The 777-300ER & A340-600 are pitched as 747-400 replacements. The fuel burn and operating performance of the three aircraft are examined and compared on seven routes of lengths from 4,800nm to 7,800nm. This takes each aircraft to the edge of its payload-range envelope.

777-300ER, A340-600 & 747-400 fuel burn performance

The air transport industry has waited several decades for aircraft that are capable of flying the world's longest routes non-stop. Despite the development of the 747, many of the world's city-pairs still could not be flown without a refuelling stop, and the need for longer-range aircraft continues. Several variants of the A340 and 777 were developed for longer ranges, and both Airbus and Boeing have two or more aircraft each fulfiling the need for ultra-long-haul performance, including the A340-600 and 777-300ER. These have similar standard-range capability for a full standard load of passengers. With the A340-600 and 777-300ER as main contenders to replace the 747-400, this analysis examines which of the two is the most efficient performer.

Both the A340-600 and the 777-300ER can carry additional freight payload above a full passenger load, but their fuel burn will be different. Despite being younger technology than the 747-400, the A340-600 and 777-300ER have smaller seat capacity, so they are less efficient per seat-mile. The operating and fuel burn performance of these three types is examined on some of the world's most challenging routes, in terms of mission length and ambient temperature at the departing airport.

Aircraft become challenged when they are operating at the edge of their payload-range envelopes or when they are departing from hot airports, and it is on these route lengths that aircraft performance can deteriorate. Aircraft operate with reduced payloads, and therefore generate less revenue, when operating at the edge of their payload-range envelopes, so the magnitude of the payload limitation on the longest routes is an important issue.

Range performance

Few aircraft are operated to their full range capability. In the past, an airline operating an ultra-long route had to factor in a technical stop. Since the effect of technical stops is to increase fuel consumption, total transit time, and crew and related subsistence costs, this was not ideal. An alternative was, and still is, to reduce the passenger load in order to increase the fuel carried, although this reduces revenue. Neither option is attractive, since both technical stops and reduced passenger loads make the route uneconomic.

As the range and operating performance of different types has grown, more non-stop routes have become possible, and costs have fallen. The 747-

The A340-600 has the smallest available payload limitations than the 777-300ER and 747-400. This is explained by the A340-600 having a larger payload-range envelope than the other two aircraft.

400 and A340-300 made London-Hong-Kong and other Europe-Asia Pacific and trans-Pacific airport-pairs possible as non-stop services for the first time. The longest routes, such as those between Western Europe and Australasia, or those between the Eastern US and more southern points in the Asia Pacific, still cannot be flown non-stop. The easterly direction of upper winds generally further increases the equivalent still air distances (ESAD) that aircraft have to fly when operating westwards.

The distance to suitable diversion airports when in the air is also an issue, since this affects the total amount of fuel required, and therefore the remaining weight of payload the aircraft can carry on the mission.

Some ultra-long routes do not have suitable diversion airports on part of their tracks. This is less of an issue for four-engined aircraft than for twin-engined types. The distance from the most desirable track to a suitable diversion airport could affect the track taken by a twin-engined aircraft, even though it can be certified for extended-range twin-engine operations (ETOPS). ETOPS is therefore only an issue for the 777-300ER, and not the four-engined 747-400 and A340-600.

Ultra-long-haul routes

Since a flight's tracked distance via particular waypoints will be at least 5% longer than the great circle distance, this can mean an increase in the distance flown, with a 7,000nm great circle distance quite easily rising to 7,400nm. The effect of upper winds also needs to be considered, while headwinds will further increase the tracked distance to a longer ESAD.

If an aircraft departs from, or lands at, an airport that is hot or high, its take-off and landing weights can be restricted, especially at airports with relatively short runways.

Performance limitations, such as long ESADs, high departure airport temperatures, high airfield elevations and short runways, all combine to restrict the payload and therefore the revenue-generating potential of the aircraft on the longest routes. The longer the ESAD, the more challenging the route will be for the aircraft and its payload.

Aircraft types

The A340-600 and the 777-300ER both compete directly with the 747-400. The three types have close or similar range capabilities, seat numbers and fuel burn, and these factors, together with the structural weights, determine the payload that each aircraft is able to carry on each route.

