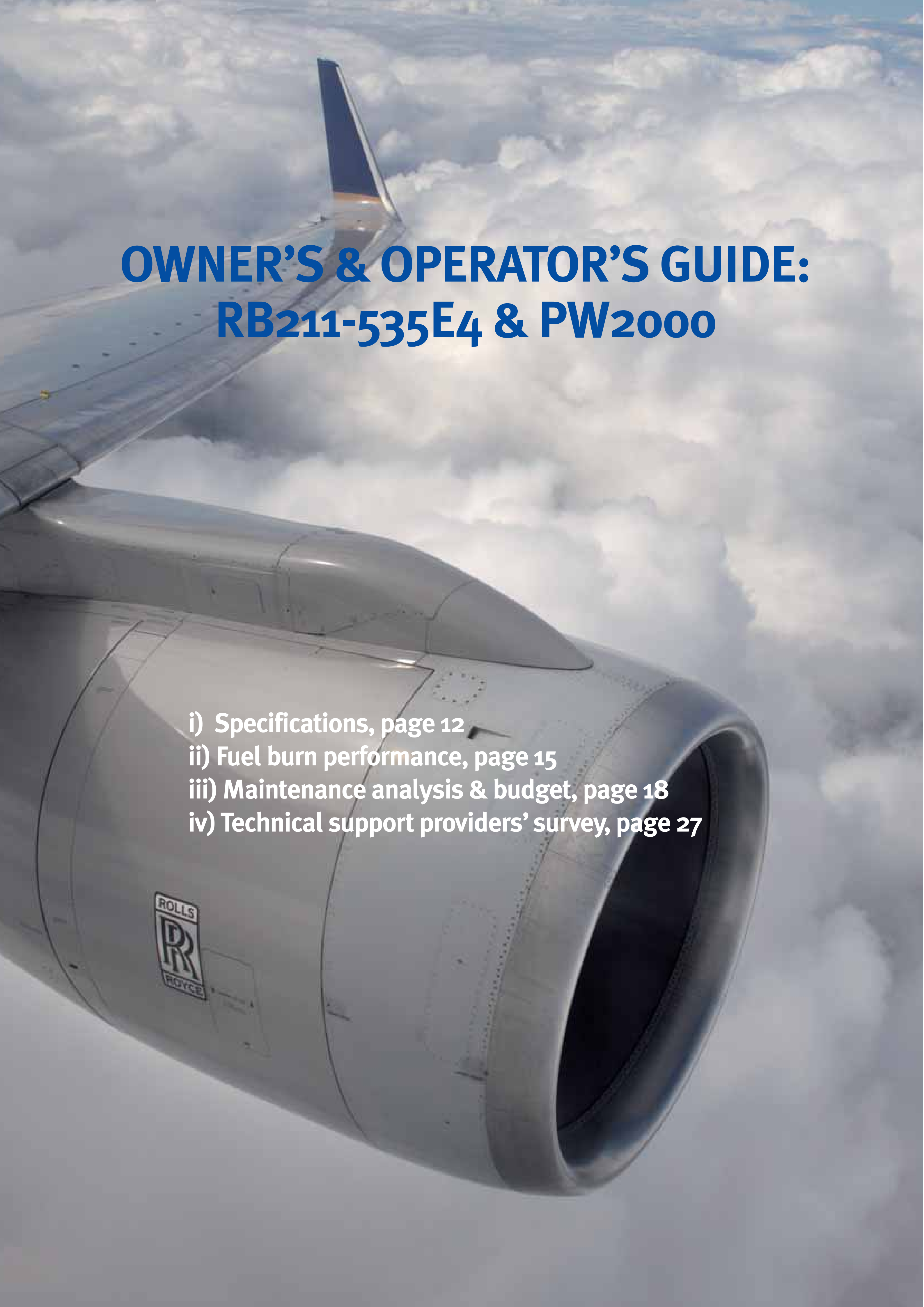

OWNER'S & OPERATOR'S GUIDE: RB211-535E4 & PW2000

PW2000 & RB211-535 specifications

The RB211-535 & PW2000 series have seven variants between them. Their characteristics and specifications are described.

The 757 family is powered by two main engine types: the PW2000 and RB211-535, each with three variants.

The 757-200 was offered with the RB211-535C, -535E4, -535E4-B, PW2037 and PW2040 engines. The 757-300 was offered with the RB211-535E4-B, -535E4-C, PW2037, PW2040 and PW2043.

The initial engine variants powering the 757-200, which entered service in 1983, were the PW2037 and the RB211-535C. Soon afterwards, Rolls-Royce (RR) developed the RB211-535E4, with the -535C powering just 58 aircraft. Pratt & Whitney (PW) introduced the higher-thrust-rated PW2040 in 1987.

RB211-535

In addition to the RB211-535C, there are three variants of the RB211-535E4: the -535E4, -535E4-B and -535E4-C.

The RB211-535E4 replaced the -535C and entered service in 1984 with Eastern Air Lines. Shortly afterwards, 18 aircraft originally fitted with the -535C were re-engined with the -535E4.

The RB211-535 has the three-shaft design of the original RB211 family. This separates the fan and low pressure compressor (LPC) on the low pressure shaft of a two-shaft engine into a low pressure shaft (fan) and intermediate pressure shaft (compressor). This allows the intermediate pressure compressor (IPC) to turn at a higher speed than the LPC is able to in a two-shaft engine. The IPC and high pressure compressor (HPC) therefore require fewer stages than the compressor sections of a two-shaft engine. This gives the RB211-535 a shorter, stiffer structure, and results in a low rate of exhaust gas temperature (EGT) margin erosion. It also reduces the need for compressor variable guide or stator vanes.

The RB211-535 has a fan diameter of 74.1 inches, a six-stage IPC, a six-stage HPC, a single-stage high pressure turbine (HPT), a single-stage intermediate pressure turbine (IPT), and a three-stage low pressure turbine (LPT). This basic configuration has been used on every variant of the RB211-535. The 12 compressor and five turbine stages compare to the PW2000's 16 compressor and seven turbine stages.

The RB211-535C was the last variant of the RB211 family to use fan blades with a mid-span shroud. The -535C is rated at 37,400lbs thrust. The new -535E4 introduced the use of wide-chord fan blades, which do not have a mid-span shroud. Their wider chord means there are fewer blades in the fan section, which improves fuel burn efficiency and resistance to foreign object damage.

The -535E4 variant has a rating of 40,100lbs thrust *(see table, page 13)*. The later -535E4-B variant, introduced on the 757-200 in 1989, is rated at 43,100lbs thrust. The -535E4-C, powering the 757-300, is rated at 43,100lbs thrust. All three variants have the bypass ratio of 4.3:1.

The -535E4 also featured extensive use of advanced computer-designed aerodynamics, resulting in, among other things, the wide-chord fan blade.

RR's development of the Trent engine family and its 04 HP (high pressure) module meant that later production examples of the RB211-535E4 benefited from Phase 5 combustor technology. This reduced NOx emissions.

RR further developed the -535E4 to become the higher-thrust -535E4-B, which went into service with American Airlines in 1989. The third variant, the -535E4-C, went into service on the 757-300 in 2001.

According to ACAS, there are currently 577 RB211-535E4-powered 757s, of which 349 have the original RB211-535E4 and 216 (757-200, -200EM, -200PCF and -300) have the -535E4-B. Only 12 757-300s have the -535E4-C, operated by Continental and the now defunct ATA Airlines.

The final order status for the 757 saw RR with 59% of the 1,049 aircraft built. The RB211-535 was also chosen by 43 (78%) of Boeing's 55 customers for the 757. The -535E4 engine has also recently been used on the Tupolev Tu-204 family.

The RB211-535E4-powered 757 is the quietest airliner in its class, and meets both Chapter/Stage 3 and 4 limits with large margins.

PW2000

There are three variants of the PW2000: the PW2037, PW2040 and PW2043.

The PW2037 entered service on the 757-200 in 1984 with Delta Airlines. It is

The RB211-535E4 became the most popular engine selection for the 757-200/-300, powering 59% of the 1,049 aircraft built.

a conventional two-shaft turbofan engine, with a 78.5-inch-wide fan, a four-stage LPC, 12-stage HPC, two-stage HPT and five-stage LPT. The two-stage HPT design gives the PW2000 better fuel burn performance than the RB211-535.

The PW2037 is rated at 38,250lbs thrust and has a bypass ratio of 6.0:1. The PW2040's thrust rating goes up to 41,700lbs, and the engine entered service in 1987 for UPS. The PW4043 was certified in 1995, but did not enter service until 2002 with Northwest, and is rated at 43,000lbs thrust.

The PW2000 was the first to offer Full Authority Digital Electronic Control (FADEC), an electric engine control system. The PW2000 also uses new materials, new airfoil profiles, new combustor configurations and other special technological features.

There are 429 757s powered by the PW2000 series engines. Most of these, 289, are equipped with the PW2037, while 140 are powered by the PW2040.

The ACAS fleet database lists no aircraft fitted with the PW2043 engines, although this could be because current PW2000 engines can be converted to a PW2043 through simple minor external modifications.

Noise compliance

Both engine series and their various models are compliant with Chapter/Stage 3 noise requirements.

In June 2001 a new Chapter/Stage 4 noise standard, more stringent than Chapter/Stage 3, was adopted. From 1st January 2006, the new standard applied only to newly certificated aircraft and to Chapter/Stage 3 aircraft for which re-certification to Chapter/Stage 4 is requested. The 757 therefore does not have to comply with Chapter/Stage 4 requirements.

Chapter/Stage 4 noise rules are that only aircraft certified after 1st January 2006 should have a cumulative noise reading of 10 EPNdB lower than their permitted Chapter/Stage 3 cumulative noise emissions.

The 757 family has Chapter/Stage 3 compliance margins varying from 11.30 EPNdB to more than 22 EPNdB. They are therefore all still Chapter/Stage 4 compliant by 1.3-12EPNdB.

Although the 757 does not have to be Chapter/Stage 4 compliant, it would if regulations change, and could become so with no additional modifications.

The RB211-535E4-powered variants have the highest noise compliance margins, with many having a margin of more than 20EPNdB.

NOx emissions compliance

The Phase 5 combustion technology and the excellent noise output, meant that the RB211-535E4 was the most environmentally friendly engine available for the 757. The new combustor allowed the engine's NOx emissions to meet CAEP IV standards. The older engines, which have Phase 2 combustors, do not have to comply with CAEP IV standards.

