The 757's popularity as a freighter, the closure and inactivity of several engine shops, and the low production rates of parts have all combined to produce a shortage of time-continued PW2000 & RB211-535 engines. The economics of the options for acquiring serviceable units are considered.

Factors affecting the supply of PW2000 & RB211-535 engines in the aftermarket

The 757-200 has proved to be popular. Of the 1,039 civil aircraft built, 984 were the -200 series and 55 were -300s *(see table, page 5)*. The aircraft has not been manufactured since 2005, and just over 600 aircraft are left in active service. More than half of these are freighters. The continued operation of remaining 757s relies partly on the availability of good quality RB211-535 and PW2000 engines, and technical support for them.

Continued 757 operation

The youngest 757s in operation are 14 years old. The oldest examples in active service are an RB211-535E4-powered freighter built in 1983, and operated by FedEx, and a PW2037-powered freighter built in 1984, and operated by Air Transport International (ATI).

The 757 has proved particularly popular as a freighter, which will give it longevity, and continue to stimulate demand for all levels of technical support and engines. Of the 307 active freighter aircraft, 229 are converted aircraft, and 78 are factory-built freighters. The 757-200 freighter fleet split by engine type is 208 RB211- and 99 PW-2000 powered aircraft.

Given the age of the oldest aircraft and typical rates of utilisation, it is possible for the youngest aircraft to remain in service for another 20 years.

More passenger aircraft are likely to be converted. The 757-200 is a unique type, and proving popular with freight carriers. The 757-200 freighter fleet is dominated by the express package consolidators. DHL, FedEx and UPS operate more than 225 aircraft between them. All three operate a mixed fleet of RB211- and PW2000-powered aircraft.

More than another 80 are operated by smaller carriers, including Blue Dart, Cargojet, SF Airlines, China Postal and Morningstar Express.

The factory-built freighter has not been available since 2005. Conversion programmes were available from Boeing and Precision Conversions. Conversion rates peaked at 25 aircraft in 2011 and reached 19 in 2018.

Precision Conversions is now the only active passenger-to-freighter (P-to-F) conversion programme. It modified 16 aircraft to freighter in 2018, and expects to convert at least 12 in 2019. Brian McCarthy, vice president of sales at Precision Conversions, estimates that it could convert a further 45-60 aircraft from the 290 passenger-configured and six combi aircraft that are still active. There are also more than 70 stored aircraft, some of which could potentially be suitable conversion candidates. It seems probable that once all conversions are completed, most of the fleet will be RB211-powered.

Some of the 22 aircraft in special roles could also be conversion candidates.

The demand for 757 freighters will be high. It is in a class of its own, with a gross structural payload of up to 84,000lbs and a total available volume of 8,390 cubic feet. As well as steady traffic growth, especially in markets such as e-commerce and China, there is also the prospect of existing 757 freighters retiring, some of which are 36 years old.

The three main issues that affect the appetite for converting more of the available 757-200s, or continuing their operation as passenger aircraft, are: the maintenance status of the airframe; the availability and maintenance status of engines on the market; and the long-term availability of technical and maintenance support for the RB211-535 and PW2000 over the next 20 years.

Airframe maintenance and engineering support, and engine maintenance is provided by some of the larger 757-200 and -300 operators. The remaining active 757-200/-300 passenger fleet is concentrated with a few airlines, including the three US majors: American, Delta and United. There are also a few smaller airlines providing some levels of technical support. These include ex-operators, such as Iberia which offers RB211-535 maintenance.

The retirement of large numbers of passenger-configured 757-200s and -300s raises the issue of what technical support will remain available to potential operators of used passenger aircraft and freight carriers.

The fleets of RB211- and PW2000-powered 757-200s are analysed in detail.

757-200 & -300 fleet

The 757-200 and -300 fleets can first be split between RB211- and PW2000-powered aircraft. The 984 757-200s built are divided between 573 equipped with RB211-535 engines, and 411 PW2000-equipped aircraft.

There were also 39 RB211- and 16 PW2000-equipped 757-300s produced.

Of the 573 aircraft built with RB211 757-200 engines, there are 16 with experimental, special VIP and government roles or are in an air taxi or business jet configuration *(see table, page 5)*. These account for 3% of the aircraft.

