Four-engine widebodies are coming under increasing pressure from modern large twin-engine types. The fuel burn and operating performance of the 747-8 and A380 are analysed here and compared to those of the 777-300ER. Nick Preston also discusses demand for four-engine aircraft.

Ultra-large widebody fuel burn & operating performance

In the past decade, the 747 family has seen the introduction of its latest variant, the 747-8, which has been joined in the ultra-large widebody category by the A380. Improvements in engine technology have led to a trend towards replacing four-engine aircraft with twin-engine types. The 777-300ER is now the most popular ultra-large widebody in service, and has replaced the majority of 747-400s. In the coming years the A350-1000 and 777-9 will also enter the 350-seat-plus segment.

Now, for the first time, *Aircraft Commerce* has access to data that will allow an operating and fuel burn performance comparison between all three ultra-large widebody types that are in service and in production. For the purposes of this analysis an ultra-large widebody is classified as an aircraft that can accommodate 350 seats or more in a typical three-class cabin configuration. There are three such aircraft in service and in production: the A380, 747-8 and 777-300ER. The fuel burn and operating performance of these aircraft is compared to that of the most popular previous-generation ultra-large widebody, the 747-400. The analysis will show how much of an efficiency gain has been provided by the latest generation ultra-large widebodies, and highlight the future prospects for four-engine aircraft, by contrasting their performance with the most popular twin-engine type in service.

Fleet developments

The global widebody fleet has been transformed over the past 20 years. The availability of more advanced and reliable engine technology means that there is far less reliance on three- or four-engine aircraft for long-haul intercontinental routes. Some long-haul sectors that would have previously been served by a three- or four-engine type are now regularly operated by medium and large twin-engine widebodies, including variants of the 777, A330 and more recently the 787 and A350. There has been a notable decline in the number of active widebodies with more than two engines.

According to Flightglobal's Fleets Analyzer, three- and four-engine types accounted for 50% of the active widebody fleet in 1997. The 747 family represented 27% of the fleet alone, but there were also a considerable number of three-engine variants in service including DC-10s, MD-11s and L-1011 Tristars, along with a growing fleet of A340s. By 2007, three- and four-engine aircraft only accounted for 29% of the widebody fleet. In 2017 there are no longer any three-engine types in passenger service and four-engine aircraft only represent 14% of the widebody fleet.

In the ultra-large widebody segment, the 747 family was in a class of its own for many years. The main three-engine types had long-range performance, but could not accommodate 350 seats in a three-class configuration, and offered capacities more comparable with today's twin-engine medium widebodies such as the 777-200ER, 787-8 and -9, A330-200 and -300, and the A350-900.

The 747 family has been joined by four other ultra-large widebodies over the past 20 years: the 777-300, which entered into service in 1998; the A340-600 in 2002; the 777-300ER in 2004; and the A380 in 2007. The latest version of the 747 family, the 747-8, entered service in 2012.

The 777-300 and A340-600 are no longer in production. Only 60 777-300s were delivered according to Fleets Analyzer and these were generally acquired by operators in Asia Pacific to replace ageing 747s on high-density regional operations. The A340-600 also saw a relatively small production run, with 95 delivered.

The fleet of active ultra-large widebodies has increased by 97% over the past 20 years. During this period, the fleet has shifted from a reliance on the 747, to a mix of types, with a prominent role for the 777-300ER. In 1997 the ultra-large widebody fleet comprised 647 aircraft, all of which were the four main 747 variants: the -100, -200, -300 and -400. By 2007 the ultra-large fleet had increased to 714 aircraft, 78% of which were four-engine types. Two-thirds of the fleet comprised 747 variants, while the rest included A340-600s, 777-300s and 777-300ERs. In 2017 there are 1,275 active ultra-large widebodies, including 777-300ERs (742 aircraft), A380s (213), 747-400 derivatives (167), A340-600s (66), 777-300s (48), 747-8s (36) and 747-300s (3). Four-engine aircraft only account for 38% of the contemporary ultra-large widebody fleet, and this portion will continue to decline.

In 1997 the operators with the largest number of ultra-large widebodies were Japan Airlines (JAL) (72), British Airways (BA) (65), United Airlines (51), Singapore Airlines (SIA) (41), All Nippon Airways (ANA) (37), Northwest Airlines (35), Cathay Pacific (32), Korean Air (29) and Qantas (26). All of the ultra-large widebodies in service in 1997 were 747 variants.

The current incarnations of these airlines are all operating fewer 747s in

The ultra-large widebody market was previously dominated by four-engine types, and the 747 family in particular. Despite the introduction of the A380 and 747-8, the past decade has seen airlines migrate towards large twin-engine types. The 777-300ER is now the most popular aircraft in the ultra-large widebody segment.

2017, or have phased them out entirely. Some, including BA and SIA, have replaced ageing 747s with a mix of A380s and 777-300ERs. Others have opted solely for the 777-300ER as a 747 replacement, while Korean Air is using a mix of A380s, 777-300ERs and 747-8s. BA, SIA, ANA, Cathay Pacific (including Cathay Dragon) and Korean Air have all increased the number of widebodies in their fleets since 1997. With the exception of Korean, all of these carriers saw ultra-large widebodies account for a lower overall percentage of their widebody fleets in 2017, due to the introduction of more medium widebodies such as the A330, 787 and 777-200ER. SIA, Cathay Pacific and Korean all increased the number of ultra-large widebodies in their fleets over the 20-year period from 1997 to 2017. BA and Qantas reduced their respective ultra-large widebody fleets slightly.

JAL's fleet has seen the most pronounced reduction in ultra-large widebodies over the past 20 years. It has completely removed the 72 747s that were in service in 1997, and replaced them with 13 777-300ERs, four 777-300s and various medium-widebodies, including 767-300ERs and 787s. The airline's widebody fleet has shrunk by 10 aircraft over this period. In 1997, ultra-large types accounted for 59% of JAL's active widebody fleet. In 2017 they account for just 15%, due mainly to other airlines operating direct, non-stop trans-Pacific services that avoid refuelling stops in Tokyo. JAL's long-haul traffic volumes have therefore declined.

In 2017, the operators with the most in-service, ultra-large widebodies are Emirates (231), Cathay Pacific (65), Lufthansa (64), BA (60), Air France (53), SIA (51), Korean Air (49) and Qatar Airways (46). Emirates' entire fleet is made up of ultra-large widebodies. It is the largest operator of the A380 (96) and 777-300ER (131). The large fleets operated by Emirates, Etihad and Qatar Airways service a high volume of connecting long-haul passengers at their airlines' respective hubs in the Persian Gulf. These airlines' fortunes are the opposite of what JAL has experienced.

Assumptions

The following fuel burn and performance analysis is based on simulated flight plan data, courtesy of Lufthansa Systems' Lido/Flight solution. The results generated by these flight plans, and additional independent calculations performed by *Aircraft Commerce*, should only be considered in the context of certain specific assumptions.

Operational assumptions

The simulated aircraft performance features assumptions for weather, including average temperatures for the month of June with 85% reliability winds.