RB211-535E4 & PW2000 THRUST RATING & SPECIFICATION DATA

Engine	Aircraft application	Take-off thrust lbs	Max EGT take-off	Bypass ratio	Flat rated temp deg C
PW2037	757-200	38,250	897	6.0:1	30.55
PW2040	757-200/-300	41,700	897	6.0:1	30.55
PW2043	757-200/-300	43,100	897	6.0:1	30.55
RB211-535C	757-200	37,400	N/A	4.3:1	29
RB211-535E4	757-200/-300	40,100	850	4.3:1	29
RB211-535E4-B	757-200/-300, Tu-204	43,100	897	4.3:1	29
RB211-535E4-C	757-300	-E4-B plus 4%	877	4.3:1	29

Etops

Shortly after the 757 entered service in the early 1980s, extended-range twin-engine operations (Etops) were pioneered, making possible the operation of twin-engined aircraft on long-range missions over water or remote areas with no suitable alternate airports. Etops is only permitted once a particular airframe-engine combination has demonstrated a specified level of in-service reliability. It also requires the aircraft to have specific equipment and safety equipment configuration, and operators to implement specific maintenance and operational procedures.

The RB211-535E4-powered 757-200 was certified for 120-minute Etops in 1986. This means that the aircraft is permitted to follow a route over water provided it is within 120 minutes' flying time of a suitable diversion airport when operating with one engine shut down.

The PW2000-powered 757 achieved 120-minute Etops certification in 1990, and a few months later the RB211-powered aircraft achieved certification for 180-minute Etops. The PW2000-powered aircraft achieved 180 minutes certification in 1992.

Most long-distance routes over water and remote areas can be flown directly with an aircraft that has 180-minute Etops certification.

Major upgrades

Most upgrades and modifications have been for the PW2000 series of engines with only a handful of active airworthiness directives (ADs) for each of the engine series.

As the PW2000 and RB211-535 were developed and superseded, more upgrades and modifications were required to improve the existing engines in operation.

PW introduced the Performance Improvement Package (PIP) in 1988, and the Reduced Temperature Configuration (RTC) in 1994. Both improved durability.

The PIP and RTC were a modification to existing engines and a new configuration for subsequently manufactured engines. The other modification available on the PW2000 was the external modification to upgrade an engine to the PW2043 specifications, which again improved durability.

RR's major upgrade (available as a modification, but rarely taken up) involved using new Phase V combustor technology.

PW2000 (PIP)

In 1988, PW brought out the PIP, a new package to improve durability (SB 72-143). This improvement involved modifications to, among other things, the fan exit case and liners, P2.5 bleed valve ducts, number 4 bearing cooler assembly and oil cooler manifolds.

PW2000 RTC

The RTC was certified in September 1993 and introduced as the improved manufactured version of the PW2000 in 1994. It was designed with new temperature reduction features as well as increased capability in the second generation FADEC. The new configuration was offered on new engines, and as an option to modify older PW2000 engines to RTC standards with a Compressor Exit Temperature (CET) kit.

The RTC modification included improvements to the second vane and

The PW2000 is concentrated among three big carriers; Northwest, United and Delta. These three operators accounts for 305 of the 429 PW2000-powered 757s built.

airseals, blade and vane clearances to optimise efficiency, and the application of a thermal coating to the first vanes. The first turbine blade had a metal temperature margin of 300°F, the fan blade and spinner cap were more robust, additional sound treatments were added, and the LPC was supercharged. These new RTC features contributed to a 1+ dB reduction in noise, a 50°F reduction in EGT and another 1% improvement in specific fuel consumption.

The RTC modification improved reliability, durability, on-wing times and environmental performance, and reduced total maintenance costs and fuel burn.

Upgrade to PW2043

PW2000 engines can be 'upgraded' to PW2043, thereby increasing their thrust rating and performance capability. The PW2043 provides additional thrust at high altitudes and/or elevated temperatures, through minor external modification (some software modifications and the addition of an extra fuel pump). Enhancements to the upgraded engine have increased its time on-wing and lowered maintenance costs.

Northwest Airlines, the intended launch customer for the aircraft/engine combination, had ordered 16 PW2043-powered 757-300s, but actually took delivery of 16 PW2040-powered 757-300s. To date, no PW2043 engines have been delivered, although it is still listed as a legitimate engine option for the 757-300.

RB211-535 Phase V

In 2000, RR introduced the Phase V combustor that would allow the RB211-535E4 engines to comply with new CAEP IV regulations for NOx emissions being introduced, even though the RB211-535E4 did not actually need to comply with CAEP IV. RR had already developed a new combustor for the Trent series of engines to meet CAEP IV emissions levels, and decided to integrate this into new-production RB211-535E4s.

The combustor was known as Phase V, and was standard in later engines. The modification (SB72-C23-) meant lower NOx emissions, with major changes to the combustor as well as some of the adjacent hardware. It proved to be less popular than expected and fewer than 200 engines have the Phase V technology.

Airworthiness directives

The RB211-535 series comes under the jurisdiction of the UK Civil Aviation Authority (CAA). The CAA has been responsible for issuing ADs for RR engines, although recently this has been more the remit of the European Aviation Safety Agency (EASA).

The PW2000 series comes under the jurisdiction of the American Federal Aviation Administration (FAA).

In 2003 the CAA issued AD G-2003-0007 for the RB211-535. It stated that focused inspections must be carried out on the Group A (critical) parts to prevent Group A (critical) rotating engine part failure.

In 2005 ADs were issued about both engine series. The FAA said that its study into failures of critical rotating PW2000 series engine parts necessitated obligatory inspections. It required revisions to the airworthiness limitations section of the manufacturer's manual and an air carrier's approved continuous airworthiness maintenance programme to incorporate additional inspection requirements. AD 2005-18-03 was issued to prevent critical life-limited rotating engine-part failure. This enhanced rotor inspection was connected to the FAA's safer skies initiative.

Acting on behalf of EASA, the CAA issued AD G-2005-0028 R1 instructing an enhanced inspection of the HPC interstage 1-2 weld for all RB211-535-series-equipped aircraft. This was after an overhaul inspection of HPCs 1 and 2 rotors had identified cracks running in an axial direction in the region of the weld and between the stage 1 and 2 rotor discs, representing a potential hazard to the rotor integrity.

A year later, EASA issued AD 2006-0182, saying that the HPT discs on the RB211-535 series failed to meet the inspection acceptance criteria and were returned to RR with cracks in the disc rim. The conclusion was that this was due to scores within the cooling air holes in the disc rim possibly introduced during manufacture or overhaul. This AD mentioned the CAA AD (G-2004-0027) that had addressed the same issue about 18 months earlier.

In the past 18 months there have been three ADs: one about the PW2000 series (AD 2007-02-06); and two about the RB211-535E4 series (EASA 2008-0045 and FAA 2008-13-20).

AD 2007-02-06 required a one-time focused inspection of PW2000 eighth-stage HPC drum rotor disk assemblies due to a failure caused by tooling damage.

A detailed inspection of the RB211-535E4's LPT discs during module overhaul and refurbishment found a processing error, which meant that items with undetected cracks could be in operation. AD 2008-0045 dealt with this problem and required removal, inspection and replacement of the affected parts. The module overhaul and refurbishment processes are being reviewed. The most recent, AD 2008-13-20 requires repetitive inspections of the aft hinge fittings and attachment bolts of the thrust reversers for signs of damage. Corrective measures were then to be taken. This AD was issued after many cases of failure, due in particular to high operational loads. AC

PW2000 & RB211-535 fuel burn performance

The fuel burn performance of the main RB211-535E4 & PW2000 variants powering passenger- and freighter-configured aircraft are analysed.

The 757-200 and -300 aircraft were each offered with four engine options. The 757-200 options were the RB211-535E4, -535E4B, PW2037 or PW2040 engines. The 757-300 was offered with the RB211-535E4C, PW2037, PW2040 or PW2043 engines. The 757-200 also briefly had the RB211-535C, but only a small number of aircraft have this engine.

This means there are eight main different official airframe-engine combinations. If all the various freighter variants are considered, then there are another eight variants that could be analysed.

The 757-300 series is equipped with the PW2040, and the -E4B and -E4C variants of the RB211-535.

The 757-200 series is operated using the two lower-thrust-rated engines in the both the PW2000 series and RB211-535E4 series.

This analysis studies the performance of the passenger variants of the -200 and -300 series, and the freighter-converted variants of the 757-200. For the passenger-configured 757-200, the lower-thrust-rated engines from both engine manufacturers have been used. For the -300 the high-thrust-rated RB211-535E4B has been used. The freighter-configured versions of the 757-200 have been studied with the RB211-535E4, PW2037 and PW2040.

There are many thrust and maximum take-off weight (MTOW) options used by different airlines. The basic specification weights, as stated by the engine manufacturers, have been used for these calculations.

Sectors analysis

The 757 has been a workhorse for both the international scheduled airlines and the European carriers involved in the leisure and all-inclusive charter markets. Most, if not all, of the big American carriers and the European charter airlines have recently operated 757s, and many still have them in their fleets. The 757-200 is economically viable on a variety of routes, which vary from short-haul domestic to long-haul inter-continental.

Two routes have been used to analyse the fuel burn of three of the most numerous airframe-engine combinations. The first route is representative of the US domestic market: Houston (IAH) to Denver (DEN) *(see table, page 16)*. There are 184 seats on the 757-200 and 216 on the 757-300, reflecting the two-class cabins the US majors typically operate.

The second route is representative of the type of flight that UK charter airlines would use the 757 for: London Gatwick (LGW) to Larnaca, Cyprus (LCA) *(see table, page 16)*. The 757-200 will carry up to 235 passengers and the -300 up to 280 on this route. This, again, reflects the typical single-class charter configuration for these two aircraft.

The standard weight for each passenger and their baggage is assumed to be 220lbs with no additional cargo carried. The payload for the US domestic route will therefore be 40,480lbs for the 757-200 and 47,520lbs for the 757-300 *(see table, page 16)*. For the longer charter route the payload will be 51,700lbs for the -200, and 61,600lbs for the -300.

Aircraft performance has been analysed in both directions on each route to illustrate the effects of wind speed and direction on the actual distance flown, also referred to as Equivalent Still Air Distance (ESAD). 85% reliability winds and 50% reliability temperatures for the month of August have been used in the flight plans performed by Jeppesen. Flight times are 110 minutes for the US sectors and 270 minutes for the charter sectors.

