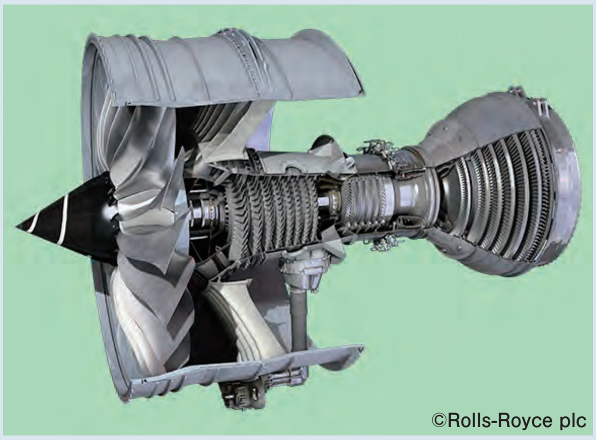
Development of Trent Series Large Turbo Fan Engines



As the demand for aircraft has been increasing, fuel efficiency needs to be improved. Therefore, the performance of the engine as well as the fuselage must be enhanced.

We are in charge of design, part manufacturing and module assembly of the intermediate pressure compressor (IPC) at development of all the Trent Series large turbo fan engines from Rolls-Royce after the Trent 1000, the first model of which helped develop in 2004, as their strategic partner. Going forward, we will promote activities to take charge of the overall IPC module as an IPC module integrator by developing proprietary design and manufacturing technologies.

Introduction

Aircraft are an essential means of transportation in global society, and aircraft manufacturers are competing to develop new types of aircraft. Engines equipping such aircraft must be highly reliable, lightweight and fuel efficient, as well as environmentally friendly (low NOx, low noise).

1 Background

The demand for aircraft is expected to grow by about 5% annually even in the long term, pushed by factors such as the rapid expansion of Low-Cost Carriers (LCCs). To meet such market needs, The Boeing Company in the US and Airbus in Europe are developing new types of aircraft. Rolls-Royce plc (Rolls-Royce) in the UK, one of the world's major aircraft engine manufacturers, has been developing and supplying its Trent series for such aircraft, and we are participating in programs to manufacture the series as a Risk- and Revenue-Sharing Partner (RRSP).

2 Development overview

The Trent series is a generic name given to engines made by Rolls-Royce for civil aircraft (wide-body), and all Rolls-Royce engines from Trent 700 on are in the Trent series, as shown in **Fig. 1**.

Fig. 1 Trent Series

We have been manufacturing parts for all Trent series engines. Particularly for the Boeing 787's Trent 1000 program, we have participated in the program from the development phase including design, parts manufacturing and assembling the various parts of the intermediate pressure compressor (IPC) modules as well as supplying Rolls-Royce with the IPC modules[1) 2)]. Furthermore, in the Trent XWB for the Airbus A350 and the Trent 7000 for the Airbus A330neo programs, we have been handling the IPC modules as a strategic partner of Rolls-Royce. To survive as an IPC module integrator going forward, we need to continue to develop our proprietary technologies described later in this article to keep strengthening our capability to propose competitive products and modules to customers.

In addition, we will continue to contribute to the overall development engines by conducting endurance and other tests for many Trent series engines in our large engine testing facilities.

3 Characteristics of the Trent engines and modules, and our development subjects

The Trent series engines are characterized by their unique triple-spool structure having an intermediate pressure system in addition to the two conventional high- and low-pressure spools, as shown in **Fig. 2**. This intermediate pressure system turns the low pressure compressor (LPC), which would normally run only at low rotation speeds into an IPC that can run at optimal rotation speeds independently from fans that restrict the speed of rotation, increasing the system's efficiency.

