SYSTEM DESIGN AND TECHNICAL DEMONSTRATIONS FOR REUSABLE SOUNDING ROCKET

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ABSTRACT

A fully reusable sounding rocket is proposed in ISAS/JAXA. Vehicle systems and ground / flight operations are conceptually designed for observations of atmospheric phenomena, micro-gravity experiments and so on. The present design of the reusable sounding rocket is summarized. In phase A in the proposed reusable sounding rocket project, technical demonstrations for key technologies to develop the reusable sounding rocket are planed as follows; 1) reusable engine development and repeated engine operation development, 2) reusable insulation development for cryogenic tank, 3) aerodynamic design and flight demonstration for returning flight, 4) fuel/oxidizer management demonstration, 5) landing gear development and 6) health management system construction.

1. INTRODUCTION

Recently, in spite of existence of many launch demands for scientific researches using sounding rockets, the opportunities of launches are actually restricted because of high-cost of rocket launches, long period of launch preparations, and so on. In order to make the access to space for researches by the sounding rocket much easier (lower cost) and make the opportunities of the rocket launches much frequent, a fully reusable sounding rocket is proposed in ISAS/JAXA. Vehicle systems and ground / flight operations are designed for observations of atmospheric phenomena, micro-gravity experiments and so on. [1],[2]

Figure 1 shows the development plan of the proposed reusable sounding rocket. In phase A of this plan, 2010-2012, demonstrations of the key and critical technologies to develop the reusable sounding rocket will be conducted for engineering verifications of subsystems before the manufacture of flight system. In phases after the phase A, 2013-2016, the flight engine and flight model of reusable sounding rocket will be manufactured and tested. Ground firing tests, take-off and landing tests, low and high altitude flight tests will be repeatedly conducted. After these system verifications, the reusable system will be operated as a sounding rocket.

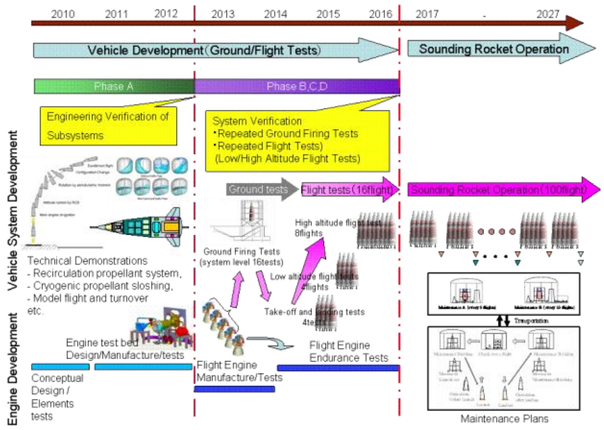

Figure 1. Development plan of reusable sounding rocket.

The key technologies with respect to the returning flight are 1) aerodynamic design and flight demonstration for returning flight, 2) fuel/oxidizer management demonstration, and 3) landing gear development. Moreover, the key technologies with respect to the repeated operations are 4) reusable engine development and repeated engine operation development, 5) reusable insulation development for cryogenic tank, and 6) health management system construction. The demonstrations of these technologies planed in phase A are introduced in this paper.

2. PRELIMINARY SYSTEM DESIGN OF REUSABLE SOUNDING ROCKET

The mission definition of the proposed reusable sounding rocket is summarized as follows:

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1. To achieve 120km in altitude and returns/lands at the launch site
2. The payload to be carried should be 100 km and returns with the vehicle
3. Flight frequency is higher than 5 times in two-month launch season, and two seasons per
4. The minimum flight interval for the turnaround capability is one day
5. Operational flight cost excluding development cost should be an order of magnitude less than the existing ISAS sounding rocket.

System and subsystem designs such as aerodynamics, propulsion systems, structures, etc were conducted, respectively. As these results, the baseline configuration was obtained as shown in Fig.2. A vertical take-off and vertical landing (VTVL) system is adopted because of 1) simple ground support equipments, 2) streamlined flight and ground operations, 3) compact system and light inert weight, and so on. The present vehicle configuration is summarized in Table 1.

Payload (instruments for the science observations) of 100kg is settled in the nose fairing which could be opened for the observations and sampling of the atmosphere. The landing gear can extend in landing phase and can be contracted in the body in other flight phase. Liquid hydrogen and liquid oxygen are use as propellants for high performance, i.e. high specific impulse, and low environmental loads.

