Widebodies in the A350, 787 & 777 families now dominate the long-haul market. These have tri-class seat capacities of 285-375 seats and ultra-long-range capability. Seven types on long- and ultra-long-range routes are compared using fuel burn data provided by the CAE Flight Plan Manager system.

Long-range fuel burn performance of 285- to 375-seat widebodies

In the past 10 years the profile of the long-haul widebody fleet has changed, with the almost complete replacement of the 747-400 by the largest twin-engined widebodies: the A350-1000 and the 777-300ER.

Most of the world's airlines also operate smaller A350 and 777 variants and types such as the 787-9 and -10, and A330-900. Many of these types have ultra-long-distance capability and account for most of the capacity provided on long-haul and ultra-long-haul routes. Most have tri-class, long-haul style cabin configurations with capacities of 285 to 374 seats.

The new-generation, widebody twin-engined types have engines with higher bypass ratios than previous generations. The long-term pursuit of engines' higher bypass ratios has continuously improved fuel burn efficiency for consecutive generations of aircraft. Modern types should therefore have longer-range performance than similar-sized older aircraft with the same specification weights and fuel volumes, and the same payloads. Their inherently superior fuel burn efficiency means that modern types can also be configured with lower specification weights, as well as larger fuel volumes to achieve longer-range performance.

The fuel burn and operating performance of these aircraft types on some long-distance and ultra-long-distance routes are analysed on five routes with tracked distances of 3,738 nautical miles (nm) to 6,772nm, using the CAE Flight Plan Manager.

The number of A380s that have been reactivated and put back into service since the Covid-19 pandemic is limited. As the A380 is only operated by a few carriers on a select number of the busiest long-haul routes, it is excluded from this analysis.

Aircraft types

There are seven main aircraft types analysed here. From the smallest, in terms of tri-class seat capacity, to the largest, these are the A330-300, A330-900 new engine option (neo), 777-200ER, A350-900, 787-10, A350-1000, and 777-300ER *(see table, page 17)*.

There are many ways an aircraft's layout of passenger accommodation (LOPA) can be configured. In the past 20 years aircraft LOPAs have moved from the traditional tri-class arrangement of first, business and economy class, since the introduction of lie-flat seats in premium aircraft cabins from 2004.

Lie-flat seats can now provide fold-out, bed-like seats that are positioned in a herringbone fashion. Some airlines provide entire luxury suites.

The increased range of premium cabin seating options that airlines can choose from means that business class is generally replacing first class as the premium cabin on the aircraft.

Most airlines have followed one of two paths in reconfiguring their long-haul LOPAs. One has been to offer a two-class product, with an economy-class cabin and a business-class cabin with lie-flat or other luxury seat configuration.

The second has been to maintain a tri-class LOPA. The three classes in this case are a business class, a premium economy cabin and a standard economy cabin. In most cases, airlines have configured their new premium-economy cabins with seats that are wider than standard economy class, so they have one or two fewer seats abreast. Seat pitch is also greater than in economy class. Premium-economy cabins therefore offer passengers more room and comfort than economy cabins, but still accommodate more seats in the same area than a traditional business-class cabin.

The use of this tri-class LOPA therefore provides a larger or similar number of seats compared to a traditional tri-class configuration, while also allowing airlines to charge higher fares for the premium-economy seating.

Economy class

Another change made by many airlines in recent years has been to increase the number of seats abreast in their economy cabins, especially with the 787 and 777-300ERs.

Boeing originally offered the 787 with eight-abreast seating as standard in the economy cabin. The 787's external fuselage diameter is six inches wider than the original Airbus widebody fuselage width of 222 inches, as used by the A300, A310, A330 and A340. All of these Airbus types have an eight-abreast economy class as standard, but a small number of European inclusive-tour operators have configured the A300-600 and A330 with nine-abreast seating. This provides narrower aisles and seats than the eight-abreast arrangement.

The small increase in the 787's fuselage width over the A330/340 meant that the 787 was originally intended to be configured in an economy class that had the same eight-abreast seating. The 787 can therefore have wider seats and aisles, and so provide a superior comfort level to that of the A330/340.

Many 787 operators have, however, opted for a nine-abreast economy-class cabin. This adds one seat for every row in economy class,by reducing seat width between armrests from 18.5 inches to 17.2 inches, as well as reduced aisle width.



The A350-900 can have a marginally larger seat capacity and longer range than the 777-200ER. On the routes lengths used, the A350-900 has a 22-24% lower fuel burn per seat.

The same technique has been used in the economy class of 777-200ERs and -300ERs by most operators. The 777's internal fuselage width is narrower than the 747's. The 747 always operated with a standard 10-abreast seating arrangement in economy class. This allowed a standard seat width of 18 inches, and an aisle width of 19.5 inches.

