Rolls-Royce Trent family specifications

The Rolls-Royce Trent engine family includes six main types. Their development, configuration, thrust ratings, bypass ratios, specific fuel consumption, and emissions standards are examined.

The Rolls-Royce (RR) Trent engine family was based on the manufacturer's three-shaft RB211 widebody engine, which was developed in the 1970s and 80s. The Trent family has six main models that have thrust ratings from 53,000lbs to 97,000lbs for widebody aircraft *(see tables, pages 5 & 11).*

Architecture

The Trent shares the same basic architecture as the RB211, although each main model has different intake fan and core engine rotor and stator disk (stages) diameters. The three-shaft or three-spool architecture is unique among turbofan designs, and is credited with giving the RB211 and Trent families greater thrust growth capacity than competing two-shaft designs.

The Trent's three-shaft configuration provides six main modules of rotating and static stages: the fan; intermediate pressure compressor (IPC); high pressure compressor (HPC); high pressure turbine (HPT); intermediate pressure turbine (IPT); and low pressure turbine (LPT).

All turbofan manufacturers have tried to increase their engines' fan diameters to achieve higher bypass ratios. That is, the ratio of the volume of air bypassing around the core engine to the volume of air passing through the core engine. A higher bypass ratio is therefore achieved with a wider intake fan; which also increases the air volume and mass. With an unchanged size of core engine, a wider fan diameter will increase the volume and mass of air bypassing around the core.

A higher volume and mass of bypassed air has multiple benefits. The prime one is that the air's exit velocity can be reduced, which improves propulsive efficiency and specific fuel consumption (sfc). A higher volume of bypassed air and slower exit speed also reduces exhaust temperature and noise emissions.

There are limitations to increasing fan diameter, however. The first is the need to limit the fan-blade tip speed. Fan tip speed has to be at a level that optimises the engine in terms of trades between fuel burn, weight, and other design parameters. As fan diameter increases, blade-tip speed increases for the same number of revolutions per minute (RPMs), because of the longer fan blades. Engine performance is optimised generally by RPMs being reduced as fan diameter is increased. Wider diameter fans therefore have to turn at slower RPMs than smaller diameter fans. Slower RPMs result in lower compression of air, however, resulting in lower efficiency.

The second limitation of wider-diameter fans is that they weigh more, and so require more power to turn them. This requires a larger turbine, with more stages and airfoils. Another issue is that because the RPMs also have to be reduced, more turbine stages are required to extract enough energy from the exhaust gases to turn the fan.

For a given core engine, the fan diameter cannot be increased beyond a certain point without incurring performance and cost penalties. First, this is because the higher weight of a larger fan and additional turbine stages outweighs the benefits of a higher bypass ratio. Second, not only will the additional weight cancel some of the fuel burn savings, but the additional number of turbine airfoils and disks will also increase the engine's maintenance costs.

Three-shaft design

A main feature of the RB211/Trent is that the fan and the first module of the core engine compressor, the IPC, rotate on separate shafts. Although each shaft requires its own turbine to turn it, the IPC rotates at higher RPMs than the fan.

This compares to two-shaft engines, where the fan and first module of the core engine compressor rotate on the same shaft. The first core engine compressor is the low pressure compressor (LPC), which turns at the same RPMs as the fan. The first compressor module is referred to as the LPC because it turns at slower RPMs than the IPC in a RB211/Trent engine.

The IPC on a Trent variant rated at 95,000lbs thrust, for example, rotates at more than 7,500 RPM. This compares to fan, and LPT, speeds of 2,000-3,000 RPMs on the same Trent engine; and other large two-shaft turbofan engines of similar thrust ratings and fan diameters.

This difference in RPMs of at least 4,000 RPMs means IPC stages in a three-shaft engine achieve a higher compression than the LPC in a two-shaft engine. Because the Trent's IPC stages are able to rotate at higher RPMs than two-shaft engines, the Trent requires fewer stages to achieve the same air compression. The engine can also achieve a higher overall pressure ratio. Moreover, the air exiting the IPC, and entering the HPC, is at a higher pressure than air exiting the LPC in a two-shaft engine. The HPC module downstream of the IPC requires fewer stages than the HPC in a two-shaft engine to achieve the same compression. The HPC and HPT can rotate at rates of up to 13,500 RPM.

The Trent's two core engine compressor modules therefore have a higher capacity to achieve the same compression with the same volume of air compared to the same-sized compressor modules of a two-shaft engine. This has several inherent advantages, which are key to RR's design philosophy on the RB211 and Trent.

