Rolls-Royce

Gas turbine technology

Introduction to a jet engine



Jet propulsion

Power through the ages

The forces associated with fluid movement are well known; we are all familiar with the power of strong winds, or waves crashing onto rocky shorelines. However, the ingenuity of mankind has enabled air and water flow, wind and wave energy to be successfully harnessed, to provide beneficial movement and power through the ages.

The gas turbine is a machine that burns fuel to provide energy to create a moving flow of air, and to extract valuable power or generate useful thrust from that movement. The jet engine has revolutionised air transport over the last 50 years, and Rolls-Royce has been at the cutting edge, pioneering many of the key advanced technologies of the jet age.

A jet engine employs Newton's laws of motion to generate force, or thrust as it is normally called in aircraft applications. It does this by sucking in air slowly at the front, and then blowing it out quickly at the back.

reliability   integrity   innovation

Newton's third law states that any action has an equal and opposite reaction. A garden sprinkler can be used to illustrate this; it rotates in reaction to the jets of water being forced through the nozzles.

With a jet engine, the action of accelerating air through the engine, has the reaction of forcing the engine forwards. We can use Newton's laws of motion to calculate the amount of thrust the engine will generate.

Accelerating air through the engine gives the air a change of momentum. Newton's second law states that thrust is proportional to the rate of change of momentum, so:
Thrust = mass of air sucked into the engine multiplied by its change in speed.

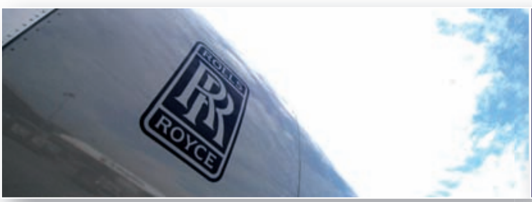
The jet engine is an internal combustion engine which produces power by the controlled burning of fuel. In both the gas turbine and the motor car engine, air is compressed, fuel is added and the mixture is ignited. The resulting hot gas expands rapidly and is used to produce the power.

In the motor car engines, the burning is intermittent and the expanding gas moves a piston and crank to produce rotary or shaft power which is transmitted to the road wheels.

In the gas turbine, the burning is continuous and the expanding gas is ejected from the engine. This is the action applied in Newton's third law, to generate thrust as the reaction.

On modern jet engines the power is used to drive a large fan on the front of the engine that draws air backwards and so produces thrust.

The gas turbine has been adapted for power generation, marine propulsion and gas and oil pumping, all benefiting from its high power and small size.



In the past five years **Rolls-Royce has invested over £3 billion in research and development**

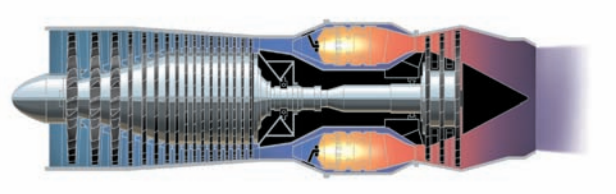
The gas turbine

Perfection in engineering

There are four main types of gas turbine:
the turbojet, turbofan, turboprop and turboshaft

Turbojet

- Simplest form of gas turbine
  - High velocity hot gas provides thrust
  - High fuel burn and high noise levels

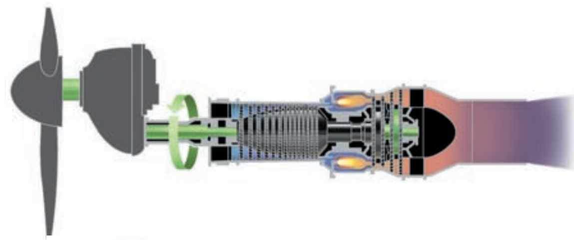


Application

- Most famously the Olympus 593 that powered Concorde
- Military aircraft

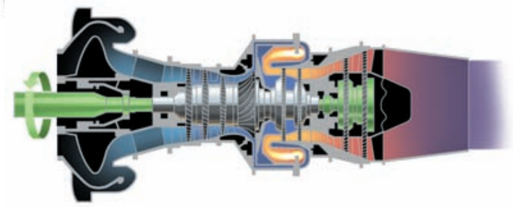
Turboprop and Turboshaft

- The exhaust stream drives an additional turbine -
  - This turbine drives a propeller or a helicopter rotor system
  - The propeller accelerates air generating thrust or lift



Application

- AE2100, the world's leading high power turboprop, powering the Hercules C-130J
- RTM322 turboshaft powering Apache helicopters



