**There are two passenger-to-freighter programmes launched for the A321. Andy Coupland, CEO of Aircraft Commerce Consulting analyses the key technical and payload characteristics of the EFW/ST Aerospace and the 321 Precision Conversions products. The A321F represents a technical challenge and a market opportunity.**

# A321F conversion programmes analysis

The number of narrowbody freighters entering the fleet has increased over the past 15 years. Large numbers of 737-300s have been converted since 2003, while a significant number of 737-400s and 757-200s has been converted since 2007. As a narrowbody, the 757-200 is in a class of its own in terms of structural payload and volumetric capacity. The number of 757-200s converted from 2012 to 2017 totals 121 units, compared to 44 737-300s and 109 -400s modified to freighter configuration during the same period. The number of 757-200s converted, however, fell from 29 in 2016 to 13 in 2017.

The 757 shares the same fuselage cross-section as the 737-300, -400, -700, and -800 variants, and is similar to, but slightly narrower, than that of the A320 family. These aircraft are all shorter than the 757-200, and of these the 737-800 has the longest fuselage. This allows it to accommodate 11 standard 'AAA/AAY' class 88-inch X 125-inch unit load devices (ULDs) on its main deck, plus a smaller container at the aft of the main deck when converted to a freighter. This creates a main deck volume of 4,977 cubic feet (cu ft).

The 757-200 freighter, by comparison, can accommodate 15 88-inch X 125-inch AAA/AAY ULDs on its main deck, providing a main-deck volume of 6,570 cu ft. This is 32% greater than that of the 737-800 P2F. It has a total freight volume, including belly holds, of 8,360 cu ft.

Above the 757-200 freighter in terms of capacity is the widebody 767-200/300. The 767-300ERF has a total containerised volume on both decks of 15,710 cu ft, so it offers almost twice the volumetric capacity of the 757-200F. The 767-300ERF's gross weight is 70% higher than the 757-200's.

## 757 market

The two largest 757 P2F programmes for the 757-200 are those of Precision Aircraft Solutions and ST Aerospace. These two programmes have converted 256 aircraft since 2000. Within this total, ST has converted 119 757s for Federal Express, and 34 for DHL, while Precision is currently inducting its 100th aircraft for conversion to be operated by DHL.

"We have seen high demand for 757 freighters in recent years," says Brian McCarthy, vice president for sales at Precision Aircraft Solutions (PAS). "We converted 39 aircraft during 2015, 2016 and 2017. This is more than the number we converted in the previous 10 years.

"Our criteria for feedstock and appropriate freighter conversion candidates are that the aircraft must be above line number (L/N) 210; have accumulated fewer than 28,000 flight cycles (FC); and be either in active service or have been in storage for only a short period," continues McCarthy. "Delta Airlines tends to extract the maximum possible utilisation and life from its aircraft, so if these are excluded there are about 240 aircraft that are suitable conversion candidates."

The number of 757-200s projected to be converted to freighters is expected to decline, however, given the diminishing number of candidate 757 airframes that will satisfy the P2F conversion criteria, despite the apparently large number of RB211-535E4- and PW2000-powered aircraft that are feedstock candidates.

"We are converting 20 aircraft this year, for the likes of SF Express and YTO in China, as well as DHL and Cargojet. Both SF and YTO continue to add aircraft to the schedule," adds McCarthy. "We expect 757 conversion activity to decline after another two to three years of conversions, which will be equal to 50-60 more aircraft.

"There are several factors that will cause this," continues McCarthy. "While there is plenty of good feedstock, the supply of good quality green-time engines will decline, requiring more engine shop visits. This is a major issue affecting carriers now, but we are encouraged to see new engine overhaul entrants like Standard Aero, and we hope more agencies will recognise this substantial market for both RB211 and PW2000 engine services. Airframes can be operated without any major issues for 15 years or more following modification to freighter. We have an abundance of low cycle 757s in operation, and nearly 195 in the feedstock queue with very low cycles. Another factor that will eventually reduce the number of 757-200s being acquired for conversion will be the supply of good quality used alternatives for modification.

"Moreover, all the airlines that have potential interest in acquiring 757 freighters have mostly satisfied their requirements for the aircraft. This includes DHL and FedEx," adds McCarthy. "Some airlines that operate for the e-Commerce giants may acquire more 757s, but this is included in the 50-60 probable remaining conversions. That said, new entrants and new breeds of logistic players could take to the air, and the 757 remains a real workhorse for a volume-hungry market. Some new entrants may also emerge in Europe as the e-Commerce giants 'square off' against each other."

## A321-200 freighter conversion

Aside from the 737-900, the A321 is the only narrowbody that can offer volumetric capacity, as a freighter, close to the 757-200. Conversion of A321-200 aircraft to freighter configuration, *The number of 757-200 freighter conversions is expected to decline over the next theee to five years. The A321 is the closest-sized alternative.*


however, represents both an opportunity and a challenge.

There are a number of different facets to the opportunity. Boeing's World Air Cargo Forecast 2016-2017 projects a growth in the global fleet of narrowbody freighters from 640 units in 2015 to 1,260 in 2035, implying average fleet growth of 31 units per year. This is all achieved by converting passenger-configured feedstock. The top end of the narrowbody sector will become afflicted by the dwindling availability of 757-200 feedstock suitable for conversion as described above. This will coincide with the dynamic growth of air express operations worldwide. This is a trend that is gathering pace, and might result in Boeing's narrowbody demand forecast being exceeded.