The flight plans were run to achieve the minimum cost track (MCT) for each aircraft on each sector. Lufthansa Systems' Lido/Flight's MCT provides optimised routes by taking fuel, navigation and operational time costs into account. Flight tracks, flight levels and cruise speeds are optimised for minimum costs, while complying with all airway rules and restrictions. The flight plans assume that all aircraft are operating under international flight rules. European Aviation Safety Agency (EASA) standards have been applied for reserve, diversion and contingency fuel requirements.

The block fuel used for each sector is the sum of the trip and taxi fuel burned by each aircraft. It is assumed that each aircraft will taxi with all engines operating. This means that the 747s and A380s will be using all four engines to taxi, and the 777-300ER will be using both of its engines. In practice, some airlines may have implemented procedures in which aircraft taxi without using all available engines, in an attempt to reduce fuel costs. The block time is the sum of the trip and taxi times. The taxi-in and -out times used in this analysis are based on average figures that are held in Lufthansa Systems' Lido/Flight for each airport.

The cost of fuel is assumed to be $1.30 per US gallon (USG). This is rounded up from the figure of $1.279 per USG, recorded in Lufthansa Systems' Lido/Flight solution for London Heathrow (LHR) airport in August 2017. In terms of fuel density, the analysis assumes that one USG is equal to 6.55lbs.

The flight plans show the maximum payload that can be carried by each aircraft variant on each airport-pair. The maximum potential payloads were determined using specific assumptions about each type's certified weights.

Aircraft weights and engines

There are multiple certified weight options available for all of the aircraft covered in this analysis. The A380 and 747-400 also have multiple engine options. Both engine family options are represented for the A380. Three main engine family options exist for the 747-400, but only the CF6-80C2B1F variant has been used here. This is considered satisfactory for providing a performance benchmark when comparing younger generation types to the 747-400, given that the CF6-80C2B1F was one of the most popular engine selections for the type.

The analysis should only be considered as a rough guide to

The 747-8 became the most recent addition to the ultra-large widebody segment when it entered service in 2012. In comparison to its predecessor, the 747-400, the 747-8 has a longer fuselage and stretched upper deck. It is currently in service with Lufthansa, Korean Air and Air China.

comparative performance, since it cannot cover all of the potential weight option and engine combinations. There are, for instance, higher and lower weights available for the A380 than those used here. This includes higher and lower maximum take-off weight (MTOW) and maximum zero fuel weight (MZFW) options. The highest potential MTOW and MZFW have been used for the 747-8 and 777-300ER, although lower weights are available for both types. The highest possible MTOW has been used for the 747-400, but lower options exist. Higher and lower MZFW options are also possible for the 747-400. Different maximum landing weight (MLW) options are also available for each type. In addition, it is possible that higher or lower engine build standards or thrust ratings may be available for some of the engine series used in the analysis. Clearly any changes to these weight or engine specifications could affect performance.

The combined MTOW, MLW, MZFW and engine specifications used in this analysis are intended to offer realistic examples of active passenger aircraft. The chosen combinations represent some of the most common in-service examples, according to an analysis of fleet data from Flightglobal's Fleets Analyzer.

The operating empty weight (OEW) or dry operating weight (DOW) used for each aircraft should be treated as a guide only. In reality OEW will vary by individual aircraft according to the cabin configuration, crew numbers and their belongings, the engine variant and catering and cabin service items. Differences in OEW between two examples of the same aircraft type can be more pronounced in the widebody segment, than for regional or narrowbody types. This is due to the number of configuration options made possible by widebodies' larger cabins, and in some cases, their multiple decks.

The OEWs used in this analysis should fall within a realistic operational range, since they are taken from averages for each aircraft type that have been recorded within Lufthansa Systems' Lido/Flight database.

Aircraft capacity

Raw flight plan data from Lufthansa Systems' Lido/Flight is used to analyse and compare each aircraft's block fuel burn performance. *Aircraft Commerce* has applied its own independent aircraft capacity assumptions to the flight plan data, to summarise each type's fuel costs per available seat mile (ASM).

Most ultra-large widebodies are operated by full-service airlines, which view their long-haul cabin products as important service differentiators. This has resulted in a wide variety of cabin-configuration and seat-capacity options. Ultra-large widebodies are often configured with three or four classes for long-haul sectors, although some operators prefer higher-density two-class arrangements. A four-class configuration will include first, business, premium economy and economy sections. Three-class cabins can include the traditional first, business and economy sections. In more recent years airlines have been offering three-class configurations comprising first or business, premium economy and economy sections. Two-class cabins typically include business and economy sections.

It would be impractical to provide average seat numbers for each ultra-large widebody type, due to the range of layout of passenger accommodation (LOPA) or cabin configuration options. Seat numbers for the same aircraft variant can vary widely by airline, and even between sub-fleets operated by the same carrier. For example, Emirates operates the A380 with 489 or 517 seats in a three-class arrangement, or with up to 615 seats in a two-class configuration. In contrast, Korean Air operates all of its A380s with 407 seats in a three-class set-up. Seat numbers for the active 747-8 fleet range from 364 seats in Lufthansa's four-class cabin to 368 in Korean's three-class configuration. The 747-400 fleet is configured with as few as 275 seats in BA's lowest-density, four-class configuration, and with as many as 533 in Corsair's high-density, two-class layout. 777-300ER seat numbers have a similarly wide range, from SIA's 264-seat four-class cabin to Emirates' 360-seat, three-class, and 427-seat, two-class, arrangements.

The OEWs used in the analysis are average figures from the Lufthansa Systems' Lido/Flight database, taken from across its available operators for each type, which means that they will fall within a realistic operational range. They do not, however, relate to precise configurations or seat capacities due to commercial sensitivity considerations. *Aircraft Commerce* has attempted to identify a realistic spread of potential seating configurations and resulting performance, by analysing the aircraft in three- and four-class configurations. It should be noted that the assumed capacities used here may result in different OEWs which would subsequently influence performance figures. The available seat miles (ASMs) and the fuel burn and cost per ASM results generated by this analysis should only be considered within the context of this potential OEW fluctuation.

Realistic three- and four-class seat capacities have been selected for each aircraft type, based on actual in-service examples. Despite the wide range of options, the chosen examples should provide an idea of the typical difference in size and seat numbers between the types. To provide the most consistent

AIRCRAFT SPECIFICATIONS & WEIGHTS USED IN FUEL BURN SIMULATIONS

Aircraft	777-300ER	747-400	747-8	A380-841	A380-861
Engine	GE90-115BL	CF6-80C2B1F	GEnx-2B67	RR Trent 970	GP7270
MTXW-lbs	777,000	878,000	990,000	1,258,839	1,258,839
MTOW-lbs	775,000	875,000	987,000	1,254,430	1,254,430
MLW-lbs	554,000	630,000	688,000	862,007	862,007
MZFW-lbs	524,000	545,000	651,000	806,892	806,892
OEW-lbs	391,501	414,491	511,472	663,591	663,591
Max payload-lbs	132,499	130,509	139,528	143,301	143,301
Fuel capacity-lbs	317,728	380,849	404,769	546,746	546,746
Fuel capacity-USG	48,505	58,141	61,793	83,467	83,467
Fuselage length	242 feet 4-inches	231 feet 10-inches	250 feet 2-inches	238 feet 7-inches	238 feet 7-inches
Main cabin width	19 feet 3-inches	20 feet 1-inch	20 feet 1-inch	21 feet 4-inches	21 feet 4-inches
Four-class seating	299	337	364	469	469
Three-class seating	360	375	410	517	517

