The Trent XWB has been in service for just over three years. Its configuration, specifications, initial in-service performance and likely removal intervals and related costs are examined.

The in-service performance of the Trent XWB

The Rolls-Royce (RR) Trent XWB is the sole powerplant available on the A350 family. When the A350 was launched in its current form, Airbus required a large engine capable of delivering 84,000-97,000lbs of thrust. Even though the A350 was launched as a response to the 787 programme, the A350 family members are similar in size to the 787-10 and in capabilities to the 777-200ER and 777-300ER.

The A350 required improved specific fuel consumption (sfc), and lower noise emissions compared to the existing engines available, such as the GE90-115, Trent 900 and Trent 7000.The Trent XWB was derived from the Trent 900 and 1000, and offered a programme that fulfilled all the technology and performance requirements.

Airbus required an engine that would give the A350 at least a 15% fuel consumption advantage over similar-sized, previous generation aircraft. The Trent XWB was officially launched in 2006, and final specifications and design were concluded in 2008. The XWB is the latest and most advanced member of the RR Trent family. The XWB shares some commonality with previous Trent family members. The in-service performance of the Rolls-Royce Trent XWB for its first few years in operation is assessed here.

Architecture & technology

As with all other members of the RR Trent family, the Trent XWB incorporates a three-shaft architecture, while other engines in the same thrust category incorporate a two-spool architecture.

In a three-shaft configuration the fan is mounted on the low pressure (LP) shaft, and turns at an optimal rate of revolutions per minute (RPM) in relation to its fan diameter. The LP shaft is turned by the LP turbine (LPT), which has six stages in the case of the Trent XWB *(see table, page 44)*.

This shaft is separate to the intermediate pressure (IP) shaft, which has an eight-stage intermediate pressure compressor (IPC). This is turned by the intermediate pressure turbine (IPT), which has two stages *(see table, page 44)*. This compares to a single-stage IPT in all other Trent models. The additional IPT stage is one of the requirements for the XWB to achieve the thrust levels required by the A350 family.

As with two-shaft engines, the Trent XWB has a high pressure compressor (HPC) with six stages. This is mounted on the HP shaft, which is turned by a single-stage HPT *(see table, page 44)*.

This three-shaft design delivers several advantages over two-shaft engines. Since the IPC is on a shaft separate to the fan, the IP shaft is free to turn at a faster rate of RPMs compared to the low pressure compressor (LPC) in a two-shaft engine.

While the LP shaft and fan can turn at optimum speeds for a wide intake fan, the IP shaft's higher RPM rate allows the IPC to achieve higher rates of compression, allowing it to be configured with relatively few stages turning at optimal RPMs to generate the required compression.

The Trent XWB designs includes a 22-bladed intake fan. The combustor is annular with 20 fuel spray nozzles.

"The engine features a unique lightweight three-shaft design, providing a tailored solution optimised for the A350 XWB. We saved weight by using composite materials, delivering a saving of 15%. Efficiency was improved through improved aerodynamics and the use of compressor blisk technology. The Trent XWB also features an optimised internal air system, which reduces core air demand and so reduces fuel consumption," says Samantha Azad, Trent XWB marketing manager at Rolls-Royce. "The Trent XWB features a two-stage IPT for efficiency and thrust growth capability. The LP thrust bearing is located in the front bearing housing for improved cycle efficiency. The Trent XWB-97 features HPT blades that are shroudless, since it is the best design for the higher-thrust variant."

The Trent uses more blisk components than previous generation Trent engines. A blisk combines the disk in the different stages of the engine with the blades as a single component. Since there is no riveting or attachment between the disks, increased aerodynamic efficiency for the blade is achieved. As the pressure and temperature inside the engine increases through the compression stages, the disks and blades get smaller. Also, a blisk is a much lighter component than one made of individual blades. The manufacture of high precision blisks requires extensive use of advance composite materials and 3D-manufacturing. The blisk technology provides 15-18% weight savings.

The Trent XWB incorporates a dual channel full authority digital engine control (FADEC). The engine FADEC incorporates an airframe interface that provides the system with digital bus communications. The FADEC uses an electronic engine

The majority of the Trent XWB's in-service performance has been gained with the lower thrust XWB-84 variant. So far, early operators of the type report reliable performance and operation.

controller (EEC). This is a dual redundant computing system, whose functions are to manage the engine control and safety functions. An example is the optimisation of the fuel flow and preventive shutdowns. The EEC is designed with two dual-redundant channels that are physically and electrically isolated and able to communicate through a datalink known as the Inter-Channel Bus. The enhanced technology in the Trent XWB FADEC is unique to the engine.