The 777's fuselage width allowed nine-abreast seating in the economy cabin as standard, and would provide slightly wider seats and a similar aisle width compared to the 747. The 777's internal cabin width, however, allows 10-abreast seating with seats that are about 17 inches wide between armrests; 1.0 inch narrower than in the 747's economy class. As with the 787, many airlines have re-configured their 777 fleets with narrower seats in a 10-abreast configuration in economy class. This again increases seat numbers for the same number of seat rows.

While increasing economy-class seating from eight- to nine-abreast in the case of the A330 and A340 is not possible, some airlines have increased the number of seats for a particular length of the cabin used for the economy class by reducing seat pitch.

Seat numbers

The analysis has used tri-class seat configurations that are representative for several airlines and operators of each type. This has analysed seat numbers for business-, premium-economy- and economy-class cabins and looked at proportionate numbers of seats in relation to aircraft cabin size. This assesses likely differences in total seat numbers between the seven types that have a fixed floor area, and limitations such as the number of main passenger doors, and their location.

The number of seats abreast in the economy class is a main issue. This analysis has used eight-abreast seating for the two A330 variants, nine-abreast for the two A350 variants and the 787-10, and 10-abreast for the 777-200ER and -300ER.

The A330-300/-900neo have the smallest area, and the 777-200ER is the next largest with about 6% more area. The A350-900 has about 3% more floor area than the 777-200ER. The 787-10 has 4% more floor area than the A350-900, and about 6.8% more than the 777-200ER.

Another factor that affects the amount of floor area that can be configured with seats is the internal length of the cabin between the first and rear cabin doors, since the floor areas adjacent to and forward of the front cabin door, and adjacent to and aft of the rear door cannot have passenger seats in them. The space used for lavatories, galleys, closets and cabin dividers between the front and rear doors also affects the number of seats.

The two smallest types, the A330-300 and -900neo, have tri-class seat capacities of 285. The next largest aircraft is the 777-200ER, with a capacity of 303 seats. The A350-900 is larger with 311 seats, while the 787-10 is the next largest with 322 *(see table, page 17)*. The A350-1000 is configured with 358 seats, and the 777-300ER has 374 *(see table, page 17)*. The 777-300ER's seat count compares is close to Boeing's tri-class standard of 370, with nine-abreast seating in economy class.

Airline cabin LOPAs and seat numbers in each class can suggest the likely seat numbers and those used for this analysis.

The A330-300 is operated with a tri-class cabin for intercontinental services by more than 15 airlines, including Cathay Pacific, Delta, Finnair, Iberia, Lufthansa, and Virgin Atlantic. Most have a business and premium-economy class, and an average number of seats of 284.

The A330-900neo has so far been delivered to just five airlines: Air Mauritius, Garuda, TAP Air Portugal and Virgin Atlantic. The same seat total for the A330-300 has been used here for the -900neo.

Examination of LOPAs used by 777-200ER operators shows that Air France, Austrian, British Airways (BA), KLM and United Airlines have a 10-abreast economy class, and business and premium-economy classes. Compared to the A330-300/-900neo, the 777-200ER will have a seat count of 303.

The 787-10 is operated by three airlines with a tri-class cabin: All Nippon Airways, KLM and United. Average business- and premium-economy-class seat numbers are in proportion with the 777-200ER, and so total seat count for the 787-10 averages 322.

The A350-900 is operated by several airlines, and most use a tri-class LOPA with business and premium-economy cabins. These include Asiana, Cathay Pacific, Japan Airlines, Malaysian, Singapore Airlines, Iberia, and Lufthansa. All operate with a nine-abreast economy class. With average seat counts in the two premium cabins close to the 777-200ER, and the A350-900 having an average of 244 economy-class seats, its total seat count is at 311.

The A350-1000's largest operators are BA, Virgin Atlantic, Etihad and Cathay Pacific. All operate with the same LOPA configuration as described for the A350-900. Average total seat count is 358.

The 777-300ER is the main long-haul type. It is the largest of all types here, with 4.5% more cabin floor space than the A350-1000. The 777-300ER has been analysed with a seat count of 374.

Nine airlines configure their 777-300ERs with a 10-abreast economy cabin, together with a business and premium-economy class. These include Air France, Cathay Pacific, KLM and United.

Aircraft specifications

There are several weight configurations and variants of each aircraft type. The variant of each type used for this analysis is that with the highest maximum take-off weight (MTOW) and largest fuel capacity.

