A recovery in international air freight traffic has coincided with a shortage of aircraft and high fuel prices. There are few MD-11Fs, 747-400Fs and 747-400ERFs available, leaving airlines to select between the 777F, 747-400SF, 747-8F and the postponed A380F.

Large widebody freighter selection

The strong recovery in the air freight industry over the past four years has led to a surge in demand for new and replacement aircraft.

In the high capacity category of aircraft, which have gross payloads of 200,000lbs and more, freight operators may choose from several aircraft types. These range from the smallest MD-11F up to the largest A380F, with five other types in between. Among these, the number of remaining MD-11s available for conversion is limited, and existing freighters are being outgrown by their operators. The 777-200F is the next largest aircraft, and is only available as a factory-built freighter. The third largest option is the 747-400, which is available as a new factory-built aircraft or now as a converted passenger aircraft. The 747-8F and the A380F are the fourth and fifth options, and are only available as new aircraft. These have gross structural payloads of 330,000lbs.

Selecting the optimum type depends on many factors besides payload capability. The payload performance of each aircraft is dependent on maximum allowable packing density, total containerised volume, volumetric payload and corresponding range. Other factors are aircraft cash operating costs and acquisition and financing costs.

The markets in which the aircraft operate also influence overall economics. Demand varies in different markets and routes, and in different directions on each route. Not only does this affect the volume of freight carried on each route, but also the net rates per lb of freight carried that airlines receive. While international markets such as China and the Asia Pacific have received a lot of attention, the large directional imbalance experienced by airlines in these markets is less publicised. Air freight leaving these countries to Europe and North America is greater than freight travelling in the other direction to China and the Asia Pacific.

Aircraft capabilities

The gross structural payload of each aircraft is the simple difference between the maximum zero fuel weight (MZFW) and the operating empty weight (OEW). The tare weight of containers and pallets used to carry freight is deducted to give net structural payload. The sum of the volume of each container or pallet used provides the total volume. There are several container and pallet configurations for each aircraft, so there is a range of net structural payloads and containerised volumes.

The net structural payload divided by the total volume provides the maximum packing density of freight that can be loaded into the containers and pallets without the aircraft exceeding its MZFW.

The maximum packing density should be considered in relation to the densities of different types of freight. Actual packing densities are about 6.5lbs per cubic foot for express packages, and 7-8lbs per cubic foot for general freight.

The payload specifications and characteristics of the different aircraft are

The number of MD-11s left for conversion are limited, and the conversion production line will close within two years. This only leaves the factory-built 777F for airlines that require a volumetric payload capacity of up to 75-80 tons. The 777F has a strong-payload range performance.

LARGE FREIGHTER PAYLOAD SPECIFICATIONS & CHARACTERISTICS

Aircraft type	MD-11F	777F	747-400SF	747-400F	747-400ERF	747-8F	A380F
MTOW lbs	633,000	750,000	870,000	875,000	910,000	970,000	1,300,727
MZFW lbs	461,300	547,000	610,000	610,000	611,000	709,000	886,258
Total container volume-cu ft	20,454	22,9762	25,714	26,597	26,597	29,792	32,553
Maximum packing density-lbs/cu ft	10.24	10.24	9.28	9.34	9.35	10.04	10.03
Volumetric payload@ 7lbs/cu ft	143,178	160,804	179,998	186,179	186,179	208,554	227,871
Range @ volumetric payload-nm	5,600	7,250	6,000	5,600	6,300	6,900	8,300
Payload @ 40% load factor-lbs	57,271	64,322	71,999	74,472	74,472	83,418	91,148
Range @ 40% load factor-nm	7,400	9,100	7,750	7,800	7,600	8,900	9,150

summarised *(see table, this page)*.

The range performance of the aircraft at maximum payloads is an important consideration in aircraft selection, and is just 3,635nm for the MD-11, and 4,900nm for the 777F. Range at maximum payload is similar for the 747-400SF and -400F at 4,300nm. The -400ERF has a longer range of 4,800nm. The 747-8F's range is 4,475nm, similar to the -400F/-400SF. The A380F has a range of 5,700nm with a full payload. These range capabilities have little significance, since they are for freight packed at the highest maximum allowable densities. Payloads will be lighter at typical packing densities, so non-stop range capability will therefore be longer.

These payloads are accommodated by total containerised volumes of 19,410-32,979 cubic feet *(see table, this page)*. These volumes allow maximum packing densities of 9.35-1.25lbs per cubic foot, with there being only a small difference between the seven aircraft types.

