The widebody engine maintenance market differs to its narrowbody counterpart, with a smaller operator base, higher investment requirements, and higher aircraft utilisations impacting shop visit patterns. This suggests a different landscape for maintenance providers, one which is heavily dependent on strategic manufacturer relationships. Charlotte Daniels summarises the widebody engine market.

Widebody engine MRO market analysis

Widebodies account for about 20% of the fleet of approximately 28,000 commercial aircraft. The next three years will herald the arrival of several new-generation widebodies, and the new engines that power them. While some maintenance, repair and overhaul (MRO) shops have the maintenance and repair licensing for these developing and sunrise engines in mind, others are prioritising a stake in the teardown market for ageing engines. Maturing engines provide the most buoyant type of MRO shop visit (SV) activity, and are an attractive focus for all engine shops because it is economic for operators to optimise heavy workscopes over an engine's service-life.

Newly entered into service (EIS) engines will typically require light work, often called a hospital visit, to overcome initial technical issues, in the first few thousand engine flight hours (EFH) on-wing. Heavy SV workscopes are not a regular occurrence until the worldwide fleet has started to reach the first scheduled removal and SV, which can be in excess of six years from EIS. Meanwhile, operators of ageing or sunset engines will try to avoid the high cost of full overhaul by sourcing used, repaired or serviceable parts. Aircraft retirements have also slowed due to stabilising fuel costs, prolonging this business.

The widebody engine MRO market is built on different dynamics and demands in comparison to narrowbody engine maintenance *(see Narrowbody engine MRO market, Aircraft Commerce, February/March 2017, page 47)*. Stronger original equipment manufacturer (OEM) relationships are apparent, so there are fewer truly independent shops. "It is important for MROs to consider the mean time between removal (MTBR) of these emerging and maturing engines," says Richard Brown, principal at ICF. "Engines are staying on-wing for longer, and this is only set to improve with the next-gen engines. While this is great news for airlines, this naturally impacts SV activity and aftermarket requirements.

"Even as the engines start to mature, material and parts availability may differ for MRO shops. It is not uncommon now for material agreements to be in place between OEMs and airlines as part of an aircraft order. This affects profit margins for MROs during an SV," adds Brown.

In-service widebodies are the 747, 767, 777 and 787; and the A330, A350 and A380 families. The main engine families covered in this article are: the General Electric (GE) GE90, GEnx, and CF6 families; the Rolls-Royce (RR) Trent and RB211-524 families; and the Pratt & Whitney (PW) PW4000-94, -100 and -112 series. As of July 2017, the in-service engines from these families power almost 4,000 passenger-configured widebodies (Flight Global FleetAnalyzer) .

AJW Group has established relationships with engine MRO specialists worldwide via its engine SV management service, which aims to optimise the logistics and efficiency of SV selections for its clients. "Overall, due to lower utilisations seen in the widebody engine market, there is lower demand on the widebody engine MRO shops for frequent SVs," explains Sam Rice, director of engines at AJW Group. "There are subsequently fewer MROs available for widebody engine types than there are for narrowbody ones. For example, there are more than 35 engine shops with CFM56-7B overhaul capability, and significantly fewer for the CF6 or GE90." An evaluation of the widebody engine market must take into account the level of OEM aftermarket involvement, the number of MRO shops in its immediate network, the number of SVs being carried out annually, and the maturity of the engine in question.

MRO & OEM Alliances

A number of new- and next-generation engines have been introduced to the market in recent years, as has been established in previous articles *(see Acquiring maintenance capability for new-generation engine types, Aircraft Commerce, February/March 2015, page 36)*. New engine types such as GE's GEnx, and RR's Trent XWB are now in service; while the Trent 7000 and GE9X are emerging engines that have yet to start operations. These engines have new technologies installed to optimise reliability and efficiency, such as 3D-printed parts, composite materials, or the introduction of bladed disks (blisks).

These technologies naturally require different repair and inspection processes of the service provider, and access to the OEM's intellectual property (IP). It has to be considered, therefore, that acquiring these capabilities and appropriate licenses require strategic relationships with the manufacturer, to be at the forefront of providing these next generation maintenance services. Each engine OEM has a slightly different approach to this, depending on how it manages its own aftermarket services to customers to optimise its engine programmes. "Generally speaking, there will be increased OEM coverage for next-generation engines," explains Norbert Moeck, director engine programmes at MTU Maintenance. "Independent providers will need to intensify their cooperation with OEMs to access both engine MRO and potentially IP protected repair licences, as well as MRO volume."

Moeck adds that whereas an airline-affiliated provider can count on some baseload volume from its parent airline, independent MROs need to acquire their entire workload from the third-party market, while airlines potentially also get better access to licences during engine acquisition. Access to IP has become more challenging over the past couple of years, due to the strong activities of the OEMs in the aftermarket, but there is still room for independent development in the widebody, large engine MRO market. An example of this is our proprietary MTUPlus repairs. MTU Maintenance has a long history as a repair developer and specialist, so we plan to develop new repairs in our partnerships with the OEMs, and perform repairs on behalf of the OEM through the OEM network.

Strategic OEM relationships fall into four main categories: a) the MRO forms a joint-venture (JV) engine shop with the OEM; b) the engine shop becomes a risk- and revenue-sharing partner (RRSP), which requires investment in the initial design and manufacturing process for the engine; c) an airline can leverage aircraft orders and engine options in exchange for appropriate IP access; and d) the MRO provider can buy tooling, training and the IP independently.

Each requires a high level of investment. While options a) and b) ensure OEM support and access to maintenance SVs, they require early involvement and significant capital to set up. Option c) needs aircraft orders for negotiation (a different type of investment), yet does not guarantee third-party maintenance business. "Airlines are not always granted third-party work," adds Brown, "plus investment in a test cell is substantial." Option d), while independent, carries a lot of risk in the early days of an engine's service lifecycle. Solid business cases, therefore, are needed before MRO shops commit to new-generation engine maintenance in its relative infancy, whether from assured in-house business, or the OEMs' need for the provider's in-house capabilities to manufacture certain engine modules.

