The 777 family and A380 dominate the long-haul market. The performance of engines powering these airframes is crucial to their overall performance, and will be determined by their reliability and maintenance costs. Several factors influence performance and shop visits, as explored.

GE90, GP7200, Trent 800 & Trent 900 performance & maintenance

The 777 has long been established in its market of medium- and long-haul routes, as the world's largest twin-engine commercial aircraft. The 777 entered service in 1995 via the 777-200, and now comprises five passenger series: the 777-200, -200ER, -200LR, -300, and -300ER. There is also a freighter version, the 777-200F. The 777 seats 310-390 passengers, depending on the series, and class configuration and layout of passenger accommodations (LOPA).

There are two main engine options available for the 777 variants: the General Electric (GE) GE90; and the Rolls-Royce (RR) Trent 800 engine families. The PW4000-112 can also equip both the -200 and -300. 473 passenger-configured 777-200 series aircraft remain in service, in addition to 747 passenger-configured 777-300 and -300ER aircraft.

The A380 now competes in some of the same markets as the 777, sharing many destinations on several operators' route networks. Emirates, for example, operates a fleet comprised solely of 777s and A380s. British Airways (BA) operates the -300ER and the A380 to Singapore and Hong Kong. The A380-800 is powered by the Engine Alliance GP7200 and RR Trent 900 series. To date, there are 125 passenger-configured A380s powered by the GP7200, and 83 equipped with the Trent 900. Although Airbus has suggested the A380-800 could carry up to 544 passengers in a three-class LOPA, operators typically have 490 seats on long-haul routes.

While the 777-200 and -300 legacy fleets are in decline, the A380 is growing. According to Flight Global FleetAnalyzer, 106 passenger-configured A380s are on order with Airbus, of which 70 are Trent 900-powered.

The GE90, GP7200, Trent 800 and Trent 900 families will therefore be examined. Each engine has previously been summarised by *Aircraft Commerce (See Big engine in-service performance & maintenance, August/September 2008, page 41, Operators and Owner's guide: GE90 Family, Issue 84 Oct/Nov 2012; Global engine shop activity, Issue 64 Jun/Jul 2009; Operators and Owner's guide: Rolls-Royce Trent family, August/September 2012, page 3).* This examination aims to show approximate removal intervals, shop visit (SV) costs and the performance capabilities of each engine. Where applicable there will be insight into key removal drivers, modification work, and service bulletins (SBs) or airworthiness directives (ADs) that might impact SV workscopes. Such factors may also force early removals and therefore affect removal intervals, or the overall mean time between removals (MTBR) if an issue is found to be fleet-wide. Life limited part (LLP) demands will also be provided.

Naturally, not all engine maintenance is routine. Newly certified engines may undergo hospital visits to inspect and restore core modules if performance loss is monitored or an irregularity observed. Unscheduled SVs can also occur.

These fall outside the scope and definition of a scheduled SV; the SV pattern typically alternating between a hot section or performance restoration, and engine overhaul. LLPs will usually be exchanged during an overhaul.

Hospital visits are usually quick-turn and require a limited workscope, with modular inspections and limited repair or component replacement, rather than full core disassembly. Fuel nozzles may have to be changed, for example, or blend repairs carried out due to borescope inspection. Overall, the workscope is light, although the hospital SV may affect and interrupt the subsequent removal to the next planned SV.

Engine performance for each engine is determined by the following parameters: specific fuel consumption, engine flat rating temperature; exhaust gas temperature margin (EGTm) or turbine gas temperature margin (TGTm); average engine flight hour (EFH) to engine flight cycle (EFC) ratio; take-off de-rate; and ambient operating temperature in addition to overall removal intervals. Engine performance allows operators to establish exactly how the engine is working for their fleet efficiency, in terms of how many EFH and EFC the engines are accumulating on-wing before they require removal and extensive maintenance in the form of a performance restoration or overhaul.

"EGTm loss is typically monitored against EFC, since it is a more accurate parameter than EFH," explains Graeme Crickett, senior vice president and head of technical at Sumisho Aero Engine Lease. Crickett explains that other factors, such as high pressure turbine (HPT) module performance, will influence EGTM, as is currently the case with the GE90-110/-115 series.

Performance monitoring

Engine health monitoring (EHM) has become increasingly sophisticated, with the emergence of Big Data Analytics and real-time data transfer. Engineering departments are becoming better at accurately pinpointing the optimum time to remove an engine for inspection and maintenance. Customers are relying more on the knowledge such data provides about the efficiency and performance of their engines.

Each engine's original equipment manufacturer (OEM) provides its own

For the GE90-110/-115 engines, MTU Maintenance indicates that the average engine performs 4,800-5,000EFH and 600-700EFC a year. The maintenance specialist conducts about 20 GE90 SVs a year from its Hannover base, and advises a MTBR of 3,000-4,000EFC.

performance monitoring services to customers, which in turn allows them to establish the performance of their fleets while in operation across their long-haul networks. There also remain independent solutions too, provided by maintenance, repair & overhaul (MRO) providers to their customers under contract.

MTU Maintenance is based in Hannover, Germany, and is responsible for the MRO of a variety of mid-size and large commercial engines. Its parent company, MTU Aero Engines, designs, develops and manufactures engines in partnership with OEMs such as GE and Pratt & Whitney. "We use our internally developed engine trend monitoring tool, called MTUPlus engine trend monitoring system, to monitor thrust, EGTm, vibration and fuel consumption as on-wing parameters," says Norbert Moeck, director engine programmes at MTU Maintenance. "In case of shifts within the values (either long-term trends or spikes), the system alerts the MTU engineers, who analyse these shifts and give our customers appropriate recommendations for corrective action."

The system identifies problems early so that action can be taken before small issues become larger and cause unwanted downtime or unplanned SVs, helping to avoid the high costs that this involves. "We use this data to forecast remaining on-wing time and optimal engine removal points, which helps overall with fleet management and SV scheduling," adds Moeck. "We also combine data from on-wing operations with actual findings during previous SVs to deduce scrap rate probabilities in relation to time on-wing. This can be particularly helpful to our purchasing and sourcing departments and has a positive effect on pricing."

Maintenance agreements

According to MTU Maintenance, 80% of new generation engines are sold with OEM contracts agreed. MTU Maintenance provides an extensive maintenance portfolio for GE90-110/-115B engines, and outlines its offerings to customers seeking MRO agreements.

