Fleets of 1980s generation narrowbody & widebody engines have been declining and imploding for the past 10-12 years. The remaining MRO market for each engine type, and some of the remaining engine shops for each type are examined.

MRO options older & mature engine types

The fleets of older aircraft and engine types are inevitably in constant decline. The fleet of older engine types therefore implodes, and so reduces the market for maintaining and repairing them. As a result, many of the major maintenance providers for these engine types leave the market in favour of pursuing the maintenance market for younger engines. This raises the question of which engine shops are available to airlines to maintain older engine types.

The main fleets of older narrowbody aircraft are the MD-80, 737 Classic and 757. These are powered by the Pratt & Whitney (PW) JT8D-200; the CFM56-3 series; the Rolls-Royce (RR) RB211-535; and the PW2000. The main fleets of older widebodies are the 747 Classics and 747-400, the MD-11 and the A300-600/A310-300. These are mainly powered by the PW4000-94 and CF6-80C2, but also the PW JT9D and the CF6-50 series. A small number of A340-300s are still in operation, powered by the CFM56-5C, and some A300B2/B4 and DC-10 freighters, powered by the CF6-50 series.

Fleet profiles

The active fleets of these main narrowbody and widebody types are about 38% of the number built. About 36% of the active aircraft of these types are operated as freighters, and more will be converted to freighters over the next few years. This includes the 737 Classic and 757, 747s, MD-11s, A300-600s and A310s, and some DC-10s. Many of these freighters operate at relatively low rates of utilisation, and so accumulate small numbers of flight cycles (FCs) per year.

The number of each aircraft type built, and the active number of aircraft in passenger and freighter configuration with each engine type, and the corresponding number of active engines, and the age range of each type in service are summarised *(see table, page 52)*.

The significance of the number in active service compared to the number built is that the retirement of a large number of aircraft results in a correspondingly large number of used and time-continued or 'green time' engines available on the market. This supply of used engines, engine modules and serviceable or unserviceable material, and engine casings alters the economics of owning or leasing and maintaining engines. Moreover, the supply of engines and associated modules or components constantly changes as aircraft are retired, engines and modules are acquired or put through varying scopes of shop visit (SV) and maintenance. The supply of engines and modules at times can be so high as to make any form of maintenance SV uneconomic. The eventual result of this is that the supply of time-continued modules and engines declines and so increases their value, with the eventual result that SV maintenance becomes economic again.

Maintenance management

Maintenance management for engines in their early and mature phases of life will be based on maintaining all major elements of the engine to achieve the longest possible intervals between maintenance removals. It will also keep the engine in a high maintenance and serviceable status.

The first element of maintenance management to consider is the engine's airfoils and its operating performance, in particular its exhaust gas temperature (EGT) margin. EGT margin will be at its maximum at delivery, and will steadily decline with continued use and operation. This is mainly due to airfoil deterioration. Performance will, therefore, decline with EGT margin, and SV maintenance will be required to restore airfoil status and EGT margin to a level that achieves a long subsequent removal interval.

Engine management may aim to have an engine removal and SV for EGT margin restoration, and airfoil maintenance status restoration in a module or several modules to coincide with the need to replace life limited parts (LLPs) of disks and shafts in the module. If achieved, all elements of the module's maintenance status is restored to its highest level at the same time. Managing engines in this way achieves the lowest maintenance costs per engine flight hour (EFH) or per engine flight cycle (EFC).

The issue is complicated by the differing rates of performance deterioration in engine modules, and also the different life limits of LLPs in EFCs in different modules. The high pressure turbine (HPT) and combustion chamber have the shortest removal intervals due to deterioration, and are often followed by the high pressure compressor (HPC). The LLPs in these two modules often have equal or similar lives.

The low pressure turbine (LPT), low pressure compressor (LPC) and fan modules will have longer maintenance intervals. They usually require disassembly for maintenance at every second SV, and in some cases every third SV. Their LLPs also have longer lives than parts in the high pressure (HP) and high temperature modules.

Maintenance and replacement of all airfoils and accessory components, and the maximum utilisation of all LLPs, as well as engine cases, is necessary to keep an engine operational and to maintain the highest market value.

These priorities change, however, when large numbers of used engines come available on the market. Management of engines in the older phases of operational life can take advantage of several issues that help operators minimise maintenance activity and costs. The first of these is that many engines will no longer be

FLEETS OF OLDER AIRCRAFT TYPES

Aircraft type	Engine type	In service passenger	In service freighter	In service other	Aircraft in service	Active engines	Age range
NARROWBODIES							
MD-80	JT8D-200	289	10	13	312	624	19-37
737-500	CFM56-3B	134	73	19	226	452	19-33
737-500	CFM56-3C	331	200	21	552	1,104	19-32
757-200/-300	PW2000	161	102	3	266	532	14-34
	RB211-535	203	205	11	419	838	14-35
WIDEBODIES							
A300-600/A310	PW4000-94	6	111		117	234	12-32
MD-11	PW4000-94		43		43	129	19-28
747-400	PW4000-94	30	58	5	93	372	9-29
A300-600/A310	CF6-80C2 - PMC	36	20	17	73	146	22-32
A300-600/A310	CF6-80C2 - FADEC	1	50	0	51	102	11-25
MD-11	CF6-8-C2 - FADEC		78		78	234	17-28
747-400	CF6-80C2 - FADEC	66	126	4	196	784	9-29
767-300/-400	CF6-80C2 - FADEC	247	194	8	449	898	0-30
A340-200/-300	CFM56-5C	98		6	104		10-25
A300B2/B4	CF6-50	4	10		14		34-38
DC-10-30	CF6-50		16	5	21		30-45
747 CLASSIC	CF6-50	1	5		6		27-31
A300B2/B4	JT9D				0		
A300-600/A310	JT9D/CF6-80A				0		
747 CLASSIC	JT9D	3	10	11	24		30-49
747 CLASSIC	RB211		1	3	4		
747-400	RB211-524G/H	39	17	0	56		
Total		**1,699**	**1,329**	**127**	**3,155**	**7,418**	

subject to fixed maintenance cost per hour or cycle contracts. Operators are, therefore, free to determine their own workscopes, and can also choose from time-and-material, never-to-exceed (NTE), or fixed-price maintenance contracts that are offered by the engine maintenance shops.

