

Simple Low NO_x Combustor Technology

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A gas-turbine combustor was developed for environment-friendly and economical aircraft engines adaptable to 50-seat class jet planes. The combustor has a simple structure and low NO_x emission characteristics. The target level of NO_x reduction was 50% or less, which corresponds to the requirements of ICAO CAEP 4. A special simple structure swirler, named a cross jet swirler, was developed. The test results revealed a significant reduction of NO_x emissions, to 56.3% of the present ICAO CAEP 4 requirements for the LTO cycle. Furthermore, CO emissions were reduced by 19%, and total hydrocarbons by 59% compared with the reference values of the ICAO requirements.

1. Introduction

The emission of NO_x from jet engines has been progressively regulated because of increasing concerns about the environment. In the meantime, since there is higher demand for low-cost flights, it is vital to deal with environmental problems by using an engine with a low-cost, simple structure. Against this background, we have pushed ahead with the development of a simply structured, low NO_x-emission combustor which can be used in environmentally compatible engine for small aircraft (ECO engine) such as 50-seat class jet planes (engine driving force : 9 000 pound class).

NO_x emissions from the present combustor now in the process of development have been targeted at 50% or less of the regulation figure set by the ICAO (International Civil Aviation Organization) in 2004, while emissions from the rest of the combustors have been targeted at 90% or less of the regulation figure. Furthermore, the combustor is also intended to be safely used in an aircraft without causing any problems such as blow off or flashback within a wide operational range.

2. Concept of the combustor

Now that a great deal of attention is being paid to aircraft engines with low emissions of NO_x, the development of combustors, to which such combustion systems as a partially lean-premixed-prevaporized

combustion system and RQL (Rich burn, Quick quench, Lean burn) combustion system are applied, is in full swing. Lean-premixed-prevaporized combustors can be expected to contribute to a drastic reduction in NO_x emissions ; however, their lean flammability limit is narrow and they tend to cause flashbacks, depending on the fuel concentration and flow velocity, compared with the commonly used diffusive combustion method. Thus, engines for aircraft that need to have an extensive operational range and high level of safety require complex structures, such as a double-layered liner and the multifaceted structure of an injector, resulting in higher production costs. As a result, the partially lean-premixed-prevaporized combustion method should be intended for an engine in a medium- or large-size aircraft, as a combustor then takes up a smaller proportion of the aircraft's total cost.

In the meantime, with engines for small-size aircraft, technology characterized by a complex structure and high production cost cannot be adopted because of strong demand for cheaper combustors. Therefore, a series of examinations were conducted in the present research, looking for a way to manufacture a low-cost combustor with a simple structure which would be able to achieve the NO_x emission targets. As a result, an air arrangement by means of the RQL combustion method was combined with an originally devised rapid-mixing-concept fuel injector (rapid mixing burner using the

cross jet swirler method) (Fig. 1). The uniformity of the mixture in the primary zone of combustion was eventually improved, bringing about a greater reduction in NO_x emissions while also reducing the amount of fuel that remained unburned.

3. Rapid mixing burner in cross-jet system

The originally devised cross jet method (patent and trademark pending) was used to rapidly mix injected fuel and air for combustion in the present combustor. Figure 2 shows an external view of an early-stage experimental cross jet combustor.

3.1 Principle of cross jet method

The rapid mixing burner that uses the cross jet swirler method is characterized by a simply structured mixing swirler for fuel and air without causing a swirl vane. Figure 3 illustrates the principle of the cross jet swirler. The cross jet swirler used for the present combustor was developed by further improving the principle of promotion of combustion by mixing fuel and air, regarding the swirl burner^{(1), (2)} for which gas is used as fuel. This swirler creates strong swirls (between swirl number seven and ten) in a cylindrical mixing portion through a tangentially installed air channel; at the same time, it causes a straight jet to collide with a swirl through ports located in intervals inside the cylinder. As a result, a forced vortex can be broken, thereby allowing a strong turbulence layer to form. This strong turbulence makes it possible to further promote the mixture of fuel and air compared with mixing in a shear layer. There are several reported cases regarding the phenomenon of vortex breakdown^{(3), (4)}; and the effect of rapid mixing by using vortex breakdown has been confirmed for another premixed method-applied burner originally created as well, despite differences in structure.⁽⁵⁾

A forced vortex sometimes remains tornado-shaped fairly far downstream in the swirler involving only a strong swirl. It causes lengthy recirculation flow and flames downstream in the burner, often having an