There are contract variations to serve different customer needs, risk profiles and ownership horizons. Moeck explains that as an independent maintenance provider, MTU Maintenance has noticed a number of trends.

First, there is a distinct trend towards customised solutions for operators. "There is a huge range of options out there, so it is about the customer picking the option that suits them perfectly, or working with the provider to create it," says Moeck. "One solution is comprehensive support, in our case as part of our Total Engine Care (TEC) programme, that comes in the form of full-service 'one-stop' solutions that include engine maintenance, as well as a range of additional services that can be combined on a modular basis.

"These are typically deals based on a flat rate, paid based either on flown EFH or EFC," continues Moeck. "The agreed fees can be paid up-front on a monthly basis, or by a payment per event (PPE) scheme whereby a pre-agreed rate is due at the time of the engine SV. The main difference between the two variants is the mode of payment. Of course, operators can choose flat-rate contracts without additional services, but they usually include engine condition monitoring, and often spare engine support coverage."

As described by MTU Maintenance, full-service solutions are designed to transfer the risk and responsibility to the service provider and make everything worry-free for the operator. "They tend to be popular among start-ups and smaller operators, but also for first-tier operators that fly brand-new engine technology. We see this in particular on current and next generation engines," adds Moeck. "OEMs are increasingly selling the latter with this type of aftermarket contract, since customers want predictable costs and minimised operational risk."

Conversely, customers with large engineering departments often want to define workscopes themselves, so other contract agreements are needed to meet varying levels of requirement. MTU Maintenance explains this can go all the way down to single SVs on the basis of time and material (T&M), fixed-price or not-to-exceed (NTE) agreements. "We see greater interest in more flexible solutions for more mature engines, since cost-reduction becomes the biggest factor in maintenance decisions," says Moeck.

Engine and aircraft lessors require a different level of scope. "Among lessors, MTU Maintenance sees increased interest in solutions that combine MRO services with asset management understanding, which we offer through MTU Maintenance Lease Services B.V., our joint venture with Japanese Sumitomo Corporation," Moeck adds. "Engine ownership is increasingly moving from the operator to the investor community. We estimate that 40% of the global commercial fleet is now under operating lease, and expect this to rise to 50% over the next few years.

"This shift in ownership is important, because investors have different overall goals: ensuring asset retention and optimising their exit strategy. Therefore, we are seeing interest in services that mitigate owner and operator risk, such as solutions across the entire engine revenue service and beyond, from engine fleet phase-in asset management, to engine SVs and operator transitions, all the way to maximising value at the end of the engine's service life. This could be through a sale, extended lease-out or a teardown for serviceable material. The contract type is flexible here: EFH, PPE or fixed-pricing structures."

Fly-by-hour contracts last as long as the contract period. MTU Maintenance explains that if the engine undergoes lease

According to MTU Maintenance, the three main removal drivers for the -110 and -115 engines are: the HPT stage 1 nozzle; the HPT stage 2 nozzle; and the HPT stage 1 shrouds. These often trigger the first SV. The typical workscope for the first planned SV therefore focuses on repairing hot section distress, which generally results in an engine performance restoration.

transitions, the process of transferring a contract can be complicated. "The lessor or asset owner will agree maintenance terms with the lessee. These usually cover lease return conditions, such as LLP status, inclusion of SB or AD updates, and documentation requirements," says Moeck. "The lessee is responsible for performing agreed maintenance, otherwise they will be liable for penalties as defined in the contract. Lessees generally have contracts with their chosen MRO provider covering the engine while it is in their fleet."

That being said, MTU Maintenance offers a portable maintenance solution for lessors and lessees that can follow the engine across some or all phases of its service life, and focuses on mitigating risk for all parties in terms of maintenance and ensuring maximum asset value.

"MTU Maintenance can provide the lessee with direct engine operating costs (DOCs) and support while lease engines are being phased in and out of their fleets. Under such a programme, maintenance reserves for pre-consumed life are carried forward, giving the lessor and lessee the reassurance that they are covered when the next scheduled engine removal occurs and do not have to plan financially for it," explains Moeck. "This significantly reduces DOCs and mitigates operational risks. Furthermore, MTU Maintenance can determine the actual condition of the engine and take on the associated risks during the lease transition phase.

"The MTU Maintenance programme covers corrective action required by findings during an end-of-lease check, which is not always guaranteed in such agreements," says Moeck. This means that once an engine is covered by MTU Maintenance's programme, MRO is taken care of at all stages.

Engine maintenance programmes

There are several sources of documentation, and various considerations to be taken into account when establishing the most suitable maintenance framework for an operator. As established previously *(see Regional aircraft engine maintenance, Aircraft Commerce, October/November 2016, page 59)*, OEMs provide engine manuals, component maintenance manuals, powerplant manuals and maintenance planning guides for each engine type. The engine maintenance manuals (EMM) are used as a basis for work carried out, because the engine, modules and piece parts are all covered within. MROs such as MTU Maintenance may also provide a 'shop handling guide' that incorporates this literature from the OEM with its own technical knowledge from maintaining the engine type.

This, combined with customer requirements, finds its way into a customised maintenance specification guide that usually contains soft times for modules and accessories, build-life (for example, minimum remaining EFC for LLPs), SB requirements and further technical information. This becomes the basis for any work an MRO then carries out on the engine.

Considerations

The figures shown in this examination are guideline estimations only, and are therefore not to be treated as exact overhaul and performance costs, nor guaranteed removal intervals. As will be disclosed, European operators can have different MTBRs, for example, compared to those in the Middle East. Climates significantly affect MTBRs and may not necessarily align with OEM predictions. EFH:EFC ratios and average flight time also affect removal intervals. It should be noted that a large portion of the current A380 operators are Middle Eastern and Asian carriers, for which air pollution, hot and humid environments, and desert climates are all significant factors.

IBA is an independent aviation consultancy firm that specialises in asset management, advisory services and commercial market analysis for lessors, operators and financiers."Operators in harsh environments will also experience different EGTm behaviours, and outside operating air temperatures (OATs)," adds Kane Ray, head analyst of commercial engines at IBA. "These conditions also contribute to HPT nozzle damage and the erosion of protective coatings in the engine." Such influences can be managed through regular borescope inspections, and will usually drive the engine off wing, although IBA adds that proper management and regular compressor washing can usually help time the engine removal to coincide with A or C checks; therefore minimising downtime.