Established relationships and alliances will be expanded on throughout this feature. A new agreement has recently been announced between the MRO Air France Industries KLM Engineering & Maintenance (AFI KLM E&M) and OEM RR for the Trent XWB. This allows AFI KLM E&M to form part of the RR 'CareNetwork'; allowing the engine shop to perform engine maintenance and some component repairs.

In addition, Lufthansa Technik AG (LHT) has recently collaborated with GE to form a JV called XEOS to repair and overhaul GEnx-2B and GE9X engines from 2018 and 2021 respectively, and will be located in Poland. This JV is in addition to LHT and RR's JV, N3 engine overhaul services, which have been providing MRO for the Trent 500, 700, 900 and XWB for 10 years.

MTU Aero Engines is a key partner to engine OEMs in the development and production of several major programmes. It acts as an RRSP for many new-generation types, for example for the GEnx (share 6.5%) and GE9X (share 4%), and the Engine Alliance GP7000 (share 22.5%). On the GEnx and GE9X, MTU Aero Engines has the system design responsibility for the turbine center frame (TCF), so it will act as the OEM's TCF repair facility under OEM contract.

As an RRSP, MTU is not only involved in developing and producing modules for the engine, it also gets, to the extent of its RRSP share, revenues from the OEM's aftermarket activities, such as from spare parts as well as flight-by-hour payments. MRO activities are carried out by its subsidiary, MTU Maintenance while spare parts are sold by MTU Aero Engines. Via MTU Maintenance, it is part of the MRO network of the OEM.

For the next-generation engine models, MTU will act as an OEM network provider for now, meaning it cannot act as an independent service provider at the early stages in these lifecycles. "MTU Maintenance will continue to act as an independent MRO provider for most engines in our portfolio, such the CF6-50/-80C2 and the GE90-110/-115B," adds Moeck. "We can offer customers tailored workscopes and independently managed services for these engines over their entire life cycle. Among these are engine leasing, on-wing and LRU support, engine condition monitoring, as well as asset and material management."

SV considerations

As has been covered in the recent narrowbody engine market survey *(see Narrowbody engine MRO market, Aircraft Commerce, February/March 2017, page 47)* several factors affect the scope and requirement of an engine SV. The environment the engine is operated in will affect the MTBR and therefore the frequency of an SV, in addition to the extent of corrosion and exhaust gas temperature margin (EGTM) deterioration. The engine's age will also affect its SV requirements and priorities. *Aircraft Commerce* splits the engine lifecycle into three main stages: sunrise, which is effectively a new EIS engine in its initial period of operation; maturing, which covers the mid-life of an engine undergoing first to third or fourth removals and SVs; and sunset, which is an ageing engine at the end of its operational lifecycle. Sunset engines are often considered to be phased out of fleets in the short- to medium-term.

While it is generally defined that an engine will undergo hospital visits in its early service life, followed by alternating performance restorations and overhaul work, a 'sunset' engine will have different priorities during a SV. For instance, an operator is likely to consider it uneconomic to invest millions in a sunset engine overhaul, when it will be phased out within 24 months. As such, it may try to source a leased engine with sufficient EFH left before a major SV to cover this

The Trent 1000 is installed on 787 family aircraft, so its design is compatible with the aircraft's requirements for electrical rather than bleed-air dependent systems. The Trent 1000 will also be installed on the 787-10 when it shortly enters service.

period. Hence, whether the focus of an SV will be on parts or hot-section repair, full engine overhaul, life limited part (LLP) replacement or the use of serviceable over new parts will depend on the engine's stage in the lifecycle.

"While there is no definitive rule to follow for a SV, it does tend to depend on the respective engine programme and its maturity within the lifecycle," says Moeck. "Also, technical engine issues can generate a sudden unforeseen peak in SVs, for example as a result of an airworthiness directive (AD). In that case, the share of lighter visits may increase, albeit for a short period of time only.

"MRO work on current but not fully mature programmes, such as the GE90, see an increasing number of major/overhaul SVs compared to smaller fixes," adds Moeck. "These also increasingly involve LLP replacement as the programmes become more mature.

"Mature engines, such as the CF6, are more complicated in this regard," adds Moeck. "MRO work will either involve full overhaul workscopes including LLP exchange (typically for longer-term operations) or 'minimised' workscopes, which are then tailored to specific needs (typically for shorter-term operations). Whereas the focus of an overhaul visit is a long on-wing time, the latter ones are aimed at lowering cost and matching a pre-defined operational timeframe where investing in an overhaul visit is no longer deemed economic or necessary. "Mature engines programmes are therefore ideal for such situations, since they focus on reducing costs for operators of ageing engines through cost-effective MRO alternatives (such as smart repairs and used parts) and alternatives to MRO (instant power solutions such as engine lease, sale and exchange)."

Of the subject engines in this feature, AJW describes the GE90-115B, GEnx, Trent 900, Trent 1000 and Trent XWB as sunrise engines. The GE90-94 and -115B, Trent 700 and Trent 800 are maturing families, whereas the RB211-524, CF6-80C2, CF6-80E1 and PW4000 are end-of-life or sunset types. "We are naturally seeing high levels of used serviceable material (USM) activity and demands for CF6-80C2, PW4000-94 and GE90-94 engines," explains Rice. "The CF6-80C2 and PW4000 are also experiencing high leasing demands for green-time engines. It may be more economic for operators and lessors to avoid an ESV on a CF6-80C2 or PW4000-94 due to the availability of serviceable engines on the market." The availability of USM arises from engine teardown, and several engine shops have specialised in performing this in order to obtain serviceable parts. AJW adds that StandardAero, MTU Maintenance, SR Technics, Air France Industries KLM Engineering and Maintenance (AFI KLM E&M) and Iberia Maintenance are among the most prominent providers of this service for ageing engine types.

