Engine System Technology

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The research and development of environmentally compatible engine for small aircraft (ECO engine project) was started in 2003. The objective of this project is to improve engine system integration capability and to establish the advanced technologies required for next generation small aircraft engines, which are environmentally friendly and economically viable. To satisfy these requirements, a large number of advanced component technologies has been developed and incorporated in the engine system design. The total number of stages has been reduced by half from current same class engines. This paper describes the outline of the engine system design, which satisfies the ECO engine project goal.

1. Introduction

The research and development of environmentally compatible engine for small aircraft (ECO Engine Project) are intended to secure the leading edge in the field of the next generation civil engine development by strengthening competitiveness through the establishment of differentiated technology and achieving the advancement of integration technology for the engine system.

As far as the targeted 50-seat class engine is concerned, acquisition and maintenance costs take up a relatively high percentage of the direct operating cost. Thus, the key to the success depends upon how simple the engine structure should be in order to meet the reduction in fuel consumption and the demand for environmental compatibility.

The preliminary design for the engine was prepared by the advanced integration of the following: simplification of such components as the fan, compressor, combustor, and turbine, which had all been developed by the end of 2006; high-performance promotion technology; and environmentally compatible technology. As a result, the stage number was successfully cut down by almost half - down to 11 from 21 stages used by the existing same-class engine - and the direct operating cost can be reduced by 15% or more compared to the existing same-class engine.

This paper reveals the outlines of the engine system technology such as the result of the engine cycle selection, the engine structure design which contributes to the reduction in acquisition and maintenance costs, and the engine total integration including the nacelle.

2. Engine preliminary design

2.1 Target specifications and engine cycle

Table 1 shows the engine target specifications. The goal is to reduce the total direct operating cost including fuel consumption cost, acquisition cost (engine price), and maintenance cost by 15% (engine-related cost) as compared to the existing same-class engine with enough emission and noise margin, the regulation of which are predicted to be increasingly tightened from now on. The study on the engine cycle meeting the present target specifications was carried out.

Table 1 Engine target specifications

Items	Specifications	Remarks
Thrust	8 000 to 12 000 pounds	Designed for a 40-to-60-seat aircraft
Fuel consumption, acquisition cost, maintenance cost	Cut in total direct operating cost by 15% compared to the existing same-class engine	Engine-related cost
Noise	−20 dB	Comparison with ICAO Chapter 4
NO_x	−50%	Comparison with ICAO CAEP 4

(Note) ICAO : International Civil Aviation Organization
Chapter 4 : Noise levels regulated by ICAO, which have been applied since 2006
CAEP 4 : Emission gas levels controlled by ICAO, which have been applied since 2004

Figure 1 illustrates the results of the study on the engine cycle as a design parameter with respect to the turbine inlet gas temperature (TIT) and overall pressure ratio (OPR) and its process. The minimum point for the specific fuel consumption is relatively low as compared to large-sized engines; the same holds true for the turbine inlet gas temperature and overall pressure ratio (**Fig. 1-(a)**). This results from the size effect unique to the small engines, such as the Reynolds' number effect accompanying a decrease in blade height.

Next, the minimum point for the fuel consumption for which the engine weight is considered shifts toward a somewhat higher point in terms of turbine inlet gas temperatures (**Fig. 1-(b)**). The reason for this shift is that the smaller the engine size becomes, the lighter the engine weight can be made.

Last, the minimum point for the direct operating cost for which the engine price and maintenance cost are given consideration is the one whereat the overall pressure ratio falls (**Fig. 1-(c)**). This is because the smaller the stage number and the fewer the components become, the lower the engine price and maintenance cost can be made.

2.2 Engine structure design

The engine structure in which the stage number and the number of parts were drastically reduced was established through the application of the simple component design technology acquired in the development of the direct operating cost reduction technology. **Figure 2** has the overview of the three-dimensional digital mock-up engine.

The engine structure dispenses with a low pressure compressor by reducing the stage number for a highly loaded compressor from 14 stages for the existing same-class engine to half those and adopting the zero hub fan, which has the capability of increasing the hub side pressure ratio. Furthermore, a frame strut is eliminated from the engine structure by adopting aerodynamic shape designed based on the simple and low noise fan technology and the integrated fan OGV (Outlet Guide Vane) structure (IOS) provided with an engine support function. The optimization of fan blade and vane axial spacing is reflected in the engine structure design in order to reduce fan noise.

