe Aviation.

Aircraft that are utilised on short- or medium-haul services can have the daily check performed each day at their homebase, usually as an overnight check. Aircraft used on long-haul operations are often unable to return to homebase once every 24 hours so, if permitted, a 48-hour interval can allow the daily check to be performed at the homebase when the aircraft returns, according to its operating schedule. These checks have to be performed by mechanics.

“However, the transit and pre-flight checks can be carried out by flightcrew members after completion of a training programme authorised by the operator’s local authority,” says Dadic. “The transit check is performed at every transit and following a daily check, while the pre-flight checks are performed prior to each departure.

“An extended-range, twin-engine operations (Etops) service check also has to be done prior to an Etops flight,” continues Dadic. “These tasks cannot be done by flightcrew, due to the specific Etops tasks included in the Etops service check”. To obtain Etops approval operators must perform some special MPD tasks. Examples of daily tasks for an Etops include: reading the status messages, existing faults and fault history and taking appropriate actions; checking engines and the APU for oil consumption; and checking the cargo compartment linings for damage.

“Next is the service check, which has to be performed every eight days, or no more than every 216 hours,” explains Dadic. “This is often called the weekly

check by many operators.

“The pre-flight check mainly comprises visual inspections,” says Dadic. “Although routine checks can be performed by flightcrew, any defects that they find have to be rectified by mechanics. A defect can be deferred if it is a minimum equipment list (MEL) item. The length of the deferral is listed in the MEL. Items not listed in the MEL are no-go items, which means that they have to be rectified before the aircraft can fly again. The aircraft’s technical log should also be examined to observe the listed outstanding defects.”

Transit checks are almost the same as pre-flight checks. “The routine visual inspections of these two checks include pitot tubes, lights, bay doors and access panels, slats and flaps, engine inlets, and wheels and landing gears,” continues Dadic. “Interior inspections include items such as radios, fire detectors, flightdeck oxygen and other emergency equipment. Other tasks include inspection of the radome latches, ram air inlet and outlet doors, left and right integrated-drive generator oil levels, and a fuel drain from all fuel tanks.”

The Etops service check includes an inspection to see that the engine oil filler cap seal is in good condition and that the cap is correctly fitted.

Daily checks are slightly larger in content than transit and pre-flight checks. The routine tasks are the same as those for transit and pre-flight checks, but also include additional tasks for line mechanics, such as the manual checking of tyre pressures, brake disc wear, and shock absorbers. Engine oil levels should also be checked, as should the APU bay. “The daily check also includes ensuring that the toilets and the potable water

The 777’s maintenance programme has about 2,000 tasks and 125 different task intervals. Operators are free to group tasks into checks according to their operation, rate of utilisation and FH:FC ratio. This makes maintenance planning more efficient and results in lower MH requirements than older generation aircraft.

system are serviced, and that the passenger cabin is checked for general condition and cleanliness. The aircraft’s maintenance log and cabin discrepancy log are also reviewed,” says Dadic.

Weekly checks have the same content as the daily checks plus a few additional tasks. “These include examining the magnetic chip detectors and landing gear shock absorbers, draining and refilling water, and checking emergency gas bottles and cargo compartment doors,” explains Dadic.

As well as the MPD tasks with transit or daily intervals, operators can choose to include additional tasks in the line checks according to their own experience.

“In addition to the pre-flight and transit checks, which are valid up to four hours prior to the flight’s departure, there is an after-landing check,” says Walid Elkhafif, aircraft system senior engineer at Egyptair Maintenance & Engineering Company. “This is required after each arrival at base for stops that are four hours or more.”

Koch gives an example of a line maintenance programme of pre-flight and transit checks, a daily check at 48 hours, and a monthly check every 30 days.

An example of a line maintenance programme is given by Fabrice Defrance, aircraft maintenance and engineering vice president at Air France Industries. “We have the usual pre-flight, and then daily and weekly checks. The content of the daily and weekly checks is similar, with the weekly having just a few more tasks. We also have an ‘M’ check, which has an interval of 850FH. This is the first significant check over the line maintenance programme, and has an interval similar to many operators’ ‘A’ checks. This has a downtime of about eight hours and takes 20-30 man-hours (MH) to complete. Our ‘A’ check interval is 1,200FH, and we hope to escalate the check to 1,500FH in 2009. This check is a hangar check.”

A checks & base maintenance

Most operators group tasks with intervals from about 500FH, 200FC and 60 days into generic A checks or higher base checks.

Delta’s programme for the 777 is one example. “We used to have an A check every 500FH, 100FC and 50 days,

777 OPERATOR'S HANGAR CHECKS & INTERVALS

Airline operator	Air France	Delta Airlines/ Tech Ops	Egyptair	El Al	United Airlines	VEM
Lower check	'M'check 850FH					
A check	1,200FH	250FH 50FC 25 days	500FH	600FH	300FH X 24 = 7,200FH	500FH X 12 = 6,000FH
C check	7,800FH 960FC 18 months	7,500FH 1,250FC 500 days	7,500FH 750 days	7,500FH 24 months	18 months	10,000FH 4,000FC 750 days
Heavy/structural check	4,000FC 66 months 8,000FC 108 months		36,000FH 3,000 days			

whichever interval was reached first," says Sifnaios. "We recently divided this into intervals of 250FH, 50FC and 25 days to help us achieve our operational goals (see table, this page). This has effectively made the checks into half A checks.

"The next highest checks are our 'C' checks. We used to have a system of a base check every 12 months. Every second check was a heavy check because many of the structural tasks were grouped into two-year intervals," continues Sifnaios. "The base check cycle was effectively completed every eight checks because the highest intervals of most tasks coincided with the eighth check. Later checks would, however, have more tasks because some have higher initial thresholds. We have recently changed our base check system to a 'C' check with intervals of 7,500FH, 1,250FC and 500 days, whichever is reached first (see table, this page). At our utilisation of about 5,250FH and 480FC per year, this check comes due every 16 or 17 months. This C check captures system, structural and zonal tasks. There is in fact no particular cycle of checks, and tasks are continuously added as the aircraft ages. There are, for example, tasks with intervals of 4,500 days or 30,000FC. The 777 has a continuous, rather than cyclical, maintenance programme, which consists of 52 C checks. Every sixth check (C6, C12, C18 etc) is the heavy check because it has 1C, 2C, 3C and 6C tasks. The C7 check, by comparison, has 1C and 7C tasks."

The A check in VEM's case has an interval of 500FH, as well as intervals in FC and days. Koch explains that there are 1A, 2A, 3A 4A, 6A and 12A tasks with intervals that are corresponding multiples of 500FH. The A check cycle is therefore completed at the A12 check at 6,000FH.

Koch explains that, like all operators' base maintenance programmes, VEM's is based on grouping tasks. "Most structural tasks are those with intervals of 4,000FC or higher, and many operators put these tasks into SC or heavy maintenance checks that have higher intervals than generic C checks, which have mainly system-related tasks. We, however, had an operator with a different approach. Most of the system tasks were in the A check multiples. The 1C check had an interval of 10,000FH, 4,000FC and 750 days, whichever was reached first (see table, this page). Most tasks in the 1C check were structural and zonal, and so had mainly FC and calendar time intervals."

