The 747-8 has proved most popular as a freighter. It has a larger payload capacity than the -400F. The payload capacity, and fuel burn and operating performance of the 747-8F is compared with four variants of the 747-400 freighter on long-haul missions.

Payload and fuel burn comparison of 747-400 & 747-8F

The 747-8 has proven popular as a freighter. As of July 2013, 36 747-8Fs had been delivered, accounting for more than 80% of the 747-8s in service.

The 747-8F's main competitor in the very large freighter market is its predecessor, the 747-400, which is available as a factory-built freighter, the -400F/-400ERF, and as a conversion. *Aircraft Commerce* has analysed and compared key aircraft selection criteria for 747-400 and 747-8 freighters, including aircraft acquisition costs, weight and payload characteristics, range capability, and fuel burn performance.

Weight & characteristics

There are four 747-400 freighter variants. Two are factory-freighters: the -400F and the longer range -400ERF. There are also two passenger-to-freighter conversion programmes, offered by Boeing and IAI Bedek. Boeing-converted aircraft are given the designation -400BCF, while those modified by IAI Bedek are the -400BDSF. Both passenger and combi 747-400s can be converted.

There are three engine options for 747-400s: the General Electric (GE) CF6-80C2; the Pratt & Whitney (P&W) PW4000-94; and the Rolls Royce RB211-524G/H. There are a number of different variants within each engine family, which can offer different levels of thrust.

In general, aircraft with CF6- and PW4056 engines have lower hull weights than those with RB211 engines, a difference of up to 2,000lbs. The potential advantage in gross payload makes CF6- and PW4056-powered aircraft the most attractive candidates for freight conversion.

This analysis will focus on GE-powered 747-400s, since they represent more than half of the active freighter fleet of this aircraft type. GE is the sole engine provider for the 747-8F.

The 747-400 combi is also a good candidate for conversion. It can hold a mix of passengers and freight on the main deck. Since it already has a main deck cargo door and a strengthened floor and cargo loading system in the rear, it is cheaper to modify to a full-freight configuration than passenger variants.

747-400F

The 747-400F has the same dimensions as the passenger variant with the exception of the upper deck. On the 747-400F the upper deck is not stretched, and is the same length as on the 747-200. The ceiling height of the forward section of the main deck immediately below the upper deck is restricted to a maximum height of 96 inches. The main section of the main deck, unrestricted by a second floor level, has a higher maximum height of 120 inches, so the shorter upper deck increases the freight payload capacity.

The 747-400F has two freight doors, one in the nose and the other on the rear port side of the fuselage. The nose-hinge door allows faster loading and unloading of freight, and the loading of longer containers or unit load devices (ULDs) or pallets than would be possible through the side door. These can be 30-40 feet in

747-400F/-400ERF/-400BCF/-400BDSF & 747-8F SPECIFICATION WEIGHTS

Aircraft Converted		747-400BCF Basic	747-400BDSF Basic	747-400BDSF Max-range
MTOW-lbs		870,000	870,000	875,000
MZFW-lbs		610,000	610,000	610,000
MLW-lbs		652,000	652,000	652,000
Usable fuel-USG		53,765	53,765	53,765
Range-nm		4,100	4,100	4,400
Aircraft Factory Freighters	**747-400F Basic**	**747-400F Max-range**	**747-400ERF Basic**	**747-8F Basic**
MTOW-lbs	800,000	875,000	910,000	987,000
MZFW-lbs	610,000	610,000	611,000	726,800
MLW-lbs	652,000	652,000	653,000	763,000
Usable fuel-USG	53,765	53,765	53,765	59,734
Range-nm	3,190	4,455	4,980	4,120

ULDS & PALLETS FOR USE ON 747 FREIGHTERS

Main deck devices	M1H ULD	M1 ULD	PMC Pallet	PMC Pallet
Base width-inches	96	96	96	96
Base depth-inches	125	125	125	125
Profile	Contoured	Square	Contoured	Square
Maximum height-inches	118	96	118	96
Volume-cubic feet	759	618	745	560
Tare weight-lbs	672	606	375	375

Lower deck devices	LD-1 ULD	LD-29 ULD	LD-7 Pallet
Profile	Half-width winged	Full-width winged	Full-width winged
Top width-inches	92	186	160
Bottom width-inches	61.5	125	125
Height-inches	64	64	64
Depth-inches	60.4	88	88
Volume-cubic feet	175	510	495
Tare weight-lbs	180	584	375

length. Its main restriction is the lower ceiling height at the front section of the main deck, which means that containers and pallets loaded through the nose are limited to 96 inches in height.

