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Development study of precooled-cycle hypersonic turbojet engine for flight demonstration

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Abstract

This paper describes a development study of a precooled-cycle hypersonic turbojet engine for the first stage of TSTO space plane and hypersonic airplane. With reflecting the key technologies accumulated from ATREX (expander cycle ATR engine) ground tests, the next flyable subscale engine "S-engine" is now developed. S-engine has 23 cm × 23 cm of rectangular cross-section, 2.2 m of the overall length and about 100 kg of the weight employing a variable-geometry rectangular inlet and nozzle. It produces 1.2 kN of thrust at SLS, which corresponds to $\frac{1}{4}$ of the ATREX engine. Design of the hypersonic components such as the inlet, precooler and nozzle has been finished and their aerodynamic performances were verified by wind tunnel tests and CFD analyses. A prototype model of the diagonal-flow compressor whose pressure ratio is 6 was manufactured. Its rotating tests under the very-low pressure conditions are now in progress. The reverse-flow annular combustion chamber was successfully tested.

The first flight test of the S-engine is to be conducted in 2008 by the balloon-based operation vehicle (BOV) which is about 5 m in length, 0.55 m in diameter and 500 kg in weight. The vehicle is dropped from an altitude of 40 km by a high altitude balloon. After 40-s free-fall, the vehicle pulls up and S-engine operates for 30 s at about Mach 2. High altitude tests of the engine components corresponding to the BOV's flight condition have been conducted.

1. Introduction

A turbine-based combined cycle system (TBCC) is one of the promising candidates for the propulsion system for low cost, high reliability and routine access to space. JAXA (Japan Aerospace eXploration Agency) has been developed a precooled-cycle turbojet engine for the first stage of the TSTO space plane (Fig. 1). This engine can operate from take-off to Mach 6 at 26 km of altitude continuously without mode transition. The precooled-cycle turbojet engine is also applied to the hypersonic airplane which cruises at Mach 5. A Mach 5 demonstrator to verify the technologies on the hypersonic vehicle is described in the JAXA's long-term vision.

A development roadmap of the hypersonic turbojet engine in JAXA is shown in Fig. 2. The air-turbo ramjet engine with the expander cycle "ATREX" was developed for 10 years by ground system firing tests as well as by several component tests. Key technologies on the system optimization, engine control, precooling system, variable geometry inlet and nozzle were accumulated through this development.

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With reflecting development study of the ATREX engine, our study was shifted to the next flight demonstration engine designated "S-engine" shown in Fig. 3 [1]. The aerodynamic design and tests have been finished using wind tunnel models. Flight models of the components are now under fabrication. The first system firing test and the flight test of the S-engine will be conducted in March of 2007 and June of 2008, respectively. These tests verify the precooled engine cycle, system and component performance and engine control below Mach 2. After that, high enthalpy wind tunnel tests corresponding to Mach 5–6 conditions are planned. The S-engine will be modified to endure the aerodynamic heating by using the carbon–based composite materials. Finally, the hypersonic demonstrator will be developed to verify all system including the system control.

Fig. 1. TSTO space plane.

In this paper, the present status of the development study of the S-engine and its Mach 2 flight test plan using a high-altitude balloon are discussed.

2. Development study of subscale engine (S-engine)

2.1. *Descriptions of S-engine*

In this development study, we have treated two different size engines: a full-scale engine and subscale demonstration engine (S-engine). Most analytical studies have been conducted on the full-scale engine such as optimizing of the engine specification, system feasibility study, weight estimation and engine installation and interference with the vehicle. Meanwhile, S-engine is studied for building fundamental technologies by making hardware. The small engine makes difficulties to manufacture the complicated structures and to match both similarities on dimensions and on thermal dynamics simultaneously. However, it is important to realize an early and flexible demonstration under the actual flight condition with reasonable costs.

The S-engine consists of an inlet, precooler, core-engine, afterburner, nozzle and connecting ducts to demonstrate the overall engine system under the wide flight range from sea-level-static (SLS) to Mach 5–6. The engine cycle has been designed using a parametric optimization study. A three-dimensional CAD tool is used for the detailed design and mass estimation.

Main dimension and performance of the S-engine are listed in Table 1 compared with ATREX-500. S-engine has 23 cm × 23 cm of rectangular cross-section, 2.2 m in overall length and about 100 kg in weight. S-engine

2003	2004 ~ 2007	2008 ~ 2012	2013 ~ 2020
Ground Tests of ATREX Engine	*Development of the Subscale Engine (S-engine) for Flight Demonstration*		Development of Hypersonic Demonstrator

System Tests at SLS	M2 Flight Test	Wind Tunnel Tests under M5 Flight Condition

Fig. 2. A road map of the precooled turbojet engine development.

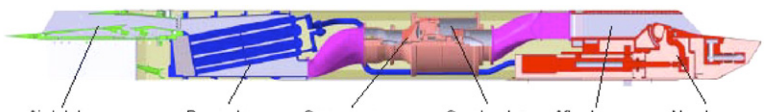

Fig. 3. Cross-section of subscale engine (S-engine).