Elkhafif explains that Egyptair has organised the 777's maintenance programme into phases of 500FH, and the equivalent FC and day intervals according to its pattern of operation, rate of utilisation and task intervals. Tasks are grouped into a multiple of 500FH according to their interval. The interval for Egyptair's generic 'A' check is 500FH, and the FC and day equivalents. "The first A check is performed at the first phase of 500FH. The first base or 'C' check is performed at the 14th phase, which is 7,500FH and 750 days, and the FC equivalent (see table, this page). C check multiples are therefore performed at multiples of these intervals. The heavy check interval is at phase 72, which is 36,000FH and 3,000 days, and the FC equivalent," explains Elkhafif. "There are also structural tasks, which are grouped for combining with the heavy check. The initial interval for this is 6,000FC and 1,125 days. Repeat intervals thereafter are 4,000FC and 750 days."

Air France Industries has a programme of M checks every 850FH, and A checks every 1,200FH (see table,

this page). The A checks include several system tasks that some operators might include in A check multiples or base checks. "Our base maintenance programme is based on calendar and FC intervals," explains Defrance. "We have a C check every 18 months, 7,800FH and 960FC, whichever is reached first (see table, this page). These checks alternate between a C1 and a C2 check. This compares with the earlier interval of 12 months for the C1 and 24 months for the C2 checks.

"The lighter C1 check has mainly system tasks, and the C2 check is the C1 plus some additional (zonal) tasks, and has a downtime of about five days," continues Defrance. "We also have SC checks for performing structural tasks. The SC1 has an interval of 66 months and 4,000FC, whichever is reached first, while the SC2 check has intervals of 108 months and 8,000FC. The SC check has also been escalated from its original interval of 48 months.

"It makes most sense for us to combine the SC checks with a multiple of the C check so as to reduce downtime. This means, for example, performing the C2 slightly early at 66 months, rather than at 72," continues Defrance. "The SC2 is the heaviest maintenance visit, because it includes a C1 or C2 check, the SC1 and SC2 structural inspections, interior refurbishment, and airworthiness directives (ADs) and service bulletins (SBs) with more significant MH."

United, like Delta, has divided its original A check package with an interval of 500FH into two 300FH checks for the purposes of Etops. This is an escalation from an earlier interval of 250FH. It has 24 A check segments, with the A24 check having an interval of 7,200FH. The base maintenance programme is a sequence of four checks, each of which includes

The 777's base check MH inputs are low relative to older types like the 747. Although the number of routine tasks will increase as the aircraft ages, MH will still be relatively low.

system, structural and zonal tasks. The current interval is 18 months. This is an escalation from the original interval of 12 months.

Line & A check inputs

Pre-flight and transit checks use small amounts of labour and materials. Dadic says that during a usual turnaround the 777 uses up to 2.5MH for these checks. Even though some of this labour can be provided by flightcrew, a conservative estimate of maintenance costs assumes that all labour is provided by mechanics. A generic labour rate of \$70 per MH equals a labour cost of \$175.

The materials and consumables used during these checks include oil, shock absorber cleaner, lightbulbs, and any items related to non-routine occurrences. A budget of \$50 should be allowed for these checks.

A daily check will use a little additional labour because of the larger workscope, and Dadic estimates that 4-5MH will be needed. This equals up to \$350. One mechanic is usually sufficient to complete the job. The actual labour amount will depend on any findings and non-routine work that arise from the routine tasks. There are also items such as refuelling tyres and changing lightbulbs. A budget of \$200 should be allowed for materials and consumables.

A weekly check has a larger scope than the daily check, but is often used to clear the smaller accumulated deferred defects that have arisen since the last weekly check. Dadic suggests that a budget of 6-8MH be used for labour, equal to \$420-560, and up to an additional \$500 should be allowed for materials and consumables.

A check inputs vary by operator as a consequence of differing maintenance programmes and styles of operation. A budget of 500MH and \$25,000 for materials can be used to reflect inputs for a generic maintenance programme. This is equal to a total cost of \$60,000.

Aircraft on annual medium-haul operations of 3,000FH and 1,000FC will require 1,000 pre-flight and transit checks, and 355 daily and 50 weekly checks per year. The total annual cost for these checks will be \$470,000, so reserves for these will be \$147 per FH (see first table, page 23).

While the generic A check interval is



500FH, the actual interval between A checks is likely to be 350-450FH, which means that the aircraft will also have seven to nine A checks. Reserves for these will be \$135-170 per FH (see first table, page 23).

Aircraft on long-haul operations at 4,750FH and 650FC will require about 650 pre-flight and transit checks, and 355 daily and 50 weekly checks each year. The total annual cost for these will be \$390,000, so the reserve will be \$82 per FH. Reserves for A checks will be similar to those for aircraft on medium-haul operations (see second table, page 23).

Base check contents

The content of the base checks will be more than just routine task card inspections and the non-routine rectifications that arise as a result. The downtime, tooling and gantry in the hangar provided by base checks mean that there is scope for several other elements to be added.

The first of these usually includes clearing all accumulated technical defects that are recorded in the aircraft's technical log. Other items are interior cleaning and varying levels of interior refurbishment, depending on which check is being performed. Modifications and upgrades are also usually included, as are ADs and SBs. Routine inspections can often reveal faults with system rotatables, and some hard-time components that have to be removed. The aircraft's downtime will also be exploited at some stage so that the aircraft can be stripped and repainted.

As operators are free to plan their own maintenance programmes, these can vary considerably. A generic programme

of a base check every 18 months is used here to illustrate the inputs for the base maintenance cycle up to the first heavy check, which will include a large number of structural tasks, removal and installation of a large number of rotatable components, and interior refurbishment. The heavy check is the C6 check, and the C3 check is a medium-sized check. The C6 check has the 3,000-day/100-month tasks, and the C3 check the 1,500-day/50-month tasks.

The actual interval achieved between checks is likely to be 15-16 months. Medium-haul aircraft will achieve 3,900-4,000FH between checks, and long-haul aircraft 5,900-6,300FH between checks. The C6 check will be completed at about 90 months, equal to seven and a half years, and equal to 22,500-23,500FH for medium-haul aircraft, and 35,000FH for long-haul aircraft.

Routine inspections

The routine inspections in the base checks will be a combination of system, structural and zonal tasks. The ability of operators to plan their own maintenance programmes and checks means that these tasks are now dealt with more efficiently than on previous generation aircraft.

Routine inspections use 800-900MH for the lighter C1, C2, C4 and C5 checks. These MH include removing and installing a small number of rotatable components, as well as a little interior work.

Further MH are required to clear defects that have arisen during operation and for non-routine rectifications that arise as a result of the routine task cards. With the clearing of defects included, the non-routine ratio will be more than



100%. The MH used for the C1, C2, C4 and C5 checks will be 1,000-1,400.

The C3 check will use 2,150MH and, like lighter C checks, will include removal and installation of rotatable components and some lighter interior work.

The C6 check is the heavy maintenance visit and will use 3,000MH. Another 2,000MH could be used to remove and install rotatable components. A major interior refurbishment will be included in this check, but the inputs for this are treated separately.

Engineering orders

Engineering orders (EOs) cover all modifications, upgrades, SBs and ADs. The 777 has so far been relatively free from major ADs or SBs. A few have arisen since the aircraft entered service, however.

One example of an SB included in base checks is AD 2007-11-23, which incorporates SB 777-27A0071 and relates to trailing edge flaps, the flap support pin, ball set and bushing replacement.

Another example is SB 777-27-0072, which relates to flight controls that affect the aileron and flap control, and requires a wire routing revision.

One SB requires the replacement of the passenger door seal, while another modifies or replaces the ram air door.