This leaves 557 757-200s in passenger and freight roles.

To date, seven RB211-equipped aircraft have been written off, while another 134 have been retired, and 55 are in storage. These 196 aircraft account for 34% of aircraft built *(see table, page 5)*.

This leaves 361 757-200s in active service in a mixture of passenger, combi and freighter configurations *(see table, page 5)*. That is, 63% of the RB211-

equipped 757-200 fleet is still active.

Of the 411 PW2000-powered aircraft, five have experimental, VIP or government roles. These account for just over 1% of PW2000-equipped 757-200s. This leaves 406 aircraft in passenger and freighter roles.

Two aircraft have been written off, 17 are in storage, and 145 have been retired. This group of 164 inactive aircraft *(see table, this page)* represents 40% of the PW2000-equipped 757-200 fleet.

This leaves 242 aircraft in service in passenger, combi and freighter configurations *(see table, this page)*. This is 59% of the PW2000-powered 757-200 fleet.

There are thus 290 active aircraft in passenger configuration, and another six active combis equipped with both main engine types. There are a further 307 active aircraft operating as freighters with both main engine types, accounting for most of the active 757-200 fleet. The total fleet of active aircraft is 603 units.

RB211-535 fleet

The RB211-535 fleet can be split between two main variants. The RB211-535C was the original RB211 variant, and powered 40 aircraft. Of these, 34 were operated by British Airways, and were subsequently converted to freighter in the late 1990s and operated by European Air Transport (EAT), DHL's European subsidiary. Five of the 34 freighter aircraft are still active, but are due to retire over the next few years, and the other 29 are already retired. There were another six aircraft with -535C engines. Five are retired, leaving one active aircraft in a special role.

This leaves 533 757-200s with two variants of the RB211-534E4. Excluding the 15 aircraft in special roles, the remainder of aircraft built are sub-divided between 308 with -535E4 engines and 210 with -535E4B engines. The main difference between the -535E4 and -535E4B is the thrust ratings of 40,100lbs and 43,100lbs.

The -535E4 fleet includes 223 active aircraft, 25 stored aircraft, 56 that have been retired, and four that are written off. Clearly the active fleet provides potential aircraft for continued operation and freighter conversion. Some of the 80 stored and retired aircraft may also be possible conversion candidates, or have engines and components worth acquiring.

The active fleet of 223 comprises 75 passenger and five combis. The larger fleets among the passenger aircraft are Air Astana (4), American (9), Icelandair (17), Jet2.com (11), Royal Flight (6) and TUI UK (11).

The five combi aircraft include three operated by US airline ATI and two in service with the New Zealand Air Force.

757-200 & -300 FLEET SUMMARY

RB211-535-powered fleet

Engine type	757-200 RB211-535C	757-200 RB211-535E4	757-200 RB211-535E4B	Total	757-300 RB211-535 E4B/E4C
Special role aircraft					
Experimental, VIP, govt, special role	1	12	3	16	
Active aircraft					
Passenger		75	73	148	39
Combi		5		5	
Factory-freighter		3	40	43	
Converted freighter	5	140	20	165	
Sub-total active	**5**	**223**	**133**	**361**	**39**
Inactive aircraft					
Storage - passenger		17	30	47	
Storage - combi		3		3	
Storage - freighter		5		5	
Retired	34	56	44	134	
Written off		4	3	7	
Sub-total inactive	**34**	**85**	**77**	**196**	
Total fleet	**40**	**320**	**213**	**573**	**39**

PW2000-powered fleet

Engine type	757-200 PW2037	PW2040	Total	757-300 PW2043
Special role aircraft				
Experimental, VIP, govt, special role	5		5	
Active aircraft				
Passenger	133	9	142	16
Combi	1		1	
Factory-freighter		35	35	
Converted freighter	51	13	64	
Sub-total active	**185**	**57**	**242**	**16**
Inactive aircraft				
Storage - passenger	1	12	13	
Storage - combi				
Storage - freighter	1	3	4	
Retired	138	7	145	
Written off	2		2	
Sub-total inactive	**142**	**22**	**164**	
Total fleet	**332**	**79**	**411**	**16**

The stored group of 25 aircraft includes 17 passenger examples, eight of which were retired in 2018 and two that were retired during 2019. Two are now due to be converted for SF Airlines in China, and four were previously operated by Xiamen Airlines. Another aircraft that is being converted to freighter is due to enter service with Cargojet.