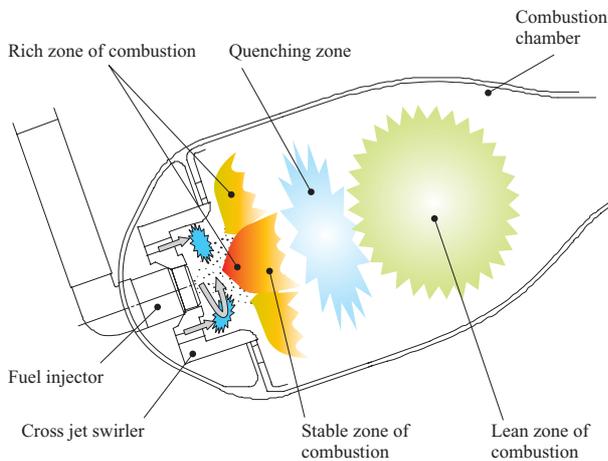


Fig. 1 Concept of combustor

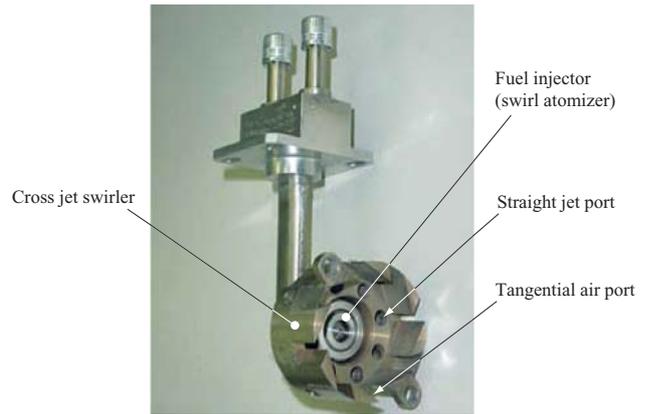


Fig. 2 Initial prototype of cross jet burner (with duplex type fuel nozzle)

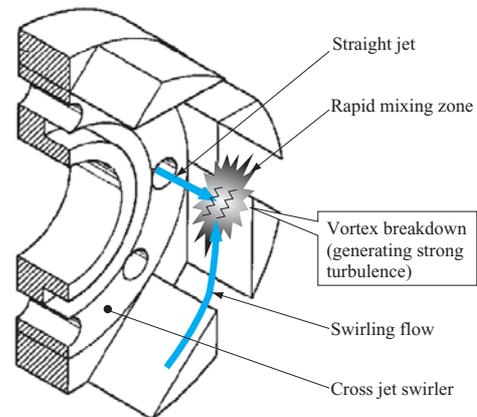


Fig. 3 Principle of cross jet swirler

adverse effect on the combustion efficiency during a low loading and exit-temperature distribution. However, a forced vortex can be eliminated by using the cross jet method, thereby bringing about the possibility of using the burner within such an extensive loading range as one for aircraft.

The combustor developed this time, a rapid mixing burner combined with a cross jet swirler, adopts a swirl nozzle in an atomizing method. Since a pressure atomizer has difficulties in mixing fuel with air in a proportionately small zone compared with an air blast atomizer, it tends to cause a lengthy, diffusive flame. Because of this shortcoming, a pressure atomizer is not suitable for the highly loaded combustors that have been developed recently. Since the temperature is high in some zones and the fuel concentration is too high in many zones, it is difficult to sufficiently curb the emissions of NO_x and smoke compared with an air blast atomizer.

Even so, the possibility of rapidly mixing fuel and air in conjunction with a rapid mixing burner that uses the cross jet swirler method has made it possible to reduce as much NO_x as a pre-mixing burner does. By

contrast, the state of atomization can be readily adjusted compared with the air blast method; and it is possible to highly stabilize combustion by taking advantage of the pressure atomizer which can be set independently from the air for combustion.

The combustor experimentally made this time comprises a swirl nozzle with dual orifices which have been proved to be effective thus far, installed in the atomizing part.

3.2 Confirmation of effectiveness of cross jet method through single sector test

The improvement in combustion efficiency under low loading conditions was confirmed by means of a box-type sector combustor with a single injector consisting of one injector as shown in Fig. 4. The state of a flame can be observed from the downstream side as well as from the lateral side of a combustor during a combustion test.

The conditions for inlet temperatures and pressure with a low-loading combustor are simulated to match the conditions when an actual engine is idle. The inflow of primary and secondary air from a liner was also simulated to mimic an actual combustor. Figure 5 demonstrates the improvement in combustion efficiency achieved after adding the cross jet method. The horizontal axis indicates the overall equivalent ratio of the combustor, while the vertical axis shows the combustion efficiency. The combustion efficiency for the cross jet method is superior in every equivalent ratio to a conventional burner without a straight jet; the favorable expansion of a flame as well as the improvement in the combustion efficiency thanks to the cross jet method was confirmed.