Figure 3 shows an image of the IPC module specific to the Trent series, and **Fig. 4** presents a cross-section

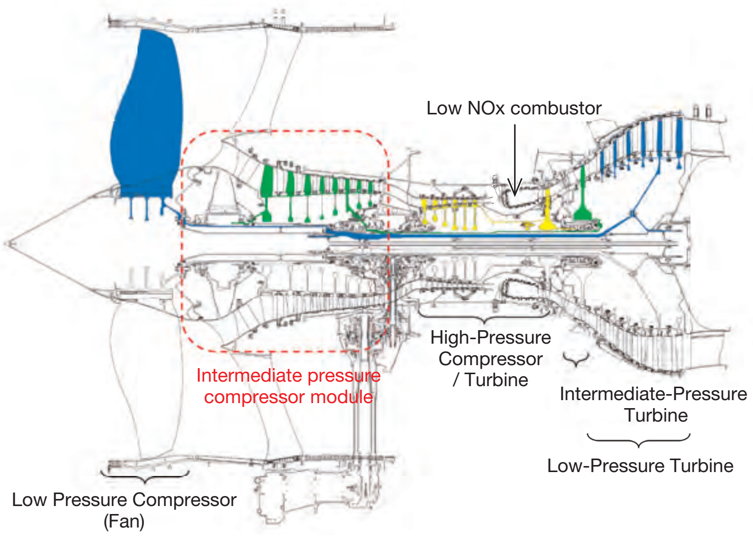


Fig. 2 Characteristics of the Trent Series (Trent 1000)

Fig. 3 Appearance of the IPC module

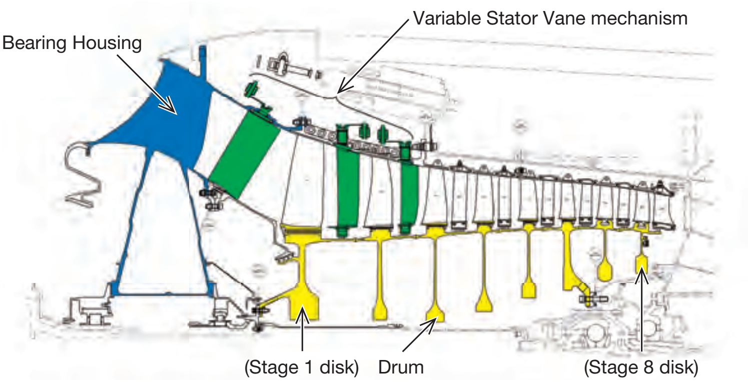


Fig. 4 Cross-section of the IPC module

drawing. The IPC module's unique features and our development subjects are described below.

① The Front Bearing Housing functions as a stator vane that rectifies the airflow from the fans to the engine core, as well as functioning as the main structure that holds the bearing. This requires a complicated design to accommodate oil and air passages while maintaining high strength.

② The IPC module has an eight-stage structure (the high pressure compressor (HPC) has six stages), making it the main part of the compressor. As it operates at higher rotation speeds than the LPC of a conventional twin-spool engine, high strength is crucial.

③ A Variable Stator Vane mechanism, which sits in the HPC in conventional twin-spool engines, is adopted in the IPC Module. The mechanism positions the Vanes with high accuracy corresponding to various flight conditions. The adoption of the mechanism made the IPC structure complex.

4 Design and development

(1) Our achievement

In the commercial aero large turbo fan engine market, the demand for safety, reliability, weight reduction, fuel efficiency, long life cycle and noise reduction continually increases year by year. Relentless efforts were made to keep meeting the demand. The significant performance improvements seen in recent years have been driven by a mixture of various technical studies and edge production technologies. Aerodynamic design has been studied, evaluated and demonstrated through rig testing and analysis, and the state-of-the-art production technology such as Linear Friction Welding (LFW) has been introduced. The Trent XWB series consumes 15% less fuel and is 15% lighter than conventional engines in the same class.

In the development of the IPC modules for Trent 1000, Trent 7000 and Trent XWB, we mainly took charge of structural and mechanical design and analysis, particularly contributing to increasing the accuracy of the Variable Stator Vane (VSV) mechanism, as well as reducing weight and extending the life cycle of the rotor disks.

