**Spare engines might be required to cover scheduled or unscheduled maintenance or to avoid a shop visit altogether. The most in-demand regional and narrowbody aircraft engines are examined here. Current market values, lease rates and demand trends are discussed.**

# The used market for regional & narrowbody engines

The fleet of in-service, passenger-configured regional and narrowbody aircraft has increased by one-third over the past 10 years. This growing fleet will require used spare engines for various purposes, including the provision of cover for maintenance shop visits.

*Aircraft Commerce* has analysed the regional and narrowbody used engine market to provide a summary of demand, value and lease rate trends.

## Used engine demand

There are multiple scenarios that could lead to demand for used engines.

"Operators might source spare engines to cover scheduled or unscheduled maintenance events," says Chris Grey, principle at Aer Auster. "When airlines take delivery of a new aircraft type they might start to receive airframes regularly at relatively short intervals, such as one per month. In future, this could lead to a number of engines requiring shop visits simultaneously. These operators might introduce spare engines to introduce stagger into the shop visit schedule.

"Operators of older aircraft types may source spare engines for shop avoidance purposes," continues Grey. "For some older types an engine shop visit will cost more than the value of the aircraft, at which point it is more efficient to source used 'green-time' engines with limited remaining life."

"There is often a surplus of units available in the mature engine market," explains Martin Friis-Petersen, managing director at MTU Maintenance Lease Services B.V. "These engines often have half-life or a small number of cycles remaining. Powerplants with half-life or few remaining cycles are referred to as green-time engines, and can be used as a cost-effective way of continuing to fly an aircraft without expensive engine shop visits. Acquiring a green-time engine makes sense when the cost of a shop visit is out of proportion to the engine's remaining lifespan.

"Engines can also be bought and used as spares, or torn down to provide used serviceable material," adds Friis-Petersen. "The aim of this is to minimise the cost of shop visits for engines that will only be flown for a relatively short period of time before being phased out."

## Engine sourcing options

Once a requirement to source a used engine has been identified, operators need to decide whether they will obtain one via an outright purchase or through a lease.

Several types of engine lease deals are available, including finance and operating leases. "We are increasingly finding finance leases dressed up as operating leases," explains Graeme Crickett, senior vice president and head of technical at Sumisho Aero Engine B.V.

Finance lease deals are increasingly likely to be arranged for new engines with the current low interest rates helping some lessees. They establish agreed lease rental payments between the lessor and operator over a relatively long period.

"Newer finance leases are typically eight to 12 years long, where the terms used to be five to seven years," says Crickett. At the end of the payment term the operator assumes ownership of the engine and the associated residual value risk, so a finance lease can be considered a method of outright purchase.

Used engines are more likely to be sourced via an operating lease, whereby the operator pays the lessor agreed monthly lease rentals and maintenance reserves. The lessor will then access the reserves for specified maintenance events agreed in the lease contract. The engine is returned to the lessor at the end of the lease term, after undergoing any maintenance required in the lease return conditions. The lessor carries the residual value risk for engines on operating lease.

Operating leases can be short- or long-term. "IBA defines engine operating leasing in terms of long-term, short-term or all-in green-time lease rates," explains Kane Ray, head analyst of commercial engines at the International Bureau of Aviation (IBA). "Each of these categories means the engine will have at least some operational life remaining.

"A long-term lease is in excess of one year, and is common for thriving engine variants," continues Ray. "A short-term lease could be up to 12 months and in many cases significantly less. Short-term leases are commonly used for shortages relating to unforeseen events, entry-into-service requirements or short-term cover.

"An all-in green-time lease would be for a set period of time, usually not exceeding three years," adds Ray. "This is common for mature engine and aircraft pairings, and involves building an engine to last for a specific time period."

"The main drivers for lease demand are fleet size and utilisation, original equipment manufacturer (OEM) service coverage, fleet reliability, on-site support, fleet management, and spare engine ownership structure," says Friis-Petersen.

"The decision to lease or buy a used engine depends on how long it is needed for," says Mark Hughes, executive vice president, corporate finance at Falko. "If it is a long-term requirement it will make more sense to buy where possible."

"When comparing the merits of buying or leasing an engine, operators must take into consideration the direct costs of ownership, engine storage costs and the potential to release cash," says Ray. "The operator's inventory holding and fleet planning strategy will be factors, including how long it plans to keep the aircraft type in its fleet. In addition, OEMs and maintenance & repair organisations (MROs) offer very attractive, all-encompassing maintenance and repair packages for hourly fees. These place all maintenance, storage and preservation responsibility with the OEM or MRO. These are available for the newest and oldest engine technology."

MTU Maintenance is one MRO that

*The majority of turboprops with more than 30 seats are powered by PW100 family engines. The PW127 series is one of the most numerous in operation. The PW127M powers the ATR 42-500 and -600, and ATR 72-500 and -600.*

also offers engine leasing. Through its two joint ventures with the Sumitomo Corporation it offers various engine support services. Through MTU Maintenance Lease Service B.V. it can provide short-term leasing, stand-by arrangements, engine pooling, and asset and material management. Sumisho Aero Engines B.V, in which MTU has a 10% stake, offers long-term leasing and sale and leaseback (SLB) financing.

Under an SLB transaction an operator sells an engine to a lessor, and then leases it back for a term. Once the engine has been sold, the transaction functions like a regular operating lease. Operators see SLBs as a good way to raise cash. "SLBs for engines are common with new aircraft types, since airlines can get good discounts from the OEM and then sell the asset to leasing companies at, or close to the full list price," explains Crickett.

