One factor in selecting between factory-built and converted freighters is the difference in their operating performance, payload carriage and revenue generating capacity. The operating and fuel burn performance of two factory-built and two converted variants of the 747-400 freighter are analysed.

The operating & fuel burn performance of four 747-400 freighter variants.

There are several variants of the 747-400 freighter: the factory-built -400F; the extended-range -400ERF; and the -400BCF and -400BDSF, two passenger-to-freighter programmes provided by Boeing and Bedek Aviation respectively.

These four variants differ in specification weight, fuel capacity, available freight volume and capacity, and payload-range performance, so there are also differences in revenue-generating capacity. This is also affected by their operating and fuel burn performance, which is considered here.

The revenue-generating performance of the aircraft across a route network must also be considered in relation to operating costs. Direct or aircraft-related costs are similar for all four variants. Factory-built freighters will have lower maintenance costs than converted aircraft at mature ages, but the factory-built -400F will have higher financing charges or lease rentals. Fuel burns should be equal for all variants, when equipped with the same engine type, and when operating at the same speeds and all-up weights. Small differences may occur because the condition of some engines in converted aircraft has deteriorated compared to factory-built freighters.

Candidate aircraft

Production of the 747-400 started in 1989 with the passenger variants and the first factory-built freighter was delivered in 1993. The 747-400 is offered with three basic engine options: the General Electric (GE) CF6-80C2; the Pratt & Whitney PW4000-94; and the Rolls-Royce RB211-524G/H.

There are two variants of the CF6-80C2: the -B1F rated at 58,090lbs thrust; and the -B5F rated at 60,800lbs thrust, which powers the 747-400ER. This has a higher maximum take-off weight (MTOW) than all other variants.

There are also two variants of the PW4000-94. The PW4056 is rated at 56,750lbs thrust, and the PW4062A is rated at 62,000lbs thrust. This engine powers the 747-400ER models.

There are three RB211-524G/H variants. The -G is rated at 58,000lbs thrust, and the -H at 60,600lbs thrust. Rolls-Royce later introduced a hybrid version known as the -524G-T or -524H-T, depending on thrust. The -T upgrade integrates the Trent 700's high pressure core module. These engines have the same thrust ratings as the original variants.

747-400F

The 747-400F was a latter variant of the -400 series. The -400F has the same fuselage and wing of the -400, but not the same extended upper deck. The -400F has the same upper deck as the 747-200, and its floor reduces ceiling height of the maindeck below to eight feet. The length of this upper deck means that the ceiling height allows 10-feet-high containers.

There are five specification variants of the -400F, with MTOWs ranging from 800,000lbs to 875,000lbs. Most operators have selected the two higher options of 870,000lbs and 875,000lbs. The ability to upgrade to a higher MTOW will be limited by wing number.

The maximum landing weight (MLW) for these two heavier variants is 666,000lbs, while the two options for maximum zero fuel weight (MZFW) are 610,00lbs and 635,000lbs *(see table, page 64)*. The operating empty weight (OEW) is a combination of hull weight, unusable fuel and weight or crew and associated items. Hull weight is also influenced by engine type, with the CF6-80C2 having the lowest weight. The PW4056 is marginally heavier, while RB211-powered aircraft are 2,000lbs heavier. The CF6-powered aircraft has an average OEW of 364,000lbs. This gives the aircraft a gross structural payload of 271,000lbs *(see table, page 64)*.

Besides specification weights, the payload-range performance of the aircraft is determined by fuel capacity. Standard fuel capacity varies slightly with engine type, but is 53,765 US Gallons (USG) for the CF6-powered aircraft. There is the option of an additional tailplane fuel tank with a capacity of 3,300USG, which takes capacity up to 57,065USG *(see table, page 64)*.

Under standard operating conditions and zero wind, the aircraft can carry a full payload up to 4,300nm *(see table, page 64)*. Moreover, the aircraft's payload-range profile gives it a range of 5,300nm with a gross payload of 200,000lbs. The additional tailplane fuel only increases range by 300-400nm when the aircraft is carrying payloads lighter than 150,000lbs. This may be useful to airlines operating in markets with directional imbalances, such as between the Asia Pacific and Europe. Loads are often high westbound to Europe, and lighter flying to the Asia Pacific. The additional range provided by the tailplane tank may allow non-stop operations, when carrying lighter loads, thereby avoiding expensive refuelling stops.

