Narrowbody engines dominate the engine MRO market, and account for more than half the engine maintenance activity. Charlotte Daniels examines evolution of this market segment, including a summary of some key service providers and repair specialists for narrowbody engines.

Narrowbody engine MRO market analysis

Narrowbodies provide their operators with capacity planning flexibility because they can operate regional, short- and mid-length routes. Their use on most of the global route network is reflected by high fleet numbers of about 13,600 units. Consequently there is a large fleet of installed and spare engines that power them. The narrowbody engine maintenance, repair and overhaul (MRO) market is therefore large enough for several maintenance providers.

While the airliner fleet is populated by legacy aircraft, the introduction of new-generation airframes, such as the 737MAX and the A320 new engine option (neo), has added further demand for the maintenance of emerging, new and improved engine types, including the CFM International (CFMI) LEAP series, and the Pratt & Whitney (PW) PW1000G engine family.

The main legacy narrowbody types include the 737 Classic and 737 Next Generation (NG) families, the 757-200/-300, and the A320 current engine option (ceo) family. These are powered by a range of engines. While the Rolls-Royce (R-R) RB211-535E4 and PW2000 power a declining 757 fleet, the 737 Classic, 737NG and A320ceo are equipped with CFM International CFM56-3, -7B and -5A/-5B engines. Also, the V2500 engine, manufactured by International Aero Engines (IAE), powers about half of the A320ceo fleet.

The 737 Classic and 757 fleet is declining, and the introduction of the 737MAX and A320neo families, will inevitably see the engine MRO market continue to decline for some engine types.

While legacy aircraft are still flying, the CFM56 and V2500 will still prosper in the MRO market. It is to be expected, however, that the number of RB211-535s and PW2000s will decline as the 757 fleet continues to be phased out.

This means that MRO providers will need to prioritise active engines that yield sufficient numbers of shop visits (SVs) in years to come. As will be seen, how engines mature will affect SV patterns and therefore engine maintenance volume for MROs. Assuming that most legacy aircraft operators take delivery of new-generation fleets in the coming years, it can be expected that legacy fleets will be sold or scrapped. A portion of these fleets will be desirable in developing countries, in areas such as Africa, Latin America, Eastern Europe or the Commonwealth of Independent States (CIS).

Harsh environments alter the frequency of engine SVs, as well as the maintenance workscopes of these mature and ageing engines, as will be explored.

Market developments

It has long been observed that engine original equipment manufacturers (OEMs) want to manage the engine aftermarket for new generation engines differently *(see Acquiring maintenance capability for new generation engines, Aircraft Commerce, February/March 2015, page 34)*. The changing engine aftermarket means that new generation engines are not expected to have the same number of options in MRO and specialist repair providers that has been available for older engine types, at least during the first 10 to 15 years of their operation. It has been recognised in recent years, for example, that OEMs are keen to ensure that a high percentage of the repair and overhaul work carried out on their engines and associated parts is either performed in their facilities, or remains under their branded agreement or services network of shops.

Of course, while older engines will inevitably provide more MRO options for airline-owned and independent shops, this has to be balanced with the fact that these fleets are in constant decline.

Where thousands of shop visits are expected for maturing engines, such as the V2500 and CFM56-5B, an OEM will need support from several shops to meet this demand from the market. As yet, demand is low for SVs for new generation engines, especially for those that have recently entered service. When demand does increase, in several years' time, it is unclear as yet what capacity and capability will be required from independent MROs that are not aligned with OEMs.

Demand for SVs is expected, however, to be less frequent and intensive than for older types, due to the expectation that the new designs and materials of emerging engines will further improve on-wing performance and in-service reliability.

The purpose of this article is to establish key trends and SV activity for legacy and emerging engine types on narrowbodies. *Aircraft Commerce* last investigated this in 2014 *(see 2014 global engine maintenance market, Aircraft Commerce, June/July 2014, page 35)*. A summary of the main narrowbody engine fleet is provided *(see table, page 59)*. As will be seen, changing demands have impacted the engine MRO market in various ways.

ICF specialises in MRO advisory services in its aviation and aerospace consultancy branch. It provides comprehensive strategy, market research and analysis, maintenance benchmarking and valuations and appraisals for customers, among other services. In a recent report regarding the engine MRO market and key trends, it established that

The LEAP engine family is new in service, meaning heavy SV workscopes are not expected for several years. Early SVs, often called hospital visits, are being carried out at GE and Safran shops.

more than half the 58,500 installed commercial engines in operation are for narrowbodies. In a recent report regarding the engine MRO market and key trends, it established that there are almost 30,000 narrowbody engine types in operation.

ICF has forecast this total to increase to about 38,100 by 2026, meaning a fleet growth of about 4.5% per annum.

About 55% of the MRO market segment is for maturing engines. "The engine MRO market is the most active aviation MRO market," says Richard Brown, principal at ICF. "Asia Pacific remains the most active region for engine MRO spend, closely followed by North America and Europe."

According to Canaccord Genuity Aerospace and Defense, the number of narrowbody engine shop visits is expected to ramp up in 2017, particularly for the CFM56-7B.

Aircraft retirements from legacy families, such as the 737 Classic, will bolster teardown and part-out activity, meaning higher spares availability and green-time engine options for operators of the 737 Classic and the 737NG. These retirements, and subsequently the presence of used serviceable material (USM) among older aircraft, will also naturally increase with the greater presence of new-generation aircraft in the market.

Shop visit process

In addition to a market overview, this analysis aims to provide comprehensive overviews and capabilities of its participants. Through this, one can establish whether an MRO has in-house OEM and Designated Engineering Representative (DER) repair capabilities, for instance. Further examples include whether the provider can offer full overhaul services for a particular engine series, variant or type, or just a modular inspection.

In the event that an engine requires performance restoration or life limited parts (LLP) replacement, the analysis will show whether the entire work package will be performed by the MRO provider, or some of it will be sub-contracted to third parties or the OEM. While some service providers will be able to strip, inspect and rebuild almost any engine, it requires greater capability to be endorsed to clean, carry out workscope items and offer repair or modification work where necessary.

The shop visit process has been extensively explored *(see Analysing the engine shop visit process, Aircraft Commerce, February/March 2009, page 45)*. The cost structure of an engine SV is generally determined to be 80% for materials, and 20% for labour man-hours (MH).

The following are the main elements of an engine SV process:

- Pre-induction inspection & borescope. The initial phase of the shop visit starts with the engine being visually inspected. Its component configuration and LLP status is established, and a borescope often performed to determine interior condition. The work required per module, however, cannot be confirmed until the engine is disassembled.
- Engine disassembly. This is relatively easy for an MRO shop, because it does not require OEM approval to perform it. The engine is split into modules and sub-modules, and disassembled into piece parts for thorough inspection depending on the purpose of the visit.
- Modular inspection. The configuration of modern engines means that they can be worked on in parallel. If a shop has limited capacity, such as a single engine test cell, it may need to sub-contract certain work to either the OEM or a similarly-endorsed MRO. If the MRO has sufficient capacity and capability, it will break modules into piece parts, and clean and inspect them accordingly. Specialist repairs are then performed in-house or sub-contracted. It is common for OEMs to be the only source of every single type of hi-tech parts repair capability for an engine.
- Cleaning of gas path components and parts. This process requires specialist equipment, such as chemical baths and laser drilling capability. The cleaning of non-airfoil parts, particularly for new-generation engines, may also require specialist processes and tooling.
- Parts inspection. Typically inspection techniques involve non-destructive testing (NDT), manual/visual, and dimensional inspection. There are two types of parts inspection. The first type establishes overall condition and ascertains whether there is evidence of cracks, oxidation or erosion. The second type is a dimensional inspection that determines whether the part is within the engine maintenance manual (EMM) limits, such as exhaust gas temperature (EGT) margin.
- Parts repair. The ability of a maintenance shop either to perform OEM-endorsed repairs, or develop in-house repair methods, is one of the most lucrative aspects of the MRO aftermarket for engine maintenance. A repair that restores EGT margin, because it is close to the EMM limits, for example, is more common among shops. It is the complex repairs, such as welding of HPT blade tips, that require a significant investment by engine shops if they are to perform them. Capabilities that enable complex repairs include TIG welding, electron beam (EB) welding and electrical discharge machining. The investment involved may only be justified for maintenance shops performing a large number of SVs.