An example of an AD that is included in the 777's base checks is AD 2007-17-12, which is the horizontal stabiliser trim actuator ballscrew lubrication and inspection.

AD 2007-15-05 is a functional check on the elevator surface freerplay.

These ADs and SBs do not require large inputs of MH, but they do affect the aircraft because they have a relatively

high frequency of inspection.

Major ADs affecting the 777 involve the inspection and repair of the station 246 floorbeam, and the replacement of the wing torque tube and the gimbal support. These ADs and AD 2007-11-23 are large enough to require a special visit separate from a base maintenance visit, or to be included in a large check. Estimates by United Airlines are that it can take 3,500-7,000MH to complete.

An allowance of 500MH for the input of ADs and SBs will be made for lighter C1, C2, C4 and C5 checks, while 800MH should be budgeted for the C3, and a large input of 4,000MH should be used for the C6 check.

Rotatable components

Base checks will involve the removal of some hard-timed components. In the case of closed-loop components the removed rotatables are tested and repaired and then reinstalled on the same aircraft. Some components are replaced with new items. In the case of open-loop components the removed items cannot be repaired in the time allowed by the check's downtime, and serviceable items are installed on the aircraft.

Most of the rotatable components on the 777 are maintained on an on-condition basis. There are 2,300 rotatable components installed on the 777, although the number varies depending on the variant and exact configuration. Of these, about 1,700 are maintained on an on-condition basis, and the remaining 600 are maintained on a hard-time basis. Hard-time components include safety-related items, such as emergency escape slides, oxygen bottles, life rafts and batteries.

Heavy component maintenance costs account for 10-12% of total maintenance costs. About half of heavy component costs are related to brake repairs.

The remaining components that are maintained on an on-condition basis are removed during line checks in the event of malfunction or failure. They are then replaced during these line checks with serviceable units from an inventory of components. System checks during A and base checks may reveal component malfunction or failure, however. In this case replacement rotatable items will be required.

Interior work

The items that have to be refurbished at varying intervals are seat covers, carpets, sidewall and ceiling panels, overhead bins, passenger service units (PSUs), galleys and toilets. The intervals for refurbishing some of these items relate more to appearance and marketing considerations than airworthiness.

United uses a cabin maintenance module (CMM) to refurbish seat covers and carpets at intervals of 400FH or more. Delta inspects and cleans seat covers once every 10 days, but replaces them every two to four years in most cases. Similar intervals apply to carpet replacement.

Sidewall and ceiling panels have similar refurbishment intervals to overhead bins and PSUs. Air France, for example, refurbishes these items at every SC check, which has an interval of 66 months. Similarly, Egyptair refurbishes these items at every fourth C check, which takes place every six to seven years. VEM refurbishes these items at even longer intervals of up to 10 years, while Delta does this at every sixth C check, which is every eight or nine years.

Most operators refurbish galleys and toilets at similar intervals to panels, overhead bins and PSUs, with a heavy check affording the opportunity and downtime for the size of the workscope.

In the analysis used here, the major interior refurbishment is made at the C6 check. This includes the items described above, and consumes 5,500MH for an aircraft operated on medium-haul operations after seven to eight years, but 6,500MH for an aircraft that has accumulated a larger number of FH over a similar period. The cost of materials for this element of the base check would be \$200,000-250,000.

Stripping and painting was traditionally performed before and after the D check, which was 5-6 years in the

777-200/-300 HEAVY COMPONENT MAINTENANCE COSTS

Operation	Medium-haul	Long-haul
FH:FC	3.0	7.5
FH per year	3,000	4,750
FC per year	1,000	650
FH:FC	3.0	7.5
Number of main & nose wheels	12 + 2	12 + 2
main/nose tyre retread interval-FC	360/250	360/250
Tyre retread cost-\$	1,050/670	1,050/670
Number of retreads	3/2	3/2
New main & nose tyres-\$	1,550/1,050	1,550/1,050
\$/FC retread & replace tyres	45	45
Main/nose wheel repair interval-FC	1,440/1,000	1,440/1,000
Main & nose wheel inspection cost-\$	2,650/1,800	2,650/1,800
\$/FC wheel inspection	26	26
Number of brakes	12	12
Brake repair interval-FC	1,800	1,800
Brake repair cost-\$	60,000	60,000
\$/FC brake repair cost	400	400
Landing gear interval-FC	10,000	6,500
Landing gear exchange & repair fee-\$	1,250,000	1,250,000
\$/FC landing gear overhaul	125	192
Thrust reverser repair interval-FC	12,000	6,000
Exchange & repair fee-\$/unit	400,000	400,000
\$/FC thrust reverser overhaul	67	133
APU hours shop visit interval	7,500-8,500	7,500-8,500
APU hours per aircraft FC	3,400-5,500	3,400-5,500
APU shop visit cost-\$	400,000-500,000	400,000-500,000
\$/FC APU shop visit	75-156	75-156
Total-\$/FC	738-819	872-953
Total-\$/FH	246-273	116-127

case of most aircraft types. This is treated on an on-condition basis by most operators, and intervals have been extended to six to eight years in most cases.

Stripping and repainting will use 2,500-3,000MH and \$20,000 for paint and other materials. Using a standard labour rate of \$50 per MH, the cost for stripping and repainting is \$160,000-180,000.

Base check reserves

The total number of MH required for routine and non-routine rectifications, removal and installation of rotatable components, incorporation of ADs and SBs, and clearing of defects and interior work will be 2,400-2,800MH for the C1, C2, C4 and C5 checks.

The corresponding cost of materials and consumables for each of these checks will be \$150,000-175,000.

The total will be 5,500-6,000MH for the intermediate C3 checks, and materials and consumables will cost \$250,000.

Inputs for the heavy C6 check will be 17,000-18,000MH and \$700,000-800,000 for materials, consumables and interior refurbishment parts.

Total inputs over the six checks will be 33,000-35,000MH and \$1.6-1.7 million in materials, consumables and parts. Using a standard labour rate of \$50 per MH, and including a strip and repaint, the total cost for the base maintenance will be \$3.4-3.6 million.

When amortised over a total interval of 23,000FH, reserves for medium-haul aircraft are \$148 per FH. The interval of 35,000FH for long-haul aircraft results in a lower reserve of \$97-103 per FH (see second table, page 23).

Heavy components

Heavy components comprise four

main categories: the landing gear, wheels and brakes, thrust reversers, and the APU.

The 777's landing gears comprise two main legs, each with six wheels, and a nose leg with two wheels. The 12 wheels on the main landing gear have carbon brakes.

Wheels are removed when tyre treads are worn. Tyres are removed for remoulding, which also gives the opportunity to inspect the wheel rims. The rate at which tyre treads wear depends on the harshness of braking action during landing, and the weight of the aircraft. Removal intervals vary, but averages can be established. Nose wheels have shorter intervals, and Elkhafif says that the average remould intervals for nose wheel tyres are about 250FC.

Main wheels have longer intervals. Elkhafif records an average of 360FC. Sifnaios says that main wheel tyres can last up to one year for an operation with a long average cycle time. In Delta's case this is 330-350FC.

Tyres can be remoulded several times before being replaced. The number of remoulds depends on airline policy and tyre manufacturer. "We have used radial Michelin tyres, and remoulded these three times before replacing them," says Koch.

Elkhafif says that at Egyptair nose wheel tyres are usually remoulded twice, while main wheel tyres are remoulded three or four times before being replaced. United remoulds tyres up to six times, however.

