The 747F/777F/MD-11F are the backbone of the large freighter fleet that is capable of payloads more than 75 tonnes. Replacements must be found as older types age. High performing 777 family cargo conversions by IAI, KMC and Mammoth Freighters are analysed.

777 cargo conversions readying to replace 747Fs & MD-11Fs

Israel Aerospace Industries (IAI), Kansas Modification Centre (KMC) and Mammoth Conversions are all developing 777 passenger-to-freighter (P-to-F) conversion supplemental type certificates (STC). The cargo conversions are intended to reach gross payloads of 93 to 105.7 metric tonnes, and gross packing densities of 7.13lbs to 10.14lbs per cu ft. Importantly the cargo conversions will provide the first 777-300ER dedicated freighter.

IAI and KMC P-to-F conversions will be based on the big 777-300ER platform. Mammoth Conversions is developing a high packing density-focused 777-200LR conversion STC, and also a 777-300ER conversion.

The 777-200LR shares the same main characteristics as the popular 777F factory freighter, which made its debut in 2008, as Boeing's response to customer demands for a new-generation dedicated freighter to replace ageing DC-10Fs, MD-11Fs and 747Fs. It now makes up half of the large freighter fleet in 2022.

As 747-8F production ends, the 777F fleet is the only one still growing in this size sector. Yet the introduction of tough emission standards in 2028 means production of this popular large freighter must end.

The 777-8F is expected to make its debut in 2027, and serve as a 777F replacement. Boeing's 777-8F will be capable of a gross payload of 118 tonnes and achieve a maximum packing density of 9.67lbs per cu ft. By 2027, however, Airbus expects to have entered the large production freighter market with its A350F *(see Step into the arena: the A350F, Airbus' 109 tonne freighter, page 42)*. The 109-tonne A350F, which will have a maximum packing density of 9.41 lbs per cu ft., is planned to have an entry-into-service (EIS) date of 2025.

In the meantime, the 242ft long 777-300ER cargo conversion will have more cargo volume than most existing mainline freighters, except for niche special mission freighters, and the 747-8F.

The 747-8F was launched in 2005, and has a maximum payload of 139 tonnes. Its high volumetric and gross payload makes the 747-8F unique. Existing 747-8F operators are expected to fly the type for many years to come, and it is unlikely that significant numbers will be released to the market soon. Despite its impressive performance, low availability limits its suitability as a 747-400F and MD-11F replacement.

Unplanned heightened utilisation rates during the pandemic mean that operators now want to replace depreciated 747-400 and MD-11F freighters. For many operators the replacement freighters must have a lower capital expense (Capex) than factory rivals to make economic sense.

Markets

A lack of lower-lobe freight capacity on passenger widebodies in 2020 and 2021, caused by the pandemic, resulted in a surge in dedicated freighter operations. Freight rates and yields thrived partly thanks to exponential growth in eCommerce demand at the time. To alleviate capacity shortage, legacy freighters were pulled from desert storage facilities.

Spire Aviation flight-tracking data shows that MD11F/747-400F/747-8F/777F operations increased in the 12 months from September 2020 to September 2021, but from September 2021 to 2022 utilisation rates for the MD11F/747-400F/747-8F then declined. 777F utilisation increased from 20,000 flights per month during 2021, to slightly below 25,0000 per month by 2022.

The 777F saw the biggest utilisation increase among cargo aircraft over the past two years, exceeding the 747-400F, which was the leading air cargo carrier in 2021. The number of operational 747-8Fs and MD-11Fs has remained stable over the past two years.

MD-11 Freighter

The MD-11F was available as a factory freighter, while the MD-11BCF is a Boeing-converted freighter variant. The oldest MD-11F in service was built in 1990, and the youngest in 2001.

The MD-11F has been out of production for more than 20 years, and has no active P-to-F conversion programme. The active fleet of 117 will fall in number as aircraft are retired.

Nonetheless a gross structural payload of 202,000lbs for the MD-11F and 194,700lbs for the MD-11BCF means they are capable of heavy payload relative to their volume *(see table, page 50)*. As a result, the factory freighter has a maximum packing density of 9.91 lbs per cu ft, and the P-to-F conversion 9.55 lbs per cu ft.

In late 2022 there are three operators of MD-11F and MD-11BCF types: FedEx (58), UPS (42) and Western Global (17). "These are all US-based cargo carriers. UPS and FedEx are express carriers, and Western Global is a traditional freight carrier,"says Adam Guthorn, managing director at Alton Aviation Consultancy.

"The MD-11F fulfils a unique mission profile," says Guthorn. "UPS and FedEx fly it on relatively short stage lengths within the US. Their typical missions are

The 747-400F is used as a factory line-built freighter that has a 'nose loading' capability and as a passenger-converted freighter that is reliant on an aft main cargo door. The Boeing-converted freighter (BCF) and IAI's Bedek Special Freighter (BDSF) 747-400 conversions can attain payloads higher than 125 tonnes. The 747-400 freighters are on a par with the latest A350F and 777-8F designs in terms of volume, but they are all 'volumetrically' smaller than 777-300ER P-to-F conversions.

three to four flight hours (FH) per flight cycle (FC), whereas Western Global operates it on its trans-oceanic routes in the Atlantic and Pacific regions. Including a tech-stop in Anchorage, the average trans-Pacific stage length is 5.5 FH per FC."