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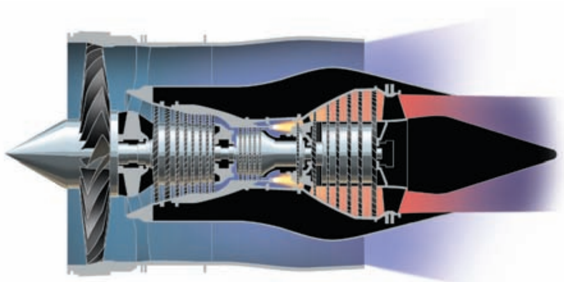
The design of a gas turbine powerplant is a careful balance of many interacting parameters. The ideal powerplant would be the most fuel efficient at its thrust, the most reliable, the lightest, the quietest and the cleanest engine; all made at the lowest cost. In reality, several design parameters are in conflict and attributes must be traded, one against another, to create the best blend of characteristics for the design task.

The optimum blend of characteristics for one type of aircraft may not be the same for another. For instance long range aircraft favour high fuel efficiency and low weight, with payload revenues being important and operating costs being dominated by fuel costs, whereas shorter range regional aircraft need an engine with lower acquisition cost and a greater emphasis on cyclic reliability and low maintenance cost.

Turbofan

- Also called the bypass engine
  - Bypass and core flows both provide thrust, with the bypass flow accounting for around 80 per cent of the total thrust
  - More environmentally friendly with better propulsive efficiency and lower noise levels



Application

RB211 and the Trent family such as the:

- Trent 1000 powering the Boeing 787 Dreamliner™
- The latest Trent powering the Airbus A350 XWB

It gives a **fuel economy equivalent to a family car with four passengers** per passenger kilometre

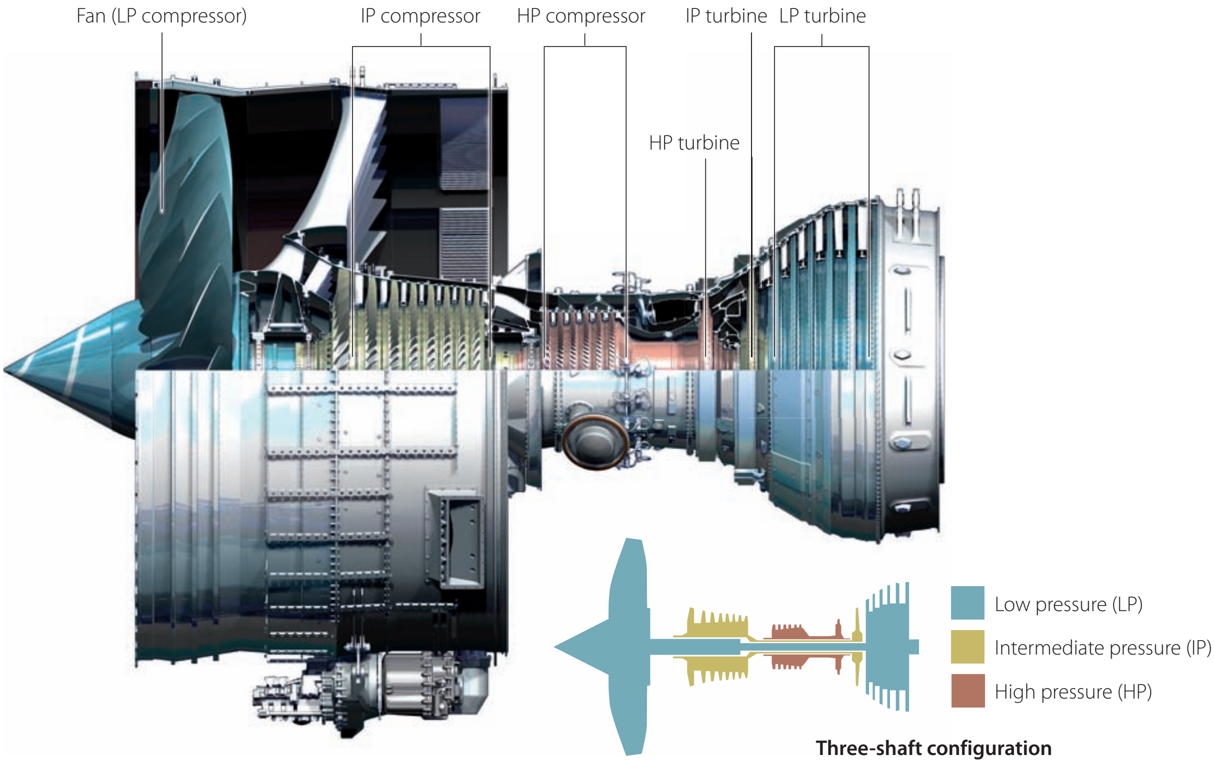
Three-shaft design

Revolutionary technology

Turbofans are usually designed with either a two-shaft or three-shaft configuration. The three-shaft design, which Rolls-Royce pioneered over 30 years ago, has proved advantageous for a wide variety of applications.