"There is a difference between a strip and build shop; and a strip, repair and build shop," says Nick Hankins, senior engineer at Jet Engine Management.

APPROXIMATE NARROWBODY ENGINE FLEET AND SV NUMBERS 2017

Aircraft Application(s)	Engine type	No. aircraft in service 2017	No. active engines 2014	No. active engines 2016	SV estimate 2014	SV estimate 2016
A320neo, 737MAX	LEAP	30	N/A	60	N/A	N/A
A320neo, C Series, Embraer E2, MRJ	PW1000G	72	N/A	144	N/A	N/A
A320ceo family	V2500	2,925	4,946	5,850	800	800
737-300,-400, -500	CFM56-3	858	1,614	1,716	260	245
A320ceo family	CFM56-5B/5C	3,535	6,256	7,070	460	600
737-600,-700, -800,-900, 900ER	CFM56-7B	5,870	9,166	11,750	810	1,100
757-200,-300	RB211-535	448	648	896	140	70
757-200,-300	PW2000	281	498	562	120	110
MD-80, 727-200 DC-9	JT8D-200	380	1,178	760	290	160
Total		**14,399**	**24,306**	**28,808**	**2,880**	**3,090**

Source: active (in-service) fleet numbers provided by Flight Global Fleet Analyser (March 2017)

"While acquiring hi-tech repair capability is a heavy investment for MROs, it yields the most profit from a typical workscope." Of course, there has historically been an appetite for DER repairs, and the use of parts manufacturer approved (PMA) components. These are a popular option for legacy engines, and have provided an alternative for MRO shops to develop and market separate repairs and part options to the OEMs. With the onset of the LEAP and PW1100G, however, and the decline of ageing engines, such as the PW2000 and CFM56-3, Hankins believes that this trend may be phasing out. "By using DER repairs, an MRO is distancing itself from the OEM," says Hankins. "This may damage independent shops' ability to maintain newer engines in 10 years' time."

Access to OEM-endorsed repairs often requires access to the OEM's Intellectual Property (IP). CFM explains that General Electric (GE) and Safran license their intellectual property related to high technology part repairs on a case-by-case basis. All parts repairs are available for sale to all MROs as part repair services from GE and Safran. Repair licensees also compete globally, offering their part repair services to all engine maintenance providers.

OEM contracts, such as Rolls-Royce TotalCare, or GE's TrueChoice flight hour (FH) agreement (a power-by-the-hour (PBH) contract) also influence the type of activity other maintenance providers may gain in the engine aftermarket. "If a high percentage of airlines are tied into an OEM PBH contract, then an MRO needs to be aligned with the OEM to be involved in maintenance work for that customer," adds Hankins. "In that respect, once a shop is established as part of the OEM's network it can receive offloaded business from the OEM." With the LEAP and PW1100G not due to see a high SV demand for a number of years, it remains to be seen what portion of contracted airlines will influence the aftermarket for MROs. It is understood, however, that a large percentage of airlines signed up for new-generation aircraft have also reached contractual support agreements with the airframe and engine OEMs.

The other element of an SV whereby MRO businesses can profit is in parts, spares or materials. "Although maintenance businesses can benefit from a thriving USM or spares business for mature and ageing engines, if airlines agree materials contracts with OEMs, which is another possibility, this could reduce this option for independent and non-aligned shops," says Brown.

Maintenance evolution

ICF has also investigated the market share of MRO business for narrowbody engines in 2016. According to Brown, CFM and GE undertook an estimated 35% of all CFM56-5B SVs and 44% of CFM56-7B maintenance. The remaining 65% and 56% were divided between airline third parties, independent MROs, OEM joint ventures (JVs) and airline in-house business *(see table, page 54)*.

An engine's age will influence the type of workscope required, in addition to SV volume. In turn this will influence the aftermarket for new, maturing and ageing engines. For the LEAP and PW1100G, for example, it is expected that SVs to prevent early issues will be the primary requirement in the coming years to remedy engine contaminants, fuel leaks, and other unforeseen incidents.

Meanwhile, the CFM56-7B and V2500, will be undergoing overhauls, LLP exchanges and performance restorations. JT8D-200 and CFM56-3 operators will be looking for rectification work, also known as 'check and repair'. Because overhauls and full refurbishments are no longer economic, operators will prioritise the extension of the remaining useable time left in the engine at minimal cost.

"Once the LEAP matures, the number of MRO shops licensed for the engine will need to match the demand for SVs," continues Hankins. "The production rate for new generation engines, such as the LEAP, is unprecedented, and it dwarfs that of the CFM56-5B/-7B. It is introducing a totally new dynamic to the marketplace, even when compared to the introduction of the CFM56-7B when the CFM56-3 was being phased out.

"OEMs will need to establish a robust support network for these engines in time," says Hankins. "One of three things will need to happen. OEMs will substantially increase their current capacity, or free up capacity by offloading CFM engines elsewhere; or the LEAP market will be opened up to more providers."

It is expected, however, that these networks will not expand substantially for some time. "It is difficult for independent MRO shops to build business cases now to acquire the appropriate licences for new-generation engines," adds Brown. "We typically see a period of 15 years in service before these properties come available and the market opens up. I anticipate that independent shops will begin building business cases in the mid-2020s, once they have determined how many SVs the business stands to get."

Another factor needs to be taken into account that may shift future market demands. "The LEAP and PW1100G are going to perform as well as, or better than, existing engines," continues Brown. "This is even taking into consideration the performance of the CFM56-7B and V2500-A5, which has been outstanding. On-wing times have generally been extended, and we could end up with the PW1100G, for example, requiring only two performance restorations rather than three, in its lifetime. One could reasonably anticipate that engines may perform for a decade without the need for an SV. MRO providers have to take this into account."

Market survey

Below is a market overview for each main narrowbody engine family, followed by an overview of MRO shops that have licences and capabilities to perform services. Not all maintenance providers for the subject engines are mentioned. Only those mentioned by the OEMs, and

MTU is an RRSP for the PW1000G family. It has design responsibility for the LPT and several stages of the HPC. It will be offering MRO services at part of PW's network.

MRO providers that participated in this survey have been included to ensure that accurate capabilities of each provider are given. Other MRO options per engine may be available, with varying levels of repair, overhaul and general inspection or maintenance capabilities associated.

CFM International LEAP

CFM is a 50:50 joint venture between General Electric and Safran Aircraft Engines. Its latest product, the LEAP engine family, has three models for various aircraft applications. These include the Airbus A320neo (the LEAP-1A), and 737 MAX (LEAP-1B) and the COMAC C919 (LEAP-1C).

The LEAP engine has three low pressure compressor (LPC) and 10 high pressure compressor (HPC) stages, plus two high pressure turbine (HPT) and five (LEAP-B) to seven (LEAP-1A/-1C) low pressure turbine (LPT) stages. It has thrust ratings of 23,000-35,000lbs across the series. Composite materials and 3-D printed parts (also known as additive layer manufacturing, or ALM) are the new technologies used in the engine.

The current market

According to CFM International, there are 60 LEAP engines in service. A further 12,200 engine orders and commitments have been placed for the family. At this time, the LEAP engine is being supported at GE's Lafayette, IN site; as well as the Safran sites in Belgium and France.

The LEAP engine entered service in mid-2016, so CFM does not expect performance restorations or overhauls for several years. Most early entry-into-service (EIS) support, sometimes referred to as hospital visits, is occurring at the GE and Safran shops.