Another advantage to the maintenance management of older engines is that LLPs in the fan, LPC and LPT modules have lives of up to 25,000EFC, and in a few cases 30,000EFC. The main benefit of this is that in engines operated on long-haul and long EFH:EFC ratios, the replacement of LLPs in these modules may have only been performed once, and at the latter part of the engine's life. Since aircraft operate long- and medium-haul flights, engines operate at 3.0-8.0EFH per EFC, so engines and LLPs will only accumulate 350-1,000EFC per year. This means it is possible to operate older engines without ever having to replace all or at least some of the LLPs for a second time. This generates substantial cost savings.

When the longer life LLPs of LPT modules is combined with relatively long maintenance intervals, it is also possible to swap the modules of different engines according to maintenance status. It is, therefore, feasible to avoid the maintenance of several modules or even an entire engine by swapping the modules of two or more engines according to maintenance status to produce one engine that can continue to operate with the minimum of maintenance inputs.

Another element to consider is the use of used serviceable material (USM). This applies to airfoils, smaller components, LLPs and external accessory components. In the case of USM, airfoils can be repaired to the level that achieves a subsequent removal and maintenance interval that is economic for the operator. Extensive and hi-tech repairs or the replacement of parts will incur higher costs while increasing EGT margin and engine performance, which may not necessarily be required by the operator.

The cost of performing maintenance on each module, the acquisition cost of the engines, the likely interval before the next maintenance workscope is required and the probable cost of the workscope for each module, and the operator's fleet plans, all have to be considered. This will be on a case-by-case basis, since these factors, particularly engine and module values and the cost of SVs, are constantly changing. Many engine shops that perform maintenance for mature and older types have developed techniques and SV workscopes that provide adequate EGT margin and performance, and, therefore, maintenance intervals that meet the operator's requirements.

PMA parts & DER repairs

One issue that affects the economics of continued operation of these engines is the use of manufacturer approved (PMA) parts and engineering representative repairs (DERs).

PMA parts are designed, developed and manufactured by companies other than the OEM. In the case of the CFM56-3, some airfoil components have been made by HEICO and Chromalloy. Moreover, Pratt & Whitney Engine Services reverse-engineered the CFM56-3 and developed a range of PMA parts for airfoils in the engine. PMA parts are generally viewed as having the same operational and performance qualities as OEM parts, but have the advantage of being cheaper and reducing SV costs. It is possible to reduce the cost of an SV input by as much as $100,000 through the use of PMAs. The saving will be less in the case of older engine types that are undergoing smaller and minimal workscopes that avoid a high level of parts replacement.

The use of PMA parts has become controversial, and is avoided by some airlines because the OEMs are not able to provide warranties and guarantees for the remaining components and parts of the engine when used in association with PMA parts. Airlines are free to use PMA parts, however, and they will lower SV costs if used.

DER repairs are non-OEM, hi-tech and specialist repairs developed by independent and airline-affiliated engine shops. Similar to the qualities of PMA parts, DER repairs are regarded as having similar or equal qualities to OEM repairs. As DER repairs are cheaper, they can also contribute to reducing the cost of SVs. A mix of DER and OEM repairs is offered on airfoils by specialist providers such as Chromalloy.

MTU Maintenance is a provider of DER repairs. While it also offers OEM repairs, MTU Maintenance has developed its in-house DER repairs which it markets as MTU Plus. MTU Maintenance states that the use of DER repairs greatly increases the cost-effectiveness of an SV workscope when compared to replacing parts with new parts or using OEM repairs. DER repairs contribute to lowering the scrap rate of parts, improving durability of hardware, and reducing the engine's specific fuel consumption (sfc). Overall, MTU Maintenance states that DER repairs help combat high parts and material costs and considerably increase engine removal intervals. The repairs can give components up to three more lives. Most customers will consider DER repairs to reduce maintenance costs for older engines in their last years of operation.

Some shops report that customers no longer want PMA parts, but want to use DER repairs. A main factor in this choice is that airlines know they are still able to acquire time-continued and green-time engines and modules with sufficient remaining time on-wing to avoid full SV workscopes. Also, the use of USM material and use of surgical strikes and relatively cheap repairs is often the most economic option for most airlines.

"Some of our customers do ask to use PMA parts in SVs, when one is required, and we allow this if requested," says Gordon Humphreys, director of sales and business development at LMES, a small provider of CFM56-3 maintenance. "We do not actually market the use of PMA parts, but PMA airfoils and exterior components are available and can be used.

"We do a lot of part repairs in-house, and these include some for vanes and stators, honeycomb seals, combustion chambers, fan blades, and engine cases," continues Humphreys. "We do not do repairs for rotating airfoils. The repairs we offer are OEM-approved repairs, and we sub-contract the repair of rotating airfoils to providers, such as Chromalloy, for DER repairs to help reduce the cost of the SV."