Regional considerations

Just because an operator is based in, for example, Europe, it does not always mean that a European engine shop carries out its engine MRO work. "Logistics and transport costs are small compared to the cost of a full overhaul on widebody engines," says Rice. "Europe and Asia have large concentrations of widebody engine MROs, some with unique capabilities outside of the OEM (Air France KLM E&M with the GE90-94B for example), which may affect where the main MRO activity happens.

"Via AJW's ESVM service, we tend to prioritise MROs local to the engine removal location wherever possible. If a PW4056 is removed in Asia, for instance, we would approach local MROs in our network before opening up to the wider market," says Rice. It is not unusual, however, for engine MRO to occur in different continents or countries to the operator's base. As will be established, OEMs tend to establish JVs or a network of approved providers to cover the main regions of activity.

OEM contract options

A further matter that has the potential to widen divisions between independent and strategically aligned maintenance shops is the power of an OEM aftermarket agreement to influence the availability of ad-hoc third-party business. OEM maintenance programmes suggest retainership of maintenance business post-engine sale. The quality and coverage these agreements provide have become more sophisticated and adaptable in recent years, meaning that a large percentage of airlines (particularly those minus in-house engine shops) agree sales with pre-agreed maintenance contracts.

The 'Total Care' package offered by RR, for example, during engine contract negotiations ensures a large portion of its customers go straight to the manufacturer post-sale. Under this contract RR offers extensive aftercare support from standard maintenance, through to performance restorations, repair and overhaul. Higher residual value is often suggested for engines enrolled in Total Care.

"Airlines enjoy the risk-free transfer that power-by-the-hour (PBH) contracts give them," adds Brown. "They make sense to airlines, especially those with newly EIS engine types, so it follows that OEMs offer these agreements as part of an aircraft order." This is reflected in the high percentage of recent Trent orders placed with a TotalCare agreement included.

RR offers aftermarket support and maintenance agreements to Trent customers via its TotalCare, SelectCare LessorCare and Foundation Services contracts. The 'TotalCare' suite of products includes TotalCare Life, TotalCare Term and TotalCare Flex.

WIDEBODY ENGINE MARKET FORECAST - SHOP VISITS 2016-2026

Widebody engine	Number in operation	Number built 2016	SVs 2016	SVs forecast 2017	10 year SV forecast
General Electric					
GE90-94B	322	0	39	40	388
GE90-115	1,915	196	305	338	4,460
CF6-80C2	2,283	32	519	493	3,478
CF6-80E1	554	48	145	164	1,656
Pratt & Whitney					
PW4000	1,906	6	357	416	2,827
Rolls-Royce					
RB211-524	280	0	40	39	261
Trent 700	1,476	72	367	389	4,006
Trent 800	350	0	71	69	443
Trent 900	336	24	49	68	936
Trent 1000	410	120	13	25	1,359
Trent XWB	170	104	0	0	1,441

Source: ICF
Figures provided are estimations

TotalCare Life, according to RR's website, provides a $/EFH rate for the duration that an airline operates an engine. The agreement includes core services such as off-wing maintenance and on-wing availability, aircraft-on-the-ground (AOG) support and other optional services.

Meanwhile, TotalCare Term provides the same core services as standard, but the $/EFH rate only funds SVs expected to occur over a fixed calendar period.

TotalCare Flex, in addition, offers the fully-reserved benefits of TotalCare Life, but focuses on mature engines, as described on the RR website. Green-time management is offered to minimise costs for engines approaching retirement.

SelectCare is another agreement offered by RR. The website describes SelectCare as offering a core fixed-price overhaul (OVH) arrangement for airlines, which remains the same for the duration they operate the engine.

RR also offers LessorCare, a lessor-focused agreement that has recently been added to the TotalCare service portfolio. LessorCare aims to aid transition between lessees, and maximise the asset value of leased engines. Customers with LessorCare can use off-wing maintenance and on-wing availability services when an aircraft is between operators.

Foundation Services are event-based services for customers who require neither risk transfer nor long term services contract. The main elements of Foundation Services are fixed-priced overhauls and time and material (T&M) shop visits. Customers can also procure other service options, such as on-wing services, training or dedicated spare engine leasing, without an engine overhaul.

General Electric (GE's) portfolio of maintenance contracts for customers is called TrueChoice. Within the TrueChoice umbrella of agreements, GE's website includes TrueChoice Flight Hour, TrueChoice Overhaul, TrueChoice Material and TrueChoice Transitions. As the name suggests, TrueChoice Flight Hour is essentially a PBH programme, enabling full risk-transfer engine maintenance.

TrueChoice Overhaul offers fixed price agreements customised to each specific engine's requirements. TrueChoice Material offers new and used part, repair and upgrade solutions, while TrueChoice Transitions accommodates an engine's evolving maintenance requirements throughout its lifecycle, including time and material (T&M) or PBH programmes, engine and module exchanges, custom workscopes and traditional and green time engine leases; as GE's website explains.

RR large engines

RR's in-service widebody, large engine portfolio includes the Trent 700, 800, 900, 1000, XWB and RB211-524. The Trent 700 powers the A330-200 and -300, and has been in operation for more than 20 years. The RR Trent 800 is a powerplant option for the 777 family, entering service in 1996. The series comprises Trent 875, 877, 884, 892 and 895 variants. The last two digits of the series denotes its thrust rating in thousands of lbs. The Trent 875 and 877 variants power the 777-200, delivering 74,600lbs and 77,000lbs take-off thrusts. Meanwhile, the Trent 884 equips the 777-200ER, at 84,950lbs of take-off thrust, and the Trent 892 delivers 91,600lbs of thrust for the 777-200ER and -300. Last, the Trent 895 is installed on 777-200ER aircraft, giving up to 95,000lbs take-off thrust.

