Some freight carriers may be dissuaded from the younger generation 737-300/-400 & 757-200 freighters by their financing charges. An analysis of their available payloads and fuel burns on challenging routes illustrates their economic superiority over the 737-200 & 727-200

Narrowbody freighter payload performance

Fleet planning and aircraft selection for freight operations are usually a foregone conclusion. Most freight operations have low aircraft utilisations, so operators' routine strategy is to choose aircraft with the lowest acquisition cost. This generally favours older aircraft. An aircraft's economic suitability starts with its revenue-earning potential, however, and not just operating costs. The payload-carrying capability of all candidate aircraft across an airline's route network should be considered first, since some types can be weak performers. The payload performance of narrowbody freighters on some of the most challenging routes and operating conditions is analysed here, including: the older 737-300F and -400 available under several passenger-to-freighter conversion programmes; and the 757-200F modified to freighter by Precision Conversions and Alcoa-SIE. These are compared with the 737-200F and 727-200F.

New generation freighters

Younger generation aircraft can be a more economic option overall, despite relatively high capital costs, because they may have superior operating performance, lower fuel burn and higher payload capacity.

Maximum available payload cannot be taken for granted, however, when operating from hot-and-high airfields or other situations where the operating performance of the aircraft is challenged. Although the total operating costs of the oldest aircraft may be lower for freight operations, older types also tend to have poorer take-off performance. This is especially true of certain variants of the 727-200F with lower rated variants of the JT8D, the DC-80-50F and -60F, 737-200F and DC-9F. Poor performance results in restricted take-off weights, which together with higher relative fuel burn consequently limit payload and revenue. These factors result in high fuel consumption and cost per ton-mile.

If the revenue-generating ability of older types is lower than the payload-carrying and revenue-generating ability of similar-sized, younger aircraft on particular routes, then the overall economics of older and newer types can be brought closer together. Older types have impaired payload, making them less economic overall. This is a classic example of technical differences between aircraft types directly affecting their relative economic performance.

Testing performance

The acid test for freighters is to analyse their maximum permitted take-off weight and resultant available payloads on some of the most challenging routes departing from hot-and-high airfields. Challenging airfields, which have high elevations and high ambient temperatures, will limit take-off-weight and therefore payload. The aircraft's maximum structural payload must first be considered The typical packing densities of freight mean that even when the aircraft's volume is completely used, the structural payload is not fully utilised. The volumetric payload at 100% load factor is therefore often a percentage of structural payload. Furthermore, payloads are rarely at 100% of volumetric payload capacity, so only a percentage of the aircraft's structural payload is used in most operations. Another consideration is that aircraft all have a burden of tare weight for pallets or containers. This has to be deducted from the available structural payload.

This analysis examines the payload-carrying capacity of three main 737 models, the 727-200F and the 757-200F from three of Latin America's most used hot-and-high departure points: Mexico City (MEX), with an elevation of 7,316 feet above sea level and a runway length of 12,966 feet; Bogota, Colombia (BOG), with an elevation of 8,360 feet above sea level and a runway length of 12,467 feet; and Quito, Ecuador (UIO), with an elevation of 9,223 feet above sea level and runway length of 10,236 feet.

These three airfields also experience high ambient temperatures. This analysis uses midday temperatures for July: 22°C at MEX, 20°C at BOG, and 20°C at UIO. These are relatively high compared to the international standard atmosphere (ISA) temperatures for their elevations.

The standard ISA temperature at MEX's elevation is 1°C, so the ambient

HOT-AND-HIGH AIRPORT CHARACTERISTICS

Airport	Mexico City	Bogota	Quito
Ambient temperature deg C	22	20	20
Elevation (feet)	7,316	8,360	9,223
Runway length (feet)	12,966	12,467	10,236

temperature is ISA plus 21°C. The standard ISA temperature at BOG's elevation is -2°C, so an ambient temperature of 20°C is also ISA plus 22. The standard ISA temperature at UIO's elevation is -3°C, making the ambient temperature of 20°C equal to ISA plus 23.

All three airfields clearly have high temperatures for their elevations, which reduces air density, thereby placing severe limitations on aircraft field performance. Quito also has a relatively short runway.