All costs are based on average data and industry estimations. Where possible, standard OEM data is also provided.

General Electric GE90

The main three GE90 variants explored in this feature, due to their respective market activities, are the GE90-94B, the GE90-110B and the GE90-115B.

The GE90-94B entered service in 1996, while the -110B and -115B entered service in 2004.

The -90B and -94B are variants with a 123-inch diameter fan, and power 127 777-200ER aircraft. The -110B and the -115B have a 128-inch diameter fan. The -110B equips 39 777-200LR (long-range) aircraft. The -115B is installed on 16 777-200LR and 709 777-300ERs as of April 2017.

The -94B has a flat rate temperature of 30deg; a pressure ratio at maximum climb of 40:1; a thrust-to-weight ratio of

5.6:1, and a bypass ratio of 8.7:1. In terms of engine architecture the type has three low pressure compressor (LPC) and 10 high pressure compressor (HPC) stages, in addition to six low pressure turbine (LPT), and two HPT stages.

It follows that the GE90-110B and -115B are rated at 110,000lbs and 115,000lbs. The 777-300ER, the latest 777 variant, is powered solely by the -115B, and the -200F solely by the -110B. Most 777-200LRs are powered by the -110B, although a small number of aircraft are powered by the -115B.

The -110B is flat rated at 33deg whereas the -115B is rated at 30deg. The difference to the -110B/-115B's core engine over the -94B's core is that it has an additional LPC stage to increase core flow, which is required to turn the larger fan at the optimum speeds required. It also has one fewer HPC stage. A result of the higher coreflow is that the GE90-110B/-115B have a bypass ratio of 7.2:1. The -110B/-115B's fan uses the same fan blade technology and same number of fan blades as the GE90-94B. The -110B/-115B's 5-inch larger fan diameter means it has a 12% higher airflow than the GE90-94B's fan. This contributes to the growth engine's higher thrust rating. The GE90-110B/-115B have an overall pressure ratio of 40-42. While the fan blade diameter on the -110/-115 series is larger than the -94B, the outside fan case size has only half an inch difference.

GE90-94B LLP SHIPSET

LLP item	Life Limit FC	2017 List Price $
Fan Blades (22)	30,000	2,868,800
Fan Disk	20,000	494,600
Booster Spool	20,000	544,300
Fan FWD Shaft	20,000	272,300
Fan Mid Shaft	20,000	446,000
Cone Shaft	20,000	261,600
HPC Stage 1 Disk	20,000	233,000
HPC Stage 2-6 Spool	15,000	1,072,700
HPC Stage 7 Disk	20,000	147,000
HPC Tube Supporter Ring (Impeller)	20,000	45,730
HPC Stage 8-10 Spool	16,700	829,200
HPC CDP Seal	20,000	184,600
HPT FWD Seal	15,000	423,300
HPT Stage 1 Disk	15,000	891,900
HPT Interstage Seal	15,000	453,200
HPT Stage 2 Disk	15,000	485,400
HPT AFT Seal	15,000	200,400
LPT Stage 1 Disk	19,800	225,100
LPT Stage 2 Disk	12,300	354,200
LPT Stage 3 Disk	14,900	402,500
LPT Stage 4 Disk	14,600	330,200
LPT Stage 5 Disk	13,400	244,600
LPT Stage 6 Disk	20,000	255,400
Static Parts		
HPT Turbine Case	14,700	408,100
LPT Case	17,900	990,300
Total		**$13,064,430**

Performance

According to Flight Global FleetsAnalyzer, 473 777-200 passenger-configured aircraft are in operation (April 2017), and 747 777-300 aircraft.

There are 34 777-200 operators, although not all use the GE90 family to power their fleets. Key carriers include: Air France, which operates 25 GE90-powered -200s with an average fleet age of 17 years; KLM, which operates 15 -94B-powered -200ERs with an average age of 12; and United Airlines, which has a fleet of 22 GE90-equipped -200s with an average age of 16. Air France Industries KLM Engineering and Maintenance (AFI KLM E&M) performs both in-house and third-party base maintenance services for the GE90-94 and -110/-115 engines, in addition to the GP7200. The MRO provider also uses Prognos, AFI KLM E&M's EHM solution, to monitor engine performance and parameters. AFI KLM E&M carries out more than 100 GE90 SVs a year, and estimates the average first removal for the -94 is 36,000EFH, while for European carriers of the -115 it is 32,000EFH.

Meanwhile, recent figures indicate there are 39 777-300 operators. Most aircraft are -300ERs. Airlines that have GE90-powered -300s include: Air Canada, with 19 -300ERs at an average age of seven years old; All Nippon Airways (ANA) with 22 -300ERs ranging from two to 10 years old; and Emirates Airlines, which has 138 -300ERs, most of which are equipped with GE90 engines.

IBA has provided key performance statistics across the GE90 engine family. With regard to the -94B, the aviation consultancy specialists advise an average annual utilisation for the type of 4,500EFH and 750EFC, with an anticipated EFH:EFC ratio of 6.1-6.5:1.

Regarding SV patterns for engines, the first SV is typically described as a performance restoration, which includes overhaul for the HPT and combustor modules. Other engine modules might receive repair and AD generated workscopes.

Given the maturity of the engine type, first removal intervals are no longer relevant. 10% of the fleet has exceeded 10,000EFC. IBA does advise, however, a typical mature removal interval of 21,000-26,000EFH, and an EGTm deterioration rate of 3.5deg per 1,000EFC performed. IBA also suggests that OEM overhaul figures indicate just below $9.0 million for the -94B.

SGI Aviation is based in the Netherlands, and provides technical consultancy to aircraft owners and operators worldwide. While it focuses mainly on smaller airframes and engines, it gains significant market intelligence via its asset management arm. "We see an average MTBR for the GE90-94B of 2,600EFC," adds Francesco Baccarani, engine department team leader at SGI Aviation.

Baccarani advises that, in reality, second SVs typically cost $9.5 million, excluding LLP exchange. "It is important to distinguish the differences in SV workscopes between large engines such as the GE90, and smaller CF6 or regional engine types," continues Baccarani. "For smaller engines a performance restoration usually comprises the first SV, followed by an overhaul forming the second SV.