Spare engine demand and sourcing strategies may vary slightly between the regional and narrowbody aircraft markets. "There is a much bigger pool of available engines for narrowbodies, and a much larger number of lessors offering narrowbody engines," explains Hughes. "The regional engine market is much more concentrated with fewer participants, probably because the global fleet is smaller. Also, regional operators tend to have a much shorter hours:cycles ratio than narrowbody operators. This is often less than one hour per cycle. Higher cycles per year lead to earlier LLP replacements." Regional operators may therefore have periods of more frequent demand for spare engines to cover a number of sequential shop visits.

"Generally, the narrowbody market has the largest number of leased engines," says Friis-Petersen. "This is because it has a larger installed fleet, high order rate and broad customer base, so it is an attractive investment opportunity for asset owners.

"The spread of leased regional engines varies by region," continues Friis-Petersen. In the US there are a number of operators with large fleets of regional jets (RJs) that operate feeder flights for mainline carriers. Such regional operators are likely to have an owned spares policy. Elsewhere, however, regional airlines tend to have smaller fleets, so a spare engine pooling arrangement is more appealing."

"The approach to sourcing spare engines is usually determined by the operator rather than the type of aircraft," says Anca Mihalache, sales and marketing manager at Vallair. "The capital costs of narrowbody and regional aircraft engines are very different and there are very different patterns of pricing and availability. The lease market for narrowbody engines is much more mature than that for leased regional engines, with far more suppliers and competitors."

## Values and lease rates

A number of factors can influence values and lease rates for a particular engine series.

"From time to time OEMs might upgrade the build standard of a certain engine model series," explains Joe Jacob, senior vice president, powerplant at Acumen Aviation. "These upgrades may result from a customer requirement or experience gained since the engine entered service. The upgrades lead to performance and specific fuel consumption (SFC) improvements. The better the build standard, the higher the engine price."

"The certified thrust rating is also a big factor in used engine values," says Grey. Engines with higher thrust ratings will have higher values.

"Lease rates are driven by supply and demand and can be very volatile," says Friis-Petersen. "Short-term lease demand for in-production engines will depend on shop visit demand, which in turn is influenced by worldwide engine shop capacity and turnaround times, as well as engine reliability and on-wing times. No major lease rate changes would be expected unless unpredicted shop visit peaks occur. These peaks may result from technical issues that require programme upgrades or improvement shop visits.

"In terms of used engine sourcing in the aftermarket, there are subtle differences according to the availability of mature engines and market competition," continues Friis-Petersen. "The markets for narrowbody engines like the V2500 and CFM56, as well as the CF34 in the regional sector, are very healthy because competition is permitted to prevail and there is interest in trading used engines. The residual values of engines and piece parts remain strong as a result. The opposite occurs with engine types where there is limited competition and choice."

A summary of the current market values (CMVs) and monthly lease rates for some of the most common regional and narrowbody aircraft engines is given here. The CMVs and lease rates were provided by IBA and are for engines in half-life maintenance condition. The range in CMVs and lease rates for each engine type accounts for differences in build standard or thrust rating where applicable. The lease rates are based on the assumption that the engines are on a long-term operating lease.

This analysis does not attempt to identify demand and value trends for new engine families, such as the CFM-LEAP and PW1000G, because these have only recently entered service and are unlikely to be available in used condition in significant numbers for some time.

## Turboprop engines

Most passenger-configured turboprops with more than 30 seats are powered by Pratt and Whitney Canada (P&WC) PW100 family engines.

## PW100 family

According to Flightglobal's FleetsAnalyzer, there are 1,968 passenger-configured turboprops operating with PW100 family engines. There are 10 different active series of PW100 ranging from the PW118 to the PW150, with multiple sub-variants.

The PW127 and PW150 are the most numerous PW100 series engines in use.

There are eight sub-variants of the PW127 series. The most popular are: the PW127F, which powers the ATR 42-500 (4 aircraft) and ATR 72-500 (125); and the PW127M which equips the ATR 42-500 (12), ATR 42-600 (27), ATR 72-500 (168) and ATR 72-600 (290). The latest sub-variant is the PW127N, but this is only in service with a small number of ATR 72-600s (9).

"In the PW127 market, the later PW127M and PW127N engines hold the most value," says Ray. "There has been demand for retrofitting PW127F engines to the PW127M standard, which offers more power for better hot-and-high take-off performance. The F sub-variant can be retrofitted to PW127M standard by complying with a service bulletin (SB)."

This SB is P&WC SB21757, which includes a modification to the Engine Electronic Control (EEC) unit. Depending on the EEC that is installed, the modification may need an EEC upgrade or replacement. There are several EEC part numbers and configurations, so the potential cost could vary.

The PW150A is the only variant in the PW150 series and powers the entire fleet of Q400s (483). "Values and lease rates for the PW150A have been strong recently due to shortages resulting from a combination of planned removals and reactive maintenance," explains Ray. In 2015 an airworthiness directive (AD) was released that required the inspection of the No. 4 keywasher in the PW150A *(see Regional aircraft engine maintenance, Aircraft Commerce, October/November 2016, page 59)*. This increased the frequency of PW150A shop visits, since it required the removal and inspection of all in-service engines.