A340-600, 777-300ER & 747-400 CONFIGURATIONS

	A340-600	777-300ER	747-400
Seats			
Manufacturers 3-class	380	365	416
Average airline 3-class	302	327	369
Range average airline seat numbers	7,800	7,600	7,300
Engine option	Trent 500	GE90-115B	CF6-80C2B1F
Thrust (lbs)	56,000	115,300	58,090
Max. structural payload (lbs)	134,703	140,395	165,300
Max. fuel capacity (USG)	51,746	47,890	57,285
Weights (lbs)			
MTOW	837,756	775,000	870,000
MZFW	511,472	523,999	565,659
OEW	376,769	383,604	400,359
Belly freight capacity			
Containers	42 LD-3	44 LD-3	30 LD-1
Volume (cu ft)	6,132	6,424-7,553	5,332-6,025

SUMMARY OF OPERATING PARAMETERS FOR THE PERFORMANCE ANALYSIS

Airport	Runway	Runway length (ft)	Temperature - Av. daily highs - June (deg.C)	Airport terminal elevation(ft)
Adelaide (ADL)	05/23	10,171	16	20
Auckland (AKL)	23L/05R	11,926	14	23
Dubai (DXB)	12L/30R	13,200	38	62
	12R/30L	13,200		
Los Angeles (LAX)	06L/24R	8,925	27	126
	06R/24L	10,285		
	07L/25R	12,091		
	07R/25L	11,096		
San Francisco (SFO)	10L/28R	11,870	21	13
	10R/28L	10,602		
Sydney (SYD)	07/25	8,301	17	21
	16R/34L	12,999		
	16L/34R	7,999		
Noumea (NOU)	11/29	10,663	24	52
Perth (PER)	03/21	11,299	19	67

All the aircraft have been compared using the same routes, weather, tracks flown, and operating conditions. The objective is to identify the permitted take-off weight, actual take-off weight, total payload and the fuel used for each type on each route, in order to reveal which type is the most affected by long mission lengths at the edge of their payload-range envelopes.

Aircraft structural weights, as well as operating conditions, will determine the payload that can be carried.

The maximum take-off weight (MTOW) will define the upper limit of take-off weight. The payload-range profile determines the maximum payload and range possible with different payloads. Aircraft can require full fuel tanks and a reduction in payload so that total weight is less than the MTOW in order for the aircraft to be able to make the trip on the longest missions within their payload-range profile. Take-off weights can be restricted to below MTOW because of high temperatures or short runways. In this case the aircraft would suffer a payload limitation, meaning that payload would have to be reduced for the aircraft to complete the

The 777-300ER has the lowest fuel burn per seat-mile compared to the A340-600 and 747-400. This is explained by its higher seat capacity and twin-engined design compared to the A340-600, and more recent technology compared with the 747-400.

mission non-stop.

The MTOWs of the aircraft analysed are 837,756lbs for the A340-600, 775,000lbs for the 777-300ER, and 870,000lbs for the 747-400.

The operating empty weight (OEW) is therefore important, because a higher OEW will reduce available payload and increase fuel burn. The OEWs used are averages for each type.

OEWs for the same aircraft type vary between different operators, due to different seat and interior configurations, as well as crew numbers and items loaded on board for cabin service. The OEWs used here reflect typical weights for operators of the A340-600, 777-300ER and 747-400.

A three-class layout has been used in each case. The standard tri-class layout on an A340-600 is 380, but the average number of seats is 302 for aircraft in operation. Average configurations for the 777-300ER are 327 seats, which compares to Boeing's standard tri-class configuration of 365. The largest aircraft, the 747-400, has a standard configuration of 416, while the average airline layout is 369.

There is also a compromise to be made between the number and weight of passengers and baggage and the additional amount of belly freight that could be carried. A more spacious interior and lower seat count improves comfort standards, especially on these ultra-long-range routes, but it has the effect of reducing seat numbers and passenger payload and increasing potential belly-freight payload. OEWs may be similar, however, because of more generously proportioned seating in the larger premium cabins.

Both the 777-300ER and the A340-600 have similar maximum ranges of about 7,900nm with their standard tri-class layouts of 365 and 380 seats. The 747-400 is larger, although it has a smaller range, despite its maximum fuel capacity being greater than that of the A340 and 777.

Other than the structural weights, the other major difference between the three types is their engine options. The A340-600 is powered by four Rolls-Royce Trent 500s. The 777-300ER is powered by two GE90-115s. The 747-400 has three engine options, the most popular being the CF6-80C2B.