The Trent 900 is the RR option for the A380 aircraft family. Its main two series, the Trent 970 and 972, are installed on the A380-800. As is characteristic of the Trent range, the 900 is a three-shaft turbofan engine. Its thrust variants range from 70,000lbs to 77,000lbs, with bypass ratios varying from 7.7:1 to 8.5:1.

The Trent 1000 is installed on 787 family aircraft, so its design is compatible with the electric aircraft's requirements for electrical rather than bleed-air dependent systems. The Trent 1000 has a 10:1 bypass ratio, and thrust ratings between 53,000lbs and 78,000lbs.

The Trent XWB is exclusive to the A350-XWB, currently comprising the A350-900, with the -1000 about to EIS.

The RB211-524 has been in operation for almost 30 years. The -524G-T variant powers the 747-400, while the -524H is installed on 747-400 and 767-300 aircraft.

Engines in operation

According to RR, current in-service figures per type as of June 2017 are:

- Trent 700: 68 Trent 700s now equip freighter versions of the A330, and 1,408 are installed on passenger-configured aircraft in service.

According to ICF, 72 Trent 700 engines were built in 2016, and about 370 SVs were carried out. The aviation analyst estimates that 390 SVs will be undertaken during 2017, and 4,000 over the next 10 years *(see table, this page)*.

- Trent 800: RR says that there are about 350 Trent 800s powering passenger-configured 777s today.

ICF estimates that about 70 Trent 800 SVs occurred in 2016, with a similar number forecast for 2017. Due to the gradual phasing out of the 777 legacy models, ICF says that about 450 SVs will

The GEnx has three main GE service partners associated: Air India is licensed for the GEnx-1B; Etihad Airways Engineering (formally Adu Dhabi Aircraft Technologies) can perform MRO for both the GEnx-1B and -2B; while LHT has formed a brand new JV with GE, called XEOS. This will overhaul GEnx-2B engines from 2018.

take place over the next decade.

- Trent 900: according to RR, latest figures show 336 Trent 900s are installed on 84 A380 aircraft. ICF says that about 24 Trent 900s were built last year, and that almost 50 SVs were carried out on the fleet. About 70 Trent 900 SVs are forecast for 2017, and about 950 in the next 10 years.
- There are 410 Trent 1000 engines installed on active 787-8s and -9s. The Trent 1000 TEN is due to enter service on the 787-10. ICF figures show that about 120 Trent 1000 engines were manufactured in 2016, while about 15 SVs took place during the year. ICF estimates that 25 SVs will be undertaken in 2017, and that 1,400 Trent 1000 SVs will occur in the next 10 years.
- RR says that the Trent XWB powers 85 A350-900 aircraft, with 170 engines in active service. ICF says that 104 Trent XWB engines were built in 2016, and that due to the relative infancy of the engine type, no major or heavy SVs have been performed to date. This does not account for hospital SVs, which may occur on an ad-hoc basis during the early service period of a new EIS engine. 1,441 SVs are expected over the next 10 years.

RR explains that any significant requirement for Trent XWB overhaul SVs will ramp up from 2020. Any unscheduled maintenance is fulfilled by the Trent XWB shops listed below, the latest of which, Air France Industries KLM Engineering & Maintenance, was announced at the 2017 Paris Airshow.

Of the RR engines explored, the RB211-524, which is installed on an ageing fleet of 747-400 and 767-300 aircraft, is the oldest. The manufacturer says that there are 72 -524s installed on freighter variants, and 208 powering passenger-configured aircraft. ICF has provided SV estimations of 40 SVs per year performed in both 2016 and 2017. The next decade should see about 260 SVs as the engine series is gradually phased out via fleet replacements.

The Trent CareNetwork

RR's aftermarket service network strategy comprises wholly-owned, joint ventures (JVs) and customer owned shops. RR has announced three non-equity independent, third-party maintenance providers in its Trent CareNetwork. Truly independent, third party maintenance providers are expected to increase in numbers as the demand for engine overhaul grows beyond existing capacity.

OEM shops and JVs

RR has both wholly-owned, JV, and non-equity maintenance shops, in place to manage aftermarket activity for its Trent and RB211 engines. These are in Europe and the Asia Pacific, although as will be established, the OEM has a worldwide 'CareNetwork' of independent shops, suppliers and authorised maintenance centres (AMCs) to further cover aftermarket activity. Its own engine shop, EOS Derby UK, is 100% RR owned, and can provide MRO services across the full Trent engine family.

Meanwhile, Hong Kong Aero Engine Services Limited (HAESL), which is a 50:50 JV between RR and Hong Kong Aircraft Engineering Company (HAECO), provides MRO for the RB211-524, Trent 700, Trent 800 and Trent XWB.

Singapore Aero Engine Services Pte Limited (SAESL) is another 50:50 JV, this time between RR and SIA Engineering Company Limited (SIAEC). According to its website, SAESL is the world's largest Trent engine MRO, with capability to support all products in the Trent family. SAESL can provide MRO and test services for the Trent 700, Trent 800, Trent 900, Trent 1000 and Trent XWB. SAESL Engine Overhaul services can support all workscopes such as hospital, check and repair, and full refurbishment visits. In addition, it can carry out engine disassemblies, LLP exchanges, parts and accessory repairs, engineering support and engine status reporting.

Another JV is N3 Engine Overhaul Services (N3EOS), which is a 50:50 JV between RR and Lufthansa Technik (LHT). Based in Arnstadt, Germany N3EOS can provide maintenance, repair and component services for the Trent 500, Trent 700, Trent 900 and Trent XWB engines.