The volumetric payloads at packing densities of 7.0lbs per cubic foot, typical of general freight, provide the seven aircraft with volumetric payloads of 143,000lbs to 227,000lbs. The corresponding range for each aircraft with these payloads is longer than the standard range, and is 5,600nm for the MD-11F and 747-400F, 6,000nm for the 747-400SF, 6,300nm for the 747-400ERF, 6,900nm for the 747-8F, 7,250nm for the 777F, and 8,300nm for the A380F *(see table, this page)*. Range capabilities will be longer when aircraft are carrying less than a full payload.

Aircraft often operate with payloads at less than 100% of capacity, resulting in their being able to operate on longer routes. To illustrate this, the volumetric payloads at a load factor of 40% and the corresponding range of each aircraft is listed *(see table, this page)*. These payloads are 57,000-91,000lbs, with range capabilities being extended to 7,400-9,100nm *(see table, this page)*.

Markets & routes

The payload-range capabilities of these aircraft determine their revenue-generating capability on different routes and in different markets. The majority of routes with high enough traffic volumes to justify the use of the MD-11F or larger aircraft are East-West, rather than North-South. The three main East-West markets are: the transatlantic; the trans-Pacific; and Europe-Asia Pacific and China. "Our busiest markets are the Europe-Asia Pacific, followed by the transatlantic," says Robert Van de Weg, senior vice president sales and marketing at Cargolux.

Examples of transatlantic route distances are about 3,000nm for London Stansted-New York, and up to 5,050nm for Los Angeles-Frankfurt. This means that most transatlantic city-pairs can be operated non-stop in a westerly direction when experiencing headwinds, if all aircraft carry a full volumetric payload packed at 7lbs per cubic foot. The MD-11 may suffer a payload limitation on a few routes.

Tracked distances for Europe-Asia Pacific routes are longer than transatlantic routes, and are 4,400-5,800nm from London Stansted to Beijing, Seoul, Hong Kong and Singapore. Distances to these cities from Amsterdam are only 200nm shorter.

These distances are also within the full volumetric payload capabilities of the 777F, 747-400ERF, 747-8F and A380F, especially since tailwinds in an easterly direction reduce equivalent flying time.

Headwinds in a westerly direction increase the distance flown by 600nm, making longer routes outside the full range capability of the MD-11F and 747-400-400F/-400SF with a full payload.

The trans-Pacific has the longest routes. The six main points in the Asia Pacific are Tokyo, Seoul, Beijing, Shanghai, Hong Kong and Singapore. The five main gateways in North America are Seattle, Los Angeles, Chicago, Dallas and Miami. These points represent 30 major routes in this market.

Further points in the two regions are Singapore and Hong Kong, and Chicago, Dallas and Miami. Tokyo is the closest city to North America, with Tokyo-Seattle the shortest route at 4,200nm. Route lengths to other North American cities all increase from further Asia Pacific gateways. Route lengths from Singapore to the five main North American points are 7,100-9,200nm.