AIRCRAFT SPECIFICATIONS & WEIGHTS

Aircraft types	A330-300	A330-900	777-200ER	A350-900	787-10	A350-1000	777-300ER
Engine	Trent 772B	Trent 7000-72	GE90-94B	Trent XWB-97	GEnx-1B74	Trent XWB-97	GE90-115BL
Engine bypass ratio	5.0:1	10.0:1	8.4:1	9.6:1	9.1:1	9.6:1	9.0:1
Take-off thrust rating - lbs	71,100	72,834	93,700	97,000	74,100	97,000	115,540
MTOW - lbs	533,519	540,132	632,500	617,295	560,000	703,275	775,000
MZFW - lbs	385,809	390,218	430,000	431,445	425,000	491,631	524,000
Basic empty weight - lbs	277,461	286,601	304,745	292,994	280,000	325,182	374,785
OEW/APS - lbs	285,136	294,276	312,795	301,074	288,230	334,267	384,185
Max payload - lbs	100,673	95,942	117,205	130,371	136,770	157,364	139,815
Fuel capacity - USG	36,744	36,744	45,220	43,589	33,399	41,949	47,890
Tri-class seat configuration	285	285	303	311	322	358	374
Passengers carried	228	228	242	249	258	286	299
Passenger payload - lbs	52,440	52,440	55,752	57,224	59,248	65,872	68,816
Approx range with full passenger payload - nm	6,400	7,300	7,200	7,500	6,800	8,200	7,300

ROUTE CHARACTERISTICS FOR ANALYSIS OF AIRCRAFT PERFORMANCE

Route	LHR-DEL	LHR-HKG	LHR-KUL	LHR-SIN	LHR-CGK
Tracked distance - nm	3,738	5,572	5,893	6,034	6,772
Average wind component - kts	28	27	16	16	13
ESAD - nm	3,515-3,537	5,250-5,275	5,682-5,700	5,823-5,841	6,581-6,599
Flight time - mins	445-475	662-707	712-756	729-775	820-874
Alternate airport	ATQ	MFM	SIN	KUL	HLP

A330-300/-900neo

The A330-300 first entered service in 1992, and production continued until 2020. During this period many weight variants (WVs) were developed for it, as well as for the shorter A330-200. In fact, there are 34 different weight variants for the -300 series, all with a usable fuel volume of 25,765 US Gallons (USG). The MTOW of these 34 variants ranges from 405,650lbs to 518,086lbs. WV055 gives the A330-300 with the highest possible MTOW of 518,086lbs, and the highest possible maximum zero fuel weight (MZFW) of 385,809lbs.

The A330-300 also has four high gross weight variants (WV080, WV081, WV082 and WV083) with MTOWs of 524,700lbs and 533,519lbs, and an MZFW of up to 385,809lbs. These four variants have a high fuel capacity of 36,733USG.

The A330-300 in this analysis has a Rolls-Royce Trent 772B engine, with a bypass ratio of 5.0:1. The aircraft variant used here will have a range of 6,400nm with a full passenger payload.

The A330-900neo shares the same fuselage as the -300 series, but it has significantly higher weight characteristics. It is equipped with the Rolls-Royce Trent 7000-72, which has a bypass ratio of 10:1.

The -900neo series has 15 WVs. The MTOW ranges from 451,948lbs to 553,360lbs, and the highest possible MZFW is 399,037lbs *(see table, this page)*. An MTOW of 540,132lbs is examined in this analysis. All 15 variants have a usable fuel capacity of 36,744USG.

The highest possible MTOW variant will have a range of 7,300nm with a full passenger payload.

777-200ER

The 777-200ER was the second 777 family member to enter service, following the -200 series, which had a lower gross weight and smaller fuel capacity.

The 777-200ER was in production from 1997 until 2013, and 422 were built. Its capacity and range pitched closest to the A340-300 and MD-11, with fewer than 40 A340-300s left in passenger service. The 777-200ER is therefore the same generation as the A330-300, and provides a comparison for the younger but similarly-sized 787-10 and A350-900.

The 777-200ER has an MTOW of 632,500lbs (about 99,000lbs higher than the high gross weight A330-300). The 777-200ER is also 92,500lbs heavier than the A330-900. The 777-200ER used in this analysis is equipped with the General Electric GE90-94B engine, which has a bypass ratio of 8.4:1.

The 777-200ER also has a large fuel capacity of 45,220USG, and long-range performance of 7,200nm with 303 passengers.

787-10

The 787-10 is the third series of the 787 family. The 787-8 and -9 series have shorter fuselages and so smaller seat counts, and are closer in seat capacities to the 767-300ER, 767-400ER and A330-200. The 787-9 is close in size to the A330-300 and A340-300.