(i) Highly accurate Variable Stator Vane mechanism

The IPC module's VSV mechanism shown in **Fig. 5** positions the angle of the stator vanes to rectify the main airflow streaming through the compressor. This enables compressors to work with high efficiency under a wide range of flight conditions. The higher compressor efficiency, the less fuel is consumed. Vane mechanism requires sufficient stiffness and being produced close to the nominal geometries to operate efficiently, stably and precisely as intended in the aerodynamic design. Aircraft engines, however, must be as light as possible. Parts of the Trent series large engines, whose diameters are large, are expected to be as thin as possible. Their large and thin walls make it difficult to reduce the mechanical tolerances or increase stiffness. Finite Element Method (FEM) analysis and a number of rig tests were conducted to optimize the layout and the thickness of the components comprising the VSV mechanism. The VSV mechanism is now not only designed as thin as possible but also as stiff as possible. It can manage massive airflow in highly efficient compressors.

(ii) Light and long life cycle rotor disks

The recent compressors run at higher speed, under higher temperatures, generating massive gas dynamic force as they become more efficient. As the operating conditions of the compressor rotors become more severe, it is necessary not only to prolong the life of the rotors for

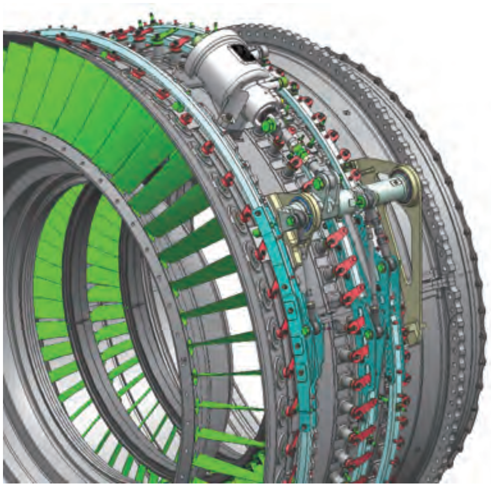


Fig. 5 Variable Stator Vane mechanism of the IPC module

cutting the life cycle cost but also to the further reduction of their weight. While the stress level has drastically increased compared to conventional aircraft engines, the disk stiffness has been reduced to its limit to minimize weight. Achieving minimal disk weight requires satisfying various conflicting conditions, such as optimizing rotor stiffness to maintain high compressor efficiency by an appropriate rotor-tip clearance. However, rotors need to have a long service life while enduring high stress. To alleviate this problem, we used design criteria that take into account every foreseeable risk, and optimized the design by incorporating various state-of-the-art analysis and production technologies, in addition to performing the conventional low cycle fatigue life evaluation and crack propagation life analysis.

(2) Our continuous journey

In the engine programs for civil aircraft we have joined, we have mainly taken charge of structural design and various analyses such as stress, thermal and vibration analyses. Going forward, we will expand our role to cover compressor design integration including aerodynamic design and compressor module system design (engine subsystem), and aim to be a so-called module integrator. To that end, we are conducting various research programs towards developing compressor modules for future large turbo fan engines.

(i) Compressor component technology development

To further improve the performance of compressors in large turbo fan engines, we are focusing on developing technology for designing blisks/blings, improving sealing performance, and improving the accuracy of VSV mechanisms.

Recently, the mainstream of compressor rotors design has been shifting from bladed disk to the blisk for further weight reduction and higher performance. As the compressor blisks with large outer diameter will rotate at high speeds under a massive dynamic force generated by airflow running through the compressor, technologies to suppress such phenomena as cascade flutter need to be developed. Consequently, conventional design methods and criteria are refined and analyses and rig tests are performed.

Compressor modules are furnished with numerous air sealings, and these are mainly labyrinth seals. Air leakage from seals causes the loss of compressor main and secondary air, decreasing compressor efficiency. And as the flight conditions influence sealing performance, it is challenging to maintain a high level of seal performance. Another challenge is to minimize the deterioration of seal performance in long-term use, contributing to cutting the life-cycle cost. One of the objectives in our research and development is new types of sealing for better performance and longer service life.