The first is that the Trent can use fewer IPC and HPC stages than a two-shaft engine to achieve the same compression. The compressor stages can run closer to optimum speeds than in a two-shaft engine, thereby enhancing efficiency and increasing pressure ratio.

The Trent 700, for example, powering the A330 family has 14 stages: eight IPC and six HPC. This compares with the CF6-80E1's four LPC and 14 HPC stages; 18 in total. This has a further advantage of making the three-shaft engine shorter.

The second is that in some cases the compressor modules in a three-shaft engine can be of a smaller diameter compared to the compressor modules in a two-shaft engine to turn a fan of equal diameter. Compressor modules of a smaller diameter allow the three-shaft engine to achieve a higher bypass ratio than a two-shaft engine for the same fan size.

A third is that the three-shaft engine has more potential to be developed to a wider range of thrust ratings; which the Trent family has achieved.

Nevertheless, the three-shaft configuration has some disadvantages.

The first is that the fan, IPC and HPC turning on three shafts each require a turbine; resulting in three turbine modules: the LPT for the fan; IPT for the IPC; and HPT for the HPC. This increases engine weight and complexity of construction.

This complexity of construction has particular relevance to maintenance, since the HPC/HPT typically has shorter intervals for maintenance than the fan/LPT and IPC/IPT. The engine will require full disassembly, however, to allow the HPC/HPT, the high pressure spool, to be removed and disassembled.

Despite these disadvantages, the Trent's three-shaft configuration generally means it requires fewer turbine stages than two-shaft engines with similar fan diameters and thrust ratings. Five of the six Trent models have single-stage HPTs and IPTs; which turn the HPC and LPC. Many competing two-shaft engines have dual-stage HPTs; although they of course do not require an IPT. Trent models generally have LPTs with fewer stages than competing two-shaft engines.

The Trent has been developed to use additional technologies to improve efficiencies of successive family members.

A main objective with the Trent family has been to increase overall pressure ratio. This increases thermal efficiency, and the sfc. A higher pressure ratio can only be achieved through improvements in 3D aerodynamics, component efficiencies, and material capabilities.

Later variants of the Trent, starting with the 900 and 500, used wider chord swept fan blades. These gave the fan higher aerodynamic efficiency through reduced drag and higher massflow.

A higher thermal efficiency also has the added advantage of lower CO2 emissions. It also, however, increases NOx emissions. This increase has to be offset by improved combustor design.

The Trent family has been in development since the late 1980s, and the most recent models are due to enter service with the A350XWB family in 2013-2017. In contrast to the RB211-524 models that powered variants of the 747 and had limited sales success, the Trent family has won larger shares of firm orders for the aircraft they power.

The first Trent model in development was the Trent 600; originally intended for the MD-11. This variant was dropped following order cancellations from its only two customers.

ROLLS-ROYCE TRENT 500, 700, 800 & 900 SPECIFICATIONS TABLE

Engine Model				Trent 768	Trent 772	Trent 772B
Thrust rating-lbs				67,500	71,100	71,100
Fan diameter (inches)				97.4	97.4	97.4
Fan blades				26	26	26
Bypass ratio				5.1	5.0	5.0
Overall pressure ratio				33.7:1	34.5:1	35.5:1
SFC: lb/lbf/hr				0.56	0.56	0.56
Flat rate temp.				30	30	38
Application				A330-300	A330-200/-300	A330-200/-300
Engine configuration						
Fan stages				1	1	1
IPC stages				8	8	8
HPC stages				6	6	6
HPT stages				1	1	1
IPT stages				1	1	1
LPT stages				4	4	4

Engine Model	Trent 875	Trent 877	Trent 884	Trent 892	Trent 892B	Trent 895
Thrust rating-lbs	74,600	77,200	84,950	91,600	91,600	95,000
Fan diameter (inches)	110	110	110	110	110	110
Fan blades	26	26	26	26	26	26
Bypass ratio	6.2	6.1	5.9	5.8	5.8	5.8
Overall pressure ratio	42:1	42:1	42:1	42:1	42:1	42:1
SFC: lb/lbf/hr	0.56	0.56	0.56	0.56	0.56	0.56
Flat rate temp.	30	30	30	30	30	25
Application	777-200	777-200	777-200ER	777-200ER	777-200ER	777-200ER
Engine configuration						
Fan stages	1	1	1	1	1	1
IPC stages	8	8	8	8	8	8
HPC stages	6	6	6	6	6	6
HPT stages	1	1	1	1	1	1
IPT stages	1	1	1	1	1	1
LPT stages	5	5	5	5	5	5