For most aircraft, the available take-off weight (ATOW) from these airfields will be lower than their certified maximum take-off weights (MTOW).

How much an aircraft's payload is reduced on a particular route depends on its ATOW, as well as the fuel required to be carried to complete the trip and for the legal minimums for reserves. The analysis here uses a total taxi time of 25 minutes, enough reserve fuel for a 30-minute hold and 200nm diversion, plus 5% of sector fuel for navigational tolerance.

The difference between the ATOW and the operating empty weight (OEW) will determine the combined weight of payload and fuel. The aircraft prepared for service (APS) weight is more appropriate than the OEW. APS is the OEW plus the weight of crew and other items required for the aircraft to operate. The longer the trip and the more fuel required, the lower the payload that can be carried.

All aircraft types have to accept reduced payloads on long sectors at the edge of their maximum payload-range. The reduction in payload will be greater when the ATOW is lower than the MTOW. Available take-off weights are reduced by increased airport elevation and ambient temperature as well as by shortened runway length.

The actual ATOW for a particular flight, and therefore the available payload, on routes departing from hot-and-high airfields has to be calculated for each aircraft type.

The actual take-off weight that can be achieved by any aircraft at an airfield is dependent upon a number of factors. All aircraft performance is affected by three factors: runway length, airfield elevation and ambient temperature during take-off. Differences between aircraft types at the same airport under the same conditions also depend on the aircraft design, engine thrust and original mission design. All of the aircraft evaluated here were originally designed for passenger operations from lower elevation airfields. The standard hot-and-high airport used in aircraft design for the past 30 years is Denver, Colorado (5,000ft elevation) on a 25°C day. The airfields examined here are all more restrictive than that basic design consideration. The weight limited payload capacity of a freighter is typically 50% higher than that for the passenger version of the same aircraft, so take-off weight restrictions bite earlier and harder.

As a passenger aircraft, the PW2040-powered 757-200 could carry 195 passengers from Mexico City to Miami, which is 95% of maximum capacity. As a freighter the same aircraft can carry only 86% of its maximum capacity. The 737-400 as a passenger aircraft can carry 67% of its maximum payload on the same route, but only 50% as a freighter.

All western built commercial aircraft that are currently used as freighters were originally designed and sold as passenger aircraft with lower payload demands. The normal design criterion was to carry a maximum passenger load on 90% of the routes that the aircraft was envisioned to operate. Designing an aircraft to meet potential higher demands as a second-life freighter would put additional costs on the aircraft that would be unacceptable to the first buyer.

Rick Methven, director of Aerocom Aviation Software, points out that in this particular study, and from the particular airports chosen, the main limitation on all aircraft is the second-segment climb phase. This is from landing gear retraction to the point at which air speed is high enough for flaps to be retracted.

Before commencing an operation, operators first have to calculate the ATOW. This considers the combination of specific operating conditions at the airport: the runway length; the runway slope; the airfield pressure elevation and the temperature. There are two limitations to take-off weight: the runway-limited take-off weight and the second-segment climb-limited take-off weight. The permitted take-off weight to be used for payload calculations is the lower of these two weights. In actual operations the take-off wind component would also be used. In this study zero wind has been assumed.

Analysis

The first weight that must be considered for each type is the APS weight, which comprises the OEW of the aircraft plus some allowance for crew. APS does not include tare weights of pallets or containers, however.

The tare weight of pallets and containers is included in each aircraft's available gross structural payload. This will vary with each route, and tare weights of a preferred container or pallet configuration should be deducted from it in each case on a given route to calculate the available net payload.

Other important aircraft specifications include engine type, MTOW variant and maximum zero fuel weight (MZFW).

The ambient airport temperatures chosen for the analyses were taken at midday local time in the month of July. The characteristics of the airfields used are summarised *(see table, page 65)*.

The performance of the aircraft was assessed by dividing them into two groups according to size.

The first group of aircraft comprises the 737-300F and -400F, which have recently come onto the market with conversion programmes from Boeing, Bedek Aviation, Pemco and Aeronautical Engineers Inc (INC). These modern types are compared with an older type they are likely to replace; in this case the 737-200. These aircraft are analysed on a short-haul route, departing from BOG to Caracas, Venezuela (CCS). This has a tracked distance of 635nm and a mean 15-knot en-route wind component.