The MD-11F and MD-11BCF are identical in terms of loading configuration. Both can carry 26 main-deck 96-inch x 125-inch PMC pallets, and 10 96-inch x 125-inch PMC pallets in the lower hold. The significant difference between the factory freighter and the P-to-F conversion is a 3.3-tonne maximum payload differential in favour of the MD-11F *(see table, page 50)*. At a 8.5lbs per cu ft. packing density the factory freighter can achieve a maximum revenue payload of 173,213lbs. Revenue payload is gross payload minus tare weight.

Operating at packing density of 7.5lbs per cu ft. translates to a maximum revenue payload of 152,835lbs *(see table, page 50)*.

According to Guthorn, the MD-11F is a difficult freighter to replace, partly because it occupies a unique segment within the market. Its 20,378 cu ft. of available volume puts it on a par with the A330-300P2F, yet the legacy freighter has a 30-tonne advantage in maximum payload.

In terms of replacements operators must forfeit payload when choosing the A330-300P2F, or opt for the 777F, which has an incremental increase in maximum payload, yet a 13% increase in volume.

Furthermore, a 777F will have a different cost structure to the MD-11F and its legacy CF6-80C2 and PW4460 series engines. Longevity of service means that most MD-11Fs are a low capital cost asset, with most now being fully depreciated. Replacing them is likely to incur finance and lease rents, plus maintenance reserve costs.

"The MD-11F is not the most fuel-efficient aircraft, but it does have a tried and tested engine maintenance programme, costs are reasonable and there is a lot of material on the aftermarket. Because of this I do not believe that these aircraft will retire soon," adds Guthorn. "It is likely they will be forced into retirement when they begin to hit their structural limitation of 20,000FC, or need an expensive life extension programme."

MD-11F monthly lease rental ranges from $130,000 to $155,000. Half-life market values start at $3.1 million for an early build year example and rise to $4.5 million. The average age of the fleet is about 28 years, and operators are happy to store the aircraft for a few months during spells of low traffic if needed. Low rates of utilisation mean it will be possible to operate the type for 40 years or more. Its longevity of service will be due partly to the lack of any direct replacement.

"The MD-11F was not used in the charter-brokering market. It has long-haul credentials, but in terms of payload and cost it is not comparable with the 747F. Before the advent of the 777F, nothing could compete with the 747-400F on long-haul routes," explains Neil Dursley, chief commercial officer, and member of the board of Chapman Freeborn and Magma Aviation.

On a 2,000 nautical mile (nm) trip, the MD-11F operating at the highest optional weights produces 338 grams CO2 per tonne-km in carbon emissions, burning 13.3 litres (L) per 100 tonne-km.

747-400 Freighter

The 747-400F fleet underwent a renaissance during Covid-19, and during the capacity crunch when stored examples were reactivated. To date the 747-400F is very popular and operated with more than 30 carriers globally. There are almost 220 currently in service.

Large fleets of 747-400Fs include Atlas Air (35), Kalitta Air (24), China Airlines (18), Cargolux (16) and UPS (13). Most (61%) are powered by CF6-80C2 engines, while 31% are fitted with PW4000s, and 7.5% with RB211-524G/H engines.

The oldest 747-400F in-service examples were produced in 1989, and the youngest in 2009. Of this number 63% are more than 20 years old.

"The active fleet consists of factory-built 747-400Fs, and -400ERFs with nose-door loading capability. There are also the Boeing-converted freighter (BCF) and IAI Bedek Special Freighter (BDSF) cargo conversions that have a more conventional side cargo door fitted," explains Guthorn. "The BCF conversion is no longer available, and the IAI-converted freighter is 'technically' still available, but it has been many years since one was last converted."

According to Guthorn there are about 20 potential candidates remaining within the 747-400 passenger fleet that are 15-20 years old, and could be eligible conversion candidates. "It is unlikely that any of these aircraft will be converted, as the fleet is now fixed and is declining," adds Guthorn.

Resurgence

Some 747-400 operators are not happy that numbers are in decline because there is no immediate 'like-for-like' alternative.

According to Shmuel Kuzi, executive vice president and general manager of aviation group at IAI, investor interest in 747-400BDSF conversions has risen. "The issues for the 747-400 are maintenance costs, service life, and whether investing in it will generate a return," adds Kuzi. "The 747-400 has an excellent service life, but its maintenance costs will increase as it ages. The 747-400BDSF has some of the highest gross payloads, so phasing it out is not easy."