According to IBA, a PW150A in half-life maintenance condition would have a CMV of $1.45-1.60 million and a monthly lease rate of $23,000-27,000 *(see table, page 8)*. It is estimated that a PW127M has a CMV range of $1.00-1.10 million, while a PW127F has a CMV of $695,000-780,000. Both PW127 variants are estimated to have monthly lease rates of $15,000-22,000.

The next highest CMVs belong to: the PW127B, which equips a small number of Fokker 50s (7); and the PW127E which powers 80 of the ATR 42-500 fleet. IBA says that both variants could have half-life CMVs of $650,000-680,000, and lease rates of $15,000-20,000. IBA suggests that the basic PW127 variant that equips the ATR 72-210 (18) would have similar lease rates, but a wider range in potential CMVs of $630,000-700,000.

Other active PW100 family engines include: the PW118 series, which equips the EMB-120 Brasilia fleet (82); the PW119 series, which powers the Dornier 328 (43); the PW120 series, which powers some ATR 42-300s (30) and Dash 8-100s or Q100s (106); the PW121 series, which also equips ATR 42-300s (42) and Q100s (67); the PW123 series, which equips the entire fleet of Q200s (57) and Q300s (179); the PW124 series, which powers the ATR 72-200 (27); the PW125 series, which equips most active Fokker 50s (52); and the PW126, which is the sole option for the remaining fleet of passenger-configured BAE ATPs (4).

CMVs for PW123 series engines can be $500,000-690,000 depending on the sub-variant. It is estimated that CMVs for the PW126 will be $580,000-650,000, and that the PW124B and PW125B will be $550,000-620,000. The PW121 has a CMV of $500,000-590,000, while the PW120 series will be $450,000-520,000. Values for PW118 and PW119 series engines will be $480,000-530,000.

## REGIONAL AIRCRAFT ENGINE HALF-LIFE VALUES & LEASE RATES

| Engine type | Aircraft platform | CMV range ($-M) | Lease rates ($) |
|---|---|---|---|
| **Turboprop** | | | |
| **PW100 Family** | | | |
| PW118 | EMB-120 Brasilia | 0.480-0.530 | N/A |
| PW119 | Dornier 328 | 0.480-0.530 | N/A |
| PW120 | ATR42-300 | 0.450-0.520 | N/A |
| PW120A | Q100 | 0.450-0.520 | N/A |
| PW121 | ATR 42-320/Q100 | 0.500-0.590 | N/A |
| PW123 | Q300 | 0.540-0.630 | N/A |
| PW123B | Q300 | 0.580-.0690 | N/A |
| PW123D | Q200 | 0.500-0.540 | N/A |
| PW123E | Q300 | 0.560-0.640 | N/A |
| PW124B | ATR 72-200 | 0.550-0.620 | N/A |
| PW125B | Fokker 50 | 0.550-0.620 | N/A |
| PW126 | BAE ATP | 0.580-0.650 | N/A |
| PW127 | ATR 72-210 | 0.630-0.700 | 15,000-20,000 |
| PW127B | Fokker 50 | 0.650-0.680 | 15,000-20,000 |
| PW127E | ATR 42-500 | 0.650-0.680 | 15,000-20,000 |
| PW127F | ATR 42-500/ATR 72-500 | 0.695-0.780 | 15,000-22,000 |
| PW127M | ATR 42-500/-600, ATR 72-500/-600 | 1.00-1.10 | 15,000-22,000 |
| PW150A | Q400 | 1.45-1.60 | 23,000-27,000 |
| **Regional Jet** | | | |
| **CF34 Family** | | | |
| CF34-3A1 | CRJ100 | 0.850-0.900 | N/A |
| CF34-3B1 | CRJ200 | 1.10-1.20 | 25,000-30,000 |
| CF34-8C1 | CRJ700 | 1.50-1.60 | N/A |
| CF34-8C5 | CRJ700/900 | 3.00-3.10 | 30,000-45,000 |
| CF34-8C5A1 | CRJ900/1000 | 3.10-3.20 | 30,000-45,000 |
| CF34-8C5B1 | CRJ700 | 2.70-2.80 | 30,000-45,000 |
| CF34-8E5 | E-170/-175 | 3.30-3.40 | 38,000-47,000 |
| CF34-8E5A1 | E-170/-175 | 3.40-3.50 | 38,000-47,000 |
| CF34-10E5 | E-190/-195 | 5.20-5.30 | 57,000-70,000 |
| CF34-10E5A1 | E-190/-195 | 5.60-5.70 | 57,000-70,000 |
| CF34-10E6 | E-190/-195 | 5.20-5.30 | 60,000-80,000 |
| CF34-10E6A1 | E-190/-195 | 5.70-5.80 | 60,000-80,000 |
| CF34-10E7 | E-190/-195 | 6.10-6.20 | 60,000-80,000 |
| **AE 3007 Family** | | | |
| AE 3007A | ERJ 135/-140/-145 | 0.800-0.900 | 15,000-25,000 |
| **LF507 Family** | | | |
| LF507-1F | RJ85/RJ100 | 0.340-0.380 | 5,000-8,000 |
| **RB.183 Tay Family** | | | |
| Tay Mk 620 | Fokker 70/100 | 0.650-0.750 | 22,000-26,000 |
| Tay Mk 650 | Fokker 100 | 0.950-1.10 | 25,000-30,000 |

Source: IBA
Current market values and lease rates are for engines in half-life maintenance condition.

## RJ engines

The General Electric (GE) CF34 family equips more than 70% of the active RJ fleet. Other significant engine families in this market include the Rolls-Royce (RR) AE 3007, Honeywell LF507 and RR RB.183 Tay.

