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Application of Turbine-based Combined Cycle Engine in Hypersonic and Aerospace Vehicles

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Abstract

Faster speed and higher altitude are the eternal pursuit of human beings. The proposal of the "air and space integration" strategy will make the traditional boundary between sky and space no longer exist, and make advanced hypersonic and aerospace vehicles necessary. At present, hypersonic and aerospace vehicles have become the research objects of various aerospace powers, and they are regarded as "another revolutionary product that changes the rules of the game of war after combat aircraft and nuclear weapons." Turbine-based combined cycle (TBCC) engines will be the main power plant for hypersonic and aerospace vehicles in the future. This article summarizes the current research status of TBCC engines at home and abroad for the needs of space transportation, high-speed transportation, and long-range rapid strikes. The potential technical advantages and possible application directions of TBCC engine are analyzed, and the key technologies in many aspects that must be solved to carry out TBCC engine technology research are analyzed. Combining with the future military requirements for high-speed and aerospace vehicles, it illustrates the necessity for the country to carry out TBCC engine technology research.

Keywords

Hypersonic vehicle; Aerospace vehicle; TBCC engine Manuscripts.

1. INTRODUCTION

Hypersonic aircraft refers to an aircraft with a Mach number above 5 in the atmosphere. Since the late 1950s, hypersonic technology powered by rocket engines has been widely used in various tactical and strategic missiles and spacecraft. Limited by the low specific impulse of the rocket engine, this type of aircraft has limited flight time and is very unstable. As a new type of aircraft that combines aerospace and aviation, the aerospace vehicle has significant military advantages, which will make it a strategic weapon platform for the major aerospace powers to compete for space dominance and space superiority. Since the 21st century, various countries have launched a large number of hypersonic aircraft and aerospace vehicle development plans. In these studies, the aspiration hypersonic propulsion technology has always been the core technology, and has become the possibility of hypersonic and aerospace flight technology. The key to breakthrough progress. The turbine-based combined cycle (TBCC) engine refers to a power unit composed of a turbine engine and other types of engines. It is one of the key power systems for hypersonic and aerospace vehicles to achieve self-acceleration, powered horizontal landing and repeated use.

2. BASIC INTRODUCTION AND RESEARCH STATUS OF TBCC ENGINE

The TBCC engine refers to a power unit that is a combination of a traditional gas turbine engine and other types of engines (such as ramjets engine, detonation engine). It is one of the

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key power systems for hypersonic and aerospace aircraft to achieve self-acceleration, powered horizontal landing and repeated use.

The turbine-based combined cycle can realize the variable cycle working process, so that the aircraft can obtain good propulsion performance under different flight conditions (subsonic, supersonic, and hypersonic). When the aircraft is flying at low speed, the airflow enters the turbine engine under the action of the regulating valve, and the combined engine works as a turbine engine at the time. When the aircraft is flying at high speed, the airflow enters the ramjet under the action of the regulating valve. At the time, the combined engine works as a sub-combustion ramjet or a super-combustion ramjet.

Scholars began to explore the concept of TBCC since the 1950s. In 1957, the French Griffon2 aircraft equipped with the ATAR101E3 turbo ramjet combined engine created the new flying speed at that time on the 100km route, which verified the feasibility of the TBCC engine. In 1966, the J58 engine equipped with the American SR-71 Blackbird reconnaissance aircraft had turbo-ram-combined power characteristics, flying at an altitude of 30 km, and a maximum Mach number of 3.4. In the 1980s, the Central Aero Engine Research Institute (CIAM) of Russia conducted a comprehensive ground test of the size TBCC engine researched the key technology of TBCC. In recent years, with the extensive development of hypersonic technology research, more and more attention has been paid to the research on engines that are the key to hypersonic flight, and the research on TBCC engines has also become more and more in-depth.

