BAE Systems is investigating the potential for a P-to-F conversion programme for RJ85s and RJ100s. The operational benefits of these aircraft are considered against those of current regional and narrowbody freighters. Potential sources of demand are also considered.

Is there a market for Avro RJ freighter conversions?

For many years BAe 146-200 and -300 Quiet Trader (QT) and 146-200 Quick Change (QC) aircraft were the only regional jet (RJ) freighters in service. In August 2016 BAE Systems Regional Aircraft announced that it was considering the launch of a passenger-to-freighter (P-to-F) conversion programme for the next generation Avro RJ family.

Potential demand for an Avro RJ conversion programme is addressed and proposed specifications for converted Avro RJ freighters are summarised. The potential payload performance of Avro RJ freighters is considered against that of existing turboprop, RJ and narrowbody freighter options they could potentially compete with or replace. Comparative acquisition and conversion costs and prospective operators are also identified.

Potential RJ freighters

The Avro RJ family includes the RJ70, RJ85 and RJ100, introduced in 1993 as next generation successors to the BAe 146-100, -200 and -300.

The original equipment manufacturer (OEM) BAE Systems is the only body publicly marketing the potential for an Avro RJ P-to-F conversion programme. "The aim of developing a conversion modification is to extend the economic life of Avro RJ airframes, some of which have barely reached their half-lives in terms of utilisation," explains Sean McGovern, managing director at BAE Systems Regional Aircraft.

The main candidates for conversion are the RJ85 and RJ100. The smaller RJ70 is unlikely to be converted for dedicated commercial freighter operations, although BAE Systems believes that there could be certain military or other niche applications suited to RJ70s fitted with large freight doors.

"BAE Systems is the OEM for the RJ85 and RJ100, and owns all 146QT freighter modification intellectual property rights (IPR)," explains McGovern. "The 146QT modification has proven successful and would form the basis for the Avro RJ conversion to minimise costs. This would include using the same large freight door design."

BAE Systems is targeting a minimum of 10 Avro RJ conversions to achieve economies of scale for the programme. "We are forecasting up to 10 aircraft, but the initial hurdle is to justify the demonstrator. We believe this is essential to stimulate the market," he says.

Any conversions would be completed under an OEM service bulletin (SB). A third-party maintenance, repair & overhaul (MRO) organisation would complete physical conversion work. "Our preference is for conversion of the first aircraft to take place at an MRO near BAE Systems' facilities at Glasgow Prestwick (PIK) airport so that our specialists are on hand if needed," says McGovern. "Other options with remote BAE Systems working parties can also be considered.

"The Avro RJ freighter feasibility study was completed with initial market testing in the last quarter of 2016," continues McGovern. "We are continuing to review responses from operators to refine the specifications.

"During the process we have identified some very specific markets of interest and related changes that may enhance the freighter and passenger proposition, including more fuel capacity, remote runaway accessibility, and potentially increased floor loading," adds McGovern. "We expect a further round of market engagement with these enhancements before confirming the freighter proposition. In the immediate future, the business is compiling detailed conversion costs with a view to making a go/no-go decision on a basic demonstrator, the logic being that this could stimulate the market.

"We are moving to a position where one customer has shown an interest in paying for the prototype conversion," continues McGovern. "The prototype airframe is most likely be an RJ100."

BAE Systems has indicated that enhancements being considered for prospective Avro RJ freighters could also be made available for existing BAe 146QT aircraft.

The proposed specifications for RJ85 and RJ100 freighters are summarised here.

RJ85 freighter

An RJ85 freighter would have a basic maximum take-off weight (MTOW) of 93,000lbs and an absolute MTOW of up to 97,000lbs *(see table, page 81)*. It would have a maximum zero fuel weight (MZFW) of 79,000lbs, and a typical gross structural payload of 28,200lbs.

The potential unit load device (ULD) loading configurations for an RJ85 freighter would be the same as those for the 146-200QT. An RJ85 freighter could accommodate up to six 88-inch X 108-inch ULDs, plus a further reduced-size ULD on its main deck. ABY and AEP containers are among the ULDs typically used on 146QT aircraft. An RJ85 loaded with six ABY containers and a single AEP ULD, would offer 2,060 cubic feet (cu ft) of containerised cargo volume.

In addition to containerised volume, an RJ85 freighter could accommodate up to 670 cu ft of bulk cargo in the hold and vestibule. It could, therefore, offer a total cargo volume of up to 2,730 cu ft.

RJ100 freighter

An RJ100 freighter would offer a basic MTOW of 97,500lbs and an absolute MTOW of 101,500lbs. It would have a basic MZFW of 82,500lbs and an absolute MZFW of up to 83,500lbs. The RJ100 freighter's typical gross structural payload would be 30,200-31,200lbs, depending on the certified MZFW and operating empty weight (OEW).