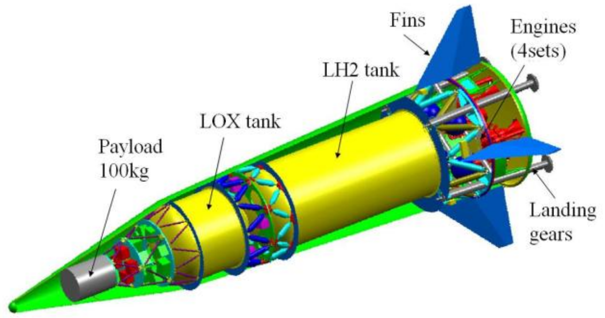

Figure 2. Baseline configuration of vehicle.

Table 1. Present vehicle configuration.

Body length	13.5 m
Body diameter	3.0 m
Take-off mass	10.8 ton
Dry mass	3.8 ton
Engine thrust	41kN×4
Engine Isp	320 sec
Mixture ratio	5.7

3. FLIGHT PERFORMANCES

A typical sequence of ballistic-flight of the reusable sounding rocket vehicle up to 120km is as follow (see Fig.3). The vehicle takes-off vertically by the main engine thrust, and cut it off in its ascent phase. Then, the vehicle flies ballistically up to the summit altitude. Around the summit, the flight speed is subsonic because the horizontal speed is low enough in this flight profile. After that, the vehicle entries into atmosphere and decelerated by aerobraking, and vertically lands to the launching site. In the landing phase, the vehicle is decelerated by the main engine thrust for a soft-landing. In the case of the nose-first entry, the "turnover maneuver" must be conducted. This maneuver changes the attitude of the vehicle from the nose-first to the base-first for its deceleration and landing by the main engine thrust.

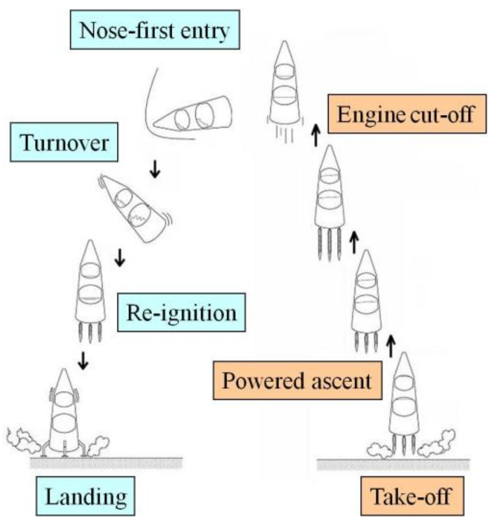

Figure 3. Typical ballistic flight sequence.

In the typical ballistic-flight up to 120km, the total flight time is about 600sec. Maximum Mach number is about 4, and the flight condition of Mach number below 1.0 (subsonic speed) is kept for about 70sec over 110km altitude. In this subsonic flight, the observed atmosphere around the vehicle is not affected by the shock wave. This is desirable for the atmospheric observation. Maximum acceleration in the flight is about 7G. For the micro-gravity experiments, the flight environments of acceleration less than 10^{-3}G, 10^{-4}G and 10^{-5}G is able to be made for about 180, 150 and 120sec, respectively.

4. DEMONSTRATIONS OF KEY TECHNOLOGIES IN PHASE A

In order to design an operative reusable sounding rocket, some key and critical technologies, which are related to returning flight and repeated operations, will be studied and demonstrated in phase-A.

These technologies are summarized in Fig. 4 and 5. Technologies with respect to the returning flight are 1) aerodynamic design and flight demonstration for returning flight, 2) fuel/oxidizer management demonstration, and 3) landing gear development. Moreover, technologies with respect to the repeated operations are 4) reusable engine development and repeated engine operation development, 5) reusable insulation development for cryogenic tank, and 6) health management system construction.