According to Kuzi, IAI 747-400BDSF P-to-F conversions are still available. "We have the conversion STC and the licence. The 777-300ERSF and the 767-300BDSF

The 777-300ERCF by KMC will have 33 main-deck and 14 lower-deck pallet positions, including 600 cu ft of bulk storage. This translates to 28,739 cu ft of revenue-generating payload, and a 41% improvement compared to MD-11Fs, and a 13% improvement against 747-400 converted freighters. The twin engine platform delivers a substantial fuel saving compared to legacy types, and will achieve a maximum revenue payload of 186,804lbs at a packing density of 6.5lbs per cu ft.

programmes are taking up most of the available hangar space in Tel Aviv. If investors want to convert the 747-400 then we can help them do it, but we cannot convert them in Israel."

To complete a 747-400BDSF P-to-F conversion the investor must partner with a Part 145 maintenance facility to complete the modification. IAI will assist and provide the expertise to complete the conversion. "There are negotiations in play at the moment," explains Kuzi.

747F daily utilisation rates for carriers such as Atlas Air, Kalitta and UPS, are 6-7FH, and 3,000-4,000FH per year. Typically, the freighter is used on long-haul routes between Asia and North America, and North America, Europe and Africa. Because of the unique capability, especially on the factory freighter, some US carriers fly military charter operations.

"The factory freighter's nose-loading ability is a bonus," says Guthorn. "The 747-8F is the last type with this capability in production now, and it is likely that a good number of 747-8Fs will remain in service for beyond 30 years. Among the 747-400Fs, the younger extended range freighter (-400ERF) is most likely to be operated for the longest period."

At its highest optional weight the 747-400F has a gross structural payload of 129 tonnes, a cargo volume of 26,067 cu ft, and a maximum packing density 10.9lbs per cu ft *(see table, page 50)*. The 747-400F has a maximum revenue payload of 195,502lbs, assuming packing density of 7.5lbs per cu ft.

A higher packing density of 8.5 lbs per cu ft yields a 221,569lbs maximum revenue payload *(see table, page 50)*, and one of the highest in this cohort.

High packing densities for the factory 747-400F and its P-to-F counterpart make the freighters ideal for heavy general cargo loads. The factory freighter's nose-loading capability improves loading efficiency for large, outsize industrial cargo. The factory freighter also has a 134-inch x 123-inch (H) side cargo door located aft. The converted freighters have a similarly-sized main-deck cargo door in the aft position.

On a 3,000 nautical mile (nm) trip, the 747-400F operating at the highest optional weights produces 343 grams CO2 per tonne-km in carbon emissions, burning 13.5 litres (L) per 100 tonne-km. On the same trip, a 747-400BCF operating at the highest optional weights produces 359 grams CO2 per tonne-km in carbon emissions, burning 14.2L per 100 tonne-km.

According to Boeing, the 777F produces 21.6% less CO2 per tonne-km in carbon emissions than the BCF, and reduces full burn by 21.1%.

"One of the most noticeable differences for legacy types is the increase in fuel burn and carbon emissions," explains chief operational officer at Kansas Modification Center, Jim Gibbs. "As the world energy crisis tightens, and people become more focused on emissions, there will be greater pressure to retire less fuel-efficient types. Recently Israel has announced measures to restrict access to airport airspace for all four-engine aircraft."

Aircraft ban

The Israel Airports Authority (IAA) will implement a quad-jet ban at Ben Gurion airport in March 2023 over growing environmental, noise and sustainability concerns. Exemptions, however, will be granted by the IAA under exceptional circumstances, after special permission has been obtained in advance. There are no scheduled passenger airlines operating in or out of Ben Gurion with four-engined aircraft, so 747 freighter family operators will be most affected.

Data illustrates that 98% of recent quad-jet departures from Ben Gurion airport are freighters, and make up less than 1.6% of the total departures for August 2022. Almost all of these are 747F family and 747-400BCFs.

There is some scepticism over the ban, and some critics believe it is part of a ploy to drive customer demand for the IAI 777-300ERSF converted freighter. According to Gibbs, regional and airport quad-jet bans could become more common in the future.