Potential ULD configurations for an RJ100 freighter would match those of the 146-300QT. The Avro RJ100 freighter

BAE 146QT AND PROPOSED RJ85/RJ100 FREIGHTER SPECIFICATIONS

Aircraft Type	146-200QT	146-300QT	RJ85 Freighter	RJ100 Freighter
Engines	ALF 502R-5	ALF 502R-5	LF 507-1F	LF 507-1F
MTOW Basic (lbs)	93,000	97,500	93,000	97,500
MTOW Absolute (lbs)	n/a	n/a	97,000	101,500
MZFW Basic (lbs)	75,000	80,500	79,000	82,500
MZFW Absolute (lbs)	n/a	n/a	n/a	83,500
OEW - typical (lbs)	49,910	51,590	50,800	52,300
Max structural payload (lbs)	25,085	28,910	28,200	30,200-31,200

Max structural payloads are estimates. These will vary by individual aircraft due to differences in OEW.

could accommodate up to seven 88-inch X 108-inch ULDs, plus one reduced-size ULD on the main deck. With seven ABY containers and a single AEP ULD the aircraft would offer up to 2,378 cu ft of containerised cargo volume *(see table, page 84).*

Like the Avro RJ85, the RJ100 would be capable of hauling additional bulk freight in its hold and vestibule. In this case an Avro RJ100 freighter would have the capacity to accommodate up to 837 cu ft of additional bulk cargo. It could potentially offer a total cargo volume of about 3,215 cu ft.

Payload and range options

Prospective Avro RJ freighters would be available in 'Basic' maximum weight and 'Absolute' maximum weight configurations. The latter would provide more payload capability, or an increase in range of 200-300 nautical miles (nm).

"The RJ85 and RJ100 have Basic and Absolute maximum weight options," explains Neil Campbell, business development executive at BAE Systems Regional Aircraft. The highest absolute maximum weight involves increases to the MTOW for both variants and also to the MZFW for the RJ100. It is expected that the weight upgrade will consist of a paperwork recertification upgrade only.

"The Basic maximum weight is used by some passenger operators to reduce landing charges," continues Campbell. "An additional fuel capacity option is available for aircraft with the absolute maximum weights. This typically includes 900 US gallons (USG) of additional fuel capacity with extra tanks situated in the pannier and the aft under-floor holds."

RJ85 and RJ100 freighters operating with the extra fuel capacity will have additional fuel tanks installed in their aft lower holds. This will result in a 50% reduction in the bulk cargo volume available in these holds.

BAE Systems estimates that RJ85 and RJ100 freighters would carry a payload of about eight tonnes when loaded at the packing densities typically used in the express freight market. It suggests that with this payload the RJ85 and RJ100 freighters would have a range of 1,000-1,800nm, depending on configuration.

In addition to these specifications, BAE Systems is investigating further potential weight modifications. "Market testing has shown interest in increasing the RJ85's MTOW and MZFW to match the RJ100's performance, and this is being considered," explains Campbell.

History repeated?

If BAE Systems does decide to launch an Avro RJ P-to-F programme the converted freighters will be following in the footsteps of their 146 predecessors.

A total of 23 146s were produced as dedicated newbuild freighters, including 13 146-200QTs and 10 -300QTs. An additional five 146-200s were built in QC configuration. A single 146-100 was also given the large freight door modification.

In 2007 BAE Systems Asset Management launched a 146 P-to-F programme in association with Aerostar of Romania. Only two aircraft, one 146-200 and one 146-300, were converted to dedicated freighter QT status before the programme was discontinued. Although the 146-300 continues to operate as a freighter, the converted 146-200 was never placed and has been broken up.

BAE Systems does not believe that the proposed Avro RJ conversion programme would suffer the same fate as the unsuccessful 146 scheme, pointing to improvements in the air cargo market and several Avro RJ advantages.

"The 146 conversion programme suffered from bad timing in that it was launched just before the 2008 global economic recession," says McGovern. "The freight market has only just started to pick up following the recession. In addition, the RJ85 and RJ100 offer several advantages compared to the 146-200 and -300, including higher payloads, lower block fuel performance and improved flight deck avionics, including Category three (CAT III) instrument landing system (ILS) capability."

The RJ85 and RJ100 have the same fuselage dimensions as the 146-200 and 146-300 and would offer the same cargo volume as their predecessors. The Avro RJ variants would, however, offer higher weight specifications *(see table, page 84).*

An RJ85 could offer an advantage of up to 4,000lbs in terms of MTOW and MZFW and up to 3,100lbs in terms of gross payload compared to a 146-200QT.

An RJ100 freighter could demonstrate MTOW and MZFW advantages of up to 4,000lbs and 3,000lbs over a 146-300QT, plus up to 2,290lbs of additional payload, depending on the OEW.

Another difference between 146 and Avro RJ series aircraft is the engines. All Avro RJs are equipped with LF507 family engines, which partly contribute to an improvement in fuel burn performance. "The RJ85 and RJ100 benefit from marginally lower fuel burn than the 146-200 and 146-300 due to drag reduction modifications and LF507 engines with full authority digital engine control (FADEC)," says Campbell. "Reduction in fuel burn is typically 2-4% per trip."

Market positioning

There are no newbuild freighter programmes available in the regional and narrowbody segments. The main competition for RJ85 and RJ100 freighters would therefore come from other P-to-F conversion programmes.

The only active RJ P-to-F conversion programmes are for the CRJ100 and CRJ200. Aeronautical Engineers Inc (AEI) offers the only large cargo door modification for these types, as part of its CRJ100/200 SF conversion. Cascade Aerospace developed a supplemental type certificate (STC) for conversion of CRJ100s and CRJ200s to Package Freighter (PF) status. Converted CRJ100/200 PFs maintain their original passenger doors, requiring bulk loading.