BEDEK AVIATION 747-400BDSF, BOEING CONVERTED FREIGHTER (BCF) & -400F WEIGHT SPECIFICATIONS

Conversion/ aircraft variant	Bedek -400BDSF	Bedek -400BDSF	Bedek -400BDSF	Bedek -400BDSF	Boeing -400BCF	Boeing -400F	Boeing -400ERF
Feature	Standard conversion	High MZFW, low MTOW	High MZFW	High MTOW -long range	Standard conversion	Standard freighter	High gross weight freighter
MTOW-lbs	870,000	811,000	870,000	875,000	870,000	875,000	910,000
MZFW-lbs	610,000	635,000	630,000	610,000	610,000	635,000	611,000
Average OEW-lbs	356,800	356,800	356,800	356,800	359,650	363,954	362,400
Gross structural payload-lbs	253,200	278,200	273,200	253,200	250,350	271,046	248,600
Containerised freight							
Freight configuration	2	2	2	2	2	4	4
Container tare weight-lbs	27,962	27,962	27,962	27,962	27,962	28,350	28,350
Net payload-lbs	225,238	250,238	245,238	225,238	222,388	242,696	220,250
Containerised volume-cu ft	26,852	26,852	26,852	26,852	26,852	27,134	27,134
Maximum packing density-lbs/cu ft	8.39	9.32	9.13	8.39	8.28	8.94	8.12
Palletised freight							
Freight configuration	5	5	5	5	5	6	6
Total tare weight-lbs	13,332	13,332	13,332	13,332	13,332	13,790	13,790
Net payload-lbs	239,868	264,868	259,868	239,868	237,018	257,256	234,810
Payload volume-cu ft	26,523	26,523	26,523	26,523	26,523	28,013	28,013
Maximum packing density-lbs/cu ft	9.04	9.99	9.90	9.04	8.94	9.18	8.38
Fuel capacity-USG	57,065	57,065	57,065	57,065	57,065	57,065	53,765
Full-payload range-nm	4,100	3,900	4,100	4,100	4,100	4,300	4,950

747-400ERF

The extended range (ER) version of the 747-400 was introduced by increasing MTOW, rather than fuel capacity. The -400ERF has a higher MTOW of 910,000lbs, while MZFW is limited to 611,000lbs and average OEW is 362,400lbs. This gives the aircraft a gross structural payload of 248,600lbs *(see table, page 64)*.

The aircraft is not available with the tailplane fuel tank, and so has a fuel capacity of 53,765USG. The -400ERF has the same cargo doors and freight accommodation as the -400F.

The aircraft's range, when its MZFW is at 611,000lbs and it is carrying a full payload, is about 4,950nm. With the option of a higher MZFW of 635,000lbs, the aircraft's payload-range performance is curtailed at distances longer than 2,750nm by its landing weight.

Its higher MTOW, however, provides it with longer range and allows it to carry a gross payload of 200,000lbs up to 6,200nm: about 900nm further than the standard -400F *(see table, this page)*. This is a strong range performance, since it removes the need for technical stops on some trans-Pacific and Europe-Asia Pacific routes, particularly when full loads are not being carried.

747-400BDSF

The 747-400BDSF is a freighter-converted passenger aircraft from Bedek Aviation of Israel Aircraft Industries, modified as a joint venture with PSF of Cyprus. There are several variants with different weight specifications. The original modification is for aircraft with an MTOW of up to 870,000lbs, which provides a standard MZFW of 610,000lbs. OEW varies by engine type, and averages 356,800lbs with the CF6-80C2B1F. This gives the aircraft a gross structural payload of 253,200lbs *(see table, this page)*. The average OEW for PW4056-powered aircraft is 358,877lbs.

Like the -400F, passenger variants have the option of the tailplane fuel tank that adds 3,300USG of fuel capacity, and takes total fuel volume to 57,065USG. A full payload can be carried 4,100nm.