"For larger engines, however, the first SV might only comprise a hot section inspection, rather than a full

GE90-115B LLP SHIPSET

LLP item	Life Limit FC	2017 List Price $
Fan Blades (22)	30,000	3,434,200
Fan Disk	15,000	589,600
Booster Spool	15,000	546,100
Fan FWD Shaft	15,000	265,200
Fan Mid Shaft	15,000	434,300
HPC Cone Shaft	15,000	184,700
HPC Stage 1 Blisk	15,000	520,500
HPC Stage 2-5 Spool	8,800	563,700
HPC Stage 6 Disk	11,500	145,400
HPC Impeller	15,000	44,570
HPC Stage 7-9 Spool	11,800	807,700
HPC CDP Seal	15,000	176,200
HPT FWD Seal	15,000	412,400
HPT Stage 1 Disk	14,300	879,800
HPT Interstage Seal	15,000	453,600
HPT Stage 2 Disk	13,500	474,900
HPT AFT Seal	15,000	194,900
LPT Stage 1 Disk	15,000	219,100
LPT Stage 2 Disk	13,800	344,900
LPT Stage 3 Disk	15,000	391,800
LPT Stage 4 Disk	15,000	321,500
LPT Stage 5 Disk	15,000	238,100
LPT Stage 6 Disk	13,000	232,400
LPT Cone Shaft	15,000	208,800
Static Parts		
HPC Stator FWD Case Assembly	25,380	729,800
HPC Stator Extension Case	7,430	584,800
Combustion Case	17,700	588,400
HPT Turbine Case	10,800	397,400
Turbine Centre Frame	14,300	3,394,400
Total		**$17,779,170**

refurbishment of the core that extends to the HPC. The HPC and core components such as the combustion chamber may not be touched, which is what drives up the cost in future SVs. While performance restorations do often occur, there can be variances in SV cost when discussing large engine maintenance inputs."

In relation to the -110/-115 GE90 engines, MTU Maintenance indicates that the average engine performs 4,800-5,000EFH and 600-700EFC; a EFH:EFC ratio of 7.1:1. The maintenance specialist also conducts about 20 GE90 SVs a year from its Hannover base. Meanwhile, MTU Maintenance's joint venture partner Sumisho sees -110 and -115 utilisations of 3,900-4,100EFH and 660-840EFC in its passenger-configured aircraft, while Flight Global FleetsAnalyzer suggests annual utilisations of 5,100EFH and 680EFC. Sumisho has a fleet of 40 GE90 engines, and performs its own asset management in house. "We have the ability to manage our engine fleets in-house," says Crickett, "Our GE90 fleet is split between MTU Maintenance and GE On Point for MRO contractual support."

"Naturally, the region of the operator also influences the GE90-115's rate of utilisation," adds Paul Brooker, chief technical manager at IBA. "For instance, we typically see Middle Eastern carriers achieving 4,500EFH and 550-600EFC per year, which may vary slightly to European or US operators. IBA also states that the typical EFH:EFC for Middle Eastern carriers is 7.5:1.

According to Crickett, the -115B has approximate EGTm figures of 33-35°C test cell EGTm and 44-47°C on-wing. Meanwhile, the -110B has 45-48°C test cell EGTm and 60°C on-wing in general. Crickett advises that the typical rate of deterioration for the -110 is about 10°C for the first 1,000EFC, and then 4-5°C per 1,000EFC thereafter. "We anticipate a similar degradation for the third SV interval, although most of the engines have yet to experience this," he adds.

"Some early serial number (S/N) engines will have had LLPs replaced due to the early termination of some LLP part numbers (P/Ns) and their inability to attain the 'Ultimate' life," says Crickett. "For most engines, the on-going issue is the LPT Stg 6 blade which is subject to AD 2009-25-14 and multiple SB inspections, improvements and blade replacement. These can be done in the field, as well as during the MRO SV.

"Later engines have benefited from GE's significant investment in development and earlier S/Ns have been upgraded over their initial SV events."

Regarding first removals for the -115, IBA advises that while GE suggests an anticipated first removal of 27,000-34,000EFH, because of the hot climates in which many of these engines are operating, real-world removals are more likely to be 20,000EFH and 2,700EFC. Meanwhile, SGI confirms that European carriers are experiencing MTBRs closer to 3,100EFC, equal to about 23,000EFH. Moreover, MTU Maintenance states that many of its customers manage 3,000-4,000EFC for the first -110/-115 removal, equal to 22,500-30,000EFH. "The second removal interval is usually slightly longer due to the HPT repair undergone in the first SV," adds Moeck.

"Some fleets are seeing down to 2,300EFC, while others in more benign climates can see 3,800EFC as a first removal interval," adds Crickett. "Typically 2,800-3,200EFC would be normal, although there are -115B engines coming off at about 2,600EFC. Generally speaking, flight length and environmental factors are the main drivers influencing these intervals."

According to MTU Maintenance, the three main removal drivers for the -110 and -115 engines are: the HPT stage 1 nozzle; the HPT stage 2 nozzle; and the HPT stage 1 shrouds. These often trigger the first SV.

"Most engines suffer from hot end distress, especially the earlier serial numbers, while the LPT stage 6 blade still seems to be a significant trigger," adds Crickett. He explains that not all removals result in an SV event, however, since the LPT stage 6 blade can be addressed on site. "There was a raft of removals for a transfer gearbox shaft issue, but this has largely been addressed," continues Crickett. "By the end of 2008, there were only 425 GE90-100 engines and now there are more than 2,000 in the global fleet, which means a larger cross-section of operational issues." Meanwhile, engines with a long time on wing can bump into LLP expiry issues such as the HPC stage 2-5 spool,

GP7200 LLP SHIPSET

LLP item	Life Limit FC	2017 List Price $
Hub Assy	15,000	702,903
Coupling Assy	15,000	338,409
Drum Assy	15,000	568,457
Stubshaft, HPC Forward	15,000	170,100
Blisk HPC Stage 1	15,000	452,900
Spool HPC Stage 2-5	8,600	539,800
Ring, Tube Support	15,000	35,600
Disk HPC Stage 6	8,600	126,400
Stage 7-9	15,000	701,800
CDP Seal	15,000	145,300
Seal, Forward	8,200	342,300
Stage 1 Disk	8,200	758,600
Seal Mid	10,400	370,100
Stage 2 Disk	15,000	397,800
Seal Aft	15,000	157,300
Fan Mid Shaft	15,000	356,200
LPT Disk Stage 1	15,000	293,416
LPT Disk Stage 2	15,000	271,989
LPT Disk Stage 3	15,000	277,540
Disk Low Pressure Turbine Rotor, Stage 4	15,000	236,834
Disk Assy LPT Stage 5 & Shaft	15,000	491,246
Disk Low Pressure Turbine Rotor, Stage 6	15,000	273,841
Seal-Air, Rotor, LP Stage 2	15,000	92,513
Seal-Air, Rotor, LP Stage 3	15,000	92,513
Seal-Air, Turbine Rotor, Stage 4	15,000	83,263
Static Parts		
HPT Case	22,000	319,900
Combustor Case	23,500	463,300
HPC Forward Case	26,700	636,900
HPC Stator Extension Case	4,900	522,200
Total		**$10,219,425**

which is still limited at 8,800EFC.