### CF34 family

The CF34 family is installed on 2,471 in-service RJs, and comprises five different engine series: the CF34-3, CF34-8C, CF34-8E, CF34-10A and CF34-10E. The CF34-10A series is not considered here, since it was designed for Comac's ARJ21 RJ and only two of these aircraft have entered service so far.

The CF34-3 series includes the CF34-3A1 and CF34-3B1, which are the sole respective engine options for active CRJ100s (39) and CRJ200s (500). Both variants have a fan diameter of 44 inches, but Jacobs notes that they have different turbomachinery hardware. "A CF34-A1 can be converted to –B1 status during a shop visit, but this is expensive," he says.

"Demand for CF34-3B1 series engines remains very strong since there are few spare engines in the market," says Crickett. "Those that surface are quickly snapped up."

"CF34-B1 engines in good condition often trade for a little over $1.0 million," says Ray. "This has been a constant figure for a good number of years."

According to IBA, a CF34-3B1 in half-life condition could have a CMV of $1.10-1.20 million and a lease rate of $25,000-30,000 *(see table, this page)*. It estimates that a CF34-3A1 would have a CMV of $850,000-900,000.

CF34-8C series engines have a fan diameter of 46.2-inches and power the CRJ700, CRJ900 and CRJ1000. There are four active sub-variants: the CF34-8C1, which equips some CRJ700s (142); the CF34-8C5, which equips CRJ700s (40) and CRJ900s (339); the CF34-8C5A1, which powers CRJ900s (50) and CRJ1000s (51); and the CF34-8C5B1, which is used by some CRJ700s (123).

The CF34-8E series is the exclusive engine option for the E-170 and E-175 and, like the -8C series, has a fan diameter of 46.2-inches. There are two active sub-variants: the CF34-8E5, which equips most E-170s (131) and E-175s (389), and the CF34-8E5A1, which powers the rest of the E-170 (15) and E-175 (15) fleets. "The -8E series benefits from improvements to the -8C's design, so it seems more reliable," says Crickett.

"Excluding engine accessories and aircraft-specific components like quick engine change (QEC) kits, the CF34-8C and -8E engines have high commonality of parts between them," explains Ray.

"The -8C and -8E share the same life limited part (LLP) stack and have significant additional commonality," adds Hughes. "There is, however, almost no commonality with the -10E series."

CF34-10E engines are larger than the -8C and -8E variants with a fan diameter of 53-inches. They are the exclusive engine options for the E-190 and E-195. There are five active sub-variants within the CF34-10E series: the CF34-10E5, which equips 162 E-190s and 30 E-195s; the CF34-10E5A1, which powers 89 E-190s and 32 E-195s; the CF34-10E6, which is installed on 187 E-190s and nine E-195s; the CF34-10E6A1, which equips 21 E-190s and five E-195s; and the CF34-10E7, which is installed on 25 E-190s and 75 E-195s.

"Within each of the three CF34-8C, -8E and -10E series, engines can be transitioned between sub-variants fairly easily," says Hughes. "This is subject to cost, particularly if the engine is being up-rated."

"Within each of the CF34-8C, -8E and -10E engine series, there is commonality at sub-variant level," explains Ray. For example, the -10E5 and -10E7 have extensive commonality between them. "The main difference is software and take-off/climatic thrust performance, which can be interchanged using different software plugs," adds Ray.

"CF34-8C engines have attracted traders in the secondary market due to some aircraft retirements and fleet exits,"

## NARROWBODY AIRCRAFT ENGINE HALF-LIFE VALUES & LEASE RATES

| Engine type | Aircraft platform | CMV range ($-M) | Lease rates ($-m) |
|---|---|---|---|
| **CFM56 Family** | | | |
| CFM56-3B1 | 737-300/-500 | 0.500-0.530 | 23,000-27,000 |
| CFM56-3B2 | 737-300/-400/-500 | 0.600-0.630 | 25,000-30,000 |
| CFM56-3C1 | 737-300/-400/-500 | 0.920-0.970 | 28,000-35,000 |
| CFM56-5A1 | A320 | 1.10-1.40 | 30,000-35,000 |
| CFM56-5A3 | A320 | 1.80-2.00 | 32,000-38,000 |
| CFM56-5A5 | A319 | 1.80-2.00 | 32,000-38,000 |
| CFM56-5B1 | A321 | 5.60-6.60 | 60,000-65,000 |
| CFM56-5B2 | A321 | 5.80-6.90 | 60,000-65,000 |
| CFM56-5B3 | A321 | 5.90-7.00 | 70,000-76,000 |
| CFM56-5B4 | A320 | 5.30-6.40 | 60,000-65,000 |
| CFM56-5B5 | A319 | 3.90-4.80 | 50,000-55,000 |
| CFM56-5B6 | A319/320 | 4.30-5.30 | 50,000-55,000 |
| CFM56-5B7 | A319 | 5.30-6.40 | 60,000-65,000 |
| CFM56-5B8 | A318 | 3.50-4.50 | 45,000-50,000 |
| CFM56-5B9 | A318 | 5.60-6.60 | 45,000-50,000 |
| CFM56-7B20 | 737-600/-700 | 3.90-4.40 | 45,000-50,000 |
| CFM56-7B22 | 737-600/-700 | 4.40-5.60 | 50,000-55,000 |
| CFM56-7B24 | 737-700/-800/-900 | 5.20-5.70 | 55,000-60,000 |
| CFM56-7B26 | 737-700/-800/-900/-900ER | 5.90-6.40 | 65,000-68,000 |
| CFM56-7B27 | 737-800/-900ER | 6.20-6.70 | 65,000-73,000 |
| **V2500 Family** | | | |
| V2500-A1 | A320 | 1.00-1.20 | 27,000-38,000 |
| V2522-A5 | A319 | 4.20-4.60 | 50,000-60,000 |
| V2524-A5 | A319 | 4.70-5.20 | 60,000-70,000 |
| V2527-A5 | A320 | 5.40-6.10 | 75,000-80,000 |
| V2527E-A5 | A320 | 5.80-6.40 | 75,000-80,000 |
| V2527M-A5 | A319 | 5.80-6.40 | 75,000-80,000 |
| V2530-A5 | A321 | 5.80-6.60 | 75,000-80,000 |
| V2533-A5 | A321 | 6.40-7.30 | 80,000-90,000 |
| V2525-D5 | MD-90 | 2.50-2.60 | 80,000-90,000 |
| V2528-D5 | MD-90 | 2.80-3.00 | 80,000-90,000 |
| **PW2000 Family** | | | |
| PW2037 | 757-200 | 2.80-3.20 | 45,000-65,000 |
| PW2040 | 757-200 | 3.00-3.30 | 45,000-65,000 |
| **RB211 Family** | | | |
| RB211-535E4 | 757-200 | 2.80-3.20 | 50,000-65,000 |
| RB211-535E4B | 757-200/-300 | 3.00-3.30 | 50,000-65,000 |
| **BR700 Family** | | | |
| BR715A | 717-200 | 2.60-3.00 | 30,000-50,000 |
| **JT8D Family** | | | |
| JT8D-217 | MD-80 | 0.475-0.525 | 17,000-22,000 |
| JT8D-219 | MD-80 | 0.575-0.625 | 17,000-22,000 |