3. ADVANTAGES AND APPLICATION PROSPECTS OF TBCC ENGINE

3.1. Technical Advantages

Air-breathing hypersonic and aerospace vehicles powered by TBCC engines have the following technical advantages:

(1) A true level take-off and landing can be achieved;

(2) Fully reusable;

(3) It is not restricted by the launch and landing location, and it can be used at general military and civilian airports;

(4) Good maintainability, low maintenance cost and long service life;

(5) It can complete 1,000 missions per year;

(6) The flying Mach number reaches 4 or more;

(7) The thrust-to-weight ratio is greater than 10;

(8) Low launch cost;

(9) Conventional fuels and lubricants can be used.

3.2. Application Prospects

(1) As the first stage propulsion system of the orbiter

Whether it is the earlier American NASP plan or the German Sanger plan, research on TBCC engines is carried out to meet the requirements of a reusable space-to-earth transportation system. As the new space arms race continues to heat up, the establishment of space military bases has become the direction for the development of advanced aerospace countries, and the premise must have fast, highly maneuverable, and reusable high-speed aircraft to meet high-frequency transportation tasks. High-speed aircraft powered by TBCC engines have considerable advantages in meeting the future delivery of payloads to military bases in space

(2) As a power plant for low-cost high-speed flight test platforms

During the flight test, the take-off of the high-speed aircraft is generally completed by rocket assist or carried by the aircraft. If the high-speed aircraft fails during the flight test, it will not

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be able to return, which will cause a huge loss of test funds and extend the test cycle. And the aircraft using TBCC engine as the power unit has the characteristics of horizontal take-off and landing, which can avoid such problems. And the aircraft using TBCC engine as the power unit can reach the flight speed of Mach 6, which can basically complete the flight test of the new high-speed aircraft (for example, it can be used as the propulsion system of the flight test platform similar to the American X-43A high-speed aircraft). One of the reasons the US Air Force is interested in the pre-cooled turbine-based combined cycle engine (Steamjet) is that it hopes that Steamjet can be used as a power unit for a small high-speed flight test platform.

(3) As the power system of high-speed cruise missiles

At present, the power plant of the world's main battle cruise missiles is mainly turbofan engines. Limited by the use of turbofan engines, this type of cruise missiles generally fly at subsonic speeds, so they are easily intercepted by air defense missiles and cannot achieve the purpose of effective attack. Therefore, the flight speed of cruise missiles must be increased. Although scramjet is a hot research topic now, and its flying Mach number can reach more than 6, but due to technical difficulties, it is temporarily difficult to be used as a power device for cruise missiles. The TBCC engine has become one of the ideal choices for high-speed cruise missile power plants due to its technical characteristics. The short-term goal of the US RTA program is to use TBCC engines as high-speed cruise missile power plants.

(4) As a propulsion system for high-speed reconnaissance aircraft

Affected by the Kosovo War, the Afghanistan War and the Iraq War, all countries have placed unprecedented emphasis on the development of unmanned reconnaissance aircraft. At present, many high-altitude unmanned reconnaissance aircraft have a flying Mach number of less than 1, and are vulnerable to missile attacks. Therefore, the development of high-altitude and high-speed unmanned reconnaissance aircraft is a new direction, and the pre-cooled TBCC engine is its ideal power plant. In fact, the pre-cooled TBCC engine was the first product of the Cold War period. In order to develop high-speed interceptors, the United States carried out research on pre-cooled TBCC engines in 1955 and completed a lot of work; but with the end of the Cold War, high-speed interceptors It has lost the meaning of its existence, and the research on the pre-cooled TBCC engine has been terminated accordingly. But the TBCC engine is feasible as a high-altitude and high-speed unmanned reconnaissance aircraft power unit.

4. TECHNICAL PROBLEMS TO BE SOLVED IN THE APPLICATION OF TBCC ENGINE

4.1. Integrated Comprehensive Design Technology of Aircraft and Engine

From the perspective of aircraft platform design, the complexity of engine working mode brings many difficulties to integrated aircraft/engine integrated design. Compared with traditional aircraft, aerospace aircraft need to strengthen the integrated design of flight and launch.