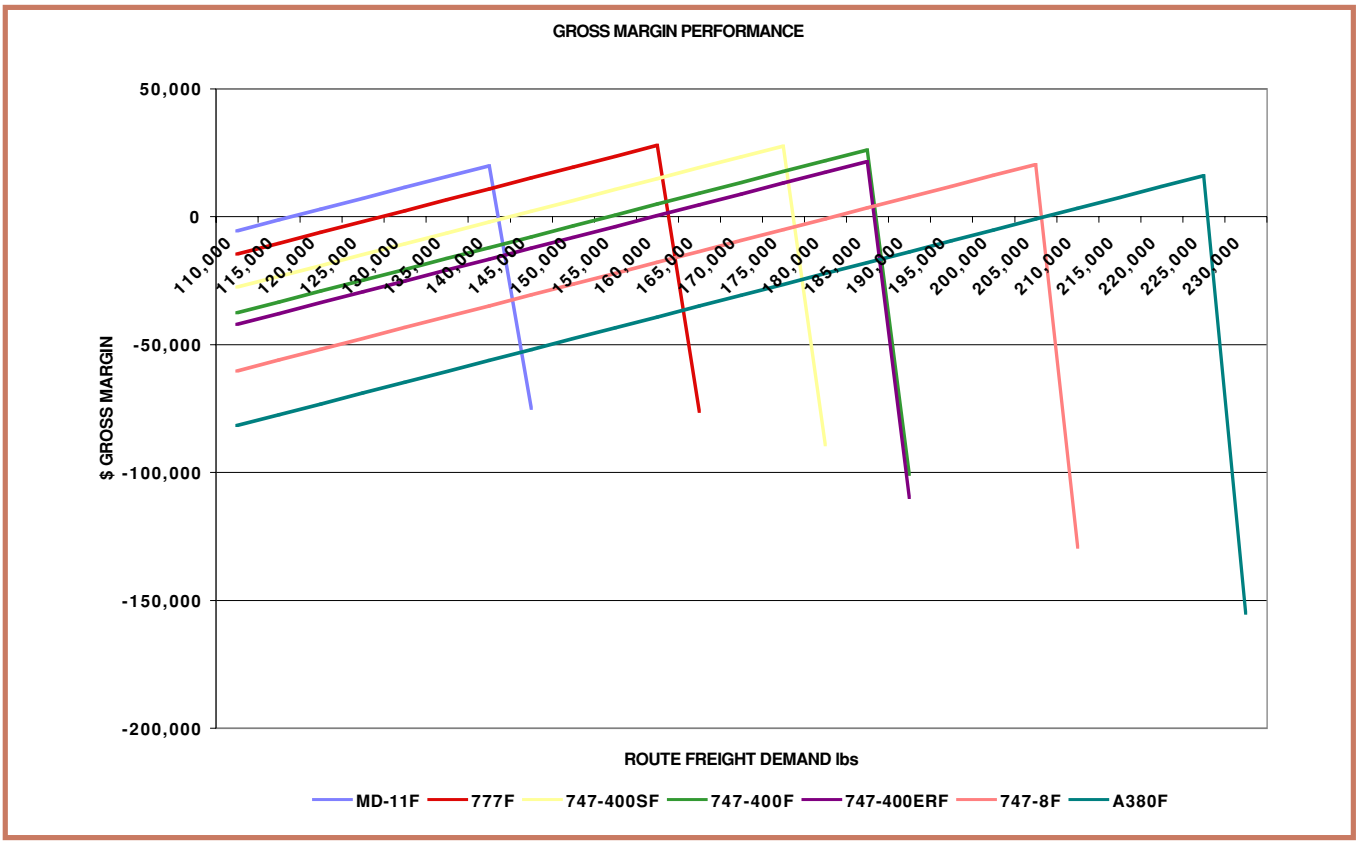
Most route lengths exceed the MD-11F's and 747-400F's/-400SF's range with a full volumetric payload at 7lbs per cubic foot, except for routes from Tokyo and Seoul to Seattle and Los Angeles. Moreover, only a few more routes come within the 747-400ERF's range due to its 700nm longer capability.

The 747-8F and 777F can service half the routes non-stop on the same basis. About four routes are out of reach of the A380F with a full payload, while the majority can be operated non-stop.

Airlines operating the longest routes have the option of technical stops at intermediary airports, although this incurs several costs. Anchorage serves as a midway point in the trans-Pacific, and is situated almost exactly in the perfect position for the 30 city-pairs described, being 3,000nm from Tokyo, 4,500nm from Hong Kong, and 5,900nm from Singapore. These lengths are within the range capabilities of most aircraft. Singapore-Anchorage is just outside the range performance of the MD-11F and 747-400F/-400SF with a full payload. Aircraft rarely operate with a full payload, and are likely to reach Anchorage with their usual load factors.

Route economics

Traffic imbalances to the Asia Pacific are large. Traffic leaving Asia for Europe is estimated to be 3.4 times the volume travelling from Europe. Traffic across the



trans-Pacific from the Asia Pacific is up to four times the volume of exports from North America to the Asia Pacific.

Directional imbalances influence the need for technical and refuelling stops at Anchorage. High freight loads are experienced by airlines leaving the Asia Pacific and China for North America and Europe. These high loads are therefore carried eastwards with a tailwind en route to North America, with the benefit that the route length is reduced by 500-600nm, thereby eliminating the need for refuelling stops on some of the routes.

High freight loads travelling westwards towards Europe face headwinds en route, making it impossible for the MD-11F and 747-400F/-400SF to carry a full load without technical stops when operating from cities such as Singapore and Hong Kong. The 747-400ERF can operate these longer routes with a small payload reduction.