Notes:
1). Fuel capacity figures are converted from lbs using 1 USG = 6.55lbs.
2). 747 and A380 cabin widths refer to lower decks only - both types have reduced upper deck widths due to fuselage contours.

comparison, the same carrier has been used as the seat-capacity source where possible, since they are most likely to have a uniform cabin product across the different types. For the four-class configuration, BA's LOPAs for the 777-300ER, 747-400 and A380 are used; while Lufthansa's LOPA has been used for the 747-8. The assumed four-class capacities for these types are 299, 337, 469 and 364 seats. For the three-class configuration, Emirates' LOPA has been used for the 777-300ER and A380, and China Airlines' and Thai Airways' LOPAs have been used for the 747-400. This results in capacities of 360, 517 and 375 seats. For the 747-8, Boeing's proposed 410-seat, three-class configuration has been used, since only one operator is flying the type in a three-class LOPA and its seat numbers seem low.

Baggage and cargo

Baggage and cargo are generally loaded in unit load devices (ULDs), or containers, on passenger flights operated by ultra-large widebodies. Assumptions have been made regarding average passenger, baggage and lower deck container weights. These weights can be subtracted from each aircraft's total available payload to provide an indication of the potential net payload remaining for cargo.

EASA says it plans to start a rulemaking task in 2018, which will review standard passenger masses. EASA's most recent study in this area was performed, on its behalf, in 2009 by NEA, a member of Panteia. This survey recommended assumed average weights of 194lbs for an adult passenger, plus their hand luggage, and 37lbs per hold or checked bag. These weights are meant as averages for all flights regardless of sector length, or destination. These assumptions have been applied in this analysis, although it should be noted that they are not currently used in EASA's acceptable means of compliance, which use lower passenger weight assumptions.

Aircraft Commerce also assumes that each passenger will check in 1.2 hold bags on average, and that each hold bag has an approximate volume of eight cu ft. This allows the remaining volume available for cargo to be calculated.

There are clearly multiple factors that could result in variations in passenger and baggage weights, and the number and size of checked bags. These include the gender and age of passengers, the purpose of their trip, the time of year they are travelling and the length and destination of the flight.

The analysis assumes that the A380 and 777-300ER would accommodate 38 and 44 LD-3 containers in their lower holds, with the 777-300ER having more capacity than the A380. The 747-400 and 747-8 would accommodate up to 32 and 38 LD-1 ULDs. It is assumed that an LD-3 container has an internal volume of 153 cu ft and a tare weight of 200lbs. The LD-1 specifications used here assume an internal volume of 173 cu ft and a tare weight of 270lbs. This means that the A380, 777-300ER, 747-8 and 747-400 would have 5,814 cu ft, 6,732 cu ft, 6,574 cu ft and 5,536 cu ft of lower deck volume available for baggage and cargo. In practice, airlines might use different lower deck containers to those specified here. ULD volumes and tare weights can also vary by manufacturer.

All calculations relating to remaining cargo payloads assume a 100% passenger load factor (LF), that all the passengers are adults and that each aircraft is carrying its full complement of lower deck containers.

Aircraft

The precise specifications used for each aircraft in this analysis have been summarised *(see table, this page)*. Each type has been analysed in potential four- and three-class configurations.

The 777-300ER has General Electric (GE) GE90-115BL engines and an MTOW of 775,000lbs *(see table, this page)*. It has an OEW of 391,501lbs and a maximum structural payload of 132,499lbs. The 777-300ER's assumed capacity is 299 seats in a four-class layout and 360 seats in a three-class configuration.

It is assumed that the four-class passenger configuration would result in 359 hold bags, while the 360-seat, three-class capacity would require 432 bags to be checked in. In the four-class arrangement, 19 LD-3 ULDs would be required for baggage. This increases to 23 LD-3s when the 777-300ER is configured in the three-class layout. If the aircraft is loaded with its full complement of lower deck containers, the total weight of the passengers, baggage and ULDs is 80,089lbs in the four-class configuration, and 94,624lbs in the three-class set-up. The net payload remaining for cargo can be calculated by subtracting these weights from the 777-300ER's total available payload on each sector. There would be 25 LD-3s remaining for cargo in the four-class configuration and 21 in the three-class configurations These would offer volumes of up to 3,825 cu ft and 3,213 cu ft for freight.

The 747-400 has GE CF6-80C2B1F engines, an MTOW of 875,000lbs and an OEW of 414,491lbs. It has a maximum

The A380 offers the highest seat capacities of any in-service aircraft. Some operators have used A380s to replace ageing 747s. There are a number of airlines that have replaced 747 fleets with a combination of A380s and large twin-engine widebodies such as the 777-300ER.

structural payload of 130,509lbs. The assumed four- and three-class capacities for the 747-400 are 337 and 375 seats. These configurations would lead to 405 checked bags, which would require 19 LD-1 ULDs, and 450 checked bags, which would require 21 LD-1 ULDs. The total weight of the passengers, baggage and ULDs is 89,003lbs in the four-class arrangement and 98,040lbs in the three-class configuration. There would be up to 13 LD-1s remaining for cargo in the four-class set-up, and 11 LD-1s in the three-class set-up. These would offer freight volumes of up to 2,249 cu ft and 1,903 cu ft.

The 747-8 has GE GEnx-2B67 engines, an MTOW of 987,000lbs, an OEW of 511,472lbs and a maximum structural payload of 139,528lbs. In this analysis, it is assumed that the 747-8 is configured with 364 seats in a four-class layout and 410 in a three-class layout. With a 100% LF, these seat capacities would result in 437 and 492 checked hold bags, which would need to be accommodated in up to 21 and 23 LD-1s. The total weight of the passengers, baggage and ULDs is 97,045lbs in the four-class configuration and 108,004lbs in the three-class arrangement. There would be 17 LD-1s remaining for cargo in the four-class configuration, and 15 LD-1s in the three-class configurations providing potential freight volumes of up to 2,941 cu ft and 2,595 cu ft.

Two variants of the A380 have been analysed to ensure that both engine family options are represented. The A380-841 has Rolls-Royce (RR) Trent 970 engines, while the A380-861 has Engine Alliance (EA) GP7270 engines. Both A380 variants have an MTOW of 1,254,430lbs, an OEW of 663,591lbs and a maximum structural payload of 143,301lbs. In practice, there would be a slight difference in OEW between aircraft with RR and EA engines, due to weight differences between the two engine families, but these should not be significant enough to require the use of separate OEW figures in this analysis.

It is assumed that both A380 variants would be configured with 469 seats in the four-class configuration and 517 in the three-class set-up. The four-class configuration would result in 563 hold bags, requiring up to 30 LD-3s, while the three-class configuration would need 621 hold bags and up to 33 LD-3s. The total weight of the passengers, baggage and ULDs is 119,417lbs in the four-class configuration and 130,875lbs in the three-class layout. There would be eight and five LD-3s remaining for cargo, offering potential freight volumes of 1,224 cu ft and 765 cu ft.