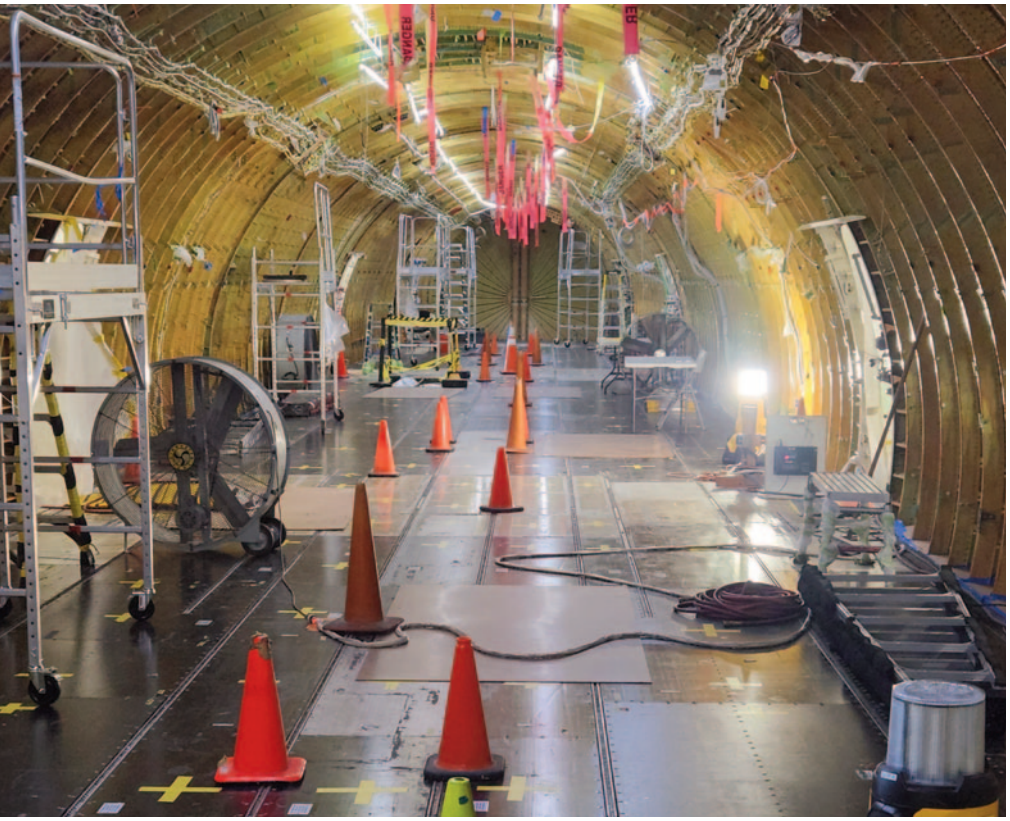
"National aviation authorities (NAAs) and freight carriers will increasingly ask 'why are we operating four-engine aircraft when the same mission can be completed more efficiently with a twin-engine aircraft?'" says Gibbs. "Being less efficient is one of the reasons why legacy aircraft have been axed from the passenger market. However, with the introduction of Extended-range Twin-engine Operations Performance Standards (ETOPs) rated freighters, most four-engine types will eventually disappear."

Rising fuel prices are concerning many freight operators at present. Recently FedEx adjusted its preliminary forecast, indicating a slowing of the global economy and worsening macro conditions. FedEx reports the reduction in volumes is outpacing its cost-cutting measures, and as a result it is cutting flights and focusing on fuel prices.

Lease rents for converted freighters range from $195,000 to $250,000 per month, with BCFs commanding a marginal increase in premium over BDSFs. Monthly lease rates for factory freighters start at $300,000, and rise to $455,000. Lease rates for sought-after 747-ERFs are about 10% and 20% higher than 747-400Fs.

777F

The 777F is the newest member in this sector and has the largest cargo capacity of any twin-engine freighter currently in service. The 777F meets stringent quota



Mammoth Freighters is developing both 777-200LR and 777-300ER P-to-F conversion STCs. The 777-200LRMF has very similar payload characteristics to the popular 777F and achieves a maximum payload greater than 105 tonnes. The 777-300ERMF has a gross payload greater than 99 tonnes and a maximum packing density of 7.66 lbs per cu ft. Mammoth Freighters has increased the size of the main cargo door for both its conversions. This improves operational flexibility and the ability to load 'oversized' and project cargo. Both Mammoth conversions are expected to work alongside existing 777F and other large freighter fleets.

count QC2 noise standards for maximum accessibility to noise-sensitive airports.

The freighter is designed to integrate with existing cargo operations and facilitate interlining with existing 747F fleets. Operators can transfer 10ft high pallets between the two types with ease via a 146.5-inch x 124-inch (H) main-deck cargo door.

Introduced in 2008, there are now more than 215 777Fs in active service with more than 20 airlines. To date a freighter version of the 777 is only available as a factory freighter that is based on the 777-200 platform. Of all 777Fs in service, 92% are equipped with GE90-110B1 engines, compared to 8% equipped with the more powerful GE90-115BL engine.

Large operators of 777Fs include AeroLogic (20), China Southern Airlines (14), FedEx (51), Emirates Airlines (10), China Cargo Airlines (9) and Ethiopian Airlines (9).

In 2019, the 777F list price was $352.3 million. Lower monthly lease rates are about $730,000, and higher rates are $1.2 million.

High 777F utilisation rates are needed to offset the capex. This means the aircraft must be operated as frequently as possible for investors and operators to generate a good return and cover lease rentals. Since factory freighters are younger than their P-to-F siblings, despatch reliability rates are fundamentally better. Furthermore, new aircraft are typically covered by factory warranties and a large support network.

777F carriers typically operate it at 7-9FH per FC and use it for 5,000FH per year; more than MD-11Fs and 747-400Fs. "The younger freighter is more efficient and has the lowest variable operating costs, so you fly this asset the hardest," says Guthorn.

To create the 777F, Boeing mates the -200 fuselage with the wings of the -300ER. The shorter -200 fuselage and improved wing loading mean the 777F is an excellent performer in terms of gross payload and maximum packing density.

