The belly capacity of widebody aircraft is used as a bonus to market aircraft. Consideration has to be given to range performance, passenger baggage, freight packing density and freight yields for the revenue from belly freight generating capacity to be fully assessed.

What is the value of belly freight?

Belly freight in widebody passenger aircraft is a vital revenue source. The payload-range performance of widebodies is taken into consideration during aircraft selection, including the total revenue generation from an aircraft, and how to maximise it. Belly freight, the amount of cargo that can be carried by passenger flights, can contribute significant revenue, provided that an aircraft's range and payload capacities do not become constraints.

The range of any aircraft is affected by several factors, including the maximum take-off weight (MTOW), fuel capacity and fuel efficiency of its engines, operating empty weight (OEW) and maximum zero fuel weight (MZFW). MZFW minus OEW equals gross structural payload, which is the physical limit to an aircraft's revenue earning capacity. The gross payload of all passenger aircraft is well in excess of the weight of a full passenger load, so the surplus weight capacity can be used to carry freight where additional volume is available. Aircraft with a low OEW and a high MZFW are thus desirable.

MTOW affects range, since it is the sum of OEW, payload and fuel weight. All commercial aircraft are designed for MTOW to be reached when carrying maximum payload, but less than full fuel tanks. Payload can be traded for fuel, while keeping MTOW constant, with payload reducing and fuel weight increasing.

The payload-range performance profile of an aircraft is such that the maximum range of an aircraft while carrying only a full payload of passengers is further than its range with a full gross payload. Both these range capabilities are important. The maximum range with a full load of passengers indicates the longest routes an aircraft can fly, without impacting passenger revenue. Although passenger revenue is high compared to belly freight, the maximum range with a full payload indicates which routes can be flown where revenue can be maximised.

An aircraft's performance in terms of flight time, fuel burn and payload that can be carried in both directions on each route in an airline's network is the first step in aircraft selection. Once the possible payload is known, the airline can then add the weight of passengers and baggage to assess the payload capacity that will be left on each route. Any remaining weight capacity can be filled by cargo, provided there is also sufficient volume in the belly containers.

If the aircraft is expected to encounter headwinds or has a distant alternative airport, both of which would require more fuel, payload may have to be reduced, which will have an impact on revenue from cargo. In extreme conditions a full passenger payload cannot be carried, and the number of seats available for sale has to be limited.

An aircraft with the best overall payload performance on all routes on an airline's network must be identified.

Airlines have several widebody options in four or five size classes: the 767-300ER/-400ER, 787-8/-9 and A330-200 in the smallest group; the 777-200, A330-300 and A340-300 and -500 in the next largest group; the A340-600 and 777-300 in the next largest category, with the slightly larger 747-400 in a class of its own; and then the A380 and 747-8I, although the two are different sizes.

There is also the A350XWB, although its weight specifications and payload-range performance are unclear, since the aircraft is not yet launched. The variants are expected to be similar in size and capacity to the A330-200 and A340-600.

Defining requirements

The OEW is an important consideration, since it varies by operator for the same aircraft type, according to engine type, interior seating and galley configuration, catering equipment, crew rest areas, and modifications such as in-flight entertainment (IFE). Most airlines attempt to minimise OEW, since a low OEW increases payload.

IFE can add 6,000-7,000lbs of weight to a widebody. Adding more detail to the IFE increases OEW significantly. Seats must be reinforced to handle the screen weight, making them 5-7lbs heavier, which is a lot if you have 300 economy seats. The demands from airline marketing departments for complex IFE can add several tons of weight and fuel burn, while reducing weight capacity for belly freight. Galleys and crew rests have a similar impact, with some large galley and trolley combinations weighing over 17,000lbs.

The gross payload of each aircraft in this analysis can be seen *(see table, page 35)*, along with the range and full passenger loads. While examining gross payload is a good performance benchmark, it is not a definitive answer since the problem is more complex.

First, engine selection, and the various thrust options available, affects OEW and MTOW. Airlines, based on agreements with the engine manufacturers, can choose to de-rate their engines if the thrust rating selected is sufficient to meet all performance requirements. Thrust ratings influence engine purchase prices or lease rates and maintenance costs.

Some airlines benefit from having routes in their network that are well within maximum range, and from using airports that do not limit aircraft performance. Other airlines face severe

The A330-300 and A340-300 have the highest belly freight generating capacities in the 290- to 310-seat class of widebody aircraft. This is explained by the large number of LD-3 containers they can accommodate in their underfloor compartments.

performance challenges on their networks. These variables all have to be evaluated when selecting an airframe-engine package.