Airlines are likely to be carrying low payloads when operating to the Asia Pacific and China. The 7,400-9,100nm range performance of the different aircraft at a 40% load factor indicates that all types can operate to all cities without technical stops, and avoid their associated costs. "Our average load factor is 72-74%, and our directional imbalances are similar to those experienced by all other operators in the market," says Van de Weg. "We have a particular imbalance with the Europe-Asia Pacific market, so demand is weak from Europe. We can mitigate this with traffic stops en route to the Asia Pacific in the Middle East." The effect of this is to operate shorter routes, but have higher load factors and so revenue.

The decision to make technical stops is an economic one. Where high loads and long routes require a technical stop, the operation will incur a wide range of additional costs. Van de Weg explains that two missions will inevitably mean a longer overall travelled distance and flying time compared to a non-stop mission. Two sectors will also lead to increased costs due to flightcrew, airport and navigation charges, fuel and aircraft maintenance. They will also reduce the efficiency of aircraft utilisation and productivity. These additional costs have to be considered against the value of the high freight load carried. "If we fly less than our maximum payload we can fly longer routes, which may be more economic than carrying the extra revenues and incurring the higher costs of two missions," says Van de Weg.

Aircraft selection

Once the operating performance of each aircraft across a range of routes has been assessed, the gross profit that it can make should next be considered. The gross profit is the difference between the revenue received for the payload carried and the aircraft-related operating costs. Revenue generated is simply a factor of average yield per lb of freight carried multiplied by the load.

The problem of directional imbalance is that where traffic volumes are strong in one direction, leaving China for the US or Europe for example, both load factors and yields are high, but load factors and yields are low in the opposite direction where demand is weak. Demand and yields on each route have to be assessed in both directions to arrive at an average revenue. Airlines are reluctant to have insufficient capacity for peak demand in one direction, so may incur losses due to weak volumes in the other direction.

The average revenue generated has to be compared to trip cost. A low volume of freight, for example of 110,000lbs, being carried on a 3,000nm trip can be carried on all types. This will leave the 747 models and A380 with surplus capacity, but may be economic for the MD-11F or 777F to carry. Trip cost will vary little by the weight of freight carried, so gross margin will increase with increasing load. When average freight demand on a route exceeds the aircraft's capacity, it will be more economic to switch to a larger type. Once freight demand increases from the MD-11's volumetric payload of about 140,000lbs *(see table, page 52)* to 145,000lbs, the most economic option is to switch to the larger 777F.

Up to the MD-11F's full volumetric payload of 140,000lbs the most economic aircraft will depend on the difference in the MD-11F's and 777F's trip costs.

As loads increase beyond the 777F's payload of 160,000lbs, a decision must be made about which of the 747 models or A380F to select. For freight volumes of up to 186,000lbs, the decision will be

OPERATING COST & ECONOMIC PERFORMANCE OF HIGH CAPACITY FREIGHTERS

Aircraft type	MD-11F	777F	747-400SF	747-400F	747-400ERF	747-8F	A380F
Volumetric payload-lbs	143,178	160,804	179,998	186,179	186,179	208,544	227,871
Total trip cost-$	99,107	108,185	121,162	131,146	135,653	153,888	175,258
Cost per lb available freight-cents	69	67	67	70	73	74	77
Break-even load at 85 cents/lb	116,597	127,277	142,544	154,289	159,592	181,045	206,186
Break-even load factor-%	81%	79%	79%	83%	86%	87%	90%

based on the relative trip costs of the 747-400SF, 747-400F and 747-400ERF.

A similar consideration for the 747-8F and A380F is required where freight volumes exceed 186,000lbs.

Selecting aircraft on the basis of the highest gross margin is simple where only one or two routes are flown, but more complex on a larger route network where levels of demand vary. Although matching aircraft capacity to demand is desirable, having more than one type in the fleet incurs higher operating costs. "We only operate 747-400Fs, so we need to decide not which aircraft size is correct, but how many traffic stops are required to fill a 747-400F," says Van de Weg.

Aircraft operating costs are influenced by average route length and annual utilisation, with increased utilisation generally favouring new aircraft over used types with higher cash operating costs.

Selection is further complicated by the reduced payload performance of each type on longer routes, and will favour types with longer range capability.