Source: IBA
Current market values and lease rates are for engines in half-life maintenance condition.

says Ray. "Some have ended up with teardown entities, which has reduced their value, but there is still demand for the CF34-8C series as well as the -8E series, both in terms of whole engines and shop visit induction material."

"Demand for CF34-8C, -8E and -10E series engines is rising," claims Crickett. "Some CF34-10E operators are signing up to MRO agreements with engine lease support."

"Demand for aftermarket engines in the CF34-8C, -8E and -10E series is likely to increase significantly as more of these powerplants undergo expensive 25,000 engine flight cycle (EFC) overhauls for LLP replacement," says Hughes.

"Spare engine ratios average 10-11%, which is marginal to support a full shop visit phase of CF34-8C, -8E or -10E engines," suggests Crickett. "Some operators find used replacement engines, while others opt for used LLPs instead of building a full 25,000 EFC stack."

Most LLPs on CF34-8C, -8E and -10E series engines are limited at 25,000EFCs, although some have slightly shorter limits just above 24,000EFCs. These engines will require an overhaul and LLP replacement as they approach their LLP life limits. Hughes estimates the combined costs for this shop visit plus LLP replacement could be in excess of $4.00 million per engine.

"2017 list prices for new LLP stacks for the CF34-8C, -8E and -10E are well over $3.00 million, including static LLPs," explains Crickett. "When this is combined with the mechanical cost of parts and parts repairs, final invoices may top $5.00 million. It may be more cost-effective to replace engines with used ones, or even a new one from the OEM."

IBA suggests that CMVs for half-life CF34-10E series engines could be $5.20-6.20 million, depending on the sub-variant. It also estimates that lease rates could be $57,000-70,000 for -10E5 and -10E5A1 variants, and $60,000-80,000 for -10E6, -10E6A1 and -10E7 engines.

CMVs for CF34-8E series engines are expected to be $3.30-3.50 million with lease rates of $38,000-47,000. Values for CF34-8C series engines could be $1.50-3.20 million, with lease rates of $30,000-45,000.

### AE 3007

The AE 3007 is the next most common engine family in the RJ market. AE 3007A series engines exclusively power Embraer's ERJ series. They are currently installed on 549 in-service aircraft including ERJ-135s (52), ERJ-140s (31) and ERJ-145s (466). Eight different AE 3007A sub-variants are in service.

"AE 3007A series values have fallen in recent years," says Ray. "There has been a lull in trading due to large parked fleets of ERJ aircraft and OEM barriers to entry in the maintenance aftermarket."

Active ERJ numbers have fallen by more than one-third over the past decade, partly due to US-based regional operators removing 50-seat RJs from service in favour of larger types, in line with a relaxation in mainline carrier scope clause restrictions.

IBA suggests that CMVs for AE 3007A series engines will be $800,000-900,000, with lease rates of $15,000-25,000.

### RB.183 Tay

The RB.183 Tay family includes the Tay Mk 620 and Tay Mk 650 series. These are the exclusive engine options for the Fokker 70 and Fokker 100. The Tay Mk 620 is installed on 35 active Fokker 70s and three active Fokker 100s. The Tay Mk 650 is in service on 106 Fokker 100s.

"Key customers like KLM are exiting the Fokker 70 fleet," says Ray. "Values of aircraft and engines have fallen as a result, but there is still a dedicated MRO and spare engine network for the RB.183

Tay family."

Over the past 10 years KLM has phased out the Fokker 100 and reduced its Fokker 70 fleet from 21 to 11 aircraft. It has been renewing the KLM cityhopper fleet with E-175s and E-190s.