A clear requirement is emerging for a new freighter conversion programme to fulfil both replacement and market growth needs in the narrowbody freighter market with volume and weight payload broadly commensurate with 757 freighters, but with cash operating costs comparable to 737 freighters. The A321-200 P2F potentially offers air express operators this attractive combination of attributes. On-ramp acquisition costs must be contained to affordable levels if total operating costs are to be acceptable to operators whose low levels of annual aircraft utilisation provide only a limited number of flight hours (FH) to spread costs of acquisition and ownership.

Noise characteristics are also of growing importance, especially in environmentally-sensitive overnight operations to urban areas. The A321-200 will score well in respect to take-off and landing noise footprint.

At the lower end of the narrowbody freighter sector there is an increasing scarcity of suitable 737-300/-400 feedstock. While those programmes should now logically be giving way to conversion of the larger 737-800s, even the earliest such examples command prices that may render a P2F conversion economically uncompetitive in relation to capacity. In contrast, there is a potentially plentiful supply of suitable A321s available for freighter conversion at economically viable input prices.

Another factor that may drive interest in freighter conversions among A321-200 owners is the search for an aftermarket for aircraft that have been returned after primary lease periods. Aircraft configured for passenger service are frequently subject to an age-related 'Non-Addition Rule' in many jurisdictions, meaning aircraft over 15 years old cannot be added to the register of the country in question, but the same rules generally allow freighter aircraft aged up to 20-25 years old to be added. In some cases freighters are exempted altogether.

Finally, the A320/321's wider fuselage cross-section allowed Airbus to offer superior cargo volume in the belly holds than the equivalent Boeing model. The A320's outward-opening bellyhold doors also enhance access to the hold space.

As a consequence, unlike the 737 and 757, the A320 family carries structural containers on its lower decks. Maximum volumetric utilisation is achieved through use of the contoured 'AKH' or 'LD3-45W' ULD. Interline compatibility with the containerised belly holds of most medium widebody aircraft requires the use of the 'AKG' (also known as the LD3-45) ULD, but this asymmetric container sacrifices 17 cu ft of volume relative to the AKH when loaded in the hold of an A320-family aircraft. A further 20 cu ft of volume relative to the full-sized 64-inch high LD3 container is lost when the 45-inch high LD3-45 is transferred to the widebody. Both container types are loaded with a transverse orientation in the belly.

The containerisation of the belly in the Airbus A320 family (AKH/LD3-45 ULDs), therefore, offers a distinct advantage over 737 and 757 freighters with respect to both volumetric utilisation and turnaround time. Bulk-loading 737/757 bellies can be a labour-intensive process, which also exposes the cargo being loaded or unloaded to ambient conditions at ship-side. A significant further benefit of belly hold containerisation is experienced by operators wishing to transfer interline cargo in the containers to other A320 family aircraft, although this is not generally practised by major express integrators.

The A320 family lower holds can also be bulk-loaded, or a 'sliding carpet' contoured platform can be installed, which facilitates easier loading and unloading of baggage or bulk cargo.

## The challenge

The A321, along with other members of the A320 family, presents challenges to any organisation intending to certify a P2F conversion. The A320 family was designed using computer-aided-design software tools. Structurally the aircraft do not yield easily to reverse-engineering of design modifications.

The use of fly-by-wire (FBW) technology will not, in itself, present problems unless the cabling requires re-routing to effect freighter conversion.

The effect of these various issues has made any conversion a complex structural, maintenance and systems exercise.

*Aircraft Commerce* is aware of at least six A320 family conversion projects that have been launched since 2006, of which only two are finally being completed.

## A321 sub-types

The A321 can be sub-divided into three or four different main sub-types: the A321-100; the A321-200 current engine option (ceo); and the A321-200 new

**A321 FREIGHTER CONVERSION PROGRAMMES BASIC WEIGHT CHARACTERISTICS - WV00 & WV011**

| AIRCRAFT VARIANT | A321-200 | A321-200 | A321-200 | A321-200 |
|---|---|---|---|---|
| Weight variant | WV000 | WV011 | WV000 | WV011 |
| Converter | EFW | EFW | Precision | Precision |
| MZFW-LBS | 157,630 | 162,701 | 157,630 | 162,701 |
| MZFW-KG | 71,500 | 73,800 | 71,500 | 73,800 |
| OEW-LBS | 103,175 | 103,175 | 97,950 | 97,750 |
| OEW-KG | 46,800 | 46,800 | 44,338 | 44,338 |
| Gross structural payload - lbs | 54,455 | 59,526 | 59,880 | 64,951 |
| Gross structural payload - Kg | 24,700 | 24,700 | 27,161 | 29,461 |

engine option (neo). The A321-200ceo fleet can be further sub-divided between aircraft that have been retrofitted with sharklets and those that have not.

Fewer than 100 A321-100s were built from 1993 to 2001, and they have five relatively low maximum take-off weight (MTOW) options, ranging from 171,961 lbs (78,000 kg) to 196,211 lbs (89,000 kg). Their low gross weights and age together make them unattractive candidates for freighter conversion.

There are over 1,460 A321-200ceos in active service, including 741 without sharklets and 727 with sharklets.

The first A321-200ceos were built in 1997, and the aircraft are still in production. Aircraft without sharklets were built from 1997 to 2015. The end of production of aircraft without sharklets overlapped with production of aircraft with sharklets, which started in 2012.

Aircraft with sharklets are clearly too young to be considered for conversion, so this leaves the 741 aircraft in service and another 48 aircraft in storage without sharklets as the main group of potential conversion candidates.

