The two engine options for the A380 have similar features and performance. Both have been designed particularly to reduce noise and provide a wide margin on Stage 4 and CAEP IV NOx emission standards, at the sacrifice of better fuel burn performance.

A380 engines: does either choice have an overriding advantage?

The market for the A380 will be limited to the largest airlines operating the world's busiest routes. This may explain why there are just two engines for A380 customers to choose between: the Rolls-Royce (RR) Trent 900; and the GEAE/PW GP7000. The market for the two engines is still small. Can one engine choice offer decisive advantages over the other, or will selection come down to customer loyalty and financing terms?

GP7000 configuration

The GP7000 is a joint venture between Pratt & Whitney (PW) and General Electric Aircraft Engines (GEAE). The engine will be certified at 81,500lbs, although Airbus Industrie has asked for the first variants powering the 560 ton maximum take-off weight (MTOW) version of the A380-100 passenger aircraft to be certified at 70,000lbs, and the engines powering the first 590 ton MTOW variant of the A380-100F freighter to be rated at 76,500lbs. "We are certifying the engine at 81,500lbs at the start to provide built-in capacity for thrust growth," explains Bruce Hughes, GP7000 programme manager at GEAE. "Larger developments of the A380 can have MTOW increased to more than 600 tons and they will require an engine rated at 82,000lbs. Our current specification for the GP7000 should allow growth to 84,000lbs."

The GP7000 is a combination of the high-pressure (HP) core section built by GEAE and a low-pressure (LP) section produced by PW. "This is a similar split between GEAE and Snecma in the CFM56," comments Hughes. "GE will manufacture the HPC, combustor, HPT and control system. PW will make the fan system, LPC, LPT and gearbox. The LP spool is derived by PW from the PW4090, powering the 777-200ER. The fan will use swept wide-chord fan blades made from the same material as used in the PW4090, but will use advanced aerodynamics."

The fan diameter will be 116 inches *(see table, page 33)*, four inches wider than the PW4090 engine. The LPC is like the one used in the PW4090, with five stages and is similar aerodynamically. The LPT is produced jointly by PW with MTU as a revenue sharing participant. The engine has a six-stage LPT, and also uses advanced aerodynamics that have been developed by PW. These advanced aerodynamics will produce high-lift airfoils, which are aerodynamically more efficient than the ones used in the PW4090. Besides having higher efficiency, they also deliver a slight noise reduction. This is achieved by fine tuning the number of blades and vanes, as well as their spacing.

The HP system and core is derived from the GE90-115B, the engine rated at 115,000lbs powering the 777-200LR. "The core on the GP7000 is not the same size as the one used on the GE90, but scaled down to meet the design requirements of the GP7000. The HPC has nine stages and HPT two stages," says Hughes. "One major change will be the use of three-dimensional (3-D) aerodynamics. The combustor is based on the low emissions, single annular design used on the CF6 series. We have also added technology used in the GE90 and CFM56 engines to aid a reduction in NOx emissions. The control system will be our full authority digital engine control (FADEC) 3 system. This is more advanced than the earlier systems used for earlier generation engines. FADEC 3 has a higher processing speed and will aid engine diagnostics and condition monitoring."

The core is scaled down to achieve 70% of the coreflow in the GE90-115B. "It is actually 15% smaller," says Hughes "and combined with the LP system derived from the PW4090, produces an engine with a bypass ratio of 9.0:1. This high bypass ratio is achieved on account of the core being smaller than the GE90, but the fan being similar in size to the PW4090's." The GE90-115B has a bypass ratio of 9.0:1, and the PW4090 a bypass ratio of 5.0:1. "The GP7000 has been designed with this high bypass ratio because of the noise emissions standards the A380 will have to meet," explains Hughes. Aircraft certified after 1st January 2006 will have to be Stage 4 compliant, and the A380 is due for certification after this date. Stage 4 noise levels are a cumulative 10dB reduction on permitted cumulative Stage 3 noise levels.

Besides the basic requirement to meet Stage 4 regulations, the GP7000 was under pressure to meet other certain noise criteria. A high bypass ratio generally improves specific fuel consumption (sfc), but the GP7000's four-inch larger fan gives it about a 2% higher fuel burn than the PW4090. This is due to the higher level of drag the fan incurs.

