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Reusable sounding rocket engine and its tribological subjects

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ABSTRACT – A fully reusable sounding rocket has been proposed by JAXA/ISAS to provide frequent opportunities for high altitude atmospheric observation missions at low cost and with short turnaround time, and also to improve technology readiness levels for reusable space transportation systems. This rocket will take off vertically, reach an altitude of more than 100 km, land on the launch site vertically, and be launched again within 24 hours. The main propulsion system will consist of clustered LOX/LH_2 engines with full-time abort capability in case of the failure of one engine. In order to realize the reusable sounding rocket, the main propulsion system should have advanced features of high reliability, reusability, maintainability, and survivability. To fulfill those requirements, the following points were considered and reflected in the engine system design, i.e., optimization of design margins among components for high reliability and reusability, deep throttling capability for vertical landing, and health monitoring capability for abort operation, easy inspection and maintenance for short turnaround time. Those functions and performance have been verified and demonstrated through ground tests at Kakuda Space Center/JAXA in 2014. This paper shows the design considerations, the design of the engine system and its major components, and the tribological properties of bearings and seals of turbopumps.

1. INTRODUCTION

For future sustainable space development, drastic cost reduction of the space transportation system is a major concern. One solution to cope with this problem would be to realize a reusable space transportation system. The Japan Aerospace Exploration Agency (JAXA) has carried out research and development for reusable space transportation systems. A representative activity is a series of flight test of a rocket vehicle, called the Reusable Rocket Vehicle Testing (RVT)[1], which has been conducted by the Institute of Space and Astronautical Science (ISAS) of JAXA. Following the RVT program, JAXA/ISAS has worked out a conceptual design of a reusable launch vehicle for sub-orbital high altitude sounding missions, called the Reusable Sounding Rocket (RSR), as shown in Figure 1. The RSR is a fully reusable sounding rocket with liquid propellant rocket engines [2]. One of the objectives of RSR development is to provide more frequent opportunities for atmospheric observation missions at lower cost with shorter turnaround time than the existing sounding rocket, which is an expendable one using a solid propellant rocket motor. The other objective is technology acquisition and operational substantiation of reusable rocket system to improve the technology readiness levels on reusable space transportation systems. The outcome would be exploitable for future reusable space transportation systems to be developed in Japan.

As the first step to develop the RSR, a technology demonstration project was started in 2010 by JAXA in cooperation with Mitsubishi Heavy Industries (MHI) in order to mitigate the risks of advanced features which are essential for the RSR. This project includes technology demonstrations of the vehicle development [3] and the engine development [4]. This paper presents the current status of the technology demonstration project of the main propulsion system for the RSR. Here, the design considerations of the engine system and components, the current status of manufacturing, and plan for demonstration tests are described.

Figure 1 Prospective view of reusable sounding rocket in operation.

2. OUTLINE OF RSR VEHICLE AND MAIN PROPULSION SYSTEM

The mission requirements of the RSR are specified in consideration of the scientific needs of the expected users and can be summarized as follows:

- Arrival altitude: more than 100 km
- Payload mass: 100 kg
- Operational cost: 1/10 of the present cost
- Reusability: 100 flights
- Turnaround time: within 24 hours
- Survivability: Full-time abort

Figure 2 shows the flight sequence of a nominal operation. After ignition of its main propulsion system, the RSR will take off vertically from a launch site and reach an altitude of 100 km or more. After the powered ascent and ensuing ballistic flight, the vehicle will begin its descent in nose-first entry. Before re-ignition, the vehicle will turn over for the vertical landing. The RSR will return to the launch site, be refueled and be launched again within 24 hours.

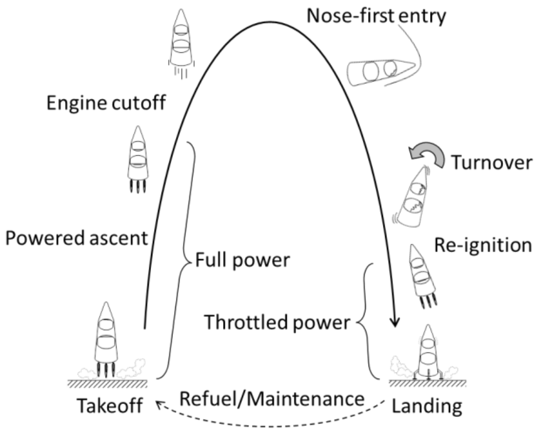


Figure 2 Flight operation.