Several airlines have shown interest in overhaul licences for the LEAP, and CFM expects industry capacity to grow over time as engine overhauls come due, as they did for its predecessor, the CFM56. CFM explains that it has a different approach to MRO and OEM competitors as follows:

- By limiting FH contract coverage (through PBH contracts) of the fleet with the OEM, which results in a large number of overhauls available for competition.
- CFM grants licences to all engine shops interested in competing for overhaul, which results in a competitive overhaul segment. This gives CFM airline customers, which do not have their own in-house capability, a choice of engine shops.
- A competitive overhaul segment allows a USM segment. By comparison, engine OEMs that have very high FH contract coverage and very little overhaul competition, control the USM segment, opting not to buy used engines or used spare parts, according to CFM. CFM explains that this allows customers to optimise engine residual values.

According to Hankins, SVs for the LEAP will not occur for at least three years. "Removals will be unplanned or retrofit upgrades at this stage," he says. "The first scheduled SVs for performance restoration and LLP replacement will not be until 2020." As a large number of CFM56-5B and -7B engines are still first-run, Hankins also expects that there will be a substantial overlap of demand between the LEAP and the CFM56 engines. There also remains a huge appetite for 737NG and A320ceo aircraft. This in turn will also influence the direction of the MRO activity.

MRO & repair providers

Lufthansa Technik AG (LHT) has been appointed as one of the first maintenance providers for the LEAP engine family. LHT's engine division is located in Hamburg, Germany, which will also be the location for LEAP maintenance.

Various JV shops and subsidiaries form part of LHT's overall maintenance capabilities. These include Airfoil Services Sdn Bhd (Petaling Jaya/Malaysia), BizJet (Tulsa/USA), N3 Engine Overhaul Services (Arnstadt/Germany), Lufthansa Technik AERO Alzey (Alzey/Germany), Lufthansa Technik Turbine Shannon (Shannon/Ireland), XEOS (JV GE Aviation and Lufthansa Technik, Środa Śląska/Poland).

LHT is a leading example of an airline MRO shop that also works closely with OEMs, so it provides high-level and extensive coverage of the engines it maintains.

Its wider shop presence means that LHT offers maintenance services across Europe, North and South America, and most of Asia Pacific, Middle East and Australia. LHT's first official SV for the LEAP engine is a 'B' event scheduled for 2021. A 'B' category SV involves a moderate workscope, such as a performance restoration or module repair. An 'A' event requires major work, such as total engine overhaul, whereas a 'C' level SV is relatively minor, such as a single component repair.

As established previously, MRO providers need access to OEM IP, licences and the ability to invest in new tooling and repair technologies so as to acquire sufficient capabilities on new-generation engines. Several hundred repairs have been developed for the LEAP engine, for instance, including to composite fan blades and bladed disks (blisks) present in the engine. The HPT blades are also a different design to older CFM engines.

"There are two reasons why LHT has gained access to new engine types and obtained the required licences," explains Marc Wilken, director of product sales and engine lease at Lufthansa Technik AG. "OEMs seek our partnership early in the lifecycle of these new engines, to

Aero Norway specialises in CFM56 maintenance and repair. It can undertake various turbine, compressor and combustor repairs in-house.

improve their products and deal with early technical removals. LHT entered into partnerships with OEMs, for example, to support new engine types with on-site or on-wing solutions to keep engines with teething problems flying.

"LHT also performs early repair and overhaul work on the LEAP and other new-generation engine types," continues Wilken. "Our strong airline connections add further strength. As LHT acts as the competence centre for all MRO-related activities in the Lufthansa Group, customers such as Lufthansa, Swiss, Austrian, Brussels, Germanwings, Eurowings, Lufthansa Cargo and Lufthansa CityLine use LHT's services via long-term agreements. This generates added experience and value as an airline MRO. Programmes such as LHT's smart.life, which is aimed at reducing MRO cost by optimising workscopes, material usage and time on-wing, would not be possible without that experience."

The ability of MRO providers to perform extensive in-house repair is a further benefit. Engines are expected to remain on-wing longer, and improved performance and technologies, such as 3D printing, have promoted a trend for lower replacement rates of expensive engine components. The Lufthansa Technik Parts repair unit EPAR (Engine Parts and Accessories Repair) has a broad range of high-tech repairs for narrowbody engines, including the LEAP. EPAR repairs are performed within the global network at following locations: LHT Hamburg for the repair of fan blades, rotating and stationary airfoils, engine components and cases; LHT Berlin for the repair of engine tubes and ducts; LTTS (Lufthansa Technik Turbine Shannon) Shannon (Ireland) for the repair of LPT vanes and HPT shrouds; ASSB (Airfoil Services) Kuala Lumpur (Malaysia) for the repair of HPC and LPT blades; and Bizjet in Tulsa (USA) for the engine teardown process.

After successfully developing GEnx full capability, Air France Industries KLM Engineering and Maintenance (AFI KLM E&M) next target is adding the LEAP 1A and 1B to its maintenance portfolio. An example of an airline/MRO that has maintained successful alliances to OEMs, AFI KLM E&M has been performing endurance tests of the LEAP engines since 2014. AFI KLM E&M also announced the creation of a JV with Safran, specialising in airfoils repair. The airline/MRO boasts many subsidiaries and JVs that bolster its repair and maintenance capabilities, including Aero Maintenance Group and Barfield (Miami), AFI KLM E&M Components China, CRMA (Paris), EPCOR (Amsterdam), KLM UK Engineering (UK), AAF Spares (Miami), AMES (Dubai), ATI (Morocco), Bonus Tech (Miami), IGO Solutions (Paris), and Spairliners (Hamburg).

CFM explains that its intentions for the LEAP are similar to the CFM56 family, in that CFM will make LEAP overhaul licences available to MROs that want to enter the overhaul segment. Since the fleet is small and performance restoration overhauls are many years away, CFM expects interest from third parties to increase once the fleet grows in size and performance restoration overhauls begin in large quantities, as was the case for the CFM56.

PW1000G family

The PW1000G PurePower engine family, also known as the geared turbofan (GTF) engine, counts the A320neo, Bombardier C Series, Mitsubishi MRJ and Embraer E-Jets (E2) among its main applications. Alongside the standard architecture seen in jet engines, the PW1000G's design incorporates a gearbox between the fan and the LPC. Each PW1100G series has three LPC stages, eight HPC stage, two HPT stages and three LPT stages.

The current market

Canaccord says that 138 PW1100G engines were built in 2016. It is forecasting that 350-400 units will be built in 2016, with a further 800 in 2018. By 2020, it estimates that production will ramp up to 1,200 engines. In 2017, therefore, only some initial light-scale SV work will be needed.

PW Columbus Engine Centre, based in Georgia, USA,was announced by PW as the first facility to begin maintaining PW1100G-JM engines in June 2016. In addition to this facility, PW has established a network of MRO providers (MTU, Japan Aero Engines Corporation (JAEC) and Lufthansa Technik) to support the ramp-up of the engine into active service. Over time, as the volume of overhauls grows, the network is expected to expand to include airlines and other MRO shops.

The strength of relationships between the OEM and MRO shops is often exemplified via a risk and revenue sharing partnership (RRSP) agreement. Partners, such as MRO shops that have RRSP agreements with engine OEMs invest a certain stake towards the manufacture and design of the engine, to benefit from the maintenance activity once the engine is in service. The PW1100G has one such RRSP network involved in its aftercare.

MRO & specialist repairs

In July 2016, Lufthansa Technik became a member of the aftersales service network for the PW1100G engine family. As part of PW's RRSP network, it offers a range of MRO services for the type. In February 2017 LHT announced a JV company with MTU Aero Engines. This

ESTIMATIONS FOR MARKET SHARE - NARROWBODY ENGINE MRO SPEND

	CFM56-5B	CFM56-7B	V2500
Engine OEM	35%	44%	32%
Airline Third Party	16%	15%	8%
Independent	16%	19%	43%
Joint Venture	10%	4%	N/A
Airline In-House	9%	9%	2%
Unknown	14%	9%	15%
Total	100%	100%	100%

Source: Guide estimations provided by ICF for 2016

is a 50:50 investment whereby the companies will set up a new engine shop specifically for the GTF engine. This shop is anticipated to undertake 300 GTF SVs every year, once it is set up in 2020. The location is yet to be determined.

