The 777-300ER and A380 are two of the main candidates to replace ageing 747-400s on high capacity long-haul services. The fuel burn, block time and payload performance of the 777-300ER, A380 and 747-400 are compared here.

Fuel burn & operating performance of the A380, 777-300ER & 747-400

Boeing's 747 family dominated the ultra-large, long-haul widebody market for many years. In 2005, for example, there were more 747-400s in active passenger service than any other large widebody type.

The active 747-400 fleet has gradually declined over the past 10 years, as airlines have replaced these aircraft with more efficient types. Consistently high fuel prices have been one major factor.

Large and ultra-large widebody options are the 777-300ER, the A380 and the 747-8I. Only the 777-300ER and A380 have sold in significant numbers.

Aircraft Commerce has analysed the fuel burn and operating performance of the 777-300ER and A380 against the 747-400. The level of operating efficiency improvements offered by the 777-300ER and A380 against the 747-400 are examined here.

747-400 replacements

Some airlines have replaced 747-400s with larger A380s, smaller 777-300ERs, a combination of both, or a combination of A380s or 777-300ERs with other smaller twin-engine, long-haul aircraft.

British Airways (BA) was the largest 747-400 operator in 2005 (57). Since then, it has reduced its active 747-400 fleet to 43 and added A380s (9), 777-300ERs (12), and 787-8s (8).

Widebody leasing specialist Amedeo believes the A380's size and capacity are a unique selling point. "The A380 is the world's largest commercial passenger aircraft, and will remain so for decades due to its unrivalled market positioning," claims Irena Badelska, head of business development at Amedeo.

"The A380 altered the competitive landscape in the ultra-large widebody market after nearly 40 years of success for Boeing's 747 family," adds Badelska. "The A380 is redefining that market segment. The 747-400 and 747-8I are less attractive than the A380 in terms of size, comfort, and operating cost parameters. The A380's key competitive advantages are its revenue- and profit-generating capabilities, and its unit and operating cost efficiencies. It can fly one mission instead of two, where the additional frequencies do not add extra value."

Amedeo believes the A380's main competition in the large widebody market will come from the 777-9X.

Assumptions

A number of simulated flight plans have been generated to compare the fuel burn performance of the 747-400, 777-300ER and A380. These are based on typical long-haul routes that these aircraft are operated on by airlines, departing from London Heathrow (LHR) and operating eastwards to five destinations in the Middle East and the Asia Pacific. The results generated by the flight plans depend on a set of specific assumptions.

Aircraft weight & engine variants

To generate the flight plans, specific weight variants and engine options were chosen for each aircraft type.

Some of these aircraft have multiple weight variants and engine options. The use of different weight specifications and engine variants will affect an aircraft's fuel burn performance.

The specifications and variants selected were thought to reflect what some operators may choose, but they may not represent the highest available weights or the highest-rated engine variants of each type.

The operating empty weights (OEWs) used in the analysis can only provide a rough guide to an actual OEW in service. OEW will vary by individual aircraft and is influenced by factors such as the cabin configuration, engine variant, crew size and luggage, and the amount of catering and cabin service items on board.

The OEWs used in the analysis should offer a realistic example for each aircraft type, but it was not possible to tailor them to the exact seating configurations used here.

Aircraft seating configurations

There are many different cabin configurations available for modern large widebody aircraft.

Some airlines view first- and business-class cabins as important product differentiators in a highly competitive marketplace, leading to various advanced configurations, with features such as lie-flat beds and internet access via satellite.

Cabin configurations can vary by airline and aircraft type. Some airlines have multiple layouts for the same type.

There are currently 747-400s and 777-300ERs operating in four-, three- and two-class configurations. All A380s operate with four- or three-class layouts.

The different configuration options have led to a wide range of potential seat capacities for large widebodies. It is, therefore, difficult to establish an average capacity for the aircraft in this analysis.

The seat capacities chosen here are based on realistic three-class layouts with first, business and economy cabins. The capacities used for this analysis were partly selected in an attempt to reflect the approximate difference in size and seat numbers between the 777-300ER, A380 and 747-400. Clearly any variation in the selected seat configuration will provide different results to those shown here.

Operational assumptions

A number of operational assumptions were made to generate the flight plans used in this analysis.