The 777F is capable of a 106.6-tonne gross payload and has a maximum packing density of 10.23lbs per cu ft. Configured with 27 main-deck 96-inch x 125-inch pallets and 10 lower-deck 96-inch x 125-inch pallets, the freighter has a revenue packing density of 9.75lbs per cu ft *(see table, page 50)*. At a revenue packing density of 7.5lbs per cu ft, the freighter can carry a payload of 172,283lbs: 12% lower than the 747-400F, and 13% greater than the MD-11F.

At revenue packing density of 8.5lbs cu ft, the 777F can achieve a maximum payload of 195,254lbs per cu ft; 12% lower than the 747-400F, and 11% greater than the MD-11F. Configured with 37 PMC pallets, the 777F has a 22,971 cu ft of capacity and the second lowest in its class, yet 4,380 cu ft more than the A330-300P2F.

According to Dursley, the typical mission for the 777F is largely route-dependent. "These are long-haul aircraft. In terms of cargo and density, it is not uncommon for a 777F operating out of China on a transpacific or European route to be loaded with eCommerce cargo. Alternatively in another region the aircraft could be loaded with 'project-cargo' such as oil and gas equipment."

"There will be a place for both 777F and P-to-F conversion aircraft, because the freighters will be handling multiple industry verticals. This could include transporting perishables such as fresh fruit, vegetables and flowers out of Nairobi, and then dense automotive equipment and military hardware from another region. I see them as being the workhorse of supply chains in the future," adds Dursley.

777-300ERCF

KMC has formed a partnership with NIAR WERX to develop a 777-300ER cargo conversion. Identified by its 777-300ERCF designation, the converted freighter is expected to have a maximum payload of 93 tonnes and be granted a Federal Aviation Administration (FAA) STC approval no later than June 2024.

"It will be possible to use the 777-300ERCF for both general freight and eCommerce missions. We have completed many studies, including analysis for cargo loads that are difficult to haul," says Gibbs. "Ultimately, we are replacing a large portion of the floor structure and have inbuilt running loads sufficient to support general cargo weights. The freighter will be able to handle a GE90 engine and heavy oil field equipment."

Based in Wichita, KMC will be responsible for the 777-300ERCF STC and accountable for customer support, procurement and parts manufacturing authority. NIAR WERX will provide the engineering, test and certification and modification 'touch' labour.

NIAR was established in 1985 and its applied research facilities have previously completed projects on behalf of Boeing and the FAA. It has its own virtual engineering and test labs, aircraft structural test and evaluation centre, and a national centre of aviation training.

WERX is part of the NIAR group and was established in 2018. NIAR WERX has recently partnered with Precision to provide Part-145 labour and additional conversion capacity to the A321-200PCF programme. NIAR WERX also has experience in firebomber conversions, and is modifying two 737-500s for oil spill response roles.

WERX is located at a former Boeing Wichita modification centre. Skillsets include design, stress analysis, powerplant, plus flight testing and certification.

According to Gibbs, the eCommerce express operations are driven by volume, so freighters are limited by volume rather than gross payload. Configured with 33 main-deck 96-inch x 125-inch PMC pallets, the 777-300ERCF has an main deck capacity of 22,441 cu ft, and a lower deck capacity of 5,698 cu ft, plus 600 cu ft of bulk storage. The 777-300ERCF has total volume of 28,739 cu ft in this configuration. This is 10% more than the 747-400BDSF, and 41% more than the MD-11F *(see table, page 50)*.

"We expect eCommerce packing density to rise in future, as manufacturers improve the way that goods, such as electronics, are packed. We have designed the 777-300ERCF to handle dense and volumetric payload for today's market and in the future. We feel that there will be very few times that packing density will be the limiting factor on this aircraft," says Gibbs.

The 777-300ERCF has a maximum packing density of 7.13lbs per cu ft and a maximum revenue packing density of 6.64lbs per cu ft *(see table, page 50)*. At a 6.5lbs per cu ft packing density the 777-300ERCF will have a maximum revenue payload of 186,804lbs. Total revenue payload at this packing density 7% greater than the 777-8F and 13% more than the A350F.

The operating empty weight (OEW) of a baseline specification 777-300ERCF equipped with a manual cargo loading system (CLS) is 329,000lbs *(see table, page 50)*. NIAR WERX analysis shows that a 5,000lbs reduction in OEW translates to a 184lbs per hour saving in fuel. Assuming a typical fuel charge of $3 per gallon, this could save more than $247,000 annually.

"The comparatively low 329,000lbs OEW of the KMC STC will save on average 1,840lbs in fuel on each 10-hour flight. If the average aircraft utilisation rate is 3,000-4,500 FH per year, the operator will save millions during the aircraft's operational life," adds Eric Kivett, NIAR WERX programme manager for the 777-300ERCF.

Comparing the 777-300ERCF to the factory freighter, Gibbs adds that "the capex variable will influence a lot of the general freight and express operators. If you need a 777F the only option is to buy a brand new one. It is a capable aircraft, but the 777-300ERCF can perform most factory freighter missions at a much lower capex."

Mammoth

The Mammoth 777-200LRMF conversion is based on the 777-200LR platform, while its 777-300ERMF is based on the 777-300ER. The production run for the 777-200LR long range (LR) totals 62 examples from 2006 to 2021.