Trent XWB Variants

There are two main versions of the engine: the Trent XWB-84, rated at 84,200lbs, which powers the A350-900; and the Trent XWB-97, rated at 97,000lbs, which powers the A350-1000 *(see table, page 44)*. There are 295 A350-900s in service with Trent XWB-84 engines, and 37 A350-1000s in service equipped with XWB-97 engines.

There is also a small sub-fleet of 10 Trent XWB-75-powered A350-900s. The XWB-75 was designed for the now defunct and smaller A350-800 family member. Two aircraft are operated by Japan Airlines, and eight by Singapore Airlines (SIA).

Externally both engines look similar, but the Trent XWB-84 was designed for the A350-900 which has a maximum take-off weight (MTOW) of 617,295lbs, whereas the Trent XWB-97 was designed for the A350-1000 which has a MTOW of 696,661lbs. The A350-1000 is 11% heavier than the A350-900. To deliver a higher thrust, the Trent XWB-97 has incorporated internal changes in the LLPs and the core that allow a thrust increase of 9%.

The specifications of each variant are listed *(see table, page 44)*. In order to produce 97,000lb of thrust, the main fan on the Trent XWB-97 turns at RPMs 6% faster than on the Trent XWB-84. The XWB-97's combustor operates at higher temperatures. The engine core on the Trent XWB-97 is also scaled up, compared to the XWB-84's core, to increase the higher airflow required by the compressor and to account for the higher combustor and turbine temperatures.

As a consequence of higher combustion temperatures, the HPT also operates at a higher temperature. The escalation of speeds and operating temperatures on the Trent XWB-97 could have resulted in early degradation of some of the engine and its life-limited parts (LLPs).

New technologies had to be developed for this more powerful engine so that thermodynamic efficiency and on-wing durability remained in line with the lower-rated Trent XWB-84 variant.

An additive layer manufactured front-bearing housing was developed to withstand the increased loads and temperatures of the more powerful engine. Additionally, new composite materials and coating were developed for the HPT blades and other critical components. Finally, the Trent XWB-97 incorporates a 'smart cooling system' that supplies the blade with the optimum amount of cooling air without compromising performance or the component's durability.

The Trent XWB-97 entered service in 2018, and all the incremental performance improvements achieved on the higher-rated variant are now being offered as a performance improvement programme (PIP) for the lower-rated XWB-84 called the Trent XWB-84 EP. Another improvement derived from the Trent XWB-97 programme is further optimisation of the Trent XWB-84's turbine tip clearance control system. The manufacturer claims that the PIP delivers a fuel consumption reduction of 1% compared to the standard variant. Whether the EP becomes the default variant "will be decided at a future date," says Azad.

Operator's base

There are more than 320 A350-900s and -1000s in service equipped with Trent XWB engines. The first A350 operator was Qatar Airways, which has been operating the engine for five years, and is also is the largest operator with 50 aircraft. It is followed by SIA (45) and Cathay Pacific (33).

"The Asia Pacific and China are the main markets for the engine," adds Azad. Qatar Airways and Cathay Pacific also operate both variants: the Trent XWB-84-powered A350-900 and the XWB-97-powered A350-1000.

The average age of the engine fleet is 2.5 years. Of all the engines in service, 86% are Trent XWB-84 variants, and another 11% are Trent XWB 97 variants.

There are 180 A350s operating in the Asia Pacific, 55% of the total worldwide. Of this number, 68 are operated in China.

There are 60-Trent XWB powered aircraft operating in the Middle East, 47 in Europe, 20 in Africa, 15 in Latin America, and 13 in North America.

ROLLS-ROYCE TRENT XWB-84 & -97 SPECIFICATIONS TABLE

Engine model	Trent XWB-84	Trent XWB-97
Thrust rating - lbs	84,000	97,000
Weight - lbs	16,043	16,640
Thrust-to-weight ratio	5.25	5.82
Fan diameter - inches	118	118
Fan blades	22	22
Bypass ratio	9.6:1	9.6:1
Overall pressure ratio	50:1	50:1
SFC: lb/lb/hr	0.478	0.478
Flat rate temperature (celsius ISA sea level conditions)	30	30
Application	A350-900/-900ULR	A350-1000
Engine configuration		
Fan - 118 inches diameter - No blades	22	22
IPC stages	8	8
HPC stages	6	6
HPT stages	1	1
IPT stages	2	2
LPT stages	6	6
Combustor nozzles	20	20

Despite the fleet being highly concentrated in the Asia Pacific, it has a wide geographical distribution. It is now operated by airlines in all types of environments, including harsh, hot and sandy (Qatar Airways), humid and high (Ethiopian Airlines), tropical (Thai Airways), sub-zero (Finnair) and polluted (LATAM). The in-service experience from operators will be illustrated. The A350 fleet operates on 700 different routes, serving more than 130 cities.