CMVs for half-life Tay Mk 620 engines could be $650,000-750,000, with lease rates of $22,000-26,000; while the Tay Mk 650 might have CMVs of $0.95-1.10 million, and lease rates of $25,000-30,000.

### LF507

The LF507 family is installed on the Avro RJ family and a small number of BAE 146s. There are two main series: the LF507-1F and LF507-1H. The LF507-1H is not considered here, since it is only installed on three active BAE 146-300s.

The LF507-1F is installed on 86 in-service Avro RJ aircraft, including 39 RJ100s and 47 RJ85s.

"The LF507 family is now out of production," says Hughes. "The cost of an overhaul is increasing relative to the aircraft's value, so there is rising demand to buy or lease green-time engines. The high prevalence of low-utilisation Avro RJ operators means that an overhaul is less economic than the green-time engine option. As a major provider of spares to the Avro RJ market, Falko Spares has started leasing LF507s to top-tier credits, and lease rates are relatively stable."

"The LF507 is a mature engine family attached to a dwindling aircraft fleet," says Ray. "Values have dropped but have now found their value floor."

CMVs for half-life LF507-1F engines are $340,000-380,000 with lease rates of $5,000-8,000.

## Narrowbody engines

The narrowbody sector sees the most trading in used engines. "AJW Leasing (AJWL) sees narrowbody engines generating the most activity," explains Alun Roberts, engine leasing manager at AJW Leasing. "Over the past few years AJWL has seen strong demand for mature narrowbody engines, including the CFM56-3C1, -5B, -7B, V2500-A5, PW2000 and RB211.

"Lower fuel prices have been a major factor in 2016 and have had a positive financial impact for airlines," continues Roberts. "This has allowed them to delay phasing out older mature aircraft, and encouraged new-entrant carriers to choose older Classic variants. Delays in aircraft deliveries have also forced operators to keep older aircraft in service."

CFM56 family engines are fitted on more than 70% of the active narrowbody fleet. The next most popular family is the V2500. Other significant engine families in the narrowbody sector include the PW2000, RB211, JT8D and BR700.

The most valuable and highly traded narrowbody engine variants are the CFM56-7B and -5B series and IAE V2500-A5 series. "Much of the spare engine leasing market still revolves around the V2500-A5, CFM56-5B and CFM56-7B," explains Ray. "All three engine series still have outstanding backlogs and significant portions of each fleet have yet to have a shop visit."

"V2500-A5, CFM56-5B and CFM56-7B engines have the best residual values due to shop visit requirements," says Roberts. "These translate either into short-term leases to provide cover for airlines or part-outs to supply material for shop visits."

### CFM56-7B

"The CFM56-7B series powers the 737NG family and has 19,500-27,300lbs in take-off thrust," explains Roberts. The CFM56-7B series is installed on 5,774 in-service aircraft including 737-600s (53), 737-700s (1,046), 737-800s (4,211), 737-900s (52) and 737-900ERs (411).

There are five main thrust variants of CFM56-7B in service: the CFM56-7B20, -7B22, -7B24, -7B26 and -7B27. The last two digits of the suffix denote the thrust

*Demand for CF34-8C, -8E and -10E engines is expected to increase as more of the in-service fleet approaches the 25,000EFC LLP replacement threshold.*

rating in thousands of lbs.

For each thrust rating, multiple engine sub-variants are available. The sub-variant is determined by the engine build standard and whether it has a single annular combustor (SAC) or dual annual combustor (DAC). It is claimed that advanced DAC technology reduces emissions by up to 40%. Engines with a DAC are denoted with a /2 suffix.

CFMI has also developed several improved build standards for the CFM56-7B as the engine has matured. The first is known as the Tech Insertion and the most recent is referred to as the Evolution standard.

"The Tech Insertion programme entered service on all new engines from 2007," explains Roberts. "It is also available as an upgrade during a regular shop visit. The Tech Insertion programme involves upgrading high-pressure turbine (HPT) and low-pressure turbine (LPT) components and redesigning the high-pressure combustor (HPC) blades. It increases fuel efficiency by 1% and exhaust gas temperature (EGT) margins by 10 degrees. Engines built to the Tech Insertion standard have a /3 suffix.

"A further enhancement to the CFM56-7B is the Evolution standard, denoted by the letter E in the variant suffix," adds Roberts. "This upgrade was a joint venture between Boeing and CFM, and includes further enhancements to the HPC, HPT and LPT. The exhaust nozzle is also redesigned for the -7BE build standard. These improvements are said to reduce fuel consumption and carbon emissions by around 2%."

Various CFM56-7B20 and -7B22 sub-variants are installed on 737-600s and -700s. CFM56-7B24 sub-variants are installed on 737-700s, -800s and -900s and the -7B26 is used by 737-700s, -800s, -900s and -900ERs. CFM56-7B27 engines are currently in operation with 737-800s and -900ERs.

"CFM56-7B demand is stable and anticipated to grow as more shop visits take place," says Ray. CFM56-7B half-life CMVs are $3.90-6.70 million with potential lease rates of $45,000-73,000 *(see table, page 10)*. Values and lease rates increase for engines with higher thrust ratings and build standards.

## CFM56-5B

"The CFM56-5B series is an engine option for the A320ceo family and offers 22,000-33,000lbs in take-off thrust," says Roberts. The CFM56-5B series is installed on 3,433 active aircraft, including: A318s (34), A319s (737), A320s (2,138) and A321s (524).

