Application and Research Based on Advanced Low-Emission Aero-Engine Combustion Chamber Technology in Domestic Large Aircraft

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Abstract. The international limits on pollution emissions from civil aviation transporta
tion are becoming more and more stringent. Combustion chambers are the only source
of pollution emissions from civil aviation engines. Reducing the amount of pollutant e
missions is an important task facing the development of combustion chambers. Low-e
mission combustion technology as one of the key technologies of civil aviation engine
s, it is the core technology that supports the development and market entry of civil avia
tion engines. In order to study the pressure oscillation characteristics of the low-emissi
on combustion chamber under typical working conditions, the self-excited combustion
oscillation characteristic test of the model combustion chamber is carried out. The res
ults show that the local equivalent ratio pulsation is one of the factors that cause comb
ustion instability. By calculating the maximum particle size of the fuel droplets in the s
econdary atomization state of the fuel, it is found that the change of the fuel droplet siz
e has a direct effect on the local equivalent ratio pulsation at the outlet of the main fuel
stage, which causes the amplitude and frequency of the combustion chamber pressure
oscillation Variety.

1. Introduction
Civil aviation engines refer to the power of commercial transport aircraft used for route operations and
general aviation power, including turbofan, turboprop and piston engines. The most representative one
s are the advanced large ducts widely used in main and regional civil aircraft. Then a turbofan engine.
Compared with military aircraft engines, civil aircraft engines have their own special design technolog
y, and have special requirements in terms of "safety, economy, environmental protection, and comfort
", especially the mandatory requirements for "environmental protection." Mandatory regulations and u
ser requirements for airworthiness. Pollutant emissions from civil aviation engines include nitrogen ox
ides (NOx), carbon monoxide (CO), unburned hydrocarbons (UHC) and smoke (Smoke), etc [1]. The
hazards are mainly divided into two categories: one is the local air quality The impact of, causing harm
to the health of passengers, airport staff and surrounding residents near the airport; the other is the imp
act on global climate change, the overall effect caused by civil aviation NOx emissions is similar to C
O2. In order to improve the efficiency of the whole machine, the increasing working pressure and temp
erature of the combustion chamber of aero engines make NOx the most difficult pollutant to control. In
addition, although the emissions of aero engines account for only a small part of the combustion pollu
tion emissions in the global thermal power plant, it has the characteristics of concentration of emission
s in regions and airspace. The degree of atomization of liquid fuel may affect the pressure oscillations caused by unstable combustion. In this paper, the influence of liquid fuel atomization on pressure oscillations is qualitatively analysed under typical working conditions for LPP combustion chambers using centrally staged LPP technology.

2. Analysis of working principle of low-emission aero-engine combustion chamber

2.1. TAPS combustion chamber

The TAPS combustion chamber is composed of a pre-combustion stage with a central diffusion flame stabilizing flame and a main combustion stage with a concentric outer swirler premixed combustion. The pre-combustion stage adopts the diffusion combustion mode and consists of a high-flow pressure atomization device including 2 co-rotating vortexes. This device assists in generating the atomization quality required for ignition and low-power conditions, and helps to produce satisfactory ignition, Flow field characteristics required by design requirements such as start-up, lean combustion stability and combustion efficiency. The main combustion stage adopts the premixed combustion mode. The fuel is injected into the rotating air of the main combustion stage and then enters the combustion zone for combustion to reduce NOx emissions. The combustion chamber can establish an ideal premixed environment, achieve high combustion efficiency, low and uniform flame temperature, thereby reducing NOx emissions, and significantly extending the life of downstream components; its air is completely separated from the head and mixer When entering, there is no need to open a dilution hole on the flame tube, which avoids stress damage and prolongs the life of the flame tube. TAPS combustion chamber adopts the following key technologies: (1) Premixed swirl technology; (2) On-duty combustion technology; (3) Lean fuel direct injection combustion technology; (4) Radial fuel classification technology; (5) Macro analysis Layer fuel nozzle technology; (6) Advanced cooling and high-temperature material technology. As shown in Figure 1, the working principle of the TAPS combustion chamber.