Rolls-Royce uses the three-shaft design on all of its large civil turbofans because it allows for far greater versatility in design.

For instance, the fan and core can be scaled differently to provide a range of thrust levels, allowing for a family of engines, such as the Trent family, which has a range of fan diameters from the Trent 700 at 97.4 inches to the latest generation at 118 inches.



Three-shaft configuration

The **force on a Trent fan blade at take-off** is almost **100 tons** (1000 kN)

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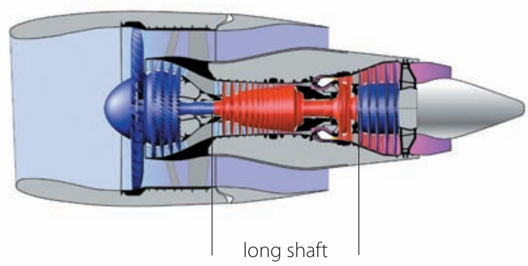
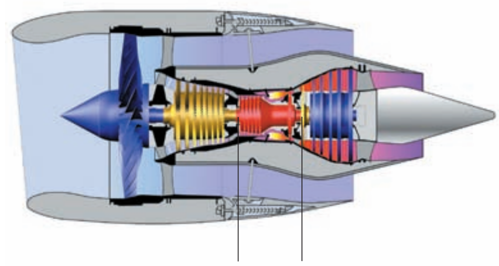
The Trent family has been developed in a way that has allowed the introduction of new advanced technology in both new and existing engines.

This is a low risk route to continuous improvement, following the Rolls-Royce philosophy of gaining maximum customer value from an invention.

Typical two-shaft engine



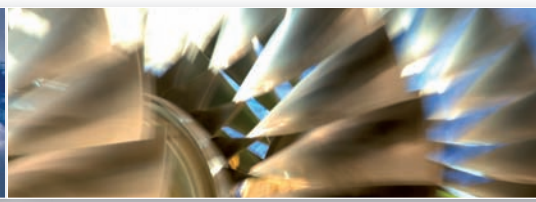
Rolls-Royce three-shaft engine



Key principles and benefits of the three-shaft engine:

- Shorter, stiffer shafts allowing improved performance retention
- Optimised blade speeds improving engine efficiency
- Lighter weight engines resulting in higher revenue earning potential
- Modular design allowing easier maintainability





This is **equivalent to hanging a main-line locomotive on each blade**

The fan

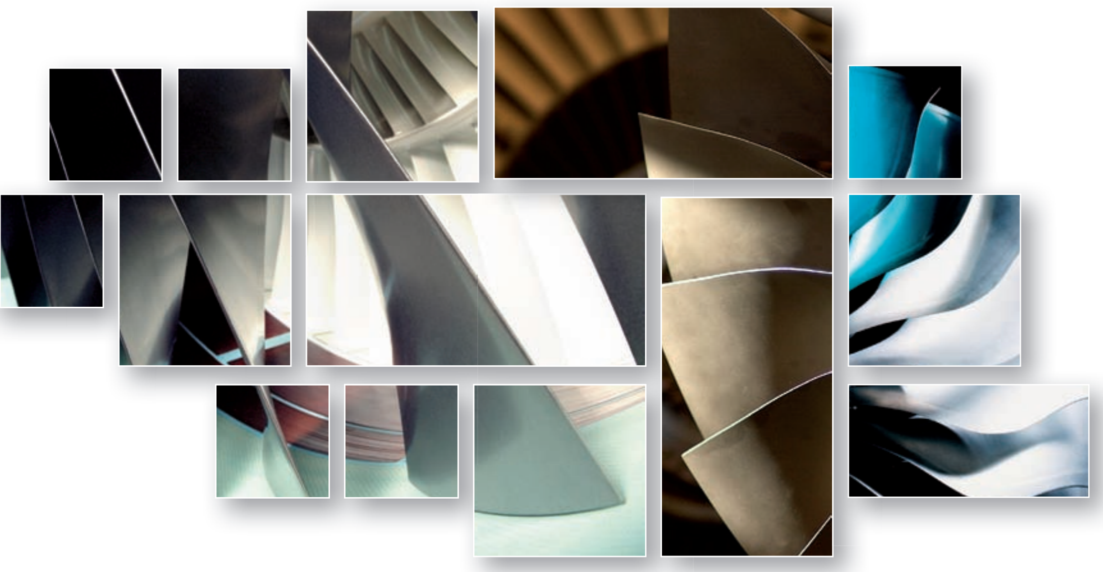
The driving force

The fan module is the assembly of the fan disc, the low pressure (LP) fan shaft and the fan blades.