This joint alliance between LHT and MTU is in addition to its JV ASSB, which was established in 2003. Airfoil Services Sdn. Bhd. (ASSB) near Kuala Lumpur specialises in the repair of LPT and HPC airfoils for the V2500 and CFM56-3/-5A/B/-7B.

LHT says that four SVs for the PW1100G were completed in 2016. It expects that about 10 B and C events will be undertaken in 2017; signifying performance restoration and modular or LLP repair work only from 2018. This should rise to about 25 scheduled B and C category workscopes in 2018. LHT says that no major, A level SVs are currently scheduled.

Headquartered in Hannover, MTU Maintenance is a business division of MTU Aero Engines. Its facility specialises in maintenance, hi-tech repair and repair development for the PW1100G engine; in addition to its anticipated JV with LHT. As an engine parts manufacturer, MTU is often responsible for elements of an engine's design, so it was established early on as a natural option to provide maintenance services once such an engine is in operation.

MTU has an RRSP share of 15-18% in the PW1100G engine, depending on aircraft application, and is therefore a key presence of PW's RRSP programme. MTU Aero Engines can act as an MRO provider as part of the OEM's MRO network, either specialising on the engine subsystem it holds the design responsibility for, or providing services for the engine as a whole.

On the GEnx and GE9X, for example, MTU Aero Engines has the system design responsibility for the turbine center frame (TCF), and will act as the OEM's TCF repair facility, carrying out all TCF repairs that are under OEM contract.

"MTU Aero Engines has system design responsibility for the PW1100G's LPT and several stages of the HPC," explains Leo Koppers, senior vice president MRO Programs at MTU Aero Engines. "We will also repair and overhaul complete engines on the OEM's behalf.

"New engine types, such as the PW1100G-JM, typically generate smaller workscopes related to infancy issues after programme EIS which require early technical removal visits," continues Koppers. "Scheduled repair visits only come years after EIS, and LLP replacement usually only occurs during second SVs and subsequent visits. For module MRO work, we are typically allocated work in the amount equivalent to our RSSP share."

Koppers explains that there will be increased OEM coverage for next-generation engines, so independent providers will need to intensify their cooperation with OEMs to access both engine MRO and IP protected repair licences and the volume of MRO work that will be available in time. "Whereas airline-affiliated providers can count on some baseload volume from its parent airline, independent MROs typically need to entirely acquire their workload from the third-party market," says Koppers. "Airlines potentially also get better access to licences during engine acquisition."

For all next generation engine models mentioned above, MTU will only act as an OEM network provider for now.

IAE V2500

The V2500 is a two-shaft high-bypass turbofan engine. The V2500-A5 series is one of the main engine options for the A320ceo family. There are five main variants: the V2522-A5, V2524-A5, V2527-A5, V2530-A5 and V2533-A5. It is manufactured by International Aero Engines (IAE), which is a consortium formed of four engine OEMs: Rolls-Royce (R-R), MTU Aero Engines, PW and Japan Aero Engine Corporation (JAEC). R-R designed the HPC, while PW developed the combustor and the two-stage air-cooled HPT. JAEC provided the LPC system, and MTU was responsible for the five-stage LPT in the V2500.

Current market

"There are about 6,000 V2500-A5 engines in service," explains Gerd Ockerman, programme manager at Jet Engine Management Limited. "This is out of a total of more than 6,500 V2500-A5s built. A320ceo production will end by 2019, so V2500-A5 engine production is expected to terminate around the same time," continues Ockerman. He estimates that on average, two heavy SVs are expected within the V2500-A5's 20,000 engine flight cycle (EFC) LLP stack life. "For low and medium thrust ratings within non-harsh environments, it is possible to reach LLP life within one overhaul run," says Ockerman.

According to Richard Hough, executive vice president of technical at Engine Lease Finance Corporation, just under 50% of all V2500 engines are still on their first SV run, so a substantial portion have yet to undergo a major SV. "There are expected to be 1,000 visits per year for the V2500 from 2017 to 2020. This is an increase of 25% from 800 events during 2016," continues Hough.

A service bulletin (SB) was issued in February 2016, signifying the need for inspection and possible replacement of an HPT due to a quality issue. This was enforced by an AD in October 2016. Because of the AD, there has been a sharp increase in SV activity and spare engine requirement. IAE is therefore working on increasing shop capacity and spare engine availability to support the in-service fleet.

PW shops for IAE V2500 engines include PW Columbus, PW Christchurch, PW Shanghai, and PW Turkish Engine Centre. Other MRO providers globally include Rolls-Royce East Kilbride, IAI Bedek, LHT, MTU Maintenance, Iberia, Turbine Services and Solutions (TS&S) and IHI Aero Engine Maintenance.

MRO & specialist repairs

LHT performed 110 V2500-A5 SVs in 2016. About 70 of these were major 'A' category visits involving engine overhaul, while the rest required lighter modular or repair work. The Lufthansa Technik EPAR division has a broad range of high-tech repairs for the V2500. These are in addition to the CFM56-5A/-5C/-5B/-7B, which will be expanded on later. "For engines overhauled on behalf of the OEM, the OEM assigns all corresponding work to LHT in accordance with our capabilities," explains Wilken. "Work related to disassembly, assembly and testing for these engines is performed in our DAT shops. All repairs are performed

IAI Bedek offers MRO capabilities for the V2500 and CFM56 families. It is a fully independent MRO provider, that maintains various technical and support agreements with engine OEMs.

in the EPAR Network, which consists of LHT-affiliated as well as OEM-affiliated EPAR shops, and is managed by LHT."

Unlike its role for the PW1100G, MTU Maintenance acts as both an independent and OEM MRO provider for the V2500-A5. It performs an average of 300 SVs per year for the engine out of MTU Maintenance Zhuhai and MTU Maintenance Hannover, which offer MRO services, complemented by ASSB, which specialises in repairing LPT and HPC airfoils.

"MRO work on current, but not fully mature programmes, such as the V2500-A5 or CM56-5B/7, sees an increasing number of major or overhaul visits compared to smaller fixes," explains Koppers. "These increasingly involve LLP replacement as the programmes mature.

"Mature engines are more complicated in this regard," continues Koppers. "MRO work will either involve full overhaul workscopes including LLP exchange (typically for longer term operations), or 'minimised' workscopes. These are then tailored to very specific needs (typically for shorter term operations). Whereas the focus of an overhaul visit is a long on-wing time, the 'minimised' workscopes are aimed at lowering cost and matching a pre-defined operational timeframe where investing in an overhaul visit is no longer deemed economic," adds Koppers. "On the V2500, we typically perform one-quarter of SVs under OEM contracts, which can vary from year to year. Furthermore, we provide a range of specialised repairs for V2500 parts, such as the LPC, HPC, combustor, HPT and LPT."

Headquartered at Ben Gurion International Airport, Israel Aerospace Industries Ltd Bedek Aviation Group (IAI Bedek) is an example of a non-airline affiliated MRO provider. In this sense, it is deemed an independent MRO business. "IAI has technical and support agreements in place with major OEMs," says Jacob Rozman, vice president and general manager, at IAI's Engine Division. IAI has additional agreements in place with the OEMs to perform maintenance of narrowbody and widebody engines, on behalf of the OEM.

IAI Bedek performs about 15 V2500-A5 SVs per year and expects to reach 25-40 SVs per year over the next three years. 80% of these visits involve major repair or overhaul work. IAI has a comprehensive list of in-house repairs it can perform on the V2500-A5 including fan casings, LPC, HPC, combustor, LPT, HPT and seals and casings). Rozman says that blade and vane repair work is often sub-contracted back to the OEM shops.

"Lately it has been more difficult to obtain access to IP for new engine types," continues Rozman. He also discloses that there are few DER repair options available for the V2500-A5.

Evergreen Aviation Technologies (EGAT) had been a JV between EVA Air and GE. Based in Taiwan, EGAT performs a limited number of up to 20 V2500-A5 shop visits per year, most of which are overhauls. While it carries out the overhaul workscope within its engine shop, EGAT subcontracts repair work to third-party vendors such as Chromalloy.