As described, the 787 can have nine-abreast in the economy cabin, while the 777 is wider and can have 10-abreast. Although the 787 has a narrower fuselage, the 787-10 has a length of fuselage between the front and rear doors that is 20 feet longer than the 777-200ER. This means that the 787-10 could have seven or eight rows of economy seats more than the 777-200ER. This is offset, however, by the 787's economy-class rows each having one seat fewer than the 777-200ER. The 787-10's tri-class seat capacity in this analysis is



The 787-10 is well positioned to replace the 777-200ER. The 787-10's length means it can be configured with about 20 seats more than the 777-200ER, and the 787-10 has 28-29% lower fuel burn per seat. The 787-10 also has a competitive fuel burn against the A350-900.

322; making it Boeing's closest-sized aircraft to replace the 777-200ER.

The 787-10 entered service in 2018, and is available with the GEnx-1B74 or the Rolls-Royce Trent 1000 engine. These have bypass ratios of 9.1-9.3:1 and 10.1:1. The GEnx-1B74 is used here.

There is a range of weights, and the highest MTOW is 560,000lbs; 72,500lbs lower than the 777-200ER. The -10 has an MZFW of 425,000lbs, just 5,000lbs lower than the 777-200ER, and a fuel capacity of 33,399USG; 11,821USG lower than the 777-200ER. Despite having a lower MTOW and fuel capacity than the 777-200ER, the 787-10 has a still air range of 6,800nm with a full payload of 322 passengers.

A350-900/-1000

The A350-900 and -1000 series are close in seat capacity to the 777-200ER and -300ER, and so are new generation replacement candidates for the Boeing aircraft.

Airbus adopted a wider fuselage width and configuration for the A350 over its A300/310/330/340 widebodies. The external diameter of the A350's fuselage is 10 inches narrower than the 777, so the A350 cannot accommodate 10-abreast seating in its economy class. The A350's external fuselage diameter is also seven inches wider than the 787's, which also has nine-abreast seating in its economy cabin. The A350 can therefore provide wider seats in the same nine-abreast configuration compared to the 787.

The A350-900 has almost the same usable internal fuselage length as the A330-300/-900, but the A350's wider fuselage gives it a higher seat capacity. The A350-900 also has a longer cabin than the 777-200ER, so overall the A350-900's tri-class seat capacity is eight seats more at 311 *(see table, page 17)*.

The A350-900 variant used in this analysis is the ultra-long-range version: the -900ULR. The variant used in this analysis is WV010. It has a MTOW of 617,295lbs, about 14,000lbs lighter than the 777-200ER; an MZFW of 431,445lbs, and fuel capacity of 43,589USG. The A350-900ULR's weights and fuel capacity are therefore close to the 777-200ER.

The A350-900ULR is powered by the Rolls-Royce Trent XWB-97, rated at 97,000lbs thrust, with a bypass ratio of 9.6:1. This is less than the GEnx-1B74 powering the 787-10.

With these weights and fuel capacity, the A350-900ULR can carry a full load of 311 passengers 7,500-7,800nm.

The A350-1000 has almost the same internal fuselage length between the front and aft cabin doors as the 777-300ER. Despite this, and being 24 feet longer than the -900 series, the A350-1000 also has eight main cabin doors. In this analysis, the A350-1000's tri-class seat capacity is 358.

The A350-1000 variant used has an MTOW of 703,275lbs, an MZFW of 491,631lbs, and a fuel capacity of 41,949USG *(see table, page 17)*. It is powered by the Rolls-Royce Trent WXB-97 rated at 97,000lbs.

The A350-1000 has a range of 8,200-8,500nm with a full passenger payload.

777-300ER

The 777-300ER is the largest and heaviest aircraft in this analysis. With a similar fuselage length to, and wider fuselage width than, the A350-1000, the 777-300ER has a larger tri-class seat capacity of 374.

The 777-300ER has an MTOW of 775,000lbs, an MZFW of 524,000lbs, and a usable fuel capacity of 47,890USG. The aircraft is equipped with the General Electric GE90-115BL engine, rated at 115,540lbs. With a full passenger load, the aircraft has a still air range of 7,300nm.

Routes for analysis

The five routes chosen for the analysis were required to operate in the same approximate direction, and cover a wide range of tracked distances. This is so that the route lengths examined were between traditional long-haul operations, and ultra-long-distance services that have now become possible with new-generation long-haul types such as the A350-900ULR.

Several parameters have to be defined for the performance to be assessed by the CAE Flight Plan Manager.

The first of these is the flight path, and the corresponding distance. On the four long-distance routes examined here, there are multiple flight paths an airline flight planner and flightcrew can choose to take.