The A321-200 offers a range of 2,000 nm in still-air conditions with full payload at an MTOW of 196,211 lbs (89,000 kg), and a longer range of 2,320 nm at the higher MTOW of 206,132 lbs (93,500 kg).

## A321-200 Weight Variants

Airbus uses the term ‘Weight Variant’ (WV) to describe each unique, certified combination of design weights that can be applied to a given aircraft in commercial operation. The weights which together constitute a WV are: maximum ramp weight (MRW), maximum taxi weight (MTW), MTOW, maximum landing weight (MLW), and maximum zero fuel weight (MZFW). The operating empty weight (OEW) is airframe-specific, and is established by weighing the aircraft.

A range of WVs will be certified by the manufacturer at the outset of the production process, and these certified weight combinations will be intended to offer the operating airline those weights that best cater for a specific operating network, whether this is driven by range, payload, or weight-related charges. Over time successive WVs will be certified that embody results of product improvements that will progressively be made during the development cycle of the aircraft type, creating ‘generations’ of WVs.

Changing an aircraft’s certified weights from one WV to another can be as a simple as a ‘paper change’ to the aircraft operating manual, or it may require structural modifications. WVs which reflect major product upgrades cannot retrospectively be applied to earlier production aircraft. A fee per unit weight of increase between each design weight of the new WV compared to the original will be levied by the original equipment manufacturer (OEM). Cost of such changes is not published.

The two most important weights for a freighter aircraft are the MZFW and OEW, since the difference between the two determines gross structural payload.

MLW is also of significance because freighters will frequently be required to carry an MZFW-limited payload. The MTOW is important for long-haul freighters where range is a key consideration.

A WV combining the lowest MTOW with the highest available MZFW will therefore be chosen for an A321 freighter conversion if the objective is to maximise payload but minimise weight-related airport and airspace user charges in a short-haul network. A WV that combines the highest MZFW with the highest MTOW will be chosen where range and payload are both of importance to the operator.

At the time of writing there are 12 different WVs for the A321-200, namely WV000 to WV011. MTOWs applicable to the A321-200’s WVs ranges from 171,961 lbs (78,000 kg) to 206,132 lbs (93,500 kg).

The A321-200 has nine different MTOW options. While six of these are in the same range as the five MTOW options for the A321-100, there are three higher gross weight options of 200,621 lbs (91,000 kg), 205,030 lbs (93,000 kg), and 206,132lbs (93,500 kg).

The MZFW of the lighter weight WV000 variant is 157,630 lbs (71,500 kg). The other four variants have an MZFW of 162,701 lbs (73,800 kg).

The only difference between the latter four variants is, therefore, the MTOW, with a consequent effect on the aircraft’s payload-range performance.

In the case of all A321 WVs, the MLW is 8,819 lbs (4,000 kg) greater than the MZFW.

## MZFW & OEW post-conversion

Freighter-conversion programmes for both Airbus and Boeing types generally result in a converted freighter with a lower OEW than the passenger-configured feedstock airframe, the net result of the numerous deletions and additions made throughout the fuselage during the P2F process. These include: removing or deactivating passenger doors; replacing or reinforcing beams within the main-deck floor matrix to provide increased running loads (bearing strength); installing a jig-built main cargo door (MDCD) and surround structure; installing safety vent doors; and replacing or reinforcing the door surround structure. The MDCD itself will require installation of a hydraulic or electric door operating system (usually hydraulic on narrow-body freighters). Mounting of a 9g rigid barrier/net at the forward end of the cargo compartment on fuselage attachment points is an essential part of the conversion process.

The area immediately behind the cockpit must be modified to provide supernumerary seating, and a crew rest area if possible. These modifications are often extensive and require considerable ingenuity in view of the very small amount of space available for such amenities.

The cargo compartment must receive a new cargo lining, ceiling and lighting, and a drainage system.

The cargo compartment must comply with FAR 'Class E' compartment criteria. Class E status, which is applicable only to freighters, necessitates a separate approved smoke or fire detector system to provide warning on the flightdeck. Controls for such mechanisms must be accessible to the flightcrew in the crew compartment. There must also be measures in place to exclude hazardous quantities of smoke, flames, or noxious gases from the cockpit compartment.

The requisite crew emergency exits must be accessible under any cargo loading condition.

A cargo loading system (CLS) must be installed on the main deck, allowing several arrangements of ULDs to be secured in the defined positions. Last, lightweight window plugs will normally be installed to replace the heavier window units of passenger aircraft.

Structural reinforcement of the main deck floor neither facilitates nor creates the certification basis for a supplemental type certificate (STC) to raise the MZFW to a level higher than that offered within the standard WVs for passenger-configured aircraft.

Such main deck floor strengthening merely increases the running loads of the floor to permit greater loads to be born by that structure.

The process of gaining an STC to increase the MZFW above that already certified by an OEM differs from that for floor-strengthening. It involves either validating the existing wing/fuselage attachment structure to safely tolerate a higher MZFW, or defining the means by which the aircraft structure can be strengthened. This load analysis may also encompass the wing box and main landing gear.

Neither of the A321-200 P2F projects considered here is known to be proposing an MZFW increase for the A321PCF. Precision has accomplished this together with a design organisation in the context of the 757.

## A321-200 P2F programmes

Several A321 P2F conversion programmes for the A321 have been mooted or initiated since 2006. At the time of writing, two such programmes, those of LCF Conversions, based in Malta, and C-Cubed Aerospace of California, are understood to be active and awaiting receipt of sufficient funds to proceed to full-scale prototyping and award of an STC.

Current A321 P2F activity is therefore dominated by two well-established programmes that are fully funded and committed to early certification of an A321 P2F conversion: those of EFW/ST Aerospace (EFW), and 321 Precision Conversions (Precision). These two products are evaluated here.