The side cargo door permits the loading of containers that make full use of the 120-inch height of the main section of the main deck. Containers or pallets that can be loaded through the side door are limited to a length of 20 feet.

There are a number of different weight specifications for the 747-400F. The basic model has a maximum take-off weight (MTOW) of 800,000lbs, a maximum landing weight (MLW) of 652,000lbs and a maximum zero fuel weight (MZFW) of 610,000lbs.

When fitted with CF6- engines, typical operating empty weight (OEW) excluding tare weight, is 348,900lbs leading to a gross structural payload of 261,100lbs. OEW varies by operator and individual aircraft. Those used in this analysis are designed to represent an accurate example. The basic variant can carry a full payload up to 3,190 nautical miles (nm).

Most in-service 747-400Fs maintain the same MLW, MZFW, OEW and gross structural payload as the basic variant, but have an increased MTOW. The most popular MTOW is 875,000lbs. This provides the optimum range for the 747-400F, allowing it to carry a full payload up to 4,455 nm *(see table, page 57)*.

The weight specifications of the 747-400F can also be altered to optimise payload-carrying capacity. It is possible to increase the MZFW to 635,000lbs, which requires the MLW to be increased to 666,000lbs. When the MZFW exceeds 610,000lbs there is an operating restriction related to MTOW. The MTOW reduces linearly from 875,000lbs to 811,000lbs, in relation to an MZFW increase from 610,000lbs to 635,000lbs. With an MZFW of 635,000lbs the 747-400F can carry 25,000lbs more payload than the basic and maximum range specifications, but only up to distances of 2,825nm. Fuel capacity for all 747-400F specifications is 53,765 US gallons (USG).

747-400ERF

The 747-400ERF is identical to the 747-400F, except that it has higher weights to increase range. The basic model has an MTOW of 910,000lbs, an MLW of 653,000lbs and an MZFW of 611,000lbs. With CF6- engines, typical OEW would be about 349,600lbs, leading to a gross payload of 261,400lbs.

A GE-powered 747-400ERF has a fuel capacity of 53,765 USG. The basic 747-400ERF can carry a full payload up to 4,980nm.

The 747-400ERF's MZFW can also be increased to carry additional payload, resulting in similar MTOW and range limitations as described for the 747-400F.

747-400BCF

A 747-400BCF retains the extended upper deck it was built with for its initial passenger role. It is fitted with a side loading cargo door in the same position and of the same dimensions as that on the factory freighters. Unlike the purpose-built aircraft, there is no nose-hinge door.

There is one main weight specification for the 747-400BDSF. It has an MTOW of 870,000lbs, an MLW of 652,000lbs and an MZFW of 610,000lbs. Typical OEW is 360,640lbs providing a gross payload of 249,360lbs. Fuel capacity for a CF6-powered aircraft is 53,765USG. With a full payload the 747-400BCF has a range of 4,100nm.

747-400BDSF

The 747-400BDSF is essentially structurally identical to the 747-400BCF, with the same upper deck and cargo door configuration. The internal dimensions offered by both conversion programmes are the same.

There are currently two different weight specifications for the 747-400BDSF. A third is being developed.

The first 747-400BDSF variant has an MTOW of 870,000lbs, an MLW of 652,000lbs and an MZFW of 610,000lbs. Typical OEW for a GE-powered aircraft is 357,000lbs, leading to a gross payload of 253,000lbs. With a full payload this aircraft has a range of 4,100nm. The second available variant has the same specifications, but with a higher MTOW of 875,000lbs. This can uplift more fuel so it has greater range of 4,400nm with a maximum payload.

The third 747-400BDSF specification is being developed. Its focus is to provide a higher payload over shorter distances. The MZFW will increase to 635,000lbs, while the increase in payload will be traded for a lower MTOW of 811,000lbs and a reduced range of 3,200nm.

747-8F

The 747-8 series has a new, larger wing, higher thrust-rated engines, and a longer fuselage than the 747-400. The latest 747 variant has been extended by 220 inches in length due to fuselage plug insertions fore and aft of the wing. The only engine option for the 747-8 is the GEnx-2B67 family.