AIRCRAFT SPECIFICATIONS & WEIGHTS USED IN FUEL BURN SIMULATIONS

Aircraft Converted	747-400	777-300ER	A380-841	A380-861
Engine	CF6-80C2B1F	GE90-115BL	Trent 970	GP7270
MTOW-lbs	870,000	775,000	1,254,430	1,254,430
MLW-lbs	630,000	554,000	862,007	862,007
MZFW-lbs	542,500	524,000	806,892	806,892
OEW-lbs	400,000	375,000	615,000	615,500
Max payload-lbs	142,500	149,000	191,892	191,392
Usable fuel-USG	57,065	47,890	85,472	85,472
Three-class seats	375	360	489	489

Notes:
1). OEWs are estimates. OEW will vary by individual aircraft.
2). Seat numbers based on real airline examples. Three-class seat numbers for these aircraft can be highly variable.

Each simulated flight sector was based on international flight rules, with standard assumptions for fuel reserves, diversion, and contingency fuel.

The routes and flight levels flown comply with all airway rules and air traffic control (ATC) restrictions, and were optimised to achieve the shortest possible flight time.

The aircraft were operated at long-range cruise (LRC) speed to maximise fuel efficiency.

The assumed weather conditions were based on 85% reliability winds and average temperatures during June.

A taxi time of 30 minutes has been assumed for all aircraft on each sector. This is added to the aircraft's flight time to provide the overall block time.

Each aircraft's taxi fuel burn is based on idle fuel flow rates for respective engine variants. It is assumed that each type will have all of its engines running during the taxi. The block fuel is calculated from the sum of the flight and taxi fuel for a sector.

A spot fuel price of $1.805 per US gallon (USG) has been assumed. This is taken from the International Air Transport Association (IATA) jet fuel price index from April 2015.

The flight plans were generated to show each aircraft's performance when operating with maximum permissible payloads on each route. This means that the available payload is the aircraft's maximum structural payload on shorter sectors in most cases. As route length increases, each type's payload-range performance dictates whether there is a decline in available payload.

The potential payload remaining for belly space cargo has been calculated by subtracting the weight of passengers and baggage, plus the tare weight of the lower deck containers required for hold luggage, from each aircraft's available payload on each route.

A weight of 187lbs has been used in respect to each passenger and cabin baggage. It is assumed that each passenger will also check in 1.2 hold bags on average. Each hold bag is estimated to weigh 57lbs and have a volume of eight cubic feet (cu ft). This takes the average weight for each passenger to 255.4lbs.

It is assumed that the 747-400 would accommodate hold luggage in LD-1 containers, and that the 777-300ER and A380 would use LD-3 containers.

Internal volumes of these containers are assumed to be 175 cu ft for an LD-1, and 153 cu ft for an LD-3. Tare weights of 180lbs and 200lbs have been used for the respective containers.

The remaining cargo payload does not account for the tare weight of any additional containers or pallets required to accommodate it.

Aircraft

The aircraft specifications used for the fuel burn analysis have been summarised for each type *(see table, page xx)*.

747-400

The 747-400 has CF6-80C2B1F engines and a maximum take-off weight (MTOW) of 870,000lbs *(see table, this page)*. Its fuel capacity is 57,065 USG.

An OEW of 400,000lbs has been assumed for the 747-400.

An analysis of the operational 747-400 fleet shows that aircraft configured in a three-class layout with first, business and economy cabins, have 330-461 seats.

A capacity of 375 seats was chosen for this analysis. This is fairly average for a 747-400 in a typical three-class layout. Thai Airways and China Airlines both operate 747-400s with 375 seats in a three-class configuration.

Typical economy class seating in a 747-400 features a 10-abreast layout.

Based on the assumptions used in this analysis, 375 passengers would check in 450 hold bags. These would require 21 LD-1 containers to accommodate them. The total weight of the passengers, baggage, and the containers is estimated to be 99,555lbs. This figure can be subtracted from the 747-400's available payload on each sector to calculate the remaining available payload for cargo.

777-300ER

The 777-300ER has GE90-115BL engines, an MTOW of 775,000lbs and a fuel capacity of 47,890 USG *(see table, page xx)*.