Koch puts the cost of remoulding at about \$670 for a nose wheel tyre, and \$1,050 for a mainwheel tyre. New tyres cost about \$1,050 for a nose wheel and \$1,550 for a mainwheel.

The overall reserve for remoulding and replacing the complete shipset of tyres over their useful life is about \$45 per FC (see table, this page).

The removal of tyres for worn treads provides the opportunity for wheel inspections. This is an on-condition maintenance process, so it can occur at different intervals to tyre remoulds. An inspection is only visual, so it does not involve any disassembly but it will reveal whether a repair or overhaul is needed. An overhaul is more detailed than a repair. "The cost of a nose wheel inspection is about \$110, and rises to \$1,650 for a repair and to \$2,000 for an overhaul. In the case of a main wheel, repairs cost about \$2,500 and overhauls \$2,900," says Koch. "Repairs occur about every fourth removal, and overhauls about every fifth removal."

The reserve for wheel repairs and overhauls is about \$26 per FC (see table, this page).

The 777 has carbon brakes, which are lighter and have longer removal intervals than steel units. Maintenance on brake

units is on an on-condition basis, and depends on the wear and thickness of brake discs. Brake discs are checked on a regular basis during daily checks. Like tyre treads, the wear of brake discs will depend on the harshness of landing and the aircraft weight at landing. Intervals between brake overhauls vary from operator to operator: United has an average interval of 1,500FC; Egyptair an interval of 1,700-1,800FC; and VEM an interval of 2,400FC.

The cost of a shop visit for a brake unit is \$55,000-65,000. Taking an average interval of 1,800FC for a shop visit, a reserve of \$400 per FC accounts for all 12 main wheel brake units (see table, page 20).

Landing gear overhaul intervals are calendar-time- and FC-based. Actual intervals vary between operators. "The initial maintenance programme interval was 10 years or 16,000FC, whichever was reached first," explains Elkhafif. "Subsequent intervals could then be established depending on inspection results at the first shop visit."

Koch gives the interval as 10 years or 18,000FC, whichever is reached first.

Only a few airlines have their own shops, so most landing gear overhauls are dealt with on an exchange basis. Operators pay a fee for the overhaul and shop visit, and another fee for being

provided with a freshly overhauled gear shipset in exchange for the one removed from the aircraft. Market rates for overhaul and exchange fees are \$800,000-1,000,000 and \$350,000-380,000. The total will therefore be amortised over the removal interval to establish a reserve. The interval will be 10,000FC for the medium-haul and 6,500FC for the long-haul aircraft operations. Reserves will be \$115-138 per FC for the medium-haul operation, and \$177-212 per FC for the long-haul operation (see table, page 20).

Thrust reversers are maintained on an on-condition basis. Unlike the thrust reverser units on older generation aircraft, the thrust reverser units on the 777 have long removal intervals. This is mainly due to a high level of composite materials in the structures. United, for example, has removed only a small number of the 100-plus units that it operates at an average interval of 4,400FC. Most thrust reverser maintenance occurs on-wing during base maintenance. Air France and KLM have devised soft removal intervals to prevent major damage being caused to the thrust reversers from keeping them on-wing for too long. Intervals for long-range aircraft are 6,000FC, and 12,000-16,000FC for short- or medium-haul aircraft.

The average shop visit cost for a

thrust reverser shipset is about \$400,000. The reserve for two reversers on long-haul aircraft is therefore \$135 per FC, and \$65-80 per FC on the short- and medium-haul aircraft (see table, page 20).

The 777's APU is the Allied Signal 331-500. APU maintenance is performed on an on-condition basis. Average removal intervals are 7,600-8,500 APU hours. How this equates to aircraft FH and FC intervals depends on the utilisation of the APU during aircraft operation. This can be minimised by using the APU for an average of only up to 90 minutes per FC, and using it mainly for engine start and air conditioning prior to engine start, as well as for a few minutes while taxi-ing in after landing. Ground power is used for the majority of the turnaround between flights.

In other cases, the rate of APU use per FC can be higher - up to 150 minutes per FC. The removal interval will therefore be equal to 3,400-5,500FC.

Shop visit costs are \$400,000-500,000, meaning that APU reserves are \$84-141 per FC (see table, page 20).

Total reserves for all heavy components are \$738-819 per FC for the aircraft on medium-haul operations, and \$872-953 per FC for the aircraft on long-haul operations (see tables, page 23). These are equal to \$246-273 per FH for the medium-haul operation, and \$116-

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127 per FH for the long-haul operation (see tables, page 23).

Rotable components

There are about 2,300 rotatable components installed on the 777, although the actual number will depend on configuration. About 600 of these are maintained on a hard-time basis, and the remainder on an on-condition basis.

Many airlines have complete or partial inventories, and in-house repair-and-test and warehousing facilities and logistical services for managing these parts, and ensuring that they are available when required during the fleet's operation. Several specialist providers offer turnkey rotatable support packages for a range of aircraft types, including AAR, AJ Walter, Avtrade, Singapore Technologies and Lufthansa Technik.

The packages that are offered include: the supply of a homebase stock of high failure rate and no-go items that are held at the airline's main base; access to a pool stock of remaining rotatables, which can be sent to the airline by the supplier when required; and a repair, management and logistics service for all components under the agreement. These last two elements can be paid for at a fixed rate per FH.

The homebase stock for a fleet of 10 777s will have a value of \$5-8 million. Lease rentals will be equal to \$20-30 per FH for long-haul aircraft, and \$30-45 per FH for medium-haul operations.

The pool access, and repair and management fees will be \$230-260 per FH for medium-haul and \$200-220 for long-haul aircraft. This will take the total to \$260-305 per FH for medium-haul aircraft, and \$220-250 per FH for long-haul aircraft (see tables, page 23).

Engine maintenance

The 777 fleet can be subdivided into two categories: low gross weight -200s; and high gross weight -200s/-200ERs, -200LRs, -300s and -300LRs.

The 777-200s are mainly powered by the PW4074/77 and Trent 875/77/90 engines, and operate medium-haul cycles of 3.0FH. The 777-300s are mainly powered by the PW4090/98 and Trent 892, and also operate FC times of about 3.0FH. The 777-300s are powered mainly by the PW4090/98 and Trent 892, and also operate at about 3.0FH per FC.

The high gross weight -200s and -200ERs are mainly powered by the PW4084/90, GE90/94 and Trent 892/895, and operate on long-haul missions averaging 6.0-8.0FH per FC.

The -200LR and -300LR fleets are powered by the GE90-110/-115 and operate on missions of 8-11FH.

The use of different airframe-engine combinations at different FH:FC ratios influences engine removal intervals and maintenance reserves.

The PW4074/77 at 3.0 engine flight hours (EFH) per engine flight cycle (EFC) have first and second removal intervals that average 11,500EFH/3,800EFC and 8,500EFH and 2,800EFC. First and second shop visit costs are \$3.2 and \$4.3 million respectively. The total cost amortised over the first two shop visits averages a reserve of \$375 per EFH.

Mature removal intervals are 8,250EFH and 2,750EFC. The PW4000's life limited parts (LLPs) have lives of 20,000EFC, and can be expected to be replaced after a total accumulated time of about 17,500EFC. The list price for a shipset is \$7.0 million, so this will result in LLP reserves of \$400 per EFC. Overall

There are differences in maintenance reserves between different engine types, but engine maintenance accounts for about half of total aircraft maintenance costs.

reserves for shop visit costs and LLPs will therefore be about \$533 per EFH (see first table, page 23).