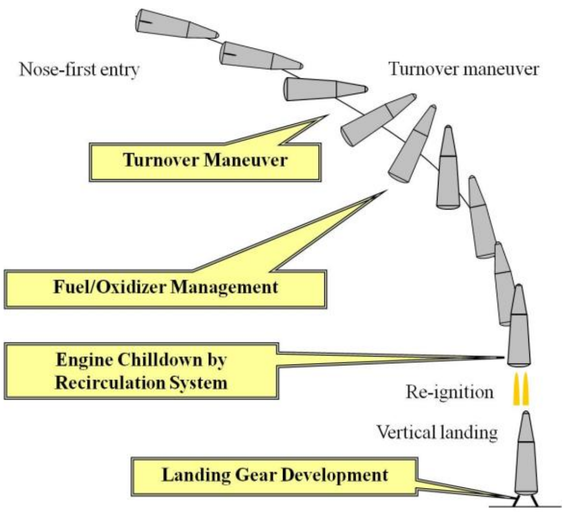

Figure 4. Key technologies in returning flight

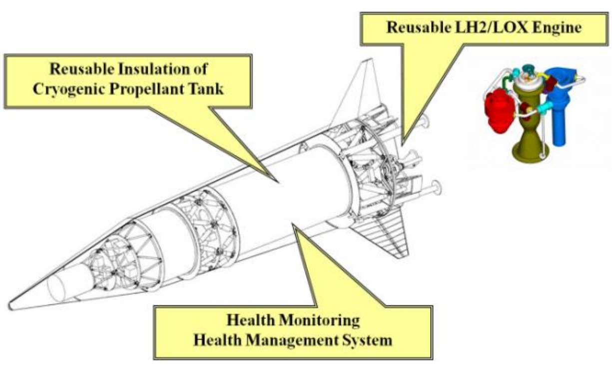

Figure 5. Key technologies in repeated operations.

4.1 Reusable engine development and repeated engine operations

As a main engine of the reusable sounding rocket, it is aimed to develop a reusable engine which can be repeatedly operated 100 times. Life-controlled design is important technique for the development of reusable engine. In the case of a rocket engine, lifetime estimations of each element are now possible using the data obtained from the critical performance tests. Lifetime of the thrust chamber is estimated to be able to reuse more than 100 times. However, lifetime of the mechanical elements such as bearings and turbo-pump seals is less than reuse 100 times. Therefore, they need to be regularly changed some parts of element. Based on such life-controlled studies, design principles of the engine for reusable sounding rocket are as follows.

1) Combustion chamber is used repeatedly.
2) Mechanical elements such as bearings, the life management by periodically exchanging.
3) Design the engine structure which is easy assembly and disassembly allow quick inspection and replacement.
4) Create a health management system that can quickly judge the health of the engine.

For the reusable rocket adopting VTVL system, main engines require not only reusability but also a wide range of throttling level and high response performance in order to achieve vertical landing capability. Phase-A study for reusable sounding rocket is aimed to develop the engine with the following performances.

1) Engine Cycle: Expander cycle (Expander-Bleed)
2) Thrust level: more than 40kN (sea level)
3) Specific impulse: more than 320 sec (sea level)
4) Throttling capability: down to 30 % of rated thrust
5) Response: 20% change in thrust per second

Figure 6 shows an image of the engine for the reusable sounding rocket and the technology demonstrations in phase-A. The engine technology demonstrator will demonstrate reusability, long life, deep throttling, health monitoring, and operability. [3]

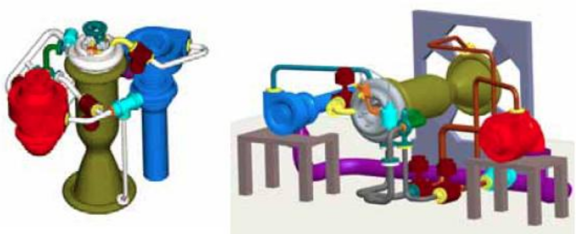

Figure 6. Engine technology demonstrator.

4.2 Fuel/oxidizer management demonstration

To demonstrate the propellant managements for quick turnaround and returning flight operation of the reusable sounding rocket, technical demonstrations with respect to fuel/oxidizer management are planed as follows.

Engine chill-down by recirculation pump system

The propulsion system of reusable sounding rocket acquires the capability of re-ignition for its vertical landing. If a main engine system is not sufficiently chilled down before the re-ignition, requirements for engine restart would be not satisfied. In order to success the prompt re-ignition of main engines, engine system must be sufficiently chilled down during a ballistic flight. It is not difficult to chill down the engines in flight by consuming and venting the cryogenic propellants to outside of vehicle, indeed. However, from the viewpoint of reducing the amount of invalid propellants and increasing the safety in flight, a recirculation system with pumps is preferable, which enables propellants used for the chilling down to return again into the propellant tanks.

In order to demonstrate the validity of the recirculation system of fuel/oxidizer and evaluate its feasibility, ground tests are planned. Figure 7 shows a schematic of the ground test configuration of recirculation subsystem. In the demonstration with liquid hydrogen as test fluid, the performance of recirculation pump, feasibility for plural feed lines, the penalty weight of subsystem, heat input to recirculation lines, and so on will be evaluated.

