**Sander de Moor, director airline operational efficiency at Aircraft Commerce Consulting examines the fuel burn & operating performance of the A350-900 & -1000. They are compared with the 787 and older generation 777 & A330 families; and the 747-400.**

# A350-900/-1000 fuel burn & operating performance

The 787 and A350 families both promised significant fuel burn reductions over similar-sized, older generation aircraft, as well as more range with the same payload. Examples of the realised efficiency gains over older aircraft types are analysed here across five long-range and ultra-long-range transatlantic sectors between London and points in North and South America. These have tracked route lengths ranging from 4,330nm to 6,450nm on flight times of nine hours and 40 minutes to about 14 hours.

In this article we will run our comparative fuel burn and operating performance analysis on a suite of latest-generation comparable aircraft in various airframe-engine combinations. We will also compare these modern types with some of their previous-generation competition. Fuel burn will be compared on an absolute and per available seat-mile (ASM) basis. As always, aircraft performance and fuel burn analysis is provided by Lufthansa Systems, and our conclusions are our own.

## Aircraft types & variants

All production versions of the two main types in our evaluation were included, meaning Boeing's 787-8, 787-9 and 787-10; and Airbus's A350-900, and A350-1000. The Airbus A350-900ULR is not included, because this aircraft type falls outside our scope of a general comparative evaluation.

As there are two engine manufacturer options for the 787 family, both aircraft-engine variants for each of the -8, -9 and -10 series were included.

Last, two variants of the A350-1000 are evaluated, the difference between them being the cabin layout and seat numbers. There is a large discrepancy between the Airbus standard cabin layout, and airline cabin layouts. The difference is large enough to warrant inclusion of the two versions.

The three 787 variants and the two A350 variants were compared with several main types. The first is the 777-200ER and 777-300ER, which are included as examples of previous-generation efficiency in this market. The 777-200ER competes most closely with the A350-900 and the 787-10 in terms of seat capacity, while the 777-300ER compares closely with the A350-1000 on the same basis.

The A330-200 was also included as a similar-sized and previous generation aircraft to compare with the 787-8, and the A330-300 was included on the same basis to compare with the 787-9.

Last, the 747-400 was included, because it has been replaced by the 777-300ER and more recently by the A350-1000. The relative efficiency will be shown of fuel burn per ASM of the twin-engined configuration of these two younger generation types against the 747's four engines and configuration with more seat numbers.

In total, 14 different aircraft variants are included in this analysis, and their weights, fuel capacities, engine types and seat numbers are detailed *(see table, page 14)*.

## Comparison basis

This group of 14 aircraft was compared at three levels. As described, the first two were relative fuel burns on an absolute basis, and then on a fuel burn per ASM basis. The third comparison would be the addition of the cost of overflying countries ('airspace access costs'). These may be referred to as air traffic control (ATC) user fees.

The number of available-seat miles (ASMs) generated by each aircraft on each route are calculated by multiplying the number of available seats in the aircraft *(see tables, pages 18 & 19)* by the actual flown distance, the equivalent still-air distance (ESAD). ESAD is the distance travelled by an aircraft through the air, rather than the tracked distance, and is affected by wind and altitude. A relative wind vector will make the aircraft cover more or less ground distance per time unit, while altitude influences the number of tracked miles to be covered due to the earth's curvature, and whether an aircraft travels a longer distance to cover the same arc along the flight path between two points on the ground. The ESAD of each route used in the analysis is given *(see table, page 15)*. These vary slightly by aircraft type because of flight profiles, but range from 4,705nm to 6,941nm *(see tables, page 18 & 19)*.

It is important that ASMs are calculated using the number of available seats. If some aircraft seats are unavailable for sale due to regulatory, performance or technical reasons (such as unserviceable seats, seats dedicated for crew rest) then such seats cannot be included in the ASM metrics of affected flights. If the aircraft has a payload restriction on a longer route, then only the number of seats that can be used are the same in the ASM calculation. This is the case for a few aircraft types on the longest route in this comparison, and resulted in a high fuel burn per ASM.

On the London Heathrow (LHR) - Rio de Janeiro (GRU) route, the A330-


*The A350-900 and -1000 series demonstrate significant fuel burn reductions over previous generation aircraft. The A350-900 has a 17.5% lower burn per ASM compared to the 777-200ER, while the A350-1000 has a 11% lower burn per ASM than the 777-300ER.*

300 had to surrender 27 seats; while on the LHR- Buenos Aires (EZE) route available seat count was lowered by 49 seats on the A330-200, 128 seats on the A330-300 and 68 seats on the two-class 747-400. On the longest route, LHR-Santiago de Chile (SCL), even the A350-900 had to leave three seats unoccupied.

The chosen five routes include three ultra-long-range sectors. All five routes originate from LHR. Two are to points in the US, and have tracked distances of 4,330-4,811 nm. The three longest routes are from LHR to cities in South America, and have tracked distances of 5,155-6,450nm. These three longer routes were included so that the relative performance of each aircraft could be examined when departing from an airport where there are no take-off weight or performance restrictions. This will illustrate the relative economic feasibility of the 14 aircraft types on long-range and ultra-long-range routes.

Aircraft performance and fuel burn were not analysed in the opposite direction, since SCL's elevation could cause performance restrictions or limitations for some aircraft types, and so influence the comparison.

The two destinations in the US are Austin (AUS), Texas; and San Diego (SAN), California. These two routes have tracked distances of 4,330nm and 4,811nm *(see table, page 15)*. They both have headwinds of 39-49 knots and 37-47 knots, and consequently have ESADs of 4,705-4,813nm and 5,204-5,424nm.

The three South American destinations are GRU, Brazil; EZE, Argentina; and SCL, Chile. These routes have tracked airway distances ranging from 5,155nm to 6,449nm. When combined with average wind components ranging from -31 to -37 knots, these routes have ESADs of 5,479 nm to 6,924 nm *(see table, page 15)*.