The Trent 892 on similar operations will have first and second removal intervals of 16,000EFH/5,300EFC and 14,000EFH/4,700EFC. First and second shop visit costs are \$4.2 million and \$5.2 million respectively. The reserve for these two shop visits is about \$315 per EFH.

The mature interval is about 13,000EFH/4,250EFC. The engine's LLPs have lives of 15,000EFC, and can be expected to be replaced after about 14,000EFC. A shipset has a list price of about \$6.0 million, so LLP reserves will be about \$430 per EFC. Total reserves will therefore be about \$460 per EFH (see first table, page 23).

For higher gross weight -200s and -200ERs, the GE90/94, PW4084/90 and Trent 892/895 should be considered.

The GE90/94B operating at about 7.5EFH per EFC will have first and second removal intervals of 18,000EFH/2,250EFC and 15,500EFH/2,000EFC respectively. Removal intervals are limited to 4,000EFC by one of the GE90's LLPs; the HPT interstage seal. The first removal workscope is usually a performance restoration, and incurs a shop visit cost of \$4.0 million. The second workscope, after a total time of 34,000EFH and 4,200EFC, will be a full overhaul, and cost \$5.0 million. The reserve for these two shop visits will be \$270 per EFH.

The majority of the GE90-90/94's LLPs have lives of 15,000-20,000EFC. Mature removal intervals will be about 2,000EFC, and so average accumulated time for LLP replacement will be about 10,000EFC. A full shipset has a list price of about \$8.1 million, so reserves will be \$810 per EFC. Total reserves will therefore be \$370 per EFH (see second table, page 23).

The PW4084/90 at the same EFH:EFC ratio will have first and second removal intervals of 19,000EFH/2,300EFC and 16,000EFH/2,000EFC respectively. Pratt & Whitney engines generally follow a simple shop-visit pattern of alternating performance restorations and overhauls. The first shop visit will incur a cost of \$3.9 million, while the following overhaul will cost \$5.5 million. The reserve for these two, amortised over a total time of 35,000EFH and 4,700EFC,

will be \$270 per EFH.

The engines will have a mature interval of about 2,000EFC. LLPs in the PW4084/90 have uniform lives of 15,000EFC, and average LLP life at replacement will be about 13,500EFC. A shipset has a list price of \$7.5 million, so LLP reserves will be about \$560 per EFC. Total reserves will be about \$340 per EFH (see second table, this page).

The Trent 892/895 at the same EFH:EFC ratio will have first removal intervals of 23,000-25,000EFH and 3,100-3,300EFC. The first shop visit will incur a cost of about \$4.8 million. The second removals will be about 20,000EFH and 2,500EFC, and the following shop visit will be \$5.5-5.8 million. The reserve for the two shop visits will be amortised over a total interval of 42,000-45,000EFH, and will be \$230-245 per EFH.

The Trent 892 and 895 have LLPs with lives of 15,000EFC and 10,000EFC. The list price for a shipset for both is \$6.0 million. LLPs will be replaced after a total time of about 14,000EFC for the Trent 892, and about 8,500EFC for the Trent 895. LLP reserves for the Trent 892 will be about \$430 per EFC, and for the Trent 895 about \$700 per EFC.

Total reserves for the Trent 892 will be about \$280 per EFH, and for the Trent 895 about \$330 per EFH (see second table, this page).

The GE90-110/-115 powering the 777-200LR/-300ER will be operated at an average EFH:EFC ratio of 10:1, but the actual ratio will depend on each airline. At this EFC time, the engine is expected to have first removal intervals of about 24,000EFH and 2,400EFC, and the first shop visit will incur a cost of about \$4.3 million. The second removal interval is predicted to be 18,000EFH and 1,800EFC. The following overhaul will incur a cost of about \$5.3 million. The cost for these two shop visits will be amortised over a total time of about 42,000EFH and 4,200EFC, with a reserve of \$230 per EFH.

The GE90-110/-115 has 26 LLPs with lives of 15,000-20,000EFC, although a few parts are limited to shorter lives. The list price for a shipset is \$8.1 million. Average accumulated time at replacement is 10,000EFC, resulting in a reserve of \$810 per EFC.

Total reserves for the GE90-110/-115 will be about \$310 per EFH.

Summary

There is a difference of \$300-900 per FH between the aircraft used on medium- and long-haul operations, depending on the exact reserves allowed for some of the maintenance, and the engine type used on the aircraft.

DIRECT MAINTENANCE COSTS FOR 777-200/-300: MEDIUM-HAUL OPERATION

Maintenance Item	Cycle cost \$	Cycle interval	Cost per FC-\$	Cost per FH-\$
Line & ramp checks	470,000	Annual		147
A check	60,000	350-450FH		135-170
Base checks	3.4-3.6 million	23,000FH		148
Heavy components:			738-819	246-273
LRU component support				260-305
Total airframe & component maintenance				788-1,043
Engine maintenance:				
2 X PW4074/77: 2 X \$533 per EFH				1,066
2 X Trent 875/877/890: 2 X \$460 per EFH				920
Total direct maintenance costs:				1,710-2,100
<i>Annual utilisation:</i>				
3,000FH				
1,000FC				
FH:FC ratio of 3.0:1				

DIRECT MAINTENANCE COSTS FOR 777-200ER: LONG-HAUL OPERATION

Maintenance Item	Cycle cost \$	Cycle interval	Cost per FC-\$	Cost per FH-\$
Line & ramp checks	390,000	Annual		82
A check	60,000	350-450FH		135-170
Base checks	3.4-3.6 million	35,000FH		97-103
Heavy components:			872-953	116-127
LRU component support				220-250
Total airframe & component maintenance				650-732
Engine maintenance:				
2 X PW4084/90: 2 X \$ 340 per EFH				680
2 X GE90-90/-94: 2 X \$ 370 per EFH				740
2 X Trent 892/895: 2 X \$ 280/330 per EFH				560/660
Total direct maintenance costs:				1,200-1,475
<i>Annual utilisation:</i>				
4,750FH				
650FC				
FH:FC ratio of 7.5:1				

The 777-200's total costs for medium-haul operations are higher than the A330-300's (see *A330-200/-300 maintenance analysis & budget, Aircraft Commerce, April/May 2008, page 20*). This is mainly due to the 777's higher line and A checks, heavy components, and engine maintenance costs. This is not surprising, given that the 777's heavier design and larger engines gave it the capability to be developed into a long- and ultra-long-range aircraft.

The 777-200ER has \$160-400 per FH

lower maintenance costs than the A340-200/-300 (see *A340-300 maintenance analysis & budget, Aircraft Commerce, June/July 2007, page 17*). This is mainly due to the A340's four-engine design. The 777 also has lower airframe and component maintenance costs. The 777 particularly benefits from lower base maintenance reserves. [AC](#)

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777-200/-300 technical support providers

There are over 700 777 aircraft in operation with the PW4000-112, GE90 or Trent 800 engine. A global survey of six major levels of support identifies the major service providers.

This survey summarises the major aftermarket and technical support providers for the Boeing 777 aircraft. It is grouped into seven sections covering the categories of technical support offered by each provider.

- Engineering Management and Technical Support (see table, page 26).
- Line maintenance and in-service operational support (see table, page 27).
- Base Maintenance Support (see table, page 27).
- Engine Maintenance (see table, page 28).
- Spare Engine Support (see table, page 28).
- Rotables and Logistics (see table, page 30).

- Heavy Component Maintenance (see table, page 30).