A second variant allows a higher MZFW of 635,000lbs *(see table, this page)* and proportionately higher gross structural payload of 278,200lbs. However, this limits the MTOW at 811,000lbs, which reduces range.

A third variant allows a higher MZFW of 630,000lbs with the MTOW of 870,000lbs *(see table, this page)*, giving the aircraft 20,000lbs extra payload, while maintaining the same payload-range profile as the standard aircraft.

A fourth variant has the highest possible MTOW of 875,000lbs and standard MZFW of 610,000lbs *(see table, this page)*. This higher gross weight increases range by a few hundred nautical miles.

The -400BDSF has only a side freight door in the rear port fuselage. The absence of a nose-hinge door means the -400BDSF has a lower OEW than the

-400F, saving about 7,000lbs in weight.

The cost of conversion is $23-25 million, including cargo loading system.

747-400BCF

The alternative passenger-to-freighter modification programme is offered by Boeing Commercial Aviation Services. It has one weight specification. With an MTOW of 870,000lbs it has an MZFW of 610,000lbs. Like other variants, OEW varies with engine type, and the average OEW for CF6-80C2B1F-equipped aircraft is 359,650lbs; about 3,000lbs heavier than the -400BDSF *(see table, page 64)*. This gives the -400BCF a gross structural payload of 250,350lbs. The aircraft can carry this up to 4,100nm.

Payload accommodation

Factory-built freighters have a longer section of maindeck that allows 10-feet tall containers from fuselage station 777 to the end of the maindeck. The longer upper deck of converted aircraft means the front section of the maindeck with an eight-feet ceiling is longer, and 10-feet containers can only be carried from fuselage station 903.

The -400F's and -400ERF's maindeck can therefore hold 11 pairs of unit load devices (ULDs), or pallets, that are 96 inches wide, 125 inches long and 10 feet high, and are loaded two-abreast. A single ULD is loaded at the rear of the maindeck, taking the total to 21 *(see table, this page)*.

The lower ceiling height at the front section of the maindeck allows seven ULDs with the same base dimensions to be loaded. Four are in pairs and three are in a single row. A total of 30 ULDs can therefore be loaded on the maindeck.

The 747-400F has two freight loading doors. One is a side door on the fuselage, and is 120 inches high and 134 inches wide. The aircraft also has a nose-hinge door at the front of the fuselage, which allows faster loading and unloading of freight, and the use of longer ULDs and pallets. Containers and pallets up to 20 feet long can be loaded through the side door, and turned longitudinally. They can therefore be up to 10 feet high.

Some containers are up to 30 or 40 feet long but they are limited to a height of eight feet because they can only be loaded through the nose-hinge door and into the front section of the maindeck.

Optimal use of the almost 20-feet-wide maindeck floor is achieved by loading pairs of containers or pallets with a base width of 96 inches.

One of the most popular types of container is the AMD/M5, with a width of 96 inches and length of 125 inches. It is contoured and the highest part is 10 feet. This has a volume of 759 cubic feet and tare of 800lbs.

The -400F/-400ERF can carry 23 AMD/M5s while converted aircraft can only carry 21. These containers provide one of the highest possible containerised volumes. This results in 15,939 cubic feet on the converted aircraft, and 17,457 cubic feet on the factory-built freighters *(see table, this page)*.

In addition, factory-built aircraft will use another five AMA/M1 square-profiled containers and two smaller 96- X 125-inch containers in the front section where the ceiling height is eight feet. These seven provide another 4,237 cubic feet and have a tare weight of 4,030lbs. The total maindeck volume for the -400F/-400ERF in this configuration is 21,694 cubic feet and the tare weight is 22,430lbs.

Converted aircraft will use seven AMA/M1 and two profiled containers. These provide a total of 5,473 cubic feet and have a tare weight of 5,242lbs. The total maindeck volume for converted aircraft in this configuration is 21,412 cubic feet and the tare weight is 22,042lbs *(see table, this page)*.