In the turboprop market the main competition for RJ85 and RJ100 freighters is likely to come from converted ATR 72s and IPR Conversions offers the only large cargo door modifications. It also offers bulk or 'structural tube' conversions for ATR 72s, where the cabin is converted to Class E status, but the original passenger and cargo loading doors are retained. ATR 72 bulk or 'structural tube' conversions are also offered by Elbit Systems of America and Aeroconseil. A bulk PF conversion for the Q400 is available from Cascade

ULD SPECIFICATION ASSUMPTIONS

Container	Internal Volume (cu ft)	Tare weight (lbs)
AAY	410	549
ABY	318	465
ABZ	328	478
AEP	152	300
ASZ	169.5	225
AYF	193	270
AYK	103	220
LD3	154	220
AAP/LD9	375	523
PBJ Pallet	352	205

Specs based on containers produced by VRR except AYF & PBJ. ASZ container for CRJ100/200 is only at design stage.

Aerospace, but no large cargo door modifications have been developed.

In the narrowbody market 737-200s, 737-300s and 737-700s will represent the closest competition to potential RJ85 and RJ100 freighters in terms of capacity.

AEI still offers a 737-200SF P-to-F conversion. 737-300 conversions are available from AEI, IAI Bedek and PEMCO. IAI Bedek is the only conversion provider to have launched a P-to-F programme for the 737-700.

Gap in market?

BAE Systems believes there is a gap in the market for its proposed Avro RJ freighters. "The RJ85 and RJ100 would sit neatly between the ATR 72 and the 737-200 and -300 in the 7-14 tonne payload segment," says McGovern.

Express package or integrator, general freight and airmail are the main sectors of air cargo operations. Airmail and express package services have similar features.

Express package services involve the carriage of small parcels, including e-commerce goods, at low packing densities of about 6.5-7.0lbs per cu ft (lbs/cu ft). These packages are generally carried in containers. Express or integrator services usually operate across hub-and-spoke networks. Aircraft might be expected to operate two sectors, or one return journey per night, from an outstation to the main hub and back. This airport-pair might be operated five or six times per week. Aircraft operating integrator services might 'cube' out, when available volume is used up before the aircraft's structural payload limit has been reached.

In contrast, general freight services often involve carriage of larger, bulkier items at higher packing densities of 9.0lbs/cu ft or more. Due to dimensions, general freight items tend to be loaded on pallets rather than in containers. General freight services are often point-to-point and feature less regular schedules than express package operations. Typical general freight demands might include urgent one-off charters for the carriage of machinery. The nature of the cargo means that an aircraft configured for general freight services is likely to reach its structural payload limit before optimum use has been made of the available volume, known as 'grossing out'.

"With the Avro RJ freighter proposals we are targeting premium regional express and niche payload markets," says McGovern. "These niche markets might include carriage of large, high-density and outsized payloads to remote locations.

"The Avro RJ85 freighter would be targeted at payload-driven operations, while the RJ100 would be more suited to volume-driven freight demands," he adds.

This suggests that BAE Systems sees the RJ85 as more suited to niche general freight operations and the RJ100 as best equipped to meet express package needs.

Payload comparison

Aircraft Commerce has performed a basic volumetric capacity analysis to compare the potential payload performance of RJ85 and RJ100 freighters to that of prospective regional and narrowbody rivals. Specifications are only compared for those P-to-F programmes that include installation of a large cargo door, since the resulting freighters are capable of accommodating containers or pallets.

The results of the payload comparison should only be considered within the context of a number of assumptions. The analysis assumes that the aircraft are loaded with containers where possible. The only pallet used is in the rearmost position of the 737-200 freighter. In reality aircraft would most likely be loaded with pallets for general freight operations. This would result in lower tare weights, higher net structural payloads and higher volumetric payloads than those seen here.

Realistic ULD volumes and tare weights have been used *(see table, this page)*. Most are based on containers made by VRR Aviation, and most are already available, with the exception of the ASZ ULDs for the CRJ100 SF and CRJ200 SF, which are only at the proposal stage. Volumes, tare weights and ULD contours can vary by manufacturer. Possible freighter loading configurations may vary by conversion provider and operators should make independent enquiries to establish which ULDs an aircraft can accommodate. Total volume figures used here include bulk freight capacity in addition to containerised volume.

The OEWs used in this analysis should provide a realistic guide to the optimum achievable weights. In reality, in-service OEWs could be higher. OEW and maximum structural payload will also vary slightly by individual aircraft. The gross structural payload used for the RJ100 assumes that the aircraft is certified at the absolute MZFW. If it were certified at the standard MZFW the gross payload would be 1,000lbs lower.

The analysis compares net structural payload, maximum packing density and volumetric payloads at typical express, and general freight package, densities.

The net structural payload is the payload remaining for cargo once the tare weight of containers or pallets has been accounted for, calculated by subtracting the ULD tare weight from the gross structural payload.

In the ULD configuration used for this analysis, the proposed RJ85 and RJ100 freighters would offer typical net structural payloads of 25,110lbs and 27,645lbs *(see table, page 84)*. The RJ85 and RJ100 freighters would provide 3,110lbs and 2,290lbs of additional net structural payload in comparison to 146-200QTs and 146-300QTs. The RJ100 would have a net structural payload advantage of 2,535lbs over the RJ85.