## Operating parameters

Aircraft performance was examined using operating empty weights (OEW) and zero fuel weights (ZFW) on the basis of operating a typical two-class, full-service operation. Aircraft configurations vary from airline to airline, both in terms of installed equipment and cabin configurations, starting with the specified manufacturer empty weight (MEW). It is therefore difficult to select an OEW that will fit all operators of each type for this comparison. MEWs alone differ significantly from operator to operator, so the chosen weights may vary significantly from what is found in a specific airline's configuration. As such, the chosen weight may have an effect on the resulting fuel burn computations or payload-range capacity. Furthermore, the aircraft were planned to operate with a full payload of passengers, and an allowance of 231lbs per passenger and associated baggage. This resulted in relatively high passenger-related payloads for each type. It is also higher than most scheduled airline operations are likely to experience in this fashion. Lower deck cargo was excluded, however, but the cargo payload that would have been available is shown *(see tables, page 18 & 19)*.

Fuel and operational performance numbers for the 14 aircraft variants were generated by Lufthansa Systems, using its Lido/Flight 4D flightplanning system. All 70 flight plans were produced based on the same assumptions and inputs. These are the baselines: European Aviation Safety Agency (EASA) International Flight Rules (IFR) with alternate, 5% contingency fuel; fixed-Mach cruise (LRC), fixed routes, 0% aircraft performance degradation, 85% average winds for June, all-engine taxi operations, normal standard operating procedures.

Lufthansa Systems' Lido/Flight 4D optimises climb, cruise and descent segments of a flight based on performance specifications (data files) of the particular airframe-engine combinations, as received from the aircraft original equipment manufacturers (OEMs), as well as specific operating philosophies (flight level caps, performance degradation factors, amended performance buffers in planning, padding) as requested by its customers. If not creating an optimised route itself, once a route has been decided, Lido/Flight will plan an optimum vertical profile based on parameters applicable to the aircraft and its operator, achieving an overall lowest total cost solution for the planned flight by balancing cost of fuel burn, time-related costs and airspace access costs.

Climb and descent profiles differed per aircraft type of course. Cruise mode for all aircraft types and variants on all routes was at fixed-Mach LRC. More operators are moving away from fixed-Mach cruise modes, such as a specific Mach number or long-range cruise (LRC) in favour of Cost Index (CI) flying, which is a more cost-conscious and economic way of managing operating costs. However, since CI flying relies heavily on operator internal cost structures and fuel prices, no two operators plan and operate flights using the same CI. This in turn would mean that a flight-for-flight comparison would not be possible. For this reason, fixed-Mach LRC speed was selected.

Last, to create the same atmosphere for all aircraft types to operate in, statistical average winds and temperatures were used. For the payload-range evaluation we used a zero-wind, ISA-standard day to assess the payload carrying capabilities of our aircraft, one range value for carrying maximum payload, and one range value for carrying passengers-only payload.

As stated, for the comparison, EASA flight planning standards and rules were used, and these were applied in a

## AIRCRAFT SPECIFICATIONS & WEIGHTS

| Aircraft Type | A330-200 RR | 787-8 GE | 787-8 RR | A330-300 RR | 787-9 GE | 777 -200ER | A350 -900 | 787-10 GE | 787-10 RR | A350 -1000 | A350 -1000 | 777 -300ER | 747 -400 3-cl | 747 -400 2-cl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Engine | Trent 772C | GEnx -1B67 | Trent 1kG | Trent 772B | GEnx -1B74-75 | GE90 -94B | Trent XWB-84 | GEnx -1B74-75 | Trent 1kJ3 | Trent XWB-97 | Trent XWB-97 | GE90 -115BL | CF6-80 C2B1F | CF6-80 C2B1F |
| Engine bypass ratio | 5.0 | 9.0 | 10.0 | 5.0 | 8.8 | 9.0 | 9.6 | 8.8 | 10.0 | 9.6 | 9.6 | 9.0 | 5.3 | 5.3 |
| MTXW - lbs | 515,661 | 503,500 | 503,500 | 515,661 | 561,500 | 658,000 | 592,824 | 561,500 | 561,500 | 698,645 | 698,660 | 777,000 | 877,000 | 877,000 |
| MTOW - lbs | 513,677 | 502,500 | 502,500 | 513,677 | 560,000 | 560,000 | 590,839 | 560,000 | 560,000 | 696,660 | 696,660 | 775,000 | 875,000 | 875,000 |
| MLW - lbs | 401,241 | 380,000 | 380,000 | 412,264 | 425,000 | 470,000 | 451,948 | 445,000 | 445,000 | 520,290 | 520,290 | 554,000 | 630,000 | 630,000 |
| MZFW - lbs | 374,786 | 355,000 | 355,000 | 385,809 | 400,000 | 440,000 | 423,288 | 425,000 | 425,000 | 491,630 | 491,630 | 524,000 | 542,500 | 542,500 |
| OEW / DOW - lbs | 273,400 | 257,500 | 257,300 | 284,400 | 267,800 | 317,000 | 308,700 | 281,100 | 281,000 | 352,900 | 352,900 | 375,000 | 414,500 | 414,500 |
| Max payload - lbs | 101,386 | 97,500 | 97,700 | 101,409 | 132,200 | 123,000 | 114,588 | 143,900 | 144,000 | 138,730 | 138,730 | 149,000 | 128,000 | 128,000 |
| Fuel capacity - USG | 36,744 | 33,340 | 33,340 | 36,744 | 33,399 | 56,516 | 35,772 | 33,399 | 33,399 | 41,211 | 41,211 | 47,890 | 57,065 | 57,065 |
| Dual-class seat | 248 | 220 | 220 | 274 | 266 | 304 | 318 | 337 | 337 | 327 | 367 | 367382 | 393 | 487 |
| Passenger payload - lbs | 57,288 | 50,820 | 50,820 | 63,294 | 61,446 | 70,224 | 73,458 | 77,847 | 77,847 | 75,537 | 84,777 | 88,242 | 90,783 | 112,497 |
| Remaining cargo payload - lbs | 44,098 | 46,680 | 46,880 | 38,115 | 70,754 | 52,776 | 41,130 | 66,053 | 66,153 | 63,193 | 53,953 | 60,758 | 7,217 | 15,503 |
| Range with full passenger payload - nm | 6,050 | 7,650 | 7,450 | 5,250 | 8,250 | 7,300 | 6,850 | 7,050 | 6,900 | 7,600 | 7,250 | 7,450 | 6,600 | 6,150 |
| MTOW/seat - lbs | 2,071 | 2,284 | 2,284 | 1,875 | 2,105 | 2,158 | 1,858 | 1,662 | 1,662 | 2,130 | 1,898 | 2,029 | 2,226 | 1,797 |
| DOW/seat - lbs | 1,102 | 1,170 | 1,170 | 1,038 | 1,007 | 1,043 | 971 | 834 | 834 | 1,079 | 962 | 982 | 1,055 | 851 |