Once an airline selects its aircraft, and knows the OEW when it has selected its interior configuration, the structural payload capacity can be determined.

Payload capacity

Gross payload is utilised by three main components: passengers, baggage and cargo. Passengers and their bags take priority for available payload, and airlines will always try to ensure an aircraft can carry a full passenger complement. This is not always possible, however. Cathay Pacific, for example, operates an A340-300 out of Johannesburg to Hong Kong during the southern winter, due to low seasonal demand. The A340-300 is unable to carry a full passenger and baggage load, however, so the flight is limited to a less-than-full passenger load.

While airlines usually load passengers and their bags simultaneously, baggage can be left behind if there are performance limitations.

Calculating passenger weight is a simple process, with an adult passenger allocated a standard weight of 85kg (190lbs) by the International Air Transport Association (IATA), including carry-on luggage. With a passenger load factor of 80%, the weight of baggage can vary from 32,000lbs on a 215-seat 767-300ER to 83,000lbs on a 555-seat A380.

Passengers account for 36% of a 767's net payload and 47% of an A380's net payload, so the 32,000lbs is 36% of 88,900lbs. This excludes the weight of stowed baggage, however.

Baggage is an issue of weight and volume. IATA lists the average baggage weight per passenger at 26kg or 57lbs, and each passenger checks in an average of 1.2 bags. The weight of baggage for the 172 passengers on a 767-300ER is 9,800lbs, and 25,300lbs for passengers on an A380.

A 767 with an 80% load factor will load 206 baggage items, while an A380 will load 530.

Belly freight capacity

Baggage not only consumes weight, but also volume, and this requires several loading containers. These are LD-1, LD-2 or LD-3 containers, depending on the aircraft *(see table, page 35)*.

LD-1 containers are used on the 747, weigh 270lbs, and each hold 175 cubic feet. LD-2 containers are used on the 767, and have a capacity of 124 cubic feet and a tare weight of 255lbs. LD-3 containers are used on all other widebodies, have a 146 cubic foot capacity and a tare weight of 245lbs.

The volume required by baggage depends on its density. Low-density baggage requires more container volume, reducing the remaining volume available for belly freight. 'Bulking out', or running out of space before exhausting structural payload capacity, is more common when carrying express packages. Achieving a high packing density is not easy with passenger baggage, and the volume used is critical to the volume left for freight.

The volume used for each piece of baggage is taken as an average of eight cubic feet. This means that the 767-300ER, for example, would use 1,650 cubic feet for the 206 items of baggage it would carry at an 80% load factor *(see table, page 35)*. The A380 would use 4,262 cubic feet for the 533 items of baggage it would carry.

This volume required for baggage has to be considered in terms of the number of belly containers available. An LD-2 container provides 124 cubic feet, so 14 such containers would be required for the 1,650 cubic feet needed for baggage.

This would leave 16 LD-2s available for freight, which would provide 1,984 cubic feet of capacity *(see table, page 35)*. The available payload also has to be considered. The 172 passengers and their associated baggage have a total weight of 41,968lbs. Deducted from the aircraft's net payload of 88,910lbs this would leave belly freight of 46,942lbs *(see table, page 35)*. This allows any belly freight to be packed at a maximum packing density of 23.6lbs per cubic foot, much higher than the packing density of all types of freight that are carried on a regular basis.

When the maximum packing density possible for belly freight is analysed, all aircraft clearly have a generous structural capacity. All aircraft have a maximum packing density of 18lbs to 32lbs per cubic foot *(see table, page 35)*, which indicates that they have been designed to be flexible in terms of varying passenger and belly freight loads. In all cases, however, the aircraft have surplus structural capacity, and their remaining cubic capacity should be considered. General freight is typically packed at 8lbs per cubic foot. The 767-300ER, therefore, can accommodate 15,900lbs of belly freight in the remaining 1,980 cubic feet of belly capacity it has available. Since the typical packing density of most freight types is less than the maximum packing density of the aircraft, the remaining container volume is the overriding factor in this analysis.

Widebody belly capacity

Widebody aircraft are all designed to accommodate either cargo pallets or containers. The current widebodies in operation in large numbers include the 767-300ER/-400ER, 777-200/300, 747-400, A330-200/300 and A340-300/-500/-600. The 787-8/-9, 747-8I, A350XWB and A380 are due to enter service in the next two to five years.

These are summarised, with their performance and payload specifications *(see table, page 35)*.