The 747-8 is the longest commercial airliner in service, with a fuselage length of 250 feet, 2-inches. It is nearly eight feet longer than the 777-300ER; 11 feet, 7 inches longer than the A380; and 18 feet, four inches longer than its direct predecessor, the 747-400. The A380 has the widest main cabin, with an internal width of up to 21 feet, four inches. Its main deck is up to two feet and one inch wider than that of the 777-300ER, and one foot and 3 inches wider than the two 747 variants. The A380's upper deck is narrower due to contouring, but still offers up to 19 feet of width. The upper decks of the 747-400 and 747-8 are also narrower than their main decks because of the fuselage contour.

A typical economy configuration would have 10-abreast seating on the main decks of the A380s and 747s. Due to the fuselage contour and reduced cabin width, the A380 would typically seat up to eight abreast in economy on its upper deck; in the same layout as standard for the A330/340. Most 747 operators tend to use their aircraft's smaller upper deck for first- or business-class cabins, but both the 747-400 and 747-8 could accommodate up to six-abreast seating on the upper deck in an economy configuration. 777-300ERs will seat nine or 10 abreast in economy, depending on the operator.

Routes

Five medium- and long-haul eastbound airport-pairs were selected for the analysis, each departing from London Heathrow (LHR). The destination airports are Dubai (DXB), New Delhi (DEL), Seoul-Incheon (ICN), Hong Kong (HKG) and Singapore (SIN). These airport-pairs were chosen because they represent markets that support ultra-large widebody services, while also offering a broad range of sector lengths that will emphasise each type's payload-range performance.

The sector lengths for each route are stated in terms of the tracked airway distance, and the equivalent still air distance (ESAD). The tracked airway distance is defined by airway rules and restrictions and can vary slightly by aircraft type according to climb, cruise and descent profiles. These performance criteria can influence which airways aircraft can operate in and when. Although most of the aircraft under analysis will follow similar tracks on each route, a subtle contrast in performance can lead to occasional, marginal differences in the airway distance flown.

BLOCK FUEL BURN PERFORMANCE OF ULTRA-LARGE WIDEBODIES

City-pair	Aircraft variant	Engine variant	PLNTOW (lbs)	PLNLW (lbs)	PLNZFW (lbs)	Available payload (lbs)	ESAD (nm)	Block time (hr:min)	Block fuel (USG)
LHR-DXB	777-300ER	GE90-115BL	654,573	544,642	524,000	132,499	2,946	06:46	16,965
	747-8	GEnx-2B67	812,362	674,745	651,000	139,528	2,946	06:48	21,285
	747-400	CF6-80C2B1F	708,581	569,415	545,000	130,509	2,947	06:41	21,494
	A380-861	GP7270	997,442	832,077	806,892	143,301	2,980	06:54	25,521
	A380-841	Trent 970	999,626	833,742	806,892	143,301	2,943	06:49	25,601
LHR-DEL	777-300ER	GE90-115BL	691,437	554,000	510,143	118,642	3,587	08:07	21,179
	747-8	GEnx-2B67	858,801	688,000	634,788	123,316	3,559	08:05	26,374
	747-400	CF6-80C2B1F	777,089	599,070	545,000	130,509	3,562	07:55	27,446
	A380-861	GP7270	1,066,561	862,007	800,093	136,502	3,543	08:04	31,527
	A380-841	Trent 970	1,069,752	862,007	798,033	134,442	3,546	08:04	32,015
LHR-ICN	777-300ER	GE90-115BL	742,126	554,000	512,934	121,433	4,826	10:39	28,898
	747-8	GEnx-2B67	925,521	688,000	638,329	126,857	4,824	10:38	36,530
	747-400	CF6-80C2B1F	842,612	595,527	545,000	130,509	4,828	10:25	37,963
	A380-861	GP7270	1,147,853	862,007	804,504	140,913	4,824	10:38	43,908
	A380-841	Trent 970	1,152,183	862,007	802,504	138,913	4,824	10:37	44,569
LHR-HKG	777-300ER	GE90-115BL	758,201	553,489	524,000	132,499	5,196	11:24	31,455
	747-8	GEnx-2B67	942,945	686,126	651,000	139,528	5,173	11:23	39,514
	747-400	CF6-80C2B1F	842,656	580,867	545,000	130,509	5,176	11:10	40,243
	A380-861	GP7270	1,147,708	845,581	806,892	143,301	5,152	11:23	46,432
	A380-841	Trent 970	1,154,945	847,560	806,892	143,301	5,152	11:23	47,234
LHR-SIN	777-300ER	GE90-115BL	775,000	540,883	507,820	116,319	5,924	12:41	35,914
	747-400	CF6-80C2B1F	875,000	554,380	514,786	100,295	5,926	12:28	45,366
	747-8	GEnx-2B67	987,000	685,326	644,877	133,405	5,925	12:39	46,317
	A380-861	GP7270	1,210,865	852,354	806,892	143,301	5,917	12:45	54,994
	A380-841	Trent 970	1,219,509	854,406	806,892	143,301	5,918	12:45	56,000

Source: Lufthansa Systems' Lido/Flight

Notes:
1). Lufthansa Systems provided block fuel figures in lbs. These have been converted to USG using 1 USG = 6.55lbs.

This might be because one type could not be cleared to change airways at the same point in time. In some instances this may lead to a slightly different and potentially longer flight track.

The ESAD, which can also be referred to as the nautical air miles (NAM) distance, considers the tracked distance, but also accounts for the influence of en-route winds. It is the effective distance flown over the surface of the earth when the wind direction and strength are considered. ESAD is lengthened or shortened compared to tracked distance by en-route winds. If the aircraft experiences a head wind, the ESAD flown will be longer than the tracked distance. The ESAD will be shorter than the tracked distance with a tail wind. The ESAD therefore considers an aircraft's relative speed over the earth's surface rather than its air speed. All ASM figures generated in this analysis are based on the ESAD rather than the tracked distance.

The shortest sector is LHR-DXB, on which the tracked distance varies from 3,028nm for the RR-powered A380-841, to 3,053nm for the EA-equipped A380-861. The 747-8, 747-400 and 777-300ER all experience a tracked distance of 3,030nm. The ESAD flown on this airport-pair ranges from 2,943nm for the A380-41 to 2,980nm for the A380-861 *(see table, this page)*. The 747-8 and 777-300ER fly an ESAD of 2,946nm, while the 747-400 operates over an ESAD of 2,947nm.

All five aircraft experience a tail wind on LHR-DXB. The A380-861 experiences an average tail wind of 12 knots (kts), compared to 14kts for the other four types. The total taxi time is assumed to be 36 minutes, based on 20 minutes for taxi-out and 16 minutes for taxi-in, while the alternate destination airport is Abu Dhabi (AUH).