conservative way. We decided that planning with an alternate was required (as, under certain conditions, EASA allows for planning without an alternate as well).

Contingency fuel was set at 5% of trip fuel (with a minimum amount to be able to hold for five minutes over the destination), taking the conservative approach as opposed to the more economic 3%+ ERA option, where a suitable en-route alternate is planned, or the 20-minute option of average cruise fuel consumption, which results in a lower amount of contingency fuel than the EASA 3%+ERA option on flights of roughly 11 hours or more.

Final reserve fuel was the normal amount required to hold for 30 minutes at 1,500 feet above ground level (AGL) over the alternate aerodrome at planned gross weight. These are standard planning procedures.

Operationally, it was assumed that all engines would be used for both taxi-out and taxi-in. Taxi times from departure point and at the five destinations were taken from the Lido database, adding 500-1,200lbs of fuel per trip in auxiliary power unit (APU) and taxi fuel burns; depending on aircraft type, season and city pair operated.

Lufthansa Systems' LIDO/Flight 4D flightplanning solution was fed with simulated operational data. This is a mix of real-world numbers and averages in terms of weights and operating philosophies in an effort to find common ground amidst the variations in operations observed around the world. As such, the results generated by these flight plans and additional calculations performed by *Aircraft Commerce Consulting*, should only be considered within the context of these specific assumptions.

The flight plans were generated using a number of operating assumptions. The simulated performance assumes that the aircraft are operating under standard IFR with reserves, diversion and contingency fuel requirements based on EASA standards. The aircraft were planned to be operating at their long-range cruise speeds (LRC) to optimise fuel economy.

Weather assumptions included average temperatures for the month of June, with 85% reliability winds. The routes and flight levels (FL) flown were optimised to achieve minimum cost, while complying with airways rules and restrictions. The minimum cost track (MCT) is based on the optimum routeing for each aircraft variant, taking into account fuel, airspace access and operational time costs.

The block time for each sector is the sum of the trip and taxi times. The taxi-out and taxi-in times are based on realistic averages across a range of operators for each airport. The block fuel is the sum of the trip and taxi fuel burn.

The 747-400, 777 variants, and the 787 family in this article do not offer a choice in operational weight combinations. The A350s, however, come with a choice of 17 weight variants (WV) in the case of the A350-900, and a further six options for the A350-1000 model. This provides operators around the world with ample choice to select one or more combinations of operational weights that best works for them in their networks, optimising cost and efficiency. With the exception of the 777 variants in this article and the A350 family, the aircraft also have multiple engine options. The 787-8, 787-9 and 787-10 models powered by both the General Electric (GE) GEnx engines and rival Rolls-Royce (RR) Trent-1000 engines are all included in the analysis.

The dry operating weights (DOWs) or operating empty weights (OEWs) used in this analysis are based on a sampling of such weights used in service. Although they should fit within a realistic in-service range, OEW will vary per individual aircraft as well as by average fleet for a specific operator. These weights are influenced by a number of factors, including cabin configuration, engine variant, crew numbers and associated belongings, catering and cabin service items. Also, manufacturers often find ways to reduce OEWs for later production line numbers of a particular aircraft variant, and it is quite common for early production aircraft to have higher OEWs than later-built examples.

## Aircraft capacity

Widebody cabin configurations vary significantly from operator to operator. There are many reasons for this, but cabin layouts are mostly driven by desired product differentiation between airlines, which view the cabin layout of their long-haul flagships as key product differentiators. Aircraft cabin layouts vary from highly specified and well-designed four-class cabins, all the way down to a single-class economy auditorium. More airlines today are opting for a two-class configuration, either with a 'real' business class section or with a premium-economy section, plus the usual economy cabin. Increasing seat count is one way to lower operating cost per ASM, which has been necessary in many cases where fares are under pressure.

In some cases, an operator may choose to fly with separate sub-fleets of the same aircraft type configured with different numbers of seats, depending on the routes and markets the airline serves in its overall network. This variation in possible cabin configurations means that it has become more difficult to identify a typical capacity for each aircraft variant.

The evaluation also attempts to demonstrate the potential payload remaining for cargo for all aircraft types, once the weight of passengers and their baggage, as well as unit load devices (ULDs) in the lower deck space have been accounted for. Making use of available widebody lower deck capacity for cargo generates incremental revenue. Most operating costs have already been covered, and carrying additional cargo only adds the cost of airport handling plus an incremental amount of fuel. Since the aircraft will be operated at an average higher take-off weight, the engines will be operated at a slightly lower de-rated value, in turn possibly increasing the operational cost over time. This can be calculated and accounted for.

In identifying the potential remaining payload for cargo a few steps were taken. First, the remaining payload against the maximum structural payload was verified. The maximum structural payload is found by subtracting the dry operating weight (DOW) from the maximum zero-fuel weight (MZFW). Then subtracting the planned payload (passengers and baggage) from the maximum payload gives the initial remaining payload for cargo.

Since these are long flights, other performance limitations also had to be checked for. These include take-off weight limitations being lower than the structural limitations, and tank capacity limitations that require the payload to be lowered so the aircraft can make it to destination. These all possibly have an effect on the maximum possible payload. This is typical flight planning and flight dispatch work.