Both models are powered by GE90-110B/115B family of engines, most 200LRs by the 110B and all the 300s by the GE90-115B family. Most of the -200LR fleet (92%) is more than 10 years old. Mammoth has acquired 10 examples from Delta Airlines.

To date Mammoth has 29 firm orders: AviaAM 777-300ERMF (6), and Cargojet 777-200LRMF (4), undisclosed (19), and 12 additional orders in the contract phase.

"We have inducted the prototype 777-200LR for conversion, and the second aircraft has now arrived at the facility. This aircraft will be inducted in January 2023 after some initial maintenance and the interior strip," explains chief executive officer Bill Tarpley of Mammoth Freighters. "The first 777-300ER has also arrived, and we will be storing that aircraft before its pre-induction flight tests ahead of its induction in March 2023."

The 777-200LRMF STC date is targeted between 4Q23 and 1Q24, and the 777-300ERMF is expected to be granted approval six months later. Much of the engineering work is complete, parts are being manufactured, and the assembly tooling is on site. According to Tarpley, Mammoth Freighters is buying over 95%

PAYLOAD CHARACTERISTICS OF 75-100 TON FREIGHTERS

Aircraft type	Boeing 777F	Mammoth 777-200LRMF	Mammoth 777-300ERMF	IAI 777-300ERSF	KMC 777-300ERCF
MTOW - lbs	766,800	766,000	775,000	775,000	775,000
MZFW - lbs	547,000	541,000	543,000	558,000	534,000
OEW - lbs	312,000	308,000	323,000	336,000	329,000
Max payload - lbs	235,000	233,000	220,000	222,000	205,000
Max payload - metric tonnes	106.6	105.7	99.8	100.7	93
Maximum packing density - lbs / cu ft	10.23	10.14	7.66	7.72	7.13
Main deck volume - cu ft	18,301	18,301	22,441	22,441	22,441
Main deck ULDs	(27) 96 X 125 PMC	(27) 96 X 125 PMC	(33) 96 X 125 PMC	(33) 96 X 125 PMC	(33) 96 X 125 PMC
Main deck tare - lbs	8,100	8,100	9,900	9,900	9,900
Lower deck ULDs	(10) 96 X 125 PMC	(10) 96 X 125 PMC	(14) 96 X 125 PMC	(14) 96 X 125 PMC	(14) 96 X 125 PMC
Lower deck volume - cu ft	4,070	4,070	5,698	5,698	5,698
Lower deck tare - lbs	3,000	3,000	4,200	4,200	4,200
Lower deck bulk volume - cu ft	600	600	600	600	600
Total volume - cu ft	22,971	22,971	28,739	28,739	28,739
Total tare weight - lbs	11,100	11,100	14,100	14,100	14,100
Maximum revenue payload - lbs	223,900	221,900	205,900	207,900	190,900
Maximum revenue packing density - lbs / cu ft	9.75	9.66	7.16	7.23	6.64
Revenue payload @ 6.5 - lbs/cu ft	149,312	149,312	186,804	186,804	186,804
Revenue payload @ 7.5 lbs/cu ft	172,283	172,283	205,900	207,900	190,900
Revenue payload @ 8.5 lbs/cu ft	195,254	195,254	205,900	207,900	190,900

Aircraft type	Boeing 777-8F	Boeing 747-400F	IAI 747-400BDSF	Airbus A350F	Boeing MD-11F
MTOW - lbs	805,000	811,000	870,000	703,275	630,500
MZFW - lbs	tbc	635,000	635,000	524,700	461,300
OEW - lbs	tbc	350,690	357,000	284,400	259,300
Max payload - lbs	260,600	284,310	278,000	240,300	202,000
Max payload - metric tonnes	118.2	129	126.1	109	91.6
Maximum packing density - lbs / cu ft	9.67	10.9	10.93	9.41	9.91
Main deck volume - cu ft	21,061	21,462	20,820	20,150	15,718
Main deck ULDs	(31) 96 X 125 PMC	(30) 96 X 125 PMC	(30) 96 X 125 PMC	(30) 96 X 125 PMC	(26) 96 X 125 PMC
Main deck tare - lbs	9,300	9,000	9,000	9,000	7,800
Lower deck ULDs	(13) 96 X 125 PMC	(9) 96 X 125 PMC + (2) LD3	(9) 96 X 125 PMC + (2) LD1	(12) 96 X 125 PMC	(10) 96 X 125 PMC
Lower deck volume - cu ft	5,291	4,085	4,085	4,980	4,150
Lower deck tare - lbs	3,900	3,000	3,000	3,600	3,000
Lower deck bulk volume - cu ft	600	520	520	399	510
Total volume - cu ft	26,952	26,067	25,425	25,529	20,378
Total tare weight - lbs	13,200	11,700	11,700	12,600	10,800
Maximum revenue payload - lbs	246,800	272,610	266,300	227,700	191,200
Maximum revenue packing density - lbs / cu ft	9.16	10.46	10.47	8.92	9.38
Revenue payload @ 6.5 - lbs/cu ft	175,188	169,435	165,262	165,938	132,457
Revenue payload @ 7.5 lbs/cu ft	202,140	195,502	190,687	191,467	152,835
Revenue payload @ 8.5 lbs/cu ft	229,092	221,569	216,112	216,996	173,213