Another option uses eight-feet-high AMJ/M1 containers on the maindeck, resulting in a smaller containerised volume of 17,800 cubic feet for the aircraft. These have a tare weight of about 17,840lbs *(see table, this page)*.

An alternative is to use load devices with a 88- X 125-inch base, which do not fully utilise the maindeck width. Other load devices are those with a 88-X 108-inch base. Their shorter length means that 34 can be loaded on the maindeck, but their smaller width means that the maindeck's space is not fully utilised.

There is also the option of 30- or 40-feet-long ULDs. These are 96 inches wide, so they are loaded in pairs. Their length means they have to be loaded longitudinally through the nose-hinge door on factory-built freighters.

The standard belly container used in the 747 is the LD-1. The -400's belly can hold 32 of these, each with a volume of 170 cubic feet and a tare weight of 185lbs. The total shipset therefore provides 5,440 cubic feet and has a weight of 5,920lbs *(see table, this page)*.

Alternatively, the belly can carry 10 LD-39s, each with a volume of 552 cubic feet and a tare weight of 650lbs, taking the total to 5,520 cubic feet and a tare weight of 6,500lbs *(see table, this page)*.

When considering the AMD/M5 and AMJ/M1 containers for maindeck and LD-1s for belly carriage of freight, there are two possible volumes and tare weights for converted freighters and two for factory-built aircraft. For converted aircraft, freight configuration number 1 provides 23,303 cubic feet and 23,762lbs with the AMJ/M1, while freight configuration number 2 provides 26,852 cubic feet and 27,962lbs with the

747-400 FREIGHTER CONTAINER & ULD CONFIGURATIONS

Freighter variant	Converted freighter	Converted freighter	Factory freighter	Factory freighter
Freight configuration	1	2	3	4
Maindeck				
Container type	96 X 125-in plus AMA/M1	96 X 125-in plus AMA/M1	96 X 125-in plus AMA/M1	96 X 125-in plus AMA/M1
Number	2 + 7	2 + 7	2 + 5	2 + 5
Total volume-cu ft	5,473	5,743	4,237	4,237
Total tare weight-lbs	5,242	5,242	4,030	4,030
Container/ULD type	AMJ/M1	AMD/M5	AMJ/M1	AMD/M5
Number	21	21	23	23
Unit volume-cu ft	590	759	590	759
Unit tare weight-lbs	600	800	600	800
Total volume-cu ft	12,390	15,939	13,570	17,457
Total tare weight-lbs	12,600	16,800	13,800	18,400
Lower deck				
Container/ULD type	LD-1	LD-1	LD-1	LD-1
Number	32	32	32	32
Unit volume-cu ft	170	170	170	170
Unit tare weight-lbs	185	185	185	185
Total volume-cu ft	5,440	5,440	5,440	5,440
Total tare weight-lbs	5,920	5,920	5,920	5,920
Total volume-cu ft	23,303	26,852	23,247	27,134
Total tare weight-lbs	23,762	27,962	23,750	28,350

747-400 FREIGHTER PALLET CONFIGURATIONS

Freighter variant	Converted freighter	Factory freighter
Freight configuration	5	6
Maindeck		
Pallet type	PMC @ 8-feet	PMC @ 8-feet
Number	2 + 7	2 + 5
Total volume-cu ft	5,438	4,212
Total tare weight-lbs	2,603	2,145
Pallet type	PMC	PMC
Number	21	23
Unit volume-cu ft	745	745
Unit tare weight-lbs	229	229
Total volume-cu ft	15,645	17,135
Total tare weight-lbs	4,809	5,267
Lower deck		
Container/ULD type	LD-1	LD-1
Number	32	32
Unit volume-cu ft	170	170
Unit tare weight-lbs	185	185
Total volume-cu ft	5,440	5,440
Total tare weight-lbs	5,920	5,920
Total volume-cu ft	26,523	28,013
Total tare weight-lbs	13,332	13,790

AMD/M5 *(see table, page 65)*.

For the -400F/-400ERF freight configuration number 3 provides 23,247 cubic feet and a tare of 23,750lbs when using the AMJ/M1 and LD-1s. Freight configuration number 4 has 27,134 cubic feet and a tare of 28,350lbs when using the AMD/M5 *(see table, page 65)*.