Primarily focused on GE's CF6 and GEnx engine services, its repair shop is targeted at widebody engines. Agreements that EGAT holds with GE are included in an engine JV, which is GE Evergreen Engine Services, covering training, parts procurement, and manuals, all of which requires access to IP. EGAT explains that securing access to any engine IP is extremely difficult for any airline-affiliated MRO, even at engine purchases during fleet renewals, in current times. At best, MROs may secure an agreement that provides MRO services to specific engine types limited to those operated by airline affiliates.

FL Technics is an MRO based in Lithuania. Its base maintenance facilities are in Vilnius and Kaunas in Lithuania, and Jakarta, Indonesia. Its network of line maintenance stations covers more than 25 locations in the UK, Russia, the CIS, Norway, Sweden, Baltic States, Saudi Arabia and Bangladesh.

FL Technics performs light maintenance services for the V2500-A5, servicing at least one engine per year to date. It performs a large part of light works within the EMM, including QEC LRU swap, engine model re-configuration, fan blade change, engine removal or installation, NDT and borescopes at its hangars in Kaunas and Vilnius.

Its main narrowbody expertise is on the CFM56 family, and regional CF34 engines. "Our primary focus is ageing, sunset and mature engine types," says Asta Albrichte, head of engines and components management department at FL Technics. "Our tailored solutions include on-wing maintenance services, DER/PMA repairs, engine exchange, green-time lease practice and surplus material usage."

PAS Technologies is a specialist repair provider for the V2500-A5. As explored previously *(see Narrowbody engine hi-tech and specialist parts repair providers, Aircraft Commerce, August/September 2015, page 62)*, PAS Technologies' repair capabilities for the engine include the HPT stage 1 cooling (TOBI) ducts and bearing housings, seals and supports. These repairs are granted under a PW designated service provider (DSP) agreement, which affords PAS the right to operate under the PW brand, with access to PW engineering resources. This includes engineering documentation and EA/IEN in support of repair development requirements for customers. PAS also repairs LPT shroud seal segments and inner duct segments. These repairs need high-tech specialist processes, such as thermal spray coatings, honeycomb brazing, EB welding, and machining.

Iberia Maintenance is headquartered

Iberia specialises in V2500, CFM56 and RB211-535 maintenance services. Based in Madrid, its facilities include five base maintenance hangars, an engine workshop, test bench, component workshop and NDT centre.

in Madrid, Spain. A subsidiary of Iberia Airlines, it performs independent third-party maintenance in addition to maintenance of its in-house fleet of engines. Iberia's fleet consists of A320ceo, A330 and A340 family aircraft. It can therefore provide MRO services for the engines powering these aircraft types, including the V2500-A5 for the A320ceo.

Iberia Maintenance acquired the certification to repair V2500 engines in 2014. V2500 SVs are ramping up, with 12 engines in 2016, and double this number expected in 2017. Iberia Maintenance can provide in-house repairs across each main engine module.

CFM56 family

Both GE Aviation and Safran Aircraft Engines produce components for the CFM56 family. GE produces the HPC, combustor and HPT. Safran manufactures the fan, gearbox, exhaust and the LP system, including the LPT. Some components are made by Avio of Italy. The engines are assembled by GE in Evendale, Ohio and by Safran in Villaroche, France. The completed engines are subsequently marketed by CFM.

The CFM56 first ran in 1974. Its design includes a fan and three-stage LPC, followed by a nine-stage HPC, annular combustor and single-stage HPT, four-stage LPT. The three series that make up the CFM56 family include the CFM56-3, the CFM56-5 and the CFM56-7. Applications include the CFM56-7B-powered 737NG, and the CFM56-5B-powered A320 family. The -5C series is the only engine used to power the A340-200 and -300 series. The CFM56-3 meanwhile powers a declining fleet of 737-300s, -400s and -500s.

Given the longevity of the engine variants in the CFM56 family, it is unsurprising that it has so many options for MRO and specialist repair services, in addition to OEM-owned facilities.

GE-owned overhaul sites for CFM56 engines include: GE Celma, Brazil; GE Strother, Kansas USA; GE Malaysia; and GE Wales. Safran-owned overhaul sites for CFM56 engine includes Safran Aircraft Engines Services Brussels; Safran Aircraft Engines Services Americas (Queretaro); Safran Aircraft Engines Services Morocco; and Safran Aircraft Engines, Saint-Quentin, France. Other OEM shops that provide maintenance services for the CFM56 include PW Shanghai, and the Turkish Engine Centre (CFM56-7B only).

Aside from the OEM shops listed above, CFM says there are a further 34 overhaul shops that provide services for the CFM56 family. Including the OEM shops, this totals 42 MRO providers globally for the engines.

Some of these are detailed in the following sections. The remaining shops include Air India, Alitalia, All Nippon Airways, American Airlines, China Airlines, Ethiopian, GA Telesis Finland, Global Engine Maintenance, GMF Aero Asia, Jordan Airmotive, Lockheed Martin Commercial Engine Services (LMCES), Korean Air, Pakistan International Airlines, Saudia Airlines and Standard Aero.

Current CFM56 market

CFM says there were about 2,300 SVs in 2016 across all CFM56 models combined, minus the CFM56-2 engines. Compared to the 2014 market survey, activity has increased by about 10%. In 2014 an estimated top-end figure of about 2,100 SVs were forecast for the year across CFM56-3/-5A/-5B/-5C and -7B series.

Hankins estimates that GE will carry out about 700 SVs in 2017. These will be divided across its shops accordingly: GE Wales, 130-140 events; Malaysia, 100; Strother, 100-150; and Celma, 300. Meanwhile it is predicted that Safran will perform 250-350 SVs this year.

In 2016, ICF estimates that there were fewer than 250 SVs for the CFM56-3. The engine is gradually declining in numbers *(see table, page 58)*. There are 1,720 engines in operation according to CFM. By 2020, SV activity is expected to halve to about 120 SVs worldwide, declining at a rate of about 10% per year. There are now not enough engines for all the MRO providers offering SV services.

As described, the workscope for CFM56-3 engines is likely to shift from performance restoration and LLP exchange, to remedial maintenance, such as minor repair work. Many of the original MRO shops have also left the overhaul market. "The -3 series is getting to the point where few people can justify refurbishment," confirms Hankins. "Operators are instead swapping modules and relying on USM or green-time engines. The lessor GECAS has also been retiring its -3 engines, opting to park its 737 Classics and sell the engines to airlines to use up the green time, or to brokers for part-out.

"Market demand has dropped further in the last couple of years," adds Hankins. "Developing regions such as Africa have developed a bit more appetite for the engines, however. The demand for new-generation types in other areas will inevitably mean more of these engines, and the airframes they equip, moving to developing regions." In essence, the CFM56-3 is a near run-out engine series, albeit with a market that is still evident 20 years after the production lines ceased to produce new engines.

According to Flight Global's Fleet Analyser, there are about 7,000 CFM56-5B and -5C engines in service for the A320ceo family. SV activity is buoyant for the CFM56-5B, which is still a reasonably young variant in the family. ICF forecasts an overall increase in SVs from about 600 to 800 per year in the

SHOP VISIT ESTIMATIONS - DECLINING NARROWBODY ENGINES

Year	CFM56-3	JT8D-200	PW2000	RB211-535
2016	245	163	110	72
2017	224	138	89	72
2018	212	128	88	94
2019	162	129	94	107
2020	120	78	83	99
2021	91	48	64	57
2022	99	14	55	27

Source: estimations and forecasts provided by ICF

next 10 years. This is compared to the 400-500 SVs that are estimated to have taken place in 2014.

Removal intervals for the CFM56-5B average 10,000EFC, or about five years, assuming normal utilisation in a non-harsh environment. "In a non-harsh environment an operator operating at low to medium thrust might be able to reach the first LLP limiter of 20,000EFC before needing a removal. In a harsh environment, however, this can drop to 3,000-5,000EFC between SVs, meaning intervals of two to three years," explains Hankins. "For non-harsh environment operators, averaging 3,000EFC a year equates to five to six years between SVs.