An RJ85 freighter would offer 9,668-10,436lbs, 12,040lbs and 12,070lbs of additional net structural payload when compared to ATR 72LCD, CRJ100 SF and CRJ200 SF freighters. It would offer 8,642lbs, 12,875-13,378lbs and 15,008lbs less net structural payload than 737-200, 737-300 and 737-700 freighters respectively.

An RJ100 freighter would provide 12,203-12,971lbs, 14,575lbs and 14,605lbs of additional net structural payload when compared to ATR 72 LCD, CRJ100 SF and CRJ200 SF freighters. It would offer 6,107lbs, 10,340-10,843lbs and 12,473lbs less net structural payload than 737-200, 737-300 and 737-700 freighters.

Maximum packing density is the density at which freight should be packed to make optimum use of the aircraft's net structural payload and available volume. It is calculated by dividing net structural payload by available volume. The RJ85 and RJ100 freighters would have maximum packing densities of 9.20lbs/cu

AVRO RJ PAYLOAD PERFORMANCE COMPARISON

Aircraft Type	CRJ100SF	CRJ200SF	ATR 72-200/-210 LCD	ATR 72-500 LCD
Conversion provider	AEI	AEI	IPR	IPR
Containers	8 x ASZ	8 x ASZ	5 x ABZ	5 x ABZ
Gross structural payload (lbs)	14,870	14,840	17,064	17,832
Containerised volume (cu ft)	1,356	1,356	1,640	1,640
Additional bulk volume (cu ft)	n/a	n/a	470	470
Total volume (cu ft)	1,356	1,356	2,110	2,110
Total tare weight (lbs)	1,800	1,800	2,390	2,390
Net structural payload (lbs)	13,070	13,040	14,674	15,442
Max packing density (lbs/cu ft)	9.64	9.62	6.95	7.32
Volumetric payload @ 6.5lbs/cu ft	8,814	8,814	13,715	13,715
Volumetric payload @ 9.0lbs/cu ft	12,204	12,204	14,674	15,442

Aircraft Type	146-200QT	RJ85 Freighter	146-300QT	RJ100 Freighter	737-200SF
Conversion provider	BAe	BAE Systems	BAe	BAE Systems	AEI
Containers	6 x ABY + 1 x AEP	6 x ABY + 1 x AEP	7 x ABY + 1 AEP	7 x ABY + 1 AEP	7 x AAY + 1 PBJ
Gross structural payload (lbs)	25,090	28,200	28,910	31,200	37,800
Containerised volume (cu ft)	2,060	2,060	2,378	2,378	3,222
Additional bulk volume (cu ft)	670	670	837	837	875
Total volume (cu ft)	2,730	2,730	3,215	3,215	4,097
Total tare weight (lbs)	3,090	3,090	3,555	3,555	4,048
Net structural payload (lbs)	22,000	25,110	25,355	27,645	33,752
Max packing density (lbs/cu ft)	8.06	9.20	7.89	8.60	8.24
Volumetric payload @ 6.5lbs/cu ft	17,745	17,745	20,898	20,898	26,631
Volumetric payload @ 9.0lbs/cu ft	22,000	24,570	25,355	27,645	33,752

Aircraft Type	737-300SF 9-position	737-300SF 10-position	737-300BDSF	737-300F	737-700BDSF
Conversion provider	AEI	AEI	IAI Bedek	PEMCO	IAI Bedek
Containers	8 x AAY + 1x LD9	8 x AAY + 1 x AEP + 1 x LD3	8 x AAY + 1 x LD3	8 x AAY + 1 x LD3	8 x AAY + 1 x AYK + 1 x AYF
Gross structural payload (lbs)	42,900	42,900	43,100	43,100	45,000
Containerised volume (cu ft)	3,655	3,586	3,434	3,434	3,576
Additional bulk volume (cu ft)	973	973	1,068	1,068	964
Total volume (cu ft)	4,628	4,559	4,502	4,502	4,540
Total tare weight (lbs)	4,915	4,912	4,612	4,612	4,882
Net structural payload (lbs)	37,985	37,988	38,488	38,488	40,118
Max packing density (lbs/cu ft)	8.21	8.33	8.55	8.55	8.84
Volumetric payload @ 6.5lbs/cu ft	30,082	29,634	29,263	29,263	29,510
Volumetric payload @ 9.0lbs/cu ft	37,985	387,988	38,488	38,488	40,118

ft and 8.60lbs/cu ft *(see table, this page)*. This compares to maximum packing densities of 8.06lbs/cu ft and 7.89lbs/cu ft for the 146-200QT and 146-300QT.

The RJ85 freighter's maximum packing density would be higher than that of all types, except the CRJ100 SF and CRJ200 SF. The RJ100 freighter would offer a higher packing density than ATR 72 LCD, 146-200QT, 146-300QT, 737-200 and 737-300 freighters.

6.5lbs/cu ft

Volumetric payload is the payload available at a given packing density. At a typical express-package packing density of 6.5lbs/cu ft, all of the aircraft cube out.

Proposed RJ85 and RJ100 freighters would offer volumetric payloads of 17,745lbs and 20,898lbs. This is equal to the volumetric payloads offered by their equivalent predecessors, the 146-200QT and 146-300QT. The RJ100 would offer 18% more volumetric payload than the RJ85 at this packing density.