WIDEBODY AIRCRAFT BELLY FREIGHT CAPACITY CHARACTERISTICS

Aircraft type	767-300ER	767-400ER	787-8	787-9	A330-200
MTOWlbs	407,000	450,000	480,000	540,000	507,000
Belly containers	30 LD-2	38 LD-2	28 LD-3	36 LD-3	26 LD-3
Container volume cu ft	3,720	4,712	4,088	5,256	3,796
Gross payload lbs	96,560	101,000	100,000	124,000	104,600
Container tare weight lbs	7,650	9,690	6,860	8,820	6,370
Net payload lbs	88,910	91,310	93,140	115,180	98,230
Range with maximum payload nm	3,900	3,700	5,300	5,300	4,300
Passengers at 80% load factor	172	194	179	208	202
Remaining belly capacity cu ft	1,984	2,728	2,336	3,212	1,752
Belly freight @ 8lbs/cu ft	15,872	21,824	18,688	25,696	14,016
Freight revenue @ $0.35/lb	5,550	7,640	6,540	9,000	4,900
Incremental fuel burn-USG	870	900	1,000	1,050	570
Incremental fuel cost-$	1,740	1,800	2,000	2,100	1,140
Gross margin from freight-$	3,810	5,840	4,540	6,900	3,760

Aircraft type	777-200	777-200ER	777-200LR	A330-300	A340-300	A340-500
MTOWlbs	580,000	632,500	766,800	507,000	609,600	837,800
Belly containers	32 LD-3	32 LD-3	32 LD-3	32 LD-3	32 LD-3	30 LD-3
Container volume cu ft	4,672	4,672	4,672	4,672	4,672	4,380
Gross payload lbs	125,000	125,000	141,000	107,100	110,500	129,630
Container tare weight lbs	7,840	7,840	7,840	7,840	7,840	7,350
Net payload lbs	117,160	117,160	133,160	99,260	102,660	122,280
Range with maximum payload nm	3,200	5,300	7,400	3,600	5,600	6,600
Passengers at 80% load factor	244	244	241	236	236	236
Remaining belly capacity cu ft	2,190	2,190	2,336	2,336	2,336	2,044
Belly freight @ 8lbs/cu ft	17,520	17,520	18,688	18,688	18,688	16,352
Freight revenue @ $0.35/lb	6,150	6,150	6,550	6,550	6,550	5,700
Incremental fuel burn-USG	775	825	850	750	790	825
Incremental fuel cost-$	1,600	1,650	1,700	1,550	1,520	1,650
Gross margin from freight-$	4,550	4,500	4,850	5,000	5,030	4,050

Aircraft type	777-300	777-300ER	A340-600	747-400	747-400ER
MTOWlbs	660,000	775,000	837,600	870,000	910,000
Belly containers	44 LD-3	44 LD-3	42 LD-3	30 LD-1	30 LD-1
Container volume cu ft	6,424	6,424	6,132	5,250	5,250
Gross payload lbs	141,200	154,000	157,190	148,400	148,100
Container tare weight lbs	10,780	10,780	10,290	81,00	8,100
Net payload lbs	130,420	143,220	146,900	140,300	140,000
Range with maximum payload nm	3,600	5,500	5,700	5,100	6,200
Passengers at 80% load factor	294	296	304	320	320
Remaining belly capacity cu ft	3,504	3,504	3,212	2,100	2,100
Belly freight @ 8lbs/cu ft	28,032	28,032	25,696	16,800	16,800
Freight revenue @ $0.35/lb	9,800	9,800	9,000	5,900	5,900
Incremental fuel burn-USG	1,025	1,075	1,000	800	825
Incremental fuel cost-$	2,050	2,150	2,000	1,600	1,650
Gross margin from freight-$	7,750	7,650	7,000	4,300	4,250

The 777-300 has the highest belly freight capacity of all widebody types. This is due to the high number and volume of its belly containers in relation to the number of passengers it carries. The 777-300ER also has a long range capability with maximum payload.

A review of this data shows that the A380 has the greatest net payload of 175,690lbs, although it is the 777-200LR that has the highest available structural payload for cargo at 74,400lbs *(see table, page 35)*. However, the 777-300 and -300ER have the highest available container volume of 3,500 cubic feet, and so the highest belly freight capacities. The A340-600 has the second highest volume.

Unsurprisingly, the A380 uses the most containers for baggage, 30, leaving it with just eight LD-3s for freight. This is due to its large number of seats and the relatively small amount of belly capacity it has in relation to its size.

Widebody categories

With different aircraft types having different capacities available for belly cargo, airlines must analyse the optimal type of cargo they should carry to maximise revenue. Widebodies have been categorised into seat size groups, and the best aircraft with the highest belly freight capacity in each group can be identified.