The 56 retired aircraft include 53 that were operated as passenger aircraft. Four were retired in 2018 and one in 2019. Some of these may be conversion candidates. Most of the others have accumulated more than 70,000 flight hours (FH) and about half have accumulated more than 30,000 flight cycles (FC).

The -535E4B fleet totals 210 aircraft. It includes 133 active aircraft, of which 30 are in storage, 44 are retired, and three were written off.

The 133 active aircraft are split between 60 freighters and 73 passenger aircraft. The latter are divided between three main fleets operated by American (26), United Airlines (40) and Icelandair (6). There is also one aircraft operated by

About 40% of the PW2000-powered 757-200s are now inactive. A portion of ex-United 757-200s were converted to freighters and are operated by FedEx.

National Airlines.

All 30 aircraft in storage are passenger-configured. Two were parked in 2019, but about half this group has accumulated more than 70,000FH. Some of these could possibly be suitable conversion candidates.

The 44 retired aircraft are all in passenger configuration. More than half have accumulated more than 70,000FH. Six were parked in 2018 and two in 2019.

Of the 75 -535E4- and 73 -535E4B-equipped active passenger aircraft, 130 come from large fleets: Air Astana (4), American (35), Icelandair (23), Jet2.com (11), Royal Flight (6), TUI UK (11, and United (40).

There are also 35 active 757-300s with RB211-535E4B engines and another four with -535E4C engines.

There are 203 757-200 freighters with RB211-535E4/E4B engines in service, and 160 of these are converted aircraft.

Most are -535E4-powered, operated by EAT/DHL (12), FedEx (66), Blue Dart (6), Morningstar Express (8), Cargojet (4), SF Airlines (23), and a group of other Chinese airlines with a fleet of 16. There are a few other small fleets.

There are also 20 -535E4B-equipped aircraft operated by SF Airlines, DHL, Cargojet and other small carriers. The remaining 43 aircraft are factory-built freighters. UPS has 40.

Most demand for any RB211-535 engines that come available will mainly be from the operators of these converted freighters, and a small number of passenger-configured aircraft. FedEx and UPS will have a supply of spare engines for their factory-built freighters.

PW2000 fleet

The PW2000 fleet for the 757-200 is split between 332 aircraft with the PW2037 rated at 38,250lbs, and 79 powered by the PW2040 rated at 41,700lbs. There are also 16 PW2043-powered 757-300s in operation.

As with RB211-powered aircraft, the main demand for PW2000 engines comes from operators of converted freighter aircraft and airlines still operating small fleets of used passenger aircraft. The source for these engines will be aircraft that are already retired, and active passenger fleets as they retire over the next five to 10 years.

Excluding aircraft with special roles, the PW2037 fleet of 327 includes 185 active, two stored and 138 retired aircraft, and two that have been written off.

The 185 active aircraft include 133 in passenger configuration, a single combi, and 51 converted freighters.

The 133 active passenger aircraft include fleets operated by Delta (109), United (14), Uzbekistan Airways (5), Azur Russia (4) and one other aircraft.

Most of the 51 converted freighters are operated by DHL carriers and FedEx.

The retired fleet of 138 includes 66 that were previously operated by Delta Airlines.

All retired aircraft were stood down by their operators from 2013 to 2018. This includes 10 in 2016, 17 in 2017 and 12 in 2018.

Excluding aircraft with special roles, the PW2040-equipped 757-200 fleet of 79 aircraft includes 57 active, 15 stored and seven retired aircraft.

The 57 active aircraft include nine passenger-configured aircraft, 35 factory-built and 13 converted freighters.

The nine active passenger aircraft are split between Aer Lingus (3), Delta (2), Azur Russia (3) and one other aircraft.

Delta Airlines therefore has 111 of the 142 active PW2000-equipped passenger aircraft, equal to 77% of the fleet.