As an alternative to containers, pallets can be used for large items of general freight. For the maindeck, pallets with a base dimension of 96 X 125 inches, the PMC, are a standard choice. These are manufactured by Driessen, Satco and Nordisk. Tare weight averages about 230lbs, although Nordisk makes a heavy-duty variant with a weight of 646lbs.

PMC pallets can be stacked to a height of 10 feet and contoured similarly to AMD/M5 containers. Each PMC provides a volume of 745 cubic feet. Converted aircraft can carry 21, and factory-built freighters 23.

More pallets stacked at eight feet high would be carried, taking volume and tare weight on the converted aircraft to 21,083 cubic feet and 7,412lbs, and to 22,573 cubic feet and 7,870lbs on the -400F/-400ERF *(see table, page 65)*.

Once combined with LD-1s in the belly, the total volumes would be similar to those provided by containers. The total tare weight would be lower, however, at 13,332lbs for freight configuration number 5 for converted aircraft, and 13,790lbs for freight configuration number 6 for the -400F/-400ERF *(see table, this page)*.

Net payload

The net payload of each freight variant is the gross structural payload less the tare weight of containers or pallets used to carry the freight. The net structural payloads for the Bedek-converted aircraft, the Boeing-converted aircraft, and the factory-built freighters are listed *(see table, page 65)*.

Using the larger AMD/M5 ULDs, the net payloads are 222,388-250,238lbs. In standard configuration the two passenger-to-freighter conversions have net payloads that are 17,000-20,000lbs lighter than the standard factory-built freighter. The -400ERF has almost the same net payload as the -400BCF, and only 5,000lbs less than the -400BDSF.

Net payloads divided by all useable volume give maximum packing density, which is 8.12-9.13lbs per cubic foot for aircraft using ULDs *(see table, page 65)*.

Net payloads are 14,000lbs higher for each variant when using pallets on the maindeck *(see table, page 65)*. Packing densities are 0.60lbs per cubic foot higher.

747-400 fleet

The choice of aircraft for conversion will be influenced by fleet mix. CF6- and PW4056-powered aircraft have lower hull weights than those with the RB211. The weight difference is up to 2,000lbs higher for the RB211, translating to an equal reduction in gross payload. The most popular candidates for conversion therefore have CF6 and PW4056 engines.

There are 37 CF6- and nine PW4056-powered combi aircraft. These will be cheaper to convert to freighter than passenger-configured aircraft, making them the preferred choice for conversion. Most CF6-equipped combis are operated by EVA, KLM and Lufthansa. Air China has most of the PW4000-equipped combis. Some of its aircraft have already been converted by Bedek Aviation.

The passenger-configured fleet has almost equal numbers of CF6- and PW4056-powered aircraft, with a total of 295 units. The larger CF6-equipped -400s are with Air France, Air New Zealand, Japan Airlines, KLM, Lufthansa, Thai International and Virgin Atlantic. There are also six CF6-powered 747-400ERs operated by Qantas. The large PW4056-equipped fleets are operated by Air China, China Airlines, Corsair, El Al, Korean Air, Malaysia, Northwest, Singapore Airlines (SIA) and United Airlines. Several United aircraft are parked and SIA plans to phase out its 747-400 fleet over the next 18 months.

There are also 101 RB211-equipped aircraft. Most are operated by Qantas, British Airways and Cathay Pacific. Some of Cathay Pacific's fleet has already been converted with the Boeing programme.

747-400 freighter in operation

A large number of 747-400Fs and -400ERFs are now in operation. Most have CF6 or PW4056 engines, and are operated in large fleets by Atlas Air, Cargolux, China Airlines, Nippon Cargo, Polar Air Cargo, United Parcel Service (UPS), Air China Cargo, Korean Air and SIA Cargo. Cargolux and Cathay Pacific also operate 17 RB211-powered -400Fs.

Another 38 -400ERFs have been delivered in recent years. These are operated by Air France, AirBridge Cargo, Jade Cargo, KLM, TNT and China Cargo Airlines, Cathay Pacific and Korean Air. Only CF6-80C2B5F and PW4062 engines have been specified for the -400ERFs.