The first is the 215- to 260-seat group, and includes the 767-300ER, 767-400ER, 787-8, 787-9 and A330-200. They all have a similar range with maximum payload of 4,000nm, with the exception of the 787-8 and -9, both of which have a range of 5,300nm.

The second group is the 290-to 310-seat range, and includes the 777-200/-200ER/-200LR, A330-300, A340-300 and A340-500. These aircraft have ranges with maximum payload that vary from 3,200nm to 7,400nm.

The third group comprises the 360- to 400-seat aircraft, which includes the A340-600, 777-300/-300ER and 747-400/-400ER. These have ranges with a maximum payload of 3,600nm to 6,200nm *(see table, page 35)*.

The final group are the ultra-large aircraft: the 747-8I and A380. These have 467 and 555 seats, and a range close to 5,600nm with a maximum payload.

Belly capacities

Aircraft within each group can be compared to determine the relative benefits of each compared to market alternatives. The passenger load factor has been set at 80% to give a comparison with a typical number of passengers.

215- to 260-seats

The 215- to 260-seat group varies in capacity *(see table, page 35)*. Of the current generation aircraft in this group, the A330-200 has the highest available structural payload of 48,800lbs, but has the smallest remaining container volume. The 767-300ER has 200 cubic feet more space, so it can carry more freight at a packing density of 8lbs per cubic foot *(see table, page 35)*. This is a capacity of 15,872lbs, compared to 14,016lbs for the A330-200.

The 767-400ER has the largest volume, at 2,730 cubic feet, allowing it to carry about 21,800lbs of belly freight *(see table, page 35)*. This is up to 3,700nm.

The 787-8 and -9 have an advantage over their closest sized rivals. The 787-8 has 2,336 cubic feet of capacity, 350 cubic feet more than the 767-300ER. This will give the 787-8 2,800lbs more belly freight, which will be combined with a 1,400nm longer range.

The 787-9 has 3,200 cubic feet of remaining volume, which is 1,500 more than the A330-200. This gives the 787-9 a payload of about 25,696lbs, 11,600lbs more weight capacity, as well as 1,100nm longer range capability.

290- to 310-seats

The 290- to 310-seat group actually provides similar, and in many cases, less container volume available for freight compared to aircraft in the 215- to 260-seat category *(see table, page 35)*.

The 777-200LR, A330-300 and A340-300 have the highest available volumes, and are all equal at 2,336 cubic feet *(see table, page 35)*. This provides 18,688lbs of belly freight capacity when packed at 8lbs per cubic foot. This is less than that offered by the 767-400ER and 787-9.

The 777-200/200ER have a similar volume, and differ from the -200LR only because of a small variation in seat numbers. These are based on Boeing's standard configurations, whereas most -200LR operators actually use fewer than 301 seats in most cases. Fewer seats will increase the -200LR's container volume left for belly freight. The -200LR is also the winner in terms of range, which is 7,400nm with a full payload, and the longest of all aircraft types.

The A340-500 is a disappointment, with the smallest volume for freight. This gives it the lowest weight of 16,352lbs *(see table, page 35)*.

There are, however, few 777-200LRs and A340-500s in service or on order.

This leaves the competition mainly to the 777-200ER, A330-300 and A340-300. The A330-300 and A340-300 have the advantage of capacity, and the A340-300 also has the longest range with maximum payload, making it the most prolific aircraft in this group.

360- to 400-seats

The widebodies in this group have the highest surplus capacities *(see table, page 35)*. The 777-300, 777-300ER and A340-600 have 3,200-3,500 cubic feet available, providing them with 26,000-28,000lbs of capacity for belly freight.

These modern generation aircraft compare well with the 747-400/-400ER, which have only 2,100 cubic feet. This is similar to the 767-300ER. The 747 has a lower total containerised volume, while the 777-300 and A340-600 have a larger number of containers because of their fuselage lengths. The 747-400/-400ER carry 16,800lbs of belly freight in addition to their full passenger loads.

The 777-300ER and A340-600 also have longer ranges with a maximum payload, compared to the 747-400. The 777-300ER has the highest remaining belly freight payload of all aircraft, but there are few in operation or on order. The 777-300 has the same weight capacity, but a shorter range of 3,600nm. The 777-300's capacity advantage over the A340-600 is 2,300lbs. The A340-600 does, however, have a long-range capability of 5,700nm.

747-8I & A380

The 460+ seat market has the 467-seat 747-8I and the 555-seat A380, which have long-range capabilities with a maximum payload, allowing them to generate additional revenue on a large number of city-pairs. Preliminary data for the 747-8I indicates it has a 600nm advantage over the A380.