The latest prospective configurations of the vehicle and the engine are shown in Figure 3. As for the vehicle, the body length is 13.5 m long and the gross mass is about 11.6 ton. The RSR propulsion system has four pump-fed rocket engines using LOX/LH_2 as propellants and each engine has a thrust of 40 kN at sea level.

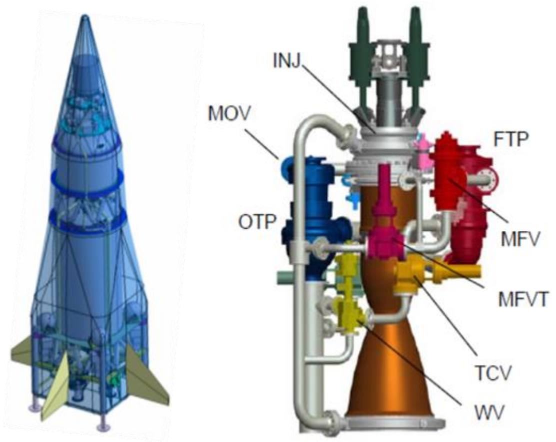


Figure 3 RSR Vehicle and engine.

3. BEARINGS AND SEALS OF THE LH_2 AND LOX TURBOPUMPS

The seal system of the LOX turbopupmp is shown in Figure 4, and Figure 5 presents the results of the element test of the mechanical seal for the oxygen turbopump. Rotational speed is 25,000 rpm and duration time is 120 minutes. This seal nose is about 2 mm in height at the first time, and is almost completed worn away after a test. Figure 6 shows the results of the element test of the hybrid ceramic bearing for the liquid hydrogen turbopump. Rotational speed is 100,000 rpm and duration is 120 minute. Some cracks formed by thermal shock appear on the contact surface of the ceramic balls, but do not further develop after some tests. The operation time of RSR is about three minutes for one flight. One-hundred and twenty minute is just about equivalent to forty flights. Given these results, replacement of the mechanical seal of OTP and bearings of FTP was set to be performed every thirty flights with some margin.

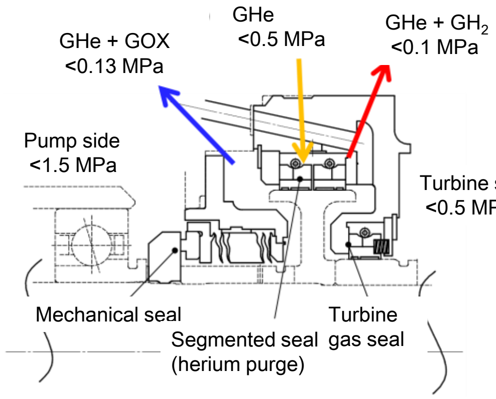


Figure 4 Seal system of LOX turbopump.

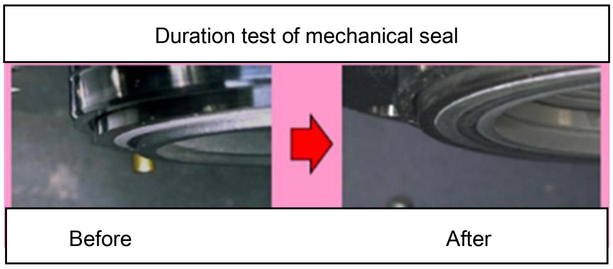
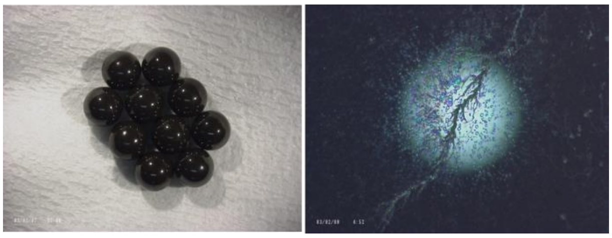


Figure 5 Wear of mechanical seal.
(LOX turbopump, 25,000 rpm, 120 min)



Before After
Figure 6 Bearing balls before and after the duration test.(LH_2 turbopump, 100,000 rpm, 120 min)

4. REFERENCES

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