Engine Model	Trent 970	Trent 972	Trent 977		Trent 553	Trent 556
Thrust rating-lbs	70,000	72,000	76,500		53,000	56,000
Fan diameter (inches)	116	116	116		97.4	97.4
Fan blades	24	24	24		26	26
Bypass ratio	8.7	8.6	8.5		7.7	7.6
Overall pressure ratio	37-39:1	37-39:1	37-39:1		36.3:1	36.3:1
SFC: lb/lbf/hr	0.518	0.518	0.518		0.54	0.54
Flat rate temp.	30	30	30		30	30
Application	A380-800	A380-800	A380F		A340-500	A340-600
Engine configuration						
Fan stages	1	1	1		1	1
IPC stages	8	8	8		8	8
HPC stages	6	6	6		6	6
HPT stages	1	1	1		1	1
IPT stages	1	1	1		1	1
LPT stages	5	5	5		5	5

Trent 700

The Trent 700 was the first Trent model developed, and it followed the RB211-524G/H that powered the 747-400 and 767-300ER. This was rated at 58,000-60,600lbs thrust, had a 86.3-inch diameter fan, and a bypass ratio of between 4.1 and 4.3:1.

The Trent 700 was initially developed to provide 67,500lbs of thrust at sea level for the initial, low maximum take-off weight (MTOW) versions of the A330-300 that entered service in 1994; referred to as the Trent 768. The Trent 700 has a 97.4-inch diameter fan and bypass ratio of 5.1:1.

The Trent 700 has an eight-stage IPC, six-stage HPC, single-stage HPT, single-stage IPT, and four-stage LPT *(see table, this page)*. The core engine has one more IPC stage and two more LPT stages than

The Trent 700 series was the first Trent family member in service. This has a sfc of 0.565lbs of fuel per lb of thrust. All Trent family members developed since have a lower sfc.

the RB211-524G/H.

All Trent family members utilise wide-chord, hollow and snubberless fan blades. These were first developed for the RB211-535E4 engines in the 1980s. Hollow blades reduce weight, while the wide chord design means fewer fan blades are required than when using older generation clappered blades, which incur more drag.

Lower drag on the fan assembly means it requires less power from the turbine to rotate it. The fan also increases airflow and so overall efficiency. The Trent 700 family has 26 fan blades.

The Trent 700's additional IPC and LPT stages allow its core to turn a larger fan and achieve a higher bypass ratio than the RB211-524G/H with similar-sized core engines.

The Trent 768's configuration allows it to generate an overall pressure ratio of 33.7:1.

The Trent 772, which has a sea level thrust rating of 71,100lbs thrust, was developed for higher MTOW variants of the A330-300, as well as the A330-200 with the shorter fuselage. While the Trent 772 has the same basic configuration as the Trent 768, the 772 achieves a marginally lower bypass ratio of 5.0:1 and has a higher overall pressure ratio of 34.5:1 *(see table, page 5)*.

The Trent 768 and 772 are both flat rated at 30 degrees centigrade, so they provide a constant static take-off thrust rating up to an outside temperature of 30 degrees. Thrust has to be reduced for outside temperatures higher than 30 degrees to prevent the exhaust gas temperature (EGT) exceeding the engine's certified red line limit. 30 degrees centigrade is the standard flat rating temperature for all Trent family and RB211 family engines.

The Trent 772B was developed for hot and high operations. Rated at 71,100lbs thrust at sea level, it differs from the Trent 772 in that the 772B is flat rated to 38 degrees centigrade *(see table, page 5)*. The 772B also produces higher thrust at airport elevations of up to 8,000 feet, so that the engine can maintain its maximum thrust rating to a higher outside temperature of 38 degrees. This makes it suitable for 'hot and high' operations.

The Trent 700 has a cruise sfc of 0.565lbs of fuel per lb of thrust. This compares to the RB211-524H's 0.603lbs of fuel per lb of thrust.

The Trent 700 has to comply with CAEP IV NOX emissions standards. The recent Trent 772 Improved variant has a CAEP IV margin of 16.9 grams per kN (g/kN) of thrust.