Aircraft trip costs

Average route length and aircraft utilisation determine aircraft trip costs. The most important markets are those serving China and the Asia Pacific, which is reflected by the number of 747-400Fs, 747-400ERFs, 747-8Fs and 777Fs that have been ordered by airlines operating from these regions. Typical route lengths are 5,000nm, and aircraft utilisations can reach 4,500 flight hours (FH) per year, although this depends on each operator and their route network. While this assumes the same rates of utilisation for all aircraft types, utilisations may actually vary between aircraft types and airlines in practice. Cargolux, for example, achieves up to 5,800 block hours per year with its 747-400Fs.

While older aircraft achieve fewer FH per year than new aircraft, the MD-11 and 747-400 maintain high reliability in passenger and freight service, are still relatively young, and have the same or similar flightdeck technology as new types.

Aircraft trip costs include fuel, direct maintenance, engine inventory costs, flightcrew, navigation charges, airport landing fees, aircraft insurance, and aircraft financing charges.

Fuel burns are more easily assessed for the MD-11F, 747-400SF, 747-400F and 747-400ERF, while estimates of reasonable accuracy can be made for the 777F, 747-8F and A380F.

A standard fuel price of $2.05 per US Gallon has been used.

This high fuel price results in fuel costs as high as $60,000 for the MD-11, $48,000 for the more fuel-efficient 777, and $69,000-96,000 for the 747-400SF/-400F, 747-400ERF and A380F. The cost of fuel has increased from 85 cents to 205 cents per USG over the past five years, and now accounts for 52-61% of total trip costs for these seven aircraft types.

Maintenance costs are well established for the MD-11F, 747-400SF, and 747-400F/-400ER. Predictions can be made for the 777F based on the passenger aircraft, taking into consideration the lack of passenger-related interior items. Estimates have been made for the 747-8F and A380F based on current types such as the 747-400F and A340.

Total direct maintenance costs for the 777F are $1,150 per FH, and $1,270 per FH for the MD-11, illustrating the advantage that young aircraft have over used. The 747-400SF has costs of $1,830 per FH, about $160 per FH more than the new-build -400F/-400ERF which benefit from lower airframe-check- and engine-related costs. The 747-8F's costs are expected to be higher at $1,800, once engine-related and component costs are taken into account. The 747-8 is expected, however, to benefit from a more efficient maintenance programme and similar airframe-related costs per FH. The A380's total costs are forecast to be $1,940 per FH.

Three flightcrew are assumed to be required on this long stage length, plus one supernumerary crew. Annual captain salaries for US airlines are $100,000 for MD-11s, rising to $120,000 for 747s. Average captain salaries are expected to be $130,000 for the 747-8F and $140,000 for the A380F. First officer salaries range from $68,000 for the MD-11F up to $106,000 for the A380F.

Annual crew costs have been increased by 35% to account for transport, meals, uniforms, hotels, training, employer's insurance and all other flightcrew-related costs. Crews are assumed to complete an average of 700FH per year, meaning that each aircraft requires six to seven crews.

Small costs are also incurred for navigation and landing fees. Navigation costs are a product of 20 cents per nm and the aircraft's MTOW factor. Landing fees vary, but are $5 per ton of MTOW.

Cash operating costs total about $84,000 for the MD-11F, $71,000 for the 777F, $97,700-$99,500 for the three 747-400 models, $111,300 for the 747-8F and $131,000 for the A380F. These have all been inflated by the rise in fuel costs, with the MD-11F's costs now being about $37,000 higher than they would have been four to five years ago. The A380F's fuel costs have been inflated by $56,000.

Aircraft financing accounts for the second largest portion of total aircraft costs, with the percentage for the MD-11F and 747-400SF being 15% and 17%. The percentages for new aircraft are higher, varying from 25% for the largest A380F to 34% for the smallest 777F.

Market lease rates for the MD-11F have risen to about $525,000 in recent years due to recovery in freight traffic and increased demand for aircraft. Market lease rates are not yet established for the 747-400SF, but are expected to be $750,000-800,000 given the high demand and short availability of aircraft.

The lease rates of the other five types are dependent on purchase discounts on list prices and financing terms. Purchase discounts of 40% have been assumed for all five types, although the relative popularity of different aircraft in the market means that some are likely to be offered to airlines with higher discounts than others. A monthly lease rate factor of 0.9% has been given to all types.

Boeing has taken the last orders for 747-400Fs/-400ERFs. This leaves freight carriers to choose between passenger-converted 747-400s and ordering the new 747-8F to provide similar payload capacities. Passenger aircraft will not come available for conversion for at least two years, however, and the first 747-8Fs will not be delivered until 2012.