"The growth of regional and short-haul operations in the Middle East, the Asia Pacific, Africa and India which are considered harsher environments than European and North American operations, is likely to lead to more -5B engines flying with shorter intervals," adds Hankins. "This would naturally lead to more SVs. If more 737NGs move to these regions with the 737MAX's service entry, then the market will see a level of revitalisation. Overall, however, the CFM56-5 MRO market remains in a period of growth for service providers.

Flight Global's Fleet Analyser shows about 12,000 CFM56-7B engines in service today. This number has grown from the 9,166 installed engines in 2014. SV activity has increased to almost 1,100 events per year according to ICF.

It forecasts that over the next 10 years activity is expected to peak at about 2,000 SVs by 2022, before commencing a gradual decline. Second and third runs are expected for the later -7B models before they are phased out. This means that -7B engines should be generating SV activity for MRO shops into the 2030s.

"Large -7B operators can be grouped into two categories," explains Hankins. "There are those with their own engine shops, such as KLM and Lufthansa, and there are those that use one of the larger MROs.

"For everyone else there remains a wide choice, with in excess of 20 shops offering a substantial range of services, all competing in this field," continues Hankins. "The bulk of -7B volume is under maintenance-cost-per-hour (MCPH) contracts, however, which are issued by GE." He also observes that MROs will cease investing in the CFM56 once the LEAP becomes more prevalent.

It is the sudden emergence of used, commercially available 737NGs, brought on by the adoption of new-generation aircraft by operators, which could impact SV activity for the CFM56-7B. The oldest 737NGs are now almost 20 years old, so retirements are inevitable. It is expected that retirements for the 737NG will increase significantly over the next four to five years; 15 NGs have reportedly already come on to the market so far in 2017. If this number increases to 50 or more used 737NGs, for example, it could dramatically change the dynamics of the CFM56-7B market.

MRO & specialist repairs

LHT provides MRO services for the CFM56-5A/-5B/-5C and -7B at its Hamburg engine shop. It performed a range of A, B and C category SVs for the CFM56-5A/-5B in 2016. These totalled 184 visits. It undertook 64 shop visits for the CFM56-7B. "LHT offers repairs on the entire gas stream on the CFM56, except HPT blades," explains Wilken. "Airfoil Services (ASSB) is a specialist repair source for the HPC and LPT blades, whereas LTTS focuses on the HPT shrouds and LPT vanes. The Hamburg shop carries out HPT vane repairs.

"EPAR also provides repairs on all the cases, stationary and rotating parts, for these series," continues Wilken.

MTU Maintenance Canada, situated in Vancouver, offers MRO services specifically for mature engines, including the CFM56-3. Its Zhuhai facility offers MRO for the -5 and -7 series, in addition to the -3. Its Hannover facility also provides services for the -7B. LPT and HPC airfoil repairs for these variants are again performed at ASSB. While -3 activity has declined to irregular SVs, MTU Maintenance carries out about 50 CFM56-5B SVs per year, in addition to 100 CFM56-7B visits.

MTU Maintenance provides full repairs on the CFM56-3/-5B and -7B variants from fan to LPC and HPC airfoils, through to the combustor, and LPT airfoils and remaining engine components. MTU Maintenance has developed MTUPlus repairs, a full set of repairs approved by the European Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) as an alternative to both OEM repairs and OEM new parts for the CFM56-7. MTUPlus repairs focus on scrap reduction through higher parts durability, increased engine efficiency, and significantly lower maintenance costs.

AFI KLM E&M is licensed to carry out the full scope of maintenance services for the CFM56-5A/-5B and -7B series. It provides MRO services for the CFM56-5A and -5B from its Paris facility, where it performs about 80 SVs per year.

CFM56-7B maintenance is carried out from its Amsterdam location, where about 100 SVs occur annually. Most of these visits are performance restorations. "For the CFM56 series no special branded agreement is necessary," says Mike Bezuijen, technical sales director engines at AFI KLM E&M. "For the CFM56 series, AFI KLM E&M can perform repairs on behalf of the OEM, and we frequently receive offloads from the OEMs for those series. AFI KLM E&M is also an official warranty repair station for the engine family."

AFI KLM E&M also develops certain inspection and repair methods on behalf of the OEM. "For example, we have developed an NDT inspection of HPC blades after blending with a borescope," continues Bezuijen. "This was developed in-house, and was already approved for the CF6 engines by GE. This process will now be introduced for the CFM. This will remove the need for a compressor top case removal, and prevent the one-off borescope inspection needed a certain amount of cycles after the blend repair," explains Bezuijen.

AFI KLM E&M in general performs in-house repairs on all modules for the CFM56-5A/-5B/-7B, except for blades and vanes. Some airfoil repairs such as HPT blades and vanes are contracted back to the OEM. AFI KLM E&M also develops in-house repair capabilities for some major parts. In-house hi-tech repair capabilities provided by the company includes inlet gearbox (IGB) shaft thread replacement (electron beam welding repair). AFI KLM E&M was the first to successfully perform the repair and offer it on the market, ahead of GE and CFM. It also offers high technics developed by its repair network such as plasma deposit, 3D printing (LMD) or laser drilling.

IAI Bedek undertakes about 90 CFM56 SVs per year, of which 25 are for the CFM56-3, while 50 are for CFM56-5B engines. Last, IAI performs an average of 15 CFM56-7B SVs each year. IAI has seen a marked increase in CFM56 SVs over the past few years, and expects to perform 110-130 SVs per year over the next five years. "For widebodies, IAI performs a large percentage of work for the OEMs, including being appointed at DP by Pratt & Whitney for JT9D series engines, while for narrowbodies most of the engines are being overhauled for the airlines," explains Rozman. "We expect the percentage of work performed directly for the OEMs to rise in the coming years." While IAI performs a comprehensive in-house OEM portfolio covering the main CFM56 engine modules, some blade and vane repair is OEM-contracted. It is able, however, to provide DER repairs for CFM engines as and when required by customers.

Aero Norway AS is an MRO that is actively focused on CFM56 maintenance. Having acquired the Norway Engine Centre from PW in 2013, the facility is geared specifically toward MRO services for the engine family. Aero Norway sees a high volume of SVs for each series. It performed 58 CFM56-3 SVs in 2016, and it expects a similar number this year. It expects about 17 CFM56-5B and -7B SVs to be carried out in 2017.

Aero Norway sees an equal divide between light workscopes, such as modular inspections; and major repairs and overhauls for the engine. While it can provide turbine, compressor, and combustor repairs in-house, certain repairs for blades, vanes and casings are undertaken by the OEM.

A business unit of TAP Portugal, TAP Maintenance and Engineering (TAP M&E) holds no OEM-branded agreements, yet undertakes a significant amount of CFM56-3/-5 and -7B engine overhaul and inspection work. 75% of its MRO activity is third-party MRO work, while the remainder relates to TAP Portugal's fleet. Since 2014, it has performed 25 CFM56-3 SVs, 64 -5B SVs, and 14 -7B SVs. Most of these have involved major repair, performance restoration and overhaul workscopes. TAP M&E provides in-house parts repair across the CFM56-3/-5 and -7B series, although it does sub-contract certain LLP and specialist repairs, including repairs to the fan disk, HPT disk, front rotating seal, and to specific parts of the fan blade, bearing and turbine blade.

FL Technics provides a range of engine repairs for the CFM56-3, -5 and -7B series, and remains dynamic in the mature engine market. In addition to OEM, DER and PMA provisions, FL Technics manages its own inventory of engines for pool support. This inventory includes 10 CFM56-3 engines. Via this service it also offers engine lease, material trading, exchange and sale services to its CFM56-3 customers. It can also provide modular exchange services for the CFM56-3 series. Last year FL Technics undertook 20 CFM56-3 SVs, three -5A/-5B SVs, and a -7B visit.

"At FL Technics, SVs make up 40% of all cases," explains Asta Albrichte, head of engines and components management at FL Technics. "In the mature engine market, workscopes depend on the demand for low build standard and cost optimisation, in addition to other factors such as OEM support in authorising special procedures. This includes allowing Quick Turn activities in certain cases.