Airlines operating converted aircraft are mainly those that already have factory-built freighters. Airlines with just converted aircraft are Kalitta Air, Martinair, Great Wall Airlines, Air Cargo Germany, and World Airways.

A large portion of 747-400 freighters are operated on some of the world's longest air freight routes, to and from the Asia Pacific. Main freight markets include the trans-Pacific, primarily involving the transportation of manufactured goods from the Asia Pacific to Europe and North America. The main freight departure hubs are Singapore, Hong Kong, various points in China including Beijing and Shanghai, several points in

Japan, and Seoul in South Korea.

The key European destinations are Frankfurt, Amsterdam, Luxembourg, Paris and London. The main freight hubs in the US are Seattle, Los Angeles, Dallas, Chicago, Miami, Memphis and Louisville.

The main feature of routes between the main Asia Pacific points and key US and European destinations is that most are longer than 5,000nm. Many routes are close to 6,000nm, and several are longer than 6,000nm. These great circle distances can be increased by 4-5% when actual navigation tracks are factored in. Headwinds on routes when operating in a general westerly direction increase the distance flown by reducing the aircraft's ground speed. Aircraft therefore need a range in excess of 6,000nm to complete most routes non-stop when flying westbound with a full payload, otherwise technical stops for refuelling are required.

Range capability improves with reduced payloads, so routes can be flown non-stop when freight volumes are lower. Freight airlines experience directional imbalance of freight volumes on most routes. For example, freight loads are high on aircraft flying from the Asia Pacific, and are lighter from Europe and North America to the Asia Pacific.

Aircraft operating from various points in the western half of the US westward to the Asia Pacific experience headwinds, on routes that can be close to 7,000nm. Their payloads tend to be low, so they can operate many routes non-stop. The 747-400BDSF/-BCF have a range of 6,800nm with a payload of 125,000lbs, so they can operate to the Asia Pacific without refuelling stops.

Aircraft in the eastern half of the US, or those carrying payloads in excess of 150,000lbs, will have to stop to refuel. Anchorage in Alaska has been used for this for many years, because it lies close to the great circle route for many city-pairs in the trans-Pacific market.

It is more challenging for aircraft flying from the Asia Pacific to Europe, since they will be carrying high payloads and operating against headwinds. They are more likely to need to make refuelling stops. Two airports close to great circle paths are Tashkent in Uzbekistan, and Almaty in Kazakhstan. These are used as refuelling transit points for some aircraft, but Dubai, Abu Dhabi and Sharjah in the United Arab Emirates are more attractive for two reasons: there is demand for freight there, so some is likely to be added to the aircraft; and the price of fuel is lower than at Almaty or Tashkent. While flying to the UAE increases the total distance flown, the additional freight and cheaper fuel available there make it more economic than flying via Kazakhstan or Uzbekistan for most airlines.

Operations eastbound from Europe to the Asia Pacific will experience tailwinds. Most routes are up to 5,500nm, and aircraft can carry payloads up to 190,000lbs on this distance. The smaller freight volumes originating from Europe mean that many flights can be flown non-stop. Only those with high payloads will require refuelling stops.

ROUTE AIRPORT CHARACTERISTICS

Airport	Three letter code	Runway length-feet	Elevation feet	Take-off temp July-deg C
Chicago	ORD	13,000	667	23
Anchorage	ANC	11,584	144	18
Shanghai	PVG	13,100	13	26
Singapore	SIN	13,517	23	28
Sydney	SYD	13,100	21	12
London Heathrow	LHR	12,802	80	18
Dubai	DXB	13,123	34	35

Operating performance

The operating performance of the four main 747-400 freighter variants is analysed by examining their performance on typical routes to and from several main points in the Asia Pacific. The aircraft are the standard models of the 747-400BDSF, the 747-400BCF, the 747-400F and 747-400F *(see table, page 68)*.

The important issue is the gross available payload, the fuel burn and the block time on each route. Aircraft are analysed on non-stop city-pairs and with refuelling stops made and transit airports.