The 747-8I also has the larger available belly freight volume, although this is just 1,925 cubic feet, which is similar to the 767-300ER. This gives it a weight capacity of 15,400lbs *(see table, this page)*.

The A380's design and requirement for large main undercarriage wells means it carries relatively few containers, and because of its large number of seats only has 1,168 cubic feet available for freight. This gives it a capacity of 9,344lbs, the lowest of all widebody aircraft.

ULTRA LARGE WIDEBODY AIRCRAFT BELLY FREIGHT CAPACITY CHARACTERISTICS

Aircraft type	747-8I	A380
MTOWlbs	970,000	1,300,000
Belly containers	32 LD-1	38 LD-1
Container volume cu ft	5,600	5,548
Gross payload lbs	168,300	185,000
Container tare weight lbs	8,640	9,310
Net payload lbs	159,660	175,690
Range with maximum payload nm	6,200	5,600
Passengers at 80% load factor	374	444
Remaining belly capacity cu ft	1,925	1,168
Belly freight @ 8lbs/cu ft	15,400	9,344
Freight revenue @ $0.35/lb	5,400	3,250
Incremental fuel burn-USG	850	950
Incremental fuel cost-$	1,700	1,900
Gross margin from freight-$	3,700	1,350

Cargo revenue

The revenue generated from belly freight is a function of the net yield an airline can gain for the freight, less the incremental fuel cost that arises on account of the extra weight.

While the amount of additional fuel burnt to carry the extra weight will be relatively small, fuel prices are high and belly freight yields are generally low.

Passenger airlines can aim for three broad types of belly freight: express packages of less than 10lbs in weight; express packages heavier than 10lbs; and general freight. Small express packages offer the highest yields.

While express packages may be desirable, contracts with the major express package consolidators are limited and are only available to a few carriers.

Belly freight yields vary widely by region, but are generally charged on a per-weight basis. In the US, for example, domestic yields are low because of the large number of passenger flights and available cargo capacity. Some long-haul markets, such as Europe-Asia Pacific routes, have limited capacity because of a small number of flights and the length of routes, although the number of dedicated freight services is growing. Yields are higher on these routes than in the US.

"Selecting the optimal cargo type is a difficult analysis," says George Smith, vice president of the transport planning group. "You constantly have to balance the trade-off between weight, fuel burn and cargo capacity to determine what type of cargo is worth carrying. Cargo yields vary significantly between routes and markets, and an airline really must know what the additional weight will do to the fuel burn before accepting. As a rule, airlines have preferred non-bulky items as they weigh the least, cost the least to transport, and have higher yields."

General belly freight that is not time-sensitive averages a net yield in the region of $0.35 per lb. However, the yields can vary significantly by route and season.

The revenue that can be generated by additional belly freight is summarised *(see tables, pages 35 & this page)*, and is in proportion with the weight of belly freight they can carry.

This additional revenue has to be considered against the incremental fuel the aircraft burns, as well as other costs of marketing and handling, and the effects of additional turn time the aircraft may experience between flights.

A sample route can be used to illustrate the effects of increased fuel burn on most types. London Heathrow-Chicago has a tracked distance of 3,900nm, and is within the maximum payload range capability of most widebodies, with the exception of the lower gross weight variants of the 777-200 and the A330-300.

The 767-300ER will burn 900USG more by carrying the additional belly freight shown *(see table, page 35)*. This will incur an incremental fuel cost of about $1,800, and still allow a gross margin close to $3,800. The A330-200 has similar performance.

The 777-200, A340-300 and A340-500 will burn 500-900USG more, and overall generate gross margins of $4,500-5,000 from the additional belly freight, provided the yield of $0.35 per lb is realised *(see table, page 35)*.

The 777-300/-300ER will generate up to $7,600 from the belly freight it carries, while the A340-600's slightly lower performance is a gross margin of $7,000 and the 747-400 about $4,300 *(see table, page 35)*. The 747-8I will generate about $3,700, and the A380 about $1,300 *(see table, this page)*.

Summary

Overall, it has been demonstrated that airlines can add cargo and generate incremental revenue from its inclusion. While most aircraft only generate $4,000-6,000 per trip, this has to be considered against the average passenger yields on many routes, which are often only $200-300 on a one-way basis. The incremental revenue from freight can make a worthwhile contribution to trip costs and overheads. However, other factors such as increased handling costs, and various cost of sales related to belly freight, can reduce the benefit to nil. Moreover, these incremental revenues are not possible when route lengths exceed the aircraft's range with maximum payload. AC