The typical workscope for the first planned SV therefore focuses on repairing hot section distress, which generally leads to engine performance restoration. "First run engines are not limited to LLP expiry, and the hot sections get a complete disassembly and restoration," explains Crickett. "While there are soft time thresholds as guidelines, as always with workscope planning guides (WSPGs), there are exceptions and allowances. The expectation is a full overhaul (known as a Level IV SV) for the combustion module and the HPT modules."

Crickett also describes SB72-0588, which emerged in late 2015 and required operators to incorporate an on-wing BSI programme for the HPT stage 1 shroud (P15 & P16) at 2,500EFC since new or installation. "The distress found has been a removal driver for some of the engines since then, and the replacement programme is to install P17/P18 shrouds," he adds, "while some engine SVs will also require the transfer gearbox radial driveshaft to be inspected and repaired if not previously completed."

Other work that comprises the typical -110 and -115 first removal includes the inspection and/or replacement of several domes, nozzles, shrouds and seals present in the combustor, HPT stage 1 & 2 nozzle guide vanes (NGV), and HPT rotor. These are subject to various SBs relating to the parts.

To counteract excessive HPT blade damage, HPT blade upgrades were also issued via SB in 2014. According to Crickett, the new blade (P09) appears more reliable and is presenting less thermal barrier coating (TBC) loss than earlier configurations, which has been a significant development for the -110 and -115 fleet.

Crickett estimates costs for first removal SVs at $6.0 million, depending heavily on the serial number date of manufacture. SGI corroborates this, although Baccarani states that the total cost in real terms is closer to $6.5 million.

Regarding second removals, IBA explains that while GE suggests 25-31,000EFH, a reduction for Middle Eastern operators is again expected. Crickett expects 2,600-3,000EFC to be undertaken before the second SV occurs, subject to flight ratios and environment. "The second SV is normally down to the same drivers as the first engine removal, although some higher priority SBs will be required for earlier serial number engines."

"According to the current WSPG, the prime modules would be beyond their recommended soft lives and be subject to the OEM guidelines," Crickett continues. "Expectations would be for most core modules to be looked at, and a minimum of Level III, performance restoration or preventative workscope, SV to be carried out," says Crickett. "MTU Maintenance generally sees the main drivers for the second SV including certain hardware deteriorations within the hot section, and removal intervals that are similar to the first removal, although it is often slightly longer due to the installation of improved designs on key hardware (for instance in the HPT) during the first SV," adds Moeck. "The second SV for the GE90-110/-115 does not usually include LLP replacement, but will be a full overhaul." This is unless the engines have not had upgraded LLP P/Ns installed, in which case some may be susceptible to LLP replacement.

The second SV is likely to be substantially more expensive than the first, even if the workscopes are similar. Hough estimates that second SVs can cost $9.0-11.0 million. Crickett at Sumisho explains that as hardware may not be repairable at this stage, and acquiring replacement parts is not cheap, which drives up the cost of the second SV.

Crickett says that rotating and static LLP expiry commonly begins to occur at around the third SV, but up to the fifth SV. "The 'Ultimate' life target for GE in the GE90-110 in rotating LLPs is 15,000EFC, and most LLPs installed today have this threshold with only a few left for final revision. At current utilisation ratios of 6:1 and 10:1 respectively, SV events for the full LLP life of 15,000EFC removals will be to a total accumulated utilisation of 90,000EFH and 150,000EFH.

"Sumisho sees that there may be an opportunity for GE to assist the operators with special minimum work SVs like the CFM56 Special Procedure 10 (SP10) programmes, whereby the SV is designed around AMM limits," continues Crickett. "This would require smaller hospital SVs to rectify just a particular mechanical issue. This would minimise the potential costs and reinstall the GE90 with the original build target achievable.

"With more digital and ECM monitoring, GE would have more sophisticated data to assess reliability on a piece part operation," concludes Crickett.

Life Limited Parts

The listed LLP stack current list price (CLP) for the GE90-94B is $13.0 million. The full shipset comprises static and rotating parts *(see table, page 87)*. The static parts consist of the HPT case and the LPT case, which have life limits of 14,700EFC and 17,900EFC. These are unlikely to be replaced in an aircraft's operational life.

There are 22 additional rotating LLPs for the -94B, in addition to a set of 22 fan blades that cost about $2.87 million. The life limits across these rotating LLPs are 12,300-20,000EFC.

The LLP stack CLP for the GE90-115B, as of 2017, is $17.8 million *(see table, page 88)*. The life limits of these LLPs vary from 8,800EFC (HPC stage 2-5 spool) to 30,000FC (fan blades), which is the expected life of an engine. A new set of 22 fan blades costs $3.43 million for the GE90-115.

The GE90-115 shipset includes five static LLPs, with a list price of $5.7 million. According to Richard Hough, executive vice president of technical at Engine Lease Finance Corporation (ELFC), GE has given all these static parts an ultimate life target of 40,000EFC. "To date, however, they have not achieved anywhere near those limits yet," explains Hough. "Current limits range from 13,000EFC to 25,280EFC for different parts in the static set, so they are effectively treated as LLPs."

Recent ADs

In September 2016, an AD was released for the -94B (AD 2016-19-09). According to the Federal Aviation Administration (FAA), this AD relates to -94Bs with HPC stage 8-10 spools of a certain P/N. The AD was raised due to cracks found on the seal teeth of this spool, and requires operators to perform eddy current inspections (ECIs) to determine whether this part must be removed and replaced. If the -94B accumulates fewer than 11,000EFC, the inspection is required before the engine reaches 12,500EFC. If the engine accumulates more than 11,000EFC, inspection is required within another 1,500EFC on-wing. Once performed, this inspection is required every SV for the affected engines.