## EFW/ST Aerospace A321P2F

The EFW/ST Aero A321P2F programme was launched, together with the A320P2F programme, in June 2015. An initial order for 10 A321-200 conversions was secured from Vallair Solutions of Luxembourg at the Singapore Airshow in February 2018. Vallair is also the launch customer for 321 Precision Conversions.

EFW is a subsidiary of both Airbus (45% ownership) and Singapore-based ST Aerospace (55% ownership). ST Aerospace will develop the STC and assume responsibility for production of the conversion kit, while EFW at Dresden will take responsibility for sales, marketing and customer support. Conversions will be performed at both locations. Airbus will provide OEM support for the converted freighter in conjunction with the STC holder. The prototype A321-200 will be inducted for conversion modification in 2018, and is due for re-delivery as a service-ready freighter by late 2019. The EFW P2F

## A321-200F CONTAINERISED & PALLETISED FREIGHT CAPACITY

| Aircraft variant | A321-200 | A321-200 | A321-200 | A321-200 | A321-200 | A321-200 | A321-200 | A321-200 |
|---|---|---|---|---|---|---|---|---|
| Configuration | Main & lower deck containers | | | | Main deck netted pallets & lower deck containers | | | |
| Weight variant | WV000 | WV011 | WV000 | WV011 | WV000 | WV011 | WV000 | WV011 |
| Converter | EFW | EFW | Precision | Precision | EFW | EFW | Precision | Precision |
| Main Deck | | | | | | | | |
| No. of Main ULD Positions | 14 | 14 | 13 | 13 | 14 | 14 | 14 | 14 |
| Type | 88" X 125" AAA/AAY | 88" X 125" AAA/AAY | 88" X 125" AAA/AAY | 88" X125" AAA/AAY | 88" X 125" PAG Pallets | 88" X125" PAG Pallets | 88" X 125" PAG Pallets* | 88" X 125" PAG Pallets* |
| | | | 1 88" X 125" PAG Pallet* | 1 88" X125" PAG Pallet* | | | | |
| Unit Vol-Cu Ft | 438 | 438 | 438 | 438 | 438 | 438 | 438 | 438 |
| Unit Tare-Lbs | 511 | 511 | 511 | 511 | 255 | 255 | 255 | 255 |
| Total Vol-Cu Ft | 6,132 | 6,132 | 5,979 | 5,979 | 6,132 | 6,132 | 5,979 | 5,979 |
| Total Tare-Lbs | 7,154 | 7,154 | 6,643 | 6,643 | 3,570 | 3,570 | 3,570 | 3,570 |
| | | | *PAG Pallet Volume in Position 14 assumed to be 65% of AAY Vol | | | | * PAG Pallet Volume in Position 14 assumed to be 65% of AAY Vol | |
| No. of ULD Positions | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Type | AKH (LD3-45W) | AKH (LD3-45W) | AKH (LD3-45W) | AKH (LD3-45W) | AKH (LD3-45W) | AKH (LD3-45W) | AKH (LD3-45W) | AKH (LD3-45W) |
| Unit Vol-Cu Ft | 127 | 127 | 127 | 127 | 127 | 127 | 127 | 127 |
| Unit Tare-Lbs | 172 | 172 | 172 | 172 | 172 | 172 | 172 | 172 |
| Bulk Vol-Cu Ft | 208 | 208 | 208 | 208 | 208 | 208 | 208 | 208 |
| Total Vol-Cu Ft | 1,478 | 1,478 | 1,478 | 1,478 | 1,478 | 1,478 | 1,478 | 1,478 |
| Total Tare-Lbs | 1,720 | 1,720 | 1,720 | 1,720 | 1,720 | 1,720 | 1,720 | 1,720 |
| Whole Aircraft | | | | | | | | |
| Total Aircraft Vol-Cu Ft | 7,610 | 7,610 | 7,457 | 7,457 | 7,610 | 7,610 | 7,457 | 7,457 |
| Total Tare-Lbs | 8,874 | 8,874 | 8,363 | 8,363 | 5,290 | 5,290 | 5,290 | 5,290 |
| Net Struct Payload-Lbs | 45,581 | 50,652 | 51,517 | 56,588 | 49,165 | 54,236 | 54,590 | 59,661 |
| Max Pack Density-Lbs/Cu Ft | 5.99 | 6.66 | 6.91 | 7.59 | 6.46 | 7.13 | 7.32 | 8.00 |

programme for the A321-200 is understood to have a list price of about $6 million, including CLS.

The EFW P2F STC for the A321 will apply to five of the 12 available WVs: WV000, WV001, WV002, WV003, and WV011. These have three different MTOWs: 196,211 lbs (89,000 kg), 200,621 lbs (91,000 kg) and 205,030 lbs (93,500 kg).

## A321P2F payload derivation

EFW indicates that the converted freighter will have the same OEW of 103,175 lbs (46,800 kg) as the original passenger-configured aircraft. Such an equality of OEW between the passenger and converted freighter is slightly unusual; in most conversions a net OEW reduction after conversion is achieved.

The actual OEW will be revealed following conversion, but subtracting this provisional OEW from the MZFW of the lighter-weight WV000 variant (157,630 lbs (71,500 kg)) provides the aircraft with a gross structural payload of 54,455 lbs (24,700 kg) *(see table, page 58)*. A gross structural payload of 59,526 lbs (27,000 kg) is achieved when the other WVs are applied.