The alternate airport for the IAH-DEN route is City of Colorado Airport, Colorado (COS). The tracked distance of 756nm on IAH-DEN increases to an average ESAD of 798nm due to a head-wind of 28-30 knots *(see table, page 16)*.

The return sector has a slightly longer tracked distance of 794nm. Due to a smaller headwind of 4 knots, the ESAD increases by a small amount to an average of 800nm, only 2nm more than the first sector. This return sector uses San

The PW2000-powered variants of the 757-200 and -300 have the best fuel burn performance. The difference with RB211-powered aircraft is only a few percent, however.

FUEL BURN PERFORMANCE OF PASSENGER-CONFIGURED 757-200 & 757-300 SERIES

City-pair variant	Aircraft	Engine model	MTOW lbs	TOW lbs	Fuel burn USG	Block time mins	Passenger payload	ESAD nm	Fuel per seat	Wind speed
IAH-DEN	757-200	PW2037	240,000	186,034	2,357	130	40,480	798	12.81	-30
IAH-DEN	757-200	RB211-535E4	240,000	187,435	2,409	130	40,480	799	13.09	-29
IAH-DEN	757-300	RB211-535E4B	272,500	211,860	2,775	130	47,520	797	12.85	-28
DEN-IAH	757-200	PW2037	240,000	188,491	2,202	134	40,480	801	11.97	-4
DEN-IAH	757-200	RB211-535E4	240,000	189,894	2,308	134	40,480	799	12.54	-4
DEN-IAH	757-300	RB211-535E4B	272,500	214,480	2,646	132	47,520	800	12.25	-4
LGW-LCA	757-200	PW2037	240,000	219,045	5,239	281	51,700	1,937	22.29	4
LGW-LCA	757-200	RB211-535E4	240,000	221,118	5,461	280	51,700	1,936	23.24	4
LGW-LCA	757-300	RB211-535E4B	272,500	252,532	6,385	281	61,600	1,937	22.80	4
LCA-LGW	757-200	PW2037	240,000	221,018	5,571	297	51,700	2,063	23.71	-44
LCA-LGW	757-200	RB211-535E4	240,000	223,134	5,805	295	51,700	2,063	24.70	-44
LCA-LGW	757-300	RB211-535E4B	272,500	254,756	6,763	294	61,600	2,054	24.16	-43

Source: Jeppesen

Antonio International Airport, Texas (SAT) as an alternate.

The second route, LGW-LCA, uses Paphos International Airport, Cyprus (PFO) as an alternate. This sector has a tracked distance of 1,954nm, and a shorter ESAD of 1,937nm due to a 4-knot tail wind.

The return sector for this route uses London Stansted, UK (STN) as an alternate. The route has a shorter tracked distance of 1,867nm. With a headwind of about 44 knots, the ESADs are longer than the third sector at 2,054-2,063nm *(see table, this page)*.

To illustrate the effect of hot temperatures on the engines, these two routes were planned with arrival into Larnaca at 1200 local time and departure from Larnaca at 1300 local time.

Flight profiles

The flight profiles in each case include standard assumptions on fuel reserves, diversion fuel (for the alternate airports mentioned above), contingency fuel, and a taxi time of 20 minutes for the whole sector. This is included in block time.

Taxiing typically accounts for a fuel burn of 2,200-2,600lbs for both ends of the sector for the 757-200, and 2,700-3,100lbs for the 757-300. All the sectors are flown using the economy cruise speed of Mach 0.80. Cruise speed affects flight time, but also fuel consumption. The use of economy cruise provides a compromise between speed and fuel burn. If longer distances were needed, a slower long-range-cruise speed would be used that consumes less fuel per nautical mile.

Fuel burn performance

The fuel burn performance of each aircraft/engine combination is shown *(see table, this page)* for both routes along with the associated burn per passenger.

The data show that for each sector, the block fuel burn increases as the actual take-off weight increases. The PW2000-powered aircraft is marginally lighter than the RR-powered aircraft, while the larger -300 is heavier than the -200.

On the IAH-DEN sector, the 757-200 equipped with the PW2037 engine has a fuel burn of 2,357 US Gallons (USG), compared to a burn of 2,409USG for the RB211-535E4-powered -200. This is a difference of 52USG on a 110-minute, 800nm trip, which gives a 2% advantage for the PW2037-equipped aircraft.

The DEN-IAH sector gives a larger advantage to the PW2037 of 4.5%.

On the longer LGW-LCA and LCA-LGW routes, the difference between the two airframe-engine types is 222-234USG. This is a 4% advantage to the PW2037 in either direction, for trips of 260-275 minutes and 1,940-2,060nm.

The block fuel-burn of the 757-300 is more than that of the -200 variant's, but that is due to its longer length, which makes it heavier. With its increase in size, come extra seats and passengers, and more potential revenue.

Economics

The results *(see table, this page)* also show fuel burn per passenger and per passenger-mile, using the ESAD (rather than the tracked distance). As the aircraft size and weight increase, so too does the required engine thrust, and the quantity of fuel burnt. Fuel burn per passenger is nevertheless lowest with the 757-300, on account of its higher seat numbers. Fuel performance is best for the 757-300 in charter configuration, only if there is a full load for each variant, as used in these flight plans.

When the fuel burn per passenger in USG is examined on the shorter route, the PW2037 is the most fuel-efficient. The longer the route, the better the fuel burn per passenger.

The fuel burn per passenger-mile in USG confirms much of what has already been said, in a general ranking order of fuel efficiency. But it also shows that all three main types have close fuel efficiencies.

757 freighters

Over 100 757s are freighters or being converted into freighters. Conversion seems to be an increasingly valid option for 757s that are no longer required by passenger operators. The 757-200 is the only 757 used as a freighter, and there are many freighter variants available, including the factory-built freighter, and several passenger-to-freighter conversion variants. The passenger-to-freighter variant that has won the most orders in recent years is Precision Conversions' (PCF) modification.

The fuel burn and operating performance of the 757-200PCF are analysed here. Not only does it account for the largest number of converted 757-200s, it has also recently increased its

FUEL BURN PERFORMANCE OF 757-200PCF

City-pair	Aircraft variant	Engine model	Fuel USG	Flight time (mins)	Freight payload (lbs)	Tracked distance-nm	ESAD nm	Wind speed factor
MIA-SAL	757-200PCF	RB211-535E4	2,998	133	72,000	975	968	3
MIA-SAL	757-200PCF	PW2037	3,013	138	72,000	975	968	3
MIA-SAL	757-200PCF	PW2040	3,003	138	72,000	975	968	3
MIA-SAL	757-200PCF	RB211-535E4	3,064	133	80,000	975	968	3
MIA-SAL	757-200PCF	PW2037	3,083	138	80,000	975	968	3
MIA-SAL	757-200PCF	PW2040	3,060	138	80,000	975	968	3
SAL-MIA	757-200PCF	RB211-535E4	3,113	135	72,000	978	987	-4
SAL-MIA	757-200PCF	PW2037	3,090	141	72,000	978	987	-4
SAL-MIA	757-200PCF	PW2040	3,073	140	72,000	978	987	-4
SAL-MIA	757-200PCF	RB211-535E4	3,173	135	80,000	978	987	-4
SAL-MIA	757-200PCF	PW2037	3,120	141	75,600	978	987	-4
SAL-MIA	757-200PCF	PW2040	3,128	140	80,000	978	987	-4

gross structural payload to 80,000lbs through an increase in maximum zero fuel weight (MZFW). The performance of the 757-200PCF equipped with the RB211-535E4, PW2037 and PW2040 engines is examined.

The two variants of the aircraft examined are those with the highest MZFW options of 188,000lbs and 196,000lbs. The RB211-powered versions of these variants have gross payloads of 72,000lbs and 80,000lbs. The PW2000-powered versions of the same aircraft have slightly higher payloads because of marginally lighter operating empty weights (OEWs).

Freighters converted by different companies and conversion programmes will have different OEWs. The difference in OEW between the -200PCF and the same aircraft converted by Alcoa-SIE (757-200ACF) is 1,823lbs in favour of the -200PCF. The -200ACF will have a 1.0-1.1% higher fuel burn. The fuel burn shown *(see table, this page)* can therefore be increased by 1% for the equivalent variant of the 757-200ACF.

As already stated, the fuel burn performance for 757 freighters will be assessed using the 757-200PCF. The engines used will be the PW2037, PW2040 and Rolls-Royce RB211-535E4, to make three aircraft/engine variations for each of the two MZFW weights.

The route used to illustrate the fuel burn performance of the freighter is El Salvador (SAL) to Miami (MIA). This is representative of the distance that many 757 freighters are likely to operate.

An average take-off temperature of 25°C has been used at both El Salvador and Miami. Average winds for the area in August have been used, as well as maximum payloads where permitted. The only example where the aircraft have a take-off weight, and therefore payload, limitation is the heavier MZFW aircraft of 196,000lbs with the PW2037 engines. This variant has a payload limitation of 4,400lbs, so it is only able to carry 75,600lbs of its maximum capacity of 80,000lbs.

SAL-MIA has an ESAD distance of 968nm, compared to an actual distance of 975nm. This sector has been helped by a 3-knot tail wind. Flight times are 133-138 minutes, with the RR-equipped aircraft being five minutes faster than the PW-equipped aircraft each time.

The return sector has an ESAD of 987nm, which was longer than the actual distance of 978nm, due to this sector's 4-knot headwind. Flight times are a little longer at 135-141 minutes due to the headwind and a very slightly longer routeing. The flight times were the same for each engine, regardless of which MZFW aircraft it was powering. The RR-powered aircraft was faster than the PW-powered examples.

On the first sector, the aircraft-engine combination with the best fuel burn was the 757-200PCF with the -535E4 engine and a 188,000lbs MZFW. On the second (return) sector, the lower MZFW again, now with the PW2040, had the lowest fuel burn. Generally, the lower MZFW and payload variants on both sectors had the better fuel burn of 1.5-3.15%, equal to 57-70USG in either direction. These additional fuel burns are small in relation to the revenue value of the 8,000lbs higher payload carried.

On the lower MZFW there are differing results on both sectors. On the first sector, the -535E4 has a better fuel burn than that of the PW engines by 0.2-0.5%. On the second sector, the PW2040's fuel burn is 0.55% better than the PW2037's and 1.28% better than the RB211-535E4's.