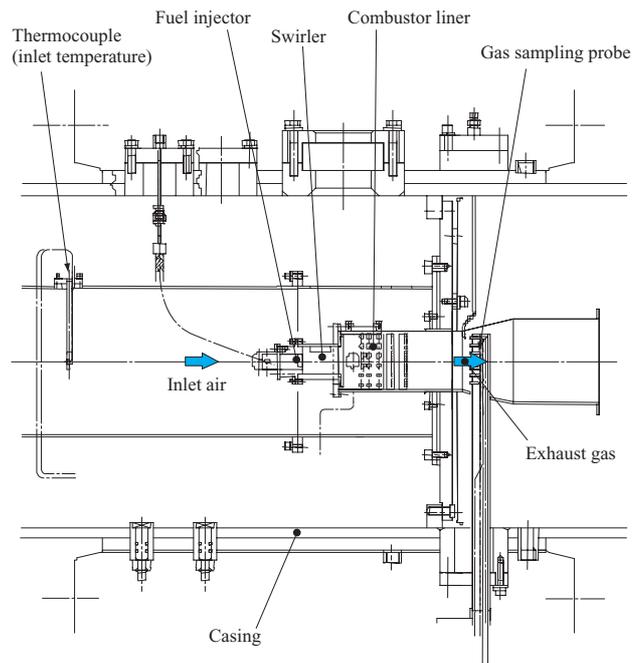


Fig. 4 Test rig of single sectional combustor

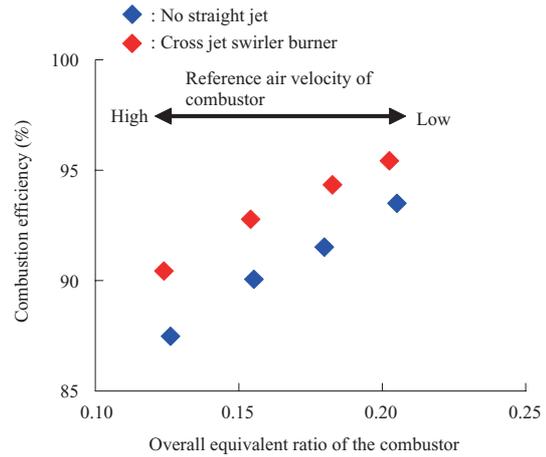


Fig. 5 Improvement of combustion efficiency by cross jet swirler

4. Results of performance test

The performance of a combustor on which the newly developed cross-jet swirler method-applied rapid mixing burner was mounted was confirmed by means of a 1/6 sector model (equivalent to three injectors) of a full annular combustor under conditions equivalent to those inside a real combustor regarding the creation of inlet temperatures, pressure, and air velocity. Figures 6 and 7 demonstrate the outline of a sector model combustor and the conditions of a sector model combustor incorporated into a high temperature and pressure test rig respectively. The test was carried out at the high-pressure combustion facility of the Aerospace Research Center of the Japan Aerospace Exploration Agency (JAXA).

The sector model combustor used a standard structure by adopting the commonly used film-cooling method for liner cooling except that it used the cross-jet swirler method-applied rapid mixing burner. Approximately 25% of all the air flowing into the liner was used to cool the liner, partition, and other parts. The results of the combustion test were evaluated based on the LTO

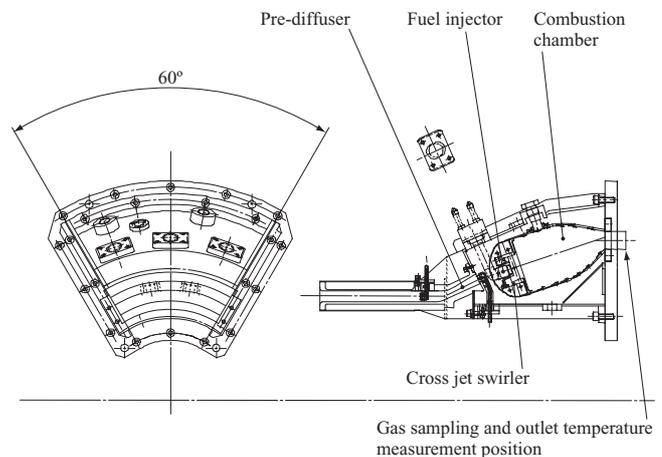


Fig. 6 1/6 sectional model of full annular combustor

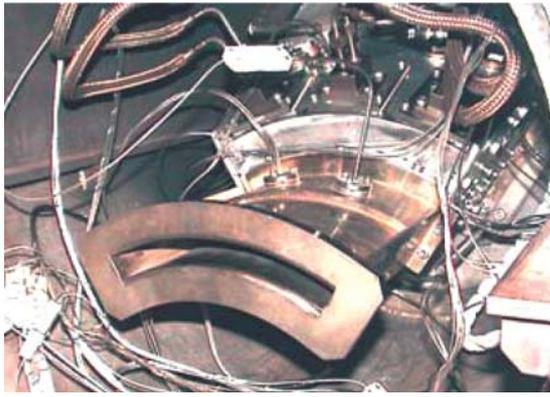


Fig.7 Photograph of 1/6 sectional model combustor in high-pressure and high-temperature chamber

(Landing and Takeoff) cycle conditions stipulated in the ICAO regulations. **Figure 8** compares the ICAO 2004 regulation figures and the design target figures.