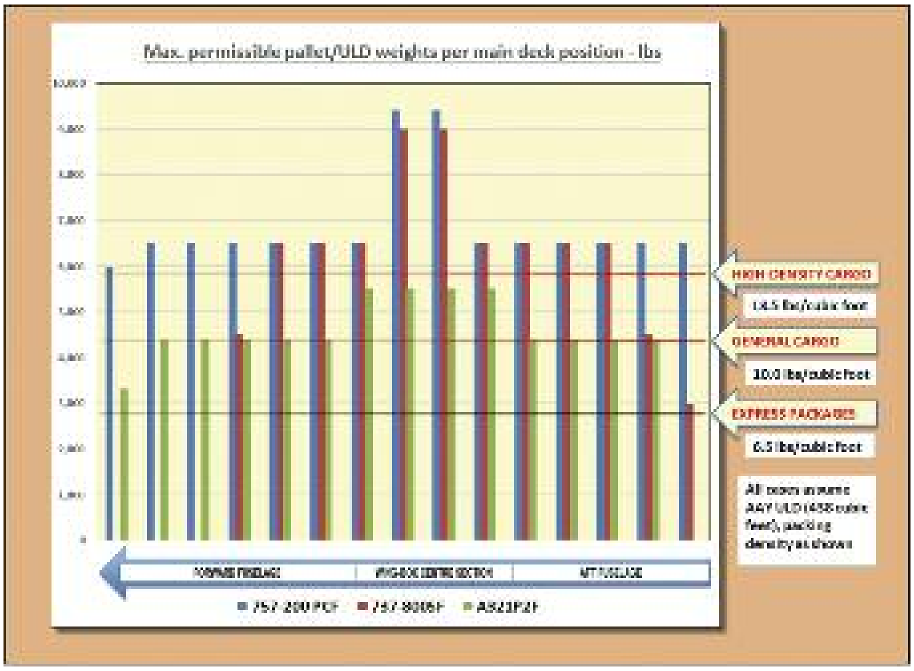
## A321 P2F main deck

The original A321 P2F main deck cargo ULD configuration, proposed by EFW when the programme was launched in 2015, provided for 13.5 positions: 13 AAA/AAY-class ULDs, and one smaller ULD or pallet in the aft-most position.

During 2017, extensive consultations with potential customers took place, with the result that "market feedback led us to reconsider the original 13.5 position offering and, at the expense of a costly and significant six-month delay, we have come back with a genuine 14-position, full ULD configuration," says Tom Centner, director of sales for aircraft conversion at EFW. "It has created a far more capable freighter."

The background to this change of main-deck configuration is complex, and equally relevant to both other potential A321 P2F conversions. It will also be relevant to prospective A321-200F operators. While provision of the full 14 ULD positions may facilitate standardisation of container/pallet use and maximisation of utilised volume, the configuration may incur additional design costs and have operational consequences.

At the root of the issue is the simple fact that the A321 fuselage tapers abreast of the 14th position, while the ULD secured in the 1st position is, of necessity, so far forward that the adjacent main passenger doors must be deactivated and cannot, therefore, be used for crew access. A new crew-entry door in the extreme forward area of the port fuselage immediately aft of the cockpit therefore has to be installed. External door-entry mechanisms also have to be installed on this door to meet safety certification




*Permissible loads shown for A321F refer to EFW conversion. Running loads for Precision conversion yet to be finalised.*

criteria.

The area immediately aft of the flight deck must, therefore, be extensively modified to provide such facilities as a vacuum-operated lavatory and crew baggage stowages. The volume available for this is inevitably limited by creation of the new access door.

The 9G rigid cargo barrier is moved forward to fuselage frame 16 from frame 20 in the original design, with the first ULD being immediately aft of it.

The cumulative effect of the forward positioning of the 9G barrier and the first ULD position is the need to use ballast in the tail. EFW will not be drawn on the quantum of such ballast.

The difference in estimated OEW between the EFW and Precision A321 P2F conversions is believed to be 5,425 lbs (2,461 kg), but it cannot be assumed that such a difference in solely due to the use of ballast by EFW. This difference will be available as greater payload for the Precision conversion if confirmed, but it must be emphasised that both conversion organisations' OEWs for the A321-200 freighter are provisional at this stage.

## Main deck ULDs

The conformal, contoured AAA and AAY containers that can be used on the A321's and A320's main decks have a base dimension of 125 inches across the fuselage width and depth of 88 inches. The height of the container at the apex is 82 inches. The internal volume used in this is analysis is 438 cu ft, and tare weight used is 511 lbs (232 kg).

The 14 AAA/AAY containers used on the EFW conversion provide a total volume of 6,132 cu ft, and have a combined tare weight of 7,154 lbs (3,245 kg) *(see table, page 60).*

The alternative to using structural containers in all 14 positions on the main deck is netted pallets. These have the same base dimensions as the AAA/AAY ULDs, but a lower tare weight of 255 lbs (116 kg). When built up they provide a similar volume for freight as the containers. They therefore allow a higher net structural payload compared to the use of ULDs *(see table, page 60).*

The A321 can accommodate 10 LD3-45 containers in total in its bellyholds, assuming that no auxiliary centre tanks are installed. Each of these has an internal volume of 127 cu ft and a tare weight of 172 lbs (78 kg). The 10 containers therefore provide a total volume of 1,270 cu ft and a collective tare weight of 1,720 lbs (780 kg).