The fuel burn figures of the higher MZFW aircraft show a different result for each sector. On the first sector, the PW2040 only narrowly beats the -535E4 by 0.13% and the PW2037 by 0.75%. On the second sector, the PW2037 has the better fuel burn figure by 0.255% (PW2040) and 1.67% (RB211-535E4), but that is because of the adjusted TOW and carrying less weight. If like-for-like are compared, the PW2040 is 1.42% more fuel-efficient than the -535E4-powered aircraft on the second sector.

On this route and with these examples, no clear aircraft-engine combination has the better fuel efficiency, so an alternative way of assessing this is in terms of lbs carried per US Gallon used. This shows the higher MZFW aircraft carrying the most, with 26lbs of freight per USG burnt (with the -535E4 and PW2040 doing slightly better than the PW2037).

The lower MZFW aircraft carry 24lbs per USG, with the -535E4 and PW2040 again doing slightly better than the PW2037. On the second sector, the higher MZFW aircraft are again carrying more per fuel load. The PW2040 is the best performer with 25.58lbs per USG, compared to 24.23lbs/USG and 25.21lbs/USG for the PW2037 and -535E4. While the PW2037, with the adjusted TOW, seemed to perform well in fuel efficiency, it is actually last when considering the payload per US Gallon.

There is little difference between each of the engines on this route, with the RB211-535E4 doing fractionally better than the PW2000 engines. The longer the route, however, the more likely it is that the PW2000-powered aircraft, especially the PW2040, will prove better on fuel efficiency. AC

PW2000 & RB211-535 maintenance analysis & budget

The majority of PW2000s & RB211-535s 757s operate at 3.0EFH per EFC. Their operation and maintenance costs are analysed here.

The RB211-535 and PW2000 engines power a total of 1,010 757-200s and -300s. The PW2000 suffered from an image of poor reliability during its first few years of operation, as a result of which it lost market share to the RB211. The RB211-535 series won orders for the majority of aircraft and customers, and now powers about 580 aircraft. The PW2000 powers 430 aircraft, 305 of which are in large fleets operated by Delta Airlines, Northwest and United Airlines.

The first 757s entered service in 1982, and the last were built in 2004. Most engines have therefore passed their first shop visit and are mature in maintenance terms. About 880 of the 757s are configured as passenger aircraft and have flight cycle (FC) times varying from 2.0 to 4.0 flight hours (FH). Another 130 aircraft are freighter variants, the majority being factory freighters. The average FC length across the 757 passenger fleet is about 2.7FH, so the PW2000's and RB211-535's maintenance costs are therefore examined in operations with this average FC.

Engines in operation

About 90% of 757s in operation are in passenger configuration. The largest number of 757s is used by US majors. This group totals 530 of the 880 passenger aircraft. American Airlines, Continental Airlines and USAirways operate 225 RB211-535-powered aircraft, while Delta Airlines, Northwest, and United Airlines operate 305 PW2000-powered aircraft.

Northwest operates a fleet of 71 PW2000-powered 757-200s and -300s. The airline's -200s are powered by the PW2037, and were first delivered in 1985. The carrier's -300s started operations in 2002 and are equipped with PW2040s. The two sub-fleets average about 3,300FH and 1,200FC per year, with an average FC time of 2.75FH.

Most of these aircraft are operated on domestic routes by their airlines, with the 757 often being used on the longer and heavier routes. An increasing number of 757s are operated on international routes by some US majors. Delta, for example, has reorganised its operation by reducing its domestic capacity, and shifting some of its 757s and other aircraft to Central and South American routes. This has affected the average FC time of these aircraft, which has now increased to about 3.0FH.

Delta has the largest 757 fleet in operation, with 137 PW2037-powered 757-200s. Some of its aircraft have extended range capability and are used on international routes for up to 11FH per day. The larger group of aircraft used on domestic flights operates at 2.83FH per FC.

European carriers account for the second largest group of passenger-configured 757s. About 190 aircraft are operated in Europe and the CIS. Large fleets of 757s are operated in Western Europe by British Airways, Condor, Finnair, First Choice, Iberia, Icelandair, Jet2.com, Monarch Airlines, Thomas Cook and Thomsonfly.

Iberia has operated the RB211-535E4-powered 757-200 for more than 10 years in its European network. The aircraft have been operating at a utilisation of 2,600FH and 1,800FC per year, a ratio of about 1.5FH per FC.

Finnair operates seven 757-200s, equipped with PW2040 engines, as charter aircraft with a high-density seating configuration. These aircraft have some of the longest average FC times in the 757 fleet. "The aircraft are relatively young, with the first one delivered in 1997," says Janne Pallonen, manager PW2000 engineering at Finnair Technical Services. "We operate the aircraft to Brazil and Mexico in the winter months, and to Mediterranean destinations in the summer. The average FC time across the year's operation is about 4.5FH."

The third largest group of 757s is in China, with Air China, China Southern, Shanghai Airlines and Xiamen Airlines operating more than 50 aircraft.

The overall 757 passenger fleet achieves annual utilisations of 3,100FH and 1,100FC per year, with FC time averaging 2.9FH.

The freighter fleet of 190 aircraft is a mix of factory-built and converted freighters. The converted freighters operated by European Air Transport and DHL are used for express package operations, as are virtually all the factory-built aircraft that are operated by United

The majority of 757 operations are medium haul, with many close to an average EFC time of 3.0EFH.

The PW2000 fleet is divided between engines that do not have the RTC modification and those with the RTC modification. The RTC modification reduces engine temperature to improve on-wing life.

Parcel Service. These aircraft generally have low rates of utilisation and average FC times of 1.0-1.5FH. The converted freighters are dominated by those modified by Precision Conversions, and are operated by Varig Log, Icelandair, Blue Dart Aviation and Cargojet. These have higher rates of utilisation, and longer FC times of 2.6-3.0FH.

EGT margin

Exhaust gas temperature (EGT) margin can be a major factor forcing removals for shop visits. EGT margin and its erosion is most important for engines operated on short engine flight cycle (EFC) times, since it is often the main cause of removals. EGT margin accounts for fewer removals as EFC time increases. Mechanical deterioration of engine hardware becomes more of an important engine removal driver as EFC time increases. Since most 757s are operated on medium-haul operations, EGT margin is not a prime removal cause for engine shop visits in the case of most engine variants.

RB211-535

The RB211-535E4 generally has sufficient EGT margin and EGT margin retention for EGT margin loss not to be a main removal driver. "The RB211-535's test cell EGT margin following a full refurbishment is 18-30 degrees centigrade, but averages about 22 degrees," explains Julian Lopez Lorite, RB211 production support manager at Iberia Maintenance & Engineering. "The reason for this variation is because the values vary, depending on whether the engines have a Phase II and Phase V combustor that meet CAEP II and CAEP IV NOx emissions standards. EGT margin on-wing is 8-9 degrees higher than test cell EGT margin. The on-wing EGT margin following a shop visit will therefore be 26-39 degrees, and average about 30 degrees."

Andrew Gainsbury, programme manager at Total Engine Support, comments that the RB211-535's typical turbine gas temperature (TGT) margin on the test cell following a level 3 shop visit is 20-25 degrees centigrade. The on-wing margin is 8-10 degrees higher at 28-35 degrees. The TGT is measured in the stages of the low pressure turbine (LPT), and is a similar measurement to the EGT that is used on other engine types.

PW2000

The PW2000 comes with, and without, the reduced temperature configuration (RTC) modification, which was introduced on the production line in 1994. The RTC modification supercharged the low pressure compressor (LPC) to increase airflow, and the combustion exit temperature (CET) modification kit could also be used to modify the low-speed rotor system of earlier-built engines to achieve the same effect. The CET kit was designed to increase core flow and turbine cooling, and to reduce EGT, thereby increasing EGT margin by up to 25 degrees centigrade.

The CET kit could be installed on engines built prior to 1994 during a shop visit. Most PW2000s have now been modified.

Engines with the RTC modification have a higher EGT margin than those without it. EGT margin erosion therefore accounts for a higher percentage of removals for shop visit maintenance in non-RTC-modified engines than those that have the RTC modification. EGT margin also depends on thrust rating, with lower-rated PW2037 engines having a higher EGT margin than PW2040 engines.

Non-RTC-modified engines have an EGT margin of 28-35 degrees centigrade, while RTC engines have a higher margin of 45-50 degrees centigrade.

"An old-standard, non-RTC-modified PW2037 has an EGT margin of about 35 degrees centigrade," says Thomas von Kaweczynski, PW2000 customer program manager at MTU Maintenance. "The higher-rated PW2040 with the RTC modification will have an EGT margin in the region of 28 degrees centigrade."

The EGT margins of RTC-modified engines are up to 20 degrees higher than those of non-modified engines. "The mature RTC engines in our fleet have a test cell EGT margin of 50-60 degrees, and the on-wing margin is similar," says Pallonen. "The RTC modification affects turbine cooling, which is where most of the benefit comes from."

Von Kaweczynski reports similar EGT margins. "A PW2037 engine with the CET upgrade kit or the new production engine, with the RTC modification, will have an EGT margin of about 55 degrees centigrade. A PW2040 engine will have a margin averaging 45 degrees, about 18 degrees more than the non-modified engines."

Delta, however, says that the restored EGT margins of its CET-modified engines are 35-40 degrees.

EGT margin erosion

TGT and EGT margin erosion is naturally the highest during the first 1,000-2,000EFC on-wing following a shop visit, and then reduces to a more stable level. The rate of TGT and EGT margin erosion, and the initial TGT or EGT margin will combine to influence whether or not TGT and EGT margin erosion is a main factor in driving engine removals.

RB211-535

"The initial rates of TGT margin loss on the RB211-535 depend on several factors. These include take-off de-rate, average FC time, and outside air temperature," explains Lopez Lorite. "At an average FC time of 2.0-3.0FH, the

The RB211-535E4 is rarely removed due to loss of TGT margin. The engine has demonstrated its ability to achieve long on-wing intervals.

initial rate of TGT margin erosion is 3.0 degrees per 1,000EFH in the first 2,000EFH on-wing, and then it slows to 2.0 degrees per 1,000EFH. An engine with a margin of 30 degrees will therefore be capable of remaining on-wing for 14,000EFH."

Gainsbury quotes similar rates of TGT margin loss. "The engine loses about eight degrees in the first 1,000EFC, and then the rate steadies to about three degrees per 1,000EFC thereafter."