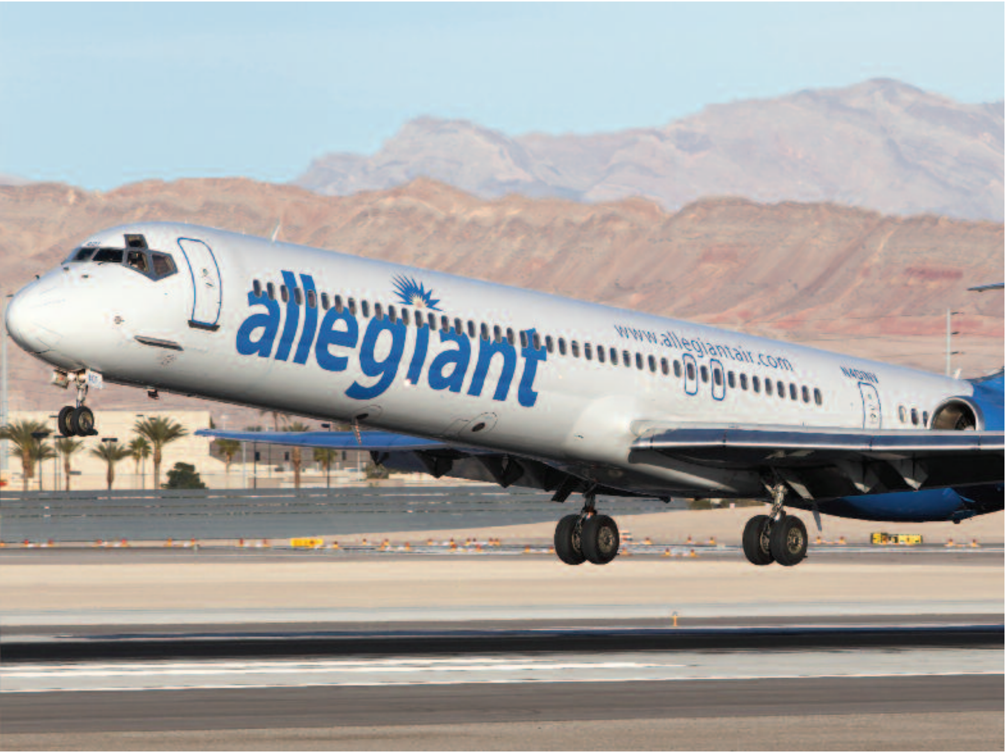
GEM has a similar policy to LMES, and does what its customers want with respect to PMA parts and DER repairs. "We will recommend the use of both PMA parts and DER repairs, but only if it makes economic sense," says Humphreys. "This will usually be the case when an airline needs an engine for a longer removal interval, and so needs a comprehensive workscope. We are very open to cheaper alternatives for engine maintenance. The savings from the use of PMAs and DERs can be substantial."

JT8D-200

The JT8D-200 exclusively powers the MD-80 family. More than 2,500 JT8D-200s and 1,191 MD-80s were built from 1980 to 1999, and 312 MD-80s are active *(see table, page xx)*. These are 19-37 years old. Of these, 289 are in passenger configuration, while 10 are operating as converted freighters. There are, therefore, more than 620 installed engines on the active fleet.

There are few engine shops left with JT8D capability, the type having two main series of the 'Baby' and -200. The Baby JT8Ds power a small number of DC-9s, 737-300s and 727s left in service.

Two main shops with JT8D capability are Aerothrust and Global Engine Maintenance (GEM), both in Miami, Florida. GEM is located west of Miami International Airport in a new 100,000 square feet facility. The company started engine maintenance in 2012. "We have the capability to do about 100 SVs per



The remaining fleet of in-service MD-80s still generate demand for engine shop visits for the JT8D-200. Active engine shops include Global Engine Maintenance and Aerothrust in Miami.

year, and are ramping this up to 150," says Faryt Kalhil, president and chief executive officer at Global Engine Maintenance. "We are building a test cell that will have a 50,000-75,000lbs thrust capability.

"We have extensive capability for engines that includes module swap, small SVs that we call 'hospital visits', on-wing or field support, engine disassembly and re-assembly, piece-part inspections, and piece-part and module repairs. This last element includes third-party work," continues Kalhil. "We perform all types of parts and airfoil repairs that include welding, and grinding and blending repairs. The only ones we do not perform are environmental and high-tech repairs, such as laser drilling or those that require plasma spray, or application of coatings."

GEM's annual activity for the JT8D-200 is only a small number of SVs. "We do see quite a lot of activity each year, but do not expect to have a long-term future in this engine. We only perform maintenance on the JT8D-200 for known or established customers," says Kalhil. "Each year we perform full SVs and performance restorations, and total SVs per year on the type reach about 15. Our main customers are Latin American airlines and those with VIP aircraft. We will keep capability for the JT8D while there is demand. We do, however, have plans to expand lines for other engine types, so we have to make room for those. We no longer actively market the JT8D."

As well as SV maintenance, GEM acquires modules and engines for sale and leasing. "We use these to sell to airlines or exchange full engines and modules. We also do a lot of engine trades," says Kalhil. "We also acquire used materials, and are always active in acquiring time-continued parts and engines. We have a lot of time-continued and overhauled parts in engines. We provide airlines with a host of options so that they can keep the maintenance cost for these engines to a minimum. We no longer lease JT8D engines, however."

CFM56-3

Of all the old engine types listed, the CFM56-3 is the most numerous *(see table, page xx)*. Out of 1,940 737 Classics built, about 780 aircraft are still in active service, and which are 19-33 years old. The 737-300 and -400 have proven to be popular freighters, with passenger-to-freighter conversion programmes offered by AEI, IAI Bedek Aviation, and Pemco. There are 273 aircraft in active service as freighters, and more aircraft will continue to be converted. There are also more than 460 aircraft in service in passenger-configuration, despite the large-scale retirement of these types by first-tier operators and major airlines.

The fleet of active aircraft means that there will be a mix of almost 1,560 installed CFM56-3B and -3C engines on operating aircraft, and up to 250 more engines will be required as effective spares. These could be sourced as green-time engines from the large number of retired aircraft. To date, about 900 737-300s/-400s/-500s have been retired or written off, so these aircraft have released about 1,800 -3B and -3C engines. These also provide a supply of USM for use by engine shops.

With almost 800 active 737 Classics, there are still several shops that offer CFM56-3 capability. Estimates are that the global CFM56-3 market equals 130 SVs per year.

The remaining shops with CFM56-3 capability include Aero Norway in Stavanger, Norway; MTU Maintenance, with shops in Canada and Zuhai, China; GEM in Miami; Lockheed Martin Engine Services in Montreal, Canada; and Israel Aircraft Industries (IAI) in Tel Aviv, Israel.

Aero Norway has become one of Europe's largest providers of CFM56-3 maintenance. "There has been a resurgence in CFM56-3 activity because of the low market values of 737 Classics and the demand for freighters," says Glenford Marston, chief executive officer at Aero Norway. "There is also the unexpected continued operation of passenger-configured aircraft. The high demand for 737NGs, with values at $12-14 million, has kept values of 737 Classics at $2-3 million. The aircraft have remained profitable to operate for longer than many expected."