The XWB 97 was key to Qantas's selection of aircraft for its Project Sunrise. There was strong competition between the original equipment manufacturers (OEMs) for this. Project Sunrise required a platform capable of operating non-stop flights from New York and London to Sydney, each with a flight time of 19 hours, subject to wind and weather conditions, and with a full payload. "The most powerful variant, the Trent XWB-97-powered A350-1000, was recently selected as preferred aircraft supplier for Qantas's Project Sunrise. The Trent XWB-97 has the highest operating temperatures and the most advanced cooling systems Rolls-Royce has ever designed in a civil engine," says Azad. The combination of the A350-1000 and Trent XWB met the requirements of Project Sunrise.

Technical issues

The engine market is highly competitive, but entry into service of a new powerplant often experiences delays and performance issues. The Trent XWB had one of the best entry-into-service records of any widebody engine. "The lead engines that are operated on Qatar Airways' A350-900 fleet have been in service since 2014. These engines have accumulated the highest amount of engine flight hours (EFH), which is in excess of 20,000EFH. They have reached their first target overhaul life in this time, meaning they have behaved exactly how we wanted them to over time, with no unplanned maintenance," comments Azad. That is not to say that the Trent XWB has not had 'teething issues' during entry in service. Some of the issues noted at entry into service and throughout the programme are described for both engine variants.

Trent XWB 84

This variant of the engine has been in service since December 2014, a little over five years. The general perception of the Trent XWB-84's performance in the market is good especially if compared with other engines' programmes. "The engine has fewer line replaceable units (LRUs) than other engines in the same category. However, some operational issues have been presented by components like nacelle anti-ice pressure regulating valves and solenoids; the front bearing housing vent valve; the oil level and temperature sensor; the engine monitor unit (EMU); the EEC; the starter air valve; and fuel pump," says Danilo Colombo, vice president of technical services at SGI Aviation Technical Consulting. This has caused delays on flights, but not many cancellations. The P30 water system trap, a part of the ECU of the FADEC system, presented technical issues that affected both variants of the engine. "The presence of excess water on the pipes of the P30 trap could potentially transmit wrong readings to the cockpit," adds Colombo. "A service bulletin (SB) was issued by the manufacturer as a result. The part has to be inspected every 300 engine flight cycles (EFC) on the Trent XWB-84, and every 100EFC on the Trent WXB-97. There were also problems with the starter motor on the Trent XWB-84. "The wording on the maintenance planning document (MPD) was misinterpreted in certain cases, and some operators did not undertake adequate line maintenance as a result," says Colombo. The wording in subsequent versions of the MPD was changed, and problems with the starter motor are now rare.

The A350's MPD for the airframe has tasks to carry out borescope inspections on the HPT blades. "There are three standards of blades available. The blades that were installed on the initial serial numbers (S/Ns) were the ones with the best quality standard. The MPD task interval will be shortened to reduce the risk of early engine removals," says Colombo.

The engine has a higher exhaust gas temperature (EGT) margin than previous members of the Trent family and other engines in the same category. If a core engine wash is undertaken regularly as a maintenance task, it is unlikely that thermodynamic degradation would be the driver for a shop visit (SV). The main drivers for a full SV are likely to be LLP expiry and rotables.

Problems with the IPT nozzle guide vane (NGV) heatshield were detected early in the engine's operation programme during borescope inspections. Several cracks and detached material were seen after a certain period of operation. SB72-AJ159 was issued as a result to address these faults. There were also issues with leakages in the HP/IP oil pipes. The manufacturer resolved this on the initial engines affected by applying a higher torque value.

The most critical limits are the HPC 4 disc and HPC 5-6 rear shaft both at 1,850 cycles if the operator counts for cycles on a 1:1 EFC system. This will be illustrated in the maintenance drivers section. Depending on the operating conditions the HPT blades will have a limit of 2,000-3,000 cycles.