Non-equity shops

In addition to one wholly-owned shops and three JVs, the following shops form part of the Trent CareNetwork, as described by RR. Two of these are non-equity AMCs: Delta TechOps, Mubadala Abu Dhabi, in addition to TS&S which is an independent Trent 700 MRO shop, and a number of independent customer-owned shops:

- Aircraft Maintenance and Engineering Corporation (AMECO), Beijing provides MRO for the RB211-535;
- ANA Engine Technics Co, Tokyo focused on the Trent 1000;
- Delta TechOps, Atlanta, USA has emerging capabilities for the Trent 1000 and the Trent XWB. It will begin overhaul services for the Trent XWB from 2020;
- Egyptair Maintenance & Engineering, Cairo is an MRO for the Trent 700;

MTU performs more than 20 SVs per year for the GE90-110/-115B. It anticipates that this will increase in coming years. For module MRO work, MTU Maintenance is typically allocated work in the amount equivalent to its RSSP share.

- Emirates Engineering, Dubai carries out maintenance on the Trent 500, 700 and Trent 800;
- Mubadala Abu Dhabi. Announced in 2016, Mubadala's AMC for the Trent XWB is under construction and anticipated to open in 2021 and to perform up to 150 XWB SVs a year;
- AFI KLM E&M is also part of the CareNetwork for the Trent XWB;
- Turbine Services & Solutions (TS&S) is licensed for the Trent 700, and completed its first fully independent Trent 700 overhaul at the end of 2016 via a contract with Sri Lankan Airlines. As such, it is considered a newly independent Trent 700 MRO shop;
- THAI Technical has Trent 700 and Trent 800 maintenance capability; and
- Last, GE's Aircraft Engine Services (GEAES) of Cardiff, Wales UK is licensed for RB211-524 overhaul.

Component Repair Network

In addition to AMCs, there are additional engine maintenance and repair shops that specialise in certain components and repairs. RR explains that AMCs can perform standard repairs and have the capability to repair bulky items such as fan-cases. For rarer and/or more complex repairs, this approach is uneconomic because there is unlikely to be a high enough volume of repairs going through each shop.

Hi-tech repairs, therefore, are performed by a smaller number of facilities, called Centres of Excellence (CofE). The CofE are a mix of RR-owned, JV and independent suppliers; offering up to three providers per repair.

Trent engine repairs can be grouped by module and shops licensed:

HP/IP bearing supports: HAESL, LHT EPAR, EOS;

Fan blades: HAESL, LHT EPAR, SAESL;

Compressor blades: SAESL, RR Inchinnan, Airfoil Services Sdn. Bhd, Kuala Lumpur Malaysia (ASSB);

Nozzle guide vanes: SAESL, Turbine Repair Technologies, Somercotes United Kingdom (TRT);

Front combustor liner tiled; SAESL, CRMA Aero Repair, Paris France (CRMA), N3EOS;

Front combustor liner non-tiled: RR Canada, Montreal Canada (RRC);

LPT blades: HAESL, Turbine Repair Technologies, Somercotes United Kingdom (TRT);

Discs and shafts seal fin repairs: HAESL, RR Inchinnan, KLM Engine Maintenance;

Complex case repairs: Barnes Aerospace, Connecticut USA (Barnes EG) Barnes Aerospace, Singapore (Barnes SG), Delta TechOps, HAESL;

Blisk repairs: EOS, N3EOS;

Compressor vanes: SAESL;

Honeycomb conventional repairs: HAESL, Chromalloy Thailand, Bangkok Thailand (CTHAI);

Bearings: Schaeffler Technologies AG & Co. KG, Schweinfurt Germany, SKF, Gloucester United Kingdom;

Honeycomb direct laser deposition repairs: SAESL, Lufthansa Technik Engine Parts and Repair, Shannon Ireland (LHT).

RR explains that at the present time, all existing hi-tech repairs can be carried out by these repair service providers; future repairs, such as material addition for Blisk repair, are being developed within RR Research and Technology Centres.

Additional MRO shops

GT Engine Services Ltd (GTES) is located at Stansted Airport, UK. It performs quick-turn maintenance services for the Trent 700, and carries out about 10 workscopes a year on type. GTES's focus is light maintenance, performing borescope, end-of-lease checks, and QEC strips/builds. It operates under European Aviation Safety Agency (EASA) and Federal Aviation Administration (FAA) maintenance licences.

PAS Technologies is a US-based repair provider that has recently been acquired by StandardAero. With additional locations in Europe and Asia, it provides hi-tech and OEM-endorsed repairs for the RB211-524 series. These include repair solutions for shrouds, half rings, air seals and assemblies, compressor rotor spinner assemblies, casing assemblies, gearbox housings, and combustion cases. Hi-tech repair processes adopted by PAS comprise welding, EDM & spark erosion, machining, metal spray, cold spray, heat treatment, balancing, water jet, brazing, plating, FIC, laser welding & cladding, grinding, painting and shot peen techniques.

Brown at ICF believes that the MRO market for the Trent 700 may open further opportunities for MRO shops. He explains that, as the worldwide fleet ages, engines are starting to come off full-coverage PBH contracts such as TotalCare and are progressing onto T&M agreements to explore cost-effective maintenance options. This suggests the potential for MRO shops to evaluate the business case for the 700. "The A330 also enjoys an excellent market," Brown adds, "which provides further assurance of SV work."