Amounts of NO_x, THC (total unburnt hydrocarbons), CO, and smoke each met the corresponding regulation figure. In addition, the target for combustion stability at lean limit (equal to or more than AFR200) could be reached under the conditions present in a flight envelope that is a plane's operational range, dealing with the engine circumferential temperature distribution. However, since there was only a small margin for smoke emissions, adjustments were made by reviewing the primary air introduction method and so forth, so that the effect of the cross jet method could be further strengthened. As a result, the amount of smoke could be drastically reduced despite a slight decline in the margin of NO_x (refer to **Fig. 8**). Furthermore, the P.T.F., the outlet temperature pattern factor ((maximum temperature of combustor outlet - average temperature of combustor outlet) ÷ average temperature rising of combustor) became equal to or less than 0.2.

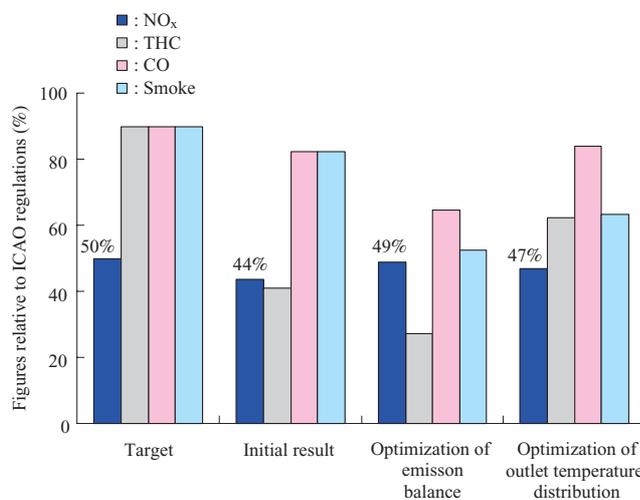


Fig. 8 Emission results of combustion tests compared with ICAO CAEP 4 regulations

It was confirmed that the present combustor had the same combustion performance as the sectional model one through the full annular combustor test. **Figure 9** shows the full annular combustor, while **Fig. 10** shows the results of the combustion tests.

5. Conclusion

This report has focused on the development of a combustor which can reduce NO_x in a simple structure applicable to an engine for environmentally compatible small-size aircraft.

It was confirmed that a combustor in which a cross jet swirler was installed achieved the target of a 50% reduction in NO_x emissions compared with the existing regulation figure under test conditions equivalent to ICAO regulations. The adoption of the present technology along with the evaluation of other performance factors made it possible to design an environmentally friendly small-size jet engine. Furthermore, the use of a pressure injector will help to speed up development and slash costs.

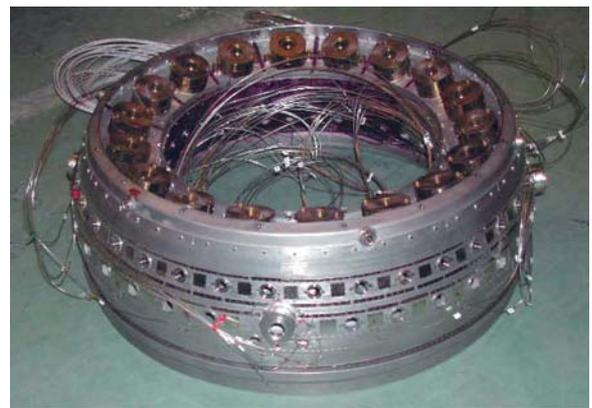


Fig. 9 Full annular combustor (liner and swirler)

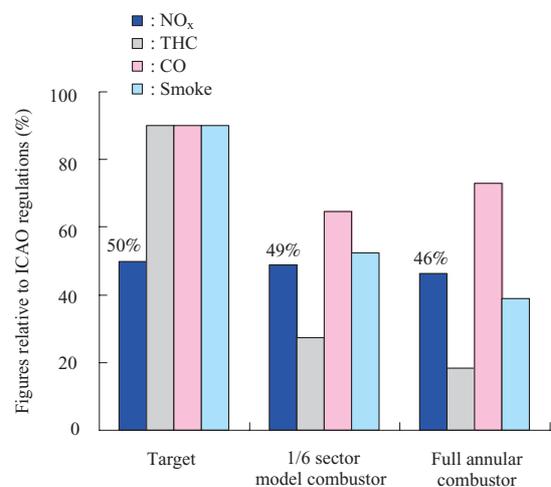


Fig. 10 Emission results of combustion tests compared with full annular and 1/6 sector model combustors

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