Unlike the Intercontinental passenger variant, the factory-built 747-8F has a shortened upper deck to maximise its main deck freight payload. Like its predecessors the 747-400F and 747-400ERF, the 747-8F has both a nose-hinge and side loading cargo door.

The standard 747-8F has an MTOW of 987,000lbs, an MLW of 763,000lbs, and an MZFW of 726,800lbs. A typical in-service OEW is 427,590lbs, leading to a gross payload of 299,210lbs. The aircraft has a maximum fuel capacity of 59,734USG and can carry a full payload up to 4,120nm.

747-400F/-400ERF/-400BCF/-400BDSF & 747-8F LOADING CONFIGURATIONS & PAYLOAD CAPACITIES

Aircraft type	747-400BCF/ 747-400BDSF	747-400F/ -400ERF	747-8F
Main deck configurations			
Option 1:			
-M1H ULDs	21	23	27
-M1	7	5	5
-Igloo ULD	2	2	2
Total volume-cu ft	21,412	21,694	24,730
Tare weight-lbs	19,554	19,686	22,375
Option 2:			
-PMC pallets-contoured	21	23	27
-PMC pallets-square	7	5	5
-Igloo pallet	2	2	2
Total volume-cu ft	20,445	20,815	23,795
Tare weight-lbs	11,200	11,200	12,700
Lower deck configurations			
Option 1:			
-LD-1 ULDs	32	32	38
Total volume-cu ft	5,600	5,600	6,650
Total tare weight-lbs	5,760	5,760	6,840
Option 2:			
-LD-29 ULDs	9	9	12
-LD-1 ULDs	4	4	2
Total volume-cu ft	5,290	5,290	6,470
Tare weight-lbs	5,976	5,976	7,368
Option 3:			
-LD-7 pallets	9	9	12
-LD-1 ULDs	4	4	2
Total volume-cu ft	5,155	5,155	6,290
Tare weight-lbs	4,095	4,095	4,860

There is an option to increase the 747-8F's MLW to 773,000lbs and its MZFW to 737,000lbs. This would increase payload but reduce range.

Payload configuration

There are two main classifications for air cargo: express package freight and general freight. This type of freight is normally packed in ULDs or containers, at a typical packing density of 7.0lbs per cu ft. General freight items are bulkier and often carried on lighter pallets, with higher packing densities, such as 8.0lbs per cu ft.

Factory-built and converted 747 freighters carry payload on the main deck and in the belly compartment or lower deck. There is a range of ULDs and pallets available, leading to a number of potential freight loading configurations.

Some of the main upper and lower deck ULD and pallet options for 747 freighters are listed *(see table, this page)*. The tare weight and volume specifications quoted offer a realistic example, but these can vary with manufacturer. A selection of potential freight-loading configurations is described *(see table, this page)*.

The net structural payload, cubic capacity, packing density and net rate per lb or kg of freight affect an aircraft's revenue-generating capacity. The aircraft's net structural payload is calculated by deducting the tare weight of ULDs or pallets from its gross structural payload.

In general, ULDs offer a greater cubic capacity but have higher tare weights than pallets of similar dimensions. Using pallets can lead to higher net structural payloads but lower cubic capacity.

The volumetric payload is calculated by multiplying available volume by packing density, and is the best indicator of the physical payload that can be carried.

The potential use of M2 ULDs has been disregarded in this analysis. These containers are 20 feet long and 96 inches high. They provide a high tare weight for a relatively low volume. This makes an M2 configuration less than optimal.

The total volume, net structural payload, maximum packing density and volumetric payload for some of the most popular 747-400 freighter and 747-8F weight specifications are compared *(see table, this page)*. Two freight-loading configurations have been analysed. The first offers the highest available volume, and the second the lowest tare weight.

747-400BCF/-400BDSF

The converted freighter options offer the same internal dimensions. The longer section of main deck, unrestricted by an upper deck, runs from fuselage station 903 to the rear of the aircraft. To maximise cubic capacity, this section can be loaded with 21 M1H ULDs. These are loaded as 10 pairs with a single container at the rear. A further seven M1 ULDs can be positioned in the front section of the main deck, with another two contoured ULDs loaded up to the nose.