On LHR-DEL, the tracked distances range from 3,717nm for the A380-861 to 3,761nm for the 777-300ER. The two 747s fly a tracked distance of 3,718nm. The A380-841's tracked distance was 3,719nm. The ESAD flown on this sector varies from 3,543nm for the A380-861 to 3,587nm for the 777-300ER *(see table, this page)*. All five aircraft experience a tail wind. The average tail wind component ranges from 21kts for the two 747s, to 23kts for the other three aircraft. The total taxi time on LHR-DEL is 39 minutes, allowing 20 minutes for taxi-out and 19 minutes for taxi-in. The alternate airport is Mumbai (BOM).

The tracked distance on LHR-ICN ranges from 4,980nm for the two A380s and the 747-400, to 4,982nm for the 777-300ER. The 747-8 operates a tracked distance of 4,981nm on this route. The ESAD varies from 4,824nm for the two A380s and the 747-8, to 4,828nm for the 747-400. Each aircraft experiences an average tail wind component of 16kts. The total taxi time is 35 minutes, assuming 20 minutes for taxi-out and 15 minutes for taxi-in. The alternate airport is Kansai International (KIX), Japan.

The two A380s and two 747-400s operate over a tracked distance of 5,340nm on LHR-HKG. This compares to 5,343nm for the 777-300ER. The ESAD ranges from 5,152nm for the two A380s, to 5,196nm for the 777-300ER. There is a tail wind, with the average wind component varying from 14kts for the 777-300ER, to 16kts for the 747s and 17kts for the A380s. The total taxi time is 40 minutes, allowing for 20 minutes taxi-out at LHR and 20 minutes taxi-in at HKG. The alternate airport is Guangzhou-Baiyun (CAN), China.

The 777-300ER used the least block fuel across all five sectors in this analysis. This is not surprising since it is the lightest aircraft and the only twin-engine type under analysis.

The longest sector in the analysis is LHR-SIN. The two 747s fly the longest tracked distance on this airport-pair at 6,019nm, followed by the 777-300ER, A380-814 and A380-861 with tracked distances of 6,018nm, 6,013nm and 6,012nm. Each aircraft experiences an average tail wind component of eight knots, resulting in ESADs ranging from 5,917nm for the A380-861 to 5,926nm for the 747-400. The total taxi time is 34 minutes, assuming 20 minutes for taxi-out and 14 minutes for taxi-in. The alternate airport for SIN is Kuala Lumpur (KUL).

Performance

The following performance assessment is split into four sections. In the first two sections, the raw flight plan data is used to summarise each aircraft's block fuel and payload and block time performance. The flight plan data is then combined with *Aircraft Commerce's* independent four- and three-class capacity assumptions to provide a potential guide to fuel costs per ASM, plus the estimated volume and payload remaining for cargo in each configuration. It should be remembered that the assumed capacities may not relate directly to the specified OEWs and that the use of different seat numbers or LF assumptions would result in different costs per ASM.

Block fuel & payload/range

The 777-300ER uses the least block fuel across each of the five airport-pairs, as would be expected. The two A380 variants burn the most fuel *(see table, page 29)*. Again, this would be expected. This is not surprising since the 777-300ER is the lightest type in this analysis and the only twin-engine aircraft, while the A380 variants are the heaviest aircraft examined here.

The 777-300ER burns 20-22% less block fuel than the 747-8 on the five sectors. It burns 21-24% less than the 747-400, 32-35% less than the EA-powered A380-861, and 33-36% less than the RR-equipped A380-841. The 777-300ER's largest advantage in block fuel burn over the two A380s and the 747-8 comes on the longest sector from LHR-SIN. It demonstrates its largest fuel burn advantage over the 747-400 on LHR-ICN.

The 747-8 uses 15-17% less block fuel than the A380-861, and 16-18% less than the A380-841 across the five routes. The 747-8 also burns 1-4% less fuel than the 747-400 on the four shortest airport-pairs, but 2% more on LHR-SIN. This is presumably due to the greater difference in planned take-off weight (PLNTOW) between the two 747s on LHR-SIN, leading the heavier 747-8 to burn more fuel.

The 747-400 uses 13-18% less block fuel than the A380-861 across the five routes, and 14-19% less than the A380-841. The 747-400's largest advantage over the A380s is demonstrated on the longest sector from LHR-SIN.

There is minimal difference between the two A380 variants in terms of their block fuel burn, although the EA-powered A380-861 has a marginal advantage on each sector. The difference in fuel burn between the two A380s is less than 1% on LHR-DXB. On LHR-ICN, the A380-861 burns 1% less fuel. This advantage increases to 2% on the other three sectors.

The two A380s offer the highest available payloads on each sector. The 747-400 offers the lowest payload on LHR-DXB, LHR-HKG and LHR-SIN; while the 777-300ER has the lowest available payload on LHR-DEL and LHR-ICN. All of the aircraft operate with maximum payloads on LHR-DXB and LHR-HKG. The 747-400 also has its maximum payload available on LHR-DEL and LHR-ICN, while the A380-861 and A380-841 operate at maximum payload on LHR-SIN.

The A380 variants, 747-8 and 777-300ER incur payload penalties on the LHR-DEL and LHR-ICN sectors. The limiting factor is not their range, but their MLWs. The 747-8 experiences the largest payload penalties with 12% and 9% restrictions on LHR-DEL and LHR-ICN respectively. The 777-300ER has 10% and 8% payload penalties over the two routes, while the A380-861 has 5% and 2% restrictions. The A380-841 has 6% and 3% payload restrictions on LHR-DEL and LHR-ICN.

Lufthansa Systems highlights how the A380 variants, the 747-8 and the 777-300ER are optimised for long-haul and ultra-long-haul sectors. The difference between their MZFWs and MLWs is not large enough to account for the required alternate fuel on LHR-DEL and LHR-ICN. The alternate fuel requirements on these sectors are the highest in the analysis, due to the distance between the primary and alternate destination airports. BOM is 647nm from DEL, while KIX is 533nm from ICN. Ultra-large types like the A380 have more specific airport selection requirements, since not all airports have the necessary infrastructure required to process them. This partly explains the large distances to some of the alternate airports. The A380s, 747-8 and 777-300ER do not experience any MLW-related payload penalties on LHR-DXB, because AUH, the designated alternate airport, is only 65nm away, resulting in a significantly lower reserve fuel requirement. Since the A380s and 747s are optimised for longer-haul sectors, none of these variants suffers from MLW-related restrictions on