Typical in-service OEWs can be 375,000-380,000lbs for 777-300ERs. An OEW of 375,000lbs has been used here.

An analysis of the operational 777-300ER fleet shows that aircraft configured in a three-class layout with first, business and economy cabins have capacities ranging from 278 to 362 seats.

A capacity of 360 seats has been used for the 777-300ER in this analysis, 15 fewer seats than the 747-400 *(see table, this page)*. Emirates operates some of its 777-300ER fleet with 360 seats in a three-class configuration.

The configuration of 777-300ER economy cabins varies by operator. Emirates uses 10-abreast seating in its 360-seat layout. Others may use nine.

It is assumed that 360 passengers would check in 432 hold bags, accommodated in up to 23 LD-3 containers. The total weight of the passengers, their baggage, and the containers, is estimated to be 96,544lbs. This can be subtracted from the 777-300ER's available payload to calculate the payload remaining for cargo on each airport-pair or route.

FUEL BURN PERFORMANCE OF 777-300ER, A380 & 747-400

City-pair	Aircraft variant	Actual TOW lbs	Available payload lbs	Seats	Available cargo lbs	ESAD nm	Block time hr:min	Block fuel USG	Fuel burn USG per ASM	Fuel cost cents per ASM
LHR-DXB	777-300ER	660,946	149,000	360	52,546	2,971	06:48	17,717	0.0166	2.99
	A380-861	1,009,294	191,392	489	60,290	2,974	06:49	26,295	0.0181	3.26
	A380-841	1,013,312	191,892	489	60,790	2,974	06:49	26,781	0.0184	3.32
	747-400	706,596	142,500	375	42,945	2,969	06:42	21,152	0.0190	3.43
LHR-DEL	777-300ER	693,450	146,336	360	49,792	3,545	07:57	21,266	0.0167	3.01
	A380-861	1,058,424	191,392	489	60,290	3,531	07:56	31,940	0.0185	3.34
	A380-841	1,063,288	191,892	489	60,790	3,538	07:57	32,503	0.0188	3.39
	747-400	746,712	142,500	375	42,945	3,549	07:50	25,772	0.0194	3.50
LHR-ICN	777-300ER	739,805	149,000	360	52,456	4,765	10:26	28,703	0.0167	3.02
	A380-861	1,133,118	191,392	489	60,290	4,755	10:26	43,546	0.0187	3.38
	A380-841	1,138,367	191,892	489	60,790	4,755	10:26	44,222	0.0190	3.43
	747-400	806,604	142,500	375	42,945	4,759	10:17	35,092	0.0197	3.55
LHR-HKG	777-300ER	773,417	149,000	360	52,456	5,399	11:39	33,329	0.0171	3.10
	A380-861	1,177,851	191,392	489	60,290	5,324	11:35	49,723	0.0191	3.45
	A380-841	1,183,951	191,892	489	60,790	5,323	11:35	50,504	0.0194	3.50
	747-400	843,531	142,500	375	42,945	5,327	11:23	40,185	0.0201	3.63
LHR-SIN	777-300ER	773,928	124,924	360	28,380	6,041	12:50	36,870	0.0170	3.06
	A380-861	1,230,641	191,392	489	60,290	5,986	12:47	57,087	0.0195	3.52
	A380-841	1,236,571	191,892	489	60,790	5,986	12:48	57,877	0.0198	3.57
	747-400	869,849	131,450	375	31,895	5,989	12:34	45,476	0.0202	3.65

Source: Navtech

A380

There are two engine families available for the A380: the Engine Alliance GP7200 series, and the Rolls-Royce Trent 900 series.

Both A380 variants are analysed here. The A380-841 is equipped with Trent 970 engines. The A380-861 has GP7270 engines *(see table, page 26)*. The A380-841 and A380-861 have an MTOW of 1,254,430lbs and a fuel capacity of 85,472 USG *(see table, page 26)*.

Typical in-service OEWs for this weight variant of the A380 can be 615,000-625,000lbs, depending on cabin configuration. An OEW of 615,000lbs has been used for the A380-841, and a slightly higher OEW of 615,500lbs for the A380-861. The 500lbs difference between the two engine variants is based on early marketing material for the A380.

Operational A380s with a three-class cabin have capacities of 407-526 seats.