At the typical express-package packing density, the proposed RJ85 freighter would provide 101% more, or double the volumetric capacity, of a CRJ100/200 SF *(see table, this page)*. It would also provide 29% additional volumetric capacity compared to an ATR 72 LCD freighter. The RJ85 would, however, offer 33%, 39-41% and 40% less volumetric capacity than 737-200, 737-300 and 737-700 freighters.

The proposed RJ100 freighter would provide 137% and 52% more volumetric capacity than CRJ100/200 SF and ATR 72LCD freighters at the typical express package packing density. It would however offer 22%, 29-31%, and 29% less volumetric payload than 737-200, 737-300 and 737-700 freighters.

9.0lbs/cu ft

A packing density of 9.0lbs/cu ft would be at the lower end for general freight operations. At this density all of the aircraft gross out, with the exception of the CRJ100/200SF and the RJ85.

The proposed RJ85 and RJ100 freighters would provide volumetric payloads of 24,570lbs and 27,645lbs. The RJ85 would offer 12% more volumetric payload than the 146-200QT at this packing density, while the RJ100 would provide a 9% volumetric payload advantage over the 146-300QT. The RJ100 would have a 13% advantage in volumetric payload compared to the RJ85.

At the general-freight packing density, the RJ85 would offer 101% and 59-67% additional volumetric payload compared to CRJ100/200 SF and ATR 72LCD freighters. The RJ85 would also have 27%, 35-36% and 39% less volumetric payload than 737-200, 737-300 and 737-700 freighters.

The proposed RJ100 freighter would demonstrate a volumetric payload advantage of 127%, and 79-88% when compared to CRJ100/200SF and ATR 72LCD solutions at the general-freight packing density. It would, however, offer 18%, 27-28% and 31% less volumetric payload than 737-200, 737-300 and 737-700 freighters.

Acquisition and conversion costs

Comparative on-ramp costs are an important consideration in freighter selection. On-ramp costs are the total costs required to acquire, convert and perform maintenance on an aircraft before placing it into cargo service.

Potential acquisition and conversion costs for RJ85 and RJ100 freighters are considered here alongside those of competing solutions. It was not possible to provide a comprehensive on-ramp cost comparison, since potential maintenance costs at the time of conversion were not available for all of the aircraft types.

The typical age range for P-to-F conversion feedstock airframes is 15-20 years. This is generally the age at which an airframe's market values and remaining operational life become harmonised to an extent that makes a conversion economically viable.

Oriel has provided estimated current market values (CMVs) for typical feedstock vintage RJ85s and RJ100s *(see table, page 86)*. There are very few 15-year-old RJ85s or RJ100s in service, but potential values have been included.

CMVs are also provided for the other regional and narrowbody freighter solutions considered in this analysis. All CMVs assume aircraft are in half-life maintenance condition with half-life engines. Where possible CMVs are quoted for 15- and 20-year-old aircraft, although the ageing nature of some of the types included here means that CMVs are provided for aircraft at the upper end of this age spectrum. CMVs are not included for the 737-200, since it is unlikely that this type will see significant numbers of additional conversions.

BAE Systems estimates P-to-F conversion costs for RJ85s and RJ100s at $2.20-2.80 million. According to Oriel, acquisition costs for typical feedstock vintage RJ85s and RJ100s in half-life condition would be about $2.00 million and $2.50 million. The total cost of acquiring and converting RJ85s and RJ100s in half-life condition would, therefore, be $4.20-4.80 million and $4.70-5.30 million *(see table, page 86)*.

Based on the assumed costs used here, an RJ100's combined acquisition and conversion costs could range from $100,000 lower to $1.10 million higher than those for an RJ85.

An RJ85's acquisition and conversion costs could potentially be $1.85-2.45 million higher than those for a CRJ100 SF, $0.75-1.85 million higher than those of a CRJ200 SF and from $4.28 million lower to $220,000 higher than those for an ATR 72LCD freighter.

RJ85 acquisition and conversion costs could be $0.20-1.00 million lower than for a 737-300 freighter and $4.40-6.10 million lower than those for a 737-700.

The acquisition and conversion costs for an RJ100 freighter might be $2.35-2.95 million higher than those for a CRJ100 SF, $1.25-2.35 million higher than those for a CRJ200 SF and anywhere from $3.78 million lower to $720,000 higher than those for an ATR 72 LCD freighter. RJ100 acquisition and conversion costs could be from $500,000 lower to $300,000 higher than those of a 737-300, and from $3.90-5.60 million lower than those for a 737-700 freighter.

BAE Systems believes it should be possible to acquire RJ100s approaching a heavy maintenance visit for as little as $1.00-1.50 million and perform C checks at the time of conversion for $400,000-500,000. If this is accurate, total on-ramp cost for an RJ100 freighter fresh from a C check could be as low as $3.40-4.80 million. These costs are favourable to sourcing other regional or narrowbody freighter solutions in half-life condition. It is unclear, however, what BAE Systems' proposed acquisition values assume in terms of aircraft age and overall position in the base maintenance cycle.