The engine has a Stage 4 cumulative noise emissions margin of 9.1 equivalent perceived noise decibels (EPNdB).

The most recent variant is the 772C, also with a sea level rating of 71,100lbs thrust. It can provide higher thrusts than other variants up to airport elevations of 8,000 feet.

In 2009, RR introduced an upgraded version of the 700, called the Trent 700EP; the EP suffix designating enhanced performance. This included a package of technological and design improvements used in the development of later family members in the interim: elliptical leading edges on compressor airfoils; and optimised fan and HPT blade tip clearances. These improvements reduced fuel consumption by 1.2% compared to the original Trent 700. Some of these improvements can be made to existing engines during shop visits.

Trent 800

The Trent 800 was developed at a similar time to the Trent 700. The Trent 800 has six variants with sea level ratings of 74,600lbs to 95,000lbs thrust, and powers the 777-200/-300 family.

The 777 family has MTOWs of 506,000lbs to 766,000lbs for the shorter -200 series, and 660,000lbs to 766,000lbs for the longer -300 series. When the first 777 variants were developed and entered service it was not clear how high the fuel capacity and MTOW of the two main variants would go. The required engine thrust ratings for later aircraft variants were therefore not certain either.

The Trent 800 was one of three engine choices for 777-200s with MTOWs of up to 656,000lbs, and for 777-300s with MTOWs of up to 660,000lbs.

The Trent 800 configuration has the same number of core engine stages as the Trent 700 family. The Trent 800's core has a wider diameter, however, and so has a higher mass flow than the 700's core.

The Trent 800 consequently has a 110-inch fan diameter, and higher bypass ratio of 5.8:1 to 6.2:1 for its six thrust ratings *(see table, page 5)*. The family generates an overall pressure ratio of 42:1.

The first variant was the Trent 875, which has a sea level rating of 74,600lbs thrust *(see table, page 5)*. The Trent 877 has a slightly higher rating of 77,200lbs thrust. These two variants power lower MTOW models of the 777-200 up to 545,000lbs.

The Trent 884 (rated at 84,950lbs thrust), the Trent 892 (rated at 91,600lbs thrust), and the Trent 895 (rated at 95,000lbs thrust) power the 777-200ER models which have MTOWs of 580,000-656,000lbs. These aircraft also have higher fuel capacities than the lighter -200 models. The Trent 892B is rated at 91,600lbs, and powers the 777-300, which has a MTOW of 660,000lbs.

The first five of the six Trent 800 variants are flat rated at 30 degrees centigrade. The highest-rated Trent 895 is flat rated only up to 25 degrees, however.

The Trent 800 has a cruise sfc of 0.56lbs of fuel per lb of thrust. It has to comply with CAEP NOx emissions standards, and has a margin of 12.7 g/kN.

The Trent 800 series, which powers the 777-200/-200ER and 777-300, has the highest rated variant of all Trent engines. The Trent 800 is one of the Trent series that is no longer winning further orders.

Its noise emissions give it a Stage 4 compliance margin of 6.5EPNdB.

Boeing later developed ultra-long-range versions of the 777-200 and -300. These aircraft, designated the -200LR and -300ER, have MTOWs of 766,000lbs and 775,000lbs and an additional 2,500 US Gallons of fuel capacity over their lighter weight counterparts. These aircraft were expected to require engines rated at more than 100,000lbs thrust. Higher rated variants of the Trent were developed from the Trent 800.

The first development engine was designated the Trent 8104, and was later scaled up to the Trent 8115; the two suffixes indicating their thrust ratings. These two engines were proposals for powering the 777-200LR and -300ER.

The Trent 8104 had the same-sized core and fan as the Trent 800, but the 8104 featured several improvements to the core and had swept fan blades.

Swept fan blades not only reduce drag, and so improve the overall efficiency of the engine, but also meant fewer fan blades were required because the swept blades had a wider chord than those used on the Trent 800. Swept blades also meant that the same fan generated more air flow for the same fan size. The fan diameter therefore did not have to change.

Several changes were incorporated to the core, which improved its efficiency. The engine was tested with three-dimensional IPC stators, and HPC rotors and stators. New blade coatings and single-crystal alloys were also tested in the IPT. Aerodynamically improved LPT blades were also added, which would add to the LPT's turning power. The LPT would therefore not have to be larger, despite the engine's higher thrust rating. The Trent 8104 reached a rating of 110,000lbs during testing.