In addition to the containers listed *(see table, this page)*, the contouring of the 747's fuselage at the nose requires two ULDs or pallets with different profiles to be loaded in tandem at the very front of the main deck. They will have a base width of 125 inches and depth of 96 inches. Two ULDs in this position could have a combined cubic capacity of 1,147 cu ft and a tare weight of 1,200lbs. Two pallets in the same position might provide a combined volume of 880 cu ft with a tare weight of 700lbs. These specifications are subject to variation by manufacturer.

In the lower deck, LD-1 ULDs provide the most volume. The converted 747-400s can hold 32 of these in 16 pairs. This high-volume configuration gives a cubic capacity of 27,012 cu ft and an associated tare weight of 25,314lbs.

In this configuration the 747-400BCF offers a net structural payload of 224,046lbs. The higher OEW of the two 747-400BDSF specifications means that it offers a slightly higher net structural payload, compared to the -400BCF, of 227,686lbs. If the ULDs were packed at a density of 7.0lbs per cu ft, all three converted freighter options would have a volumetric payload of 189,084lbs per cu ft.

The low tare weight configuration

747-400F/-400ERF/-400BCF/-400BDSF & 747-8 FREIGHTER PAYLOAD CAPACITIES

Aircraft type	747-400BCF Basic	747-400BDSF Basic	747-400BDSF Max range	747-400F Max range	747-400ERF Basic	747-8F Basic
MTOW-lbs	870,000	870,000	875,000	875,000	910,000	987,000
MLW-lbs	652,000	652,000	652,000	652,000	653,000	763,000
MZFW-lbs	610,000	610,000	610,000	610,000	611,000	726,800
OEW-lbs	360,640	357,000	357,000	348,900	349,600	427,590
Gross structural payload-lbs	249,360	253,000	253,000	261,100	261,400	299,210
Freight configurations						
Option 1: highest volume						
Main deck with M1H ULDs						
-Total volume-cu ft	21,412	21,412	21,412	21,694	21,694	24,730
-Tare weight-lbs	19,554	19,554	19,554	19,686	19,686	22,374
Lower deck with LD-1 ULDs						
-Total volume-cu ft	5,600	5,600	5,600	5,600	5,600	6,650
-Tare weight-lbs	5,760	5,760	5,760	5,760	5,760	6,840
Total volume-cu ft	27,012	27,012	27,012	27,294	27,294	31,380
Total tare weight-lbs	25,314	25,314	25,314	25,446	25,446	29,214
Net structural payload-lbs	224,046	227,686	227,686	235,654	235,954	269,996
Maximum packing density -lbs per cu ft	8.3	8.4	8.4	8.6	8.6	8.6
Volumetric payload @ 7.0lbs per cu ft	189,084	189,084	189,084	191,058	191,058	219,660
Option 2 lowest tare weight-lbs						
Main deck with PMC pallets at 118 inches						
-Total volume-cu ft	20,445	20,445	20,445	20,815	20,815	23,795
-Tare weight-lbs	11,200	11,200	11,200	11,200	11,200	12,700
Lower deck with LD-7 pallets						
-Total volume-cu ft	5,155	5,155	5,155	5,155	5,155	6,290
-Tare weight-lbs	4,095	4,095	4,095	4,095	4,095	4,860
Total volume-cu ft	25,600	25,600	25,600	25,970	25,970	30,085
Total tare-lbs	15,295	15,295	15,295	15,295	15,295	17,560
Net structural payload-lbs	234,065	237,705	237,705	245,805	246,105	281,650
Maximum packing density -lbs per cu ft	9.1	9.3	9.3	9.5	9.5	9.4
Volumetric payload @ 8.0lbs per cu ft	204,800	204,800	204,800	207,760	207,760	240,680

involves loading 21 PMC pallets in the main section of the main deck. These are stacked in a contoured fashion to a maximum height of 118 inches and have base dimensions of 96- by 125- inches. They are loaded as 10 pairs, with a single pallet at the rear. In the front section of the main deck seven square-profiled PMC pallets can be loaded behind the two specially contoured pallets positioned at the very front.

In the lower deck, the lowest tare weight is achieved by loading five LD-7 pallets and two LD-1s in the forward hold, and a further four LD-7s pallets and two LD-1s in the rear hold.

The low tare weight configuration offers a cubic capacity of 25,600lbs and a tare weight of 15,295lbs.