There are nine main variants ranging from the CFM56-5B1 to the -5B9. The -5B1, -5B2 and -5B3 can be installed on the A321; the -5B4 can be installed on the A320; the -5B5 and -5B7 are options for the A319; while the -5B6 is in-service with A319s and A320s. The CFM56-5B8 and -5B9 can be installed on the A318.

For each variant there are several sub-variants available. Like the -7B series, the precise sub-variant is determined by the engine's build standard and whether it has an SAC or DAC. Engines with a DAC are again denoted by a /2 suffix.

"In 2007 CFM made a Tech Insertion available for the CFM56-5B series," says Roberts. "The new core and LPT hardware upgrade can be installed during a regular shop visit. This claims to lower maintenance costs by 5-12% and offers up to 15% EGT improvement. Engines with the Tech Insertion modification are indicated with /3 in the suffix. CFM56-5B engines can also be fitted with a '3D Aero' package. This involves a new three-dimensional (3D) aerodynamic design of all blades and vanes, and is indicated by the suffix letter 'P' in the engine model. The latest production -5B configuration is the CFM56-5B/3 PIP (Performance Improvement Programme), which has a number of improvements in the core and fan blades. According to CFM this latest production standard provides a further 0.5% improvement in fuel efficiency and 1% lower maintenance costs."

Ray suggests that demand for the CFM56-5B remains stable, and is likely to grow in line with an increase in shop visits. CFM56-5B half-life values are $3.50-7.00 million, with potential lease rates of $45,000-76,000. Values and lease rates depend on the engine variant. For each variant they increase with thrust rating and build standard.

## V2500-A5

The V2500-A5 series is the other main engine option for the A320ceo family. It is installed on 2,822 active aircraft including A319s (424), A320s (1,599) and A321s (839).

There are five main variants: the V2522-A5, V2524-A5, V2527-A5, V2530-A5 and V2533-A5. The model description indicates the take-off thrust available. The V2527-A5, for example, has a take-off thrust of 26,600lbs. The V2522-A5 and V2524-A5 can be installed on the A319. The V2527-A5 can also be installed on the A319, but is the only variant that can equip the A320. The V2530-A5 and V2533-A5 are both designed for the A321.

"The V2500-A5 series entered service in 1993, and was an improvement of the original V2500-A1 engine," says Roberts. "The initial –A1 had a relatively low EGT margin, which meant a short life span on-wing before the engine had to be removed for restoration. The model was unsuitable to power the A321, which needed a higher thrust configuration. In comparison to the –A1, the V2500-A5 has a wider fan and core diameter, an extra stage to the LPC and improvements to the HPC. This leads to a higher core flow that reduces the bypass ratio and increases the EGT margin, which allows for a higher thrust capability."

For each of the five main V2500-A5

*CFM56-7B series, CFM56-5B series and V2500-A5 series engines remain the most valuable and highly traded narrowbody engines. Demand could grow as more engines come due for scheduled shop visits.*

variants, several sub-variants are available due to different build standards. "In 2008 the SelectOne upgrade became available," explains Roberts. This consists of aerodynamic improvements to the core and LPT that further reduce fuel burn, increase EGT margin and extends time on-wing. The SelectOne upgrade can be retrofitted during engine restoration.

"The latest upgrade is the V2500-A5 SelectTwo, which further reduces fuel burn," adds Roberts. "This entered service in 2015 and requires a SelectOne standard engine and SCN22 software upgrade. This can be performed on-wing.

In addition, two other sub-models are possible based on the V2527-A5 variant: the V2527M-A5 and V2527E-A5. Both have enhanced ratings for high altitude airport operations.

"Lease rates for V2500-A5 series engines are 60% higher than they were three years ago," explains Roberts. "This is due to high demand but also a shortage of supply, driven by an increase in shop visits, a reduction in spare engine production and traders and OEMs buying engines to support airlines during shop visits."

"There have been fleet-wide impacts with ADs and SBs affecting the V2500-A5 series," says Crickett. "ADs including FAA 2016-18-10 (HPT Hubs), FAA 2016-25-11 (No 3 Bearing) and FAA 2012-09-09 (HPC 3-10 Drum) have resulted from faults in manufacturing. Associated special inspections, accelerated shop visits, scrappage of LLPs and parts, plus manufacturing delays have had a significant operational impact," adds Crickett. "These combined circumstances have led to a large increase in demand for spare V2500-A5 engines and value premiums for those in good condition. P&W has these technical issues in hand, but it may take several years for the number of shop visits and associated spares issues to return to normal levels."

"There is a strong market for the V2500-A5 series, particularly for higher thrust engines," says Ray. "Market values are above base values for the time being."

CMVs for V2500-A5 series engines are $4.20-7.30 million, with lease rates of $50,000-90,000. Values and lease rates increase for engines with higher thrusts and build standards.

## Other narrowbody engines

Significant numbers of other narrowbody engines remain in operation, including other members of the CFM56 and V2500 families, and variants of the PW2000, RB211, BR700 and JT8D families.

There are two variants of the CFM56-3 series in service. The CFM56-3B is installed on 138 737-300s, 21 737-400s and 68 737-500s. The CFM56-3C1 is installed on 126 737-300s, 124 737-400s and 93 737-500s.

"CFM56-3 values remain stable for engines in good condition with good records," says Ray.

"Operators try to minimise shop visits for the CFM56-3 series where possible and source replacement engines via purchase or exchange," says Crickett.