A capacity of 489 seats has been used for both A380 variants in this analysis. Emirates is the largest operator of A380s, and about half of its fleet is configured with 489 seats in a three-class layout.

Amedeo believes that higher-capacity configurations of the A380 may be explored. "Future A380 customers, and existing operators considering interior refurbishment, are likely to increase the seat count and optimise the available space on the aircraft," claims Badelska. "This will allow them to benefit from the lowest unit costs the A380 can offer, while retaining the desired levels of customer comfort and personal space to fit those airlines' product strategies."

All current A380 operators have 10-abreast seating in their lower deck economy cabins. Some also have economy cabins on the upper deck, with eight-abreast layouts, due to the contour and width of the fuselage.

This analysis assumes that 489 passengers would check in 587 hold bags, accommodated in up to 31 LD-3 containers. The total weight of the passengers, baggage and the LD-3 containers would be 131,102lbs. The payload remaining for cargo can be calculated by subtracting this weight from each A380's available payload.

Routes

Five routes from Europe to the Middle East and Asia Pacific were chosen for this analysis: LHR to Dubai (DXB); LHR to New Delhi (DEL), LHR to Seoul Incheon (INC); LHR to Hong Kong (HKG) and LHR to Singapore (SIN).

These airport-pairs could all be operated by the three aircraft types being analysed. The tracked distances flown vary from 3,062nm to 6,152nm.

An aircraft's tracked distance is determined by air traffic control (ATC) and airway routeings and restrictions. Departure and arrival routeings must be complied with and airways followed.

The sector length for each route is stated in equivalent still air distance (ESAD) *(see table, this page)*. The ESAD of a sector can be longer or shorter than the tracked distance, depending on the en-route wind speed. It is based on the tracked distance, but also takes into account the aircraft's relative speed over the earth's surface, which can be influenced by factors, such as true air speed and en-route winds. If an aircraft experiences a tailwind, the ESAD will be shorter than the tracked distance; if it experiences a headwind, the ESAD will be longer than the tracked distance. The fuel burn figures used in this analysis were calculated using the ESAD for each airport-pair *(see table, this page xx)*.

On LHR-DXB, the 777-300ER flew a tracked distance of 3,085nm, while the 747-400 and A380s flew a tracked distance of 3,062nm.

Average tail winds of 14-18 knots (kts) were experienced, and the ESAD ranged from 2,969nm for the 747-400 to 2,974nm for the two A380s. The alternate airport was Dubai Al Maktoum (DWC).

Emirates is the largest A380 operator. Most of its fleet is configured with 489 or 517 seats in a tri-class layout. The A380's fuel burn per ASM is 2-5% lower than the 747-400, but about 9% higher than the 777-300ER.

All the aircraft flew a tracked distance of 3,762nm on LHR-DEL. Average tail winds of 29-31 kts were experienced, and the ESAD ranged from 3,531nm for the A380-861 to 3,549nm for the 747-400 (see table, p28). The alternate airport was Amritsar - Sri Guru Ram Dass Jee International (ATQ).

All four aircraft flew a tracked distance of 4,984nm from LHR-ICN. They experienced average tail winds of 22-23 kts. The ESAD ranged from 4,755nm for the two A380s, to 4,765nm for the 777-300ER. The alternate airport was Gimpo International (GMP).

On LHR-HKG, the 777-300ER flew a tracked distance of 5,622nm. The other three aircraft flew a tracked distance of 5,501nm. Average tailwinds of 16-20 kts were experienced. The ESAD varied from 5,323nm for the A380-841 to 5,399nm for the 777-300ER. The alternate airport was Macau International (MFM).

On LHR-SIN, the 777-300ER flew a tracked distance of 6,152nm. The other three flew a tracked distance of 6,109nm. Average tail winds of 9-10 kts were experienced. The ESAD ranged from 5,986nm for the two A380s to 6,041nm for the 777-300ER *(see table, page 28)*.

Performance

The block fuel, fuel burn per available seat-mile (ASM) and fuel cost per ASM are summarised for each aircraft across all five routes *(see table, page 28)*.

The fuel costs per trip of the 777-300ER, A380-841, A380-861 and 747-400, are compared.

Other important performance factors discussed here include block times and the impact of different sector lengths on each aircraft's available payload.