Typical aircraft OEW
Maximum MZFW
Tare weight can vary by manufacturer

IAI has a proven record in producing passenger converted freighters, including lucrative 737, 747 and 767 programmes. The prototype 777-300ERSF is expected to be redelivered in early 2023, and attain a maximum payload greater than 100 tonnes, in part attributed to a significant increase in aircraft MZFW. At a packing density of 7.5 lbs per cu ft the 777-300ERSF will have a payload of 207,900lbs, and an improvement compared to existing 747-400Fs and MD-11Fs. IAI is adding 777-300ERSF conversion capacity, including remote sites, to match anticipated levels of high demand exceeding 10 years.

of all parts from US vendors which will mitigate against international supply chain delays.

The 777-200LRMF has a maximum payload of 105.7 tonnes and a maximum packing density of 10.14lbs per cu ft. *(see table, page 50)*. The 777-300ERMF will have a maximum payload of 99.8 tonnes and a maximum packing density of 7.66lbs per cu ft.

In terms of maximum payload, the 777-200LRMF and the 777F are very similar. Volumetrically they are identical. The 777-200LRMF has a maximum revenue payload of 149,321lbs at a packing density of 6.5lbs per cu ft, and 172,283lbs at a packing density of 7.5lbs per cu ft *(see table, page 50)*. The 777-200LRMF is capable of 16% more revenue payload than the MD-11F.

The 777-300ERMF has a maximum revenue payload of 205,900lbs at a packing density of 7.5 lbs per cu ft. This is 2% more than the 777-8F and 8% more than the A350F loaded at the same packing density.

"The 777-200LRMF will complement the 777F. It has a similar payload and packing density and will work as a sistership to the factory freighter. The 777-300ERMF's lower packing density means it will probably find a different market. This could be with the same operator, but it is likely that the 777-300ERMF's primary focus will be express and eCommerce freight," adds Tarpley.

Before Covid-19, express freight made up 20% of airfreight. Despite growth rates peaking during the pandemic, express markets are growing and will remain. The general freight market is expected to remain strong. According to Tarpley, the 777-200LRMF, 777F, 777-8F, and A350F will all meet that requirement with high packing density, payload and range.

Reducing OEW is a key focus of the Mammoth designs. This increases payload, while reducing operating cost. Mammoth Freighters adds maximum zero fuel weight (MZFW) to both its 777 freighters *(see table, page 50)* without altering their existing flight envelope. According to Tarpley, the 777-300ER P-to-F conversions all have a higher OEW because of the lengthened fuselage. This results in a lower payload than the 777F and 777-200LRMF. Mammoth Freighters is confident these weights are achievable without complicating the certification process.

To improve loading efficiency, Mammoth Freighters has a main cargo door that is 16.7 inches wider than both the 777F and other 777-300ER competitors.

The improved dimensions are to help the freighter compete with a 747 nose-loader. The design allows the aircraft to handle an array of large and wide pallets and irregular-sized items. According to Tarpley, the main cargo door has a wider opening than that of the A350F. "It is much easier to transport a Trent 1000 engine, for example. With other designs there is little margin for error when loading the larger engines," explains Tarpley.

IAI: 777-300ERSF

IAI has partnered with AerCap, formerly known as GECAS, and launched the jointly funded 777-300ERSF programme in 2019. At the time GECAS committed to 15 orders and 15 options. The programme will also see IAI enter into agreements for other lessors and airlines globally.

"We expect to be granted the STC in the first quarter of 2023," explains Kuzi. "Once the prototype is in continuous operation with an airline, investor interest for the 777-300ERSF will increase significantly, and people will better understand why it is a viable proposition.

"The prototype is almost finished, we have begun the second conversion, and soon we will be starting the third," continues Kuzi. "Next year we will be completing all three aircraft in quick succession. The prototype's EIS date is expected in summer 2023."

Conversion lines for the 777-300ERSF will be directed from IAI headquarters in Tel Aviv, with remote sites in Abu Dhabi and South Korea. Additional conversion sites in North America, Singapore and China are also under consideration.

"We expect that output will be high, and that there will be enough 777 conversion work at the IAI remote sites for more than 10 years," adds Kuzi. "We must remain focused, and we must be on time. We do not want to be in a situation where demand exceeds the rate of production."

According to Kuzi, 777-300ERSF firm orders have exceeded 50, but not yet reached 100. Organisations publishing firm orders include AerCap, Cargojet, Challenge Group, Emirates Cargo, EVA Air Cargo and Hongyuan Group. Most of these orders include options. Furthermore AerCap, Emirates and EVA Air are believed to be selecting feedstock candidates from existing portfolios.

MZFW is increased to 558,000lbs and typical OEW, including a powered CLS, is 336,000lbs, enabling the 777-300ERSF to achieve a maximum gross payload of 100.7 tonnes *(see table, page 50)*. Maximum packing density is 7.72lbs per cu ft. At a revenue payload of 7.5lbs per cu ft, the 777-300ERSF can haul 207,900lbs, and more than 17,000lbs higher than a 747-400BDSF.