A key difficulty in the design of aerospace aircraft is to provide high-efficiency aerodynamics for efficient propulsion while cooperating with the integrated requirements of the aircraft's high volume ratio, structural effectiveness, controllability, and good thermal protection. The degree of coupling of various performances and the tight integrated design have caused many practical design problems about hypersonic flight, including the most basic problems of fuel selection, engine cycle and performance under off-design conditions. The integrated design technology of aircraft and engine of TBCC engine is based on the whole aircraft system to carry out the research and design of the airframe and combined engine. It mainly refers to the integration of the air inlet and the front body of the aircraft, and the integration of the tail nozzle and the rear body of the aircraft. A design method. Through the integrated design of aircraft and

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engine, technology integration, system integration, process integration, personnel integration and management information integration in aircraft design can be realized.

Due to the immature TBCC technology and the lack of test data to support the working characteristics and performance of the engine, the aerodynamic shape design of many high Mach number aircraft still uses aerodynamic characteristics as the design index, but the performance requirements of the engine are considered during the design process. It is fully incorporated into the aerodynamic shape optimization design process, and there are many parameters that affect the performance of high Mach number aircraft. There are many optimization goals for integrated aircraft design. It is necessary to in-depth study of TBCC dynamics and aerodynamic shape performance changes and simplify the optimization design model to achieve high efficiency. Integrated optimized design. Therefore, it is particularly important to develop the integrated design technology of aircraft and engine.

4.2. Combined Dynamic Mode Conversion and Control Technology

TBCC engine is different from any other single engine in the past. Its entire working process has gone from traditional turbine-based engine work, to turbo ramjet working together, and finally to ramjet working alone. The design of the control rate of the aircraft propulsion system is proposed. Challenge. The two different engines involve relay conversion, and the intake swash plate adjustment and control mechanism, the installation form and cooling of the TBCC engine, etc. are very different from the past. How to realize the coordinated control of the aircraft and the TBCC engine, realize the control of the intake air flow and the continuous control of the engine thrust during the modal conversion of the TBCC engine, determine the best modal conversion timing and the best conversion point, and ensure each sub-system Coordination, safety, and stability of work are issues that need to be studied jointly by the aircraft department and the engine department.

4.3. High-speed Propulsion System Cooling and Thermal Protection Technology

The currently adopted engine compartment cooling technology mainly uses the ram air inlets on the fuselage and vertical tail surface of the aircraft to achieve ram air intake when the aircraft is flying at high speeds to cool the engine. For hypersonic aerospace aircraft, if the traditional ram air cooling method is used, high Mach number flight will cause the aircraft stagnation point temperature to be too high, the air flow temperature of the ram air inlet is very high, and the electronic equipment in the engine compartment affects the working environment temperature Therefore, new cooling methods and cooling technologies must be adopted to meet the working environment requirements of the engine and its accessories. The research goal of high-speed propulsion system cooling and thermal protection technology is to control the working environment temperature of the combined power cabin within 150°C to ensure stable engine operation.

4.4. Energy Generation Technology based on TBCC Propulsion System

The traditional turbine engine is connected to the engine shaft through gear transmission components, and the shaft power output is converted into the required power of the aircraft. After the TBCC engine modal conversion is completed, the turbine engine stops working, and the ramjet has no rotor parts, and cannot extract power from the engine shaft to meet the needs of the aircraft. If a spare battery is used, it will inevitably increase the weight of the aircraft and affect its flight performance. Especially for long-time flying platforms, the impact is significant. Therefore, how to meet the requirements of aircraft power extraction during normal operation of TBCC engines is also a difficult problem to be solved.

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5. CONCLUSION

As all countries attach great importance to space combat platforms, there is an urgent need to develop a reusable vehicle that can be launched in time on demand, which can send the upper stage into low-Earth orbit or only make the upper stage reach suborbital speed. As such a reusable vehicle with emergency launch capability, an aircraft powered by a TBCC engine has the advantage of being able to re-enter the atmosphere and land on the airport runway after launch, and relaunch in a short time. At the same time, many military experts predict that high-speed, long-range cruise aircraft will become the main direction of weapon development in various countries. The key to achieve long-range cruise and high-speed flight is the power system. In view of the high specific impulse and large range parameters of turbine engines at low and medium Mach numbers, TBCC engines have obvious advantages in meeting long-range cruises, high speeds, and rapid strikes. Therefore, the TBCC engine is one of the promising hypersonic power concepts in the future.

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