The last step was to look at the aircraft itself, and the lower deck configurations. Using average numbers of 1.2 bags per passenger, 35 bags per ULD and the lower deck layouts as published in the various aircraft characteristics for airport planning (ACAP) documents, all aircraft types were operated in a classic configuration with P6-pallets in the forward holds and LD-3 containers in the aft holds. The bulk compartment was not used in planning.

After calculating the required number of LD-3 containers used for baggage, and rounded up to the nearest whole unit, the number of containers left for cargo was determined. With tare weights of 187lbs per container and 276lbs per pallet, the total tare weight of the ULDs was determined, and after arbitrarily setting net average cargo weights as 1,100lbs per container and 4,500lbs per pallet, the total available payload for cargo was calculated.

**ROUTE CHARACTERISTICS**

| Route | LHR-AUS | LHR-SAN | LHR-GRU | LHR-EZE | LHR-SCL |
|---|---|---|---|---|---|
| Flight times - mins | 579-610 | 638-675 | 667-715 | 790-852 | 833-896 |
| Taxi out times - mins | 20 | 20 | 20 | 20 | 20 |
| Taxi in times - mins | 11 | 12 | 10 | 13 | 9 |
| Block times - mins | 610-641 | 670-707 | 697-745 | 823-885 | 862-925 |
| Tracked distances - nm | 4,330 | 4,811 | 5,155 | 6,088 | 6,449 |
| Wind components - kts | -39 to -49 | -37 to -47 | -29 to -33 | -33 to -37 | -29 to -33 |
| ESAD - nm | 4,705-4,813 | 5,204-5,324 | 5,479-5,549 | 6,523-6,613 | 6,858-6,942 |
| Alternate airport & distance - nm | IAH/143 | ONT/112 | GIG/187 | MVD/154 | MDZ/180 |

## Aircraft specifications

The precise specifications used for each aircraft variant in this analysis are summarised *(see table, page 14)*. Since these aircraft differ significantly in a number of ways, they are not easily categorised or paired off in comparison.

The aircraft were compared in four sub-groups based on two-class seat numbers as follows: the first group with the 787-8 variants and the A330-200; the second group with the 787-9 variants and the A330-300; the A350-900 and the 787-10s grouped with the 777-200ER; and lastly the A350-1000s in a group with the 777-300ER and the 747-400s.

The baby aircraft in this round-up, the 220-seat 787-8, was analysed with two different engine options: the RR Trent 1000-G engines, and the General Electric (GE) GEnx-1B-67. Both examples have a certified maximum take-off weight (MTOW) of 502,500lbs, an OEW of about 257,400 lbs (there is a 200 lbs difference between the engine types), and a fuel capacity of 33,340USG *(see table, page 14)*.

The 787-9 is analysed with GEnx-1B-74/75 engines. An MTOW of 560,000lbs, an OEW of 267,800lbs and a fuel capacity of 33,399USG *(see table, page 14)*. The assumed dual-class cabin seats of 266, and gives it a maximum range of about 8,250nm with this payload. Range with maximum overall payload is 5,250nm.

The two 787-10 variants are equipped with the GEnx 1B74-75 engine and the RR Trent 1000J3 engine. MTOW sits at 560,000 lbs and the fuel capacity is a low 33,399USG. Airline cabin layouts on the 787-10 shows a dual-class 337 seats *(see table, page 14)*. Maximum range with this payload using the GEnx-1B 74-75 engines turns out to be around 7,050nm, and switching to the RR Trent 1000J3 engines shortens range to about 6,900nm.

The A350-900 is equipped with Trent XWB-84 engines. It has an MTOW of 590,839lbs and a fuel capacity of 35,646USG. The capacity is assumed to be 318 seats, giving it a maximum range of about 6,850nm with this payload.

The two A350-1000 aircraft are equipped with Trent XWB-97 engines. MTOW sits at 696,660 lbs and the fuel capacity is a hefty 41,211USG. The two cabin variants used show the currently deployed average 327 seats, as well as the Airbus standard 369 seats *(see table, page 14)*. This second cabin configuration gives a larger differential of 51 seats over the smaller -900 series. Maximum range with the 327-seat payload is about 7,600nm, and adding 42 seats shortens the range to about 7,200nm.

The 777-200ER is equipped with GE90-94B engines. It has an MTOW of 656,000lbs and a fuel capacity of 56,317USG. In this analysis the 777-200ER has an assumed passenger capacity of 304 seats, giving it a maximum range of about 7,300nm with this payload *(see table, page 14)*.

The 777-300ER is equipped with GE90-115BL engines, and is a standard 777-300ER in every way with an MTOW of 775,000 lbs, and a tank capacity of 47,890USG, again, the largest number here. The aircraft has a two-class cabin of 382 seats, and range with this payload is around 7,600nm *(see table, page 14)*.

The two 747-400 versions in the comparison are equipped with GE CF6-80C2B1F engines. MTOW is a respectable 875,000lbs, and fuel capacity is 57,065USG. The two cabin variants attempt to reflect the remaining market with 393 seats in a three-class cabin with business class, premium-economy and economy. The other cabin is an attempt at a probable two-class cabin layout with 487 seats. Maximum range with the 393-seat payload is about 6,600nm, and adding 93 seats shortens the range to about 6,150nm.


*The 787-10 has the lowest fuel burn per ASM of all 787 family and A350 family variants. This is partially explained by the average airline two-class cabin configuration having 19 more seats than the A350-900, and 33 seats more than the 777-200ER. The 787-10 also has lower fuel burn per ASM than the A350-1000, which has 30 more seats.*

## Routes

The main operational factors and characteristics of the five chosen routes are summarised, stating flight times, taxi times, resulting block times, and information on used distances, wind components, ESAD, and alternate airport *(see table, page 15)*.

## Performance

The net cargo payload carried, block times, fuel consumption, and ATC costs of each aircraft variant are summarised across the five routes analysed *(see tables, pages 18 & 19)*.

