The 787 family was predicted to deliver fuel burn savings of up to 20% compared to the aircraft they would replace. The fuel burn performance of the 787-8 & 787-9 is analysed and compared to competing widebodies.

Fuel burn & operating performance of the 787-8, 787-9 & competitors

It was estimated that the 787-8 and -9 would offer fuel burn reductions of up to 20% compared to the similar-sized aircraft they were positioned to replace.

With both variants now in service, *Aircraft Commerce* has analysed the fuel burn and operating performance of the 787-8 and -9 against aircraft in the same size category. The comparison aircraft include the 767-300ER, A330-200, A330-300 and A340-300.

The extent to which the 787 lives up to expected fuel-efficiency improvements is examined here.

Assumptions

A number of simulated flight plans on transatlantic routes were generated to compare the fuel burn performance of the 787-8 and -9 and four other aircraft types. The results generated by these flight plans are based on a set of specific assumptions.

Aircraft weight & engine variants

There are multiple weight variants and engine options available for some of the aircraft types included in this analysis. Specific weight combinations and engine variants were selected to generate the flight plans.

The fuel burn performance of each aircraft will clearly vary depending upon its engine variant and weight specifications. In some cases there may be higher or superior weight specifications available to those chosen here. The weight specifications for each type in this analysis were chosen because they are thought to represent some of the most numerous examples of aircraft in each type's active fleet.

The operating empty weights (OEWs) used in the analysis can only be treated as a rough guide. OEW is influenced by factors including the cabin configuration and engine variant. They also depend on crew numbers and baggage, catering and cabin service items loaded, and a variety of other issues.

In reality OEW will vary by individual aircraft and for each flight. It was not possible to provide exact OEWs tailored to the precise seating configurations used in the analysis.

Aircraft seating configurations

There are a complex number of potential seating configurations available for modern widebody aircraft. Aircraft manufacturers avoid direct capacity comparisons of their most recent designs with their competitors. Boeing quotes typical three-class seat numbers, while Airbus chooses to highlight potential two-class configurations.

On typical transatlantic services the seating capacity on an aircraft type can also vary by airline. Some carriers have multiple seating configurations for the same aircraft variant.

On most transatlantic services aircraft are configured with two- or three-class cabins, but there is a wide range of product differentiation between airlines. The traditional three-class cabin comprised first, business and economy classes. Some carriers have now moved to three-class cabins consisting of a first or business class, premium economy and economy. There are also many advanced, first- or business-class seating options that include lie-flat beds. All these different product options will influence an aircraft's total seat numbers.

To remain consistent, the seat capacities used in this analysis are based on the typical three-class layouts used by airlines that operate transatlantic services, comprising first or business class, premium economy and economy sections.

Operational assumptions

A number of operating assumptions were required to generate the flight plans for this analysis.

The simulated performance for each route was based on international flight rules, with standard assumptions for fuel reserves, diversion, and contingency fuel.

The routes and flight levels flown were optimised to achieve the shortest flight time, while complying with all airway rules and restrictions.

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

The flight plans did not, however, use the north Atlantic track system, which is a set of tracks commonly used by aircraft operating transatlantic services.

There would have been two effects of aircraft operating via the north Atlantic track system. First, the aircraft would have been unable to operate at their optimum LRC speeds. On the tracks, aircraft are required to operate at uniform set speeds to ensure adequate separation distances are maintained. Second, the tracks force aircraft to operate on routes that are longer than optimal lengths, or tracked distances. The effect of these two requirements would be to increase tracked distance and flight time.

The weather conditions used in the flight plans were based on average temperatures for the month of June and 85% reliability winds.

An aircraft's block time is the sum of the flight and taxi times on a particular city-pair. A taxi time of 30 minutes per sector has been assumed.

Block fuel is the sum of the flight and taxi fuel for a sector. In this analysis each aircraft's taxi fuel burn was estimated from the idle fuel flow figures for their respective engine variants.

A fuel cost of $1.57 per USG has been assumed. This is a spot fuel price, and is based on IATA's jet fuel price index from January 2015.