Fuel burn

The 777-300ER burned the least block fuel on all five routes, and demonstrated the lowest fuel costs per trip. This is unsurprising, since the 777-300ER is the smallest type, and also has two engines rather than the 747-400's and A380s's four engines.

More importantly, the 777-300ER had the lowest fuel burn per ASM, and, therefore, the lowest fuel cost per ASM across all five sectors. The 747-400 burned less block fuel than the two A380 variants on all routes, so the 747-400 had lower trip fuel burn and costs.

The A380's additional capacity, however, means the A380-841 and A380-861 both had lower fuel burn and fuel costs per ASM than the 747-400 on all five sectors *(see table, page 28)*.

There was a marginal difference in the fuel burn performance of the two A380 variants, with the GP7270-powered A380-861 burning slightly less block fuel on each route. This A380 variant had fractionally lower fuel costs per trip, and lower fuel burn and fuel costs per ASM than the Trent 970-powered A380-841 variant on all five sectors.

777-300ER

The 777-300ER used 16-19% less block fuel than the 747-400, 33-35% less than the A380-861, and 34-36% less than the A380-841 across the five routes *(see table, page 28)*. Its biggest advantage in block fuel burn came on the longest sector, LHR-SIN.

The 777-300ER's fuel costs per trip ranged from $31,980-66,550, compared to fuel costs per trip of $38,179-82,084 for the 747-400, $47,463-103,041 for the A380-861 and $48,340-104,469 for the A380-841.

The 777-300ER's fuel costs per ASM were 0.44-0.59 cents lower than those of the 747-400 *(see table, page 28)*. This equates to 13-16% lower fuel costs per ASM for the 777-300ER.

The 777-300ER's fuel costs per ASM were also 0.33-0.51 cents or 10-14% lower than those of the A380-841 *(see table, page 28)*.

In comparison to the A380-861, the 777-300ER's fuel costs per ASM were 0.27-0.46 cents or 8-13% lower.

The 777-300ER's biggest advantage over the 747-400 and two A380 variants, in terms of fuel burn per ASM, was demonstrated on LHR-SIN. Its fuel cost per ASM was 3.06 cents on this sector, compared to 3.65 cents for the 747-400, 3.57 cents for the A380-841, and 3.52 cents for the A380-861.

For the purposes of this analysis, the two A380s were configured with 129 more seats than the 777-300ER. This clearly means they generate more ASMs than the 777-300ER on the same route. The disparity in ASMs between the A380s and 777-300ER grew as route length increased. Despite a slight drop on LHR-HKG, there was no particular trend for the Boeing aircraft's advantage in fuel burn per ASM to shrink on the longer sectors. This is because the discrepancy in ASMs was offset by the 777-300ER's advantage in block fuel burn.

Fuel burn and fuel costs per ASM are clearly affected by an aircraft's capacity. In addition to its 489-seat three-class layout, Emirates operates A380s with 517 seats in a three-class configuration. Even if this seat capacity had been used, the 360-seat 777-300ER would still have had lower fuel burn and costs per ASM than the A380s on all routes. The 777-300ER's advantage, however, would have been more than halved in some cases.

A380

The 747-400 used 20-21% less block fuel than the A380-841, and 19-20% less than the A380-861 across the five sectors.

Unlike the 777-300ER, the 747-400's advantage in block fuel burn was not enough to offset the A380's superior ASM productivity. The A380 variants both subsequently demonstrated lower fuel costs per ASM than the 747-400 across all five routes.

The A380-841's fuel costs per ASM

The 777-300ER burns the least block fuel on each route in the analysis. It also has the lowest fuel burn and therefore the lowest fuel cost per ASM on all routes. Operational 777-300ERs configured with a traditional tri-class cabins have capacities of 278 to 362 seats.

were 0.08-0.13 cents, or 2-4%, lower than those of the 747-400.

The A380-861's fuel costs per ASM were 0.13-0.18 cents, or 4-5% lower than those of the 747-400.

Both A380s showed their largest advantage in fuel costs per ASM over the 747-400 on the LHR-HKG sector. The smallest advantage came on LHR-SIN.

The fuel burn performance of the two A380s was very similar across all five routes, although the A380-61 burned slightly less fuel on each occasion.