As the positioning accuracy of a VSV mechanism significantly influences compressor performance, we are analyzing the factors causing operational errors in order to develop and design parts for the mechanism based on a new concept. By reconsidering the layout of the mechanical system, we are aiming to achieve both lighter weight and higher accuracy positioning by integrating and/or increasing the stiffness of parts constituting the mechanism. Going forward, the objective is to achieve higher overall accuracy with a VSV system that includes actuators.

(ii) Compressor rig tests

We are redefining design criteria to design products that can meet stricter requirements and endure more severe conditions, assuming that they will be used in future compressors. We will employ rig tests to acquire data under stress, cycle and temperature conditions among others that cannot be obtained via conventional rig or material tests. Cyclic spin tests for compressor rotors, shown in **Fig. 6**, Fan Blade containment tests, and blade impact tests are planned.

(iii) Compressor module rig tests

We are conducting aerodynamic design and module system development of compressor modules, assuming they will be used for future large turbo fan engines. To demonstrate component technologies, including aerodynamics and system technologies, we plan to perform compressor rig tests at the company's facilities.

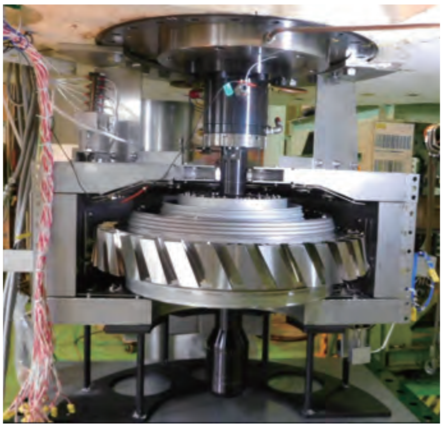


Fig. 6 Cyclic spin test rig and test unit

The plan involves designing compressor modules according to the above-mentioned criteria (redefined based on the component technology development and rig tests), and demonstrating them through compressor module rig tests to improve and mature our compressor technologies towards future engine programs.

5 Engine development tests

Our Akashi Works houses many gas turbine engine testing facilities (test cells), one of which is a large fan engine test cell for engine development tests for the Trent series. Since our cells passed both a commissioning and a cross calibration test using Trent 800 in 2000, we have performed many cyclic and endurance tests for Trent 500, Trent 1000, and Trent 7000.

Figure 7 shows an engine installed in the test cell. A cyclic test is a simulation test that repeats an operating pattern several thousand times to imitate real engine operating conditions. The purpose of this test is to assess how engine performance and its individual components deteriorate over time before fleet engines being mounted on the aircraft in service.

An endurance test is part of the testing regime required for the engine type certification; it is a critical test that engines must pass before airworthiness authorities such as European Aviation Safety Agency (EASA) and US Federal Aviation Administration (FAA) will certify them. It comprises a 150 hour-long test which includes particularly severe conditions, such as continuous operation at the maximum take-off power for 30 minutes, where it is allowed only for five minutes normally.

Fig. 7 Trent engine in test cell

In addition, cases sometimes arise when it is necessary to reproduce non-conformities observed during actual operation and perform improvement tests. In such situations, we conduct the tests together with Rolls-Royce, the test owner, as well as with aircraft manufacturers and engine component suppliers.

While engine design and development are conducted based on estimated operating conditions, engines must ultimately be verified through actual tests. Such engine tests, however, are those in a stationary state on the ground; the engine condition in flight won't be reproduced. Because of this, although feedback from actual operation is necessary, we are striving to contribute to the flight safety as much as possible by performing engine tests in Akashi.

Conclusion

The latest TEN configuration of the Trent 1000, whose IPC module we developed, has entered into service. Also, the -97 configuration of the Trent XWB, with higher thrust, has also started commercial operations. As the latest Trent 7000 is planned to enter into service, capability for mass-production is being built to consistently supply close to 600 units of the IPC modules per year. We will continue to develop our proprietary technologies in parallel with this, enabling us to supply competitive parts and modules for future aircraft engines.

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