When configured with main and lower deck containers, the A321-200P2F has a total volume of 7,610 cu ft (including the bulk compartment) and tare weight of 8,874 lbs (4,025 kg). As the EFW conversion results in a gross structural payload of 54,455 lbs or 59,526 lbs, depending on weight specification *(see table, page 60)*, this translates into a net structural payload of 45,581 lbs (20,675 kg) or 50,652 lbs (22,975 kg) *(see table, page 60)*. These payloads equate to maximum packing densities of 5.99 lbs per cu ft and 6.66 lbs per cu ft.

In either configuration, the EFW A321-200P2F converted aircraft offers a combination of containerised volume and net payload that matches the typical packing densities of the express packages experienced by the integrator's cargo airlines.

When configured with pallets on the main deck and LD3-45 containers in the belly, the aircraft has a net structural payload of either 49,165 lbs (22,301 kg) or 54,236 lbs (24,601 kg) *(see table, page 60).* Assuming the pallets provide the same volume as the containers, the aircraft will have the same freight volume. The total tare weight will be lower, however, at 5,290 lbs. This will provide the aircraft with a net structural payload of 49,165 lbs or 54,236 lbs, and maximum packing densities of 6.46 lbs per cu ft or 7.13 lbs per cu ft.

"We are convinced the A321P2F will carry 95% of all express cargo" says Tom Centner. "We have seen examples of pallet weights down as low as 1 tonne, or even less".

The EFW conversion will offer partial reinforcement of the floor matrix, to create peak running loads in positions 6, 7, 8 and 9, over the wing box of 62 lbs per inch. This equates to a maximum gross weight for an AAY ULD in each of these positions of 5,511 lbs (2,500 kg), which in turns implies a maximum cargo density in each of these positions of 12.6 lbs per cubic foot).

The adjacent fore and aft positions will each offer a maximum gross weight of 4,409 lbs (2,000 kg), equal to 9.0 lbs per cubic foot. The exception is the forward-most position, which is limited to 3,307 lbs (1,500 kg).

The longitudinal profile of position weights for the EFW A321 P2F matches that of the AEI 737-800SF and the Precision 757-200PCF in shape, if not in magnitude. While both of the latter conversions offer running loads which permit the carriage of full ULDs with higher-density cargo, the lower weights of the EFW conversion nevertheless match very closely the density characteristics of most general cargo traffic.

## Ramp operations

The main-deck cargo door on the EFW conversion is installed between Frames 30 and 35.2 on the port side of the forward fuselage. The placement of this forward door some way down the constant-section part of the forward fuselage confers two advantages, namely:

1. It obviates the need to relocate the aircraft's Angle of Attack sensor – which provides a primary data input essential to the safe operation of the aircraft – which is located between Frames 25 and 26. (The problems posed by the relocation of this sensor to permit the installation of the MDCD are understood to have created significant challenges for third-party A320 P2F programmes).

2. It allows the ULDs destined for positions 1 and 2 to be loaded first, to the forward (left) side of the MDCD, thereby avoiding the need for a tail-stand or the

*The A320/321 fuselage cross-section permits the carriage of the same maindeck containers that are carried by Boeing narrowbody freighters. The A320/321 freighters also accommodate freight containers in the belly hold.*

use of complex multi-stage loading protocols to ensure that the aircraft does not tip onto its tail the during loading process.

Despite the 'aft' position of the door, there remains more than adequate clearance between Ground Service Vehicles delivering cargo ULDs or pallets to ship-side for loading, and the leading edge of the nacelle of the port engine.

The carriage of engines of the type installed in the A321 is not considered to be a priority by EFW. "Weight and volume of the engine itself is not the issue; the clearances permitted by the engine stands and cradle are. So EFW advocate the carriage of engines in widebody freighters", says Centner. .

EFW 'expect to get competition from other conversion houses' because the A320 and A320 represent such attractive platforms for P2F.

In respect of the A321's general prospects as the basis for a package freighter, Centner adds that: "the market is coming to appreciate the real value of the 'double-decker' containerised cargo capacity of the A320 family. For an express package operator it's a very attractive aircraft."

## 321 Precision Conversions

Announced in August 2017, 321 Precision Conversions (Precision) is a joint venture between Erickson Group's Precision Aircraft Solutions (PAS) arm, and Air Transport Services Group (ATSG) subsidiary Cargo Aircraft Management.

PAS began detailed STC engineering design work in the third quarter of 2016, and the Precision JV is expected to gain STC certification in the second half of 2019. The prototype donor airframe for the programme is MSN891, an A321-200 configured to weight variant (WV) WV000, with CFM56-5B engines installed. This aircraft was delivered to Precision by Vallair, the launch customer for the conversion programme, in July 2017.

Work undertaken before delivery of the prototype had prompted Precision to make an initial announcement that their conversion would offer a 14-position AAY-class conformal-contoured ULD configuration on the main deck of the converted A321 freighter, the same as is now offered by EFW/ST Aero. Final validation of this main-deck configuration, however, would only become possible after an exhaustive geometric and structural analysis of cargo container form, fit and function within the stripped A321 PCF prototype fuselage. This was necessary to confirm that the 14 X AAY configuration would be in full compliance with Precision's desire to avoid extremely close tolerances and points of potential interference between loaded containers and the aircraft structure and cargo compartment lining and fittings.

Examination and evaluation of their previously purchased A321 passenger hull and physical prototype airframe post-delivery revealed an obstacle to implementation of the 14 X AAY configuration. It became apparent that large compromises and sacrifices would be required throughout the entire main deck configuration and centre of gravity (CoG). Precision judged these to be unacceptable to future 321 PCF operators, which regularly carry non-contoured, full-size netted cargo as a regular component of their load mix.