GE large engines

The GE90 engine family has been around for over 20 years. The GE90-94B entered service in 1996, while the -110B and -115B entered service in 2004. The -90B and -94B power 777-200ER aircraft, while the - 110B equips 777-200LR (long-range) aircraft and the -115B is installed on 16 777-200LR and

709 777-300ERs. A summary of performance and SV patterns has previously been undertaken *(see GE90, GP7200, Trent 800 & Trent 900 performance & maintenance, Aircraft Commerce, April/May 2017, page 81).*

Meanwhile, GE's CF6 engine family has been in service since 1971. The CF6-80C2 and CF6-80E1 turbofan engines each consist of a single fan, followed by a four-stage LPC and a 14-stage HPC. They both also have a five-stage LPT and a two-stage HPT. The CF6-80C2's fan diameter is 93 inches, while the CF6-80E1 has a fan diameter of 96.2 inches. Thrust ratings also differ between the two models. The -80C2 is rated at 52,200-62,000lbs thrust, and the -80E1 is rated at 65,800-69,800lbs thrust. The CF6-80C2 powers the A300-600, the 767-300ER, 747-400 and -400ER variants, and the MD-11. It is the predecessor to the CF6-80E1, which powers the A330-200 and A330-300.

GE shops & alliances

As has previously been established *(see Widebody engine hi-tech repair survey, Aircraft Commerce, April/May 2015, page 46)*, GE has several global shops that can undertake MRO work. CF6-80 engines are overhauled at GE's Caledonian and Celma facilities, while the GE90 is overhauled at GE Aviation Wales. In addition, the GEnx engines can undergo maintenance at GE Aviation Caledonian (Scotland), GE Aviation Celma (Brazil) and GE Evergreen Engine Services (Taiwan). GE also has global repair shops in Cincinnati, Ohio; Singapore; McAllen, Texas; and Hungary. All provide repairs for the GE network and third-party overhaul providers. Each of GE's repair shops focuses on specific product types:

At GE's shop in Cincinnati, OH the repair focus is on GE90 combustors, and GE90 and CF6 rotating parts and structures. At ATI Singapore GE90 and CF6 combustors are repaired, alongside the GE90 and CF6 HPT, HPC and LPT airfoils. GE Component Repair in McAllen, TX concentrates on GE90 and CF6 LPT airfoils. Last, GE Component Repair, Hungary repairs all honeycomb parts and composites.

GE also has several service partners, which form its GE Global Branded Services Network (GBSA) for in-service and developing widebody engines. These service partners include TEXL (Xiamen, China), AFI KLM E&M, Emirates and Japan Airlines (JAL) for the GE90 family.

The GEnx also has three main associated service partners: Air India is licensed for the GEnx-1B; Etihad Airways Engineering (formally Adu Dhabi Aircraft Technologies) can perform MRO for both the GEnx-1B and -2B; and LHT has formed a brand new JV with GE, called XEOS, which will overhaul GEnx-2B engines from 2018. This will also begin work on the GE9X from 2021 once it has EIS.

Engines in operation

GE has provided in-service figures for its GE90, GEnx and CF6 engine fleets, correct to July 2017. There are 380 GE90-94B engines in operation, powering 777-200ER aircraft, and more than 2,050 -115B engines on the -200LR and -300ER. Of these series, ICF estimates that SV demand for the -94B averages about 40 visits a year. It is estimated that 400 further SVs will take place for the -94B over the next 10 years.

The -115B is still in production, and ICF says that close to 200 engines were manufactured in 2016. The -115B is a maturing engine in a period of growth; while about 300 SVs took place in 2016.

PAS Technologies has recently been acquired by StandardAero. With additional locations in Europe and Asia, it provides hi-tech and OEM-endorsed repairs for the RB211-524, CF6, and PW4000 series engines.

ICF thinks that 2017 will see closer to 350 SV events worldwide. Its 10-year forecast estimates 4,500 -115B SV requirements during the period.

GE also states that there are about 800 GEnx-1B, and 530 GEnx-2B active engines in the market.

Regarding the long-running CF6-80C2 series, GE provides in-service statistics illustrating about 4,000 engines are still in operation among 144 operators. The -80C2, which has accumulated almost 230 million EFH to date, is still in production for the 767 freighter. ICF says that about 30 were built, and about 500 SVs were carried out during 2016. SV demand is likely to be similar during 2017. Overall, ICF anticipates about 3,400 -80C2 SVs for the next decade. For the -80E1, GE provides in-service data of almost 700 engines across 35 operators. Almost 50 E1 engines were built in 2016, and SV demand is rising steadily with over 150 SVs estimated to take place in 2017.

MRO shops & activity

As a service partner under the GBSA, Air India has capability for both GE90 and GEnx engines via its maintenance subsidiary, Air India Engineering Services Ltd. The company is investing in a new overhaul facility, which will be located in Nagpur, India. Until then, Air India is carrying out quick turn (QT) SVs only. The MRO advises that, as Air India's fleet comprises the GE90 and GEnx, access to IP and maintenance training was provided while they made the independent investment to procure tools.

Meanwhile, AFI KLM E&M's Amsterdam shop provides CF6-80C2 and –E1, and GEnx maintenance. It performs about 60 CF6 SVs per year on average, in addition to 20 GEnx SVs. AFI KLM E&M's Paris facility located at Orly airport, has full GE90 and GP7000 capability, and as such undertakes a further 100 GE90-94 and -115 SVs and 15 GP7000 per year. Via CRMA, AFI KLM E&M can provide in-house parts repair across both CF6 and GE90/GP7000 engine modules; GEnx repair work is in progress.

Delta TechOps has full overhaul capability for the CF6-80C2 series; performing about 115 SVs per year. According to a source, 70% of Delta's SVs are major repairs or overhauls with LLP replacement, while the remainder form light repair workscopes. Delta TechOps can provide in-house parts repair for all major parts of the engine including: fan cases, LPC, HPC, combustor, LPT, HPT and various seals and casings.

GE Evergreen Engine Services is underpinned by Evergreen Aviation Technologies Corporation's (EGAT's) engine shop. GE Evergreen Engine Services is operated similar to a GE engine shop, and is formed via an equity JV between GE and EGAT. The EGAT engine shop provides maintenance services for most GE widebody engines, including the GEnx family, the GE90-115, the CF6-80C2 and CF6-80E1. Via the GBSA and the GE engine services agreement that it holds with the manufacturer, the JV will assign the workload to the engine shop, which takes up about 75% of EGAT's engine shop maintenance capacity, and performed on behalf of GE. Such agreements allow EGAT access to the necessary IP to perform this work.