In this arrangement the 747-400BCF offers a net structural payload of 234,065lbs, compared to 237,707lbs for the two 747-400BDSF options. If the pallets are packed at a density of 8.0lbs per cu ft, all three of the converted freighters would have a volumetric payload of 204,800lbs per cu ft. This is because they have the same volume.

747-400F/ -400ERF

The 747-400F and 747-400ERF have a shorter upper deck than converted freighters. The section of main deck with its height unrestricted by the second deck floor, runs from fuselage station 777 to the rear of the aircraft. To maximise cubic capacity, the factory-built freighters can hold 23 M1H ULDs arranged in 11 pairs, plus a single container at the rear. In the front section of the main deck five M1 ULDs can be positioned, plus two contoured containers. The seven lower

OPERATING PERFORMANCE OF 747 FREIGHTERS

City-pair	Aircraft variant	MTOW lbs	Actual TOW lbs	Max payload lbs	Available payload lbs	ESAD nm	Block time	Block fuel USG	Fuel burn USG per ATM	Fuel cost $ per ATM
SIN-SYD	747-8F	987,000	942,276	299,210	297,038	3,273	07:09	27,098	0.0624	0.2060
	747-400F	875,000	818,317	261,100	261,100	3,261	07:06	25,614	0.0674	0.2224
	747-400ERF	910,000	819,662	261,400	261,400	3,261	07:06	25,661	0.0674	0.2225
	747-400BDSF	875,000	820,620	253,000	253,000	3,262	07:04	26,361	0.0715	0.2361
	747-400BCF	870,000	820,619	249,360	249,360	3,262	07:04	26,360	0.0726	0.2396
PVG-ORD	747-8F	987,000	986,976	299,210	195,870	6,263	13:04	48,069	0.0878	0.2896
	747-400ERF	910,000	880,122	261,400	177,363	6,263	13:02	46,623	0.0940	0.3103
	747-400F	875,000	874,970	261,100	174,729	6,263	13:02	46,377	0.0949	0.3133
	747-400BDSF	875,000	874,988	253,000	161,820	6,266	12:55	47,445	0.1048	0.3459
	747-400BCF	870,000	869,977	249,360	155,038	6,266	12:55	47,192	0.1088	0.3591
PVG-ANC	747-8F	987,000	970,765	299,210	299,210	3,831	08:11	31,795	0.0621	0.2050
	747-400ERF	910,000	847,578	261,400	261,400	3,831	08:09	30,520	0.0683	0.2253
	747-400F	875,000	846,329	261,100	261,100	3,831	08:09	30,489	0.0683	0.2253
	747-400BDSF	875,000	849,071	253,00	253,000	3,833	08:05	31,302	0.0723	0.2386
	747-400BCF	870,000	849,068	249,360	249,360	3,833	08:05	31,301	0.0734	0.2421
ANC-ORD	747-8F	987,000	886,366	299,210	299,210	2,442	05:28	19,506	0.0598	0.1973
	747-400ERF	910,000	764,443	261,400	261,400	2,443	05:26	18,635	0.0654	0.2157
	747-400F	875,000	763,278	261,100	261,100	2,443	05:26	18,614	0.0654	0.2157
	747-400BDSF	875,000	762,999	253,000	253,000	2,443	05:23	18,978	0.0688	0.2270
	747-400BCF	870,000	762,999	249,360	249,360	2,443	05:23	18,978	0.0698	0.2303
SIN-LHR	747-8F	987,000	987,000	299,210	200,481	6,114	12:34	47,776	0.0873	0.2881
	747-400ERF	910,000	880,235	261,400	181,531	6,113	12:32	46,327	0.0935	0.3086
	747-400F	875,000	874,999	261,100	178,674	6,113	12:32	46,098	0.0945	0.3120
	747-400BDSF	875,000	869,013	253,000	166,217	6,112	12:26	46,542	0.1026	0.3386
	747-400BCF	870,000	869,019	249,360	162,574	6,112	12:26	46,543	0.1049	0.3462
SIN-DXB	747-8F	987,000	925,503	299,210	299,210	3,076	06:38	25,188	0.0613	0.2023
	747-400ERF	910,000	797,717	261,400	261,400	3,064	06:36	23,587	0.0660	0.2177
	747-400F	875,000	796,404	261,100	261,100	3,057	06:37	23,543	0.0661	0.2180
	747-400BDSF	875,000	798,677	253,000	253,000	3,065	06:33	24,269	0.0701	0.2314
	747-400BCF	870,000	798,674	249,360	249,360	3,065	06:33	24,269	0.0711	0.2347
DXB-LHR	747-8F	987,000	933,430	299,210	299,210	3,169	06:48	26,460	0.0625	0.2063
	747-400ERF	910,000	808,796	261,400	261,400	3,168	06:45	25,127	0.0680	0.2243
	747-400F	875,000	807,576	261,100	261,100	3,168	06:45	25,101	0.0680	0.2243
	747-400BDSF	875,000	810,033	253,000	253,000	3,167	06:42	25,849	0.0723	0.2385
	747-400BCF	870,000	810,033	249,360	249,360	3,167	06:42	25,849	0.0733	0.2420