Trent 900 configuration

The RR Trent 900 is a derivative of the RB211/Trent family. The Trent 900 will be the first A380 engine to enter service, in February or March 2006. The initial Trent 900 variant for the A380-100 passenger aircraft will be rated at 70,000lbs. The engine powering the A380-100F freighter, which will enter service in 2008, will be rated at 76,500lbs. "We have designed the Trent 900 with capacity for growth up to 84,000lbs, while Airbus has a requirement for up to 81,500lbs," says Mark Baseley, Trent Product Marketing Manager at RR.

The engine retains the RB211/Trent's three-shaft design. The LP system has a 116-inch diameter fan *(see table, this page)*, which is six inches more than the fan diameter of the Trent 800 powering the 777 and rated at 73,400-93,400lbs.

"The three-shaft design means the engine requires fewer stages and overall less airfoil and vane parts than a comparative two-shaft engine," claims Baseley. "The derivative approach means the Trent 900 will also benefit from the 100 million engine flight hours (EFH) experience of the 3,200 RB211s and more than 550 Trent 700/800s installed."

The Trent 700 and 800 are designed for twin-engined aircraft, and consequently have lower bypass ratios than the Trent 500 and 900, which have been designed for quads. The bypass ratio affects the relationship between net thrust and sfc. Net thrust is low for an engine powering a quad.

The Trent 700 and 800 have bypass ratios of 5.5:1 and 6.5:1, and fan diameters of 97.5 and 110 inches.

The Trent 500, for the A340-500/-600, and the Trent 900, for the A380, have bypass ratios of 8.5:1 and 8.0:1 with fan diameters of 97.5 and 116 inches *(see table, this page)*.

The Trent 500 therefore achieves a higher bypass ratio than the Trent 700, despite having the same fan diameter by use of a scaled-down core. Similarly, the Trent 900 has a higher bypass ratio than the Trent 800, although the two have similar fan diameters. The Trent 900 uses the Trent 800's core scaled-down down by 10% plus a six-inch wider fan.

The Trent 900's LP system driving the fan will have a five-stage turbine. This compares with the GP7000's six-stage LPT.

The Trent 900's intermediate shaft will have an eight-stage compressor (IPC) and single-stage turbine (IPT).

The Trent's HP system will have a six-stage compressor (HPC) and single-stage turbine (HPT), as is the case with all RB211/Trent engines. This compares to the GP7000's nine-stage HPC and two-stage HPT *(see table, this page)*.

GP7000 & TRENT 900 CONFIGURATION & PERFORMANCE DATA

ENGINE	GP7000	Trent 900
LPC	116-inch fan 5 stages	116-inch fan
IPC		8 stages
HPC	9 stages	6 stages
HPT	2 stages	1 stage
IPT		1 stage
LPT	6 stages	5 stages
Bypass ratio	9.0:1	9.0:1
Fuel burn difference		+0.5-0.8%
Thrust rating:		
560 ton MTOW A380-100	70,000lbs	70,000lbs
590 ton MTOW A380-100F	76,500lbs	76,500lbs
Maximum cumulative emissions Stage 4	303.9 EPNdB	303.9 EPNdB
Stage 4 margin:		
560 ton MTOW	7 EPNdB	11.8 EPNdB
590 ton MTOW	5 EPNdB	
CAEP IV NOx margin	45%	35%

Technologies

The GP7000 will incorporate swept fan blades as one of its key technologies, the advantage of which is that there are fewer blades than in a conventional fan because they are wider chord. The blades are also aerodynamically more efficient and so have lower drag and aid an improvement in sfc.

The GP7000 will also use 3-D aerodynamics in the HPC. "This has already been used in the GE90 and improves the HPC's efficiency by 4-5%," explains Hughes. "3-D aerodynamics also have the advantage of cooling the engine down and overall improve fuel burn by 2-3%. 3-D aerodynamics basically mean that the blade is twisted, which reduces span-wise flow from the root to tip. A perfect blade would be one that has all the flow going chord-wise, but there are inevitable losses of air flowing root to tip. The use of 3-D aerodynamics reduces these losses."

There is also use of 3-D aerodynamic technology in the HPT and high-lift airfoils in the LPT.

The FADEC 3 system designed for the GP7000 will be used to control variable stator vanes as FADEC systems have in previous GE engines, but Hughes adds that control will be better than earlier FADEC systems. "The angle of the variable stator vanes is continuously changing, and the FADEC 3's higher processing speed means the angle of the vanes will be changed faster than with previous control systems," says Hughes.