"Major repairs account for 25% of the projects, while light inspections take up 20%," continues Albrichte. "The latter is especially the case in the CFM56-3 market, since there is high demand for re-delivery services, engine model change services to fit specific aircraft, fire detection system change, pre-purchase inspections, QEC change, and modification services. The remaining 15% are overhauls/LLP changes."

While Albrichte explains that it is rare for OEMs to order work from third-party MROs like FL Technics, typically 10-15% of all its engine teardown activity is completed in cooperation with the manufacturer. In such a case, FL Technics pre-agrees surplus material with the OEM. OEM surplus inventory is replenished by pre-checked materials with known vendors at the same time, ensuring a smooth process and stable sales impact for FL Technics.

Under its Part 145 approval, FL Technics can complete standard works in accordance with aircraft maintenance manuals, including, but not limited to, NDT (including full borescope); quick engine change (QEC); and LRU check/swap/changes; engine re-configuration; waterwash; engine leak tests; engine MAP runs; engine removal/installation; and preparation for shipment for the CFM56-5A, -5B, -3 and -7B. It can also provide these services for the V2500-A5 series.

Within its Part M approval, the MRO can provide further services including AD, SB and LLP tracking, and engine condition trend monitoring (ECTM) for the PW2000, RB211-535E4, CFM56-3, CFM56-5A, CFM56-5B, CFM56-7B, and V2500-A1/A5.

"We often see that due to the cost saving trends in mature engine types, it is useful to have the whole LPT/HPT modules or stator assemblies certified and ready for installation," adds Albrichte. "This is often in demand, because it allows quick turnaround times (TAT) for customers, and minimises costs while limiting scrap rates and workscope extensions. This is typical for the CFM56-3 HPT stator module, LPT module, LPT rotor-stator, LPT NGVs stage 1 module, and AGB module.

Due to its involvement with the CFM56-3, FL Technics sees a steady demand for DER repairs and PMA.

"During engine SVs where DER repairs are allowed, and during teardowns that are traced historically to PMA/DER, FL Technics actively uses DER repairs and also works closely with DER vendors for second-chance

As part of the IAE consortium, MTU performs MRO for the V2500. SVs are carried out at its Zhuhai and Hannover facilities, while ASSB provides LPT and HPC airfoil repairs as needed.

inspections," says Albrichte. "For engines such as the JT8D, CF6, CF34-3 and CFM56-3, where numerous technologies for DER/PMA were historically developed (including DER/PMA solution for turbine and compressor blades, shrouds and vanes) a DER repair is sometimes the only cost-effective solution, especially when the engine has already undergone DER and PMA SVs.

"This is managed on a case-by-case basis," continues Albrichte. "In our experience, using DER and PMA for mature engines is sometimes the best option, even if the engine has OEM-traced airfoils."

Iberia has been overhauling CFM56 engines since 1992. It now provides MRO services for the CFM56-5A,-5B and -7B series, undertaking 85 SVs in 2016. Much like its capabilities for the V2500, Iberia can perform hi-tech repairs for each module of the CFM56-5 and -7 series. 80% of its SV volume for narrowbody engines is for overhauls and LLP exchange work.

Singapore Technologies Aerospace Ltd (ST Aerospace) has the capability to service the full CFM56 engine series. Its JV with the Xiamen Aviation Industry, ST Aerospace Technologies (Xiamen) Company Limited (STATCO), is able to perform MRO services for CFM56-7B engines.

On average, ST Aerospace performs MRO services for 150 CFM56 SVs a year. "We have a licensing agreement with CFM International that allows us to provide extensive maintenance and repair services for the CFM56-3/-5B/-7B series engines," says Choo Han Khoon, executive vice president, Engine Total Support at ST Aerospace. "Our agreement with the OEM is based on a win-win arrangement that includes investment in machinery."

While all OEM proprietary repairs such as LPC, HPC, HPT and LPT blades and vanes are again contracted back to the OEM network of shops, ST Aerospace retains an extensive in-house parts repair capability for the CFM56 family. It is able to perform OEM-endorsed hi-tech repairs across all major modules for CFM56 engines.

SR Technics has two active locations that provide services for the CFM56-5 and -7B series. Its Zurich facility performs primary MRO services, while SR Technics Airfoil Services Ltd in Cork does hi-tech repairs on various parts including LPT airfoils.

SR Technics is approved for several OEM source controlled repairs. "We have more than 84% in-house repair capabilities, including ESM repairs and OEM source controlled repairs for the CFM56-5 and -7B series," says Roberto Furlan, vice president of engine services engineering at SR Technics. The company is an authorised CFM and PW MRO engine shop, and performs about 200 SVs per year. While SR Technics' hi-tech repair capabilities include plasma and HVOF coatings, laser-drilling, -welding and cladding, electron-beam (EB) welding and LPT airfoil repairs, applied across each main CFM56 engine module, it also sub-contracts HPC blade repair and HPT blades and vanes repairs back to the OEM.

As established in previous Aircraft Commerce surveys *(see Narrowbody engine hi-tech & specialist parts repair providers, Aircraft Commerce, August/September 2015, page 62)*, PAS Technologies also provides repair services for the CFM56-7B and -7BE series. Its portfolio includes in-house OEM hi-tech repairs for the LPT Case, HPC rear case, LPT stationary outer airseals, HPT aft outer airseals, HPT shroud hangars, compressor stator shrouds, HPC vane sectors, and fan outlet guide vanes.

Rolls-Royce RB211-535

The RB211-535 has a fan diameter of 74.1 inches, a six-stage intermediate pressure compressor (IPC), a six-stage HPC, a single-stage high pressure turbine (HPT), a single-stage intermediate pressure turbine (IPT), and a three-stage low pressure turbine (LPT). The -535E4 entered service in 1984, and powers an ageing and decreasing 757-200 and -300 fleet.

The current market

According to Rolls-Royce, there are 448 RB211-equipped 757s in active service as of February 2017. There is also a significant number of spare engines in airline use, giving a total RB211-535 active fleet of about 1,000 engines.

Whereas the 2014 survey showed that 150 SVs were performed for the RB211-535, ICF has estimated demand for about 70 SVs performed in 2016. This activity is forecast to stabilise for 2017. ICF predicts that SVs will slightly increase to 100 visits per annum until 2021, when activity will then steeply decline to about half this number. ICF estimates that 27 RB211-535 SVs will take place in 2022.

Some big shops have closed in recent years, which has removed some avenues for RB21-535 MRO services. Texas Aero Engine Services LLC (TAESL), which was a JV between American Airlines and RR, closed in early 2016, leading some providers to turn to Rolls-Royce's Derby location instead.

According to Rolls-Royce, the only Rolls-Royce owned maintenance shop currently with RB211-535 capability is Engine Overhaul Services, Derby, UK. Its other narrowbody locations are Rolls-Royce Canada in Montreal; and Rolls-Royce Inchinnan, Glasgow, UK. These provide services for the AE3007A and V2500 respectively. Each of these shops has some specialist repair capabilities for its own engines, but most Rolls-Royce repair work is contracted to third-party suppliers. Meanwhile, none of the Rolls-Royce JVs (N3EOS, SAESL and HAESL) has any narrowbody engine overhaul

AFI KLM E&M develops various engine repairs in-house via its repair subsidiaries, such as CRMA. AFI KLM E&M is able to perform repairs on all modules for the CFM56-5 and -7 series.

capability. SAESL, however, has specialist nozzle guide vane and compressor stator repair capability for the RB211-535. TRT, Derby, UK which is a 50:50 JV between RR and Chromalloy, repairs RB211-535 turbine blades in addition to NGVs.

Most RB211-535 SVs are conducted either by Iberia Maintenance, Madrid or Ameco Beijing. These two businesses are fully independent shops that are able to perform SVs for engines covered by Rolls-Royce TotalCare and SelectCare service contracts. Rolls-Royce explains that there are no RB211-535 repairs that only it, as the OEM, can perform.