Delta's 757 fleet peaked in 2010 at 180 aircraft following its merger with Northwest and its PW2000-powered 757-200 fleet. The active fleet started to gradually decline a few years later. Delta's current fleet also includes all 16 PW2043-powered 757-300s.

United has the second largest active fleet, with 14 aircraft left in service. These two fleets total 125 of the 142 active passenger aircraft, equal to 88%.

United's 757 fleet peaked at 87 PW2000-powered aircraft in 2009 and 2010, before the absorption of Continental Airlines. Continental's fleet added 61 RB211-powered aircraft, and United's total 757 fleet in 2011 was 156.

The fleet started to decline in 2013 with the gradual retirement of PW2000-powered 757-200s. The fleet dropped by 39 aircraft in 2014, and reached 14 in 2019. These are operated together with 61 RB211-powered 757-200s and -300s.

United's fleet was mainly engines without the reduced temperature configuration (RTC). Some of the retired aircraft were converted and are operated by FedEx.

The fleet of PW2000-powered 757-200 freighters therefore totals 99 aircraft, including 64 converted aircraft. FedEx operates 44 -200SFs, and others are operated by ATI (4), EAT/DHL (11) and a group of other small fleets. UPS operates all 35 PW2040-powered -200PFs.

The 15 stored aircraft with PW2040 engines include 10 that were parked in 2017-2019, plus three old freighters.

The seven aircraft that were retired in 2009-2018 would have provided a source of PW2040 engines.

Engine market

The market dynamics of a used aircraft type often result in a high percentage of a fleet that is inactive through parking and retirement providing sufficient supply of airframes, system components and engines. This reduces the market value of time-continued or 'green time' engines, with some maintenance life

A large number of 757-200s have been retired by airlines that have utilised most of the engines' maintenance life. This is one factor that has caused a recent shortage of serviceable RB211-535 & PW2000 engines with 'green time'.

remaining, to a level where it is more economic for airlines to acquire these engines rather than conduct full shop visits (SVs) and replace life-limited parts (LLPs). This will appeal to many operators of used aircraft that do not require engines to achieve the longest removal intervals.

The economics of this practice depend, however, on how the market availability and value of time-continued engines compares to the cost of full maintenance. Time-continued engines would need to have a maximum value that is equal to the pro-rated value of a shipset of LLPs according to their remaining lives. For example, a shortage of engines will push values higher than 100% of pro-rated LLP values, and so likely to favour SV maintenance.

Availability of green-time engines may be increased with a steady stream of retirements. Engines with maintenance life remaining can, however, be switched to other active aircraft left in a fleet, with the ultimate aim of retiring each fleet member when most of the engine maintenance life has been used. This is financially efficient for the original operator, but it will result in a large number of engines with almost zero maintenance life and a scrap value on the market.

There are 195 inactive RB211-powered and 164 inactive PW2000-equipped 757-200s, equal to 36% of the 757-200s built.

Several other issues, however, affect the supply of time-continued and good quality engines on the market, including: the relative cost of SVs and LLPs, the availability of SV and specialist repair capacity, and the supply of particular parts and components.

RB211-535 & PW2000 market

The actual condition of the RB211-535 and PW2000 market is one of limited or almost zero supply of time-continued engines. This shortage has resulted in airlines being quoted prices of $5 million or more for engines with 4,000EFC or more of remaining LLP life. One case was an engine fresh from an SV, with 9,000EFC LLP life remaining, being marketed for more than $9 million.

As a guide, the market value of RB211-535 engines that can achieve up to 3,000EFC on-wing before requiring maintenance is equal to about $1,000 per EFC. That is, engines that could probably achieve 2,000-3,000EFC would have a value of $2.0-3.0 million. This high rate per EFC would not apply to engines with a superior maintenance condition.

The current shortage of 'green time' engines has been compounded by a series of events over a few years, starting with the closure of several engine shops, or a reduction in their activity. The TAESL shop in Texas for the RB211-535 closed in 2016. This reduced available maintenance capacity, although it was thought it would have little effect because of the rapid retirement of American's aircraft. Some of the aircraft were in fact acquired by The Texas Aero Group and converted to freighters.