height containers can be loaded through the nose door.

The factory-built freighters have the same lower deck space as conversions. For the highest cubic capacity scenario this means that 32 LD-1s are arranged in 16 pairs.

The high volume arrangement gives a total cubic capacity of 27,294lbs and a tare weight of 25,446lbs. The optimum range specifications of the 747-400F and 747-400ERF have respective net structural payloads of 235,654lbs and 235,954lbs in this configuration. They both have a volumetric capacity of 191,058lbs at a packing density of 7.0lbs per cu ft. This is about 2,000lbs more than the converted freighters.

In the lowest tare weight set up, the factory-freighters can accommodate 25 contoured PMC pallets in the main section of the main deck. Five square profile pallets and the two smaller pallets at the front can be positioned in the forward section of the main deck.

The same combination of LD-7s and LD-1s can be used in the lower deck, as demonstrated on the converted aircraft.

The low tare weight scenario provides a total cubic capacity of 25,970lbs and a tare weight of 15,295lbs. The 747-400F would have a net structural payload of 245,805lbs in this configuration compared to 246,105lbs for the 747-400ERF. The factory-built freighters would have a volumetric capacity of 207,760lbs at a general freight packing density of 8.0lbs per cu ft, 3,000lbs more than the converted aircraft.

747-8F

The 747-8F can hold 27 M1H ULDs in the main section of its main deck, with 13 pairs and an individual unit at the rear. In the front section, five M1 ULDs sit behind the two smaller contoured containers.

When combined with 38 LD-1s in the lower deck, this loading configuration represents the highest cubic capacity option of 31,380 cu ft, with a tare weight of 29,214lbs. In this arrangement the basic 747-8F would have a net structural payload of 269,996lbs. At a packing density of 7.0lbs per cu ft the aircraft would have a volumetric payload of 219,660lbs. Compared to the 747-400 freighter specifications *(see table, page 61)* this is 30,500lbs more than converted aircraft and 28,500lbs more than the factory-freighters.

In the lowest tare weight configuration the 747-8F can hold 27 contoured PMC pallets in the main section of its main deck. Another five

The 747-400 freighter can now be acquired in a number of ways. Factory-built freighters are no longer manufactured, but used aircraft can be acquired in the market. There are also passenger-to-freighter conversion programmes available from Boeing and Bedek Aviation.

square profile pallets can be stacked in the front section plus the two smaller units in the nose.

In the lower deck the lowest tare weight is achieved by using 12 LD-7 pallets and two LD-1 containers.

The total cubic capacity offered in the low tare weight scenario is 30,085 cu ft with a tare weight of 17,560lbs. The basic 747-8F would have a net structural payload of 281,650lbs in this configuration. It would have a volumetric payload of 240,680lbs at a packing density of 8.0lbs per cu ft. This is about 36,000lbs more than the 747-400BCF and 747-400BDSF, and 33,000lbs more than the 747-400F and 747-400ERF.

Fuel burn performance

The fuel burn performance of the 747-8F is compared to that of the four main 747-400 freighter variants on a number of typical city-pairs.

The analysed aircraft are the basic specifications of the 747-400BCF, 747-400ER and 747-8F and the maximum range specifications of the 747-400BDSF and 747-400F. These offer the best range performance of each designation.

The converted freighters have CF6-80C21B1F engines while the two 747-400F have CF6-80C2B5F powerplants, although most in service have -B1F engines. The 747-8F has GEnx-SB67 engines.