On average, EGAT undertakes 20 GE90-115B SVs; 30 GEnx SVs; and 150 CF6-80s SVs each year. About 50% of these SVs involves major overhaul or repair work. The EGAT shop can perform in-house repairs on all major CF6/GEnx modules, along with some piece-part repairs, aligned to GE's network of piece-part repair centres.

MTU Maintenance is a business division of MTU Aero Engines, Germany's leading engine manufacturer and the world's largest independent provider of aero engine services. Based in Hannover, MTU Maintenance's focus is on medium-sized and large engines. Services include the GE90-110/-115B, CF6-50/-80C2 and GEnx TCF MRO high-tech parts repair and repair development. In addition, ASSB, which is a JV between MTU and LHT, offers LPT and HPC airfoil repairs for the CF6 and GP7200.

MTU Maintenance is the leading independent MRO provider for the GE90-110/-115B engine. It currently performs more than 20 SVs per year. MTU Maintenance anticipates that this will increase in coming years. Meanwhile, the engine shop performs almost 80 CF6-80C2 SVs per year at current demand. "For module MRO work, MTU Maintenance is typically allocated work in the amount equivalent to its RSSP share," says Moeck. Similar to the GEnx, GE9X TCF MRO is planned upon the engine's full EIS.

MTU Maintenance offers its customers individually tailored MRO solutions and extended services which are designed to lower their operational costs and to maximise the value of their engines. As part of its services portfolio, the company provides various high-tech repair technologies that cover the entire engine and meet the required approvals. Apart from OEM repairs, MTU Maintenance offers EASA/FAA-approved high-tech repairs which are developed in-house and marketed as MTUPlus repairs (or otherwise known as DER repairs). An example of an MTUPlus repair is the MTUPlus laser powder cladding tip repair, which can be applied to turbine blades. MTU can provide in-house repairs across all major CF6 rotating and

GE has overhaul capability for the CF6-80 series at its Caledonian, UK and Celma, Brazil facilities. It also has overhaul shops for the GE90 in Wales, UK; and overhaul facilities for the GEnx at its Caledonian, Celma, and Evergreen Engine Services, Taiwan shops.

non-rotating parts. For the GE90, MTU Maintenance provides repair solutions for the fan, accessories, cases and frames.

In addition, StandardAero Component Services & PAS Technologies specialise and provide OEM-approved repairs for the CF6-6, -50, -80A, -80C and -80E engine series. On many engine platforms, the company works with OEM partners to gain approval for departure records or engineering authorisations where a part might be slightly outside of repair limits, but still certifiable as safe for flight. An engineering review is required, where the company is licensed to work in concert with OEM partners to recover a part that would otherwise be deemed unrepairable, saving operators money.

For the GE90-94/-115B, the company provides hi-tech repairs for fan blade platforms, air oil seals, rotating seals, TCF adapters, half rings, sump covers, centre vent tubes, ducts, acoustic panels, diffusers and OGVs. For the CF6-80C2, repair solutions are offered for AFT outer liners, spanner nuts, unison rings, shroud assemblies, thermal shields, stationary seals, air oil seals, retainers, impingement manifolds & rings, gear shafts, fairings, disks, combustion liner assemblies, HPT shroud supports, spinner cones, cases & frames, TOBI ducts, HPT blade retaining plates, honeycomb seal segments and rings, and compressor vanes. Meanwhile, -E1 repairs are performed on mount link assemblies, shafts, unison rings, retainers, actuation levers, shroud supports, spanner nuts, impingement manifolds and rings.

In terms of part and material availability, ADs can significantly affect demand. "There is a (relatively) new AD on the CF6-80 fan mid-shaft that deems more than 95% of these LLPs unserviceable," explains Rice at AJW. "Demand for this particular unit in the used, serviceable market has therefore exponentially increased."

Pratt & Whitney

The PW4000 was first introduced in 1987. The engine family comprises the PW4000-94, the -110 and the -112 series. Each suffix relates to the diameter of the fan module; for example, the PW4000-94's fan diameter is 94 inches. The PW4000-94 family has an overall bypass ratio of 4.8-5.0 and a fan pressure ratio of 1.65-1.80. Its thrust rating ranges from 52,000lbs to 62,000lbs of thrust.

Since entering commercial service, P&W has delivered more than 3,500 PW4000 engines, and a small number are still in production. The -94 series powers the 747-400 and 767-300ER, alongside the MD-11, and A300-600R and A310-300. The PW4000-100 powers the A330-200 and -300 series. The PW4000- 112 powers the 777-200, the 777-200ER and 777-300.

In terms of OEM coverage, Pratt & Whitney Eagle Services Asia, located in Singapore, is P&W's global centre of excellence for PW4000 engine overhauls. It performs maintenance on all PW4000 models including the PW4000-94, -100 and -112. Eagle Services Asia is a JV between P&W and SIAEC. P&W explains that several independent shops also perform PW4000 maintenance globally.

P&W also provides PW4000 MRO services under its new EngineWise™ service portfolio. "EngineWise is about supporting customers' evolving needs throughout the entire engine life cycle, covering both mature and new engines," explains Sharon Maloney, associate director of marketing at Pratt & Whitney. "With EngineWise, P&W is helping customers optimise engine performance and keep their fleets running smoothly."

Part repairs are completed at 12 P&W repair facilities that provide global coverage. P&W explains that these locations specialise in the repair of particular part families across all three PW4000 engine models. Each facility provides hi-tech repairs such as: multi-layer abradable coating (blade outer airseals), drum rotor disk replacements (rotating parts), electron beam welding for flange replacements (cases) and Turbofix™ (turbine blades).