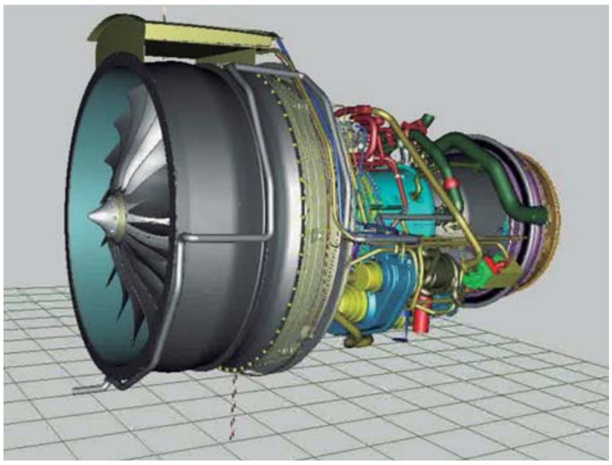

Fig. 2 Overview of 3D mock-up engine

The fuel nozzle configuration of a simple rapid mixing type with a low emission of NO_x and an outstanding burning stability was adopted as the type of combustor. As for the combustor liner, a simple effusion type excelling in cooling efficiency was adopted.

As for the high-pressure turbine, which was highly loaded, an aerodynamic type which could achieve a necessary expansion ratio at a single stage was adopted. The number of blades can be reduced by 10% by a further increase in lift coefficient of the existing low-pressure turbine blade by 10% as well as lift enhancement together with a cut in the stage number due to the low-pressure turbine being highly loaded. As for high- and low-pressure turbines, the counter-rotation system, which allowed them to rotate in the reverse direction, was adopted in order to reduce interaction loss due to shock waves.

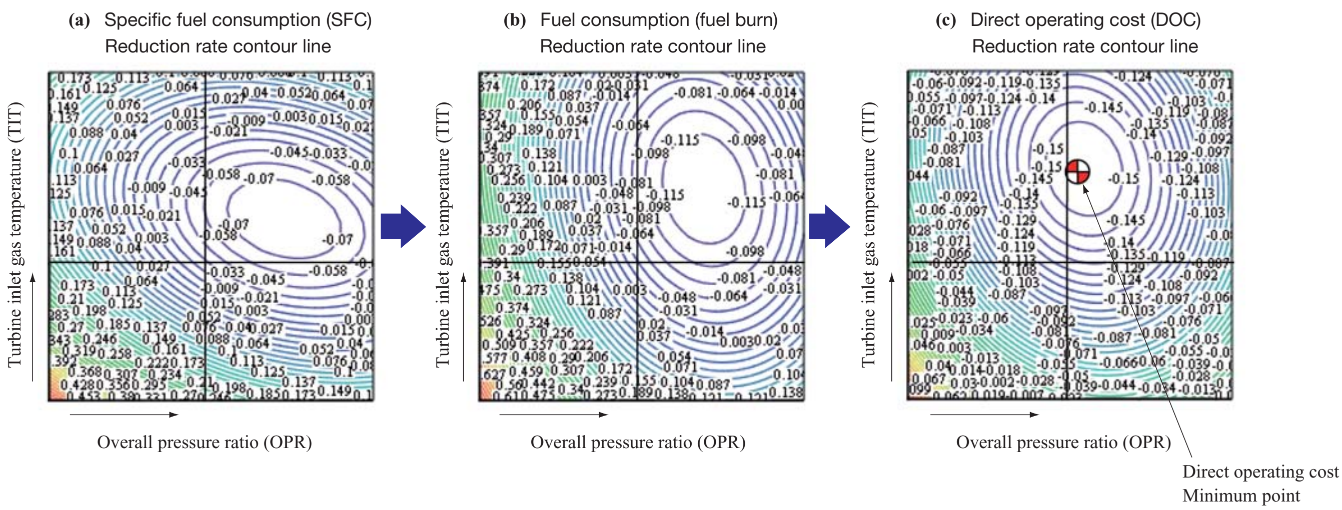

Fig. 1 Results of engine cycle study

The stage number of the engine as a whole could be cut down to 11 from 21 stages compared to the existing same-class engine through the adoption of these newly developed components. In the meantime, as each component was highly loaded, the rotor stress increased, and the engine rotations rose. In addition, the integrity of engine rotor dynamics became extremely severe due to a change in vibration features by the adoption of the counter-rotation system. Detailed engine rotor dynamics analyses, lighter weight design improvements, and higher stiffness structural design improvements of the whole engine were repeatedly made using three-dimensional models from the preliminary design stage, and designs of some components were modified by going back to the aerodynamic design; thus, the optimum design was able to be obtained.