The Trent 8115 was to have an enlarged fan of up to 120 inches in diameter; 10 inches wider than the Trent 800. The Trent 8115's core was also to be scaled up by 2.5% compared to the 8104's core. The Trent 8115 was never built, since General Electric became the exclusive engine supplier for the 777-200LR and -300ER. The Trent 8104 and 8115 nevertheless had technologies developed for them which were used in later variants.

Trent 900

The Trent 900 was one of two new family members developed in parallel; the other being the Trent 500. These two variants used technologies from the Trent 8104 development.

The Trent 900 and 500 were developed for the four-engined A380 and A340-500/-600. The Trent 700 and 800 were developed for twin-engined aircraft.

The Trent 900 and 500 share the same core engine, although the 500's core is scaled down. The Trent 900's core is scaled down by about 10% compared to the 800. The core engines have the same number of stages as the Trent 800. The Trent 900 and 500 have higher bypass ratios than the 700 and 800.

Net thrust at cruise speed is lower for engines with a high bypass ratio than for one with a narrower fan and lower bypass ratio. This is because a wider fan will experience greater intake momentum drag at the same speed as an engine with a lower bypass ratio. Engine bypass ratio can thus be higher for a four-engined aircraft than a twin, since a lower net thrust does not compromise aircraft operation in the event that power is lost from one engine.

As well as a smaller core than the Trent 800, the Trent 900 has a 116-inch fan diameter; six inches wider than the Trent 800's. This allows the 900 to achieve a higher bypass ratio than the 800.

The Trent 900 has three thrust ratings from 70,000lbs to 76,500lbs *(see table, page 5)*. The engine is capable, however, of thrust ratings up to 84,000lbs for growth variants of the A380. The corresponding bypass ratios of these three ratings are 8.7:1 to 8.5:1 *(see table, page 5)*. This compares to the 800's bypass ratios of 5.8:1 to 6.2:1.

The same three Trent 900 variants have overall pressure ratios of 37:1 to 39:1; slightly lower than the Trent 800.

The Trent 900 used several new technologies, including the swept fan blades developed for the Trent 8104. These reduce the number of blades to 24, compared to the 26 used by the 700 and 800. The 900's fewer fan blades increase air mass flow and thrust for a given RPM.

As with the 8104, the Trent 900 uses 3-D aerodynamic airfoils in its compressor and turbine sections.

RR also developed a tiled combustion chamber to achieve lower NOx emissions. An element of improved sfc and fuel efficiency is higher combustion temperatures; a higher temperature improves the efficiency of combustion and so lowers the sfc. It also has the benefit of reducing CO2 emissions.

A higher combustion temperature has several drawbacks. One is that it results in higher NOx emissions, so design technologies are required to offset this. Another issue is the need for improved cooling of the combustors, since the temperature exceeds the melting point of the combustor material. The Trent 900's combustor introduced tiling on the inner walls. Perforated tiles result in a film of cooling air forming on the inner wall of the combustor.

Another feature introduced in the Trent 900 was the contra-rotating turbine. In earlier Trent and RB211 models, the stages of all three turbine sections turned in the same direction. This caused a problem because air leaving the nozzle guide vane (NGV) of the HPT

ROLLS-ROYCE TRENT 1000 & XWB SPECIFICATIONS TABLE

Engine Model	Trent 1000-A	Trent 1000-C	Trent 1000-D Hot/High	Trent 1000-E	Trent 1000-G	Trent 1000-H	Trent 1000-J	Trent 1000-K Hot/High
Thrust rating-lbs	63,800	69,800	69,800	53,200	67,000	58,000	73,800	73,900
Fan diameter (inches)	112	112	112	112	112	112	112	112
Fan blades	20 swept	20 swept	20 swept	20 swept	20 swept	20 swept	20 swept	20 swept
Bypass ratio	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Overall pressure ratio	52:1	52:1	52:1	52:1	52:1	52:1	52:1	52:1
SFC: lb/lbf/hr	0.506	0.506	0.506	0.506	0.506	0.506	0.506	0.506
Flat rate temp.	30	30	35	30	30	30	30	33
Application	787-8	787-8/-9	787-8/-9	787-8	787-8/-9	787-8	787-9	787-9
Engine configuration								
Fan stages	1	1	1	1	1	1	1	1
IPC stages	8	8	8	8	8	8	8	8
HPC stages	6	6	6	6	6	6	6	6
HPT stages	1	1	1	1	1	1	1	1
IPT stages	1	1	1	1	1	1	1	1
LPT stages	6	6	6	6	6	6	6	6