Although there are still large numbers operating, the aircraft left are 19-33 years old. "Most 737 Classic operators try to avoid performing SVs, and most maintenance inputs are full core restorations. We do not see complete overhauls, and airlines try to avoid performing maintenance on the LP modules to save costs. The LLPs in the LP modules have lives of 25,000-30,000EFC, while those in the HP modules have lives of 15,000-20,000EFC. This helps airlines avoid workscopes on the LP modules. There are a large number of engines from retired aircraft with time-continued modules to help with this.

"We also have CFM56-5B and -7B engines, which now account for about 35% of our SV activity. The CFM56-3 accounts for about 65% of our maintenance activity. This is equal to about 38 SVs per year," adds Marston. "We could actually get more -3 work, but we are limited by capacity.

"Most maintenance visits are module swaps and small visits that we call surgical strikes," continues Marston. "This is a workscope to provide enough EGT margin to match the remaining EFC lives of the LLPs in the HP modules."

GEM actively markets its CFM56-3 capability, and its main customers are passenger operators, as well as engine lessors and traders, and freight carriers. "The -3 is a good workhorse, and we are doing 50-60 engines per year. We also own 20 or more engines, and offer them for sale or do exchanges with our customers," says Kalhil. "These engines mean we can give an operator a serviceable engine at any time, which is part of the method of managing older engines to keep maintenance costs as low as possible. Moreover, there is a strong supply of good quality engines available because of the large number of aircraft that have been retired." This includes about 450 -3C-powered aircraft.

As with Aero Norway, GEM's customers do not want full management service for their -3s. "The customers send us the engine condition and data, and we recommend a workscope and the likely cost," says Kalhil. "We give our customers a warranty of on-wing time of 18-24 months. Sometimes we can advise the customer that the engine can have a smaller workscope than thought."

MTU Maintenance is one of the largest remaining providers of CFM56-3 maintenance, performing about 20 CFM56-3 SVs per year, plus another five smaller maintenance events for the engine. Smaller events include engine teardown, end-of-lease repetitive inspections, single module repairs, and light repairs that may also be referred to as surgical strikes or hospital visits.

LMES is an engine maintenance facility that was previously operated by Air Canada and then Aveos. "We only perform about 10 SVs per year for the -3, and no longer actively market our capability for the engine," says Humphreys. "Our customers are mainly small niche operators from Canada and the US. We find, as may be expected, that many of our customers avoid full-level SV workscopes because they can keep operational by using green-time engines. We are looking to the -5B and -7B in the future for full maintenance activity, but we can still support the -3.

"We expect the market to last for another three to five years. We provide all levels of engine SV workscope, including simple module swap, module disassembly and re-assembly, full detailed module and piece-part inspections, component repairs, and airfoil parts and repairs," continues Humphreys. "We mainly offer two types of support contracts. These are usually fixed-price contracts or module swaps if the customer requires."

IAI in Tel Aviv is one of the few providers of -3 maintenance and support in the Mediterranean, Middle East and Africa. "We perform about 100 SVs per year for all engine types, and the CFM56-3 accounted for about 15 of these in 2017," says Jacob Rozman, vice president and general manager of IAI Engine Division. "The interesting issue about the -3 market is that there are several facilities in China that have removed or reduced their -3 capabilities. This is generating extra -3 business for us. We also offer module swaps as a way of reducing a customer's costs. We offer time-and-material, NTE and fixed-price contacts. We can also offer power-by-the-hour (PBH) contracts for airlines that are interested."

IAI also owns a small portfolio of engines available for lease. In addition to the CFM56-3, the portfolio includes the V2500-A5/-A7, and a single PW4000-94.

MTU Maintenance's range of capabilities is among the largest. This includes the more basic items of incoming inspection, disassembly of engines and modules into piece parts, repair and upgrade of components and accessories, gapping and grinding processes for compressor and turbine airfoils, and module and engine re-assembly.

Most shops have some level of component repair capability, but high-tech repairs are left to specialists. "We do have capability for variable bleed valve (VBV) systems and plasma spray, but not on airfoils," says Marston. "We only do manual repairs on airfoils, which are all in the original equipment manufacturer (OEM) manuals. These are described in the engine shop manual (ESM). We do not do any source-approved airfoil

The CFM56-3 MRO market is equal to about 130 shop visits per year. The large number of green time engines available on the market means that most operators seek minimal workscopes, such as surgical strikes, to avoid the cost of full workscopes. In the case of most shop visits, LP modules do require minimal work.

repairs. It is actually cheaper to sub-contract some of the specialist and hi-tech parts repairs because of the volume experienced."

Like many other providers, IAI is not authorised to perform hi-tech and specialist part repairs, such as for the HPT blades. "We do repairs on most airfoils and the combustion chambers, however, and also the nozzle guide vanes (NGVs)," says Rozman.

PW2000

The 757 fleet has about 680 active aircraft out of the 966 aircraft that were built. The fleet is sub-divided between the PW2000- and RB211-535-powered aircraft. The RB211- equipped fleet was the larger of the two, with 541 aircraft built, of which about 419 still in active service. The PW2000-equipped fleet totalled 425 aircraft, and 266 are still active *(see table, page xx)*. These are 14-34 years old, the last aircraft being built in 2004. There are about 160 aircraft still in operation as passenger-configured aircraft. Most of these are in service with Delta Air Lines, and a small number are in operation with United Airlines.

There are 102 PW2000-powered 757 freighters in operation. Many of these are factory-built freighters operated by UPS and FedEx, but there are also some converted aircraft. The 757 is also in a class of its own, and it is expected to continue in operation for another 20 years. Moreover, there are large numbers of the PW2000's military variant, the F117, in operation powering the C-17 fleet.

There are a few choices for engine maintenance capability. These include PW Columbus, CTS Engines in Miami and MTU Maintenance Hannover and Dallas, and Dela TechOps in Atlanta.