FUEL BURN PERFORMANCE IN FOUR-CLASS CONFIGURATION

City-pair	Aircraft variant	Engine variant	Available payload lbs	Pax capacity	Cargo volume (cu ft)	Net cargo payload (lbs)	ASMs	Fuel burn USG per ASM	Fuel cost per ASM (cents)
LHR-DXB	A380-861	GP7270	143,301	469	1,224	23,884	1,397,620	0.0183	2.37
	A380-841	Trent 970	143,301	469	1,224	23,884	1,380,267	0.0185	2.41
	777-300ER	GE90-115BL	132,499	299	3,825	52,410	880,854	0.0193	2.50
	747-8	GEnx-2B67	139,528	364	2,941	42,483	1,072,344	0.0198	2.58
	747-400	CF6-80C2B1F	130,509	337	2,249	41,506	993,139	0.0216	2.81
LHR-DEL	A380-861	GP7270	136,502	469	1,224	17,085	1,661,667	0.0190	2.47
	A380-841	Trent 970	134,442	469	1,224	15,025	1,663,074	0.0193	2.50
	777-300ER	GE90-115BL	118,642	299	3,825	38,553	1,072,513	0.0197	2.57
	747-8	GEnx-2B67	123,316	364	2,941	26,271	1,295,476	0.0204	2.65
	747-400	CF6-80C2B1F	130,509	337	2,249	41,506	1,200,394	0.0229	2.97
LHR-ICN	A380-861	GP7270	140,913	469	1,224	21,496	2,262,456	0.0194	2.52
	A380-841	Trent 970	138,913	469	1,224	19,496	2,262,456	0.0197	2.56
	777-300ER	GE90-115BL	121,433	299	3,825	41,344	1,442,974	0.0200	2.60
	747-8	GEnx-2B67	126,857	364	2,941	29,812	1,755,936	0.0208	2.70
	747-400	CF6-80C2B1F	130,509	337	2,249	41,506	1,627,036	0.0233	3.03
LHR-HKG	A380-861	GP7270	143,301	469	1,224	23,884	2,416,288	0.0192	2.50
	A380-841	Trent 970	143,301	469	1,224	23,884	2,416,288	0.0195	2.54
	777-300ER	GE90-115BL	132,499	299	3,825	52,410	1,553,604	0.0202	2.63
	747-8	GEnx-2B67	139,528	364	2,941	42,483	1,882,972	0.0210	2.73
	747-400	CF6-80C2B1F	130,509	337	2,249	41,506	1,744,312	0.0231	3.00
LHR-SIN	A380-861	GP7270	143,301	469	1,224	23,884	2,775,073	0.0198	2.58
	A380-841	Trent 970	143,301	469	1,224	23,884	2,775,542	0.0202	2.62
	777-300ER	GE90-115BL	116,319	299	3,825	36,230	1,771,276	0.0203	2.64
	747-8	GEnx-2B67	133,405	364	2,941	36,360	2,156,700	0.0215	2.79
	747-400	CF6-80C2B1F	100,295	337	2,249	11,292	1,997,062	0.0227	2.95

Notes:
1). Cargo volume is volume remaining for cargo in lower deck containers, after checked passenger baggage is accounted for.
2). Net cargo payload is payload remaining after pax, hand luggage, checked luggage and ULD weights accounted for.

the two longest sectors.

On LHR-SIN the 747-400, 777-300ER and 747-8 suffer payload restrictions related to their MTOWs. They do not have the range to operate this sector with a maximum payload when operating with the weight specifications stated in this analysis. The 747-400, 777-300ER and 747-8 therefore experience 23%, 12% and 4% payload restrictions on LHR-SIN. The two A380s have the payload-range capability to operate this sector with a maximum payload.

Each time an aircraft suffers a payload limitation in this analysis, due either to MLW or MTOW restrictions, it still has enough payload available to carry a full passenger and baggage payload. The restrictions will therefore only affect the payload remaining for cargo. This will be explored further when the individual aircraft performance is considered in the context of typical four- and three-class configurations.

Block time

The 747-400 has the shortest block times across each of the five sectors *(see table, page 29)*. Block times will be influenced by individual airway routeings and en-route winds, but another key factor here is that the 747-400 has the fastest assumed climb, cruise and descent procedure default speeds, in terms of Mach (M) number, used in the analysis. These are M0.85, M0.86 and M0.85.

The 747-400's block times range from six hours and 41 minutes on LHR-DXB, to 12 hours and 28 minutes on LHR-SIN. Its block times are nine to 17 minutes shorter than those of the A380-861, eight to 17 minutes shorter than those of the A380-841s, and seven to 13 minutes shorter than those of the 747-8. The 747-400's block times are five to 14 minutes shorter than those of the 777-300ER.

The A380s have the longest block times on LHR-DXB and LHR-SIN, but the 777-300ER has the longest on LHR-DEL, LHR-ICN and LHR-HKG.

The A380-861's block times range from six hours and 54 minutes on LHR-DXB, to 12 hours and 45 minutes on LHR-SIN. The two A380 variants have identical block times on LHR-DEL, LHR-HKG and LHR-SIN; but the A380-841 demonstrates five- and one-minute time savings on LHR-DXB and LHR-ICN.

The 747-8 and 777-300ER have similar block times on each sector. The 747-8's block times range from six hours and 48 minutes on LHR-DXB, to 12 hours and 39 minutes on LHR-SIN; while the 777-300ER's vary from six hours and 46 minutes, to 12 hours and 41 minutes. The difference between the two types varies from one to two minutes across all five routes. The similar block times may be partly explained by the fact that the 777-300ER and 747-8 have the same assumed climb, cruise and descent default speed of M0.84. The two A380s also have a cruise speed of M0.84, but they have a slower climb default of M0.83. The A380s do, however, have the joint fastest descent speed of M0.85.

Four-class configuration

The four-class configurations used here are based on realistic in-service examples. It is assumed that both A380 variants have 469 seats, the 747-8 has 364, the 747-400 has 337, and the 777-300ER has 299. It is possible to generate speculative ASMs and fuel costs per ASM for each aircraft across all five sectors by combining these independent capacity assumptions with the raw flight plan data from Lufthansa Systems' Lido/Flight.

The two A380s burn the least fuel per

The 747-8 burned less block fuel than the two A380 variants on all five sectors. It also burned less fuel than the 747-400 on the shortest four airport-pairs, despite being a heavier aircraft. This demonstrates the improvement in efficiency that has been made between the most recent generations of 747.

ASM, so they offer the lowest fuel costs per ASM on each sector, when the assumed four-class capacities are applied. The 747-400 has the highest fuel costs per ASM on all five routes *(see table, page 31)*.

The A380s are able to offer lower fuel burn and costs than the 747s and the 777-300ER, despite having higher block fuel burn than the Boeing aircraft on each sector. This is because the A380's capacity advantage allows it to generate more ASMs over which the fuel burn and costs can be spread. The EA-powered A380-861 demonstrates marginally lower fuel burn and costs per ASM than the RR-equipped A380-841 on each airport-pair.

The A380-861's fuel burn per ASM ranged from 0.0183-0.0198 USG across the five sectors. This compares to fuel burns per ASM of 0.0185-0.0202 USG, 0.0193-0.0203 USG, 0.0198-0.0205 USG and 0.0216-0.0233 USG for the A380-841, 777-300ER, 747-8 and 747-400.

The A380-861's fuel costs per ASM range from 2.37 cents on LHR-DXB to 2.58 cents on LHR-SIN *(see table, page 31)*. In comparison, the A380-841, 777-300ER, 747-8 and 747-400 have fuel costs of 2.41-2.62 cents, 2.50-2.64 cents, 2.58-2.79 cents and 2.81-3.03 cents per ASM across the five airport-pairs. The A380-841, 777-300ER and 747-8 have their lowest and highest cost per ASM on LHR-DXB and LHR-SIN respectively. The 747-400's lowest cost per ASM is also on the shortest route, but its highest comes on LHR-ICN.