Engine Model	Trent XWB-75	Trent XWB-79	Trent XWB-79B Hot/High	Trent XWB-84	Trent XWB-97
Thrust rating-lbs	75,000	79,000	79,000	84,000	97,000
Fan diameter (inches)	118	118	118	118	118
Fan blades	22 swept	22 swept	22 swept	22 swept	22 swept
Bypass ratio	9.3	9.3	9.3	9.3	9.3
Overall pressure ratio	52:1	52:1	52:1	52:1	52:1
SFC: lb/lbf/hr					
Flat rate temp.	30	30		30	30
Application	A350-800	A350-800	A350-800	A350-900	A350-1000
Engine configuration					
Fan stages	1	1	1	1	1
IPC stages	8	8	8	8	8
HPC stages	6	6	6	6	6
HPT stages	1	1	1	1	1
IPT stages	2	2	2	2	2
LPT stages	6	6	6	6	6

was forced to turn through 90 degrees before entering the first stage of the IPT, so that it could turn in the same direction. This requires large NGV airfoils.

The use of a contra-rotating turbine means that air leaving the HPT's NGV only has to turn through 40 degrees. The LPT then turns in the same direction as the IPT. This system allows for smaller NGVs and makes the turbine overall aerodynamically more efficient.

The Trent 900 has a cruise sfc of 0.518lbs of fuel per lb of thrust. This illustrates how the engine's configuration and use of technological developments have reduced fuel burn compared to earlier Trent and RB211 variants.

The Trent 900 has to comply with CAEP VI NOx emissions, and has a margin of 31.1 g/kN.

Noise emissions are among the lowest of all Trent family members, and give the engine a cumulative margin of 18 EPNdB over Stage 4 compliance.

The 900's high bypass ratio provides the A380 with a 11.8EPNdB margin over allowed stage 4 noise emissions for its MTOW.

In the past few years RR has introduced technical packages that result in sfc reductions. Many of the improvements can be retrofitted to engines while going through a shop visit.

The first package of improvements includes the introduction of elliptical leading edges in compressor airfoils, and improved LPT blade tip clearance. This package reduces sfc by 1%.

The second package gives optimised fan-blade tip clearance, and improved turbine case cooling, LPT seals, and elliptical leading edges of stators. This package reduces sfc by another 0.8%.

Trent 500

The Trent 500 was developed at the same time as the Trent 900. The Trent 500 has a core engine with the same configuration as the Trent 800 and 900, but is scaled down. The Trent 500 uses the same 26-blade and 97.4-inch diameter fan as the Trent 700. It therefore achieves a bypass ratio of 7.6:1 to 7.7:1 for its two thrust rated variants.

The two variants are the 553 rated at 53,000lbs for the A340-500, and the 556 rated at 56,000lbs for the A340-600 *(see table, page 5)*. The overall pressure ratio is 36.3:1.

The Trent 500 uses many of the same technological developments used in the Trent 900.

The Trent 500's design has resulted in a lower cruise sfc than other family variants of 0.54lbs fuel per lb of thrust.

It also has a CAEP VI NOx emissions compliance margin of 16.4 g/kN, and a Stage 4 noise compliance margin of 13.3EPNdB.

Trent 1000

The Trent 1000 is one of two engine choices for the 787 family. To meet Boeing's objectives for fuel burn, RR developed the Trent 1000 with the objective of a 15% lower sfc than the first Trent family member; the Trent 700. The Trent 1000 uses a wide fan diameter for similar thrust ratings than previous generation engines. The 787 has up to eight variants with sea level thrust ratings of 63,800-73,900lbs *(see table, this page)*. These overlap the Trent 700's thrust ratings.

The Trent 1000 has a 112-inch diameter fan. This is the second largest of the Trent family and just two inches wider than the 800's fan. This is turned

The Trent 500 series is one of two series that utilises technologies developed for the Trent 8104 and 8115. This includes the use of wider chord swept fan blades and three-dimensional airfoils.

by a scaled down core engine with the same configuration as the 800, 900 and 500 models; only the 1000 has a six-stage LPT, needed to turn the larger intake fan.

This fan and core configuration achieve a high bypass ratio of 10:1 to 11.0:1 for the eight variants, and an overall pressure ratio of 52:1 *(see table, page 11)*. These two factors are important in achieving Boeing's improved target fuel burn performance.