Its primary jobs are drawing air into the engine, compressing the bypass stream to produce 80 per cent of the engine's thrust, and feeding air to the gas turbine core.

The fan system must be strong, light and quiet. Modern fan blades are hollow for lighter weight and have a wide chord for better stiffness and strength. The engine must pass intense and rigorous testing before being certified as safe to fly. One such test is the fan blade-off test, which is conducted to demonstrate the ability of the fan casing to contain a fan blade should it become detached during engine running.

Another test is the bird ingestion test, which examines the ability of the fan to withstand the impact of birds during flight. As fan intake diameter increases so too does the number of birds used to demonstrate that the engine retains its integrity and the capability to continue supplying thrust, until ultimately, it can be shut down safely.



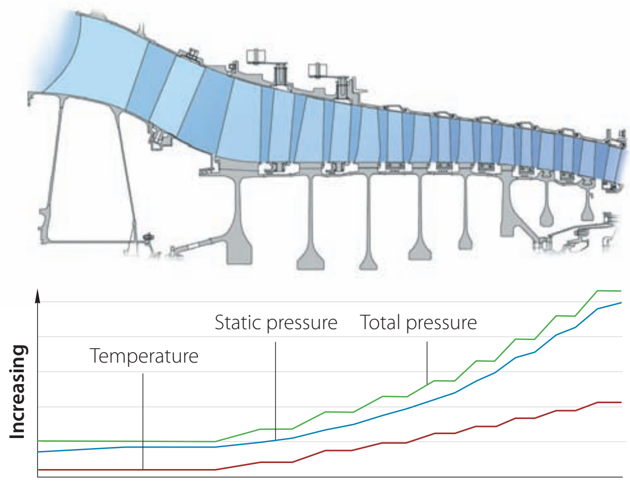
The tip of the fan blades can be travelling at speeds of over 1000mph

The compressor

Applying the pressure

The compressor is made up of the fan and alternating stages of rotating blades and static vanes. The compression system of a Trent engine comprises the fan, eight intermediate pressure stages and six high pressure stages.

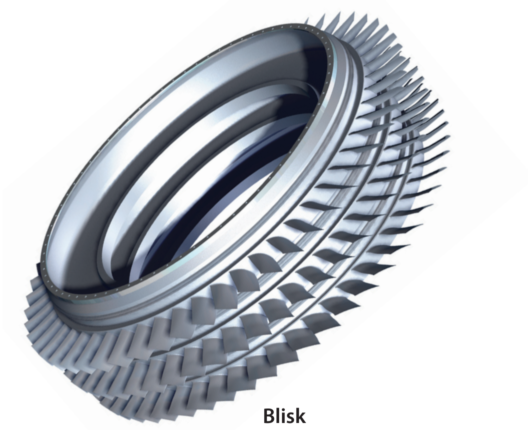
The primary purpose of the compressor is to increase the pressure of the air through the gas turbine core. It then delivers this compressed air to the combustion system.



Increasing pressure and temperature through compressors

The pressure rise is created as air flows through the stages of rotating blades and static vanes. The blades accelerate the air increasing its dynamic pressure, and then the vanes decelerate the air transferring kinetic energy into static pressure rises.

Our latest Trent, powering the Airbus A350 XWB, uses blisks, a single component comprising both blades and a disc. These reduce the weight and improve the efficiency of the compressor by removing the need for blade roots and disc slots.



Blisk

The Trent 900 draws in enough air to inflate 72,000 party balloons in one second

The combustor

Injecting the energy

The annular combustion chamber is located within a casing structure. Kerosene is introduced through fuel injectors into the front of the chamber.

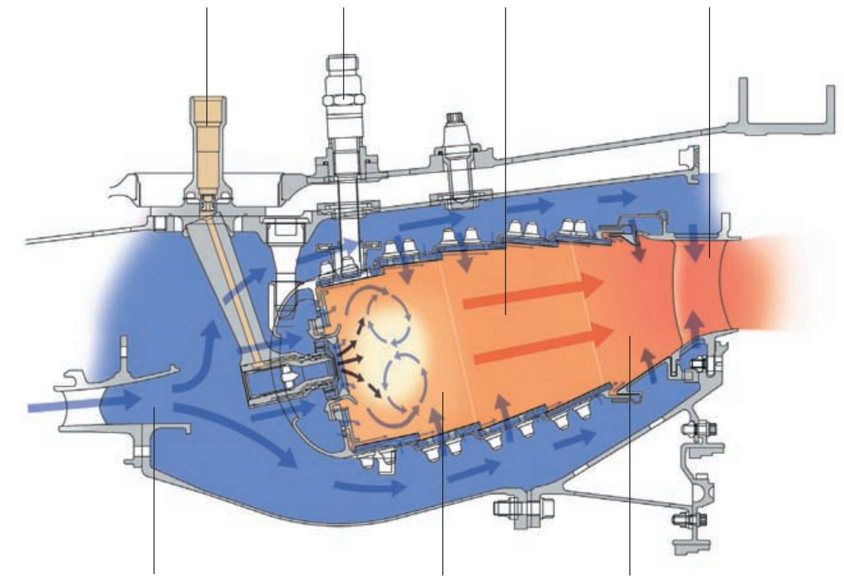
It burns fuel with air received from the compressor, sending hot gas downstream to the turbine.