The average weight of a passenger and their carry-on cabin baggage was assumed to be 187lbs. It was also

AIRCRAFT SPECIFICATIONS & WEIGHTS USED IN FUEL BURN SIMULATIONS

Aircraft Converted	767-300ER	A330-200	787-8	A330-300	A340-300	787-9
Engine	CF6-80C2B7F	Trent 772B-60	Trent 1000-C	Trent 772B-60	CFM56-5C4	Trent 1000-J
MTOW-lbs	412,000	513,677	502,500	513,677	606,271	557,000
MLW-lbs	320,000	401,241	380,000	412,264	423,287	425,000
MZFW-lbs	295,000	374,786	355,000	385,809	399,037	400,000
OEW-lbs	198,440	267,031	259,700	277,593	286,300	274,000
Max payload-lbs	96,560	107,755	95,300	108,216	112,737	126,000
Usable fuel-USG	24,140	36,744	33,340	25,765	37,153	33,384
Fuselage length	180ft 3-inches	193ft	186ft 1-inch	208 ft 11-inches	208ft 11-inches	206ft 1-inch
Cabin width	15ft 6-inches	17ft 4-inches	18ft	17ft 4-inches	17ft 4-inches	18ft
Economy config	2+3+2	2+4+2	3+3+3	2+4+2	2+4+2	3+3+3
Three-class seats	190	210	214	266	240	264

assumed that each passenger would check in an average of 1.2 hold bags, and that each hold bag weighs 57lbs. The total weight of a passenger and their baggage is therefore assumed to be about 255lbs.

The flight plans were computed to show and carry maximum available payload for each route and mission. The available payload on the shorter flights would therefore be the aircraft's maximum structural payload. The available payload on longer routes would decline according to each aircraft type's payload-range performance.

Subtracting the estimated weight of the passengers and their baggage from each aircraft's available payload, provides an idea of the payload remaining for cargo. The tare weight of the lower deck containers or pallets is not taken into consideration here, and would also need to be subtracted in order to provide the remaining available net freight revenue payload.

Aircraft

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

The aircraft can be loosely arranged in two categories according to their approximate size and seat capacity. The 787-8 is grouped with the 767-300ER and A330-200. The 787-9 is grouped with the A330-300 and A340-300.

787-8, 767-300ER & A330-200

The 787-8 is equipped with Trent 1000-C engines. It has a maximum take-off weight (MTOW) of 502,500lbs and a fuel capacity of 33,340 US gallons (USG). A capacity of 214 seats is typical for this aircraft in a three-class configuration on transatlantic services.

The 767-300ER has CF6-80C2B7F engines and an MTOW of 412,000lbs. It has a fuel capacity of 24,140USG. In a similar typical three-class layout the 767-300ER would seat about 190 passengers on transatlantic operations.

The A330-200 is equipped with Trent 772B-60 engines. It has an MTOW of 513,677lbs and a fuel capacity of 36,744USG. It is assumed that an A330-200 would seat about 210 passengers in a three-class cabin for transatlantic services.

The 767-300ER is the smallest aircraft in this analysis with a fuselage length of 180 feet 3 inches. It has an internal cabin width of about 15 feet 6 inches, which allows a standard economy configuration of seven-abreast seating.

The A330-200 and 787-8 are close in capacity. The A330-200's fuselage is longer than the 787-8's, but the Boeing aircraft is wider.

The A330-200's fuselage is 193 feet long and it has an internal cabin width of about 17 feet 4 inches. It has a standard economy-class layout of eight-abreast seating.

The 787-8's fuselage is about seven feet shorter than that of the A330-200. The 787, however, has an internal cabin width of 18 feet; about eight inches wider than the A330. This wider fuselage is used by virtually all 787 operators to provide nine-abreast seating in economy class. The nine-abreast layout is the same as that used in the Airbus A350, which has a 5-inch wider cabin than the 787.

The extra width of the 787-8 cancels out the advantage of the A330-200's additional length, because the two aircraft have similar seat numbers.

787-9, A330-300 & A340-300

The 787-9 has Trent 1000-J engines. It has an MTOW of 557,000lbs and a fuel capacity of 33,384USG. It is assumed that a 787-9 would seat about 264 passengers in a three-class layout on typical transatlantic operations. This configuration is used by Virgin Atlantic, which operates the 787-9 on transatlantic services. It also operates the A330-300 and A340-300 in the same market.