The second group of aircraft are the larger narrowbodies, comprising the 757-200F, which is available under two major passenger-to-freighter conversion programmes from Precision Conversions and Alcoa-SIE. The 757-200 is powered by RB211-535E4 and PW2000 engines, and the two conversion programmes result in aircraft with different weights, thereby generating four variants of the 757-200F. The 757-200F is pitched partially as a 727-200F replacement. The four 757 variants and the 727-200F are therefore compared on three routes from MEX, UIO and BOG to Miami, which are representative of airline operations in the region.

Bogota-Caracas

The aircraft take-off, and en-route performance and flightplan data have been calculated and provided by Aerocom Aviation Software using its Payload and Costing System (PACS). The BOG to CCS route has a tracked distance of 635nm, and en-route wind of -15 knots. The aircraft analysed on it are the 737-200F, 727-200F, 737-300F and 737-400F. The specifications of the aircraft tested on this route are summarised *(see first table, page 70)*.

There are several variants of the 737-200F with different MTOW options and variants of the JT8D. The aircraft analysed here has an MTOW of 115,500lbs and the JT8D-9.

The different variants of the 737-300F include aircraft converted to freighter by Bedek, Boeing and Pemco. These all have small variations in basic empty weight, MZFW, and gross payload *(see first table, page 70)*. The 737-300F is also analysed here at its highest MTOW variant and with the CFM56-3B2 rated at 22,000lbs thrust. This engine is selected

SMALL NARROWBODY FREIGHTER SPECIFICATIONS

Aircraft type	Engine	MTOW lbs	MZFW lbs	OEW lbs	Structural payload lbs
737-200F	JT8D-9	115,500	95,000	60,850	34,150
737-300F (Pemco)	CFM56-3B2	139,500	106,500	68,500	38,000
737-300F (Boeing)	CFM56-3B2	139,500	109,600	68,100	41,500
737-300F (Bedek)	CFM56-3B2	139,500	109,600	66,500	43,100
737-400F (Pemco)	CFM56-3C1	150,000	117,000	70,200	46,800
737-400F (Boeing)	CFM56-3C1	143,500	113,000	71,100	41,900

OPERATING PERFORMANCE OF NARROWBODY FREIGHTERS: BOGOTA-CARACAS

Aircraft type	Actual TOW lbs	Maximum payload lbs	Available payload lbs	Block fuel USG	Block time mins	Block fuel per ton-mile
737-200F	88,161	34,150	10,489	1,639	133	0.55
737-300F (Pemco)	105,075	38,000	19,713	1,537	123	0.27
737-300F (Boeing)	105,075	41,500	20,113	1,537	126	0.27
737-300F (Bedek)	105,075	43,100	21,713	1,537	126	0.25
737-400F (Pemco)	107,625	46,800	20,464	1,551	126	0.27
737-400F (Boeing)	107,625	41,900	19,564	1,551	126	0.28

because older aircraft with these engines are the most likely to be converted to freighter.

Two specification variants of the 737-400F analysed are aircraft resulting from conversions offered by Boeing and Pemco. These have small differences in specification weights *(see first table, this page)*. The 737-400F is analysed with its highest MTOW variant and the CFM56-3C1 with the highest rating of 23,500lbs thrust.

The 737-200F has been included, since it is one of the closest aircraft to the 737-300F and -400F in payload terms. The 727-100F is also close to the 737-400F, but there are no 727-100Fs in operation. The 737-300F and -400F have lower fuel and maintenance costs, but higher lease charges than the -200F.

The various 737 models have been analysed on the BOG-CCS route because this is short enough for them to deliver reasonable payload performance. The routes from MEX, BOG and UIO to Miami are longer, and severely affect the take-off weights and available payloads on the 737 models. The reduction in payloads is so large as to make the 737s unviable on these longer routes.

The analysis reveals how in practical operating conditions the aircraft are only suitable for routes of up to 100 minutes' flight time when departing from hot-and-high airports. Another example of a short route is BOG to San Jose, Costa Rica (SJO), which has a great circle distance of 678nm.

The flightplan results *(see second table, this page)* show that the 737-200F is only capable of carrying a structural payload of 10,489lbs, which is 31% of its maximum structural payload. The aircraft's RTOW is 88,161lbs, which is 27,339lbs lower than its MTOW. This payload is unlikely to make the aircraft economic on this short sector.