Routes in three markets have been analysed. The first is an intra-Asian route, between Singapore (SIN) and Sydney (SYD). This has a great circle distance of 3,395nm. Most major intra-Asian freight routes have distances similar to this or less, so most can be operated with full payloads by the different variants.

The second group is trans-Pacific routes. Most routes from points in the Asia Pacific to the US are in excess of 6,000nm and up to 7,500nm, and clearly need to be operated via a refuelling point.

Chicago is in the centre of the US, and 6,000-7,300nm from major airports in the Asia Pacific. Performance from Shanghai to Chicago is also examined, both non-stop and via Anchorage.

The third market is routes between the Asia Pacific and Europe, with Singapore-London Heathrow (LHR) as a representative route. Performance non-stop and via Dubai (DXB) is examined.

Aircraft performance will be affected by allowable take-off weight, which is determined by runway length and ambient temperature at time of departure. The most testing conditions are in the hottest months, so performance during July has been analysed here, although evening temperatures have been used since most freight operations avoid departing in the middle of the day when temperatures are at their highest.

The longest runways at most of these airports are longer than 12,000 feet. The exception is ANC's, which is 11,584 feet. All of these airports are less than 1,000 feet above sea level, and all but two have an elevation of less than 100 feet.

With these runway lengths, there are no restrictions in take-off or landing weights. The runways' length and elevation and the ambient temperature of each airport are summarised *(see table, page 68)*.

The only factor likely to limit allowable payload will be distance flown. All aircraft have been analysed on all routes at a cruise speed of Mach 0.85; a little faster than the long-range cruise speed of Mach 0.848. Headwinds will reduce the ground speed from the true airspeed; usually when flying westbound. Headwinds and reduced ground speeds increase the equivalent still air distance (ESAD), which is shown for each route.

The routes have all been analysed using standard long-range mission rules concerning diversions and operating procedures. A time of 20 minutes has been used for taxi out and taxi in.

The allowable take-off weight, actual take-off weight, maximum and allowable payload, ESAD, block fuel burn, block time, and ESAD payload limiting factor are summarised for each route *(see table, page 68)*.

The first route, SIN-SYD, clearly shows each aircraft being able to carry its full payload on shorter routes. A more capable variant of the -400BDSF with a 20,000lbs higher MZFW and structural payload is also available.

The direct operation between Shanghai (PVG) and Chicago (ORD) has an ESAD of 6,242nm, so all aircraft are operated at MTOW, and have to trade payload for a higher fuel load to operate non-stop. Available payload is is less than maximum payload, with the -400BCF and -400F having 3,000-4,000lbs lower