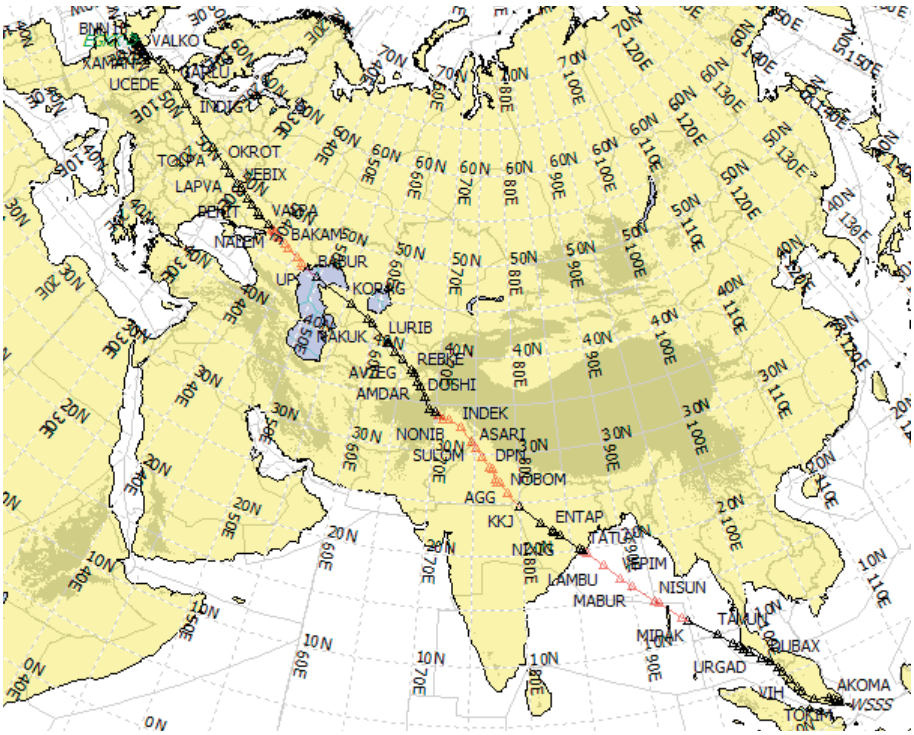
The effects of wind speed and direction at cruising altitudes will affect the difference between the tracked distance and the actual equivalent still air distance (ESAD) of the flight on the day of operation.

The track taken is also in some cases affected by geopolitical issues. The great circle route for all of these five routes would require the aircraft fly most of the track over the Russian Federation. This is to reflect typical airline operating procedures and subsequent aircraft performance over the long term. Airlines also have to circumnavigate Iraq and Afghanistan over the long term.

The London Heathrow (LHR) - Hong Kong (HKG) route has a large portion of its great circle flight path and optimum track over Russia. The four routes to Delhi International (DEL), Kuala Lumpur (KUL), Singapore (SIN), and Jakarta (CGK) have a smaller portion of their flight paths over Russia.

The great circle paths of the four routes to DEL, KUL, SIN and CGK all pass over the north-eastern corner of Afghanistan. The track paths operated by airlines would therefore pass north of Afghanistan, and then through northern Pakistan and India. This would increase the tracked distance.

The tracked distances used were



The graphic of the LHR-SIN flight path produced by CAE's Flight Plan Manager. This track for the route has a distance of 6,304nm. The average annual wind component over a year is a tailwind of 15-16 knots, taking the ESAD to 5,823-5,841nm, depending on average cruise speed.

supplied by CAE Flight Plan Manager, and are based on typical airline flight paths in use with airlines.

Five routes operating to the Asia Pacific from LHR were chosen. The shortest is to DEL, with a tracked distance of 3,738nm.

The other four routes are generally regarded as ultra long-distance. These are:

- LHR to HKG, with a tracked distance of 5,572nm
- LHR to KUL, with a tracked distance of 5,893nm
- LHR to Singapore (SIN), with a tracked distance of 6,034nm
- LHR to Jakarta (CGK), with a tracked distance of 6,772nm

Realistic and representative aircraft performance calculations are only possible if suitable airports are selected as alternates to each of the five destinations. The alternate for DEL is Amritsar (ATQ), for HKG it is Macau (MFM), for KUL it is SIN, for SIN the alternate is KUL, and for CGK it is Halim Perdanakusuma International (HLP) airport Jakarta.

Aircraft OEW

An important factor affecting each aircraft's performance is its operating empty weight (OEW), or what can often be referred to as aircraft-prepared-for-service (APS) weight. This comprises four main elements. The first of these is basic weight, which is the weight of the empty aircraft without any crew or on-board catering and service items added. The basic weight is affected by the number and type of seats, galleys and lavatories, and in-flight entertainment (IFE) system. This varies between operators. Representative basic weights are listed *(see table, page 17)*. The basic weights for each aircraft type were supplied by CAE Flight Plan Manager, and are representative of configurations used by airlines with tri-class seat layouts.

The weight of catering and service items is sometimes referred to as pantry weight. It will include the weight for blankets and pillows. An allowance of 15lbs per seat has been made for pantry weight. This varies from 4,275lbs to 5,670lbs for the seven aircraft types *(see table, page 17)*.