The A380-861's fuel costs per ASM are 0.03-0.04 cents lower than those of the A380-841 across the five routes. This is equivalent to a difference of 1-2% per ASM. The A380-861 demonstrates fuel cost per ASM savings of 0.06-0.13 cents, 0.18-0.23 cents and 0.37-0.51 cents compared to the 777-300ER, 747-8 and 747-400. This is equivalent to differences of 2-5%, 7-8% and 13-17% per ASM.

The A380-841 has similar fuel costs per ASM to the 777-300ER on LHR-SIN. On the other four sectors, the A380-841 demonstrates 0.04-0.09 cents per ASM fuel savings over the 777-300ER, equivalent to 2-4%. Its fuel costs per ASM are 0.14-0.19 cents and 0.33-0.47 cents less, or 5-7% and 11-16% lower than those of the 747-8 and 747-400 respectively, across the five airport-pairs.

The 777-300ER has lower fuel costs per ASM than both 747 variants across all five routes. They are 0.08-0.15 cents or 3-5% lower than those of the 747-8, and 0.31-0.43 cents or 11-14% lower than those of the 747-400. The 747-8's fuel costs per ASM are 0.16-0.33 cents, or 5-11% lower than those of the 747-400.

Freight capacity

All five aircraft variants can operate with a maximum four-class passenger and baggage payload on each airport-pair and still have payload and volume remaining for lower deck freight. According to the assumptions used here, the two A380s would have 1,224 cu ft of volume remaining for cargo in this configuration, after passenger baggage has been accounted for. This is the lowest remaining cargo volume of all the types under analysis. The 777-300ER would offer the most remaining volume, with 3,825 cu ft available, followed by the 747-8 and the 747-400 with 2,941 cu ft and 2,249 cu ft *(see table, page 31)*.

The two A380s have the lowest net cargo payloads on each sector, with the exception of LHR-SIN, despite operating with the highest total payloads on all five routes. The 777-300ER provides the highest net cargo payloads on LHR-DXB and LHR-HKG when all of the aircraft operate at maximum payload. The 747-8 offers the highest cargo payload on LHR-SIN, while the 747-400 has the most cargo payload available on LHR-DEL and LHR-ICN, where the other types are payload restricted due to their MLWs.

The higher capacity of the A380s means the total weight of their passenger and baggage payloads exceeds that of the other types, leaving less payload remaining for cargo in most cases. In the four-class configuration the A380s have an assumed passenger and baggage payload of 111,817lbs. This is 25,032lbs, 31,454lbs and 40,528lbs of additional passenger and baggage payload compared to the 747-8, 747-400 and 777-300ER. Both A380 variants offer net cargo payloads of 23,884lbs on LHR-DXB, LHR-HKG and LHR-SIN, but the A380-861 offers 14% and 10% more cargo payload than the A380-841 on LHR-DEL and LHR-ICN. The A380-861's net cargo payloads range from 17,085-23,884lbs across the five sectors, while the A380-841's varies from 15,025-23,884lbs *(see table, page 31)*. Both aircraft offer their lowest cargo payloads on LHR-DEL where they experience their largest performance restrictions due to their MLWs. In comparison, the 777-300ER, 747-8 and 747-400 offer net cargo payloads of 36,230-52,410lbs, 26,271-42,483lbs and 11,292-41,506lbs. The 777-300ER provides 52-126% more net cargo payload than the A380-861 across the five sectors, and 52-157% more than the A380-841. The 747-8 offers 39-78% of additional cargo payload compared to the A380-861, and 52-78% more than

FUEL BURN PERFORMANCE IN THREE-CLASS CONFIGURATION

City-pair	Aircraft variant	Engine variant	Available payload lbs	Pax capacity	Cargo volume (cu ft)	Net cargo payload (lbs)	ASMs	Fuel burn USG per ASM	Fuel cost per ASM (cents)
LHR-DXB	777-300ER	GE90-115BL	132,499	360	3,213	37,875	1,060,560	0.0160	2.08
	A380-861	GP7270	143,301	517	765	12,426	1,540,660	0.0166	2.15
	A380-841	Trent 970	143,301	517	765	12,426	1,521,531	0.0168	2.19
	747-8	GEnx-2B67	139,528	410	2,595	31,524	1,207,860	0.0176	2.29
	747-400	CF6-80C2B1F	130,509	375	1,903	32,469	1,105,125	0.0194	2.53
LHR-DEL	777-300ER	GE90-115BL	118,642	360	3,213	24,018	1,291,320	0.0164	2.13
	A380-861	GP7270	136,502	517	765	5,627	1,831,731	0.0172	2.24
	A380-841	Trent 970	134,442	517	765	3,567	1,833,282	0.0175	2.27
	747-8	GEnx-2B67	123,316	410	2,595	15,312	1,459,190	0.0181	2.35
	747-400	CF6-80C2B1F	130,509	375	1,903	32,469	1,335,750	0.0205	2.67
LHR-ICN	777-300ER	GE90-115BL	121,433	360	3,213	26,809	1,737,360	0.0166	2.16
	A380-861	GP7270	140,913	517	765	10,038	2,494,008	0.0176	2.29
	A380-841	Trent 970	138,913	517	765	8,038	2,494,008	0.0179	2.32
	747-8	GEnx-2B67	126,857	410	2,595	18,853	1,977,840	0.0185	2.40
	747-400	CF6-80C2B1F	130,509	375	1,903	32,469	1,810,500	0.0210	2.73
LHR-HKG	777-300ER	GE90-115BL	132,499	360	3,213	37,875	1,870,560	0.0168	2.19
	A380-861	GP7270	143,301	517	765	12,426	2,663,584	0.0174	2.27
	A380-841	Trent 970	143,301	517	765	12,426	2,663,584	0.0177	2.31
	747-8	GEnx-2B67	139,528	410	2,595	31,524	2,120,930	0.0186	2.42
	747-400	CF6-80C2B1F	130,509	375	1,903	32,469	1,941,000	0.0207	2.70
LHR-SIN	777-300ER	GE90-115BL	116,319	360	3,213	21,695	2,132,640	0.0168	2.19
	A380-861	GP7270	143,301	517	765	12,426	3,059,089	0.0180	2.34
	A380-841	Trent 970	143,301	517	765	12,426	3,059,606	0.0183	2.38
	747-8	GEnx-2B67	133,405	410	2,595	25,401	2,429,250	0.0191	2.48
	747-400	CF6-80C2B1F	100,295	375	1,903	2,255	2,222,250	0.0204	2.65

Notes:
1). Cargo volume is volume remaining for cargo in lower deck containers, after checked passenger baggage is accounted for.
2). Net cargo payload is payload remaining after pax, hand luggage, checked luggage and ULD weights accounted for.

the A380-841. The 747-400 provides 74-143% and 74-176% more cargo payload than the A380-861 and A380-841 on the shortest four sectors. On LHR-SIN, the A380s offer 112% more net cargo payload than the 747-400, because their superior payload-range performance allows them to operate at maximum payload, while the 747-400 faces a payload restriction.

Three-class configuration

All of the aircraft demonstrate lower fuel burn and lower fuel costs per ASM in the three-class configuration, because the assumed three-class seat numbers are higher. This means each type generates more ASMs on each airport-pair.