OPERATING PERFORMANCE OF 747-400 FREIGHTERS

City-pair	Aircraft variant	MTOW lbs	Actual TOW lbs	Max payload lbs	Available payload lbs	ESAD nm	Block fuel USG	Block time	Payload limitation
SIN-SYD	747-400BCF	870,000	823,587	250,350	250,350	3,343	28,198	7:27	MZFW
	747-400BDSF	870,000	847,582	253,200	253,200	3,343	28,198	7:27	MZFW
	747-400F	875,000	853,543	271,000	271,000	3,343	28,912	7:27	MZFW
	747-400ERF	910,000	833,942	248,600	248,600	3,343	29,545	7:37	MZFW
PVG-ORD	747-400BCF	870,000	870,000	250,300	154,266	6,242	48,718	13:23	Fuel load
	747-400BDSF	870,000	870,000	253,200	157,117	6,242	48,718	13:23	Fuel load
	747-400F	875,000	875,000	271,000	153,446	6,242	48,930	13:23	Fuel load
	747-400ERF	910,000	910,000	248,600	172,990	6,242	51,386	13:39	Fuel load
PVG-ANC	747-400BCF	870,000	849,747	250,300	250,300	3,791	31,965	8:22	MZFW
	747-400BDSF	870,000	849,747	253,200	253,200	3,791	31,965	8:22	MZFW
	747-400F	875,000	875,000	271,000	266,921	3,791	32,590	8:22	Fuel load
	747-400ERF	910,000	862,353	248,600	248,600	3,791	33,636	8:35	MZFW
ANC-ORD	747-400BCF	870,000	778,547	250,300	250,300	2,608	21,712	5:54	MZFW
	747-400BDSF	870,000	802,031	253,200	253,200	2,608	21,712	5:54	MZFW
	747-400F	875,000	807,866	271,000	271,000	2,608	22,334	5:54	MZFW
	747-400ERF	910,000	785,313	248,600	248,600	2,608	22,543	6:02	MZFW
SIN-LHR	747-400BCF	870,000	870,000	250,300	149,304	6,494	49,433	13:56	Fuel load
	747-400BDSF	870,000	870,000	253,200	152,154	6,494	49,433	13:56	Fuel load
	747-400F	875,000	875,000	271,000	148,598	6,494	49,628	13:56	Fuel load
	747-400ERF	910,000	910,000	248,600	169,740	6,494	51,854	14:13	Fuel load
SIN-DXB	747-400BCF	870,000	821,400	250,300	250,300	3,374	27,883	7:31	MZFW
	747-400BDSF	870,000	844,866	253,200	253,200	3,374	28,382	7:31	MZFW
	747-400F	875,000	850,695	271,000	271,000	3,374	28,502	7:31	MZFW
	747-400ERF	910,000	831,030	248,600	248,600	3,374	29,126	7:41	MZFW
DXB-LHR	747-400BCF	870,000	815,291	250,300	250,300	3,330	27,004	7:26	MZFW
	747-400BDSF	870,000	838,180	253,200	253,200	3,330	27,004	7:26	MZFW
	747-400F	875,000	843,865	271,000	271,000	3,330	27,518	7:26	MZFW
	747-400ERF	910,000	823,907	248,600	248,600	3,330	28,100	7:38	MZFW

Source: AviationSoftwareSystems.com

available payload than the -400BDSF. The -400F suffers the largest reduction in full payload capability of 43%. The -400ERF performs best, and loses the smallest portion of its maximum payload.

A clear benefit of flying via Anchorage (ANC) is that the two converted models are able to operate with a full payload on both sectors. The -400BCF and -400BDSF carry up to 62,000lbs more payload, instead of using 5,000USG more fuel, and having a one-hour longer block time and the cost of a refuelling stop.

The -400F carries 56,600lbs more payload flying via ANC, compared to 6,000USG higher fuel burn, a one-hour longer block time and all the costs of a transit stop.

The -400ERF carries 69,000lbs more payload, versus a 4,800US higher fuel burn and longer block time.

The situation is similar on SIN-LHR. Operating from Singapore to London, the -400BDSF has a higher payload performance than the -400BCF and -400F. The -400ERF clearly benefits from its stronger performance with a 21,000lbs higher payload.

The benefit of a refuelling stop along the route is higher in this case compared to the PVG-ORD operation, since the aircraft operate against headwinds when travelling westbound from the Asia Pacific. Both converted models carry 101,000lbs more payload than when operating direct to LHR, instead of using 5,450USG more fuel and having a one-hour longer block time.

The -400F benefits the most from the technical stop by being able to carry 122,400lbs more payload, instead of burning 6,400USG more fuel, and having a longer flight time and higher costs.

The -400ERF is able to carry 78,900lbs more, because it is less penalised when operating non-stop. The technical stop is probably beneficial, since it burns only 5,400USG more fuel by flying via Dubai (DXB).

Summary

The 747-400ERF's stronger performance is clear when the other models are operating at MTOW, and additional payload-range performance is achieved from a higher MTOW capability. On shorter routes where aircraft are not departing at MTOW, all four models will have similar payloads. The -400ERF also outperforms the other variants when operating non-stop services on longer routes, particularly on ESADs longer than 5,500nm. It is on these routes that the -400ERF's superior performance is realised through a higher payload advantage. There are some routes where the -400ERF's available payload makes it economically viable to operate non-stop.

There is little difference in performance between the other three variants, so operators with converted aircraft can expect similar payloads on the same routes as the -400F. The -400BDSF with the higher MZFW option of 630,000lbs has a 20,000lbs higher payload on missions up to 4,000nm. AC