Typical practice would be to roster four flightcrew. This would be two on active duty, plus two supernumerary pilots. A crew of three may be rostered on shorter routes, such as LHR-DEL, to allow for overnight services. An average weight of 190lbs per crew member has been used.

The minimum number of cabin crew that can be carried has to be at least equal to the number of main cabin passenger doors. All aircraft types, except the 777-300ER, have eight main passenger doors. The 777-300ER has 10.

On all five routes, 50-60% more cabin crew than the minimum required are used to allow some crew members to rest for part of the flight time, while maintaining cabin service. The A330-900neo, 787-10, and 777-200ER have 16 crew, and the A350-1000 and 777-300ER have 18. An average weight of 170lbs per crew member has been used. The weight for these crew members is 2,640lbs for five types, and 2,970lbs for the two larger types *(see table, page 17)*.

The OEW or APS for the seven aircraft types range from 285,136lbs for the A330-300, the lightest aircraft, to 384,185lbs for the 777-300ER, the largest and heaviest aircraft *(see table, page 17)*.

The OEW is one issue that affects the relative performance of competing types. The five smaller aircraft have capacities of 285-322 seats. The 787-10 and A350-900 are pitched as 777-200ER replacements. The 777-200ER is eight and 19 seats smaller than its two modern counterparts. Despite this, the 777-200ER is 25,000lbs heavier than the 787-10, and 12,000lbs heavier than the A350-900. Similarly, the 777-300ER is 50,000lbs heavier than the A350-1000, which is 10% lighter per seat.

Passenger payloads

The aircraft types have been analysed here with a number of passengers equal to a load factor of up to 80%. Some of them could be payload-restricted on some of the longest routes, and so would be forced to carry a smaller number of passengers. A load factor of 80% has been used to reflect likely long-term load factors experienced by airlines on long-range and ultra-long-range routes.

The weight of each passenger plus their checked baggage determines the payload carried. The standard weight of 230lbs.

The 80% load factor translates into 228 passengers on the A330-300 and -900neo, 242 on the 777-200ER, 249 on the A350-900, 258 on the 787-10, 286 on the A350-1000, and 299 on the 777-300ER *(see table, page 17)*. The corresponding weights for these passenger loads are listed.

The addition of passenger payload to the OEW/APS takes the total zero fuel weight (ZFW) of each aircraft type to 337,576lbs to 453,001lbs *(see table, page 17)*. These weights have been used by the CAE Flight Plan Manager.

Airlines will examine the performance of all aircraft with load factors of up to 100%. Most types could also carry an additional gross weight of belly freight on most routes, depending on their MZFW. This additional weight is 43,500lbs for the A330-900 and up to 91,400lbs for the A350-1000. Again, the younger types have more additional capacity for freight than their older counterparts.

Operating assumptions

Several operating assumptions have been used when making this analysis.

The first is that the analysis has been made for each route using the CAE Flight Plan Manager over 52 weeks for a full year. This is to examine the variation in performance of each aircraft on each route, and to establish an annual average for