The A340-300 is equipped with CFM56-5C4 engines. It has an MTOW of 606,271lbs and a fuel capacity of 37,153USG. It would accommodate about 240 passengers in a three-class configuration on transatlantic routes.

The A330-300 has Trent 772B-60 engines, an MTOW of 513,677lbs and a fuel capacity of 25,765USG. It is assumed that an A330-300 would accommodate about 266 seats when configured with a three-class cabin for transatlantic services. This is the configuration used by Virgin Atlantic.

The 787-9, A330-300 and A340-300 offer similar capacity options.

The A330-300 and A340-300 have the same fuselage dimensions, and accommodate eight-abreast seating in a typical economy layout.

The fuselage of the A330-300 and A340-300 is two feet longer than the 787-9's, but the Boeing aircraft is wider *(see table, this page)*.

The 787-9 has the same fuselage width as the 787-8, and both have a nine abreast configuration in economy class.

The 787-9's nine-abreast economy layout means it has similar seat numbers to the A330-300.

The A340-300 has 24 seats less than the 787-9 and 26 less than the A330-300 in this analysis.

In theory the A340-300 can accommodate the same number of passengers as the A330-300.

A number of airlines operating both types on transatlantic services, configure the A340-300 with fewer seats.

This may be because it is an ultra-long-haul aircraft, and the airlines have

FUEL BURN PERFORMANCE OF WIDEBODY AIRCRAFT ON TRANSATLANTIC ROUTES

City-pair	Aircraft variant	Actual TOW lbs	Available payload lbs	Passenger payload seats	Available cargo lbs	ESAD nm	Block time hr:min	Block fuel USG	Fuel burn USG per ASM	Fuel cost cents per ASM
LHR-JFK	787-8	448,896	95,271	214	40,604	3,268	07:20	11,544	0.0165	2.59
	767-300ER	393,609	96,545	190	48,019	3,301	07:44	12,847	0.0205	3.22
	A330-200	487,804	107,739	210	54,105	3,276	07:37	14,257	0.0207	3.25
	787-9	501,262	126,000	264	58,563	3,281	07:18	13,169	0.0152	2.39
	A330-300	498,608	108,216	266	40,291	3,283	07:37	14,810	0.0170	2.66
	A340-300	518,067	112,737	240	51,441	3,300	07:41	15,589	0.0197	3.09
LHR-ORD	787-8	454,850	95,300	214	40,633	3,653	08:07	12,904	0.0165	2.59
	A330-200	497,343	107,755	210	54,121	3,666	08:25	15,976	0.0208	3.26
	767-300ER	406,824	96,560	190	48,034	3,668	08:32	14,517	0.0208	3.27
	787-9	515,189	126,000	264	58,563	3,660	08:05	14,891	0.0154	2.42
	A330-300	513,408	107,135	266	39,210	3,667	08:26	16,809	0.0172	2.71
	A340-300	534,434	112,737	240	51,441	3,676	08:30	17,614	0.0200	3.13
LHR-MIA	787-8	476,634	95,271	214	40,604	4,157	09:06	15,025	0.0169	2.65
	767-300ER	411,375	86,479	190	37,953	4,159	09:30	16,281	0.0206	3.23
	A330-200	513,428	105,808	210	52,174	4,166	09:31	18,244	0.0209	3.27
	787-9	532,594	125,973	264	58,536	4,156	09:02	17,040	0.0155	2.44
	A330-300	513,430	93,716	266	25,791	4,167	09:32	18,544	0.0167	2.63
	A340-300	556,035	112,737	240	51,441	4,167	09:32	20,317	0.0203	3.19
LHR-LAX	787-8	500,732	92,330	214	37,663	4,973	10:44	18,318	0.0172	2.70
	767-300ER	411,361	69,269	190	20,743	4,983	11:20	18,855	0.0199	3.13
	A330-200	513,409	74,482	210	20,848	4,981	11:12	21,249	0.0203	3.19
	787-9	556,939	117,825	264	50,388	4,972	10:41	20,764	0.0158	2.48
	A330-300	513,438	71,540	266	3,615	4,981	11:13	21,636	0.0163	2.56
	A340-300	587,320	111,963	240	50,667	4,983	11:19	24,776	0.0207	3.25

Source: Navtech

Notes:
1). Remaining cargo payload excludes Tare weight of lower deck containers/pallets.

optimised it for longer routes by reducing seat numbers to improve comfort standards on longer routes.