The Trent 900's main feature is its high bypass ratio of 8.0:1, due mainly to the 116-inch fan. The benefits derived from this are a reduction in sfc and lower noise emissions.

The Trent 900 will also use swept fan blades, which were initially designed for the Trent 8104, the engine proposed for the 777-200LR/-300ER. These were not used on the Trent 500. The use of swept wide-chord fan blades means that the Trent 900 will use only 24 blades, instead of the 26 used on the Trent 800. A smaller number of swept blades incurs less drag, lowers the weight of the fan section and provides better bird strike protection.

Like the GP 7000, the Trent 900 will also use 3-D aerodynamic airfoils in the

Rolls-Royce will use swept fan blades in the Trent 900 it developed for the Trent 8104. These have the effect of reducing drag, which contributes to lower fuel burn. The additional effects of swept fan blades is that less are required, reducing weight and making another contribution to reduced fuel burn.

compressor and turbine sections. These were originally intended for the Trent 8104, and were later incorporated in the Trent 500. Like the GP7000, these will improve efficiency and reduce noise.

The combustor will use tiling, used to reduce NOx emissions. This again was used by the Trent 500.

One new feature of the Trent 900 is a contra-rotating turbine. Air passing through the nozzle guide vane (NGV) as it leaves the high pressure turbine section in conventional turbines is forced to turn through an angle of about 90 degrees so that it can enter the next section (intermediate pressure) to make it turn in the same direction. To achieve this large NGV blades are required.

In the Trent 900's contra-rotating turbine, as air leaves the high pressure stage it only has to turn through an angle of about 40 degrees through the NGV. The HPT therefore turns in an opposite direction to the IPT and LPT. Consequently the NGV blades are smaller and lighter, reducing the size and weight of the turbine section. The turbine is also aerodynamically more efficient.

Environmental standards

The two key environmental issues facing the Trent 900 and GP7000 are noise and NOx emissions.

As previously described, both engines will be certified after 1st January 2006, and will therefore be required to meet Stage 4 noise rules, which prohibit an aircraft with an MTOW higher than 850,000lbs from having a cumulative noise emission level of more than 303.9EPNdB. This is 10 EPNdB lower than the allowed Stage 3 emissions of 313.9 EPNdB for an aircraft of this size. Combined Stage 4 noise levels for the three measuring points have to be at least 10 EPNdB lower than the allowed Stage 3 noise emissions for aircraft of the same MTOW.

Hughes says the GP7000 powering the 560 ton A380-100 will have a margin of seven EPNdB on Stage 4 noise levels, and the 590 ton A380-100F will have a five EPNdB margin on permitted Stage 4 noise levels.

Aircraft powered by the Trent 900 will be permitted the same maximum cumulative noise emission of 303.9EPNdB. The A380-100 powered by the Trent 900 with an MTOW of 560 tons will have a cumulative margin of 11.8 EPNdB below Stage 4 levels. This margin is expected to increase to 13 EPNdB when the engine is certified.

In addition to Stage 4 noise compliance, many airlines are concerned with compliance at individual airports. For example, London Heathrow has a quota count (QC) system, which gives each airline a daily QC that it cannot exceed. Each aircraft type also has a QC for arrivals and departures: the QC for departures is one, two or four points (QC1, QC2 and QC4); and for arrivals the QC is half, one or two points (QC0.5, QC1 and QC2). Aircraft with higher noise emissions have higher departure and arrival QCs, and so use up an airline's daily QC quota in less daily flights than quieter aircraft.

"One challenge we had with the GP7000 was having a low London Heathrow QC rating, since many A380 customers will operate to Heathrow," explains Hughes. "The GP7000 on the 560 ton A380-100 has a QC2, although the engine on the 590 ton A380-100F is not QC2 guaranteed. Higher weight aircraft will obviously have smaller Stage 4 margin and possibly higher Heathrow QC count."

The Trent 900-powered 560 ton A380-100 is expected to have a QC2 rating for departures and QC1 rating for arrivals.

Both engines will have to meet CAEP IV standards for NOx emissions, since all engines certified after 2004 will have to meet CAEP IV standards. Hughes expects the GP7000 will have a wide margin of 45% over CAEP IV NOx emission levels. The Trent 900 will have NOx emissions 35% lower than allowed by CAEP IV standards.

Economics

The most important factors that determine economic performance are fuel burn and maintenance costs.