The engine could therefore remain on-wing for 8,000-9,000EFC, which would be equal to 24,000-27,000EFH. TGT margin erosion is rarely a driver of removals for shop visits for the RB211-535, however. Gainsbury explains that the RB211-535, like other RR engine types, tends to undergo a reducing rate of TGT margin loss, and so it experiences the deterioration of hot-section components before TGT margin is completely lost.

PW2000

"The initial rate of EGT margin erosion for the PW2000 may be 4.0-4.5 degrees per 1,000EFH during the first 2,000EFH on-wing," explains von Kaweczynski. "The rate of EGT margin then reduces slightly to an average of 3.5 degrees per 1,000EFH when operating an average EFC time of 3.0EFH, although the actual rate is dependent on the operator."

EGT margin is naturally higher in the higher-rated PW2040 at 8.0 degrees per 1,000EFC, and 6.0 degrees per 1,000EFC in the PW2037.

This rate of erosion will allow a non-RTC-modified PW2040, with the lowest EGT margin, to remain on-wing for about 9,000EFH or 3,000EFC. The lower-rated non-RTC-modified PW2037 will be able to remain on-wing for about 2,000EFH longer, at 11,000EFH or 3,700EFC.

The RTC-modified engines clearly benefit from their higher EGT margins. The lower-rated RTC-modified PW2040 will be able to remain on-wing for 14,000-15,000EFH, or up to 5,000EFC. The lower-rated RTC-modified PW2037, which has the highest EGT margins, will be able to achieve a removal interval of 17,000-18,000EFH or about 6,000EFC.

Northwest, for example, which operates the PW2037 and PW2040, has EGT margins of 50 degrees following heavy engine maintenance, and experiences EGT margin erosion rates of 3.0 degrees per 1,000EFH.

Life limited parts

The removal intervals that are possible with TGT and EGT margins, the probable removal intervals of engines when actual removal causes are considered, shop visit workscopes at each removal, and the pattern of shop visits must all be considered in relation to the lives and list prices of life limited parts (LLPs).

A high proportion of maintenance reserves for the RB211-535 and PW2000 operated on the 757 will be accounted for by LLP reserves when the aircraft is operated at EFC times of 2.0-3.0EFH. The lowest reserves will be achieved when LLPs are removed with the shortest possible remaining lives or 'stub lives', and when LLPs are removed and replaced during a heavy shop visit when the engine already requires full disassembly. Higher maintenance reserves are the result when LLP life expiry coincides with a shop visit that would otherwise be relatively light were it not for the need to replace LLPs, or when LLP life expiry occurs between planned shop visits and so forces an early removal.

RB211-535

LLPs in the RB211-535 are grouped into Group A LLPs and Group B LLPs. Gainsbury explains that Group A LLPs are the same as those found in other engine types, for example disks, shafts and hubs. Rolls-Royce, however, only recommends that Group B LLPs be treated like LLPs, and limited lives are therefore not actually mandatory, although most operators still choose to use limited lives.

The RB211-535 has six main turbomachinery modules, which have 14 Group A LLPs. These are the fan or LPC, intermediate pressure compressor (IPC), high pressure compressor (HPC), high pressure turbine (HPT), intermediate pressure turbine (IPT) and LPT.

The two parts in the fan module for the -E4B engine have lives of 17,200 and 22,600EFC, and a list price of $310,000. One part has a life of 14,230EFC in the higher-rated -E4C engine.

The two parts in the IPC have a list price of $408,000, and lives a little over 26,000EFC in the -E4B and -E4C variants.

The three parts in the HPC have a list price of $487,000. Lives are 12,600-25,000EFC for the -E4B and -E4C engines.

The HPT disc has a list price of $340,000, and a life of 15,000EFC in the -E4B and 10,000EFC in the -E4C variants.

There are two parts in the IPT, with list prices of $244,000. These have lives of 26,500EFC.

There are four parts in the LPT, with a list price of $311,000. These have lives of 16,000-27,650EFC in the -E4B variant. Lives in the -E4C are the same, except for one turbine disc that has a life of 23,200EFC.

Besides the fan and LPC, the parts with the shortest lives are found in the HPC, HPT, and the LPT.

In addition to these 14 Group A LLPS, there are also 44 Group B LLPs. These comprise 22 fan blades and 22 fillers between fan blades on the fan disk.

The main cause of removals for the non-RTC modified PW2000 engines is loss of EGT margin. PW2000 engines which have the RTC modification are also removed because of EGT margin, but do achieve longer removal intervals.

The fan blades each have a list price of $45,000 and have a life limit of 23,000EFC in the -E4B variant, and a life limit of 17,600EFC in the -E4C variant. The list price for the total shipset is $983,000.

The 22 fillers in the LPC have lives of 10,000EFC in the -E4B and -E4C variants. This will force a removal and a relatively heavy shop visit at 10,000EFC, since a high level of engine disassembly will be required to replace these parts.

These 44 fan blades and fillers can easily be accessed by removing the spinner. The blades can then be removed for inspection and repair, without the need to disassemble any engine module, as is the case with Group A LLPs. While the fan blades have lives of 17,600EFC or 23,000EFC, this is equivalent to 50,000-75,000EFH over a 16-25 year period. Dents or bending of the airfoil shape and erosion to leading edges will be experienced during this period, so these blades and fillers will be periodically removed for inspection and repair. Airfoil Technologies International, for example, is a specialist provider of repairs for engine blades, and is capable of repairing fan, IPC and HPC blades.

Overall, the full shipset of LLPs in the RB211-535 series engine has a 2008 list price of $3.15 million, up from a 2005 list price of $2.65 million. This indicates that the list prices have increased at a rate of 6% per year.

PW2000

There are different configurations for the LLPs. "The older engines had a configuration of 30 LLPs," explains von Kaweczynski. "Later configurations have only 25 LLPs. The reduction in LLPs is achieved by combining several parts. One example is where the HPT stage 1 disk and an airseal have been combined to form one part. Another example is where the stage 16 and stage 17 disks and the rear shaft have been combined as one part and are now a drum. The compressor discharge pressure (CDP) seal also forms part of this drum, so four parts have been combined to make one."

The most recent configurations on the PW2000 are for 25 LLPs in the complete shipset. Unlike those in most PW engines, the LLPs in the PW2000 do not have uniform lives.

The majority of parts have lives of 20,000EFC. These are parts in the LPC, HPC and LPT modules.

The HPT, however, has six parts with lives of 15,000EFC.

The LPT hub, HPC drive shaft and LPC drive shaft all have lives of 30,000EFC.

The complete shipset of LLPs has a 2008 list price of $3.6 million. This compares to a 2005 list price of $2.5 million, indicating that the list price has increased at a rate of 10% per year.

The reserves for LLP replacement must take into account the likely timing for replacement, and the stub life of parts at removal.

Removal causes & intervals

The loss of TGT and EGT margin, and therefore engine performance, is the main cause of removals for engines operated on short EFC times. TGT and EGT margin and performance loss become less of an issue for engines with high TGT or EGT margins and those operated on medium or long EFC times, in which case mechanical deterioration and LLP expiry become more of a removal cause.

RB211-535

The RB211-535 is generally not forced off-wing for shop visits by loss of TGT margin and performance. "The loss of TGT margin is almost never a removal cause for shop visit maintenance," says Gainsbury. "The main removal cause for the RB211-535 is the thermal deterioration of the hot-section components, in particular the HOT blades, nozzle guide vanes (NGVs), and combustion chambers.

"HPT blade distress and deterioration is the biggest removal cause, and Rolls-Royce's engine maintenance programme (EMP) recommends that these are replaced every shop visit," continues Gainsbury. "The HPT blades can actually last 6,000-8,000EFC and be repaired after an interval of about 4,000EFC. They are then likely to force a removal after another 2,000-3,000EFC. Replacing them at each shop visit means that their lives are limited to 5,000-7,000EFC. The cost of replacing a shipset of HPT blades is about $600,000.

"The NGVs also get tired after a similar interval and their replacement is also recommended. A full shipset costs $500,000-600,000," continues Gainsbury. "It may be possible to repair NGVs, but they deteriorate faster afterwards and would force an earlier subsequent removal."

Combustion cans also wear out after 5,000-7,000EFC on-wing, but different parts of these can be replaced at different shop visits. They are therefore in a continual state of repair.

"The typical life between level 3 and level 4 shop visits, those that are used to restore engine performance, is 15,000-20,000EFH, and 5,500-7,000EFC," says Gainsbury.

Lopez Lorite at Iberia also comments that the deterioration of HPT blades and combustion chamber distress are main removal drivers. "An engine operating at an EFC time of 2.0EFH can remain on-wing for about 16,000EFH," says Lopez Lorite. "This will increase to about 18,500-20,000EFH for engines operated at 3.0EFH per EFC.

Condor, for example, operates at 3.0EFH per EFC and has a mature planned interval of about 18,000EFH and 6,000EFC.

The Rolls-Royce engine maintenance plan requires level 3 or level 4 workscopes on all engine modules at scheduled shop visits. This puts the cost of shop visit inputs at a high level relative to other engine types.

PW2000

As described, the EGT margins of the PW2000 series vary, while non-RTC-modified engines have margins 15-20 degrees less than the enhanced variants.

Loss of performance is a main removal driver for non-RTC-modified engines. As described, the non-RTC-modified PW2040 is likely to remain on-wing for about 9,000EFH, while the PW2037 could possibly remain on-wing for longer, up to 11,000EFH. Northwest, for example, has an average interval between shop visits and minor repairs of about 8,000EFH. Von Kaweczynski says that non-RTC-modified engines will achieve 10,000-12,000EFH between shop visits. "Main removal causes are loss of performance and EGT margin."

RTC-modified engines tend to have fewer removals forced due to loss of EGT margin, although some are still due to loss of performance. As described, their 15-20-degree higher EGT margins can be expected to allow removals of 14,000-15,000EFH.

"RTC-modified engines are still removed mainly because of EGT margin erosion, but they have longer shop visit intervals of 15,000-18,000EFH," says von Kaweczynski. Pratt & Whitney's record for RTC-modified engines is an average interval of 16,500EFH.

Delta, which has a typical operation of about 2.9EFH per EFC, has a mature planned removal interval of 18,000EFH and 6,000EFC on its domestic fleet. Its international fleet operates at longer cycles of about 4.9FH per FC, and the planned interval is 20,000EFH and 4,000EFC.