Trent XWB-84 ADs

The European Aviation Safety Agency (EASA) has issued airworthiness directives (ADs) for this variant.

The Trent XWB incorporates modern technologies compare to earlier Trent family members.

AD 2016-0242 applies to a limited number of older engines. The LPC case support inboard pins, dowels and bolts are subject to a one-time inspection, and need replacement if any defects are found.

AD 2017-0088 applies to the IPT stage 2 locking plates on a limited number of older engines, and they must be replaced if any faults are reported during inspection.

AD 2019-0071 applies to the LPT rear support seal panel. The parts have to be replaced during the next qualified SV, and about 50 engines are affected.

AD 2019-0112 applies to the EEC software, which must be modified and updated in all engines.

AD 2019-0175 applies to the engine mounts and thrust links washers. All engines should have been inspected at this stage, and the component must have been replaced if any fault was found.

AD 2019-0234 applies to the front engine mount support structure, which involves an inspection of the outlet guide vanes outer mount ring every 1,000FC.

Trent XWB 97

This version of the engine has been in service for just over two years, with the first A350-1000 going into service with Air Caraibes in late 2017.

Because of the XWB-97's higher core temperatures, it is more likely to be impacted by the environment it operates in. The calcium magnesium alumina silicate (CMAS), also called silicon-containing sand dust, is a pollutant present in some operating environments where this variant of the engine operates.

Fleets operating in these locations have been subject to early deterioration of the HPT NGV's hardware due to thermal barrier coating loss when exposed to CMAS. This problem is not unique to the Trent XWB-97 engine, but it was expected, so new vanes have been designed by Rolls-Royce to mitigate it. Again, due to operating environments, some of the engines in the fleet have experienced higher than expected oil consumption. Oil consumption seems to be higher than average during the first 2,000EFC since new, and then it stabilises. Rolls-Royce is working closely with affected operators and solutions are being implemented.

Issues with LRUs, like the fuel pump and the ignitor box, have created operational issues, and have been reported. These issues have caused delays in missions, but resulted in few cancellations. Routine tasks that have been added since service entry include IPT stage 2 blades inspection before 1,300EFC since new, and inspection of the LPT module within 1,500EFC.

Most of the IPT module LLP limit stands at 1,800EFC if the EFC cycle counting system is used. EASA has issued the AD 2019-0175 for all engines in service. The engine mounts and thrust links washers must be inspected and replaced if any fault is found in the component.

Maintenance drivers

The main limiters to on-wing and engine removal intervals are particular LLPs in the engine's complete shipset. These are the HPC 4 disc and HPC 5-6 rear shaft, which both have current life limits of 1,850EFC.

However, this life limit is likely to increase as the programme matures. There is a learning curve, and Rolls-Royce has already extended the limits on some LLPs.

The A350's airframe maintenance planning document (MPD) and the Trent XWB's LLP life limits are set by the OEM.

A350 operators have two methods to account for accumulated EFC on the Trent XWB.

The first is the EFC method. "The EFC accounts for cycle on a 1:1 basis, or even more drastically if an engine is operated at full maximum thrust for extended periods of time," says Colombo. This means that at the most a single cycle flown is counted as 1.0EFC of LLP life. For higher take-off thrusts, the ratio is lower, for example at 0.8EFC life limit per 1.0EFC flown. In this case a part with a life limit of 5,000EFC would have to be removed after 4,000EFC. An example of this lower ratio being applied is when an engine is fitted with a thrust bump, the life limits for the parts get reduced.

Rolls-Royce has developed a second method that allows the direct accumulated counts (DAC) life usage calculator. "An operator that uses the Rolls-Royce DAC method has the flexibility to not account for a full cycle every time the engine completes a mission," adds Colombo. This is the equivalent to account for a percentage or fraction of a cycle, depending on the AMP and the conditions under which the engine was operated during the mission. This results in longer LLP limits. Thus, 5,000EFC flown could translate to the part having to be removed after 6,000EFC.

"Finnair has implemented the DAC method to extend LLP life. It is expected that the first SV for the Trent XWB-84 variant should occur at 3,000-3,500EFC for operators that implement the DAC method.

The cost of a first run SV for a Trent XWB-84 is expected to be about $7.5 million. The list price for a full LLP stack is in the range of $9.0.

Authorised engine shops for this variant are EOS Derby, HAESL, SAESL and N3.