With about 266 aircraft in service, there will be at least 532 active commercial engines in operation. Estimates are that this generates 100 SVs per year. "This increases to about 200 SVs per year when the military variant F117 is included," says Vesa Paukkeri, president and chief operating officer at CTS Engines. "We will start to offer PW2000 capability from late 2018. We have already begun to tear down engines, which will provide us with modules and USM. So far we do not have any customers secured, but there are about 300 C-17s, each with four engines. We expect freight operators and lessors to use us. We see the PW2000 as a niche market, and expect to keep operational for the next 20 years. We expect a wave of 757 retirements, but there will still be big operators."

MTU Maintenance performs about 20 PW2000 SVs per year, and so has about 10% of the total estimated market, but about 20% of the civil PW2000 market. It also performs another five smaller SV events for the PW2000 each year. The smaller events are small or light repairs, end-of-lease returns and teardown.

As with other engine types, MTU Maintenance has developed extensive maintenance capability for the engine. Its main aim with older engines, like the PW2000, is to repair as much material as possible, rather than replace with new parts. It aims to repair as many parts as possible in-house within the MTU network. MTU Maintenance can, therefore, maintain better cost control. As with other engine types, MTU Maintenance actively promotes and uses its in-house DER repairs as a contribution to keeping engine maintenance costs to a minimum.

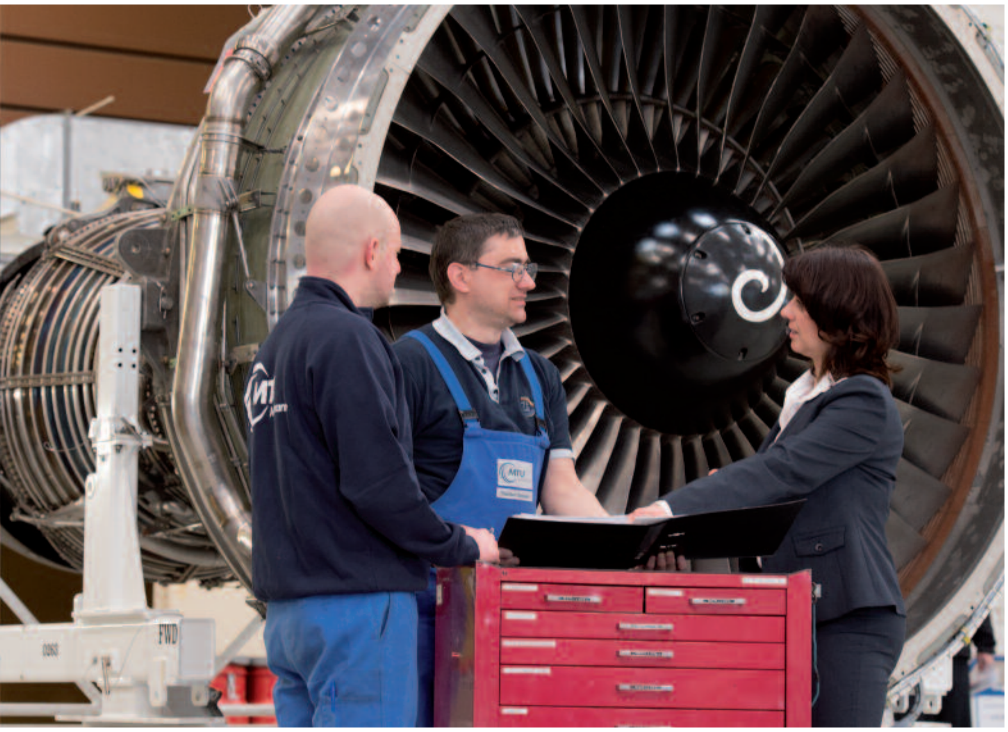
CFM56-5C

The CFM56-5C is the sole engine on the A340-200/-300 fleet. There are 104 active aircraft out of 236 built. The active fleet has 416 installed engines. The retirement of more than 130 aircraft and of complete fleets by several airlines means there will be more than 550 retired and time-continued engines on the market.

The remaining 104 aircraft are operated by a mix of original operators and airlines that have acquired used aircraft. Original operators include Aerolineas Argentinas, Air France, Air Mauritius, Lufthansa, South African Airways, TAP Air Portugal, and Turkish Airlines. Many of these fleets are due for retirement over the next few years, and will be replaced by several types that include the 787 and A350. This will release further CFM56-5Cs onto the market. Airlines operating used fleets include Air Belgium, Edelweiss, SWISS, Hi Fly, Joon, Kam Air and Plus Ultra.

There were several engine shops in Europe that had -5C capability, but many have now left the market. Remaining engine shops Iberia Maintenance, TAP Maintenance & Engineering, Turkish Technic and Lufthansa Technik. Lufthansa Technik has retained its capability for use on the Lufthansa fleet, and it also supports SWISS and Aerolineas Argentinas. Lufthansa will be phasing its fleet out over the next few years, although the exact timing will depend on fuel prices. "The rate of retirement by Lufthansa, therefore, affects its engine maintenance strategy," says Marc Wilken, product sales senior director at Lufthansa Technik. "Over the last few years we have completed 20-30 SVs per year for the CFM56-5C. The -5C is maintained on the same product line as the -5A at our Hamburg engine shop.

"We offer customised engine maintenance, and have a product called SmartLife," continues Wilken. "We offer this for older engines in the latter part of their life, and we provide bespoke solutions for airlines operating older engines. We examine the LLP status of each engine, and what maintenance is



The PW2000 is a select market, although the fleet of active 757s plus about 300 C-17s generates a market estimated at about 200 shop visits per year.

required to achieve a particular removal interval, taking the operator's fleet plans into consideration. We also offer mobile engine services, where we can perform some engine repair work on-site as an alternative to performing a full SV at our Hamburg shop. We have several repair stations, located in: China; Tulsa, Oklahoma; Frankfurt, Germany; and Montreal. Engine repair work on-site is similar to hospital visits offered by General Electric."

Lufthansa Technik has extensive engine shop capability that includes all levels, from incoming inspection and disassembly into modules, to parts and component repairs. Lufthansa Technik has its own hi-tech and specialist engine parts repairs called EPAR. It also has a specialist repair facility in Shannon, and a joint venture with MTU Maintenance in relation to a component repair facility in China. "We find that mid-life engines, such as the CFM56-5C, have the highest level of mid-life parts repairs," says Wilken. "The number of repairs performed depends mainly on the availability of USM from retired engines. Mature engines tend to repair fewer parts repairs, and module swaps become more common. We may have to eventually drop our CFM56-5C capability if demand for these specialist repairs falls below an economic level."