BLOCK FUEL PERFORMANCE OF A330-300, A330-900, A350-900, A350-1000, 777-200ER, 777-300ER & 787-10 ON LONG-HAUL ROUTES

City-pair	Aircraft variant	Engine variant	Seats	Payload carried - lbs	Tracked dist - nm	ESAD - nm	Flight time - mins	Trip fuel - USG	USG per seat	Diff USG	% diff USG	Trip fuel/ ASM
LHR-DEL	A330-300	Trent 772B	285	52,439	3,738	3,515	475	13,523	47.4			0.013
	A330-900	Trent 7000-72	285	52,439	37,38	3,523	442	10,721	37.6	9.8	20.7	0.010
	777-200ER	GE90-94B	303	55,753	3,738	3,526	459	15,677	51.7			0.014
	A350-900	Trent XWB-97	311	57,223	3,738	3,532	445	12,620	40.6	11.2	21.6	0.011
	787-10	GEnx-1B74	322	59,247	3,738	3,527	447	12,037	37.4	14.4	27.7	0.010
	777-300ER	GE90-115BL	374	68,815	3,738	3,537	458	17,438	46.6			0.012
	A350-1000	Trent XWB-97	358	65,872	3,738	3,531	448	14,240	39.8	6.8	14.6	0.011
LHR-HKG	A330-300	Trent 772B	285	52,439	5,572	5,250	707	20,729	72.7			0.013
	A330-900	Trent 7000-72	285	52,439	5,569	5,251	687	17,075	59.9	12.8	17.6	0.011
	777-200ER	GE90-94B	303	55,752	5,567	5,260	679	24,071	79.4			0.014
	A350-900	Trent XWB-97	311	57,223	5,567	5,258	666	19,257	61.9	17.5	22.1	0.011
	787-10	GEnx-1B74	322	59,247	5,567	5,263	662	18,310	56.9	22.6	28.4	0.010
	777-300ER	GE90-115BL	374	68,815	5,567	5,275	677	26,639	71.2			0.013
	A350-1000	Trent XWB-97	358	65,872	5,567	5,262	662	21,678	60.6	10.7	15.0	0.011
LHR-KUL	A330-300	Trent 772B	285	52,439	5,893	5,682	756	23,017	80.8			0.014
	A330-900	Trent 7000-72	285	52,439	5,893	5,687	738	18,729	65.7	15.0	18.6	0.011
	777-200ER	GE90-94B	303	55,753	5,893	5,690	728	26,750	88.3			0.015
	A350-900	Trent XWB-97	311	57,223	5,893	5,695	712	21,016	67.6	20.7	23.5	0.011
	787-10	GEnx-1B74	322	59,247	5,893	5,689	717	20,180	62.7	25.6	29.0	0.011
	777-300ER	GE90-115BL	374	68,815	5,893	5,700	723	29,498	78.9			0.013
	A350-1000	Trent XWB-97	358	65,872	5,893	5,695	715	23,744	66.3	12.5	15.9	0.011
LHR-SIN	A330-300	Trent 772B	285	52,439	6,034	5,823	775	23,475	82.4			0.014
	A330-900	Trent 7000-72	285	52,439	6,034	5,827	756	19,165	67.2	15.1	18.4	0.011
	777-200ER	GE90-94B	303	55,753	6,034	5,828	746	27,284	90.0			0.015
	A350-900	Trent XWB-97	311	57,223	6,034	5,835	729	21,461	69.0	21.0	23.4	0.011
	787-10	GEnx-1B74	322	59,247	6,034	5,828	729	20,601	64.0	26.1	28.9	0.011
	777-300ER	GE90-115BL	374	68,815	6,034	5,841	741	30,108	80.5			0.013
	A350-1000	Trent XWB-97	358	65,872	6,034	5,833	733	24,234	67.7	12.8	15.9	0.011
LHR-CGK	A330-300	Trent 772B	285	49,895	6,772	6,581	874	26,920	94.5			0.014
	A330-900	Trent 7000-72	285	52,439	6,772	6,587	852	22,269	78.1	16.3	17.3	0.012
	777-200ER	GE90-94B	303	55,753	6,772	6,589	840	31,533	104.1			0.015
	A350-900	Trent XWB-97	311	57,223	6,772	6,593	822	24,598	79.1	25.0	24.0	0.012
	787-10	GEnx-1B74	322	59,247	6,771	6,584	820	23,657	73.5	30.6	29.4	0.011
	777-300ER	GE90-115BL	374	68,815	6,772	6,599	832	34,666	92.7			0.014
	A350-1000	Trent XWB-97	358	65,872	6,772	6,591	826	27,820	77.7	15.0	16.2	0.011

Source: CAE Flight Plan Manager

payload, ESAD, maximum range cruise (MRC), flight time and fuel burn.

Performance of the aircraft in an easterly direction shows that for all six routes the tailwind experienced is relatively small. This is 12-16 knots on the three routes to KUL, SIN and CGK; and 26-28 knots on the two routes to DEL and HKG.

These tailwinds make the ESAD 201-223nm shorter than the flight path on LHR-DEL. There are similar differences on the routes to KUL, SIN and CGK. The ESAD is 301-322nm shorter on LHR-HKG.

The average MRC of the aircraft type affects this difference, with slower aircraft having a marginally shorter ESAD when experiencing a tailwind.

These small reductions in effective distances flown will make only small reductions in flight time and fuel burn, and are unlikely to affect allowable passenger payloads of most types on most routes.

First, the performance data will reveal which aircraft types are required to carry payload that is smaller than an 80% passenger load factor on which routes.

From this data the trip fuel burn, fuel burn per available seat, fuel burn per actual seat available, and the fuel cost per seat and per seat-mile using a particular fuel cost can all be examined.

Several aircraft operating parameters affect the performance and fuel burn of each aircraft. International Flight Rules (IFR) have been used, and each aircraft operated at MRC speed. The flight profile and the altitude or flight level (FL) are all selected by the CAE Flight Plan Manager.

Reserve fuel policy used was 5% for contingency, no diversions or in-flight delays were actually experienced, and sufficient fuel to reach the alternate was carried. Fuel weight in lbs was converted to USG by using a factor of 6.7lbs per USG.



The A350-1000 is pitched as a 777-300ER replacement and ultra large widebody with ultra long-range capability. The A350-1000 has a 15-16% lower fuel burn per seat than the 777-300ER.