Under the DAC, the first SV interval is expected to take place at 2,500-3,500EFC. It is expected to cost $7.5-8.5 million, depending on the SV workscope and the operating environment. The list price of the LLP stack is expected to be about $10 million, because 80% of the LLPs on the Trent XWB-97 have been redesigned. This means that there is commonality on only 20% of LLPs between the Trent XWB-97 and Trent XWB-84.

Authorised MROs are EOS Derby and HAESL.

The A350-900ULR provides ultra long-haul services, and is powered by the Trent XWB. The XWB-97 powers the A350-1000, and it has been chosen for Qantas' sunrise programme.

Operator feedback

Finnair is one of the earliest operators of the engine. It was one of the first A350-900 operators, and it has a total of 14 aircraft in its fleet and a further four on order. "The entry into service of the Trent XWB-84 has been very successful from an operational perspective," says Sara Mosebar, A350 programme manager at Finnair Technical Operations. "There have been some technical issues with a few individual components, which has resulted in a higher maintenance burden, in the form of maintenance actions or component replacements, but these have not compromised safety and have had no significant impact on reliability."

There has not been any higher than expected EGT degradation since the engine was inducted for the Finnair. "Quite the opposite. On the Finnair fleet we have seen performance improvement during service," continues Mosebar. In terms of non-routine inspection, Mosebar adds that "so far Finnair has only had one unscheduled SV, which was due to findings on the HPT blade during scheduled maintenance, which is under investigation along with Rolls-Royce."

Finnair's hub is located in a benign environment. Helsinki is located at sea level, with cold to mild temperatures all year round and a clean operating environment. The carrier, however, has a diverse network that means that the Trent XWB engine also has to operate from harsh environments like Bangkok and Dubai. The operator has already implemented the DAC cycle accounting system. "The introduction of the DAC data files, and the associated impact on the LLPs has challenged Finnair to reassess how we plan our engine maintenance. This has been positive overall, since it has allowed better utilisation of the life of the components," explains Mosebar.

Finnair has four years' experience operating the Trent XWB-84. "Finnair is quite satisfied with the technical performance of the engine. The dispatch reliability is on average one operational interruption per 1,000 departure," concludes Mosebar.

Iberia has more than one-and-a-half years of experience with the type. It has been operating the Trent XWB-84 engine since 2018, and has six aircraft. Iberia has a further six on order.

Iberia's total fleet will comprise 24 engines and the pool of spares. Iberia says its experience with Trent XWB engines has been positive so far. The fleet has shown an excellent track of dispatch reliability. There has been only one incident affecting the Trent XWB-84 engine, which will be illustrated in the following section.

In-flight shutdowns

The Trent XWB family engine has accumulated more than 3.0 million flight hours, but has only experienced one in-flight shutdown not originating by human error. The incident happened just over two months after Iberia took delivery of the aircraft. Iberia's flight 6252 from New York JFK to Madrid (MAD), operated by an A350-900 aircraft received a warning in the cockpit indicating that the EGT on the port engine exceeded the permitted limit. This happened about one-and-a-half hours into the flight on September 2018 in Canadian airspace.

The aircraft was flying at cruise speed and 41,000 feet altitude when the alert was recorded in the cockpit. The flight crew decided to descend to 25,000ft and return to JFK. This warning was subsequently followed by an 'engine fail' message in the cockpit. At this point the crew shut down the engine, declared an emergency and requested diversion to Boston. The aircraft landed safely in Boston and all passengers were evacuated safely.

The engine was replaced and ferried back. Investigation revealed the cause was related to a fault in the engine on the EEC unit, and there was no mechanical failure. The issue was promptly addressed by Rolls-Royce and the software has already been updated, as per AD 2019-0112. No further incidents of this kind have been reported by the carrier.

In summary

All the major engine manufacturers have faced huge challenges to provide powerplants that meet the requirements of the aircraft manufacturers and operators.

One of the reasons behind this is that aircraft manufacturers are usually in a race against time to be the first company to introduce a new product in the market. This results in shortened times for suppliers to undertake enough testing and conduct sufficient research and development of their products, hence the shortfall between initial specifications and actual on-wing performance.

A second reason is competition between suppliers to capture market share on an aircraft programme in early stages of development.

The Trent XWB has not been subject to pressure originating from either of these factors and it was designed in close cooperation with the airframe manufacturer. As the sixth member of the family, the Trent XWB has also benefited from the de-risked technologies from previous iterations of the Trent family of engines. All these factors have contributed to its success in the market. AC