"Boeing created an excellent platform with the 777-300ER. This is one of the reasons we can extract such a high payload from the P-to-F conversion," says Kuzi.

The 777F is popular with freight operators and makes up about 50% of the large freighter fleet. New factory freighters including the expected A350F and 777-8F will have higher initial capital costs compared to P-to-F conversions. The 777-200LRMF is almost identical to the 777F in terms payload, yet with a comparatively low on-ramp cost. Despite lower maximum packing densities, operators will make 777-300ER conversions work, and take advantage of its volumetric payload, which is greater than that of most freighters.

"Then factor in IAI, and its 45 years of experience in delivering cargo conversions such as 737/747/757/767. Our engineers can look at the solution though a wide lens of knowledge, so the 777-300ERSF will have excellent payload and quality."

777-300ERCF forward door

The 777F main cargo door is placed aft of the wing and the rear portion of fuselage. Placing the door at the rear mitigates the possibility of a strike between cargo loading equipment and the engine and its surrounding structure. However, the fuselage structure aft of the mainplane is subjected to high loads because the tail section stabilises the aircraft during flight.

"The horizontal and vertical stabilisers are used to manoeuvre the aircraft. Pushing down on the tailplane will cause the aircraft to pitch up and vice-versa," says Kivett. "Imagine the high forces exerted throughout the aft sections of the fuselage during an engine-failure scenario. The aircraft is flying on one engine, and the pilot must use a lot of rudder inputs to simply maintain flight in a straight line."

According to Kivett, additional structure must be built into the aircraft in this area to overcome the high loads. Ultimately placing the cargo door in the aft area increases build complexity and adds weight that is detrimental to the aircraft's OEW.

The MD-11F, 737F and 767F have main cargo doors in the forward sections of the fuselage. The 777 fuselage comprises several sections. Designated Section 41 is the forward section including the cockpit and the tapered section of the fuselage.

Section 43 contains the aft part of the forward fuselage that is constant diameter cross-section and ends at the front of the wing box. Sections 44 and 45 contain the fuselage from the front of the wing-box section to the aft end of the main gear wells. Sections 46 and 47 contain the aft fuselage from the main landing gear wells to the aft pressure bulkhead.

"The Section 43 is 18ft longer on the 777-300 than on the 777-200 and the factory freighter," explains Kivett. "This makes it possible to position the main cargo door on a 777-300ER forward of the wing and maintain sufficient clearance between the engines and loading equipment. The 777-300ERCF's forward main cargo door is unique among 777 freighters. We end up with less reinforcement, lower risk to the structure, and an overall lighter installation."

According to Kivett, loaders will typically place two to four main-deck containers forward of the cargo door first to prevent tipping during the loading sequence.

IAI 777-300ERSF and Mammoth Freighters 777-300ERMF have aft-main-deck cargo-doors, partly to maintain commonality with the factory freighter, including the 777-8F.

777-300ER feedstock

A fundamental benefit for P-to-F conversion programmes is the high number of available feedstock examples. "The 777-300ER is a relatively young fleet of about 830 aircraft. The 777-300ER shares the same GE90-115B family of engines and airplane information management system (AIMS) and electrical load management system (ELMS) system. Apart from some minor differences, there is a high degree of commonality between all feedstock candidates," says Gibbs.

Production of the 777-300ER started in 2003, and production is in decline as new customers migrate to the 777-X, whose EIS is due in 2025. Examples built from 2003 to 2006 make up 8% of the 777-300ER passenger fleet, while aircraft built from 2007 to 2011 add up to 29%. Younger aircraft built from 2012 to 2016 total 48%, and aircraft built from 2017 to 2021 add up to 15%.

AIMS groups together the aircraft's most essential systems including the flight management computer (FMC), central maintenance computer (CMC), and aeroplane health monitoring (AHM). ELMS controls multiple electrical power sources, and distribution of electrical power.

Normally these systems are self-contained line replaceable units (LRU). Grouping them together means they can share one power supply, while also reducing weight and power requirement. "In terms of baseline configuration, 777-300ER feedstock candidates are very similar and the underpinnings are almost identical," adds Gibbs.

Half-life value for a 12-year-old 777-300ER is $21 million, and $19 million for a 15-year-old one. Many investors will want feedstock to be close to half life condition to have sufficient FC to remain in service for many years. 777-200LR half-life values are $16.5 million for a 12-year-old aircraft, and $14.7 million for a 15-year-old one.

Some 777-200LR and -300ER feedstock candidates have a smaller aft lower-hold cargo door, so the aft-lower-lobe can handle the LD3 container, but not the 96-inch x 125-inch PMC pallet. "The larger aft lower-lobe cargo door gives operators more flexibility," adds Tarpley. "The LD3 container has a higher tare weight, which is detrimental to revenue payload." About 38% of 777-200LR and 28% of 777-300ER feedstock candidates may have the smaller door. AC