Finnair, which operates at one of the longest EFC times of all 757 operators, reports that loss of EGT margin and performance is rarely an issue with its PW2040 RTC-modified engines. "Besides our long average EFC times, we also have the advantage of operating in a cold environment," says Pallonen. "The main removal causes are mechanical deterioration, and we try to keep maintenance costs optimal by not leaving the engine on-wing for too long. If the engine is left on-wing for too long, then the turbine deteriorates and the compressor suffers. If the turbine blades exceed the overhaul limit they have to be replaced rather than repaired, which obviously pushes up the shop visit cost. With our long average EFC time we can keep the engine on-wing for a long time, so the physical state of the engine determines when we remove the engine for shop visit maintenance.

"The first runs were naturally the best. For these we had a target of about 20,000EFH, and then a target of about 15,000EFH for mature engines," continues Pallonen. "We actually got longer intervals, and managed to achieve first runs of 22,000-23,000EFH. The second runs have been about 15,000EFH and 4,000EFC."

Shop visit workscopes

RB211-535

There are four levels of workscope for the RB211-535. A level 1 shop workscope is only a serviceability shop visit, and is only used on a module when it is not being stripped. It usually consists of no more than an external visual inspection. "A level 1 workscope is a package of work for completing serviceability tasks or troubleshooting," explains Lopez Lorite.

A level 2 workscope is a check and partial repair shop visit on a particular module. It involves stripping and disassembling a module, but is only used when there is some specific damage. It does not involve performance restoration work. "A level 2 workscope is a 'check and rectify' shop visit," says Lopez Lorite. "It is a package of work that restores the engine to a serviceable condition for its remaining residual life. The tasks are listed in Rolls-Royce's EMP 'module check and rectify' section."

Level 3 and 4 workscopes involve rework on all engine modules. The workscope results in restoration of engine performance, so these two workscopes incur the highest shop visit costs.

"A level 3 workscope is a refurbishment shop visit. Unlike a level 2 workscope, it involves the disassembly of modules. It is used for a complete performance restoration, and the repair of parts that have suffered thermal deterioration," explains Gainsbury. "This allows the module to be zero-lifed. It is normal to carry out a level 3 workscope on all modules at the same time, which results in the best on-wing life."

"The level 3 workscope is a refurbishment shop visit," says Lopez Lorite. "It is a package of work that at the minimum completes the module 41 (HPC, HPT and combustion chambers) refurbishment and the IP mini-module 51 (IPT, LPT and LPT case) refurbishment in accordance with the appropriate EMP section."

"A level 4 workscope is a full overhaul. It involves a complete disassembly of each module to piece-part level and carrying out a full inspection of all parts," continues Gainsbury. "It may be necessary to have a level 4 workscope on a module that requires full LLP replacement.

Most PW2000s follow a simple alternating pattern of performance restorations and overhauls. This makes shop visit inputs cheaper than the RB211-535E4's, but the PW2000 achieves shorter removal intervals.

"For a normal pattern of shop visits, operators are recommended to follow a pattern of alternating level 3 and level 4 workscopes," continues Gainsbury. "A level 3 workscope gives the necessary performance restoration. Provided that no LLPs have to be replaced, all operators can have level 3 workscopes at every shop visit. Operators need to only have level 3 workscopes on the LPT, IPC and IPT modules at every other removal.

A level 4 workscope involves more in-depth work, and usually a higher rate of parts replacement. There are a few issues with the IPC that affect the size of the workscope. "The original standard of the IPC is known as a list 1 standard," explains Gainsbury. "This was later replaced with a list 2 IPC, which was thought to be an improved version. However, this actually suffered from cracking, so it had to be de-bladed for an inspection to be made to detect the cracking problem. This means the blades also have to be inspected. The list 1 IPC was then reintroduced as a result of the difficulties with the list 2 IPC."

Lopez explains that unlike other engine types, the recommendation for the RB211-535 is that there is at least a level 3 workscope on each main module at every shop visit. "The general recommendation is that a level 3 workscope shop visit is followed by a level 4 shop visit, and then the engine follows a pattern of alternating shop visits. I think it is possible for the engine to have two level 3 workscopes and then a level 4 workscope. The requirement for a workscope on each module nevertheless makes the shop visit costs of the engines relatively high," explains Lopez.

Gainsbury estimates that level 3 workscopes cost in the region of $3.0 million. About $400,000 of this is accounted for by sub-contract repairs, another $800,000 is for labour, and $1.8 million is for parts and materials, but not including LLPs.

Gainsbury puts the cost of a level 4 workscope at about $3.5 million.

Lopez makes a similar estimate for a level 3 workscope, with a total cost of $2.8-3.0 million. A level 4 workscope requires more labour and may have more findings and a need to replace more parts because of the high level of disassembly. The total cost will be $3.3-3.4 million. The relatively small increase of $0.4-0.5 million is because all modules have workscopes in both levels of shop visit.

PW2000

Most PW engines usually follow a simple pattern of alternating shop visit workscopes. These are usually a hot-section inspection or performance restoration followed by a complete overhaul. "We like to try to follow a pattern of a hot-section heavy maintenance (HSHM) and then have an overhaul every second removal," says Pallonen. "The HSHM at least includes work on the HPC, HPT, combustor and nozzle guide vanes between the exit of the combustors and the first stage of HPT blades. We may also add work on the LPC in the workscope. This will include partial disassembly of the module, and leave the blades installed. There will be a visual inspection and clearances will be restored. There are also abradable rubber seals in the LPC casings, and replacing these restores performance.

"An overhaul of engine heavy maintenance (EHM) involves the full disassembly of all modules," continues Pallonen. "The fan and LPT modules are therefore added to the workscope, and the engine has a full teardown."

The lighter core or performance restoration shop visit will consume about 3,500MH, $400,000 in sub-contract repairs, and $1,0-1.6 million in parts and materials. At a typical labour rate of $70-80 per MH, this will take the total cost to $1.7-2.3 million.

Heavier overhauls will use 5,000-5,500MH, about $500,000 in sub-contract repairs, and $1.6-2.1 million. The total cost of this workscope will be $2.5-3.0 million when labour is charged at $70-80 per MH.

Unscheduled shop visits

Unscheduled shop visits fall into engine-related and non-engine-related events.

Engine-related events involve the failure of engine hardware, and are divided between light and heavy events. Light events are issues such as oil leaks, hospital visits for damage to the HPC, and other minor incidents that do not require full engine disassembly.

These occur at a rate of about once every three to four scheduled shop visits, and incur shop visit costs of up to $500,000. These do not interrupt the schedule of planned shop visits, and so a budget of $8 per EFH should be made for the RB211-535, and $6-9 per EFH for the PW2000 to cover for these events.

Heavy events are major failures such as bearing failure, and these result in heavy shop visits that usually require a full workscope on every module.

Non-engine-related events are items such as birdstrikes and foreign object damage (FOD). These also often result in a heavy shop visit and full disassembly.

Heavy engine-related and non-engine-related events should be considered as one category because of the high shop visit cost they incur, which can be up to $3.0 million. These occur at a rate of once every four to five planned shop visits. One of these events therefore replaces one of the four or five planned shop visits. Since these events always usually result in a heavy shop visit, and will therefore replace a performance restoration on about half the occasions they occur, the cost of half of one of these visits should be amortised over the

RB211-535E4 & PW2000 REMOVAL INTERVALS, SHOP VISIT INPUTS & MAINTENANCE RESERVES

Engine type	RB211-535E4	PW2000 non-RTC	PW2037 RTC	PW2040 RTC
1st removal-EFH	17,000-19,000	10,000-12,000	15,000-16,000	14,000
1st shop visit-$	3,000,000	1,700,000	2,200,000	2,200,000
2nd removal-EFH	17,000-19,000	10,000-12,000	15,000-16,000	14,000
2nd shop visit-$	3,500,000	2,500,000	2,800,000	2,800,000
Shop visit reserve-$/EFH	171-180	200	167-173	178-189
LLP reserve-$/EFC	185	200	200	189
Total reserve-$/EFH	263-272	292-295	259-268	259-268

Planned shop visit engine maintenance reserves based on 3.0EFH per EFC.

interval of four or five planned visits. This is equal to $22 per FH for the RB211-535, and $19 per FH for the PW2000.

The total allowance for unscheduled shop visits should therefore be $30 per EFH for the RB211-535E4, and $25-28 per EFH for the PW2000.

Maintenance reserves

The maintenance reserves for the two main engine types are summarised *(see table, this page)*. This includes non-RTC-modified and RTC-modified PW2000 engines. These are for engines operating at 3.0EFH per EFC.

The RB211-535E4 will have intervals of 17,000-19,000EFH between successive shop visits. This is equal to 5,700-6,300EFC. It is assumed that the engine follows a shop visit pattern of alternating level 3 and level 4 workscopes. These have shop visit costs of about $3.0 million and $3.5 million. The reserve for these two will therefore be equal to $171-180 per EFH *(see table, this page)*.

The RB211-535E4's LLPs have lives of 14,000-27,650EFC, and will therefore be replaced every second, third or fourth shop visit at intervals averaging 12,000EFC, 18,000EFC and 24,000EFC. On this basis the reserve for these parts will be $122 per EFC. The additional reserve for the fan blades and fillers will be a further $63 per EFC. These can be removed from the fan disc without the need for a full disassembly. The total reserve for LLPs will therefore be $185 per EFC.

The total reserves for the shop visit maintenance, unscheduled maintenance and LLPs for the RB211-535E4 operated at the EFC time of 3.0EFH will therefore be $263-272 per EFH *(see table, this page)*.

The non-RTC-modified PW2000 engines have shorter intervals of 10,000-12,000EFH between shop visits. This is equal to 3,300-4,000EFC. Most engines follow a pattern of a core and performance restoration workscope followed by an overhaul, over a total interval of 22,000-24,000EFH. This is equal to 7,300-8,000EFC. The first shop visit will be $1.9-2.0 million, and the overhaul $2.5-2.8 million. The total cost of $4.4-4.8 million for the two visits amortised over the interval will be about $200 per EFH *(see table, this page)*.

Replacement of LLPs in the non-RTC-modified engines fits well with the typical intervals of 3,300-4,000EFC, and the interval of the second shop visit, the overhaul with a higher level of disassembly, about once every 7,500-8,000EFC. This would allow the small number of LLPs lifed at 15,000EFC to be replaced at every fourth shop visit after full utilisation of their lives. The majority of parts would be replaced every sixth shop visit, again at or near to their full life of 20,000EFC. The small number of parts with lives of 30,000EFC would be replaced every eighth shop visit. Overall, this would result in a reserve of $200 per EFC.