Routes

Four typical transatlantic routes were chosen for this analysis: London Heathrow (LHR) to New York JFK (JFK); LHR to Chicago O'Hare (ORD); LHR to Miami (MIA); and LHR to Los Angeles (LAX).

These city-pairs provide an accurate example of the route types that would be operated by the aircraft under analysis. They have tracked distances of 3,070nm to 4,799nm.

The sector length of each route is stated in tracked distance and equivalent still air distance (ESAD).

The tracked route is determined by air traffic control (ATC) and airway routeings and restrictions. Aircraft are required to follow airways and comply with departure and arrival routeings over land. The tracked distance partially accounts for this.

The ESAD is based on tracked distance, but also takes account of the aircraft's relative speed over the earth's surface by including the effect of en-route winds and the aircraft's true or actual air speed throughout the route. If the aircraft experiences a headwind, then the ESAD will be longer than the tracked distance, but if there is a tailwind the ESAD will be shorter than the tracked distance. The fuel burn figures calculated here are based on the ESAD for each city-pair.

LHR-JFK has a tracked distance of 3,070 nautical miles (nm) *(see table, this page)*. Average headwinds of 29-32 knots (kts) were experienced, so the ESAD ranged from 3,268nm for the 787-8, to 3,301nm for the 767-300ER. The alternate destination airport was Newark (EWR).

The tracked distance on LHR-ORD is 3,516nm. Average headwinds of 18-20 knots were experienced on this sector, so the ESAD ranged from 3,653nm for the 787-8 to 3,676nm for the A340-300. The alternate airport was Chicago Rockford (RFD).

LHR-MIA has a tracked distance of 3,968nm (except for the 767). The ESAD ranged from 4,156nm for the 787-9, to 4,167nm for the A330-300 and A340-300, with average headwinds of 20-22 knots experienced. The alternate destination was Southwest Florida International (RSW).

The tracked distance on LHR-LAX is 4,799nm. All of the aircraft experienced average headwinds of up to 17 knots. The ESAD varied from 4,972nm for the 787-9 to 4,983nm for the 767-300ER and A340-300. The alternate airport was San Diego (SAN).

Performance

The block time, block fuel and fuel cost per available seat-mile (ASM) are summarised for each aircraft across all four routes *(see table, this page)*. There are several issues to consider from the results. The first is actual block fuel. The second is that fuel burn per seat or ASM depends on seating configuration. Aircraft configured with higher-density

The 787-8 burned less block fuel than competing aircraft in its size category. This meant it had the lowest fuel costs per trip. It nearly achieved the estimated 20% reduction in fuel burn when compared to the A330-200 on LHR-ORD.

seating will benefit from a lower fuel burn per seat or per ASM, so the seat configurations that have been selected allow the aircraft to be analysed in similar cabin layouts.

Another important factor to take into consideration is each aircraft's operating performance. This is first in terms of the total available payload on each route, and how this varies or declines on longer route lengths. The 787-8 and -9 should have larger payloads than the 767-300ER, A330-200 and A330-300 on longer routes.

On each of the four routes the 787-8 burned the least block fuel, but the 787-9 demonstrated the lowest fuel burn and fuel cost per ASM. The 787-9 has higher seat capacity, than the smaller variant and so generates more ASMs.

The A340-300 burned the most block fuel on each of the four routes, but had a lower fuel burn per ASM than the smaller 767-300ER and A330-200 on some of the sectors.

A more detailed analysis of the aircraft's comparable performance can be achieved by looking at the two different size categories.

787-8, 767-300ER & A330-200

On all four routes the 787-8 burned the least block fuel in this size category. It also had the lowest fuel burn per ASM, and therefore the lowest fuel cost per ASM on each sector.

The 787-8's advantage in terms of block fuel burn and fuel cost per ASM over the 767-300ER and A330-200 shrinks for longer routes *(see table, page 26)*.