The A380-861's fuel costs per ASM were 1-2% lower than those of the A380-841 across the five airport-pairs, with the largest gap coming on the shortest sector, LHR-DXB.

Block times

The 747-400 had the shortest block times across all five airport-pairs, with each aircraft operating at LRC speed where applicable.

The 747-400's block times were 6-16 minutes shorter than the 777-300ER's, 7-14 minutes shorter than the A380-841's and 7-13 minutes shorter than those of the A380-861 *(see table, page 28)*.

The 777-300ER had the longest, or joint-longest block times, on all but the shortest sector, LHR-DXB, by up to four minutes. The two A380 variants operated identical block times on LHR-DXB, LHR-ICN and LHR-HKG. On LHR-DEL and LHR-SIN the block times for the GP7270-powered A380-861 are one minute less than those of the A380-841.

The two A380 variants' greatest advantage in block time over the 777-300ER was four minutes on LHR-HKG.

Block time can be influenced by the ESAD flown, as well as the aircraft's climb, cruise and descent speeds.

Available payload

The A380-841 and A380-861 both had the largest payload remaining for cargo across the five routes (see table, p28).

The A380-841 had a payload of 60,790lbs remaining for cargo on each of the five sectors. This is slightly higher than the 60,290lbs payload remaining for the A380-861 on each route, owing to the latter's slightly higher OEW.

No payload restrictions were needed for either A380 variant and both aircraft operated with their maximum structural payloads on all five routes.

The 747-400 was able to operate with its maximum structural payload and offer a potential cargo payload of 42,945lbs on each route except LHR-SIN. It offered less payload for cargo than the 777-300ER on the LHR-DXB, LHR-DEL, LHR-ICN and LHR-HKG sectors.

On LHR-SIN, the 747-400's available payload was restricted to 92% of its maximum structural payload, leading to an available cargo payload of 31,895lbs. The 777-300ER suffered a larger restriction on this sector, where its available payload was restricted to 84% of its maximum structural payload. The 777-300ER subsequently had an available cargo payload of 28,380lbs on LHR-SIN, the lowest of all four aircraft analysed here.

The 777-300ER was able to operate with its maximum structural payload on LHR-DXB, LHR-ICN and LHR-HKG. On these routes its available cargo payload was 52,456lbs. The 777-300ER suffered a slight payload restriction on the LHR-DEL sector, which led to an available cargo payload of 49,792lbs.

Despite having an advantage of 8,000-32,000lbs in available cargo payload over the 777-300ER, the two A380s would potentially have less volume available for cargo.

A 777-300ER can accommodate up to 44 LD-3 containers in its lower deck compared to 38 for the A380s (see *The belly freight capacity of widebody passenger aircraft, Aircraft Commerce, December 2014/January 2105, page 52*). Based on the assumptions used in the analysis, the 777-300ER would have 21 LD-3s remaining for freight after passenger baggage has been accounted for. The A380s would have just seven.

Summary

As would be expected, the smaller, twin-engined 777-300ER burned less block fuel and had lower fuel costs per trip, and per ASM, than the 747-400 and two A380 variants on all five sectors.

The 747-400 burned less block fuel than the two A380s, but the older generation and smaller 747-400 had inferior fuel costs per ASM.

The GP7270-powered A380-861 burned fractionally less fuel than the Trent 970-equipped A380-841.

The 747-400 flew the shortest block times on all five sectors. The 777-300ER flew the longest or joint-longest block times on each sector except LHR-DXB.

The two A380 variants offered the highest available payload for cargo on every sector, both able to operate without payload restrictions on all five routes.

The 777-300ER offered an inferior potential cargo payload than the A380s on each route. Despite this it would potentially offer a greater remaining volume for cargo.

The 777-300ER and A380 are the most likely replacement candidates for 747-400s, both offering lower fuel costs per ASM than the 747. The 777-300ER offers better fuel burn performance based on the assumptions used in this analysis.

Despite this, fuel burn performance is just one deciding factor. Issues such as an individual carrier's capacity requirements, influenced by traffic demand, take-off slot availability, and scheduling factors, will also affect aircraft type selection.

The A380 is in a class of its own in the very large capacity market, but will only be chosen for certain routes. AC