The 777F and 747-400F have similar list prices of $220-240 million, with the -400ERF's list price being only $10 million higher. Resulting lease rates are $1.15-1.3 million per month for each of these three aircraft. The 747-8F's lease rental is $1.5 million, and the A380F's $1.58 million.

Total trip costs are lowest for the MD-11F at $99,000, and at $108,000 for the 777F. While the 777F benefits from lower fuel and maintenance costs, it loses this advantage because of its higher financing costs, even at this high rate of utilisation. The two aircraft have similar costs per lb of available volumetric payload, with the 777F four cents cheaper overall *(see table, page 55)*.

The three 747-400 models range from $121,000 for the -400SF up to $136,000 for the -400ERF *(see table, page 55)*. The -400SF's main benefit is its low financing charges in relation to its new counterparts. Overall it has the lowest cost per lb of available payload.

The 747-8F and A380F have higher total costs per lb of payload *(see table, page 55)*. Their cash operating costs are also higher even though they are the largest aircraft types.

Gross margin performance

Aircraft trip costs are also compared to revenues generated from different loads, with gross margins displayed against payload carried *(see chart, page 54)*. A saw-tooth curve is shown for each aircraft. These have been illustrated using a yield of 85 cents per lb of freight carried.

Headwinds on a 5,000nm route cause a small payload reduction for the MD-11F and 747-400F. Other types have sufficient payload-range capability not to be affected by this.

The MD-11F is the first to reach its maximum payload at 140,000lbs where it generates the highest possible gross margin. This then drops as demand surpasses the MD-11F's capacity and it is forced to make two trips with twice the trip cost. At this stage the 777F generates the highest gross margin, since only one trip is required, and its trip cost is also lower than the other types'. The 777F generates the highest margin from 140,000lbs to 160,000lbs *(see chart, page 54)*. The MD-11F is more commonly used in shorter North-South markets and transatlantic routes. There are also limited numbers left for conversion, so the 777F is more likely to be selected.

The 747-400SF generates the highest margin of all three 747-400 models, but only up to its payload capacity of 180,000lbs. The lighter -400F then has a cost advantage over the -400ERF up to 186,000lbs *(see chart, page 54)*. Operators are likely to utilise only one type, even where demand varies across their networks. The -400SF will be preferred where high loads and aircraft utilisations are not expected, while the -400F will be chosen by airlines operating in strong markets that are experiencing high growth rates over sustained periods.

The -400ERF has an advantage on certain routes where it can carry a superior payload to the -400SF and -400F.

As expected, the 747-8F and A380F excel where loads exceed the -400F's capacity *(see chart, page 54)*.

Considering the issues of availability with the MD-11F, 747-400F and 747-400ERF, the selection comes down to the 777F with loads up to 160,000lbs, the 747-400SF with loads from 160,000lbs to 186,000lbs, the 747-8F with loads from 186,000lbs to 205,000lbs, and the A380F for loads higher than 205,000lbs.

The break-even loads and load factors required when yields are 85 cents per lb are also summarised *(see table, page 55)*. These are equal to load factors of 79-90%, with the 747-400SF and then the 777F having the lowest break-even load factors. The 747-8F and A380F have the highest break-even load factors, which indicates that they require the strongest markets and demand levels for airlines to justify their use.

Costs are clearly high due to current fuel prices, but costs for engine inventory, emergency maintenance, ground handling and other crew members are excluded.

Summary

Although seven types are analysed, three can be disregarded because of lack of real availability: the MD-11F, because its numbers are limited and it is better suited to other markets; the 747-400F and -400ERF, which are relevant to the ultra-long-haul market, but for which the last orders have been placed. Airlines are therefore forced to choose between the 777F, 747-400SF, 747-8F and A380F.

The first 777Fs and 747-8Fs will enter service in 2012. The A380 has met delays and there are doubts over the freighter variant. Airlines that are interested in the 747-400SF also face delays. While there were some aircraft on the market in 2005 and 2006, values of -400s have increased again to a level that makes it uneconomic for lessors to acquire and convert aircraft. All seven types are therefore in limited supply. The analysis illustrates, however, the relative economics of the seven aircraft at current operating cost conditions. As 747-400s start retiring in larger numbers following the entry of the 747-8 and A380 into passenger service, it will become economic for lessors to convert 747-400s once their market values drop below the $30 million level. Lease rates will drop accordingly, and choice will be narrowed to the 777F, 747-400SF, 747-8F and A380F. AC