The A330-200 burned the most block fuel in this size category on each of the four sectors.

The A330-200 and 767-300ER demonstrated similar fuel costs per ASM on all four routes. The A330-200 had lower costs per ASM on the LHR-ORD sector, but the 767-300ER had slightly lower costs than the A330-200 on the other three routes.

The 787-8 used between 14-19% less block fuel than the A330-200 across the four transatlantic city-pairs, with the greatest difference coming on LHR-ORD.

The 787-8's fuel costs per trip ranged from $18,124-28,759. This is $4,260-5,054 lower than the A330-200's. These differences would of course differ with a lower or higher fuel price.

The 787-8's fuel costs per ASM were 0.49-0.67 cents less than those of the A330-200. This is equivalent to 15-21% lower fuel costs. The 787-8's largest advantage was demonstrated on LHR-ORD, where its fuel cost per ASM was 2.59 cents compared to 3.26 cents for the A330-200.

The 787-8 used 3-11% less block fuel than the 767-300ER across the four transatlantic routes. The largest discrepancy was evident on LHR-ORD. The 787-8's fuel costs per trip were $843-2,532 lower than those of the 767-300ER.

In comparison to the 767-300ER, the 787-8's fuel costs per ASM range from 14% less on LHR-LAX, to 21% less on LHR-ORD. The actual difference was 0.43 to 0.68 cents per ASM.

With the flight plans using LRC on both overland and overwater phases of the flight, the 787-8 had shorter block times than the A330-200 and 767-300ER on all four city-pairs. The 787-8 had block times that were 17-28 minutes shorter than the A330-200's. The 767-300ER's block times were 24-36 minutes longer than the 787's, with the 767-300ER having a low LRC speed of Mach 0.80. The 787 had cruise speeds of Mach 0.84-0.85.

Block time is influenced by an aircraft's climb, cruise and descent speeds, and by any en-route winds.

The 787-8 has similar total available payloads to the 767-300ER on the two shortest routes of up to 3,700nm *(see table, page 26)*. This is because both aircraft would be operating at maximum or near-maximum payload. The 767-300ER therefore has about 7,400lbs more available cargo payload, because it carriers fewer passengers.

The 767-300ER suffers from greater payload restrictions than the 787-8 on LHR-MIA and LHR-LAX *(see table, page 26)*. The 787-8 can therefore carry more freight than the 767-300ER on the MIA and LAX sectors.

As the larger aircraft, the A330-200 has the largest available cargo payload on every sector, except LHR-LAX. The 787-8's longer range and superior payload-range profile mean that it carries more freight than the A330-200 on that route.

The A330-200 and 767-300ER only have 69% and 72% of their maximum gross payloads available on LHR-LAX. This is still enough for them to operate with a full passenger and baggage load *(see table, page 26)*.

787-9, A340-300 & A330-300

The 787-9 burned the least block fuel in this size category across all four routes. It also had the lowest fuel burn per ASM and therefore the lowest fuel costs per ASM *(see table, page 26)*.

The A340-300 had the highest block fuel of all six aircraft types on each sector, and so also had the highest fuel costs per ASM *(see table, page 26)*. This is not surprising since the A340-300 is a four-engined aircraft, and has a higher gross weight than the 787-9 and A330-300; which are similar in size.

The A340-300's comparable fuel cost per ASM is also hampered by the assumed capacity used in the analysis. This is 24 and 26 seats fewer than the 787-9 and A330-300. The A340-300 therefore generates fewer ASMs. It has already been noted that the A340-300

The A340-300 burned the most block fuel of the aircraft analysed here. This is not surprising, since it is the only four-engined aircraft included in the comparison. The A340-300 had the highest fuel costs per trip.

could accommodate the same number of seats as the A330-300. Even if a capacity of 266 seats had been assumed, the A340-300's block fuel burn performance would result in higher fuel costs per ASM than the 787-9 and A330-300; these two having the advantage of twin-engined performance.

The 787-9 burned 4-11% less block fuel than the A330-300, which is configured with almost the same number of seats, on the four city-pairs. The largest fuel saving was experienced on LHR-ORD, and the smallest on the longest route, LHR-LAX *(see table, page 26)*. The 787-9's fuel burn advantage decreased as route length increased.