The total reserve for shop visit maintenance, unscheduled shop visits and LLPs for the non-RTC-modified PW2000 engines at the EFC time of 3.0EFH will therefore be $292-295 per EFH *(see table, this page)*.

The RTC-modified engines will follow the same type of removal and shop pattern, but with longer intervals. In the case of the PW2037 this could be removed at an average of 16,000EFH. This is equal to about 5,300EFC. If the engines are operated at 3.0EFH per EFC, then the intervals will be limited to 15,000EFH and 5,000EFC because of LLP life limits.

The cost for the two successive shop visits will be $5.0-5.2 million, and reserves will therefore be $167-173 per EFH.

LLPs in this engine will have to be managed differently. Parts with lives of 15,000EFH will either have to be replaced at the second shop visit, or the total interval of the third shop visit will be limited to 15,000EFC. Parts with lives of 20,000EFC will have to be replaced at the fourth shop visit, and parts with lives of 30,000EFC replaced every sixth shop visit. Again, LLP lives will be almost or completely utilised, and reserves will be $200 per EFC.

The total reserve for shop visit maintenance, unscheduled shop visits and LLPs for the RTC-modified PW2037 at the EFC time of 3.0EFH will therefore be $259-268 per EFH *(see table, this page)*.

The higher-rated PW2040 engines will be removed at an average of 14,000EFH, at this ratio of 3.0EFH, and equal to 4,700EFC. The reserve for these engines will therefore be $178-189 per EFH *(see table, this page)*.

The three groups of LLPs with lives of 15,000EFC, 20,000EFC and 30,000EFC will still be replaced at the third, fourth and sixth shop visits, but lives will not be fully utilised because of the shorter average removal interval of about 4,700EFC. These replacement intervals will be about 14,000EFC, 19,000EFC and 28,000EFC. Reserves will be $189 per EFC.

The total reserve for shop visit maintenance, unscheduled shop visits and LLPs for the RTC-modified PW2040 at the EFC time of 3.0EFH will therefore be $259-268 per EFH *(see table, this page)*.

Summary

The total reserves for the main engine types are summarised *(see table, this page)*. While the RB211-535E4 clearly has longer removal intervals, its higher shop visit costs offset this advantage in the case of some PW2000 variants. The RB211-535E4's reserves are $233-242 per EFH, and these are lower than those for the two main groups of the PW2000.

The non-RTC-modified PW2000s have the problem of relatively short intervals, which result in total reserves of $260 per EFH.

The RTC-modified PW2037 gains from longer intervals, and despite the resultant slightly high shop visit costs, has reserves of $227-233 per EFH. The higher-rated RTC-modified PW2040 has shorter intervals and does not achieve the same degree of LLP life utilisation. Reserves are $241-252 per EFH. AC

RB211-535 & PW2000 technical support providers

While the majority of the maintenance market for the RB211-535E4 & PW2000 is controlled by the OEMs, there are a large number of other providers that provide a variety of support services.

This survey summarises the major aftermarket and technical support providers for the Pratt and Whitney PW2000 and Rolls-Royce RB211-535E4 engines. It is grouped into six sections covering the categories of technical support offered by each provider.

- Line maintenance and in-service operational support.
- Engine management.
- Engine provisioning.
- Engine components.
- Shop-visit maintenance.
- Specialist repairs.

Companies that are listed in most of the six sections are 'one-stop-shop' service providers for one or both of these two engines. This means that they provide most, if not all, of the technical support services that a third-party customer would require. The tables show the range of services that the RB211-535E4 and PW2000 overhaul shops are capable of offering.

Rolls-Royce owns and operates two overhaul facilities that specifically deal with the RB211-535E4: one near its head offices in Derby, UK; and the other in Canada.

Pratt and Whitney (PW) owns and operates many facilities all over the world, but its main facility for the PW2000 is in Cheshire, US.

RB211-535E4 market

Much of the RB211-535E4 engine overhaul is done either at Rolls-Royce's own shops, or at those that are joint ventures between Rolls-Royce and airlines or independent maintenance providers.

The two Rolls-Royce-owned overhaul shops in the UK and US account for just over 25% of the market. They are second only to Texas Aero Engine Services (TAESL) which has over 27% of logged contracts, according to FlightGlobal's ACAS maintenance database. This equates to 418 individual shop visits. TAESL is a 50:50 joint venture between Rolls-Royce and American Airlines. This means that Rolls-Royce's partner shops or joint ventures account for over 50% of engine contracts.

The next biggest overhaul facility in terms of market share is Iberia, which has nearly 17% of logged contracts, with airlines including British Airways and China Southern Airlines. After Iberia, the overhaul facilities with the next biggest market share are Ameco Beijing with over 5% and Lufthansa (nearly 2%). Ameco Beijing is a joint venture between Lufthansa and Air China, meaning that Lufthansa is connected to about 7% of the market.

Contracts that are completed by airlines in-house still account for more than 16% of maintenance, repair and overhaul (MRO) provision for the RB211-535E4. The remaining 6% of contracts are either unknown or up for tender.

The largest fleet of engines is operated by American Airlines, which has 248. These are overhauled by both TAESL and American's own in-house engineering team.

The next biggest number of engines is operated by Continental. They have more than 100 RB211-535E4-Bs, and these are overhauled by both Iberia and Rolls-Royce Aero Repair & Overhaul. Iberia is also responsible for Continental's 16 -535E4-C engines.

TAESL is not the only MRO to be a joint venture between Rolls-Royce and airlines. Rolls-Royce has similar ventures with airlines all over the world, such as SAESL with Singapore Airlines and HAESL in Hong Kong. TAESL is,

The majority of RB211-535E4 shop visit activity is controlled by Rolls-Royce or engine shops where Rolls-Royce has a joint venture with an airline or independent maintenance provider. Iberia Maintenance & Ameco Beijing are the only independent engine shops for the RB211-535E4.

RB211-535E4 & PW2000 LINE MAINTENANCE & IN-SERVICE OPERATIONAL SUPPORT

	On-wing maintenance	Line maintenance	Hospital repair/ Quick turn repairs	On-wing support	AOG/field services	Borescope inspection
RB211-535E4						
Air Atlanta Aero Engrg	Y	Y	-	Y	-	Y
Air Concepts Repair	-	-	Y	-	Y	-
Ameco Beijing	-	-	Y	Y	Y	Y
ATC Lasham	Y	-	-	-	-	-
Condor Cargo Tech	Y	Y	Y	Y	Y	Y
El Al Tech	-	Y	-	-	Y	-
Far Eastern Air Trans	Y	Y	-	Y	-	Y
GAMECO	Y	Y	-	Y	Y	Y
HAECO	Y	Y	Y	Y	Y	Y
HAESL	Y	-	-	Y	-	Y
Iberia Maintenance	Y	Y	Y	Y	Y	Y
Icelandair Tech	Y	Y	Y	Y	Y	Y
Louro	Y	Y	Y	-	Y	-
Air BerlinTechnik	Y	Y	Y	Y	Y	Y
Monarch Engineering	Y	Y	Y	Y	Y	Y
Shannon Aero	Y	Y	-	-	-	Y
TAESL	Y	-	Y	Y	Y	Y
PW2000						
Air Atlanta Aero Engrg	Y	Y	-	Y	-	Y
ATC Lasham	Y	-	-	-	-	-
Condor Cargo Tech	Y	Y	Y	Y	Y	Y
Delta TechOps	Y	Y	Y	Y	Y	Y
Far Eastern Air Trans	Y	Y	-	Y	-	Y
GAMECO	Y	Y	-	Y	Y	Y
HAECO	Y	Y	Y	Y	Y	Y
Louro	Y	Y	Y	-	Y	-
Air Berlin Technik	Y	Y	Y	Y	Y	Y
Monarch Engineering	Y	Y	Y	Y	Y	Y
MTU Maintenance Hannover	Y	-	Y	-	Y	Y
Northwest Airlines	Y	Y	Y	Y	Y	Y
Pratt & Whitney Cheshire	Y	Y	Y	Y	Y	Y
Shannon Aerospace	Y	Y	-	-	-	Y
United Services	Y	Y	Y	Y	Y	Y

RB211-535E4 & PW2000 ENGINE MANAGEMENT

	Maintenance management & check planning	ADs/SBs management	Documentation management	Health/ condition monitoring
RB211-535E4				
Ameco Beijing	Y	Y	Y	Y
ATC Lasham	Y	Y	Y	-
Condor Technik	Y	Y	Y	Y
Far Eastern Air Transport	Y	Y	Y	Y
GAMECO	Y	Y	Y	Y
HAESL	-	-	Y	-
Iberia Maintenance	Y	Y	Y	Y
Icelandair Tech Services	Y	Y	Y	Y
Air Berlin Technik	Y	Y	Y	Y
Monarch Engineering	Y	Y	Y	Y
TAESL	-	Y	Y	-
PW2000				
ATC Lasham	Y	Y	Y	-
Condor Technik	Y	Y	Y	Y
Delta TechOps	Y	Y	Y	Y
Far Eastern Air Transport	Y	Y	Y	Y
GAMECO	Y	Y	Y	Y
Air Berlin Technik	Y	Y	Y	Y
Monarch Engineering	Y	Y	Y	Y
MTU Maintenance Hannover	Y	Y	Y	Y
Northwest Airlines	Y	Y	Y	Y
Pratt & Whitney Cheshire	Y	Y	Y	Y
United Services	Y	Y	Y	Y

however, the only airline collaboration that maintains RB211-535E4 engines.

Rolls-Royce has also undertaken joint ventures with other maintenance facilities, in effect forming a third organisation. For example, it has formed HAESL with Hong Kong Engineering Company (HAECO), which means that more engine types and capabilities can be offered in the Asia Pacific region.

PW2000 market

Like the maintenance for the RB211-535E4, many of the contracts available on PW2000 engines are completed at Pratt and Whitney's own facilities or those of its joint ventures. Generally Pratt and Whitney does not take part in joint ventures to the extent that Rolls-Royce does.