A typical in-service combustor is shown below.

Air and fuel flow through the annular combustor. Air is diffused around the outside of the combustion chamber, slowing it down; the speed at which the air leaves the compressor would blow out the flame were it to pass directly through. In the illustration, blue shows the combustion feed air from the HP compressor, and white through yellow to red, the hot combustion gases in the burning zones being cooled before entering the turbine system.

The gas temperatures within the combustor are above the melting point of the nickel alloy walls. Cooling air and thermal barrier coatings are therefore used to protect the walls and increase component lives. Dilution air is used to cool the gas stream before entering the turbines.

The combustion chamber is designed for long life and low emissions.



Fuel is burned in the combustion chamber at temperatures of over 2000°C, about half the temperature of the sun

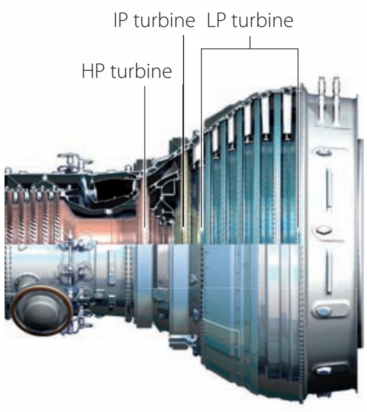
The turbine

Harvesting the power

The turbine is an assembly of discs with blades that are attached to the turbine shafts, nozzle guide vanes, casings and structures.

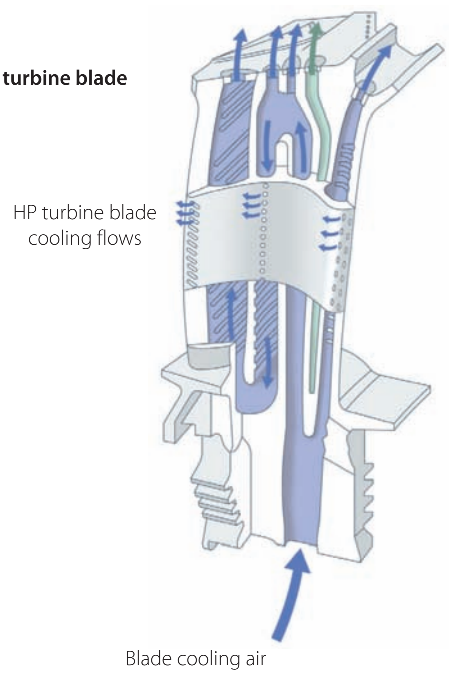
The turbine extracts energy from the hot gas stream received from the combustor. In a turbofan this power is used to drive the fan and compressor.

Turbine blades convert the energy stored within the gas into kinetic energy. Like the compressor, the turbine comprises of a rotating disc with blades and static vanes, called nozzle guide vanes. The gas pressure and temperature both fall as it passes through the turbine.



HP turbine blades and nozzle guide vanes are designed with cooling passages and thermal barrier coatings, to ensure long life while operating at such high temperatures. Cooling air is taken from the compressor and is fed around the combustor into the blades to cool the aerofoils.