As a result of the engine structure design thus far explained, the engine production cost was reduced by approximately 30% due to a decrease in material and processing costs thanks to the simple structure design in addition to the effect of a reduction in the stage number as compared to the existing same-class engine. The maintenance cost was reduced by approximately 40% through the reduction of the stage number for the high-temperature portion and the extension of the time in between overhauls thanks to the appropriate longevity design as compared to the existing same-class engine. The goal of reducing the direct operating cost by not less than 15% together with the lowering of fuel cost thanks to the high-performance and lighter weight can be achieved.

The study on the assembly and maintenance was carried out using three-dimensional digital models for all the engine parts including rigging and piping in the engine structure design. As for accessories, there was a demand that their installation and removal on the wing could be executed within 30 minutes to facilitate regular landings and take-offs. Therefore, consideration was given so that mounting and removal could be executed without the targeted accessory having any interference with other accessories or piping as illustrated by **Fig. 3**.

Since fan blades are subject to damage due to intake of FOD (Foreign Object Damage) such as birds, there is a demand for their replacement on wing to be executed in a short period of time. Hence, a feasibility study was conducted on fan blade removal and mounting using three-dimensional models as shown in **Fig. 4**.

In addition, the study on the design which makes a borescope inspection easy was conducted as shown

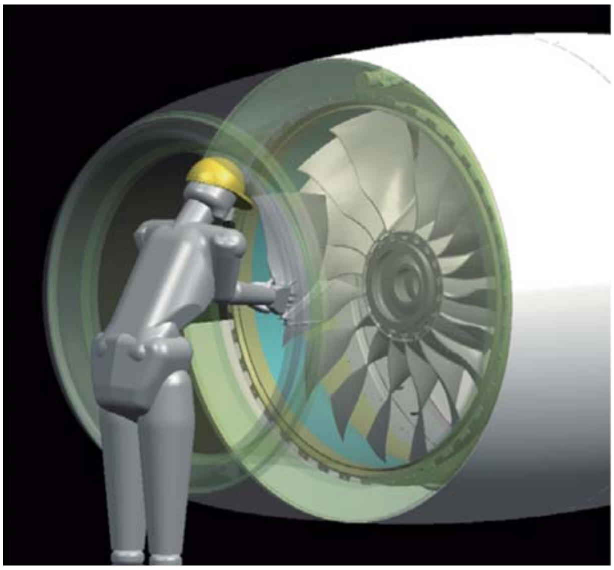

Fig. 4 Feasibility study of on-wing fan blade removal