The flight planning system did not contain the 747-400BDSF or 747-400ERF. As these are structurally the same as the 747-400BCF and 747-400F respectively, weights were altered for these aircraft to accurately simulate the performance of the missing derivatives.

The flight plans were based on international flight rules, average temperatures for July and 85% reliability winds. Standard assumptions are made for reserve, diversion and contingency fuel. The flight levels and routes offering the shortest flight time were selected. All airway rules and restrictions are complied with. A taxi time of 20 minutes per sector is assumed. Taxi fuel burn is based on all-engine taxi. Aircraft are operated at typical cruise speeds: Mach 0.85 for the 747-400F, 747-400ERF and 747-8F; and Mach 0.86 for the two conversions.

Routes in three key freight markets have been analysed: intra-Asia; Asia Pacific to North America; and Asia Pacific to Europe.

Some of the world's longest air freight routes involve transporting manufactured goods from the Asia Pacific to North America and Europe. There are often demand imbalances, with freight loads higher departing the Asia Pacific and lighter on the return leg. Many of these routes are longer than 5,000nm, and some are in excess of 6,000nm. Operators of longer routes can either sacrifice payload to operate non-stop, or select a stopover point to refuel and potentially take on additional freight.

The intra-Asia route selected is Singapore (SIN) – Sydney (SYD). With an equivalent still air distance (ESAD) of 3,261–3273nm *(see table, page 62)*, only the 747-8F has a minor payload restriction. The ESAD indicates the effective distance flown by accounting for en-route winds in addition to the tracked distance, which is determined by air traffic control and airways restrictions. The ESAD will increase with headwinds and decrease with tailwinds.

The Asia Pacific–North America route chosen is Shanghai (PVG) – Chicago (ORD). The ESAD on this route is 6,263–6266nm *(see table, page 62)*. Performance was analysed on a non-stop basis, as well as operating via Anchorage (ANC).

The Asia Pacific–Europe route selected is SIN–London Heathrow (LHR). The ESAD on this city-pair is 6,112–6,114nm. Performance was looked at on a direct basis and via Dubai (DXB).

The available payload, block fuel, block time, and fuel burn per ton-mile are listed for each aircraft on each sector *(see table, page 62)*. The fuel cost per ton-mile was also calculated, based on an assumed fuel price of $3.30 per USG.

The 747-8F burns the most fuel of all of the aircraft in each scenario, because it is larger and is carrying a greater payload than the various 747-400 derivatives. A more accurate way to consider freight aircraft's performance is to compare its fuel burn per available ton-mile (ATM).

When the additional payload-carrying capability of the 747-8F is taken into account, its performance advantage becomes clear. The 747-8F has a lower fuel burn per ATM than any of the 747-400 freighters across all of the city-pairs analysed. This translates to lower fuel costs per ATM.

The two factory-freight aircraft have the lowest fuel burn and cost per ATM of the four 747-400 variants considered here. They carry a higher payload and burn less block fuel than the converted freighters on each city-pair. The 747-400ERF is the best performing -400 variant on the longer distance routes. In this analysis the 747-400BDSF has a slight performance advantage over the 747-400BCF. This is due to its marginally lower OEW, which allows for a slender improvement in payload.

The difference in fuel cost per ATM between the 747-8F and the four 747-400 variants is most pronounced on the longest routes. On PVG-ORD the 747-8F's fuel cost per ATM is 28.96 cents. This is 2.06 cents lower than the 747-400ERF and 5.62 cents lower than the 747-400BDSF.

SIN-LHR shows similar results. The 747-8F has a fuel cost per ATM of 28.81 cents, 2.05 cents lower than the 747-400ERF and 5.05 cents lower than the 747-400BDSF.

The 747-8F has a gross structural payload 28,000-42,000lbs higher than various 747-400 freighters. The 747-8F's fuel burn cost is 2.0-5.6 cents per ATM lower than the different 747-400 freighter variants.

To operate PVG-ORD and SIN-LHR non-stop, all the aircraft were required to sacrifice payload. The 747-8F was able to carry 65% of its maximum payload on PVG-ORD. The 747-400ERF and 747-400F were able to carry 68% and 67% of their respective maximum payloads. The two converted freighters saw the biggest reduction. The 747-400BDSF and 747-400BCF carried 64% and 62% of their respective maximum payloads.