HP turbine blade





The melting point of the material in the combustion chamber is 1300°C

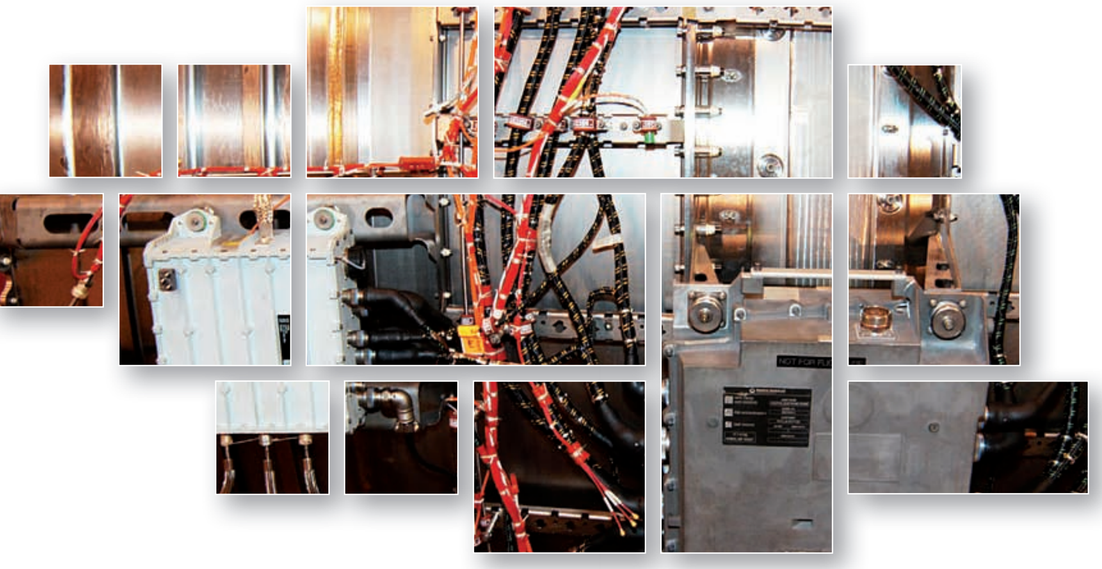
Accessories and aircraft interface

Staying in control

Not only does the engine provide thrust but it also provides power for engine and aircraft accessories.

Engine accessories include the Engine Electronic Controller (EEC), the starter, fuel pumps and oil pumps, whilst aircraft accessories include hydraulic pumps and electrical generators for cabin power.

The engine control system ensures that the pilot has ultimate control with minimum workload and exceptional reliability. This requires fully integrated systems utilising state-of–the-art technology. Engines are now controlled by Full Authority Digital Electronic Control (FADEC) systems, that are becoming smaller, lighter, more reliable and more capable as technology develops.



The **Trent 1000 transfers 438kVA** to the aircraft **Equivalent to powering 146 kettles** to **make 1022 cups of tea**

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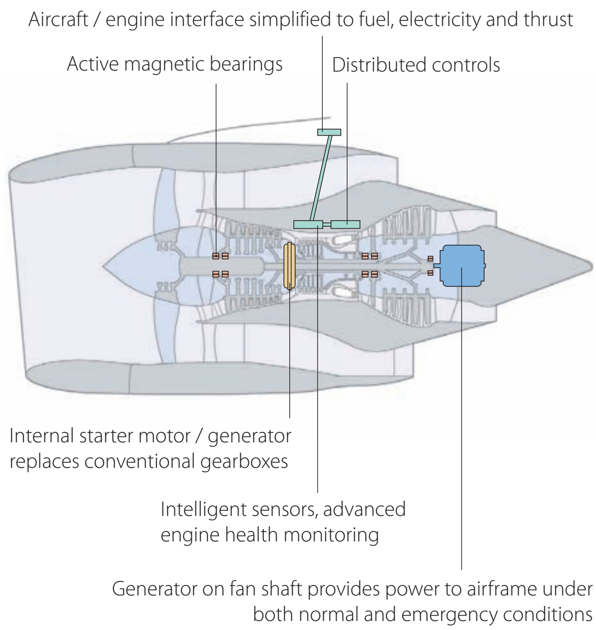
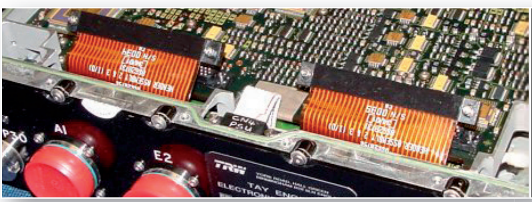
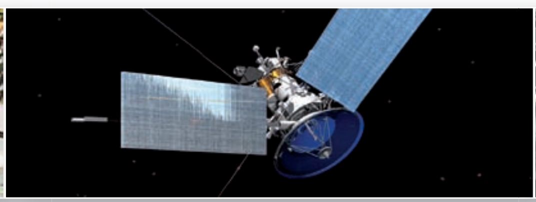
The effective monitoring of engine health is fundamental to ensuring economical operation. Health monitoring technology enables early fault diagnosis and allows airlines to schedule maintenance more cost effectively. Monitoring tools developed by Rolls-Royce allow even earlier warning of developing faults. Further technologies under development analyse oil system debris in real time. Rolls-Royce Data Systems and Solutions (DS&S) provide a complete engine condition monitoring service to airlines.