A wide range of companies is able to perform RB211-535 repairs. Other independent repair facilities include Standard Aero, and various Chromalloy sites such as: Tilburg (Netherlands); Somercotes (UK); Windsor (Connecticut); Newnan (Georgia); Dallas (Texas); San Antonio (Texas); and Guaymas (Mexico).

MRO & specialist repairs

Iberia Maintenance is the largest independent MRO shop for the RB211-535 series. It performed 48 shop visits for the -535 in 2016. The MRO shop consists of five hangars, capable of accommodating 15 narrowbody and widebody positions. Hi-tech repair services that Iberia Maintenance can provide for the RB211-535 series in-house includes CNC shot peening, laser grinding, HVOF plasma spraying, and HPC airfoil repairs such as laser welding and robotic machining.

JT8D-200

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. The -200 also has a single stage LPT module, a single- stage high-pressure turbine (HPT) and the same low-pressure compressor (LPC) booster as its JT8D baby predecessor.

The current market

While *Aircraft Commerce* established that about 300 SVs took place during 2014, the JT8D-200 is now in significant decline. ICF estimates that about 160 SVs took place in 2016, and this is expected to fall further to 140 visits during 2017. By 2026, this is expected to decrease to about 20 events. These visits are likely to derive from business in developing countries that may continue to prolong the serviceable life of this sunset engine.

Pratt & Whitney continues to fully support JT8D fleet operations from a safety, technical and material perspective. The company maintains two designated service providers (DSPs) that provide maintenance services for the JT8D-200 fleet.

MRO & specialist repairs

MRO providers offering services for the JT8D-200 series include; Delta TechOps, Aerothrust, FJ Turbine Power, HAECO Americas, ITR, Turbine Engine Centre and Summit Aviation.

PW2000

The PW2000 also powers the 757-200 and -300 fleets, entering service in the mid-eighties. The PW2000 consists of a two-shaft turbofan engine, with a 78.5-inch-wide fan, a four-stage LPC, 12-stage HPC, two-stage HPT and five-stage LPT. The main difference to the RB211-535 is the two stage HPT, where the -535 is single stage. It powers all models of the 757 family, alongside various military aircraft. The engine is overhauled at PW's Columbus Engine Centre.

The PW2000 engine entered revenue service in 1984 as the first commercial engine with full authority digital engine control (FADEC) technology. PW later introduced a revised version of the PW2000, with reduced temperature configuration (RTC) in 1994.

The current market

Although it is an ageing engine that is declining in activity, PW2000 maintenance demand has plateaued in recent years. In 2014 100-130 SVs were anticipated, while ICF's market summary has estimated demand for 110 SVs for the PW2000 in 2016. This is expected to reach a gradual decline to about 55 annual SVs by 2022.

Before the PW1000G entered service, the PW2000 series and V2500 were the active narrowbody products offered by PW. The repair facilities owned by PW provide repair services for all PW models, and are mainly located in Asia and America. These are:

- Asian Compressor Technical Services, Taiwan: Its repair capabilities focus on the engine compressors, stators, shrouds and HPC seals.
- Component Aerospace Singapore: CAS's repair services extend to the combustion chambers, fuel nozzles, and fuel NGVs.
- Connecticut Rotating Parts, USA: repair focus is on PW2000 and V2500 major rotating parts.
- Connecticut Stators and Components, USA: a sister facility specialising in HPC stator and honeycomb seal repair.
- Dallas Airfoil Repair Operations, USA: components in the exhaust gas path form the repair basis here, including HPT/LPT blades and vanes, alongside airfoil coatings.
- International Aerospace Tubes, Singapore: repairs tubes, ducts and manifolds.
- North Berwick Part Repair Operations, USA: capabilities include airseals, shrouds, ducts, vane supports

SR Technics performs maintenance and repair for the CFM56-5 and -7 series. Its Cork facility, SR Technics Airfoils Services Ltd, performs hi-tech parts repairs on LPT blades and vanes.

and bearing components.

- Pratt & Whitney Auto Air, USA: repair of thrust reversers, nacelle components and composites.
- Pratt & Whitney Component Solutions, Singapore: PW's facility in Asia focuses on stators, variable vanes, ducts, airseals, split cases.
- Repair Supplier Logistics, USA: provides repair logistics.
- Turbine Overhaul Services, Singapore: HPC, HPT and LPT airfoils, and transition ducts.
- 1-Source Aero, Greece: main focus is accessory repair.

PW2000 engine parts repairs are also performed at the PW engine overhaul facility Columbus Engine Centre, Columbus, Georgia, USA.

MRO & specialist repairs

MTU Aero Engines both developed and designed critical elements of the PW2000. As such, it holds more than a 21% stake in the PW2000 and created repair solutions for it. MTU Maintenance, Hannover offers full module and parts repair capability for the PW2000, including: the fan, LPC and HPC airfoils, the combustor, specialised repairs for the HPT, and LPT airfoils, cases, gearbox, and accessories. It performs about 25 shop visits per year.

Delta's designated maintenance facility, Delta Tech Ops, is headquartered in Atlanta. As previously highlighted *(see Narrowbody engine hi-tech & specialist parts repair providers, Aircraft Commerce, August/September 2015, page 62)* it provides modification, repair and overhaul, and full restoration across all engine modules for the PW2000. It also carries out performance restoration to certain components, including those used in the gas path. Delta Tech Ops can perform repairs for the fan, bearing housings, LPT seal segments, HPT shroud hangers, liners, engine mounts, HPC airfoils, LPC airfoils, combustor, frames, gearboxes and cases, among others.

Delta uses a wide range of OEM-endorsed hi-tech repair techniques, such as plasma spray, anti-friction and thermal barrier coatings, laser welding, tip welding, electron beam welding, laser cladding, heat treatment, high pressure waterjet stripping, high-velocity oxygen fuel (HVOF) coating, computer numerical control (CNC) shot-peening, and silver-, chrome-, and nickel-plating capability. As and when DER repairs are requested or PMA is used, unique stripping, welding, coating and machining techniques can all be applied.

Summary

It is clear that a cultural shift is in progress within engine MROs, encouraging closer alliances with the OEMs so that MRO shops can optimise their presence in the aftermarket. "OEM-aligned shops that use OEM hardware, and do not use PMA parts or DER repairs, are likely to maintain relationships with the OEMs in the future," says Hankins. "While demand for CFM capacity will continue into 2030, big MROs often struggle to cater for a range of workscopes, so independents are probably better placed to offer this service for maturing engines.

"Flexibility in offering creative ways of keeping -5B/-7B engines flying, such as shops offering core exchanges and module swaps, will be attractive to operators as the asset values start to drop," continues Hankins.

Airline-owned MRO subsidiaries, understandably have leverage with OEMs due to aircraft orders. These businesses therefore have an advantage over independent shops, in addition to companies that manufacture and design elements for new engines. Hankins also thinks that independent shops will be able to take advantage of new-generation engine MRO activity, however. "The huge increase in numbers of LEAP and GTF engines, together with the current CFMI portfolio and the trend for worldwide growth mean that demand will stay high, so significant opportunities will remain for airline and non-airline non-OEM shops," adds Hankins.

"In time, market pressure to increase capacity might force OEMs to be more open to relaxing their requirements. The key factor for MRO providers will be the willingness and ability to cover the costs required to be OEM-aligned, so that they can be considered as an offload avenue for the OEM shops," says Hankins.

"There is still a future for these legacy engine types, with another 20 years or so of SV activity. Workscopes will change in the last 10 years of these engines' life from performance restorations and overhauls to repair activity. I anticipate that OEMs will not want to get as involved in repair workscopes because the LEAP will be starting to thrive, so there will be significant opportunity for MRO shops to get involved in repair workscopes. The question is whether this will last as long as older engines have. It will also hinge upon shops' willingness to be aligned to OEMs," concludes Hankins.

"OEMs will need partners to cope with the expected SV volumes," confirms Ockerman. "Few new aircraft acquisitions between airlines and OEMs are signed without an OEM maintenance contract nowadays, so the OEM ultimately becomes the customer of the engine shops in time." AC