The A380s have 517 seats in the three-class configuration, while the 747-8, 747-400 and 777-300ER are assumed to have 410, 375 and 360 seats.

The 777-300ER offers the lowest fuel burn per ASM and subsequently the lowest fuel costs per ASM on each of the five airport-pairs in the three-class configuration *(see table, this page)*. The 777-300ER generates the fewest ASMs on each route due to its smaller seat numbers, but its block fuel burn performance is superior enough to overcome this disadvantage. The two A380s offer the next lowest fuel burn and costs per ASM, while the EA-powered A380-861 has marginally lower costs than the RR-equipped A380-841 on each sector. The 747-400 has the highest fuel burn and costs per ASM.

The 777-300ER's fuel burn per ASM ranged from 0.0160-0.0168 USG across the five sectors. This compares to fuel burns per ASM of 0.0166-0.0180 USG, 0.0168-0.0183 USG, 0.0176-0.0191 USG and 0.0194-0.0210 USG for the A380-861, a380-841, 747-8 and 747-400.

The 777-300ER's fuel costs per ASM range from 2.08 cents on LHR-DXB to 2.19 cents on LHR-HKG and LHR-SIN. In comparison the A380-861, A380-841, 747-8 and 747-400 have fuel costs of 2.15-2.34 cents, 2.19-2.38 cents, 2.29-2.48 cents and 2.53-2.73 cents per ASM *(see table, this page)*. The A380s and the 747-8 experience their lowest fuel costs per ASM on LHR-DXB, and their highest on LHR-SIN. The 747-400's lowest fuel costs per ASM come on LHR-DXB but its highest are on LHR-ICN *(see table, this page)*.

The 777-300ER's fuel costs per ASM are 0.07-0.15 cents lower than those of the A380-861 and 0.11-0.19 cents lower than those of the A380-841 across the five sectors. This is equivalent to 3-6% and 5-8% lower costs per ASM. The assumed seat capacity is the only variable that has changed between this configuration and the four-class layout, in which the Airbus aircraft demonstrated the lowest fuel costs per ASM. The difference in capacity between the A380s and 777-300ER was 170 seats in the four-class arrangement. In the three-class layout the difference is 157 seats, a disparity that is not large enough for the A380s to generate the number of ASMs required to offset their higher block fuel burn.

The 777-300ER's fuel costs per ASM are 0.21-0.29 cents and 0.45-0.57 cents lower than those of the 747-8 and 747-400. This is equivalent to 9-12% and 18-21% lower fuel costs per ASM.

The A380-861's fuel costs per ASM are 0.03-0.04 cents, 0.11-0.15 cents and 0.31-0.44 cents, or 1-2%, 5-6% and 12-16% lower than those of the A380-841, 747-8 and 747-400 across the five sectors.

The A380-841 has fuel costs per ASM that are 0.08-0.11 cents and 0.27-0.41 cents, or 3-4% and 10-15% lower than

Despite demonstrating the highest block fuel burn on each sector, the analysis suggests that the A380 can be competitive with current large twin-engine widebodies on a cost per ASM basis. This depends, however, on the A380 having a large enough capacity advantage so that it can spread it higher fuel costs over a greater number of ASMs.

those of the 747-8 and 747-400.

The 747-8's fuel cost per ASM advantage over its predecessor ranges from 0.17-0.33 cents, or 6-12% across the five sectors.

Freight capacity

All the aircraft can operate with a maximum passenger and baggage payload across the five sectors, and they would each offer additional payload and lower deck volume for cargo.

According to the assumptions used in this analysis, the 777-700ER offers the most remaining volume for cargo in a three-class configuration, with 3,213 cu ft available. This is followed by the 747-8 and 747-400 with 2,595 cu ft and 1,903 cu ft of cargo volume. The two A380s have 765 cu ft of volume remaining for cargo, which is the lowest of all the types in a three-class configuration *(see table, page 34)*.

The 777-300ER also offers the highest net cargo payloads on LHR-DXB and LHR-HKG, when all aircraft operate at maximum payload. The 747-8 offers the highest cargo payload on LHR-SIN, while the 747-400 has the highest cargo payloads on LHR-DEL and LHR-ICN. The A380s offer the lowest net cargo payloads on all sectors except LHR-SIN, despite operating with the highest total payloads.

The higher capacity of the two A380s again means that their total passenger plus baggage payloads exceed those of the other types, resulting in their lower net cargo payloads. In the three-class configuration the A380s have a passenger and baggage payload of 123,275lbs. This is 25,531lbs, 33,875lbs and 37,451lbs higher than that of the 747-8, 747-400 and 777-300ER.

Both A380 variants offer net cargo payloads of 12,426lbs on the LHR-DXB, LHR-HKG and LHR-SIN sectors. The A380-861 offers 5,627lbs and 10,038lbs of cargo payload on LHR-DEL and LHR-ICN, which is 58% and 25% more than the A380-841. Both variants offer their lowest cargo payloads on LHR-DEL due to MLW limitations. In contrast, the 777-300ER, 747-8 and 747-400 offer cargo payloads of 21,695-37,875lbs, 15,312-31,524lbs and 2,255-32,469lbs across the five sectors. The 777-300ER provides net cargo payloads that are 75-327% higher than those of the A380-861 and 75-573% higher than those of the A380-841. The 747-8's cargo payloads are 88-172% and 104-329% higher than those of the A380-861 and A380-841. The 747-400's cargo payloads are 161-477% and 161-810% higher than those of the A380-861 and A380-841 on the four shortest sectors. On LHR-SIN, however, the superior payload-range performance of the two A380s means they can operate with a maximum payload and offer net cargo payloads that are 451% higher than those of the 747-400.

Summary

There has been a clear shift in demand towards twin-engine aircraft in the widebody market over the past 20 years. The trend has been seen in the ultra-large widebody segment with the 777-700ER superseding the 747 as the most popular type in this category. The main reason for this shift is the lower operating costs provided by twin-engine types, both in terms of fuel burn, and maintenance.

In this analysis, the 777-300ER burns 20-36% less block fuel burn than competing four-engine, ultra-large widebodies on each sector. The A380 variants had the highest block fuel burn. When fuel costs per ASM are considered, the performance summary suggests the 777-300ER could offer lower fuel costs per ASM than the larger four-engine types, depending on the comparable seating configurations. The analysis also saw the A380s offering lower fuel costs per ASM than the 777-300ER on all five sectors in the four-class configuration. In both the four- and three-class layouts, the A380s had lower fuel costs per ASM than the 747-8.

The ASMs generated here and any related conclusions should be treated as a rough guide, since it was not possible to directly match the OEWs to specific seat numbers. The performance analysis does generally suggest, however, that the latest generation four-engine types, and particularly the A380, can compete with current ultra-large, twin-engine aircraft on a fuel cost per ASM basis, provided they have a large advantage in seat numbers.

Four-engine types are likely to come under increasing pressure as the next generation of even larger and more efficient twin-engine widebodies prepares to enter service. The A380 is likely to be the only four-engine widebody in service in significant numbers in the future. It is likely to maintain a niche presence in the market, as long as it maintains its capacity advantage, providing a particular appeal for operators serving slot-congested hubs. AC