Engine Health Monitoring (EHM) is a system of collecting data from sensors throughout the engine. The data is continuously monitored and can be transmitted from an aircraft in-flight to the ground via satellite, to give a real-time diagnostic capability. The data is used to detect, prevent and correct engine problems.

The more electric engine removes mechanical drives and bleed air off-takes, creating a more efficient gas turbine. All the engine accessories are electronically driven and the air for the pressurisation and cabin conditioning is supplied by a dedicated electrical system.

One vision of the future



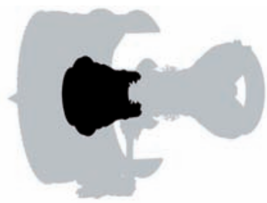

Engine build

A perfect arrangement

A Trent engine is assembled in separate modules

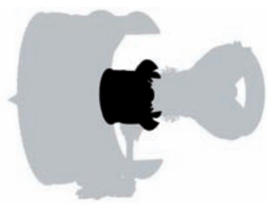
Module 01 low pressure (LP) compressor rotor

- Fan disc on its shaft driven by the LP turbine
- Dovetail slots machined into the disc locate the fan blades
- Trent engines have between 20 and 26 fan blades, with 20 on the Trent 1000



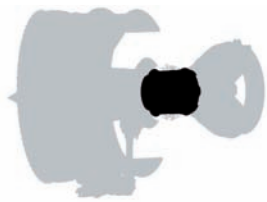
Module 02 intermediate pressure (IP) compressor

- The front bearing housing holds the roller bearings for locating the LP and IP compressors
- The IP compressor is an assembly of discs and blades into a drum
- The latest Trent uses weight-saving blisks to improve engine efficiency



Module 03 intermediate case intercase

- Sits between the IP compressor and the HP compressor
- Internal hollow struts provide access for oil tubes, cooling air and the gearbox drive shaft
- Houses the location bearings for each shaft



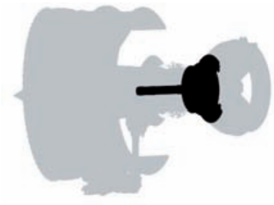
Module 04 high pressure (HP) system

- Consists of the inner casing, HP compressor, combustion system and HP turbine
- Trent 700, Trent 800 and Trent 500 have co-rotating HP systems
- All Trents, from the Trent 900 onwards, operate a contra-rotating HP system

The contra-rotating HP system delivers **superior efficiency** for the HP and IP turbine systems

Module 05 intermediate pressure (IP) turbine

- Consists of the turbine casing, blades, vanes, turbine disc, shaft and the roller bearings for HP and IP shafts
- Nozzle Guide Vanes (NGVs) are mounted into the casing
- LP stage 1 vanes contain thermo-couples for measuring gas temperature

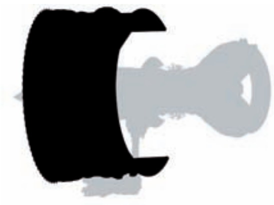


Module 06 high speed gearbox (HSGB)

- Mounted onto the LP compressor case and driven by the internal gearbox housed in the Intercase
- Provides drive to accessories including fuel, oil, hydraulic pumps and electrical generators for the aircraft
- The drive speed provided by the gearbox can be as high as 15,000rpm

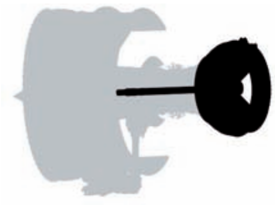
Module 07 low pressure (LP) compressor fan case

- The largest module is formed through the assembly of cylindrical casings and the ring of outlet guide vanes
- The forward case is designed for fan containment
- Both casings contain acoustic linings to reduce noise levels



Module 08 low pressure (LP) turbine

- Bolted discs with blades form the LP turbine rotor
- The LP turbine drives the fan through the LP turbine shaft
- The Trent 900 LP turbine provides 80,000 horsepower, the equivalent of around 1000 family cars



This is achieved by a **reduction in gas turning** also allowing for **fewer parts** and thus a **reduction in weight**