CF6-50/-80C2

The General Electric CF6 has been one of the most successful widebody engines. Two of the four distinct variants were the CF6-6, powering the DC-10-10, and the CF6-80A, powering the early variants of the 767-200 and the A310. Only a small number of these engines remains in service.

The other two variants still in operation in larger numbers are the CF6-50, powering the A300B2/B4, DC-10-30 and 747 Classics, and the CF6-80C2, powering 1980s generation widebodies that are the A300-600, A310-300, MD-11, 747-400, and 767 family.

There are still 41 A300B2/B4, DC-10-30 and 747 Classics in operation that are powered by CF6-50s *(see table, page xx)*. This amounts to 115 active installed engines.

The 14 A300B2/B4s are mainly freighters, and are operated by AeroUnion, Global Charter and DHL. A few passenger-configured aircraft are operated by Iran Air. The 21 DC-10-30s are operated by FedEx, plus a few aircraft configured as firefighting aircraft. There are five freighter-configured 747-200s that are mainly Iranian and Belarussian.

There are 396 A300-600s, A310-300s, MD-11s and 747-400s in service, which equates to about 1,262 active installed CF6-80C2 engines *(see table, page xx)*. To date, 138 A300-600/A310-300s, 41 MD-11s and 134 747-400s equipped with CF6-80C2 engines have been retired. This is equal to more than 900 engines coming onto the used market.

There are, however, another 531 CF6-80C2-powered 767-300ERs and -400ERs still in service, while 69 CF6-80C2-equipped 767s have been retired. Therefore, more than 1,000 CF6-80C2 engines have released onto the used market due to retirements.

The remaining in-service CF6-80C2 fleet comprises about 2,300 engines, and so is the largest of older widebody engine types on the market, second to the PW4000-94 which has a larger installed base. There are also additional CF6-80C2s in service with military aircraft, while the CF6-80C2 is also still in production with remaining 767PFs to be built over the next six years.

The number of retired and in-service engines has to be treated with caution. The CF6-80C2 fleet is sub-divided between two fleets of power management control (PMC) and full authority digital engine control (FADEC) units. There are different thrust-rated variants within each sub-family, but it is not possible to swap variants between each family.

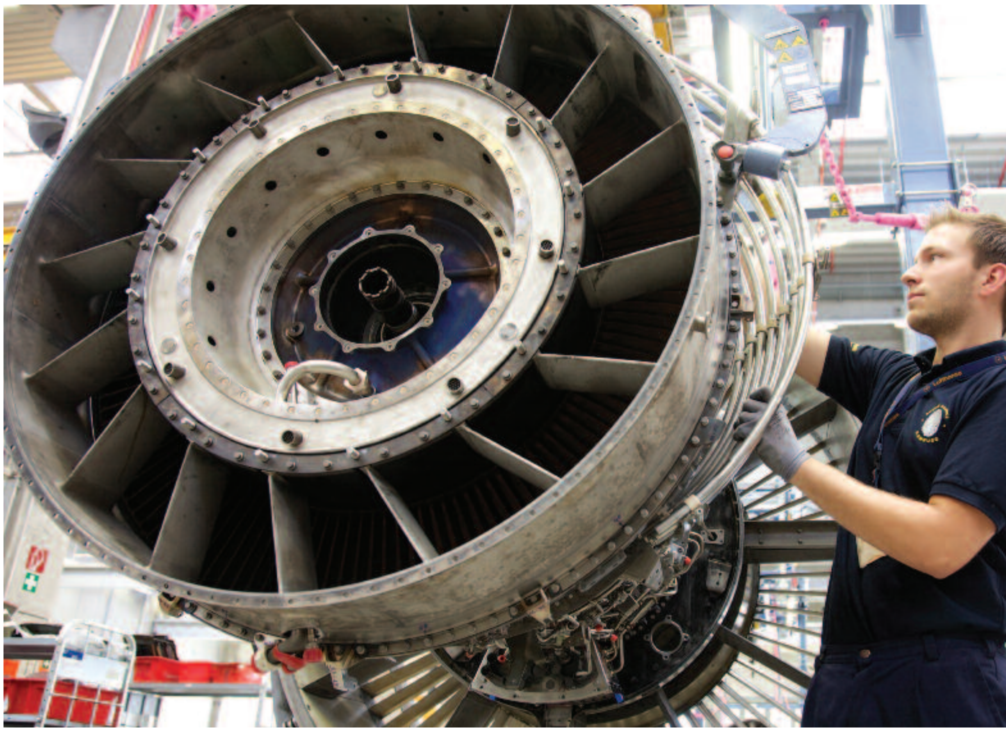
The A300-600 and A310 were equipped with a mix of PMC and FADEC engines, while the MD-11 and 747-400 were equipped exclusively with FADEC engines. The majority of CF6-80C2-powered 767-300s/-400s were equipped with FADEC engines, although 124 older aircraft were equipped with PMC engines.

In total, there were 986 aircraft of all four main types built with FADEC engines, of which 212 have been retired, written off or parked. Most of the retired aircraft are 747s, and so this released at least 660 FADEC-equipped engines onto the aftermarket. There are 774 aircraft with more than 2,000 FADEC-equipped engines installed.

While the 767-300ER fleet is largely stable and remains popular, large numbers of A300-600s, A310-300s and 747-400s have been retired, with additional aircraft to be retired over the next few years, releasing additional engines onto the market.

The A300-600s/A310-300s in service are operated by a mix of small fleets that include Air Transat, Ariana Afghan Airlines, Iran Air, Mahan Air, MNG, and Turkish Airlines. The remaining MD-11s are freighters operated by FedEx, Western Global, Lufthansa Cargo, Sky Lease and UPS. The smaller fleets among these are likely to retire over the next few years if high fuel prices are sustained.