The fuel burn per ASM, and the combined fuel cost at $1.69 per USG with ATC costs of each aircraft variant are summarised in cents per ASM across our five sectors *(see tables, pages 18 & 19)*.

Before we examine the grouped aircraft performances, in a nutshell, the 787-10 clearly sets the standard on all five routes with some of the best fuel burn per ASM performance ever seen for such longer-haul routes. On each route, the aircraft with the closest performance are the 367-seat A350-1000 and the A350-900. The A350-900 and -1000 with 367 seats both have a fuel burn and ATC cost performance about 11% higher per ASM. The A350-1000 with 327 seats has a fuel and ATC cost per ASM that is 21-22% higher than the 787-10's.

The 787-9 lags by a surprising 15.0-16.0% in fuel burn and ATC en route costs per ASM compared to the larger 787-10, despite having a 7.8-8.3% lower total fuel burn. The lower fuel burn is negated by the -9's lower seat count of 266, which increases fuel burn per ASM.

Where aircraft now have passenger number restrictions, the 787-9 has the fourth lowest fuel and ATC cost per ASM. The 777-300ER is ranked fifth, and the 747-400 with a higher seat count of 487 is ranked sixth. The A330-300 follows closely behind, but this is only the case on the two North American routes. The aircraft suffers a payload restriction of 27 passengers on LHR-GRU with an ESAD of 5,548nm.

The 777-200ER is ranked eighth and is also very close to the A330-300, and the two types are virtually equal in fuel cost and ATC performance per ASM where neither suffer passenger number limitations. The 787-8 variants are ranked ninth and tenth, and the Trent-powered version has a cost of about 0.10 cents per ASM higher. The A330-200 is ranked last of all the 14 types analysed. This is the case where no types suffer a passenger payload limitation.

The two 787-8 variants are not the most efficient aircraft in terms of cost per ASM however. In fact, they are 32.2-38.5% more expensive per ASM than the best performing aircraft here, the 787-10. This is equal to 0.65-0.75 cents per ASM higher for the 787-8.

## Aircraft group performance

### 787-8 & A330-200

The first group is made up of the two 787-8s and the A330-200. At first glance the vastly expected improvement in fuel burn performance per ASM over the A330-200 is not there.

First, the Trent 1000G powered-version of the 787-8 shows 2.8-3.7% higher cost than the GEnx-1B67-powered aircraft. This may largely be due to the Trent's higher thrust rating (64,722lbs).

Then, compared to the 787-8s, the A330-200 scored best on LHR-GRU with a higher cost per ASM of only 0.8-3.6%. On the North Atlantic routes this cost difference was higher at 3.2-6.9%.

Once taking on the very long-haul flights, the A330-200 lost terrain quickly. On LHR-EZE, the maximum allowable payload dropped by 49 seats; and on the longest sector, LHR-SCL, this reduction in payload increased to 84 seats, vastly increasing cost per ASM. The differences with the 787-8s grew to 24% and 54%.

The Trent 772C-powered A330-200 holds its own on sectors of up to 12 hours against the 787 aircraft. The aircraft does cruise at a few Mach points slower than the 787-8s. Observed differences in ground speeds translate into 2-3 minutes for every hour spent in cruise flight.

### 787-9 & A330-300

When comparing the 266-seat 787-9 and the 274-seat A330-300 significant differences in operating cost and performance were expected. The A330-300 was never seen as an aircraft 'with legs'. Of all aircraft in this analysis, the A330-300 has the smallest full-payload range profile. In comparison, the 787-9 can operate for another 2,000nm before payload starts to become restricted.

When compared to our 787-9, the Trent 772B-powered A330-300 showed 16-17% higher fuel and ATC costs per ATC on the two shorter routes where the A330-300 does not have a passenger payload restriction.

The A330-300 starts to get penalised on LHR-GRU as the aircraft experiences a reduction of 27 passengers. The A330-300's operating performance is inadequate to make it competitive on the longer LHR-EZE and LHR-SCL routes with ESADs of 66,13nm and 6,942nm *(see table, page 19).*

## A350-900, 777-200ER & 787-10

With 318 seats in the A350-900, 337 seats in the 787-10s and 304 seats in the 777-200ER, these aircraft serve a specific bracket in cabin size. As stated earlier, the 787-10 is the clear overall winner when comparing the performance of all aircraft on all routes

For the A350-900, the cost per ASM for fuel burn and en route charges relative to the 787-10s has already been described in the section above. This is an advantage of 0.23-0.26 cents per ASM for the 787-10.

When the 787-10 is considered against the 777-200ER, there is a larger difference. The 777-200ER, which carries a full passenger load on all routes, has a fuel and ATC cost that is 0.46-0.56 cents per ASM higher than the 787-10's.

## A350-1000, 777-300ER & 747-400

The group of four aircraft variants with 327-487 seats includes the two A350-1000s, a 777-300ER and the two 747s.

First, with respect to the two A350-1000s, with two different cabin layouts, the lower-density aircraft only has 327 seats, which is a number that is close to the currently deployed cabins with the small number of operators. Our second version shows the standard cabin as put forward by Airbus in its ACAP document, which has an additional 40 seats.

When pairing these two versions off against each other, the higher-density aircraft naturally wins hands-down. The lower-density A350-1000 shows lower absolute fuel burn by 400-550USG per trip, but has 0.24-0.30 cents higher cost per ASM due to the smaller seat count.

Going forward, comparing the best-performing A350-1000 with 327 seats to the 777-300ER is perhaps a surprise, with operating costs of the 777-300ER on a par with those of the lighter A350-1000 variant. The 777-300ER is 80,000lbs heavier and larger than the A350-1000 and, together with previous-generation technology in airframe and engines, shows this in 18-19% higher fuel burn.

With the 777-300ER's larger seat count of 382, the impact on cost per ASM is far less, with results that are 10.2-11.0% higher than the 367-seat A350-1000. The 777-300ER has a small advantage of less than 1% compared to the 327-seat A350-1000.