Maloney outlines the 12 PW4000 repair facilities, which are:

- Asian Compressor Technological services (Taiwan) provides repairs for compressors, stators, shrouds and HPC seals;
- Component Aerospace Singapore specialises in repair for combustion chambers, fuel nozzles, fuel nozzle guides, tubes and manifolds;
- Connecticut Rotating Parts performs repairs on major rotating parts, and Connecticut Stators and Connecticut Stators & Components specialises in repair for HPC stators and honeycomb seals;
- Dallas Airfoil Repair Operations specialises in HPT/LPT blade and vane repairs, plus airfoil coatings;
- North Berwick Part Repair Operations repairs airseals, shrouds, ducts, vane supports and bearing components;
- P&W Auto Air (Michigan, USA) performs thrust reverser, nacelle components and composite repairs;
- P&W Component Solutions (Singapore) repairs airseals, carbon seals, rotating seals, LPC stators, HPC shrouds and variable vane repair solutions;
- Pratt & Whitney PSD (Arkansas, USA) performs repairs for major cases;
- Repair Supplier Logistics (Connecticut, USA) specialises in parts repair logistics;
- Turbine Overhaul Services (Singapore) repairs HPC, HPT and LPT airfoils, and transition ducts;
- 1-Source Aero (Greece) repairs controls and accessories.

AFI KLM E&M's Amsterdam shop provides CF6-80C2 and –E1, and GEnx maintenance,. and its Paris facility located at Orly airport, has full GE90 capability.

Engines in operation

According to PW, more than 2,900 active PW4000 engines are installed on A300, A310, A330, 747, 767, 777 and MD11 fleets. According to ICF, six PW4000 engines were built in 2016, and 350 SVs occurred *(see table, page 58)*. ICF estimates another 400 engines will undergo SVs in 2017, and SV figures over the next nine years will reach about 2,800.

MRO shops & activity

GTES is a light maintenance service provider for the PW4000 engine family, performing about 15 end-of-lease checks annually for the series from its UK location. As for the Trent 700, GTES typically performs end-of-lease checks, QEC strips and builds in addition to borescope inspections.

MTU Maintenance also offers PW4000 on-site and on-wing services via its Hannover base.

Air India Engineering Services Ltd also carries out full overhaul services on the PW4000 series from its location in New Delhi. It holds DGCA and FAA licences for its maintenance work. It carries out an average of 10 PW4000 SVs a year, of which 20% are quick-turn/light workscopes, while 80% require major repair and overhaul.

Air India has in-house repair capabilities for PW4000 fan cases, minor repair solutions for LPC and HPC airfoils, HPC, (excluding outer air seals and high speed grinding of rotor), LPTs (excluding airfoils and duct segments, HPTs (excluding airfoils) and OAS segments, and minor repairs for seals and casings. Hi-tech repair methods include plasma spray repairs and electro-plating. Air India has to sub-contract elements to the OEM such as airfoil repairs, combustor repairs, high speed grinding, honeycomb repair for OAS, and KE seal repairs. In addition, it provides some DER repairs that are sub-contracted via third-party vendors.

Meanwhile, Delta TechOps offers full overhaul services on the PW4000-94. About 80 SVs are performed each year at its Atlanta shop, 10% of which are on behalf of PW. Again, Delta can provide a range of in-house repairs for all major engine parts. OEM repairs on blades and vanes are sent to PW, but Delta TechOps has developed its own approved repairs for these parts. According to a source, Delta TechOps can offer DER repairs on both types for most blades and vanes, in addition to 'airline repairs'. These are minor repairs (as defined by the FAA), but can save substantial amounts of money. These are developed by Delta, but are not DERs and do not involve parts manufacturer approved (PMA) parts. As explained by the source, an example might be to blend a scratch on a fan case which might otherwise be declared scrap.

FAR 1 defines a major repair in one of three different ways: if improperly done, it might appreciably affect weight, balance, structural strength, performance, powerplant operation, flight characteristics, or other qualities affecting airworthiness; if it is not done according to accepted practices; or it cannot be done by elementary operations. A minor repair covers everything else.

Israel Aerospace Industries (IAI), Bedek Aviation Engines Division, is headquartered at Ben Gurion Airport. It carries out about 14 SVs a year for the PW4000-94 family. IAI has been providing maintenance services for PW WB Engines for over 20 years, starting with the JT9D-7J engines. IAI was designated the DSP (Designated Service Provider) by PW for the JT9D series engines, which complemented its progression to the PW4000 engine family. IAI has a signed engine offload agreement with UTC PW for PW4000-94 engines, as well as technical support, engine documentation and materials support agreements. According to IAI, 70% of its PW4000-94 workload is major repair, while 30% is inspection level. About 25% of IAI's PW4000-94 SVs are allocated by the OEM. This allocated work is mainly from EL AL, which is a customer of the OEM and sends its engines to IAI via the offload agreement.

In addition, IAI provides in-house part repairs for 85% of the PW4000-94 engine family parts. IAI says that the main parts it cannot repair in-house are HPT/LPT airfoils. In terms of hi-tech repair, IAI performs shotpeening on fan disks, shotpeening and glass bead peening for fan blades, and high speed grinding for the HPC. DER repair is also available.

Last, PAS Technologies and Standard Aero provide PW4000 hi-tech repairs for rings and assemblies, seal and support assemblies, disks, hubs, HPT duct supports, heat shields, combustor chamber guide assemblies, LPC compressor blades, diffuser case assemblies, and blade assemblies.

Next-generation aircraft are due to emerge in the near future, while some of the legacy fleets such as the 767 will be phased out. It is clear, therefore, that there will be changes to the MRO market for widebody engine shops. "Independent shops need to evaluate whether the economics make sense," says Brown. "Extensive MTBRs for widebody engines mean that only a small number of engine shops is needed for SV activity. We may therefore see the market narrow or consolidate." AC