The variants of the 737-300F and -400F provide better performance. The younger CFM56-powered 737-300Fs can carry about twice the -200F's payload. This may not be surprising, especially since the 737-200F is powered by the JT8Ds. The -200's fuel burn is the same as for the -300/-300, but the -200 has half the payload.

The various versions of the 737-300F have available payloads of 19,713-21,713lbs. These are 48-52% of gross structural payload. The larger 737-400F has available payloads of 19,564-20,464lbs, which is 44-47% of its maximum structural payload *(see second table, this page)*. The 737-300F is therefore the better option, providing similar payload but incurring lower operating costs than its larger -400F counterpart.

The fuel burn data from the flightplan also shows that the 737-300F and -400F have lower fuel consumption per ton-mile compared to the 737-200F. The 737-200F's fuel burn rate per ton-mile is about twice that of the -300F.

727-200F & 757-200F

The second group in the analysis comprises the larger JT8D-15-powered 727-200F, and four variants of the 757-200F, which is tipped as the 727-200F's main successor.

The four 757-200F variants are first divided into aircraft converted by Alcoa-SIE and Precision Conversions. These are further sub-divided into aircraft equipped with PW2040 and RB211-535E4B engines *(see first table, page 72)*.

All four variants have been analysed at their highest MTOW option of 250,000lbs. Aircraft converted by Precision Conversions have lower OEWs (and consequently lower APS weights) than those converted by Alcoa-SIE. This gives the aircraft converted by Precision Conversions a proportionately higher gross structural payload. The difference between these two conversions with the same engine type is about 1,850lbs *(see first table, page 72)*.

The 757-200F, equipped with PW2040 engines, is slightly lighter, and has lower fuel burns than the RB211-535-E4B-powered aircraft *(see first table, page 72)*. The PW2040-powered aircraft can therefore carry up to 3,000lbs more payload on the three routes analysed.

The three routes, all with MIA as the destination, have been used to show how the younger and more powerful 757-200F compares with the popular 727-200F. In terms of size (MTOW and structural payload), the 757 is the closest replacement candidate for the 727-200F. This is until the A320F and A321F converted freighters from EADS-EFW start becoming available in 2010 or 2011.

The first route, MEX-MIA, has a great circle distance of 1,108nm and represents a typical medium-range operation, but it is also a likely freighter route in the Central American-US region. The route has a tracked distance of 1,135nm and the ambient midday temperature is 22°C. The long runway at MEX and the 20-knot tailwind en route to Miami reduce the tracked distance to a shorter equivalent still air distance (ESAD). This reduces the amount of trip fuel required to be carried, thereby increasing the available payload.

None of the aircraft can achieve their

LARGE NARROWBODY FREIGHTER SPECIFICATIONS

Aircraft type	Engine	MTOW lbs	MZFW lbs	OEW lbs	Structural payload lbs
727-200F	JT8D-15	195,000	151,000	94,800	56,200
757-200F (Precision)	RB211-535E4	250,000	188,000	115,500	72,500
757-200F (Precision)	PW2040	250,000	188,000	115,500	73,000
757-200F (Alcoa-SIE)	RB211-535E4	250,000	188,000	117,350	70,650
757-200F (Alcoa-SIE)	PW2040	250,000	188,000	116,750	71,250

OPERATING PERFORMANCE OF LARGE NARROWBODY FREIGHTERS

Aircraft type	Actual TOW lbs	Maximum payload lbs	Available payload lbs	Block fuel USG	Block time mins	Block fuel per ton-mile
MEX-MIA						
727-200F	168,214	56,200	32,750	4,539	186	0.27
757-200F (Precision)	210,490	72,500	60,332	3,450	186	0.11
757-200F (Precision)	212,905	73,000	62,883	3,489	192	0.11
757-200F (Alcoa-SIE)	210,490	70,650	58,482	3,450	186	0.12
757-200F (Alcoa-SIE)	212,905	71,250	61,133	3,489	192	0.11
UIO-MIA						
727-200F	152,557	56,200	9,290	5,516	238	0.83
757-200F (Precision)	197,328	72,500	41,117	4,311	240	0.15
757-200F (Precision)	199,360	73,000	43,419	4,330	245	0.14
757-200F (Alcoa-SIE)	197,328	70,650	39,267	4,311	240	0.15
757-200F (Alcoa-SIE)	199,360	71,250	41,669	4,330	245	0.15
BOG-MIA						
727-200F	171,463	56,200	31,667	5,023	204	0.26
757-200F (Precision)	204,982	72,500	52,772	3,741	205	0.12
757-200F (Precision)	206,823	73,000	54,775	3,777	210	0.11
757-200F (Alcoa-SIE)	204,982	70,650	50,922	3,741	205	0.12
757-200F (Alcoa-SIE)	206,823	71,250	53,025	3,777	210	0.12