The GP7000 and Trent 900 have both been designed with high bypass ratios, which generally reduce sfc. They have both, however, been derived from engines designed to power twin-engined aircraft. The 'thrust loop' characteristics of twin-engined aircraft should be different from those of four-engined aircraft. This is because twin-engined aircraft require higher net thrust than quads, and so the thrust versus sfc profile of engines powering twin-engined and four-engined aircraft need to be optimised differently.

"We anticipated many potential customers would want to have an aircraft

The A380 is an aircraft that only airlines operating routes with the highest traffic densities will require the aircraft. This will limit customers to a few key airlines for the first decade of production. With little difference in economic performance between the Trent 900 and GP7000, selection may come down to which engine types A380 customers already operate.

with a low Heathrow QC rating. This pressure came from Singapore Airlines, which wanted a Heathrow QC2 rating for the aircraft," says Hughes. "We thus designed the engine with a high bypass ratio and could not think of reduced fuel burn alone. If we had designed for reduced fuel burn alone, we would have used a fan diameter smaller than 116 inches. Increasing fan diameter reduces fuel burn up to a point, but then increases drag and weight. Having a fan larger than the PW4090's 110-inch system made fuel burn 2% higher than it otherwise would have been."

To counter this effect GEAE/PW re-designed the fan and LPT sections derived from the PW4090 to get a better thrust-sfc profile suited to four-engined operations. Hughes estimates a GP7000-powered A380-100 has about a 10% lower fuel burn per seat than a CF6-80C2-powered 747-400. "We also expect the GP7000 to have a 0.5-0.8% fuel burn advantage over the Trent 900," says Hughes.

Like the GP7000, the Trent 900 has also been designed with a high bypass ratio to achieve a Heathrow QC2 rating and lower fuel burn compared to older generation engines. Baseley estimates the Trent 900 will have an 8% lower sfc than the Trent 800. "This has been achieved mainly due to the increased fan diameter and scaled-down core size, which in turn increased bypass ratio from 6.5:1.0 to 8.0:1.0. This has also optimised the thrust-sfc profile for a four-engined aircraft," explains Baseley. RR concedes that the GP7000 has a small fuel burn advantage over the Trent 900 of less than 1%.

Maintenance costs of four-engined aircraft are important because they can account for more than 50% of total aircraft maintenance costs. Engine-related maintenance costs per engine flight hour (EFH) are determined by time on-wing and shop visit costs. Hughes expects the GP7000 to achieve similar on-wing times to the CF6-80C2 and PW4000 on the 747-400. These are in the region of 14,000EFH between scheduled removals for typical long-haul operations. "The GP7000's shop visit costs will be 30-50% higher than 747-400 engines, and so engine maintenance cost per seat will be similar between the 747-400 and A380 because the size difference between the two aircraft is similar."

RR also expects the Trent 900 to achieve similar on-wing times to earlier Trent family members. Engine-related maintenance cost differences between the A380 and 747-400 will therefore depend on the relative difference in shop visit costs between the Trent 900 and RB211-524G/H. In most cases, RR engines are overhauled in shops in which RR has a controlling interest. Most maintenance contracts for RR engines involve fixed rates per EFH, agreed as part of the purchase deal.

Since the two engines are expected to have close fuel burns, the maintenance contracts offered by RR have to be compared to similar arrangements offered by GEAE/PW for the GP7000. Airlines that could repair their own engines will have to consider the GP7000's expected maintenance costs compared to the fixed rates offered on the Trent 900.

Market share

To date the GP7000 has only secured a firm order from Air France, while the Trent 900 has orders from Virgin Atlantic, Qantas, Singapore Airlines and ILFC. Engine selections have yet to be made by Emirates, Lufthansa and FedEx. Emirates has placed the largest order (22 aircraft) for the A380.

The Trent 900 is therefore the market leader, but this could change when outstanding selections have been made.

Fuel burn will not give either engine a cost per seat-mile advantage on the A380, so only maintenance costs can make an impact. With a limited number of airlines ordering the A380 in early years and the fleets operated by each being relatively small, most airlines are likely to rely on the manufacturers to provide engine maintenance, which is also likely to be combined with spare engine provisioning arrangements. The terms of these contracts will thus make the financial difference between the GP7000 and Trent 900.

On the basis of similar economics, airlines will be left with issues of existing fleets and current suppliers as the main influence in engine selection. AC