The closure of TAESL was soon followed by Rolls-Royce's problems with the Trent 1000, and the subsequent need to transfer all RB211-535 work out of its Engine Overhaul Services (EOS) shop in Derby, UK. Rolls-Royce has awarded StandardAero an exclusive licence to perform maintenance for RB211-535s managed under TotalCare contracts at its Texas facility, but StandardAero's shop is not yet at full capacity. This has left Ameco Beijing and Iberia Maintenance as the two main shops.

In the case of the PW2000, the main engine shops are with Pratt & Whitney Engine Services (PWES), United Technical Operations, Delta Tech Ops, and MTU Maintenance. United Airlines, however, outsourced the maintenance of its PW2000s to other providers. Moreover, it has performed few PW2000 SVs in recent years. Delta Tech Ops is reported to have carried out SVs for only third-party customers, but not engines for Delta Airlines. Most PW2000 engine SV activity has been provided by MTU Maintenance and Delta Tech Ops in recent years. United Technical Operations is available for third-party work.

This reduction in maintenance capacity has been compounded by the reduction in activity at specialist repair providers. Moreover, the production of particular components and parts has slowed or even halted. Examples are high pressure turbine material and the diffuser case for the PW2000, and components for the combustor on the RB211-535.

The situation has been exacerbated by the retirement of large numbers of aircraft with little or no maintenance left on their engines by American, Delta and United. A final factor has been the large number of 757-200s that have been converted to freighter, which means that the 757 fleet has not retired to the same extent as most other aircraft types.

The overall consequences of these developments are that engine SVs are taking a long time to perform. The typical turn time of 60-75 days has been extended to more than 90, partly because engine shops maintain lower levels of part and component inventory. Some specialist repair shops are taking up to 50 days to return components to the engine shops. Some individual engines have been stuck in engine shops for more than a year waiting for particular parts to be provided.

These factors have compounded the shortage of time-continued engines, and led to engines having to undergo SVs, and airlines having to accept the resulting costs.

SV costs for PW2000 engines are from about $4.0 million for a performance restoration, and $5.5 million and higher for an overhaul. This excludes the cost of replacing LLPs. Caution should be taken for findings,

which can add another $250,000-400,000.

In the case of the RB211-535, most operators are having to put engines through a Level 3 SV. This is now reaching a cost of $5.2-5.8 million, and airlines are accepting this and the likely subsequent removal interval. Again, an allowance should be made for findings.

A deeper Level 4 SV will incur a higher cost, and can be escalated with the chance of findings at engine disassembly. A light workscope, such as a Level 2, can help an RB211-535 achieve 2,000-3,000EFC more on-wing.

The 2019 cost of a shipset of LLPs for PW2000 engines is about $7 million, and close to $6 million for RB211-535s. These escalate at about 6% per annum. The LLP lives for the PW2000 are 20,000EFC for all modules, except parts in the high pressure turbine (HPT), which have lives of 15,000EFC.

The LLPs in RB211-535s have varying lives, according to the engine's operating profile. Current list price for a shipset is in the order of $5.8 million.

PW2000 engines are divided between earlier-built non-RTC engines and those with the RTC modification. Lower-rated PW2037 non-RTC engines achieve intervals of 3,800-4,000EFC, and higher rated PW2040 may have 3,400-3,800EFC between removals when used with passenger aircraft.

RTC engines have longer intervals of 6,000-7,000EFC on the PW2037, and about 5,400-6,300EFC on the PW2040.

The RB211-535 is known for its durability, and is capable of achieving removal intervals of up to 7,500EFC, and even longer, when operated at about 2.0EFH per EFC in passenger operations. Engines with a high degree of repaired material can be expected to achieve shorter intervals.

The SV costs can result in relatively high reserves per EFC, not including any consideration for LLPs. This can be up to $800 per EFC in the case of the RB211-535; and in the range of $775 per EFC for RTC PW2000 engines and up to $1,300 per EFC for non-RTC engines.

Express package carriers, however, operate the 757-200 at lower all-up weights than passenger aircraft, and so have a high degree of engine de-rate. Longer removal intervals can therefore be expected. Current and prospective 757 operators therefore have to take into account several economic considerations.

RB211-535 support

Current and prospective 757 operators will need to be assured of several levels of technical and engineering support for RB211-535 engines. This will include engineering management to plan removals and SVs, support from the original equipment manufacturer (OEM) that includes both engineering and the production of components and parts, and sufficient SV capability and capacity.