Many of the technical support providers that are listed in most, if not all, of the six sections can be termed as 'one-stop-shop' service providers for the 777. This means that they provide most of the technical support services that a third-party customer would require.

The tables summarise the range of services that these facilities offer.

As the tables show, the maintenance, repair and overhaul (MRO) and other technical support facilities are able to offer a complete range of line and base maintenance services, as well as engine and heavy component maintenance for the 777.

The major maintenance providers include: Ameco Beijing, Austrian Technik, Delta TechOps, El Al Tech, Evergreen

Aviation Technologies Corp. (EGAT), Hong Kong Aircraft Engineering Company (HAECO), Japan Airlines International (JAL), Lufthansa Technik AG (LHT), Malaysian Airlines, Singapore Airlines Engineering Company (SIAECO), Thai Airways International (Thai), Triad International Maintenance Corporation (TIMCO), United Services, Gameco and VEM Maintenance and Engineering (VEM).

Due to the financial, personnel and time and tooling costs of certain specialist jobs, none of the facilities are able to offer every single listed capability, but some come close.

With the development of the 777-200LR and Freighter, the number of 777s is growing. By 2015, there are expected to be over 1,080 777s in operation, so the maintenance market will need to grow by nearly 50%. This is especially true as many 777s will need more in-depth heavy maintenance over the coming years as the maintenance requirements of older aircraft increase.

Many of these additional deliveries are to existing operators, so maintenance arrangements may therefore already be in place. There are also smaller operators which need MROs to offer capability. In addition, there are also 777s on order with new customers such as Turkmenistan Airlines and Arik Air that will need maintenance programmes and technical support in the future. Such operators with small fleets will need extensive third-party support, and providers and facilities will be increasingly in demand.

Engine & APU market

When looking at the maintenance of the engines of the 777, there are only a few providers that offer various levels of engineering and engine shop support on all three engines. These include Evergreen Aviation Technologies Corp (EDAT); HAECO, including Hong Kong Aero Engine Services Limited (HAESL); and SIAECO, including Singapore Aero Engine Services Limited (SAESL). There are additional facilities that can offer maintenance for two of the three engine types.

SIAECO provides one of the most comprehensive levels of technical & maintenance support for the 777 available in the world. This is partly explained by SIA having the largest global fleet, with 77 aircraft.



777-200/-300 ENGINEERING MANAGEMENT & TECHNICAL SUPPORT

	Outsourced engineering service	Maint records service	DOC & manuals manage	Maint prog manage	Reliability stats	AD/SB orders manage	Check planning	Config & IPC manage	Total tech support
Abu Dhabi Aircraft Technologies		Y	Y	Y	Y	Y	Y		Y
Air France Industries / KLM	Y	Y	Y	Y	Y	Y	Y	Y	Y
Alitalia Servizi Engineering & Maintenance				Y	Y	Y	Y		
Ameco Beijing	Y	Y	Y	Y	Y	Y	Y	Y	Y
Aveos (Air Canada Technical Services)					Y				
Delta TechOps	Y	Y	Y	Y	Y	Y	Y	Y	Y
El Al Tech	engine	Y	Y	Y	Y	Y	Y	Y	Y
Emirates				Y	Y	Y	Y	Y	
Evergreen Aviation Technologies	Y	Y	Y	Y	Y	Y	Y	Y	Y
GAMECO			Y	Y	Y	Y	Y		
HAECO incl. HAESL & SAESL	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lufthansa TechnikAG	Y	Y	Y	Y	Y	Y	Y	Y	Y
Malaysia Airlines	Y	Y	Y	Y	Y	Y	Y	Y	Y
SIA Engineering Company	Y	Y	Y	Y	Y	Y	Y	Y	Y
Thai Airways International	Y	Y	Y	Y	Y	Y	Y	Y	Y
TIMCO (Greenbro)	Y	Y	Y	Y		Y	Y	Y	Y
United Services	Y	Y	Y	Y	Y	Y	Y	Y	Y
VEM Maintenance & Engineering	Y	Y	Y	Y	Y	Y	Y	Y	Y

The ACAS database, produced by Flight Global, assesses the contracts of various maintenance facilities and airlines, from which the market share can be worked out. This data is for the period up to the summer 2008.

Engine maintenance contracts that are performed in-house represent 17% of the market. This figure does not, however, include the in-house work done by airlines that also offer third-party engine work. These are carriers such as Air France, United, KLM and JAL. Therefore, the figure will be much higher and closer to 30-35%. Unknown contracts equate to just over 10%. Of the engine manufacturers, Rolls Royce (RR) has the highest percentage of contracts, with 27% being issued to RR and its joint ventures (JVs).

GE Engine Services and its facilities around the world have taken nearly 20% of the market, leaving Pratt and Whitney (PW) with less than 5%. Airlines that operate PW4000-powered 777s are more likely to maintain engines in-house. What is clear, though, is that RR keeps a tight control of engine maintenance, with only its own joint ventures and Trent 800 operators doing work on the engines.

Over 50% of 777 APUs are overhauled by the original equipment manufacturer (OEM), Honeywell. The second place for market share is in-house engineering with 17%. Other airline engineering departments account for nearly 11% and unknown contracts or those up for tender amount to 7%.

Base maintenance market

The market shares for C checks and heavy maintenance visits are similar. In both cases the highest percentage of

contracts (nearly 46% and 36% respectively) goes to in-house airline engineering departments. As also mentioned for the engines, this does not include those in-house airline engineering facilities that also offer third-party capability. Such facilities are Air France Industries and SIAECO, which have nearly 13% and 12% respectively of the C check and heavy maintenance market.

British Airways Maintenance Cardiff (BAMC) is one exception. Due to the large BA fleet of 42 aircraft, BAMC has nearly 9% of the global market, and so ends up having its own entry in the ACAS market share data. BA does not offer third-party maintenance at Cardiff. Therefore, in-house engineering's market share for C checks stands at over 51% and for heavy checks it is nearly 42%.

Engineering companies that are independent of an airline only seem to get less than 2.5% of the market each for the C checks. But they do better on the heavy checks, with Ameco and ST Aviation Services Pte Ltd (SASCO) getting nearly 10% and 6% respectively.

Asia Pacific

The majority of 777s are operated by airlines in the Asia Pacific area, which accounts for over 40% of the global fleet. In addition, 128 new 777s will be delivered over the coming years to the region. This represents 35% of forthcoming deliveries.

This is then echoed in the range of service providers in the same area. Some of the major providers include: Ameco Beijing, HAECO, SIAECO, TAECO and Gameco.

The technical providers in the Asia Pacific area are mostly attached in some

way to an airline, in much the same way as the rest of the world. But they also stand independently in their branding and position in the market place.

This is true of Gameco and HAECO which are historically the maintainers of China Southern and Cathay Pacific aircraft respectively. Ameco Beijing, on the other hand, is a joint venture between LHT and Air China. LHT's market share should only grow over the coming years.

LHT also has a joint venture with Philippine Airlines, called Lufthansa Technik Philippines, which traditionally overhauls the aircraft from Philippine Airlines. This airline is due to take delivery of six 777-300ERs by 2011, which are likely to be maintained by Lufthansa Technik Philippines. SIAECO is also developing widebody maintenance facilities in the Philippines.

Over 20% of the global C check contracts, according to ACAS, go to facilities in the Asia Pacific area. This figure excludes many of the airlines, such as those from Japan and China, that have in-house engineering and maintenance departments. SIAECO alone accounts for nearly 12% of the C check and heavy check contract market share.