Strengths

BAE Systems believes the RJ85 and RJ100 have a number of operational

ESTIMATED ACQUISITION AND CONVERSION COSTS FOR HALF-LIFE AIRCRAFT

Aircraft Type	Engine	Year built	CMV	Conversion cost ($-millions)	Total acquisition & conversion cost ($-millions)
ATR 72-200	PW124B	1997	3.00	1.58-1.68	4.58-4.68
ATR 72-210	PW127	1997	4.00	1.58-1.68	5.58-5.68
ATR 72-500	PW127F	1997	5.80	1.58-1.68	7.38-7.48
ATR 72-500	PW127F	2002	6.80	1.58-1.68	8.38-8.48
CRJ100	CF34-3A1	1997	0.50	1.85	2.35
CRJ200	CF34-3B1	1997	1.10	1.85	2.95
CRJ200	CF34-3B1	2002	1.60	1.85	3.45
RJ85	LF507-1F	1997	2.00	2.20-2.80	4.20-4.80
RJ85	LF507-1F	2002	2.00	2.20-2.80	4.20-4.80
RJ100	LF507-1F	1997	2.50	2.20-2.80	4.70-5.30
RJ100	LF507-1F	2002	2.50	2.20-2.80	4.70-5.30
737-300	CFM56-3C1	1997	2.40	2.60-2.80	5.00-5.20
737-700	CFM56-7B22	1997	6.00	3.20-3.30	9.20-9.30
737-700	CFM56-7B22	2002	7.00	3.20-3.30	10.20-10.30

CMV source: Oriel

Notes

1). CMVs based on aircraft in half-life maintenance condition with half-life engines.

2). 737NG Values assume aircraft are equipped with blended winglets.

3). 737 conversion costs taken from Aircraft Commerce FRT article in Issue 108. Some of these are based on best estimates.

benefits that could make cargo variants a competitive or unique proposition compared to existing regional and narrowbody freighter solutions.

"The RJ100 can carry 60% more payload and would also have a speed advantage over a turboprop freighter," claims McGovern. "The additional speed would allow improved utilisation and scheduling." This could permit operators to fly more daily sectors than would be possible with a turboprop, spreading the operating cost over higher units of utilisation. "Another benefit is the flexibility to complete more flights with later cut-off times for freight pick-up," adds McGovern. An RJ85 or RJ100 freighter operating the same sector as a turboprop could potentially depart later and still arrive at the same time due to shorter trip times. This could allow more flexibility in terms of cargo delivery times at the departure point. Alternatively the RJ85's and RJ100's speed advantage could be beneficial in time-sensitive integrator networks. These hub-and-spoke systems depend on freight being fed into hubs and then dispersed on connecting flights or other modes of transport. The speed of the RJ85 and RJ100 could permit the operation of new long-thin routes that would not have met the desired connection times if operated by slower turboprops.

BAE Systems estimates that on sectors of 300-500nm a typical turboprop could have 15- to 30-minute longer trip times than an Avro RJ.

Another potential benefit of the proposed RJ85 and RJ100 freighters relates to noise compliance. Some airports, particularly those in city centres, impose operating restrictions on noise emissions, often involving a complete overnight flight ban for all aircraft, or a limit on the operating hours within which aircraft with a higher noise footprint can operate. Such restrictions often coincide with the main period of activity for freighters. Due to high-bypass geared turbofan engines, the RJ85 and RJ100 are capable of compliance with CAEP Chapter 4 noise standards. This could provide flexibility in terms of locations and times when operations are allowed.

The RJ85 and RJ100 might not have speed- or noise-related advantages over competing jet freighters, but they would provide other benefits. Some operators might need jet speed on long-thin routes that require more payload capability than the CRJ100/200 SF, but less than the smallest available 737 solutions.

BAE Systems highlights short take-off and landing (STOL) and unpaved runway capabilities of the RJ85 and RJ100 that might allow them to operate to and from more restricted airports than competing jet freighter solutions.

"The basic design of the 146 and Avro RJ families has key features that enable unpaved runaway operations and STOL performance," says Campbell. "These key features include the high wing and engine design, which significantly reduce ingestion and damage from foreign object debris (FOD). The large wing, spoilers, flaps, rear air brake, wide undercarriage track and large brakes enable more stable, slower approach speeds, steeper descent rates and operation from short runways. The aircraft can also be cleared for unpaved runways without payload restrictions using standard or low-pressure tyres and BAE Systems can provide a simple gravel runway protection modification kit.

"A typical low wing aircraft, such as the 737-200, requires a more complex modification kit to prevent FOD damage," continues Campbell. "This can include a nose-wheel gravel-deflector ski, intake vortex dissipation using engine bleed air, and other damage protection guards. Later 737 Classics are not gravel-runway capable, due to proximity of the powerplant to the runway surface."

McGovern adds that the RJ85 and RJ100 freighters would also benefit from a low loading freight door, which would not require a main deck loader.

Weaknesses

There is likely to be a degree of scepticism related to the proposed Avro RJ conversion programme, despite potential advantages and market niches.

"The market's perception of the operational economics of a four-engine jet aircraft is an area we need to work on," admits McGovern.

"I believe there is room in the market for turboprop, narrowbody and CRJ freighters, but I do not see any advantages now or in the future for converted BAe 146 or Avro RJ aircraft," says Jacob Netz, senior analyst at the Air Cargo Management Group, expressing his own opinion.