There are two ADs for the GE90-100 series, released in 2017. As stated by the FAA website, AD 2017-07-04 supersedes AD 2013-24-17 for GE90-110B1 and GE90-115B turbofan engines with certain HPC rotor stage 2-5 spools installed. AD 2013-24-17 required removing these spools from service at times determined by a drawdown plan. This AD retains the same requirements as AD 2013-24-17. AD 2017-07-04 also applies to additional P/N HPC spools, and was prompted by reports of cracking on these spools.

AD 2017-08-06 is effective from May 2017, and applies to the engine oil cooler fuel/oil lube/servo coolers ('main fuel oil heat exchangers'), which require replacement. This AD was prompted by a report of an engine and aircraft fire. It applies to certain S/Ns that are fitted with particular P/Ns as outlined in the AD. This must be carried out within 12 months of the effective date of the AD.

ICF specialises in OEM and MRO strategy, market research and analysis. The ICF team forecasted demand for about 40 GE90-94B and just over 300 -115B SVs in 2016, at approximate global MRO spends of $275M and $2.5B respectively. These costs are in accordance with 2016 constant dollar values and therefore do not account for inflation.

TRENT 800 LLP SHIPSET

LLP item	Life Limit FC	2017 List Price $
Fan Disk	13,650	683,361
Fan Shaft	15,000	141,114
LPT Shaft	15,000	243,237
LPT1 Disk	15,000	196,003
LPT2 Disk	15,000	196,003
LPT3 Disk	15,000	236,560
LPT4 Disk	15,000	244,638
LPT5 Disc	15,000	141,962
IPC Drum	12,500	1,390,363
IPC Rear Stub Shaft	15,000	88,752
IPT Shaft	15,000	106,281
IPT Disc	11,610	594,846
HPC1-4 Shaft	5,580	633,804
HPC5-6 Shaft	5,000	998,635
HPT Disc	7,000	660,755
Fan Bade (26)	15,000	3,134,504
Anullus Filler (26)	6,700	348,712
Total		$10,039,534

GP7200

The GP7200 engine family consists of two main variants: the GP7270 and GP7270E, which both have certified thrust ratings of 72,000lbs. The 'E' suffix denotes an extended corner point temperature. The family is designed and marketed by the Engine Alliance (EA); a joint venture between GE and PW of United Technologies Corp. As such, the GP7200's core design is developed from two legacy heavyweights: the PW4000 and GE90 engine families. The engine has a flat rated temperature of 30deg, a bypass ratio of 8.8:1, and an overall pressure ratio at take-off of 36:1.

The GP7200 entered service on the A380 with Emirates in 2008. Its core architecture consists of a fan module with a fan tip diameter of 116 inches and 24 swept fan blades. Its five-stage LPC is based on PW4000 design, while the nine-stage HPC takes after the GE90's design. The GP7200's single annular combustor (SAC) was built by GE, while the six-stage LPT was manufactured by MTU Aero Engines. Last, the engine's main modules consist of a two-stage HPT.

Performance

The GP7200 powers 125 A380s in operation today, meaning there are about 500 engines in active service. There are five global carriers that operate GP7200-equipped A380s: Emirates, Air France, Korean Air, Qatar Airways and Etihad Airways.

Sources have previously indicated that the initial perception is that the GP7200 has lower costs per SV than its competitor, the Trent 900 series. IBA, however, believes that this needs further consideration. "When comparing specific SV costs it is easy to assume that one engine is cheaper than another for an

TRENT 900 LLP SHIPSET

LLP item	Life Limit FC	2017 List Price $
Fan Disk	11,600	589,058
Fan Shaft	12,500	144,602
IP Compressor Drum	4,357	1,343,661
IP Compressor Rear Stub Shaft	12,500	101,612
HP Compressor Stage 1-4 Drum	4,000	461,408
HP Compressor Stage 5 Disc	4,000	216,247
HP Compressor Stage 5 Disc & Cone	4,000	816,119
HP Turbine Disc	3,800	808,816
HP Turbine Cover Plate	3,800	206,320
IP Turbine Disc	4,000	595,268
IP Turbine Shaft	12,500	114,033
IPT Rear Air Seal	12,500	48,159
LP Turbine Stage 1 Disc	12,255	144,254
LP Turbine Stage 2 Disc	12,377	144,254
LP Turbine Stage 3 Disc	12,377	175,444
LP Turbine Stage 4 Disc	12,136	197,638
LP Turbine Stage 5 Disc	12,136	105,021
LP Turbine Shaft	4,200	219,051
Fan Blades (24)	15,000	2,284,704
Annulus Fillers (24)	16,200	347,256
Total		**$9,062,925**

aircraft," says Ray. "However, one needs to look at how long the engines stay on-wing before the SV occurs too. In addition, more time is needed for an overview of the long-term cost of each engine before making realistic economic comparisons of engine families."

According to IBA, GP7200-equipped A380s are operating at about 4,550EFH and 500EFC a year, an average EFH:EFC ratio of 9.1:1. Brooker provides EGTm information of test cell, 60-76 deg and a deterioration rate of 12-15 deg loss in the first 250EFC/2,500EFH on-wing, with 5.0 deg per 1,000EFC thereafter.

In terms of removal intervals, IBA suggests that operators in harsh environments are carrying out first SVs at 15,000EFH, rather than the 20,000EFH proposed by the OEM.

Depending on the extent of the performance restoration and its repair and refurbishment requirements, SGI Aviation and IBA advise SV costs of $5.7-6.5 million. Furthermore, SGI advises that the average MTBR for GP7200 first SVs is 2,500FC, equal to 22,750EFH.

The second SV is anticipated to occur about 17,000EFH after the first removal, although it is unlikely that any second scheduled SVs have occurred yet. According to Flight Global FleetAnalyzer, the highest recorded accumulated FC of a GP7200 powered A380 is 5,000FC, so the oldest A380s are likely to only just be commencing second engine removal for scheduled work.

An expected workscope for the second SV comprises a typical performance restoration, in addition to a number of module soft time limits. For example, the LPT and Turbine Centre Frame as well as the LLP limit on the HPT stator case (*see table, page 90*).