The maximum zero fuel weight (MZFW) for each aircraft always remains the same, and determines maximum structural payload. For the A340-600 the MZFW in this analysis is 511,472lbs. For the 777-300ER the MZFW is 523,999lbs, while the 747-400 has an MZFW of 565,659lbs *(see table, page 27)*.

Operating conditions

There are a number of areas where operational situations can affect the performance of an aircraft.

At both the departure and arrival airport the winds and temperatures can affect performance. Standard rules have been followed for the flight plan analysis with long-range cruise (LRC) and average wind and temperature figures for the month of June. These affect the ESAD, which in turn gives an indication of the fuel burn per seat-mile.

The seven routes used were selected for their increasing great circle distance so that all types would be tested at the edge of their payload-range envelopes when upper winds and the resulting ESADs are considered. These seven routes have ESADs ranging from 4,811nm to 7,796nm *(see table, page 30)*.

Dubai (DXB) was chosen as the departure point for all the flights, since its high ambient temperature at take-off will reveal any performance limitations of the aircraft. Perth (PER) is the shortest route at 4,811nm, followed by Adelaide (ADL) at 5,790nm, Sydney (SYD) at 6,347nm, and Noumea (NOU) at 6,964nm. Then there are two westbound flights to San Francisco (SFO) and Los Angeles (LAX) at 7,595nm and 7,246nm respectively. The longest route is to Auckland (AKL), which is 7,796nm. The route with the longest great circle distance is DXB-AKL at 7,668nm, but the tailwind reduces the ESAD on this route to 7,375nm. The DXB-LAX route is affected by a headwind, which gives it an ESAD of 7,796nm.

Average daily temperatures for the month of June mean that DXB is 38 degrees centigrade, while average temperature at the seven destinations varies from 14 to 27 degrees centigrade *(see table, page 27)*. The elevations of the airports vary from 13 feet to 126 feet, with SFO being the lowest and LAX being the highest.

All the routes are within the maximum ranges of the A340-600. The 777-300ER and 747-400 may have their available payloads reduced below the maximum number of passengers on the longer routes. Considering its range with standard seat numbers, the 747-400 is only capable of carrying a full passenger load on the first three routes. It can therefore be assumed that the 747-400's passenger numbers will be severely reduced on the longer routes.

Performance results

The performance results for each aircraft on each route provide a total available payload. This has been converted to passenger numbers plus

FUEL BURN & OPERATING PERFORMANCE FOR A340-600, 777-300ER & 747-400

Route	Great circle distance (nm)	Tracked distance (nm)	ESAD (nm)	Wind (kts)	Block time	Block fuel burn (USG)	Payload (lbs)	Passenger numbers	Cargo (lbs)	Fuel burn lbs per ton-mile	Fuel burn USG per seat-mile
A340-600											
DXB-PER	4,874	4,922	4,811	11	10:36	30,556	134,703	302	68,263	0.71	0.0210
DXB-ADL	5,938	5,983	5,790	16	12:36	37,603	134,703	302	68,263	0.72	0.0215
DXB-SYD	6,500	6,611	6,347	20	13:45	41,794	134,703	302	68,263	0.73	0.0218
DXB-NOU	7,044	7,080	6,964	8	14:56	46,187	129,770	302	63,330	0.77	0.0220
DXB-AKL	7,668	7,697	7,375	21	15:52	48,325	114,969	302	48,529	0.86	0.0217
DXB-SFO	7,041	7,405	7,595	-12	16:23	49,098	109,028	302	42,588	0.89	0.0214
DXB-LAX	7,246	7,588	7,796	-12	16:50	50,075	101,678	302	35,238	0.95	0.0213
777-300ER											
DXB-PER	4,874	4,922	4,814	11	10:19	29,535	140,395	327	68,455	0.66	0.0188
DXB-ADL	5,938	5,983	5,795	16	12:18	35,230	135,646	327	63,706	0.67	0.0186
DXB-SYD	6,500	6,611	6,366	19	13:28	37,928	116,556	327	44,616	0.77	0.0182
DXB-NOU	7,044	7,080	6,967	8	14:37	40,736	96,333	327	24,393	0.91	0.0179
DXB-AKL	7,668	7,697	7,396	20	15:36	42,680	83,148	327	11,208	1.04	0.0176
DXB-SFO	7,041	7,405	7,592	-12	16:07	43,380	77,518	327	5,578	1.11	0.0175
DXB-LAX	7,246	7,588	7,796	-13	16:33	44,310	70,908	322	68	1.20	0.0177
747-400											
DXB-PER	4,874	4,922	4,816	11	10:09	37,847	165,300	369	84,120	0.71	0.0213
DXB-ADL	5,938	5,983	5,798	16	12:06	45,341	142,823	369	61,643	0.82	0.0212
DXB-SYD	6,500	6,611	6,357	20	13:14	48,677	119,365	369	38,185	0.96	0.0208
DXB-NOU	7,044	7,080	6,969	8	14:24	52,111	95,332	369	14,152	1.18	0.0203
DXB-AKL	7,668	7,697	7,386	21	15:20	54,001	74,880	340	80	1.47	0.0215
DXB-SFO	7,041	7,405	7,573	-11	15:47	53,972	61,395	279	15	1.74	0.0255
DXB-LAX	7,246	7,588	7,792	-13	16:13	54,013	44,234	201	14	2.35	0.0345