![Figure 1. Working principle of TAPS combustion chamber.](image)

2.2. Trapped vortex combustor

The trapped vortex combustor is an innovative combustor that uses the trapped vortex cavity in the combustor to achieve flame stability, as shown in Figure 2. The most typical third-generation trapped vortex combustor includes 2 duty classes and 1 main combustion stage. The duty class consists of a trappe
d vortex cavity inserted into the flame tube of the combustion chamber. Fuel and air enter the two trapped vortex chambers in an appropriate manner, and form a vortex structure here. The key to the design of the trapped vortex cavity is to make the vortex structure stay in the trapped vortex cavity, so that the injected fuel and air are fully mixed and burned in the trapped vortex cavity to form a stable combustion zone. The trapped vortex combustor stabilizes the flame by capturing the vortex in the cavity inside the combustor wall, and is not affected by the main airflow [2]. Therefore, the recirculation zone can be designed to be smaller than the conventional combustor and has better operability. The small reflux area can shorten the residence time and make the shift on the NOx emission value smaller. Placing the duty class and the main combustion stage in parallel, the length of the combustion chamber can be shortened and the quality reduced; the high temperature zone can be reduced, and the NOx emission value can be reduced. Therefore, it has the characteristics of strong stability in a wide working range, strong ground/air ignition ability, high combustion efficiency, short length and simple structure.

![Figure 2. Working principle of trapped vortex combustor.](image)

3. Specific research on LESS combustion chamber technology

3.1. Related experimental conditions

The test measured the combustion chamber pressure oscillations under similar grading ratios and different inlet conditions. The working conditions of the combustion chamber are shown in Table 1, including the inlet pressure $P_{in}$, the inlet temperature $T_{in}$, the inlet air flow $m_{in}$, the relative pressure drop of the combustion chamber $\xi$ (the ratio of the pressure difference between the inlet and outlet to the total inlet pressure), and the pre-total grading ratio $S_p$ (the ratio of pre-combustion fuel mass to total fuel mass) and total fuel-air ratio $F_{air}$ (the ratio of total fuel flow to total air flow).

| Happening | $P_{in}$ / kPa | $T_{in}$ / K | $m_{in}$ / (kg/s) | $\xi$ / % | $S_p$ / % | $F_{air}$ |
|-----------|----------------|--------------|------------------|-----------|-----------|----------|
| 1         | 1421           | 656          | 1.12             | 4.35      | 11.04     | 0.0264   |
| 2         | 2775           | 809          | 2.11             | 3.52      | 11.05     | 0.0265   |
| 3         | 1109           | 747          | 0.969            | 3.75      | 10.9      | 0.0262   |
| 4         | 2632           | 845          | 1.981            | 3.41      | 11.09     | 0.0263   |
3.2. Test system
The main frequency of pressure oscillation in the centrally graded lean premixed pre-evaporation combustion chamber is 100-2000 Hz, which is mainly related to the local equivalent ratio pulsation, pressure oscillation coupling, and flame vortex interaction in the combustion chamber. The sound waves of the main frequency band are generated in the flame tube of the combustion chamber, and there are two propagation directions: (1) The upstream head section passes through the swirl channel and enters the diffuser part of the plenum and is reflected back; (2) It encounters downstream. The exit section of the combustion chamber is reflected back when it encounters the wall cooling structure. In the flame tube structure, the flame tube cooling structure can be regarded as an acoustic impedance unit, so the part of the sound wave from the flame tube to the plenum can be ignored [3]. The dynamic pressure acquisition frequency is 10kHz, the sample duration is 3s, and the frequency resolution is 0.3Hz.

3.3. Experimental results
In this test, while maintaining the fuel-gas ratio of the main fuel stage and the pre-combustion stage, the fast Fourier transform (FFT) was performed on the pressure oscillation signal collected in the test of the plenum, and the results were obtained under the four operating conditions in Table 1. The frequency and amplitude of the pressure oscillation during this period. The pressure oscillation frequency spectrum measured under test conditions 1 to 4 is shown in Figure 3. It can be seen from the figure that under working condition 1, the main frequency of pressure oscillation occurs at 514 Hz, and the oscillation amplitude is 4.8 kPa; under working condition 2, the first and second main frequencies of pressure oscillation occur at 1802 and 900 Hz, respectively. The amplitudes are 4.8 and 2.0kPa, respectively; in condition 3, the main frequency of pressure oscillation occurs at 976Hz, and the oscillation amplitude is 3.6 kPa; in condition 4, the main frequency of pressure oscillation occurs at 959Hz, and the oscillation amplitude is 4.4kPa.

![Figure 3. Pressure spectrum under typical LTO conditions.](image-url)
4. Principles and methods of aero-engine pollutant control
The conventional combustion chamber adopts the fuel-rich combustion mode, and mainly diffuse combustion. The combustion organization runs along a route where the temperature gradually rises and the n falls. It passes through the high NOx generation area. The combustion equivalent ratio of the main combustion area is near the appropriate aviation kerosene chemical ratio, resulting in a large high-temperature combustion area, a long residence time, and extremely thermal NOx emissions. Large, but the NOx reduction reaction before export is very slow. This is the core problem existing in the conventional combustion chamber, which leads to it not meeting the low NOx emission requirements [4].