Estimates by ICF consultants are that the number of RB211-535 SVs for the global fleet will be about 107 in 2019, 99 in 2020, and fall to about 57 in 2022.

One of the first issues to consider is the level of support the OEM will provide the engine over the long-term. The cessation by the OEM of the manufacture of LLPs and critical parts, especially airfoils, would mean that continued operation of the engine is only possible for a limited number of years.

First, the remaining engine shops with RB211-535 capability are StandardAero, located in Texas; Iberia Maintenance, in Madrid, Spain; and Ameco Beijing, Beijing China. Rolls-Royce itself performs RB211-535 maintenance at its EOS shop in Derby, United Kingdom. Rolls-Royce itself offered a range of technical and maintenance services that include its TotalCare, SelectCare, LessorCare, and

RTC-modified PW2000 engines are capable of achieving removal intervals of up to 7,000EFC. Shop visits can incur costs of up to $5 million, and so operators need to be aware of potential maintenance reserves.

time-and-material contracts. About half of RB211-535 engines are maintained under TotalCare contracts, and Rolls-Royce says that about 42% of the fleet is currently not covered by a TotalCare or SelectCare package.

Rolls-Royce has issued StandardAero with an exclusive licence to perform engineering support and SV maintenance for all engines under TotalCare contracts at its Texas engine shop. StandardAero is therefore Rolls-Royce's designated end-of-life engine maintenance service partner. The maintenance work will be transferred to StandardAero over the next 18 months. Standard Aero's Texas engine shop is not yet up to capacity, however. As part of this development, Rolls-Royce has said it is committed to supporting the engine, operators and maintenance shops while there is a viable fleet size.

Operators can opt to leave TotalCare contacts and instead use alternatives, such as time-and-material, if TotalCare no longer meets their requirements.

Standard Aero will be performing all RB211-535 maintenance for engines under TotalCare from January 2021. This will include work that has previously been performed by Rolls-Royce at its EOS shop. Rolls-Royce has started the process of transferring RB211-535 TotalCare maintenance work from its own shop, and will use its EOS shop for maintenance work on its other engines.

All three remaining shops of StandardAero, Iberia Maintenance, and Ameco Beijing will be free to perform maintenance on engines managed under all other types of contact. This will be for the 42% of engines not under a Rolls-Royce Care package. This will be for maintenance contracts such as time-and-material, not-to-exceed prices, and fixed prices.

These are the types of contracts airlines are more likely to select as aircraft change to a freighter operation or approach retirement. These contracts also give airlines the freedom to avoid full SV workscopes and LLP replacement, and swap modules for other time-continued modules and used serviceable material (USM) in SVs.

StandardAero says it has the capacity to support and maintain engines that are not under TotalCare contracts as well as those that are.

Iberia Maintenance in Madrid is a Rolls-Royce-approved shop. Although it will no longer be designated as one of Rolls-Royce's shops for maintenance of TotalCare engines, it will continue to market its capabilities for other types of contract. This is likely to be for an increasing portion of the fleet of engines as more 757s are retired by their primary operators.

Iberia has 10 customers that it contracts for third-party maintenance independently of Rolls-Royce. These are offered the three main types of contract. Iberia Maintenance expects to perform 52 RB211-535 SVs in 2019, a high portion of the total market. This will include about 22 engines managed under pure third-party contracts.

Iberia Maintenance has a high level of parts repair capability. It may also acquire RB211-535 engines in the future if they are needed by its customers and are available on the market.

PW2000 support

There are several high-profile engineering support and maintenance providers for the PW2000, including Pratt & Whitney Engines Services (PWES), Delta Tech Ops, United Technical Operations, CTS Engines, and MTU Maintenance. CTS Engines will start to perform SVs by the end of 2019.

The other four have been the main maintenance providers for a global fleet of more than 400 aircraft. This fleet includes 99 freighters, and the number could increase by another 25-30 aircraft. The main passenger fleets include 14 left with United and 111 left with Delta. Once these fleets have fully retired the remaining active fleet is unlikely to exceed 150 aircraft, taking into account some future freighter conversions. The PW2000, however, has a military counterpart: the F117-PW-100, which powers the C-17 transport. There are more than 270 of these four-engined aircraft in active service. This suggests that the five main engine shops for the PW2000 could have a substantial market to satisfy for an extended period.