The last aircraft in this round-up is the venerable 747-400. Some 135 of these aircraft are still operating in passenger configuration. Of the aircraft here the 747-400 has the highest seat capacity, the highest operating weights, the highest fuel burn and en route costs, and yet, it is still relevant. Our two cabin layouts are 94 seats apart, yet the difference in absolute operating costs between these two versions is not large in relevant terms.

Compared to the A350-1000, they count of course, as the A350-1000 is a much lighter and more economical aircraft type by 44.4-59.0% in absolute terms. Cost per ASM is an entirely different picture however, and especially in the case of the 487-seat 2-class equipped 747-400, the difference in fuel and ATC cost per ASM is 0.40-0.48 cents per ASM on the first three routes.

The difference between the 747-400 with 393 seats is more at 0.85-1.05 cents per ASM, clearly indicating the efficiency of the new generation A350-1000.

The 747-400 starts to have passenger payload restrictions on the longer routes

**BLOCK FUEL BURN PERFORMANCE OF A350-900/-1000, 787-8/-9/10, A330-200, A330-300, 777-200ER, 777-300ER & 747-400**

| City-pair | Aircraft variant | Engine variant | Seats | Cargo payload lbs | ESAD nm | ASMs | Block time Hours | Block fuel USG | Fuel /ASM | ATC cost $ | Fuel & ATC c/ASM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LHR-AUS | A330-200 | Trent 772C | 248 | 14,825 | 4,763 | 1,181,224 | 10:39 | 19,145 | 0.0162 | 2,042 | 2.91 |
| | 787-8 | GEnx-1B67 | 220 | 19,112 | 4,705 | 1,035,100 | 10:10 | 15,434 | 0.0149 | 2,025 | 2.72 |
| | 787-8 | Trent 1kG | 220 | 19,112 | 4,705 | 1,035,100 | 10:10 | 16,045 | 0.0155 | 2,025 | 2.82 |
| | A330-300 | Trent 772B | 274 | 10,511 | 4,785 | 1,311,090 | 10:41 | 20,276 | 0.0155 | 2,042 | 2.77 |
| | 787-9 | GEnx-1B74-75 | 266 | 23,822 | 4,726 | 1,257,116 | 10:13 | 16,422 | 0.0131 | 2,118 | 2.38 |
| | 777-200ER | GE90-94B | 304 | 21,271 | 4,774 | 1,451,296 | 10:27 | 22,244 | 0.0153 | 2,271 | 2.75 |
| | A350-900 | Trent XWB-84 | 318 | 23,075 | 4,744 | 1,508,592 | 10:11 | 19,157 | 0.0127 | 2,172 | 2.29 |
| | 787-10 | GEnx-1B74-75 | 337 | 26,994 | 4,745 | 1,599,065 | 10:14 | 17,907 | 0.0112 | 2,118 | 2.02 |
| | 787-10 | Trent 1kJ3 | 337 | 26,994 | 4,764 | 1,605,468 | 10:14 | 18,293 | 0.0114 | 2,118 | 2.06 |
| | 777-300ER | GE90-115BL | 382 | 31,427 | 4,813 | 1,838,566 | 10:28 | 26,095 | 0.0142 | 2,443 | 2.53 |
| | 747-400 3cl | CF6-80C2B1F | 393 | 15,034 | 4,806 | 1,888,758 | 10:18 | 34,589 | 0.0183 | 2,566 | 3.23 |
| | 747-400 2cl | CF6-80C2B1F | 487 | 7,839 | 4,806 | 2,340,522 | 10:18 | 35,901 | 0.0153 | 2,566 | 2.70 |
| | A350-1000 (327) | Trent XWB-97 | 327 | 31,741 | 4,765 | 1,558,155 | 10:14 | 21,825 | 0.0140 | 2,330 | 2.52 |
| | A350-1000 (367) | Trent XWB-97 | 367 | 31,718 | 4,766 | 1,749,122 | 10:15 | 22,266 | 0.0127 | 2,330 | 2.28 |