Given that second SVs have not yet begun to take place, IBA advises a 15-20% increase on the cost of the first SV. This would take the estimated guideline cost of a second SV to $6.8-$8.0 million.

The GP7200 has been in service for almost nine years, so some of the life limits attributed to the LLPs are still relatively low. Assuming SGI's MTBR of 2,500EFC, for example, it is likely that the HPC stator extension case will have to be replaced by the second SV, since the static LLP currently has a limit of 4,900EFC. This LLP costs $522,000 *(see table, this page)*. In addition, the forward seal and stage 1 disk could end up being replaced by the third SV. These parts are both limited at 8,200EFC, and cost a total of $1.1 million according to 2017 CLP.

LLPs

The table on page 90 shows that the full shipset of LLPs has a 2017 list price of $10.2 million. The 25 LLPs are rotating parts with life limits of 8,200-15,000EFC. The set of rotating parts has a list price of $8.28 million. The static shipset of LLPs comprises the HPT case, combustor case, HPC forward case, and HPC stator extension case. Life limits for these items are 22,000EFC, 23,500EFC, 26,700EFC and 4,900EFC.

Recent ADs

Two main ADs were issued in 2016. According to the FAA website, the AD applies to GP7270 turbofan engines and requires replacement of non-conforming honeycomb cartridges in the HPC adjacent to the HPC rotor stage 2-5 spool and stage 7-9 spool. This AD requires removal and replacement of the affected HPC rotor stage 2-5 and stage 7-9 spools and adjacent honeycomb cartridges.

The second AD supersedes AD 2013-02-06 for all GP7270 and GP7277 engines with certain P/N HPT stage 2 nozzle segments installed, per the FAA website. AD 2013-02-06 required initial and repetitive borescope inspections (BSI) and the removal from service of these nozzles before further flight if one or more burn holes were detected in any HPT stage 2 nozzle segment. AD 2013-02-06 also required removal from service of these HPT stage 2 nozzle segments at the next engine SV.

The AD released in 2016 requires the same inspections as AD-2013-02-06, requiring removal of affected HPT stage 2 nozzles at the next piece part exposure, and adds certain P/Ns to the applicability. This AD was prompted by another report of inadequate cooling of the HPT stage 1 shroud and stage 2 nozzle, leading to damage to the HPT stage 2 nozzle, burn-through of the turbine case, and in-flight shutdown.

For the GP7200, ICF estimates demand for approximately 47 engine SVs in 2016. This is expected to climb to the region of 111 SVs by 2026 as more enter service. MRO spend for 2016 was approximately $220M according to the firm.

Rolls-Royce Trent 800

The RR Trent 800 is the other powerplant option for the 777 family. The series that form the 800 family consist of the Trent 875, 877, 884, 892 and 895. 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 800 entered service in 1996. According to the RR website, the engine is 8,000lb lighter than the GE90-

The GP7200 powers 125 A380s in operation, meaning there are about 500 engines in active service. There are five global carriers that operate GP7200- equipped A380s today. According to IBA, GP7200-equipped A380s are operating at about 4,550EFH and 500EFC a year, an average EFH:EFC ratio of 9.1:1.

94 option for the 777. To date, the Trent 800 family is installed on 174 777-200s/-200ERs and -300s aircraft. The Trent 892 powers about 110 of these aircraft, while the Trent 895 powers another 41 -200ERs.

In 2014, RR introduced an upgrade option to customers called the Trent 800EP. This involved upgrading the intermediate pressure compressor (IPC) and HPC blades to increase fuel efficiency.

The core architecture of the Trent 800 family comprises a fan of 110 inches diameter and 26 fan blades. Rather than an LPC, the Trent 800 has an eight-stage IPC, followed by a six-stage HPC. A single stage HPT and single stage intermediate pressure turbine (IPT) follows the combustor, in addition to a five-stage LPT. The Trent 800 family has a bypass ratio of 6:2, and an overall pressure ratio of 40:7. Each variant has a flat rating of 30deg.

Performance

14 operators use Trent 800 engines to power their 777 fleet: Cathay Pacific, Thai Airways, VIM Airlines, Rossiya Airlines, NokScoot, Singapore Airlines, Emirates, Air New Zealand, American Airlines, Delta Airlines, BA, El Al and Omni Air International.

American Airlines is the largest 777 operator, with Trent 800 engines installed on a fleet of 47 777-200ERs. The average age of its fleet is 16 years old, and is equipped with the Trent 892 variant. Annual utilisation for American Airlines is about 4,450FH and 502FC.

In general, IBA has observed a change in usage for the 777-200 and -300, due to its ageing fleet, which is gradually becoming superseded by new generation aircraft. According to Ray, global utilisation averages are closer to 3,700EFH and 700EFC across the Trent 800 family of engines. "Ageing usage has shifted more towards charter work for some operators, in addition to shorter routes, all of which reduces annual FH and increases accumulation of FC," he explains. This leads to an average EFH:EFC of 5.2:1 across the Trent 800 engine fleet.

Again, the declining -200/-200ER and -300 fleet, in addition to global accumulated EFH means that first removal MTBRs are no longer relevant for the Trent 800 engine family. IBA suggests that global mature removal intervals for core refurbishments and overhauls is 17,000-22,500EFH and 3,300-4,300EFC, depending on the operator. SGI Aviation's SV analysis shows its clients perform first run engine removals every 3,400EFC on average, suggesting that first SV events occur about every five years. Subsequent runs have an MTBR of about 2,300EFC.

According to SGI, a performance restoration costs $6.5 million per Trent 800 for the first SV. IBA also advises that subsequent overhaul workscopes are likely to cost $8.0-$9.0 million by the OEM. All figures exclude any LLP exchange.

LLP information for the Trent 800 is listed *(see table, page 91)*. While many static and rotating parts have a fixed life limit of 15,000EFC, some are as short as 5,000-7,000EFC. This suggests that LLP exchange began to occur from the first and second SVs in accordance with the suggested MTBRs.

"Later SVs, such as the third and fourth removals, are usually down to LLP drivers," adds Ray. "Commercially speaking, the engine is Phase 2 or 3 by this stage, with a host airframe that is ageing in a declining fleet. Costs will therefore be managed carefully if LLP exchange is needed, for instance sourcing used serviceable material (USM) or low-life LLPs to manage a cheaper SV."