"It is true that the BAe 146/Avro RJ was a pioneer and potential conversion feedstock exists, but these aircraft are old

COMPARISON OF BLOCK FUEL BY SECTOR LENGTH

Sector Length	ATR 72-210F lbs/kg	ATR 72-500F lbs/kg	Avro RJ85F lbs/kg	Avro RJ100F lbs/kg	ATR 72-500F vs Avro RJ100F
100nm	844lbs/383kg	858lbs/389kg	2,277lbs/1,033kg	2,394lbs/1,086kg	-64%
200nm	1,382lbs/627kg	1,415lbs/642kg	3,507lbs/1,591kg	3,735lbs/1,694kg	-62%
300nm	1,903lbs/863kg	1,951lbs/885kg	4,533lbs/2,056kg	4,788lbs/2,172kg	-59%
400nm	2,432lbs/1,103kg	2,529lbs/1,147kg	5,628lbs/2,553kg	5,955lbs/2,701kg	-58%

Source: ATR courtesy of IPR Conversions

Notes

1). Assumptions include: highest design weights, ISA at airfield and en-route, no wind, 10 min taxi, JAR 5% fuel reserves, 100nm standard alternate.

2). AVRO RJ100F performance data based on publicly available BAE estimates. Assumed max structural payloads of 8.5 tonnes for ATR 72-500F and 14,0 tonnes for AVRO RJ100F.

3). ATR max payload value based on ATR's best estimate of OEW with structural tube bulk cargo conversion & highest design weights. AVRO RJ100F based on publicly available BAE estimates.

4). ATR provided fuel burn in kg only. This has also been converted into lbs by Aircraft Commerce using 1lbs = 0.4536kg.

technology and expensive to maintain," adds Netz. "To meet short runway and low noise requirements, the technology of the day required a four-engine configuration. Today, the same operating performance can be achieved with two.

"One could say that the BAe 146 had limited success as a freighter," Netz adds. "The fuselage cross-section does not permit the carriage of standard 88-inch X 125-inch narrowbody ULDs, and engine maintenance was quite expensive."

Most arguments against converting RJ85s or RJ100s into freighters will centre on additional fuel burn and costs that might be incurred by operating a four- rather than two-engine aircraft.

A fuel burn comparison provided by ATR, courtesy of IPR Conversions, suggests that in certain configurations, and with a set of specific operating assumptions, an ATR 72-500 freighter would burn 58-64% less block fuel than an RJ100 on sectors of 100-400nm. The advantage in fuel burn would decrease as route length increases *(see table, this page)*. This comparison is based on an ATR 72 bulk freighter that has not undergone LCD conversion. An ATR 72 LCD freighter would, however, offer similar fuel burn performance.

Campbell at BAE Systems argues that, despite its higher fuel burn, an RJ100 freighter could generate more than one-and-a-half times the revenue tonne kilometres (RTKs) of an ATR 72 freighter in certain circumstances. This would be due to its ability to carry 60% more containerised or bulk payload than an ATR 72 freighter at jet speeds, allowing more flights in a day. The ATR 72 would still have an advantage in terms of fuel burn per trip, but BAE Systems suggests that in certain circumstances the RJ100's overall costs per cu ft of payload could be comparable or less costly.

Despite a turboprop's advantage in fuel burn performance, the RJ85 and RJ100 freighter would be able to carry larger payloads over longer distances.

In terms of maintenance, BAE Systems points out that removal rates for the LF507 engines used on the RJ85 and RJ100 have been half those of the ALF502 that powered the preceding 146 variants.

Supply and demand

According to Flightglobal's Fleets Analyzer data from February 2017, there are 62 active and stored RJ85s in passenger configuration, and 53 active and stored RJ100s. The age profile of these fleets is 14-24 years for the RJ85s, and 15-24 years for the RJ100s. There are 49 RJ85s and 38 RJ100s aged between the typical feedstock conversion thresholds of 15-20 years. Only two further RJ85s are due to enter this conversion window. The remainder of the fleet is over 20 years old, and so may be considered too old for conversion. Nevertheless, the 87 Avro RJs that already fall within the feedstock age window should provide more than enough supply to meet demand should the P-to-F programme be launched.

BAE Systems offers a life extension programme (LEP) for the RJ85 and RJ100 once these aircraft approach a cumulative utilisation of 40,000 flight cycles (FCs). "Any additional inspection criteria related to the LEP will be minor and integrated into the overall airframe inspection regime," says McGovern. In some cases it is unlikely that prospective feedstock airframes will require the LEP. If it is assumed that an RJ85 or RJ100 freighter will operate one return airport-pair per day, six days per week, and that the owner will require 15 years of utilisation post-conversion, the maximum number of FCs the aircraft would operate over this period would be 9,360. Analysis of aircraft within or due to enter the typical feedstock age threshold shows that up to 47 RJ85s and 14 RJ100s could operate as freighters for 15 years without requiring the LEP, based on prospective feedstock being converted with their current cumulative FCs.

BAE Systems believes that demand for the proposed RJ85 and RJ100 freighters could come from operators with replacement requirements for ageing jet freighters with similar payload and operating capabilities, or from turboprop operators with capacity growth demand. Start-up and niche requirements could lead to demand for Avro RJ freighters.

Replacement market

The most obvious candidates for replacement by the proposed RJ85 and RJ100 freighters are their direct predecessors, the 146-200QT and 146-300QT. Some of these QT freighters have already reached 30 years of age and the youngest are 25 years old. The proposed RJ85 and RJ100 freighters represent the closest replacement solutions for current 146-200QT and 146-300QT operators that might wish to renew their ageing fleets without significantly adjusting their capacity or operational capabilities.