Singapore Airlines (SIA) has the largest 777 fleet, with 77 aircraft. As the world's largest provider of technical and maintenance support for the 777 its maintenance division, SIA Engineering Company (SIAECO), has a comprehensive technical support and maintenance capability at all levels, which it is able to offer to other operators.

SIAECO is capable of handling four 777 base checks at any one time within its hangars. It also has tarmac space for line and light maintenance.

777-200/-300 LINE & LIGHT MAINTENANCE SUPPORT

	Maint operations control	AOG support	Line checks	A checks	Engine QEC changes	Engine changes	Landing gear changes	APU changes	Thrust reverser changes
Abu Dhabi Aircraft Technologies		Y	Y	Y					
AeroMexico- Aeroviasde MexicoSA de CV	Y	Y	Y	Y	Y	Y	Y	Y	Y
Air France Industries / KLM	Y	Y	Y	Y	Y	Y	Y	Y	Y
Alitalia Servizi Engineering & Maintenance		Y	Y	Y					
Ameco Beijing	Y	Y	Y	Y	Y	Y	Y	Y	Y
Austrian Technik	Y	Y	Y	Y	Y	Y	Y	Y	Y
Delta TechOps	Y	Y	Y	Y	Y	Y		Y	Y
El Al Tech	Y	Y	Y	Y	Y	Y	Y	Y	Y
Emirates Engineering	Y	Y	Y	Y	Y	Y	Y	Y	Y
Europe Aviation		Y	Y						
Evergreen Aviation Technologies	Y	Y	Y	Y	Y	Y	Y	Y	Y
HAECO - incl. HAESL & SAESL	Y	Y	Y	Y	Y	Y	Y	Y	Y
Japan Airlines International	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lufthansa Technik AG	Y	Y	Y	Y	Y	Y	Y	Y	Y
Malaysia Airlines	Y	Y	Y	Y	Y	Y	Y	Y	Y
Monarch Aircraft Engineering	Y	Y	Y		Y	Y	Y	Y	Y
SIA Engineering Company	Y	Y	Y	Y	Y	Y	Y	Y	Y
ST Aviation Services Pte. Ltd. (SASCO)	Y	Y	Y	Y	Y	Y	Y	Y	Y
ST Mobile Aerospace (MAE)	Y		Y	Y	Y	Y	Y	Y	Y
Thai Airways International	Y	Y	Y	Y	Y	Y	Y	Y	Y
United Services	Y	Y	Y	Y	Y	Y	Y	Y	Y
VEM Maintenance & Engineering		Y		Y	Y	Y	Y	Y	Y
Victorville Aerospace LLC		Y		Y	Y	Y	Y	Y	Y

In addition, SIAECO is adding a sixth hangar to further improve its market presence.

When looking at the market share for heavy checks in the general Asia Pacific area, the share of global business is well over 35%. This again excludes many of those checks that are completed in-house, although the figures reaffirm that heavy checks are more likely to be outsourced than C checks.

Engine shops in the Asia Pacific region include: GE Engine Services (Japan and Malaysia), HAECO (through associates HAESL), Eagle Services Asia (ESA), and SAESL; and the major airlines' engine shops such as JAL and THAI.

ESA is a JV between Pratt & Whitney and SIAECO, while SAESL is a JV between Rolls-Royce and SIAECO. SIAECO is able to offer technical support and shop visit maintenance for the PW4000, GE90 and Trent 800 through ESA and SAESL, with ESA providing support for the PW4000 and GE90, and SAESL for the Trent 800.

Besides the in-house market share of 10% of global engine overhaul contracts, the next biggest provider is Singapore-based SAESL. SAESL has taken 14% of the contracts available globally, and is a joint venture between HAESL, RR and SIA. HAESL itself is a joint venture between HAECO and RR, and is based in Hong Kong. In addition, HAECO also owns TAECO in Xiamen, China, and has taken over a GE facility at the same Chinese location. This means that,

777-200/-300 BASE MAINTENANCE SUPPORT

	C checks	IL & D checks	Composites	Strip/paint	Interior refurb
Abu Dhabi Aircraft Technologies	Y	Y	Y		
AeroMexico			Partial		Y
Air France Industries / KLM	Y	Y	Y	Y	Y
Alitalia Servizi Engineering & Maintenance	Y		Y	Y	
Ameco Beijing	Y	Y	Y	Y	Y
American Airlines	Y	Y	Y		Y
Austrian Technik	Y		Y		Y
Aveos (Air Canada Technical Services)	Y		Y	Y	
Delta TechOps	Y		Y	Y	Y
Egyptair Maintenance & Engineering	Y	Y	Y		
El Al Tech	Y	Y	Y		Y
Emirates	Y	Y	Y		
Evergreen Aviation Technologies	Y	Y	Y	Y	Y
Lufthansa Technik AG	HAECO	HAECO	Y	Y	Y
Malaysia Airlines	Y	Y	Y	Y	Y
Marshall Aerospace	Y	Y	Y	Y	Y
SIA Engineering Company	Y	Y	Y	Y	Y
ST Aviation Services Pte. Ltd. (SASCO)	Y	Y	Y	Y	Y
ST Mobile Aerospace (MAE)	Y	Y	Y	Y	Y
TAECO	Y	Y	Y	Y	Y
Thai Airways International	Y	Y	Y	Y	Y
TIMCO (Greenbro)			Y		Y
United Services	Y		Y		
VEM Maintenance & Engineering	Y	Y	Y	Y	Y
Victorville Aerospace LLC	Y	Y	Y	Y	Y

777-200/-300 ENGINE MAINTENANCE - GE90, PW4000-112 & TRENT 800

	GE90	PW4000-112	Trent 800	Engine health monitor	Engine maint manage	On-wing engine maint	Engine shop visits	Parts repair schemes
AeroMexico	Y			Y	Y	Y		
Air France Industries/KLM	Y			Y	Y	Y	Y	Y
Alitalia Servizi Engineering & Maintenance	Y		Y			Y		
Austrian Technik	Y	Y	Y	Y	Y	Y		
Delta TechOps	Y		Y	Y	Y	Y		
Emirates			Y	Y	Y	Y	Y	
Evergreen Aviation Technologies	Y	Y	Y	Y	Y	Y	GE90	GE90
GAMECO	Y	Y		Y	Y	Y		Y
GE Engine Services	Y			Y	Y	Y	Y	Y
HAECO - incl. HAESL & SAESL	Y	Y	Y	Y	Y	Y	GE&Trent	GE & Trent
Japan Airlines International	Y	Y		Y	Y	Y	Y	Y
Lufthansa Technik AG		Y		Y	Y	Y	Y	Y
Malaysian Airlines			Y	Y	Y	Y		
Pratt & Whitney		Y		Y	Y	Y	Y	Y
Rolls Royce			Y	Y	Y	Y	Y	Y
SIA Engineering Company	Y	Y	Y	Y	Y	Y	Y	Y
TAESL			Y	Y	Y	Y	Y	Y
Thai Airways International			Y	Y	Y	Y	Y	Y
United Services		Y		Y	Y	Y	Y	Y
VEM Maintenance & Engineering	Y			Y	Y	Y		