Vision technologies

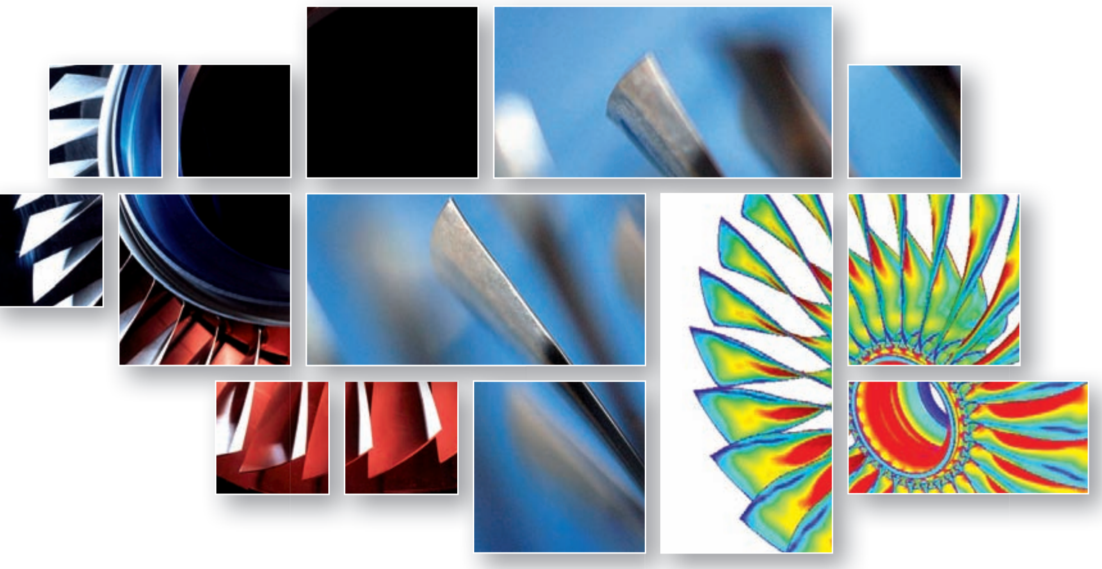
Evolving in harmony

Rolls-Royce is committed to providing the world's best gas turbines in all aspects of design and operation, now and in the future.

The Rolls-Royce 'Vision' describes the technologies we are acquiring to ensure future generations of our products maintain our market leadership. This process achieves the right balance of thrust, size, weight, fuel efficiency, reliability and cost, while minimising environmental impact.

The company leads the way and participates in international technology validation programmes such as NEW Aero engine Core concept (NEWAC), EnVIronmenTALy friendly Aero engine (VITAL), Engine 3E (E3E) and Power Optimised Aircraft (POA).

Rolls-Royce is developing new technologies such as active magnetic bearings and lean burn technology, to the point where they can be incorporated in new engine programmes or retro-fitted to existing fleet engines.



The Rolls-Royce Vision philosophy identifies, develops and demonstrates technology

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Vision5

Latest proven technologies applied to existing architectures, near term upgrade and improvement programmes.

Vision10

Leading edge technology validation. Technologies currently at demonstration stage.

Vision20

Includes technologies that are emerging or as yet unproven. Innovations are typically targeting environmental efficiency and operations benefits for aircraft, engines and systems.

Rolls-Royce is committed to technology acquisition to ensure that our products and services remain market leaders. Strong collaborative research links spanning the globe, provide world leading research in aerothermal technology, manufacturing and materials.

The integrated application of these technologies is highlighted in the design and manufacture of our fans, compressors, combustors and turbines.

The core gas turbine technology of our civil aerospace business also finds application in the defence aerospace, marine and energy businesses of Rolls-Royce.

It provides proven and mature advances for new engine design

Technology and the environment

Powering a better world

Rolls-Royce engines are designed to achieve maximum customer benefits, with the minimum impact on the environment.

Air transportation has a small but growing impact on the environment, through increasing demands for air travel.

The continuous growth of the air-travel market presents manufacturers with the challenge of minimising the environmental impact of a growing aircraft fleet. The task is made more challenging by design conflicts. Strategies to reduce noise, limit pollution and use less energy can have adverse effects on each other.

Rolls-Royce gas turbines have reduced fuel burn per passenger mile by 50 per cent during the jet era.

The company is committed to further reducing the environmental impact of future generations of engine designs.

For more information visit **www.rolls-royce.com/community/environment**

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Rolls-Royce is committed to meeting the environmental challenges, and has set itself aggressive targets based on the ACARE (Advisory Council for Aeronautical Research in Europe) goals.

The Trent family embodies many features that provide class-leading environmental performance. Our Trent 900 engine uses a 116 inch swept fan, a low NOx combustor and a contra-rotating HP system which minimise emissions, noise and fuel consumption, making the Trent 900 the most environmentally friendly engine powering the Airbus A380.

Our next generation engines, the Trent 1000 powering the Boeing 787 Dreamliner™ and the latest Trent for the Airbus A350 XWB will continue to maintain leadership with environmentally friendly technologies.

Truly helping to take care of the air.

Some of the images in this brochure were obtained from 'The Jet Engine' book. It provides a complete and accessible description of the principles of the modern gas turbine, as well as a comprehensive look at the basic mechanics, assembly, maintenance and overhaul of the modern jet engine. For more information visit http://www.rolls-royce.com/history/publications/jet_engine.jsp

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