MTOW from MEX, however, and none can carry their maximum structural payload *(see second table, this page)*, despite the flight time of 161-167 minutes.

The 727-200F has an RTOW of 168,214lbs, which is 86% of its MTOW. It has an available payload of 32,750lbs, which is 58% of its maximum structural payload *(see second table, this page)*.

The four 757-200F variants have RTOWs of 210,490-212,905lbs, which account for 84-85% of their MTOW. They have available payloads of 60,332-62,883lbs *(see second table, this page)*. This is 83-86% of their maximum structural payloads. Given that maximum volumetric payload is less than structural payload, the four 757 models will be able to utilise most or all of their volume on this sector.

UIO-MIA is the most severe of the three routes. UIO has a high elevation of 9,228 feet, a runway length of 10,236 feet, and an ambient midday temperature of 20ºC. The route has a tracked distance of 1,608nm.

The 727-200F suffers the most, and has an available payload of only 9,290lbs, which is just 17% of its maximum structural payload *(see second table, this page)*. This would clearly make the aircraft uneconomic on this mission.

The 757's engines benefit from high corner point temperatures, so their thrust performance does not degrade to the same extent as the 727's older JT8Ds.

The 727-200F has an RTOW of 152,557lbs and an available payload of 9,290lbs, which is 17% of structural payload *(see second table, this page)*. This clearly makes the aircraft uneconomic on the UIO-MIA route.

The four 757-200F variants are also penalised by Quito's challenging operating conditions. Their RTOWs are 197,000-199,000lbs, equivalent to 79-80% of the MTOW. The available payload is also affected, being 39,267-43,419lbs. Although this is just 56-59% of maximum structural payload *(see second table, this page)*, it is still enough to make the aircraft economic, taking into consideration the effects of packing densities and load factors. The fuel burn per ton-mile of the 757F models is also about 18% of the fuel consumption rates of the 727-200F.

The BOG-MIA sector is less severe. Bogota has a lower elevation and longer runway than Quito. The BOG-MIA route also has a tracked distance of 1,340nm, which compares to 1,608nm for UIO-MIA.

The 727-200F has an RTOW just 24,000lbs less than its MTOW. Its available payload is still affected by the fuel it requires to fly the mission, which is 31,667lbs or 56% of its structural payload.

The four 757-200F variants all have superior performance. RTOWs are 204,982-206,823lbs, equivalent to 82% of MTOW. Available payloads are 50,922-54,775lbs for the 757-200F models, accounting for 72-75% of structural payload *(see second table, this page)*. The fuel burn per ton-mile of the 757-200F is 43-46% of the 727-200F's fuel burn.

In practice, 727-200Fs rarely fly direct routes from BOG to MIA. Common operational procedures are for airlines to fly multiple, shorter sector operations. This means that airlines will fly an initial shorter route from BOG to a nearer airport which preferably has an elevation closer to sea level. The aircraft can then operate a shorter second leg with a payload closer to its maximum structural payload to MIA. While this is common with the 727-200F, multiple sector operations incur more costs than single-leg operations with the 757-200F.

Summary

The 737-200F and 727-200F in particular clearly suffer from their JT8D engines. These have the disadvantage of high fuel burn, which results in the high fuel load offsetting the remaining payload.

The 737-300/-400 and 757 have much lower fuel burn, engines with higher flat-rated temperatures, and overall stronger operating performance. The aircraft therefore have less restrictive take-off weights and higher payloads, and is clearly superior to the 737-200F and 727-200F in challenging conditions. AC