There are four active 146-200QTs, with a further five aircraft in storage. The age profile of the fleet is 28-30 years. Pionair in Australia is the largest operator, with two active aircraft.

There are 11 active 146-300QTs with no additional aircraft in storage. The age profile of these aircraft is 25-27 years. The largest operator is ASL Airlines Spain (8 aircraft), which operates on behalf of TNT and was formerly known as PAN AIR. Cobham Aviation Services in Australia is the only other operator (3).

BAE Systems believes that Avro RJ freighters could be considered as replacements for 737-200 freighters. "A number of 737-200 freighters are used to operate from unpaved or unsealed runways in remote locations, such as Northern Canada, with payloads of about 12 tonnes," McGovern adds.

AEI acknowledges that its 737-200 conversion remains available due to this

Avro RJ85 and RJ100 freighters could offer slightly superior payloads and improved operating economics compared to 146-200QTs and 146-300QTs. The proposed RJ solutions will fill a payload capability gap between the largest turboprop and smallest narrowbody freighters.

niche. "The remaining 737-200 feedstock is old, but there is still a chance of one or two conversions, due to its ability to operate on dirt runways, courtesy of its engine ground clearance and the available gravel kit," says Robert Convey, senior vice president of sales and marketing at AEI.

"The 737-200 freighter fleet is running out of remaining economic life," says McGovern. "They cannot be replaced by 737-300s, -400s or -700s on unpaved runway operations since these aircraft have less engine ground clearance and would be more susceptible to damage from FOD. The RJ85 and RJ100 can, however, operate from unsealed runways, in part due to their high wing design and would subsequently represent an effective replacement option for the 737-200."

There are 19 active and 11 stored 737-200 freighters. The age profile of these aircraft ranges from 28 to 47 years. The largest operators of active 737-200 freighters are TransAir (4), Northern Air Cargo (3), Africa Charter Airline (2) and Jayawijaya Dirgantara (2).

Capacity growth

"An Avro RJ freighter would be ideal for cargo airlines looking to grow from turboprop to jet operations," claims McGovern.

The most numerous large turboprop freighters in service are the ATR 72 and BAe ATP.

There are only 27 BAe ATP freighters in service, most of which are operated by West Atlantic (25). It is unclear if West Atlantic would need Avro RJ freighters, since it has already begun adding 737-300 and 737-400 freighters. The airline does operate CRJ200 PFs (2), however, indicating some long-thin routes in its network that require the speed of an RJ freighter.

There are 60 ATR 72 freighters in service, with a further six in storage. The largest operators are ASL Airlines Ireland (16), ASL Airlines Switzerland (10), Mountain Air Cargo (9), Empire Airlines (6), and Swiftair (6). The ASL group already includes an operator of 146-300QTs (ASL Airlines Spain), but these aircraft were inherited through a takeover of TNT's airline operations. Some airlines within the group have been adding 737 Classic freighters, so it is unclear if there would be a demand for RJ85 or RJ100 cargo aircraft. Swiftair has also been adding 737 Classic freighters. Mountain Air Cargo and Empire Airlines both operate all-turboprop cargo fleets in the US on behalf of FedEx Express. Any potential demand for RJ85 and RJ100 freighters may be determined by integrator requirements.

Start-ups & niche users

"Key areas of demand for RJ85 and RJ100 freighters could come from low-cost start-up operations and those looking for niche utility capability," suggests McGovern. "This would include remote point-to-point operations and those from noise-restricted airports or unpaved runways."

Key 146QT operators include Australian airlines using the aircraft to serve remote locations linked to mining. Any growth in demand from these types of operation could benefit the proposed Avro RJ P-to-F programme.

If the RJ85 and RJ100 P-to-F programme is launched, the aircraft could face some competition for niche freighter requirements from Lockheed Martin's newbuild LM-100J Super Hercules. The LM-100J was launched in 2014 and is expected to enter service in 2018. It will be able to accommodate up to eight 88-inch X 108-inch pallets. Like the RJ85 and RJ100, the LM-100J will be capable of operating to remote airports with limited infrastructure. With an expected price tag of $65.00-70.00 million, however, it is unlikely to appeal to the same type of operators as the prospective Avro RJ freighters.

Summary

The proposed RJ85 and RJ100 freighters would offer slightly superior payload potential and improved operating economics compared to 146-200QTs and 146-300QTs. They would sit between ATR 72LCD and 737-200, -300 and -700 freighters in terms of their payload-range capabilities.

RJ85 and RJ100 freighters could offer an effective solution to certain niche cargo requirements, including remote and unpaved airfield operations. They would be the closest matching replacement candidates for 146QT operators and could potentially be used to replace ageing 737-200s. For those operators looking to adjust or optimise capacity, RJ85 and RJ100 freighters would offer more payload than current large turboprop solutions, but less than the smallest narrowbodies.

Ultimate levels of demand will be determined by contrasting the weaknesses of the proposed freighters, including their four-engine configuration, and corresponding higher fuel costs, with their unique, niche operating capabilities and, in some cases, potentially lower acquisition and conversion costs.

The obvious advantages of two-engine configurations over four-engine designs means RJ85s and RJ100s will not be converted in large numbers. Even so, the Avro RJ's niche operating capabilities could lead to modest demand from replacement, growth and new start-up markets. It is possible this demand will be enough to secure the 10 conversions BAE Systems requires to officially launch the programme. - *NMP* AC