4.1. Rich oil combustion
Since the formation of NOx in rich and lean combustion conditions can be suppressed, on the basis of conventional rich combustion, if rich combustion can be quickly converted to lean combustion, it will be greatly compressed in both space and time. The existence of chemically appropriate ratio combustion can reduce NOx emissions. This idea is RQL. The current RQL combustion technology is based on the conventional fuel-rich combustion chamber technology, which weakens the return effect of the main combustion hole jet, and maintains the fuel-rich combustion downstream of the head with a uniform space equivalent ratio of 1.4-2.0, in an oxygen-deficient, fuel-rich low temperature environment For the purpose of forming an "active group pool", the blended jet is used to quickly reduce the equivalent ratio to 0.6-0.7 and burn in a lean state, oxidize hydrocarbon groups and soot, effectively avoid burning at a proper ratio, and inhibit NOx generate. This not only reduces pollution emissions, but also maintains the ignition and flamelout performance of conventional combustion chambers, ensuring a balance between "safety" and "environmental protection."

4.2. Lean burning
Lean combustion is the most direct way to reduce combustion temperature and NOx emissions, and has the greatest potential for reducing emissions. At a lower equivalent ratio, the combustion efficiency and stability of aviation kerosene combustion will deteriorate. The primary goal of the lean-burning low-emission combustion chamber is to reduce NOx emissions under high power conditions. At low power, only the pre-combustion stage works and uses diffusion combustion to ensure stability, with little improvement in NOx emissions. In the transition state, it will be restricted by two aspects: smoke from the pre-combustion stage and inefficient combustion of the main fuel stage. It is difficult to optimize and match the classification strategy [5]. Of course, staged combustion will increase the structural complexity of the combustion chamber and fuel nozzles, and put forward higher requirements for fuel control, which is more prominent in small and medium-sized engines. In order to ensure the rapid and uniform mixing of fuel and air, it is necessary to develop micro-nozzle technology and flash or supercritical fuel injection technology, and put forward requirements for new aviation fuels with better coking resistance. At the same time, from the perspective of reducing carbon emissions, newly developed low-emission combustion chambers are also required to be adaptable to new fuels, and new fuels also have a positive effect on reducing combustion gaseous pollutants and particulate matter. However, based on safety considerations, more development is needed. Extensive verification.

4.3. Realization method of extremely lean combustion
The limitation of lean combustion to further reduce NOx emissions is the increase of CO at low equivalence ratios (less than 0.6), and of course flame stability and oscillating combustion. At present, foreign countries are also actively exploring ways to use unconventional means to achieve extremely lean combustion, which can greatly reduce the generation of NOx, and at the same time have no obvious adverse effects on CO emissions and stability [6]. For extremely lean combustion, the use of hydrogenation combustion has been proposed abroad. Pure hydrogen has great potential in low-polluting combustion, but due to its small volumetric calorific value, large changes in engine and aircraft structure and many other defects, it cannot be used as a single aviation fuel in the short term. However, with the development of technologies such as plasma ionization hydrogen production, kerosene reforming hydrogen prod...
duction, and low-temperature superconducting residual hydrogen, it has become possible to use hydrogen and aviation fuel as multiple fuels. The scientific principle is to use the large amount of hydroxyl (OH) produced by hydrogen combustion to promote CO oxidation and flame propagation, thereby broadening the stable range of lean oil, making combustion occur at a lower equivalence ratio and flame temperature, and achieving the goal of reducing NOx emissions.

5. Conclusion

With the continuous revision of the International Civil Aviation Organization’s emission standards, the requirements for reducing emissions from civil engines have become increasingly stringent. Foreign low-emission combustion chamber technology research has a history of more than 40 years. The continuous implementation of various special plans at different stages has promoted the continuous advancement of low-emission combustion chamber technology, developed a variety of low-emission combustion chamber technologies, and successfully applied them to civil aircraft on. Under the traction of large-scale civil aircraft projects, China has carried out low-emission combustion chamber technology research. As a core technology closely related to the civil aircraft market, the research work needs to be continued and undertaken, and new ideas and programs are constantly proposed to strengthen the basic principles. The research and verification, the development of low-emission combustion technology with independent characteristics and intellectual property rights, and boosting the development of China’s civil aviation engines.

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