Large numbers of mainline 747-400 fleets have been retired. The 66 passenger aircraft that remain in operation include Asiana, KLM, Qantas, Lufthansa, Thai Airways International and Virgin Atlantic. Many of these are due for retirement, and so will release more engines on to the market. There are also 126 freighters and Combi aircraft in operation, but most of these more are likely to remain in service.



Lufthansa Technik has maintained its CFM56-5C capability. The fleet of A340-200s/-300s is now about 100 active aircraft, and generates demand for 20-30 engine shop visits per year for the provider.

The CF6-50 maintenance market is estimated at 25 events and SVs per year, with another 40 maintenance events for the USAF KC-10 tanker fleet.

The extensive use and popularity of the CF6-80C2 resulted in a large number of shops with capability. These are now declining. Estimates are that the annual maintenance market is equal to 500 SVs per year, excluding military engines used on types such as the 767 refuelling tanker.

There are now few providers of CF6-50 engine maintenance. Shops that still have the capability are CTS Engines in Miami, and LMES at its facility in Montreal. CTS Engines' main customer for the CF6-50 is the US Air Force (USAF), for the KC-10 fleet.

The other main supplier for the USAF is LMES. "We perform maintenance for the CF6-50 on military contracts for more than 40 KC-10s that are operated by the USAF," says Humphreys. "Unlike civil engines, these USAF engines have full maintenance management, since they will probably continue to be operated for another 10-12 years.

"We do not do a lot of marketing to commercial customers for the CF6-50, because there are very few operators left," continues Humphreys. "We do, however, have the capability for the engine. We can perform about 75% of parts repairs in-house, and subcontract the rest. The repairs we perform in-house include those for vanes and stators, honeycomb seals, combustors and fan blades. Sub-contracted repairs tend to be the specialist repairs for rotating airfoils, and we can use DER repairs from providers such as Chromalloy for these."

Providers of CF6-80C2 capability include Air France Industries KLM Engineering & Maintenance, Lufthansa Technik, MTU Maintenance and CTS Engines.

"The advantage of our having the capability for the CF6-80C2 is that the market has been going up over the past few years, despite the large number of retirements," says Paukkeri at CTS Engines. "This is explained by many large operators retiring fleets and changing to other engine types in their shops. Independents like GE Caledonian have also left the market, and some shops like Lufthansa Technik have less CF6-80C2 activity. The past few years has also seen many airlines using time-continued engines and modules to minimise maintenance costs, but these have now been used. Airlines are now having to perform full workscopes, at least on some modules because of the supply being used up. The economy is also picking up, and this is driving demand for cargo. A shortage of freighter capacity has materialised, and types like the 747 are in demand again."

Lufthansa Technik has maintained substantial CF6-80C2 activity for several types operated by Lufthansa, but its fleet has declined. "We perform 25-30 SVs per year," says Wilken. "Lufthansa still operates about 13 747-400s and it also operates MD-11Fs. Despite this, we rarely see big tenders from airlines for maintenance contracts for the engine type because airlines have been taking advantage of the supply of used and time-continued engines and modules on the market, as well as competition among suppliers."

MTU Maintenance performs about 12 SVs and events per year for the CF6-80C2. MTU Maintenance experiences mainly lighter workscopes for the CF6-80C2. Like CTS Engines, MTU maintenance has experienced a revival in the CF6-80C2 maintenance market. It claims this is due to the rise in freighter capacity and a lower rate of retirement and the fewer older CF6-80C2-powered aircraft being parked. This latter factor is due to delays in new widebody programmes, and older aircraft have become attractive again. All of these issues have diminished the availability of surplus material and engines.

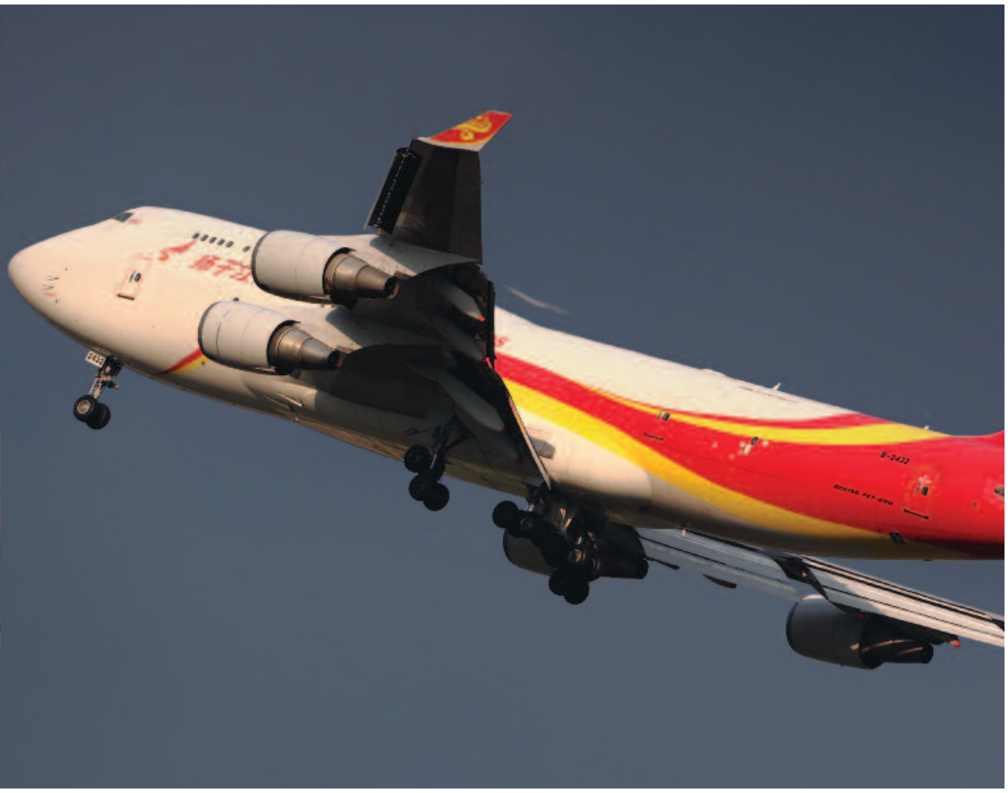
CTS Engines' customers include the USAF for the E-4B fleet, Asiana, DHL and Lufthansa. "Despite Lufthansa still operating the 747-400 and Lufthansa Cargo operating the MD-11, not a lot of its engines go through Lufthansa Technik," says Paukkeri. "We have also been buying engines, although we are not getting into trading. We are filling every slot with overhauls and are getting the best value from full SVs."