"Lease demand and associated rates can be seasonal," explains Grey. "The CFM56-3 is susceptible to deteriorating EGT margins at high ambient temperatures. The CFM56-3 is not as robust as the -5B and -7B, and its EGT margin will deteriorate much faster in higher temperature scenarios." This could lead to increased shop visit requirements and demand for spare engines during the summer months.

"The CFM56-3C1 has recently seen some demand resulting from passenger-to-freighter conversions for 737-400s," says Jacob.

"Lower oil prices have caused some operators to keep older aircraft flying longer," says Mihalache. "The CFM56-3 and CFM56-5A have therefore seen higher demand recently. CFM56-3C1 lease rates have risen since 2015, driven by a short supply for use on high gross weight 737-400 aircraft and hot-and-high operators."

CMVs for half-life CFM56-3 series engines are $500,000-970,000, with lease rates of $23,000-35,000 *(see table, page 10)*.

The CFM56-5A series equips some older A319s, and A320s. The CFM56-5A1 and -5A3 are installed on 134 and 73 A320s respectively. The CFM56-5A4 and -5A5 are installed on seven and 132 A319s respectively. "Values for the oldest engine variants in the A320 family have been decreasing recently," says Ray.

CMVs for CFM56-5A series engines are $1.10-2.00 million, with lease rates of $30,000-38,000.

The V2500-A1 is installed on 40 older A320s. CMVs are $1.00-1.20 million, with lease rates of $27,000-38,000.

"Vallair will manage five V2500-A1s, and the operators prefer to module swap between them to optimise the build of two engines and a short-build, green-time, spare engine," explains Mihalache. "Towards 2020 we expect a lower demand for CFM56-3, -5A and V2500-A1 engines. Vallair believes that there may be a looming over-supply of aircraft in the narrowbody segment driven by increased deliveries of new aircraft, so we are adjusting our portfolio accordingly."

The V2500 family also includes the V2500–D5 series, which is installed on the MD-90. The V2525-D5 is in service with 38 aircraft while the V2528-D5 is installed on 27 MD-90s. CMVs for V2500-D5 series engines are $2.50-3.00 million, with lease rates of $80,000-90,000.

The PW2000 and RB211 families are the two engine options for the 757. There are 172 active 757s with PW2000 engines installed, and 236 with RB211-535E4 engines installed.

The PW2000-powered fleet includes 135 757-200s with PW2037s, 21 757-

200s with PW2040s, and 16 757-300s with PW2043s. The RB211-535E4-powered fleet includes 104 757-200s with RB211-535E4s, 93 757-200s and 35 757-300s with –E4Bs and four 757-300s with –E4Cs.

"Demand for the PW2000 and RB211-535E4 has remained stronger than expected due to the longevity of the 757," explains Ray. "The RB211-535E4 has been performing above expectations with market values exceeding base values over the past year or so."

CMVs for the PW2037 are $2.80-3.20 million compared to $3.00-3.30 million for the PW2040. Lease rates for both are expected to be $45,000-65,000.

CMVs for the RB211-535E4 are estimated to be $2.80-3.20 million, and $3.00-3.30 million for the RB211-535E4B. Lease rates for both models are expected to be $50,000-65,000.

The BR700 family includes the BR710 series and BR715 series. The BR715 series is the sole engine option for the 717-200. The active fleet of 717-200s is currently powered by BR715As (147) or BR715Cs (4).

"There is a stable niche market for the BR715 series," says Ray. "With the exception of a test aircraft, no other 717s have been retired."

CMVs for half-life BR715As could be $2.60-3.00 million, with lease rates of $30,000-50,000.

The JT8D family includes older model engines that power the DC-9, 737-200 and 727-200 along with later JT8D-217/219 series engines that power the MD-80 fleet.

The JT8D-217 series is installed on 86 in-service MD-80s, while the -219 series powers 277 aircraft. "JT8D engines have reached their value floor and remain stable," says Ray. "There is still a good green-time lease market for the JT8D-217 and -219. Even so, American Airlines will phase out its remaining MD-80s by the end of the decade, and Delta Air Lines will be replacing its MD-88 fleet with C Series and A321 aircraft."

CMVs for half-life JT8D-217 series engines could be $475,000-525,000 compared to $575,000-625,000 for the -219 series. Lease rates are expected to be $17,000-22,000 for both variants.

## Engine mods

Depending upon the variant, it may be possible to upgrade a spare engine's thrust rating or build standard. "Changing thrust ratings is fairly common with spare engines," says Ray. "Thrust can be leased and bought. Costs relate to engine pricing, although relationships with OEMs could be a factor in achieving discounts."

"OEMs all cater for thrust bumps, but legal thrust increases can be very expensive," explains Crickett. "CFM offers a discount formula based on the age of an engine and the life used since new. IAE does not discount very often."

"Engine build standards may be driven by operator needs, contractual aircraft lease obligations, the operating environment and the health and static maintenance condition at induction," says Mihalache. "Some operators build for EGT margin due to ambient temperatures, operating weights, airport altitudes or life cycle. The LLP status, AD status and retained EGT margin also drive the build standard."

"In the narrowbody market, build-standard retrofits have occurred in the CFM family, but this has not been the case with the V2500-A5 which is more expensive to upgrade," claims Ray.

"CFM56 retrofits are possible but they are expensive and rarely carried out," claims Friis-Petersen. "Occasionally we see a partial incorporation, such as the upgrade of an HPT for a CFM56-7B to 'E' standard during LLP replacement." *-NMP* AC