| LHR-SAN | A330-200 | Trent 772C | 248 | 14,143 | 5,290 | 1,311,920 | 11:44 | 21,468 | 0.0164 | 2,392 | 2.95 |
| | 787-8 | GEnx-1B67 | 220 | 18,319 | 5,204 | 1,144,880 | 11:10 | 17,228 | 0.0150 | 2,371 | 2.75 |
| | 787-8 | Trent 1kG | 220 | 18,305 | 5,225 | 1,149,500 | 11:11 | 17,951 | 0.0156 | 2,371 | 2.85 |
| | A330-300 | Trent 772B | 274 | - | 5,292 | 1,450,008 | 11:47 | 22,768 | 0.0157 | 2,392 | 2.82 |
| | 787-9 | GEnx-1B74-75 | 266 | 22,814 | 5,227 | 1,390,382 | 11:14 | 18,334 | 0.0132 | 2,483 | 2.41 |
| | 777-200ER | GE90-94B | 304 | 20,331 | 5,301 | 1,611,504 | 11:30 | 24,899 | 0.0155 | 2,666 | 2.78 |
| | A350-900 | Trent XWB-84 | 318 | 22,100 | 5,246 | 1,668,228 | 11:12 | 21,402 | 0.0128 | 2,547 | 2.32 |
| | 787-10 | GEnx-1B74-75 | 337 | 25,832 | 5,270 | 1,775,990 | 11:16 | 20,030 | 0.0113 | 2,483 | 2.05 |
| | 787-10 | Trent 1kJ3 | 337 | 25,832 | 5,270 | 1,775,990 | 11:16 | 20,455 | 0.0115 | 2,483 | 2.09 |
| | 777-300ER | GE90-115BL | 382 | 30,016 | 5,324 | 2,033,768 | 11:32 | 29,182 | 0.0143 | 2,873 | 2.57 |
| | 747-400 3cl | CF6-80C2B1F | 393 | 14,013 | 5,316 | 2,089,188 | 11:21 | 38,793 | 0.0186 | 3,022 | 3.28 |
| | 747-400 2cl | CF6-80C2B1F | 487 | 7,307 | 5,316 | 2,588,892 | 11:21 | 40,281 | 0.0156 | 3.022 | 2.75 |
| | A350-1000 (327) | Trent XWB-97 | 327 | 30,374 | 5,270 | 1,723,290 | 11:16 | 24,406 | 0.0142 | 2.737 | 2.55 |
| | A350-1000 (367) | Trent XWB-97 | 367 | 30,352 | 5,271 | 1,934,457 | 11:17 | 24,843 | 0.0128 | 2,737 | 2.31 |
| LHR-GRU | A330-200 | Trent 772C | 248 | 9,728 | 5,549 | 1,376,152 | 12:25 | 22,639 | 0.0165 | 12,164 | 3.66 |
| | 787-8 | GEnx-1B67 | 220 | 17,566 | 5,537 | 1,218,140 | 12:04 | 18,298 | 0.0150 | 12,057 | 3.53 |
| | 787-8 | Trent 1kG | 220 | 17,566 | 5,537 | 1,218,140 | 12:04 | 19,010 | 0.0156 | 12,057 | 3.63 |
| | A330-300 | Trent 772B | 247 | - | 5,548 | 1,368,002 | 12:24 | 23,547 | 0.0172 | 12,164 | 3.80 |
| | 787-9 | GEnx-1B74-75 | 266 | 22,042 | 5,534 | 1,472,044 | 11:58 | 19,400 | 0.0132 | 12,562 | 3.08 |
| | 777-200ER | GE90-94B | 304 | 19,847 | 5,535 | 1,682,640 | 12:00 | 26,123 | 0.0155 | 13,886 | 3.45 |
| | A350-900 | Trent XWB-84 | 318 | 21,320 | 5,534 | 1,759,812 | 11:58 | 22,496 | 0.0128 | 12,873 | 2.89 |
| | 787-10 | GEnx-1B74-75 | 337 | 25,184 | 5,529 | 1,863,273 | 11:48 | 21,075 | 0.0113 | 12,562 | 2.59 |
| | 787-10 | Trent 1kJ3 | 337 | 25,165 | 5,529 | 1,863,273 | 11:49 | 21,500 | 0.0115 | 12,562 | 2.62 |
| | 777-300ER | GE90-115BL | 382 | 29,590 | 5,507 | 2,103,674 | 11:49 | 30,409 | 0.0145 | 15,298 | 3.17 |
| | 747-400 3cl | CF6-80C2B1F | 393 | 13,667 | 5,503 | 2,162,679 | 11:40 | 40,529 | 0.0187 | 15,932 | 3.90 |
| | 747-400 2cl | CF6-80C2B1F | 487 | 7,152 | 5,479 | 2,668,273 | 11:37 | 42,027 | 0.0158 | 15,932 | 3.26 |
| | A350-1000 (327) | Trent XWB-97 | 327 | 29,501 | 5,531 | 1,808,637 | 11:53 | 25,706 | 0.0142 | 14,196 | 3.19 |
| | A350-1000 (367) | Trent XWB-97 | 367 | 29,546 | 5,531 | 2,029,877 | 11:51 | 26,147 | 0.0129 | 14,196 | 2.88 |