Pratt & Whitney provides a range of engine maintenance and management contracts. These include its EngineWise programme, which offers spare engine provisioning and maintenance management. EngineWise thus provides a similar service for the PW2000 that Rolls-Royce's TotalCare programme provides for the RB211-535.

EngineWise is a fleet management programme that charges the operator a fixed rate per EFH. This often suits new operators, but airlines are free to use flexible maintenance contracts such as time-and-material. This would allow airlines to perform their own engineering management.

Pratt & Whitney performs SV maintenance and overhaul for the PW2000 at its Columbus Ohio shop, and conducts parts repairs through its East Hartford Repair Operations facility.

Delta Airlines operates the largest fleet of PW2000-powered aircraft, and its fleet of 757s peaked at 180 units in 2010. Delta Tech Ops has a large facility at Atlanta, Georgia. It has a wide range of capabilities that include all levels of SVs up to complete overhaul, first run warranty repairs, test cell runs, and engineering support.

United Technical Operations' engine shop is located in San Francisco. It is a Pratt & Whitney-approved engine maintenance and repair shop. United Technical Operations does not, however,

operate as a shop for Pratt & Whitney's EngineWise programme. It is an independent shop, and markets to its own customers.

In addition to SV workscopes, United Technical Operations has developed a wide range of high-tech and specialised parts repairs. It uses lower-cost parts manufacturing approved (PMA) components and airfoils in SVs as an alternative to OEM parts. It also uses designated engineering representative (DER) repairs that it has developed for PW2000 components and airfoils. It says PMA parts and DER component repairs can be used as an element of cost management.

United Technical Operations also provides engineering management that includes SV workscope planning, engine and module maintenance scheduling, airworthiness directive (AD) and service bulletin (SB) review and implementation, and LLP planning.

MTU Maintenance in Hannover, Germany is a long-term PW2000 maintenance and support provider, and recently announced its commitment to its PW2000 maintenance repair and overhaul programme for the next 10 years.

MTU Maintenance is fully independent, and has full PW2000 SV capability up to piece-part disassembly and assembly, as well as parts inspection and specialist repairs. It performs about 20 SVs per year.

MTU Maintenance offers its SAVE^{PLUS} programme for mature engines. This uses maintenance alternatives such as smart repairs, the use of USM and customised engine builds, and alternatives to maintenance that include engine leasing. MTU Maintenance also develops repairs that are alternatives to those offered by the OEM. It says these reduce scrap rates and are cheaper. It recently introduced a mini tip repair for stage 2 HPT blades, which significantly extends the parts' life. It also offers repairs for HPT outer air seals, which improves engine performance and EGT margin.

CTS Engines is based in Fort Lauderdale, Florida. To date it has primarily been an engine shop for the CF6-50 and CF6-80C2 engines, but also has PW2000 capability. It says it will maintain this capability for the long term, and will have full test capability for the PW2000 by the end of 2019.

CTS Engines also has high-tech parts repair inspection capabilities that include machining, grinding, welding and non-destructive test (NDT). Its NDTs include fluorescent penetrant inspection (FPI), eddy current inspection (EDI), and ultrasonic inspection (USI) tests.

CTS Engines is focused on providing maintenance for mature engines with a civil and military application. The CF6-50 is an important engine for the KC-10 fuelling tanker in the US Air Force, and the PW2000 has both civil and military applications that will require long-term support. CTS Engines therefore expects to be in the PW2000 market for the long term. It is also exploring the purchase of parts and engines to support the PW2000's material requirements.

Summary

The current shortage of PW2000s and RB211-535s has led to an increased demand for maintenance and pushed engine values high. To prevent this situation from persisting it is inevitable that some engines will have to be put through SVs, which is made more difficult by a lack of capacity. The upside is that both engines can achieve long removal intervals, and so alleviate similar shortages for an extended period. The 757-200 has not retired as fast as many other types, and it can be expected to remain popular, especially among freight airlines. AC