When operating SIN-LHR, the 747-8F carried 67% of its maximum payload. The 747-400ERF and 747-400F carried 69% and 68% of their potential maximum payloads compared to 65% for the two converted freighters.

Introducing refuelling stops on PVG-ORD and SIN-LHR allows all the aircraft to carry their maximum payloads. The disadvantages of this strategy are the additional handling, navigation, take-off and landing charges, and time it takes to reach the final destination. Allowing for a one-hour layover to refuel, it would take the 747-8F an additional 95 minutes to fly PVG-ORD via ANC and an extra 104 minutes to operate SIN-LHR via DXB.

The fuel cost per ATM is lower for each aircraft when PVG-ORD and SIN-LHR are operated via a refuelling stop. The difference in cost between the 747-8F and the four 747-400 derivatives is also reduced. Taking SIN-LHR as an example, the 747-8F's fuel cost per ATM is 20.23 cents between SIN-DXB and 20.63 cents for the final leg from DXB-LHR.

On SIN-DXB, the 747-8F's fuel costs are 1.54 cents per ATM lower than the 747-400ERF and 2.91 cents per ATM lower than the 747-400BDSF. For the final leg between DXB-LHR, the 747-8F's fuel costs per ATM are 1.80 cents lower than the 747-400ER and 3.22 cents lower than the 747-400BDSF.

The 747-8F was the only aircraft to require a minor 1% payload restriction on SIN-SYD, to avoid exceeding its MLW. Even so, it still carried 36,000lbs more than the 747-400 factory freighters. The 747-8F's fuel costs per ATM are 1.63 cents less than the 747-400F and 3.01 cents less than the 747-400BDSF.

Acquisition costs

The 747-8F's superior payload and operating performance characteristics come at a price. Boeing's average 2013 unit price for a new 747-8F is $357.5 million, more than four times greater than current market value estimates for the youngest 747-400 factory freighters, which were produced in 2009.

Airlines can buy 747-400 passenger and combi aircraft and convert them into freighters. Aircraft of 15-20 years of age are traditionally considered optimum feedstock for freight conversion.

In its Jet Blue Book (JBB) for the second half of 2013, Avitas estimates a current market value of $24.2 million for a 1998 vintage 747-400 and $30.3 million for a 747-400 combi produced in the same year. Expressing his own personal opinions, Jacob Netz, senior consultant at the Air Cargo Management Group (ACMG), suggests that costs could be $23–27million for a passenger-to-freighter conversion, and $16–19 million for a combi-to-freighter modification.

For aircraft manufactured in 1998, this could result in total acquisition and modification costs of $47-51 million for the passenger variant, and $46-49 million for a combi. This is about one-seventh of the cost of a new 747-8F. According to Avitas' JBB a 15-year-old 747-400F has a current market value of $46.2 million. Depending on the price of conversion, used factory-built 747-400 freighters might be acquired for less than the cost of purchasing and modifying passenger or combi aircraft of the same vintage.

"The recession and financial crisis that began in 2008 significantly reduced the demand for air freight," says Netz. "Cargo airlines are struggling with high fuel prices and low yields. Some airlines are shrinking their freighter fleets, using more fuel-efficient aircraft and taking advantage of the rise in belly-hold capacity on new widebody passenger aircraft. Where the 747-400 fleet is concerned, the converted freighter becomes the biggest loser, despite the high availability of suitable feedstock at bargain prices. Some have been moved on to shorter routes, but there is unlikely to be much demand for conversions in the near term, with used 747-400Fs available at competitive prices. The 747-400Fs are slightly more fuel-efficient than the converted aircraft and every cent counts in a tough economic climate. If there is a dramatic upturn in the economy and a related increase in air freight demand, it is possible that the conversion programmes will enjoy a new lease of life."

Summary

The 747-8F has a higher payload and cheaper fuel costs per ATM than 747-400 freighters. The fuel cost advantage grows with the increasing length of a route. The benefits of the 747-8F come at a cost. Boeing's list price for the 747-8F is four times higher than the current market value for the youngest 747-400F.

Demand for air freight has fallen since the start of the global economic downturn in 2008. The higher fuel cost per ATM of converted -400s, combined with the competitive market valuations of similar vintage factory freighters, makes for a challenging environment for conversion companies. Future demand for 747-400 freight conversions is likely to be linked to the availability of 747-400Fs. AC