their baggage, using a standard weight of 220lbs, plus a surplus that represents the possible weight of any belly freight being carried.

The two main factors in the results are the available payload and fuel burn. An airline's main concern on these long routes will be the passenger payload, since this has the higher revenue-generating potential. The real test is not just payload restrictions, but by how much the payload is reduced. The longest route by ESAD is DXB-LAX at 7,796nm. This mission length, the lengths of DXB-AKL and DXB-SFO are all long enough to have an effect on available payload.

On every route the A340-600 can carry a full load of passengers of 302, but as the ESAD increases, the additional cargo payload is gradually reduced *(see tables, this page)*. The maximum amount of additional freight the aircraft can carry over a full passenger load is 68,263lbs. The aircraft does not have any restrictions on take-off weights on any of the routes.

On DXB-LAX, which has an ESAD of 7,796nm, the aircraft can carry 380 passengers but can only carry an additional 35,238lbs of cargo. This equates to 26% of the total payload. The available payload for the A340-600 on this route is limited to 75% of its original maximum payload due to performance restrictions.

The amount of belly freight starts to reduce for ESADs longer than about 6,400nm, and declines to 35,238lbs on DXB-LAX.

While the A340-600 has a strong available payload performance, it suffers on timing, being the slowest of the three analysed aircraft *(see table, this page)*.

The 777-300ER operates at MTOW on all six routes. The 777-300ER is even affected to some extent on DXB-ADL, the shortest route at 5,795nm. It has a slightly limited payload at 135,646lbs, which is 3.4% less than the aircraft's maximum structural payload of 140,395lbs.

The 777-300ER carries its full load of 327 passengers on the first five routes, which have an ESAD of up to 7,592nm. The number of possible passengers then falls to 322 on DXB-LAX *(see table, this page)*. The 777-300ER is also affected by payload limitations on all routes, and is unable to carry a full load of passengers on routes longer than 7,400nm.

The 777-300ER's available freight payload is therefore severely restricted on all routes, except the shortest, DXB-ADL. The 777-300ER can carry a maximum of 68,455lbs above a full passenger load.

The 747-400 operates at MTOW on the second, third and fourth route, and then reaches the fuel line on its payload-range profile at about 7,100nm, and so take-off weight reduces as payload is reduced as mission length increases, while the aircraft operates with full fuel tank.

The 747-400 can carry a full passenger load on the first four routes, but its passenger-carrying ability is then severely reduced on routes longer than 7,100nm because it is operating on the fuel line part of its payload-range profile. The aircraft can only carry 201 passengers, the smallest number for the three aircraft, on DXB-LAX, which is the longest route at 7,792nm. The 747-400's available payload is just 44,234lbs, or 27% of its maximum structural payload, on this route, because it is on the edge of its payload-range envelope.

The fuel burn performance of the three aircraft is considered in terms of fuel burn per available seat mile, and US Gallons (USG) per available ton-mile (fuel used per unit of payload per mile flown). In terms of USG per ton-mile, the A340-600 is the most efficient, because its payload-range envelope means that its available payload is the least affected. The A340-600 also has more modern technology than the 747-400, so the A340 is, unsurprisingly, more efficient.

In terms of fuel burn per available seat-mile, the 777-300ER is the most efficient. This is because the 777-300ER is able to carry more passengers than the A340 on all routes.

The 777-300ER is more efficient than the 747-400, because of the 777's twin-engine design and its more modern powerplants. The 777-300ER, however, also consistently has the lowest total fuel burn on each route. AC