Wilken at Lufthansa Technik says that most CF6-80C2 operators are interested in keeping the engine operational at minimal cost. "The customers leave management of determining the best workscope, what modules to swap and which LLPs to replace to Lufthansa Technik," says Wilken. "This includes the use of USM, which is up to 90% in the case of the CF6-80C2.

"In addition to this, we do permit the use of PMAs when parts need to be replaced in the CF6 if the customer requests it," continues Wilken. "Lufthansa Technik had developed PMA parts, but their use has mainly been influenced by external parties, especially lessors. We use PMA parts in the CF6-80C2s operated by Lufthansa and Lufthansa Cargo. We also use the DER repairs that were developed by our EPAR division. PMAs and DERs may not always be used that much if there is a supply of suitable USM."

Despite the remaining fleet of CF6-80C2s exceeding 2,000 engines, Wilken says he expects Lufthansa Technik to remain in the maintenance market for another three to five years, once the last aircraft operated by Lufthansa and Lufthansa Cargo retire. "The main factor will be the extent of our activity for the new engine types."

MTU Maintenance says it will keep capability for the CF6-80C2 for as long as there is sufficient customer demand, and adds that it has seen renewed interest in the engine for the past two years.



The CF6-80C2 is an active fleet of about 2,000 installed engines. The full utilisation of large numbers of green time engines from previously retired aircraft has led to a resurgence in demand for shop visit maintenance of the type.

Because many of its customers are freight operators, it does not expect to exit the market any time soon.

Reducing and then resurgent maintenance activity is typical of a declining fleet of active engines. Activity will naturally decline as the supply of time-continued engines increases, and then will rise again as that supply is used up. The continual retirement of CF6-80C2-powered aircraft will result in reductions in engine maintenance activity, followed by the inevitable resurgence of maintenance activity.

PW4000-94 & JT9D

The PW4000-94 is the second most numerous of older generation widebody engines. There are 117 active A300-600s/A310-300s, 43 MD-11s and 93 747-400s that are equipped with several thrust-rated variants of the PW4000-94 *(see table, page xx)*. These aircraft will have about 735 installed engines. This compares to 276 retired aircraft of the same three types, and these will have released 874 installed engines plus spares.

As with the CF6-80C2, the PW4000-94-powered aircraft still in operation in large numbers are 767-300ERs. The aircraft in operation are virtually all freight operators in the case of the A300-600/A310-300, while all but two MD-11Fs are operated by courier services FedEx and UPS. The PW4000-powered 747-400s in operation are split between 58 freighters and 30 passenger aircraft. Freighter operators include a variety of small cargo carriers and larger airlines, such as Cathay Pacific, Cargo Air Lines, Kalitta Air and Singapore Airlines.

Passenger-configured aircraft are still operated by Air China, Air India, Corsair, El Al, Korean Air, Saudia and Wamos Air. Many of these fleets are due to be phased out over the next several years.

The relatively small fleet of 156 passenger-configured 767-300ERs is operated by a mix of large and first-tier airlines, and smaller carriers that include used fleets. First-tier fleets include Air Canada Rouge (12 aircraft), Delta Air Lines (32), United Airlines (35), Hawaiian Airlines, Condor and Ethiopian Airlines. Smaller fleets include Air Astana, Azur Air, Ukraine International Airlines and Uzbekistan Airways.

About 62 767-300s have been retired, meaning about 1,000 engines have been released from retired and written-off aircraft.

The number of engines from retired aircraft is, therefore, almost equal to those in operation with active aircraft. The number of retired engines is also likely to increase in relatively large numbers over the next few years as airlines such as Delta and United phase out their 767-300ERs replacing them with 787s and A350s. The maintenance status of these engines coming onto the market may not be too high, since Delta's policy is to use up most available maintenance time on its engines, and swap engines and modules as it gradually phases out aircraft.

There are several shops that have maintained some level of PW4000-84 capability. These include Lufthansa Technik, Hamburg; IAI, Tel Aviv; PW Eagle Services, Singapore; Air India Engineering Services, New Delhi; and Delta Tech Ops, Atlanta. PAS Technologies and Standard Aero are providers of a selection of parts and component repairs.

Estimates are that the global maintenance market for the PW4000-94 engines is equal to 230 SVs plus smaller events, and up to 400 SVs in some years. The PW4000-94 market will experience declines and resurgences in the maintenance market as retired time-continued engines are first used by airlines to avoid expensive SVs, and then have to be sent for extensive shop events as the supply of green-time modules and engines dries up. The supply of green-time engines will not necessarily increase significantly.

"We have seen a reduction in PW4000-94 activity, as well as the JT9D which we also have capability for. We only perform about 100 SVs per year for all the types we have capability for," says Rozman at IAI. "We think it will be a few more years before the JT9D is totally gone from the market. There is still a large number of 767s operating. There are alternative shops, however, and it has become difficult to obtain USM. Moreover, PW no longer manufactures all of the parts for the engine.

"Besides the main levels of engine maintenance capability, we offer repairs that are authorised by the OEM," continues Rozman. "We are now finding that no customers are asking for PMA parts, but they did in the past. They also don't want DER repairs. This is mainly because they can still acquire time-continued engines and modules."

In the case of the JT9D, there are now only 24 active aircraft with the engine type in operation. These are all 747 Classics. They include 11 aircraft that are in government, research and VIP roles; three passenger aircraft operated by Max Air of Nigeria; and 10 freighters, most of which are operated in Iran.

"We will continue with JT9D capability until the market is dead," says Rozman. "Most aircraft are freighters and VIP, and we are now assigned as a service provider for the JT9D by PW. There seems to be little or no green-time JT9D material available. AC