The 787-9's trip fuel costs ranged from $20,676-38,899. This is $1,369-3,010 lower than the A330-300.

The 787-9's fuel costs per ASM were as much as 11% lower than the A330-300's. This was evident on LHR-ORD, where the 787-9's fuel cost per ASM was 2.42 cents compared to 2.71 for the A330-300 *(see table, page 26)*. The smallest difference between the 787-9 and A330-300 was evident on the longest LHR-LAX sector, where the 787-9's fuel costs per ASM were 3% lower. This is a difference of about 0.08 cents.

In this analysis the A330-300 is configured with several more seats than the 787-9; the two generating an almost equal number of ASMs. The A330-300 has a slight advantage of two more seats. This contributes to the reduced difference in fuel per ASM performance between the two types on the two longest sectors.

The 787-9 burned 15-16% less block fuel than the A340-300 across the four sectors. The biggest difference was seen on LHR-LAX *(see table, page 26)*, where the 787-9's fuel costs per trip were $3,798-6,299 lower than those of the A340-300.

The difference in seat numbers between the two meant that the 787-9's fuel costs per ASM were 0.70-0.77 cents, or 23-24% lower, than those of the A340-300.

Because of its faster LRC, the 787-9 flew the shortest block times in this size category on all four sectors. The A340 operated the longest block times on each occasion.

The 787-9's advantage in block time over the A330-200 and A340-300 grew as route length increased. The 787-9's block time was 19 minutes shorter than the A330-300's and 23 minutes less than the A340-300's on LHR-JFK. On LHR-LAX the 787-9's block time advantage increased to 32 minutes over the A330-300 and 38 minutes over the A340-300. The 787-9 had a cruise speed of Mach 0.85-0.86, while the A330-300 and A340-300 had cruise speeds of Mach 0.81-0.82 and Mach 0.80-0.81.

In addition to its superior fuel burn and block time performance, the 787-9 had the largest remaining payload for cargo on the LHR-JFK, LHR-ORD and LHR-MIA sectors.

The A340-300 had a marginally higher cargo payload available on LHR-LAX. The A340-300 and 787-9 did not suffer any significant payload restrictions across the four transatlantic routes. This would be expected because of their ultra-long-range performance, although the 787-9 did suffer a larger reduction in available payload than the A340-300 on LHR-LAX.

The A330-300 operated without significant restriction on LHR-JFK and LHR-ORD. On LHR-MIA its available payload was restricted to 87% of the aircraft's maximum gross payload. The available freight payload was about half of that offered by the 787-9 and A340-300 *(see table, page 26)*.

On LHR-LAX the A330-300 was only able to operate with 66% of its maximum payload. This was enough for passengers and baggage, but only left 3,600lbs available for cargo. Most of this amount would probably be consumed by the tare weight of the lower deck containers required for hold baggage, leaving little, if any, payload available for freight.

Summary

The 787-8 and 787-9 burned less block fuel, and achieved lower fuel costs per ASM, than the competing aircraft in their respective size categories on all four transatlantic routes *(see table, page 26)*.

The four-engined A340-300 used the most block fuel on each sector.

The 787-8 nearly achieved the expected 20% savings in fuel burn in some circumstances. This was based on a comparison with A330-200.

The 787-8 used 3-11% less block fuel than the 767-300ER and 14-19% less than the A330-200 across the four routes. The 787-8's fuel costs per ASM were 14-21% lower than the two competitors.

The 787-9 only achieved 4-11% fuel burn savings against competing aircraft in its size category. The 787-9 used less block fuel than the A330-300, and 15-16% less than the A340-300. Its fuel costs per ASM were 3-24% lower than its competitors'.

The 787-9 demonstrated lower fuel costs per ASM than any other aircraft on all four city-pairs, however.

The two 787 variants also flew the shortest block times in their respective size categories. This is mainly due to their faster LRC speeds. The 787-8 and 787-9 also did not experience any significant payload restrictions on the four routes.

The 787-9 had the highest remaining payload for cargo in its size class on most of the sectors flown. The 787-8 had the largest remaining payload for cargo in its category on LHR-LAX. AC