777-200/-300 SPARE ENGINE SUPPORT - GE90, PW4000-112 & TRENT 800

	On-wing support	AOG services	Short-term leases	Med/long-term leases	Engine pooling
Air France Industries / KLM	Y	Y			Y
Delta TechOps	Y	Y	Y	Y	
El Al Tech	Y	Y	Y	Y	Y
Evergreen Aviation Technologies	Y	Y	Y	Y	Y
GAMECO	Y	Y	Y	Y	
GE Engine Services	Y	Y	Y	Y	Y
HAECO -incl. HAESL & SAESL	Y	Y			
Japan Airlines International	Y	Y	Y	Y	
Kuwait Airways Corporation					Y
Lufthansa Techniks AG	Y	Y	Y	Y	Y
Pratt & Whitney	Y	Y	Y	Y	Y
Rolls Royce	Y	Y	Y	Y	Y
SIA Engineering Company	Y	Y			
Southern California Aviation	Y	Y	Y	Y	Y
Spirit Aerosystems(Europe)	Y	Y			
Thai Airways International	Y	Y			
United Services	Y	Y		Y	Y

looking at ACAS's data, HAECO and its associated companies in the Asia Pacific have nearly 18% (worth over 250 engines) of the global market for engine overhaul, and show every sign of growing. Through its various companies, HAECO is able to provide most technical services on all three engines of the 777, apart from leasing aspects. This has been further developed by forming a JV with

two of the OEMs, and benefiting from the back-up this brings.

Other than the base maintenance and engine overhaul, many of the facilities also offer day-to-day line maintenance and technical support, the main one being SIAECO. It has its main engineering base at Singapore, but also has 40 line maintenance stations around the Asia Pacific region.

North & South America

The second largest geographical area for 777 operators is North America, which accounts for 20% of the global fleet. South America has the smallest share with less than 1%, but its maintenance requirements are well catered for. The North American fleet size is not echoed in the facilities available. Many heavy checks are completed in Europe or Asia Pacific.

There are few large technical service providers in America, but there are many smaller companies that offer more specialist, local services. These include Goodrich, Southern Californian Aerospace, TIMCO and Victorville Aerospace LLC, which offer some aspects of component, line maintenance and technical support.

Two major providers are the engineering and maintenance departments of Delta TechOps (Delta Air Lines) and United Services (United Airlines). Between them they have nearly 8% of the global C check market. Neither perform heavy checks. Instead United sends its aircraft to Ameco for heavy checks, and Delta sends its aircraft to Air France Industries. HAECO has a contract for Continental's 777-200ER aircraft.

Other major American providers are Aveos (formally Air Canada Technical Services) and ST Mobile (MAE). Additionally, VEM Maintenance and Engineering in Brazil offers most services on the 777 airframe and some GE90 engine shop capability. Also in South America is AeroMexico, which offers 777

777-200/-300 ROTABLES & LOGISTICS

	Rotable inventory leasing	Rotable inventory pooling	Repair & doc manage	AOG support	PBH rotables support
AAR Corp.	Y	Y	Y	Y	Y
Abu Dhabi Aircraft Technologies	Y	Y	Y	Y	Y
Air France / KLM	Y	Y	Y	Y	Y
Alitalia Servizi		Y		Y	Y
Engineering and Maintenance					
Ameco Beijing	Y	Y	Y	Y	
Aveos (Air Canada Technical Services)	Y	Y	Y	Y	Y
Delta TechOps	Y	Y	Y	Y	Y
Emirates	Y	Y	Y	Y	
Evergreen Aviation Technologies	Y	Y	Y	Y	Y
GE Engine Services	Y	Y	Y	Y	Y
Goodrich	Y	Y	Y	Y	Y
Lufthansa Technik AG	Y	Y	Y	Y	Y
SIA Engineering Company	Y	Y	Y	Y	Y
Thai Airways International	Y	Y	Y	Y	
United Services	Y	Y	Y	Y	Y
VEM Maintenance & Engineering	Y		Y	Y	Y

777-200/-300 HEAVY COMPONENT MAINTENANCE

	Wheels tyres & brakes	APU test & repair	Thrust reversers	Landing gear	Landing gear exchanges
AAR Corp.	Y			Y	
Air France Industries/ KLM	Y	Y	Y	Y	Y
American Airlines	Y	Y	Y		
Boeing Maintenance Services			Y	Y	Y
Aveos (Air Canada Technical Services)	Y	Y		Y	
Delta TechOps	Y				
Eads Revima / Revima APU		Y		Y	Y
El Al Tech	Y	Partly	Partly		
Emirates	Y	Y	light	Y	
Evergreen Aviation Technologies	Y		Y		
Goodrich	Y		Y	Y	
HAECO - incl. HAESL & SAESL	Y		Y	Y	Y
Hawker Pacific	Y			Y	
Lufthansa Technik AG	Y		Y	Y	Y
Messier Services Asia & France	Y			Y	Y
SIA Engineering Company	Y	Y	Y	Y	Y
Thai Airways International	Y	Y	Y	Y	Y
United Services	Y	Y	Y	Y	Y
VEM Maintenance & Engineering	Y		Y	Y	Y
Victorville Aerospace LLC	Y		Y	Y	Y

line maintenance and technical support, along with some GE90 capabilities.

As far as engine overhaul providers go in America, United Services and PW's Cheshire Engine Centre deal with the PW4000-112. The Trent 800 is maintained by Texas Aero Engine Service LLC (TAESL), RR's joint venture with American Airlines. In addition, on-wing engine maintenance and management are offered by Delta Tech Ops for the GE90

and Trent 800.

Europe

The geographical area with the third largest fleet is Europe, which has the second largest maintenance market for the 777. Europe has 17% of the global fleet, but 20% for both the C check and heavy check market. This includes BA's market share but excludes general in-

house data (as mentioned previously).

The major third-party players in the European maintenance market are Air France Industries/KLM, Lufthansa Technik and Austrian Technik. At the time of writing, it is hard to tell if Alitalia's engineering companies will remain with the major European providers. Within Europe, there are large maintenance companies which have a small amount of capability on the 777, but have not yet gained full capability, such as SR Technics at its Zurich facility. Europe Aviation in France has developed line maintenance capabilities on the 777, which will be available from the end of 2008.

The smaller, more specialist companies within Europe include EADS Revima, which offers heavy component maintenance, and Shannon Aerospace. Europe also has many of the large rotatable inventory and logistics companies, such as AJ Walter, CASCO and Avtrade.

The engines for the 777 are well supported in Europe, according to ACAS data. GE Engine Services' European facilities handle nearly 16% of the global market share of all 777 engines. Rolls-Royce Aero Repair and Overhaul deals with 4% of the global market, and Lufthansa Technik completes all levels of maintenance on the PW4000-112.

Middle East and Africa

The contribution of the Middle East and Africa is nearly 16% of the global fleet, but most (nearly 14%) comes from the Middle Eastern airlines. There are many maintenance facilities in the location, but this is not reflected in the number of contracts completed, according to ACAS. The main third-party provider is ADAT in Abu Dhabi, and other facilities are those of the region's 777 operators, such as Egyptair and Emirates.

ADAT, the former GAMCO, has put major investment into its facility to assist its MRO contract with Etihad. It has built a dedicated hanger for Etihad's 777s, A340s and A320s, which was opened in the summer of 2008. Investment has paid off over the past few years, and more is due to be made over the next four years.

Global market share for the 777's heavy maintenance is low at about 1.5%, but that could grow with the investment put into ADAT. The figure is the same for C Check maintenance, but again this must grow as 110 new aircraft are due to be delivered to the area over the coming few years. Of these, nearly 100 are for Middle Eastern carriers. [AC](#)

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