Fuel burn performance

The fuel burn performance of similarly-sized aircraft types can be compared on a USG per seat and fuel consumption per ASM basis. This is made possible by the results provided the CAE Flight Plan Manager.

The analysis looks at two broad groups of aircraft: the A330-300 and 777-200ER compared to the three current generation replacement options of the A330-900, A350-900, and 787-10; and the 777-300ER against the A350-1000, its only currently available replacement candidate.

285- to 322-seat aircraft

The five smaller types have 285-322 seats. This group can be divided into two sub-groups: the A330-300 and A330-900; and 777-200ER, A350-900 and 787-10.

The A330-300 was originally intended as a medium-haul aircraft, while the A340-300 which is heavier but had the same size fuselage and wing, was configured with higher weight and larger fuel volume for long-haul operations. The A330-300's MRC is slower than the other six types examined here.

Despite this, the A330-300's MTOW and fuel capacity have been increased many times since its inception, from 405,650lbs to 518,000lbs, a rise of 51 tonnes. Similarly, fuel capacity increased from 25,670USG to 36,740USG, a rise of 43%. The higher MTOW and fuel capacity are similar to the original A340-300. The A330-300 has therefore been adapted for possible long-haul operations, following the A340-300's limited sales.

The 777-200ER was aimed at the long- and ultra-long-haul market, and introduced five years after the A340-300. The 777-200ER, while having a slightly higher seat capacity than the A330-300, is structurally heavier.

The improved and more capable A330-300 is mainly aimed at long-haul routes, while the 777-200ER has always been aimed at the ultra-long-haul market, sectors with flight times of more than nine or 10 hours.

The A330-900 offers a replacement for the -300, as well as for the lower-weight 777-200. Compared to the A330-300, the A330-900 can provide an instant fuel saving and long-haul capability, but does not have any advantage in lower maintenance. The A330-900 is offered at a price that makes it a logical low-cost replacement for the A330-300.

The A330-900 has an impressive 17-20% lower fuel burn per seat than the -300 series *(see table, page 21)*, given the historical improvements in fuel burn performance between successive generations of aircraft.

Perhaps surprising is that the A330-300 only starts to experience passenger payload restrictions on LHR-CGK, with an average ESAD of 6,581nm. This shows the performance capability of the later-build variants. Moreover, this is only equal to 11 passengers lower than its 80% load factor.

The 777-200ER versus the A350-900 and 787-10 shows a large reduction in fuel burn per seat offered by the new generation types. The A350-900 consistently has a 21.6-24.0% lower fuel burn per seat than the 777-200ER. The 787-10's performance is 27.7-29.4% lower per seat than the 777-200ER *(see table, page 21)*.

The 787-10 therefore burns 5USG per seat less than the A350-900. This is equal to a lower cost per seat of $13 for the 787-10. The 787-10 benefits from being the second stretch variant of the original 787-8, while the A350-900 is the shortest A350 family member, giving it a disadvantage.

While the A350-900 and 787-10 clearly offer better technology than the 777-200ER, they also benefit from economies of scale and higher seat counts. The 787-10 further benefits from being 57,295lbs and 72,500lbs lighter than the A350-900 and 777-200ER.

The 777-200ER is also marginally slower, with 12-15-minute longer flight times than the two new-generation aircraft.

The performance of these three types in a westerly direction to LHR shows that the wind component is the same strength, but is a headwind. This adds 240nm to the tracked distance for the ESAD on LHR-SIN.

The ESAD is about 500nm longer than when operating in an easterly direction with a tailwind component. This makes flight time about 60 minutes longer than easterly operations; an increase of 7.9-8.3%. This increases each aircraft's trip fuel burn by 9.5-10.1%. This is equal to 2,000-2,700USG, or 13,400-18,000lbs.

777-300ER versus A350-1000

The 777-300ER has a 16-seat advantage over the A350-1000. Despite this, the A350-1000 demonstrates the advantage of modern technology well, with a 15-16% lower fuel burn per seat over the five routes *(see table, page 21)*.

This is equal to 7USG less per seat on the relatively short LHR-DEL, and as much as 15USG less per seat on LHR-CGK for the A350-1000. This equals a fuel cost per seat that is $18-38 per lower than the 777-300ER.

Neither aircraft type suffers payload limitations in terms of an 80% passenger load factor on the five routes that have an ESAD of up to 6,599nm.

The 777-300ER is also slower, with flight times that are 8-15 minutes longer than the A350-1000.

With the mass retirement of 747-400s, the 777-300ER became the long-haul workhorse for most airlines. The advent of the A350-1000 positions it to replace some 777-300ERs, although the 777-9X is positioned to also replace the 777-300ER. The 777-9X will be larger than the A350-1000, and so should achieve a more economic fuel burn performance. AC

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