LLPs

The Trent 800's LLP shipset comprises 17 LLPs. The 2017 CLP of these LLPs is $10.0 million *(see table, page 91)*. 26 fan blades form half the static parts, at a price of $3.1 million and with lives of 15,000EFC, while 26 annulus fillers at a cost of $349 form the second half of the static LLPs. These have lives of 6,700EFC.

With regard to the main stack of rotating LLPs, their lives vary from 5,000EFC (the HPC 5-6 shaft) to 15,000EFC (LPT discs, LPT, fan and IPC shafts).

Recent ADs

AD 2016-25-10 was issued in late 2016 and became effective in January 2017. It concerns the 875-17, 877-17, 884-17, 884B-17, 892-17, 892B-17, and the 895-17 Trent engines. According to the FAA website, the AD requires the machining and inspection of the HPC via ECI, and replacing any HPC parts found defective. Machining of the HPC stage 3 inner shroud is required. Operators have to ensure that this inspection is carried out before the HPC stage 1-4 disk shaft cycle exceeds 5,000EFC since the previous inspection.

AD 2017-08-11, on the other hand, applies to all Trent 800 engines. It supersedes the previous AD 2012-04-01, which required the removal from service of certain rotating LLPs due to a reduction in life limits, as explained on the FAA website. AD 2017-08-11 has further revised the life limits of several LLPs.

In 2016, ICF has calculated a global MRO demand of $631M for the Trent 800 family. This spend accounts for about 70 SVs. By 2026, ICF anticipates that under 10 SVs for the Trent 800 will take place, although it forecasts that 83

Engine SV removals are subject to a wide range of factors. IBA states that initial removals for the Trent 900 are taking place at 27,000-32,000EFH and 2,900-3,400EFC. It could therefore be assumed that scheduled removals are occurring every six to seven years for the average operator.

Trent-powered 777s will still be in operation. The estimation of fewer than 10 SVs is driven by fleet demographics, and as such ICF estimates SV activity will fluctuate in the intermediary years.

Rolls-Royce Trent 900

The Trent 900 forms the second engine option for the A380 aircraft family. Its main two series, the Trent 970 and 972, are installed on the A380-800. Today, more than 330 Trent 900s are powering the A390. According to the RR website, the Trent 900 boasts the lowest lifetime fuel burn on an A380, and remains the only A380 engine that can be transported by a 747 freighter without requiring module disassembly. The use of titanium to build the fan containment system also avoids the need to apply Kevlar coatings, which helps to reduce engine fan section size and increase the engine's efficiency.

As is characteristic of the Trent range, the 900 is a three-shaft turbofan engine. Its thrust variants range from 70,000 to 77,000lbs, with bypass ratios varying from 7.7:1 to 8.5:1. The Trent 900's overall pressure ratio is 39:1. Its fan diameter is 116 inches, and the fan has 24 blades. The Trent 900 core architecture comprises an eight-stage IPC, six-stage HPC, and single-stage HPT and single-stage IPT. Last, there is a five-stage LPT.

Performance

As of April 2017, there are nine operators with installed Trent 900s in their A380 fleets, which total 83 aircraft. These operators are: Singapore Airlines, Qantas, China Southern Airlines, Lufthansa, Malaysia Airlines, Thai Airways, BA, Asiana Airlines and Emirates. Singapore is the largest Trent 900 operator, with the engine installed on 19 A380-800s in its fleet. The average Trent 900 is just over five years old, while the oldest have been in service for about 10 years. Just under half the total fleet has had enhanced performance {EP) upgrades that use Trent XWB technologies to offer continuing efficiency improvements in service.

Information provided by IBA suggests global utilisation figures for the Trent 900 equipped A380s of 4,550EFH and 490EFC per year. The EFH:EFC of the engine is therefore about 9.3:1.

For the first SV, IBA illustrates initial removals are taking place at 27,000-32,000EFH and 2,900-3,400EFC. It could therefore be assumed that scheduled removals are occurring every six to seven years for the average operator. Once again, it is important to note that these removals are subject to a wide range of factors, not least utilisation and climate. In addition, engines that have newly entered into service often experience initial issues that force modular inspection and 'hospital visits'.

The structure and extent of the first schedule SV depends on whether the Trent 900 is undergoing the EP upgrades that are available from RR. While the first SV would often comprise a refurbishment, performance enhancement modifications will increase cost and downtime for the SV. SGI suggests the refurbishment costs for the first SV is an average of $6.5 million, while if the additional EP tasks are applied the price will rise to $7.5-8.0 million. For 'N run' engines, the average SV costs is about $9.5 million. RR initially introduced the first 'EP' standard in 2012 and the second phase, EP2, in 2014. EP3, which emerged in 2016, includes upgrades such as elliptical leading edges on the engine's compressor blades. While the EP3 package will form the build standard going forward, many earlier S/Ns have also undergone the performance modifications during SVs.

Much like the GP7200, second refurbishments or overhauls have yet to be reported and are unlikely to have taken place. MTBRs provided by SGI and IBA suggest 2,800-3,000EFC will occur between the first and second SVs and thereafter. Other sources suggest a key removal driver for the second SV will be HPT blade damage.

LLPs

20 LLPs comprise the full Trent 900 shipset. The total list price as of 2017 is $9.1 million *(see table, page 92)* for the static and rotating parts. Much like the Trent 800, the static parts comprise fan blades and annulus fillers. There are 24 fan blades and 24 fillers in a set at a cost of $2.28 million (15,000EFC) and $347,256 (16,200EFC). Regarding the rotating LLP shipset, the EFC limits are relatively low to date, ranging from 3,800EFC (the HP turbine disc and cover plate) to 12,500EFC. It is expected that these life limits will be extended as the engine accumulates EFC in service.

Recent ADs

AD 2017-08-10 is effective from May 2017. It supersedes AD 2017-01-01, and is specific to the 970-84, 970B-84, 972-84, 972B-84, 977-84, 977B-84 and the 980-84. The AD requires inspections of the LPT exhaust case and support assembly or tail bearing housing for cracks and damage. Engine removal is prompted in the AD if cracks are found in these areas. Removal is immediate if cracks are greater than 2mm, and if less than 2mm must be carried out within 10EFCs.

Last, ICF says that just under 50 SVs took place for the Trent 900 according to its research. This equates to an MRO constant $ spend in 2016 of about $245M. - *CLD* AC