Six of the eight variants are flat rated up to 30 degrees centigrade. The Trent 1000-D is flat rated up to 35 degrees, and the Trent 1000-K is flat rated up to 33 degrees. These two variants also have high sea level thrust ratings, and so are configured for hot-and-high operations.

The Trent 1000 uses several technological features to achieve the fuel burn and emissions performance required of the 787. The first of these is wide-chord, low hub-tip ratio swept fan blades. This is possible through the use of a smaller diameter fan hub. This means a larger fan intake area is possible for the same fan diameter. This allows air to pass through more efficiently.

Like the Trent 900, the use of swept blades generates a higher mass flow, and so increases engine efficiency. The Trent 1000 fan has 20 of these blades *(see table, page 11)*, compared to the 900's 22 blades, and other members' 26.

The Trent 1000 also uses several technologies in the core engine, including many of the features used in the Trent 900. The Trent 1000 will also have 15% fewer airfoils than the Trent 700. This will contribute to lower maintenance costs.

Compared to other engines, the Trent 1000 powers an electric aircraft. Instead of using air bleed from the engines, the 787 uses the power of the engine to generate electrical power. The Trent 1000 has two high power generators in its IP shaft.

The Trent 1000 also uses soluble core technology. This provides better external and internal cooling of HPT blades. This raises temperature capability, and allows higher combustion temperature which improves sfc and lowers CO_2 emissions. The HPT blades use a thermal barrier and anti-corrosion coatings to prevent oxidisation, corrosion and thermal degradation.

The configuration and technologies used in the Trent 1000 give it a cruise sfc of 0.506 lbs of fuel per lb of thrust. This is about 10% less than the Trent 700's sfc. When this is combined with aerodynamic advances in the 787's airframe and utilisation of lower weight materials, the aircraft should reach its target of about 15% lower fuel burn per seat over previous generation aircraft such as the 767 and A330-200.

The 1000's high bypass ratio gives it a margin over Stage 4 noise emission standards of 20EPNdB. The engine also has NOx emissions that are 35-40% within CAEP VI standards.

In July 2012 RR announced a package of modifications and improvements to reduce sfc of standard Trent 1000s by 3%. This package is termed Trent 1000-TEN (TEN stands for Thrust, Efficiency and New technology).

The TEN package incorporates advances in the HPC and HPT, and blisk technology. The Trent 1000-TEN will be certified at 76,000lbs thrust, and will enter service in 2016. It will be used for the existing 787-8 and -9 variants, as well as the stretched 787-10X, if launched.

Trent XWB

The Trent XWB engine model exclusively powers the A350WXB family. The XWB has the highest thrust ratings in the Trent range of engines; with the A350-1000 requiring an engine rated at 97,000lbs thrust. The first XWB is due to enter service in late 2013, while the highest rated engine for the A350 is scheduled to enter service in 2017.

The lowest-rated variant is the XWB-75 with a sea level rating of 75,000lbs thrust, powering the A350-800. The XWB-79 and XWB-79B are rated at 79,000lbs, and also power the A350-800 *(see table, page 11)*. The XWB-79B has a higher flat rating temperature than the standard 30 degrees for hot-and-high operations.

The XWB-84 is rated at 84,000lbs for the A350-900, and the XWB-97 is rated at 97,000lbs for the A350-1000.

Like the Trent 1000, the Trent XWB has been configured to generate a high overall pressure ratio and a high bypass ratio to provide 16% lower sfc than the first generation Trent engines. This would be about 0.48lbs of fuel per lb of thrust.

The Trent XWB has a fan diameter of 118 inches, and uses the same fan blade design as the 1000 model. The XWB has 22 fan blades; two more than the Trent 1000.

The Trent XWB has the same core engine configuration as the 1000, except that the XWB uses a two-stage IPT. This makes it the first RB211 or Trent model to do so. The core will need a higher flow rate of air to moderate HPT inlet temperature. This will not be achieved through higher overall pressure ratio, since this is already high, and will increase turbine inlet temperature, but by using a larger core.

The core engine has high efficiency compressors which have been developed from the Vision3 programme, and the latest generation tip-clearance control.

The Trent XWB will have 10% fewer IP and HP airfoils than the Trent 700, contributing to lower maintenance costs.

The Trent XWB is expected to have similar noise and NOx emissions margins over Stage 4 and CAEP VI standards as the Trent 1000. AC