Source: Lufthansa Systems' Lido/Flight

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

on LHR-EZE and LHR-SCL *(see table, page19)*. This only has the effect of increasing the A350-1000's advantage because it suffers no limitations to available passenger numbers.

## Summary

As expected, the new generation long-haul aircraft offer a significantly lower fuel burn and operating costs per ASM compared to older generation types. The three longer sectors are punishing in terms of payload-range requirements and flight operations in general. With block times ranging from 11:50 (LHR-GRU) to 15:00 (LHR-SCL) hours, these aircraft will have to meet the reliability and comfort requirements that come with such long flights. This may explain why a number of operators do not put as many seats as possible into these aircraft.

The good news is that even on these extreme routes, almost all aircraft allow a significant amount of lower deck cargo to be carried in addition to their full passenger cabins. On the 5,515nm LHR-GRU route, weight-wise all aircraft can take more lower deck payload than they can stow volume-wise inside the aircraft.

On the 6,575nm (ESAD) LHR-EZE sector we see some payload and performance restrictions appearing, with

**BLOCK FUEL BURN PERFORMANCE OF A350-900/-1000, 787-8/-9/10, A330-200, A330-300, 777-200ER, 777-300ER & 747-400**

| City-pair | Aircraft variant | Engine variant | Seats | Cargo payload lbs | ESAD nm | ASMs | Block time Hours | Block fuel USG | Fuel /ASM | ATC cost $ | Fuel & ATC c/ASM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LHR-EZE | A330-200 | Trent 772C | 199 | - | 6,611 | 1,314,616 | 14:42 | 26,913 | 0205 | 11,475 | 4.33 |
| | 787-8 | GEnx-1B67 | 220 | 15,858 | 6,594 | 1,450,680 | 14:14 | 22,285 | 0.0154 | 11,359 | 3.38 |
| | 787-8 | Trent 1kG | 220 | 15,323 | 6,592 | 1,450,240 | 14:12 | 23,134 | 0.0160 | 11,359 | 3.48 |
| | A330-300 | Trent 772B | 146 | - | 6,613 | 967,473 | 14:45 | 27,135 | 0.0280 | 11,475 | 5.93 |
| | 787-9 | GEnx-1B74-75 | 266 | 19,925 | 6,563 | 1,745,758 | 14:07 | 23,590 | 0.0135 | 11,882 | 2.96 |
| | 777-200ER | GE90-94B | 304 | 17,938 | 6,564 | 1,995,456 | 14:09 | 31,893 | 0.0160 | 13,026 | 3.35 |
| | A350-900 | Trent XWB-84 | 318 | 5,334 | 6,590 | 2,095,620 | 14:07 | 27,432 | 0.0131 | 12,194 | 2.79 |
| | 787-10 | GEnx-1B74-75 | 337 | 8,215 | 6,557 | 2,209,709 | 13:56 | 25,682 | 0.0116 | 11,882 | 2.50 |
| | 787-10 | Trent 1kJ3 | 337 | 5,892 | 6,557 | 2,209,709 | 13:57 | 26,213 | 0.0119 | 11,882 | 2.54 |
| | 777-300ER | GE90-115BL | 382 | 25,015 | 6,531 | 2,494,842 | 13:56 | 37,072 | 0.0149 | 14,271 | 3.08 |
| | 747-400 3cl | CF6-80C2B1F | 393 | 3,320 | 6,524 | 2,563,932 | 13:44 | 49,763 | 0.0194 | 14,930 | 3.86 |
| | 747-400 2cl | CF6-80C2B1F | 419 | - | 6,523 | 2,732,262 | 13:43 | 50,273 | 0.0184 | 14,930 | 3.66 |
| | A350-1000 (327) | Trent XWB-97 | 327 | 24,254 | 6,561 | 2,145,447 | 14:03 | 31,236 | 0.0146 | 13,347 | 3.08 |
| | A350-1000 (367) | Trent XWB-97 | 367 | 16,273 | 6,560 | 2,407,520 | 14:02 | 31,820 | 0.0132 | 13,347 | 2.79 |
| LHR-SCL | A330-200 | Trent 772C | 164 | - | 6,941 | 1,137,362 | 15:23 | 27,994 | 0.0246 | 10,322 | 5.07 |
| | 787-8 | GEnx-1B67 | 220 | 12,155 | 6,924 | 1,523,280 | 14:51 | 23,666 | 0.0155 | 10,215 | 3.30 |
| | 787-8 | Trent 1kG | 220 | 8,565 | 6,923 | 1,523,060 | 14:51 | 24,579 | 0.0161 | 10,215 | 3.40 |
| | A330-300 | Trent 772B | 111 | - | 6,942 | 770,111 | 15:25 | 28,216 | 0.0366 | 10,332 | 7.53 |
| | 787-9 | GEnx-1B74-75 | 266 | 19,253 | 6,919 | 1,840,454 | 14:43 | 25,016 | 0.0136 | 10,737 | 2.88 |
| | 777-200ER | GE90-94B | 304 | 13,027 | 6,892 | 2,095,168 | 14:45 | 33,858 | 0.0162 | 11,588 | 3.28 |
| | A350-900 | Trent XWB-84 | 315 | - | 6,920 | 2,181,448 | 14:45 | 28,978 | 0.0133 | 11,040 | 2.75 |
| | 787-10 | GEnx-1B74-75 | 337 | 1,124 | 6,915 | 2,330,355 | 14:35 | 27,251 | 0.0117 | 10,737 | 2.44 |
| | 787-10 | Trent 1kJ3 | 337 | - | 6,914 | 2,330,018 | 14:34 | 27,824 | 0.0119 | 10,737 | 2.48 |
| | 777-300ER | GE90-115BL | 382 | 14,143 | 6,858 | 2,619,756 | 14:31 | 39,398 | 0.0150 | 12,539 | 3.02 |
| | 747-400 3cl | CF6-80C2B1F | 319 | 4,995 | 6,881 | 2,196,648 | 14:22 | 51,460 | 0.0234 | 13,237 | 4.56 |
| | 747-400 2cl | CF6-80C2B1F | 312 | 6,214 | 6,881 | 2,147,259 | 14:22 | 51,311 | 0.0239 | 13,237 | 4.65 |
| | A350-1000 (327) | Trent XWB-97 | 327 | 15,223 | 6,917 | 2,261,859 | 14:39 | 33,154 | 0.0147 | 11,910 | 3.00 |
| | A350-1000 (367) | Trent XWB-97 | 367 | 6,843 | 6,917 | 2,538,539 | 14:39 | 33,902 | 0.0134 | 11,910 | 2.73 |

Source: Lufthansa Systems' Lido/Flight
Notes: Lufthansa Systems provided block fuel figures in lbs. These have been converted to USG using 1 USG = 6.55lbs.

only the 777 variants, and the GE-powered 787-8 and 787-9 still operating with an underload, leaving weight available for more payload.

The real watershed happens on the longest, 6,910nm (ESAD) LHR-SCL route. The 787-9 outperforms all other aircraft in terms of payload-carrying capability, and has payload for lower deck cargo when completely loaded.

These additional cargo payloads and the revenue that they generate have not been taken into consideration in this evaluation, however. Our consideration has only been to evaluate the fuel and ATC costs and performance associated with operating the aircraft on these long routes.

Still, when using some real-world passenger and cargo yields, it turns out that the aircraft with higher cash operating costs are actually better revenue earners than the best-in-class, the 787-10, which yields a higher earning potential. Everything depends on a range of commercial factors of course, the primary ones being the chosen cabin layout, and average passenger yields and cargo shipment revenues.

The 787-8s use the least block fuel on these sectors but display a higher cost per ASM than their larger siblings. The GE-powered variant uses slightly less fuel than the higher-rated RR-powered aircraft. The differences in performance between the RR- and GE-equipped 787-8s and 787-9s should be treated with some caution. This is because there are a number of different engine specifications and thrust settings available.

The 787-10s overall steal the show. Our slightly more powerful RR-powered variant burns 1.7-2.1% more fuel than the GE-powered aircraft. When combined with slightly lower time-related costs, results in an overall 1.1% higher operating cost.

The two A350-1000 configurations have the highest revenue-earning potential of current-generation long-haul aircraft. Results of the 777-300ER are keeping up with the A350-1000s, but the 777-300ER loses some terrain when comparing operating costs. Still, even on the longest sector the aircraft can hold its own.

## In closing

The analysis has shown that in our field of 14 specific aircraft-engine models, the GEnx powered 787-10 is the most efficient aircraft on the five routes. This is when measuring by fuel burn and en route ATC charges cost per ASM *(see tables, page 18 & this page)*.

In this, a lot depends on the aircraft configuration, both physically (engine rating and weights) and in the cabin (layout, seat count) and how the aircraft are operated in airline-specific environments. One of the 787-10's main advantages is its high seat count relative to the 777-200ER. The market will choose a certain aircraft type for its operations based on many other factors than fuel burn or cash operating cost. AC