PAS' McCarthy explains the background to the decision-making process that Precision then followed. "In addition to our paramount objectives of creating an A321 P2F conversion that maximises use of fuselage volume while remaining within the CoG envelope and without resorting to ballast, we are determined to reduce the need to modify numerous areas of fuselage structure.

"We believe it is essential that an A321 freighter, which will remain in service for decades, must be engineered to ensure a high level of tolerance and flexibility immunity from both aircraft and/or cargo container anomalies and deformation," continues McCarthy. "Cargo containers can literally get bent out of shape or distorted, sometimes quite badly, so an inherent tolerance is vital."

Weight was also a factor, and argued in favour of a longitudinal orientation of the 14th position. A longitudinal pallet base orientation allows the 9G rigid barrier to be secured further aft. The entire sequence of main-deck positions can, therefore, be moved aft by an equivalent amount. This removes the need to close the forward passenger doors and create a new crew access door aft of the cockpit. Precision argues that it confers benefits in respect to weight, cost and the operational crew environment.

"Modified crew door conversion designs open inward into already taxed space, compounding congestion issues," says McCarthy. "Many designs open inward towards the 9g barrier, which blocks access to the cargo compartment when the door is open. And the crew-entry door is so close to the pilot and first officer seats that the wind makes it somewhat uncomfortable. During cold or inclement weather, the amount of cold air that infiltrates the flight-deck area because of the forward crew-entry door location is significant and has negative consequences, not least of which is that the auxiliary power unit (APU) is started abnormally early during preflight to heat up or retain heat on the flight deck during pre-departure, resulting in unnecessary fuel burn increases and additional run time on the APU."

It had also been determined that operation of the freighter conversion within the A321's inherently 'forward' CoG envelope without ballast was virtually impossible if a transverse 14th position were adopted.

**A321-200CEOS IN SERVICE OR IN STORAGE MARCH 2018**

| Variant | Status | CFM56-5B | V2530 | V2533 | Total |
|---|---|---|---|---|---|
| **Total A321-100** | **In service/retired/stored** | **41** | **30** | | **71** |
| A321-200ceo without sharklets | In service | 264 | 24 | 453 | 741 |
| A321-200ceo without sharklets | In storage | 20 | | 28 | 48 |
| A321-200ceo with sharklets | In service | 297 | 13 | 417 | 727 |
| A321-200ceo without sharklets | In storage | 10 | | 7 | 17 |
| **Total A321-200** | | **632** | **67** | **905** | **1,533** |
| **A321-200ceos in service or storage which will be 15-20 years old in 2020** | | | | | |
| All A321-200ceos without sharklets | | 88 | 9 | 71 | 168 |

Precision, therefore, decided early in 2018 that the production A321 PCF freighter would now be offered with various main-deck configuration options including:

1. 14 88-inch X 125-inch full flat pallet (PAG) positions.

2. 13 88-inch X 125-inch AAA/AAY/PAG containers plus one additional full position (the 14th), which is a flat pallet (PAG), turned longitudinally.

3. 13 88-inch X 125-inch AAA/AAY/PAG containers plus two additional LD3-45s, the same container type as is used in the A321 belly, emplaced in the 14th position. This configuration would logically be adopted by any operator planning to use the full complement of (10) LD3-45s in the bellies.

4. 12 96-inch X 125-inch positions, plus one LD3-45 & one PBX in the aft-most position.

5. 11 full 88-inch X 125-inch (AAA/AAY/PAG) + engine pallet (137-inch) + one 88-inch X 125-inch (PAG) aft.

6. 10 full 88-inch X 125-inch (AAA/AAY/PAG) + one 16-feet PRA pallet + one 88-inch X 125-inch (PAG) aft.

"We have never found an operator that wants to haul around dead weight (ballast), since the OEW-related fuel burn is a factor at any fuel price, and prices will surely climb in the future," says McCarthy. "Precision captured the 757 market by adding the 15th position (with the consequent need for a new crew-access door). That variant was a completely different aircraft, however, and a similar configuration to the 757 factory-built freighter.

"The 757-200PCF and the 757-200PF are both workhorses with their 15 positions, but this deck plan and configuration is not necessarily for everyone without fully understanding ramifications of the additional aft cargo position on the front of the aircraft," continues McCarthy. "In the case of the A321, the new crew-entry door requires that sacrifices be made and negotiated with pilots and operations personnel. Crew baggage stowage is almost non-existent, so this must go in the aft bulk pit which is very aggravating to flight crews in cold and rain, waiting for ground personnel to stow or unload."

Precision also observes that a gradual migration to higher cargo densities by virtue of smarter packing densities may render additional incremental volume of a 14th AAY (relative to a netted PAG pallet or LD3-45) unusable, given the range of installed thrust and permissible operating weight options for the A321-200.

The prototype/conformity aircraft for certification of the Precision conversion is at WV00. Post STC certification, Precision will offer as options WV001, 002, 007, and 011. Original design weights will not be affected by the conversions.

Floor running load limits will range upwards from a baseline 47 lbs per square inch. Maximum loads (which will be offered in the centre-section positions over the wing box) are a work in progress by Precision *(see chart, page 61)*.

The company is not able to disclose cost of conversion at this point in the STC development.

## Best conversion candidates

Total production of the A321 model has exceeded 1,600 units at the time of writing. First deliveries (of the -100 series) took place in 1994, with the first -200 series - L/N 633 - being delivered in 1996. The fuel-saving sharklet replacement for the traditional A320-family wing-tip 'fence' was incorporated from 2012 onwards. Almost half of all A321-200s are sharklet-equipped.

