Development Study on Air Turbo-Ramjet for Space Plane

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1. Introduction

For promoting commercialization and popularization of space activity, it is necessary to realize sharp cost reduction, improve reliability, safety, and usability of the transportation system to an earth orbit. In this purpose, it is global common recognition that the conventional expendable rocket should be replaced and reusable transportation system is indispensable. Because the most important base technology of fully reusable space transportation system is the propulsion system, it is necessary to develop a propulsion system with high reliability and durability. Although, former rocket propulsion system which use LH2 and LOX is attained more than 460 sec of ISP that is nearly the theoretical limit, when operating from the ground, the expansion ratio of a thrust nozzle cannot be greatly taken according to surrounding atmospheric pressure, ISP is quite low. In order to improve this problem, combustion pressure is set up high, and durability and reliability is decreased. Because the jet propulsion system that has both high ISP and durability under the atmospheric condition is popular for the airplane, the application of the jet propulsion for the space plane is one of the good alternatives. To apply jet engine to space plane, it is necessary to clear the difference. While most terrestrial transportation systems move to transfer the distance, space transportation system move to transfer the energy (velocity). In other words, while most of airplane's mission is to cruise, the principal mission of space plane is to accelerate. To arrive at the earth orbit, it is necessary for the space plane to accelerate up to 7.9 km/s. Although, the top speed of an airplane that applies the jet propulsion is Mach 3.2 of Lockheed SR-71, this speed is not high enough for space plane. For the first stage flyback booster of TSTO (two stage to orbit) space plane, high-speed jet engine, which works up to Mach 6, is necessary. In the Institute of Space and Astronautical Science (ISAS), LH2 fueled air turbo ramjet engine is developed initiatively in the world.

2. Outline of ATREX engine

Because ISAS devised air turbo ramjet engine adopts expander cycle, it is called ATREX engine as shown in Fig. 1. Cooling the fan incoming air cause the inter-cooling effect of Brayton cycle, and increases specific power and thermal efficiency. By cooling the high temperature air, that is approximately 1700 K at Mach 6, use of turbo jet system becomes possible up to high flight speed. Furthermore, small and lightweight core engine is achieved by adopting the tip turbine system.

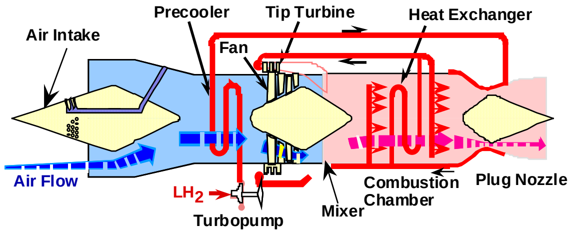

Fig. 1 Flowchart of ATREX engine

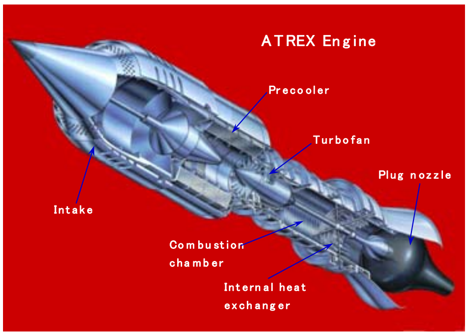

Fig. 2 Sketch of ATREX engine

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3. The situation of research and development

After the end of research and development of rocket engine, ISAS started the study of application of air breathing propulsion system to space transportation system in 1988. Because the advantageous condition air breathing propulsion system is low speed side from lift off to Mach 10, the derived type of a turbojet is observed. Then the experimental study of liquid hydrogen fueled air turbo ramjet engine is started. Since 1990, ATRE-500 engine, which is size of about 1/4 of the flyable system, is tested under the SL-static condition, and the performance and function of a system have been checked. After that, confirmation of the characteristics of turbo fan, regenerative cooled combustion chamber, internal heat exchanger and precooler is installed in the ATREX-500 engine.[1]

Fig. 3 Firing test of ATREX-500 engine

Characteristics and control performances of air intake are acquired by the wind tunnel tests of subscale model that is 1/20 of the flyable model. Wind tunnel tests are done at ISAS supersonic wind tunnel (M1.5~M4.0) and NASA Glenn Research Center 1-by 1-foot supersonic wind tunnel (M3.5~M6.0). The control test of air intake is done at ONERA S3 supersonic wind tunnel. By these tests, design data of air intake which works from lift off to Mach 6 is acquired.[2]

As a development study of air pre-cooler, fundamental researches of heat exchange characteristics between air and cryogenic refrigerant such as LH2 and reduction method of ice formation (icing) of moisture in the atmosphere on the surface of heat exchanger tubes are done using subscale model. Furthermore, precooler for ATREX-500 engine is manufactured and tested. After three times of trial manufacture, light weight precooler which is light enough for flight is manufactured, it is cleared that the injection of condensation substance such as methanol is effective for the reduction of ice formation. Because the surface temperature of pre-cooler is from 20 to 200K, liquefaction and solidification of the air is observed. An investigation and elucidation of the interference between these thermohydrodynamic phenomena is one of present subjects.[3]

Because, the incoming air temperature becomes about 1700 K, and the ram combustion gas temperature becomes more than 2000 K at the flight speed of Mach 6, high temperature materials will applied for each part of the engine. To apply carbon/carbon composites as these high temperature materials, the study about manufacture technology of complicated structure is done. The study is done not only to develop basic technologies, but also to manufacture and test of primary structural member such as the internal heat exchanger, the regenerative cooling combustion chamber and the plug nozzle.

Finally, flight tests of ATREX engine are planned. Engine performances under the flight condition are acquired using fling test bed (FTB) shown in Fig. 4. For the FTB model, both solid booster assisted model and engine self-flight model are investigated. Both models acquire engine condition during flight and it is checked after the recovery of the engine.

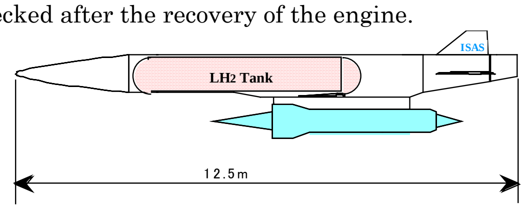

Fig. 4 Flying test bed (FTB)

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