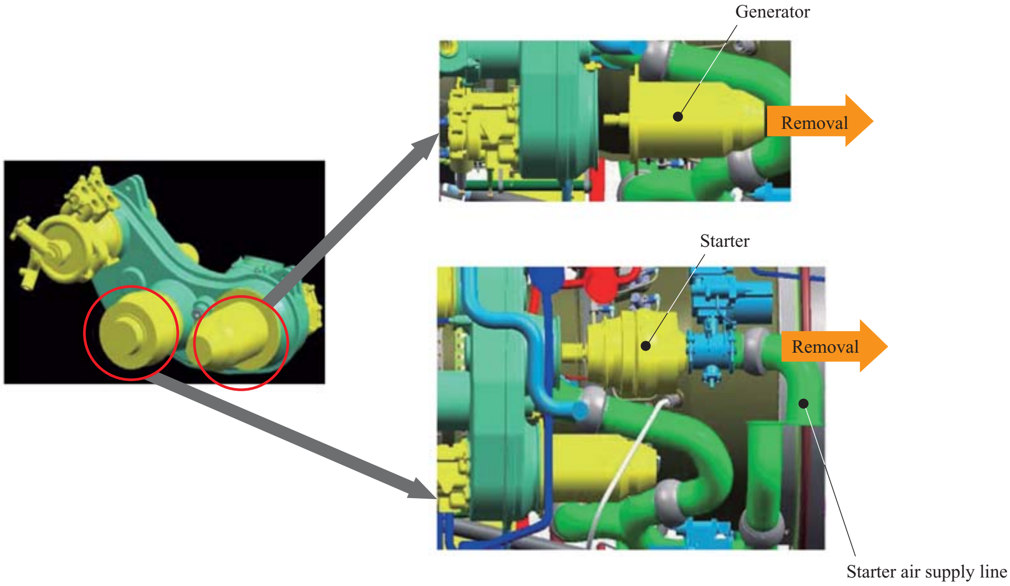

Fig. 3 Feasibility study of on-wing maintenance of line replacement unit

in **Fig. 5**. According to the side engine mount system currently adopted for 50-seat class engine, the position in which an engine is mounted on the right side differs from that on the left one and so does the configuration of fuel and engine bleed lines. The number of replacement parts for left and right side referred to as QEC (Quick Engine Change) for the purpose of the reconciliation of these differences is close to 1 000 for the existing same-class engine; it takes a week to assemble replacement parts and a day to remove and remount the engine.

The number of parts for the QEC was drastically cut down to 10 or so through the implementation of a study on the reduction of replacement parts by means of the three-dimensional mock-up engine as shown in **Fig. 6** so that the operations on the present engine from the assembly of replacement parts to remounting could be completed within six hours.

2.3 Study on external drag on engine

A feasibility study on the reduction of external drag was conducted through the optimization of the shape of the engine nacelle in developing the preliminary design for the engine. A large-scale simulation involving the whole engine including its nacelle was performed for the present study in conjunction with the Japan Aerospace Exploration Agency (JAXA), which boasts advanced technology known worldwide in the field of the CFD (Computational Fluid Dynamics) analysis.

2.3.1 Parametric study on axisymmetric nacelle

The parametric study on several axisymmetric nacelles

(a) On wing inspection by borescope (b) Inspection by borescope at shop visit

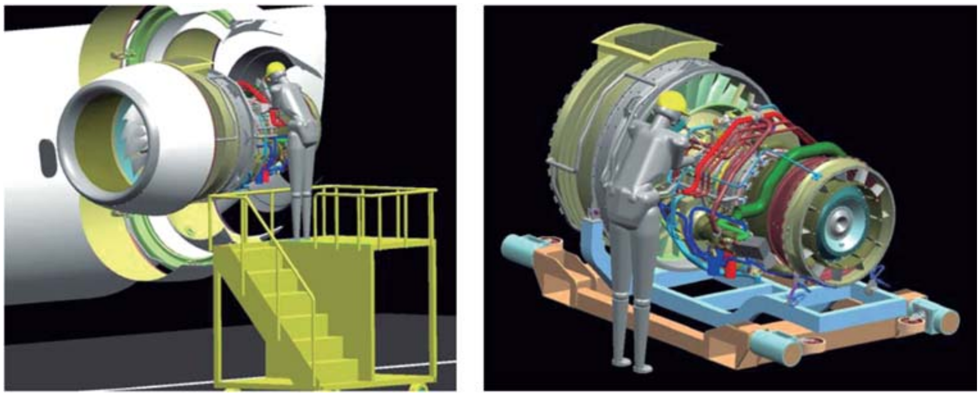

Fig. 5 Feasibility study of borescope inspection (BSI)