Split of powerplants between the CFM56 and the V2500-series is less evenly balanced within the total fleet, with 61% being V2500-powered.

## Selection criteria

Key selection criteria to be applied in choosing A321 airframes for P2F conversion are model series, age of the specific airframe (the primary driver of feedstock cost), accumulated FH and FC, and maintenance status of the candidate aircraft. Engine variant will also be a key criterion for existing A320 family operators. Availability of a batch of sisterships will be a consideration for certain operators.

The importance of the WV to which candidate aircraft are certified at induction, or to which they are capable of being upgraded, is a secondary consideration. Although only those A321s built from 2003 (L/N 1,878 plus L/N 1,794, built in 2002) can be upgraded to WV11, the highest MTOW WV available, this is not of primary importance to a narrowbody freighter operator.

Sharklet-equipped aircraft have only been in production for eight years, and this innovation will be of only marginal interest to a typical A321 P2F operator when airframes that are so equipped become candidates for conversion.

- A321 model series

It is virtually certain that only -200 series models of the A321 will be converted to freighters. The A321-100 is older and less capable than the -200. The average cumulative utilisation of the -100


*There will be 168 A321-200ceos in the 15-20 year old conversion zone in 2020, when the two conversion programmes deliver their first aircraft.*

in the fleet is forecast to be over 54,000FH and 38,000FC by 2020, when the first feedstock is likely to be inducted. There are no plans to develop an STC for the A321-100, so it is excluded from this analysis.

● Airframe age

Narrowbody freighters typically operate at low levels of utilisation by modern airline standards. Aircraft used in overnight express package operations will often generate only two, three or four FCs per night, and less than 5FH total flight time. Such flying typically generates an annual utilisation of 1,000-1,500FH.

This low level of utilisation has two consequences. Protracted periods of aircraft downtime can be used to perform line maintenance and defect rectification. Low levels of utilisation elevate the capital on-ramp cost to a matter of primary importance. This factor argues strongly for the use of conversion feedstock that is 15-20 years old, the so-called 'zone of convertibility'.

Market values of A321-200s and 737-800s within this age group are forecast to converge by 2020 in the range of US$11.5 to US$13.5 million. Such feedstock prices, which are nevertheless markedly higher than those that have recently been paid for used 737-300s and 737-400s, will result in a relatively high on-ramp cost for a 737-800 P2F relative to its payload and 6,395 cubic foot volumetric capacity. The A321-200, with up to 24.9% more payload and up to 19% more volume, is therefore an attractive alternative to both the 737-800 P2F and 757-200 PCF.

Within the pool of A321-200 aircraft falling within the 15-20 year-old age range in 2020, further filters must be applied to arrive at a core pool of candidate feedstock units.

● FH & FC

Ideally a feedstock aircraft once converted will, thereafter, be able to operate a sufficient number of FH and FC as an operational freighter to reach the end of its economic life without encountering manufacturer-stipulated ultimate life limits. In common with the A320, the A321 is subject to an Airbus 'design service goal' (DSG) of 60,000FH or 48,000FC, implying an average FC:FH ratio of 1:1.25.

Operators whose networks generate a higher ratio can choose to extend the life of their aircraft by implementing the 'intermediate service goal' (ISG) of 80,000FH or 37,500FC, in which an entitlement to fly an extra 20,000FH is earned at the expense of 10,500 fewer FCs, implying an average FC/FH ratio of 1:2.13.

The ISG is less likely to be the option of choice for a typical freighter operator than the 'extended service goal' (ESG), which allows an aircraft to continue to be operated up to 120,000FH or 60,000FC. The ESG thereby offers 100% more FH and 25% more FC than the basic DSG. While implementation of the ISG is believed likely to be a paperwork exercise, some airframes may require structural modifications for the ESG to be applied. OEM advice would be required in this respect, but such work could be carried out during the freighter conversion process to minimise additional downtime and airframe access requirements.

Given that a typical operator of an aircraft converted while 15-20 years old will expect to achieve a further 15-20 years' operation in freighter configuration, *Aircraft Commerce* has undertaken a parametric analysis of the current and projected cumulative FH and FC utilisation of the in-service and in-storage fleet of candidate feedstock. This is to determine how many years of service life an operator can expect to achieve before exceeding the DSG, and how many years of further life will be available within the ISG and ESG life-limit limitations.

Although further candidate feedstock satisfying the same age-band criterion will progressively become available after 2020, analysis of the pool available to prospective customers for the first conversions will give an indication of the life expectancy of future conversions.

The 168 candidate feedstock units which will be reaching 15-20 years of age in 2020 are forecast to have achieved, on average, almost 48,000FH and over 21,000FC by 2020, implying an average FC:FH ratio of 1:2.23.

If an aircraft with this fleet-average number of FH and FCs were thereupon converted to a freighter and operated at the assumed average rate of utilisation of 1,500 FH and 1,200 FC per year, the analysis shows that the DSG limit would be encountered after only 8.3 years of operation. The limiting factor would, therefore, be total FH.

If the ISG regime were selected instead, the aircraft could operate for 13.5 years, at which time the ISG FC limit of 37,500FC would be reached.

If, however, the ESG regime of 120,000FH and 60,000FC were chosen, the limiting factor (FC) would not arise until over 32 years of operation had been accomplished, a period almost certainly beyond the viable economic life of the aircraft.

As expected, a wide variation of logged FH and FC exists among units within the pool of conversion candidates. The lowest quartile of this group has an average utilisation of only 14,228FC and 36,024FH, and selection of an aircraft with this usage profile would provide almost 20 years' utilisation before ISG limits were encountered. AC