There are many PW maintenance facilities worldwide, such as those in Norway and East Hartford, US, many of which may occasionally undertake work on the PW2000. But most of the engine overhaul is done in one place, Pratt and Whitney's Cheshire Engine Centre in the US, which is its main location for PW2000 maintenance. When all Pratt and Whitney's facilities are added together, they account for more than 62% of the logged contracts, according to ACAS.

The second most active facility is Delta's Delta TechOps with very nearly 19% of the market share (292 engines). United Airlines' United Services accounts for more than 12.5%.

The fourth position is held by MTU's maintenance facility at Hannover, Germany, which logged nearly 5%.

SNECMA, Eagle Services Asia and SR Technics are other facilities that used to perform PW2000 maintenance, but have now ceased activity with this engine.

The largest number of engines, other than those belonging to the US Air Force (which are overhauled by Pratt and Whitney), are those with Delta (274 engines). These engines are maintained in-house by Delta TechOps. The largest contract, which is not dealt with in-house, is that with Northwest Airlines. It sub-contracts the maintenance for 110 PW2037s and 32 PW2040s to Pratt and Whitney.

Major providers

The vast majority of PW2000s and RB211-535s are powering Boeing 757s. This aircraft design is over 20 years old, so the major MRO providers are not changing much or even growing. In fact, the number of maintenance facilities are being reduced as demand changes.

Quite a few 757s are now having their usage changed and becoming freighter aircraft. The failure of airlines, such as ATA and Eos, means that more passenger aircraft are becoming available for conversion to freighter. When an engine shop no longer has a contract with a major airline to carry out maintenance for its engines, the shop could drop its capabilities for the engine altogether. This is the case with SR Technics, which carried out maintenance for XL Airways, but due to a lack of specialist tools did not do any overhaul. The engine is no longer part of their official maintenance capabilities.

More than 70% of 757s are flown by North American operators. This figure is helped by the fact that United, Delta and Continental have such large 757 fleets. This also means that these three airlines need large maintenance facilities to cope with their requirements.

The majority of Pratt and Whitney's PW2000 maintenance is carried out at its Cheshire facility in North America. This is partly because Pratt and Whitney is an American original equipment manufacturer (OEM), but also because over 85% of all PW2000-equipped 757s are operated in North America. Only 16% of the PW2000-equipped 757s operate in Europe, and few in the rest of the world.

The major provider of PW2000 overhaul facilities in Europe is MTU Maintenance in Hannover, Germany. America's main PW2000 providers (other than Pratt and Whitney) are Delta's Delta TechOps and United's United Services. Many other maintenance providers around the world offer line and/or specialist maintenance services.

Rolls-Royce, on the other hand, has two main locations (one near its head office in the UK, and one in Canada) and many joint ventures with airlines and MRO facilities all over the world. This reflects the RR-equipped 757's geographical scattering. Of the 757s with RB211-535E4 engines, 60% are in the Americas, while another 25% are in Europe. The 25% equates to 142 aircraft. This is nearly six-and-a-half times more than the number of PW2000-powered 757s in Europe, which is 22.

The remaining 15% of RR-powered 757s are operating out of Africa, China and, to a lesser extent, the Middle East and Asia Pacific.

There are more overhaul facilities around the world for the RB211-535E4, but many are partners of, or joint ventures with, Rolls-Royce. The major providers in Europe are Iberia and Rolls-Royce. In the Americas, there are Rolls-Royce and TAESL, while Ameco Beijing and HAESL are the main overhaul facilities in the Asia Pacific.

Due to the age of the RB211-535E4 and PW2000, the number and size of the maintenance facilities for these two engines are not as great as those for the CFM56-7B or the V2500. Where there are maintenance capabilities, however, these will be supported with years of practical experience of that engine model. In addition to regular engine overhaul, additional work had been produced by the various modifications and upgrades to the engines. Some of these processes were merged into planned maintenance and some were not taken up. Most, if not all, major work will therefore have been completed by now, other than that necessitated by Airworthiness Directives (ADs), as and when they are issued.

RB211-535E4 & PW2000 ENGINE PROVISIONING

	Short-term leasing	Medium- & long-term leasing	Engine pooling	Sale & leasebacks
RB211-535E4				
AAR Engine Sales & Leasing	Y	Y	Y	Y
Ameco Beijing	Y	Y	Y	Y
Engine Lease Finance	Y	Y	-	Y
GAMECO	Y	Y	-	-
GA Telesis	Y	Y	-	Y
Iberia Maintenance	Y	Y	Y	Y
Icelandair Tech Services	Y	Y	-	Y
Monarch Engineering	Y	Y	-	Y
Willis Lease Finance	Y	Y	Y	Y
PW2000				
AAR Engine Sales & Leasing	Y	Y	Y	Y
Delta TechOps	Y	Y	Y	Y
Engine Lease Finance	Y	Y	-	Y
GAMECO	Y	Y	-	Y
GA Telesis	Y	Y	-	Y
MTU Maintenance Hannover	Y	Y	-	Y
Northwest Airlines	Y	-	-	-
Pratt & Whitney Cheshire	Y	Y	Y	Y
United Services	Y	Y	Y	Y
Willis Lease Finance	Y	Y	Y	Y

RB211-535E4 & PW2000 ENGINE COMPONENTS

	QEC repair	QEC build-up & engine dressing	LRU repair	LRU pooling & logistics
RB211-535E4				
Accel Aviation Accessories	-	-	Y	-
Ameco Beijing	Y	Y	Y	-
Far Eastern Air Transport	-	Y	-	-
GAMECO	-	Y	Y	Y
HAECO	-	Y	-	-
Iberia Maintenance	Y	Y	Y	Y
Icelandair Tech Services	-	-	-	Y
Air Berlin Technik	-	Y	-	-
Monarch Engineering	Y	Y	Y	Y
TAESL	-	Y	-	-
PW2000				
Able Engineering & Component Services	Y	-	-	-
ATC Lasham	Y	Y	-	-
Delta TechOps	Y	Y	Y	Y
Far Eastern Air Transport	-	Y	-	-
GAMECO	-	Y	Y	Y
HAECO	-	Y	-	-
Air Berlin Technik	-	y	-	-
Monarch Engineering	Y	Y	Y	-
MTU Maintenance Hannover	Y	Y	-	Y
Northwest Airlines	Y	Y	-	Y
United Services	Y	Y	Y	Y

RB211-535E4 & PW2000 SHOP-VISIT MAINTENANCE

	Hot-section inspection	Module change	Module overhaul	Full overhaul	Mods & upgrades	Disassembly/ build-up	On-site test cell	Specialist processes
RB211-535E4								
Ameco Beijing	Y	Y	Y	Y	Y	Y	Y	Y
Chromalloy	-	-	-	-	-	-	-	Y
GAMECO	Y	Y	-	-	Y	-	-	-
HAECO	-	-	-	-	-	-	-	Y
Iberia Maintenance	Y	Y	Y	Y	Y	Y	Y	Y
Lufthansa Technik Intercoat	-	-	-	-	-	-	-	Y
Monarch Engineering	Y	-	-	-	-	-	-	-
Praxair Surface Technologies	-	-	-	-	-	-	-	Y
Shannon Aerospace	Y	-	-	-	-	-	-	-
TAESL	Y	Y	Y	Y	Y	Y	Y	Y
PW2000								
Chromalloy	-	-	-	-	-	-	-	Y
Delta TechOps	Y	Y	Y	Y	Y	Y	Y	Y
Far Eastern Air Transport	-	Y	-	-	-	Y	Y	-
GAMECO	Y	Y	-	-	Y	-	-	-
Lufthansa Technik Intercoat	-	-	-	-	-	-	-	Y
Monarch Engineering	Y	-	-	-	-	-	-	-
MTU Maintenance Hannover	Y	-	Y	Y	-	Y	Y	Y
Northwest Airlines	-	-	-	-	-	-	-Y	-
Pratt & Whitney Cheshire	Y	Y	Y	Y	Y	Y	Y	Y
Praxair Surface Technologies	-	-	-	-	-	-	-	-y
United Services	-	Y	Y	Y	-	-	Y	Y

RB211-535E4 & PW2000 SPECIALIST REPAIRS

	Fan blade repair	Vanes & stator repair	Compressor blade repair	Turbine blade repair	Combustor repair	Casing repair	Seals repair	On-site DER authority	PMA parts approved
RB211-535E4									
ATI UK	Y	Y	Y	-	-	-	-	-	-
Ameco Beijing	Y	Y	Y	-	-	Y	Y	-	-
Chromalloy	-	Y	-	Y	Y	Y	Y	Y	-
HAECO	Y	-	-	-	-	Y	-	-	-
Iberia Maintenance	-	Y	-	-	Y	Y	Y	-	-
Icelandair Tech Services	-	-	-	-	-	-	-	-	Y
Monarch Engineering	Y	Y	-	-	-	Y	Y	Y	-
PAS Technologies	Y	Y	Y	-	-	-	Y	-	-
PW2000									
Able Engineering & Component Services	-	-	-	-	-	-	-	-	Y
Chromalloy	-	Y	-	-	-	-	Y	Y	Y
Delta TechOps	Y	Y	Y	Y	Y	Y	Y	Y	Y
Monarch Engineering	Y	Y	-	-	-	Y	Y	Y	-
MTU Maintenance Hannover	-	Y	-	-	-	-	Y	Y	-
Pratt & Whitney Cheshire	-	Y	Y	Y	Y	Y	Y	Y	-
United Services	Y	Y	Y	Y	Y	Y	Y	Y	Y

Aftermarket perspectives

Development of the aviation industry in India and China means that 757s rather than 737s could be increasingly looked at as options on the longer, busier routes. An airline in the Russian Federation is being set up by a Russian travel company using 757s, emphasising the suitability of the aircraft, and either engine option, to the charter market.

The vast majority of the freighters are operated by American companies, but because they could be flying anywhere in the world, engine maintenance facilities are required worldwide. The number of PW- and RR-powered 757s, used as freighters, has gone up in recent years and there are more conversions from passenger configuration being performed. FedEx is one of the cargo airlines that are converting a number of RB211-535E4-powered 757s.

One issue to consider is the preference freight carriers will have for engine types on converted 757 freighters. While the RB211-535E4 may have been the most popular with passenger operators, the fact that RR controls the overhaul and repair market may see a preference for the PW2000 among freight operators. This is because there is some flexibility with the workscopes of engine shop visits for the PW2000, and this will suit carriers operating at low rates of utilisation. The RB211-535E4, however, has high shop-visit costs and just one level of shop-visit workscope. AC