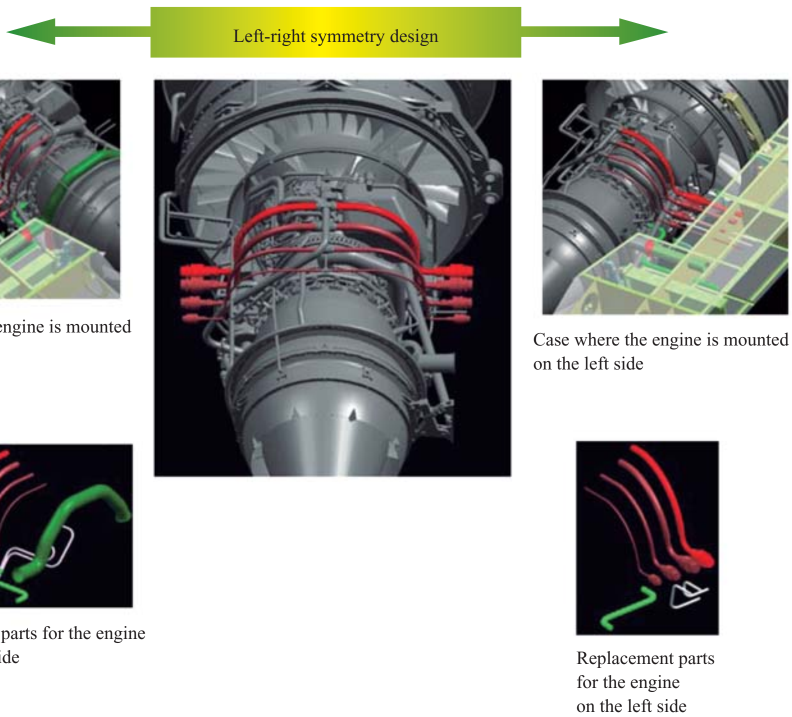

Fig. 6 Parts count reduction study of quick engine change

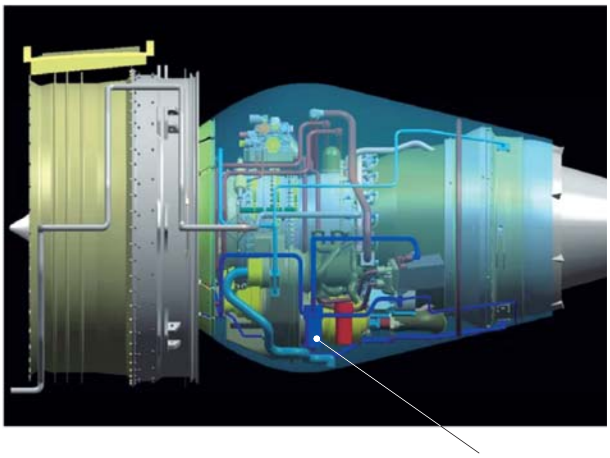

Fig. 7 Engine external design to reduce nacelle drag

designed differently was conducted by CFD analysis in order to grasp the basic impact on external drag on the engine by the shape of each part of the engine nacelle. It was found that the external drag on the engine could be reduced if the boat tail angle was made as small as possible because the impact on the external drag on the axisymmetric nacelle depended for the most part on the effect of boat tail angles. In the meantime, it was learned that the impact of the size of accessories was comparatively small if the boat tail angle of the nacelle could be made as small as possible through the devisal of the configuration of accessories surrounding the engine.

The shape of the cowl surrounding the accessories as shown in **Fig. 7** was figured out in consideration of the results thus far obtained; subsequently, a study on their size and configuration was conducted so that they could fit into this cowl.

2.3.2 Study on nacelle with pylon

The study on external drag on the engine contained in the non-axisymmetric nacelle with pylon was conducted in the wake of the study on the axisymmetric nacelle. The CFD result of the nacelle pressure distribution with pylon is shown in **Fig. 8**. As a result of the CFD analysis, the tendency of external drag on the engine with a pylon being on the rise due to the interference of the nacelle with the pylon could be quantitatively figured out as compared to the case where the axisymmetric nacelle was used.

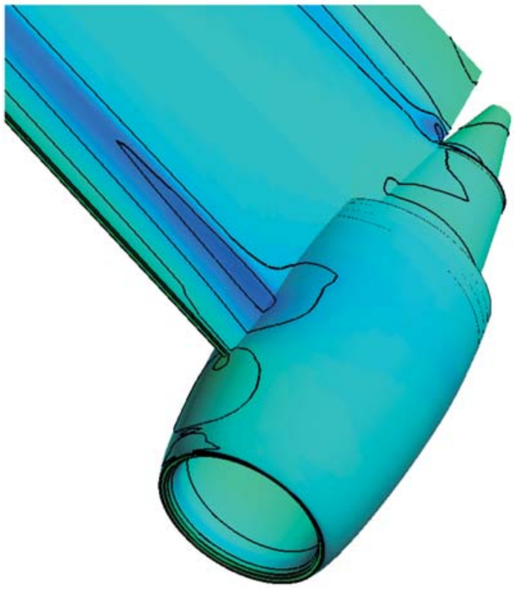

Fig. 8 CFD result of nacelle pressure distribution with pylon

3. Conclusion

The preliminary engine design was completed reflecting the latest component design, which was developed to reduce direct operating cost as well as to enhance environmental compatibility. The study on the assembly and maintenance of the engine was conducted by taking advantage of the three-dimensional engine digital mock-up. The study on the external drag on the engine was also conducted through the optimization of the whole structure of the engine including the method of mounting as well as the CFD analysis of the nacelle pressure distribution with the pylon in consideration of the fuselage.

The current engine design activities provide us with bright prospects for reducing the engine-related direct operating cost by more than the goal of 15%.

— **Acknowledgements** —

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