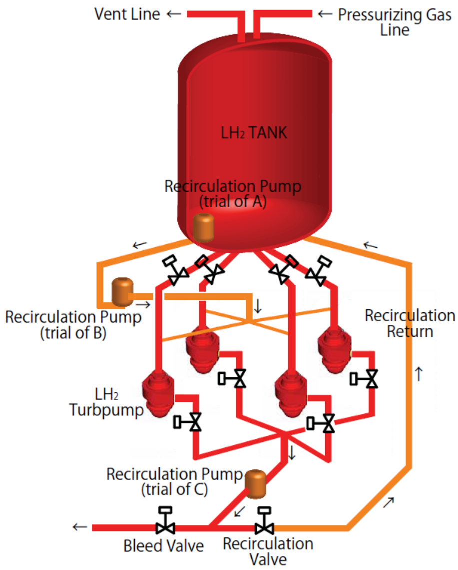

Figure 7. Demonstration of recirculation system.

Sloshing of cryogenic liquid propellant

The suppression of sloshing in fuel/oxidizer tanks is one of the important problems for the propulsion system. If one of the main engines should accidentally fail during its powered flight, the engine at opposite position would be shut down promptly. During the period from occurrence of engine failure to the second out shut down, the attitude of the vehicle would change largely due to the misalignment of the thrust vector. Moreover, the vehicle needs attitude maneuver before its landing. From the viewpoint of propellant management, the lateral acceleration in both cases could induce sloshing with large amplitude in the propellant tanks. At the same time, the sloshing could enhance the heat exchange and phase-change on the gas-liquid interface and cause the sudden change in tank pressure. Hence, the suppression of sloshing and avoiding vapor-suction would be important problem. In order to assess the characteristics of the heat exchange and phase-change induced by sloshing of cryogenic propellant, and to optimize the configurations of internal devices equipped in tank, ground experiments and numerical simulations were planned. Figure 8 and 9 show preliminary numerical and experimental results of sloshing. [4]

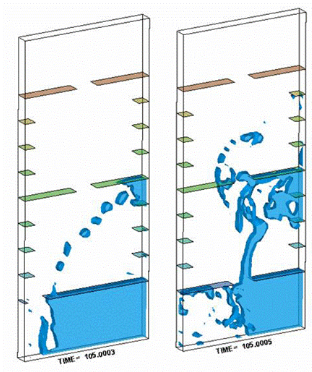

Figure 8. Numerical simulations of liquid propellant sloshing with damping devices.

Figure 9. Visualization of LH2/LN2 sloshing.

Reusable insulation for cryogenic propellant tanks

Insulation of cryogenic propellant tank occupies a relative large amount of weight in the propellant system of reusable rocket. Two types of insulation system are generally used for the cryogenic propellant tank. The one, vacuum insulation, can be reused almost infinitely and has sufficient performance as cryogenic insulation, but the weight of system tends to be so heavy. The other, foam insulation such as poly isocyanate foam (PIF), is relative light, and used for cryogenic propellant tank in existing expendable rocket systems. However, the performance of foam insulation is inferior to that of vacuum insulation in general, and furthermore some cracks in the foam insulation will grow through repeated use in cryogenic environment and bring further insulate performance degradation. Hence, some technical investigations are needed to use the current insulation systems for reusable rocket, for example lighter vacuum insulation or countermeasures against crack growth in foam insulation. In order to demonstrate the reusable insulation systems, experiments using liquid hydrogen are planned. Figure 10 shows a preliminary test for the cryogenic insulation. In this study, it is planned to evaluate the combination of some insulations to improve the reusability, light vacuum insulation system made of composite, non destructive inspection (NDI) method of insulation such as acoustic emission, simple and quick replacement method of foam insulation, and so on.

Figure 10. Insulation cycle test by using LH2.

Aerodynamic design and flight demonstration for returning flight

As mentioned above, the vehicle has to turn its attitude over before the landing. Some typical concepts can be considered for such inversion maneuver of the vertical landing rocket vehicle. The aerodynamic turnover maneuver, which is one of the most adoptable methods, is schematically shown in Fig. 11. The vehicle begins this maneuver by instable aerodynamic characteristics caused by the configuration change such as a retraction or an expansion of aerodynamic control surfaces. Aerodynamic moments make the vehicle pitching up initially and pitching down finally. Control torque of a reaction control system (RCS) stabilizes the vehicle in a tail-first attitude and maintains an angle of attack of 180 deg before a re-ignition of main engines.

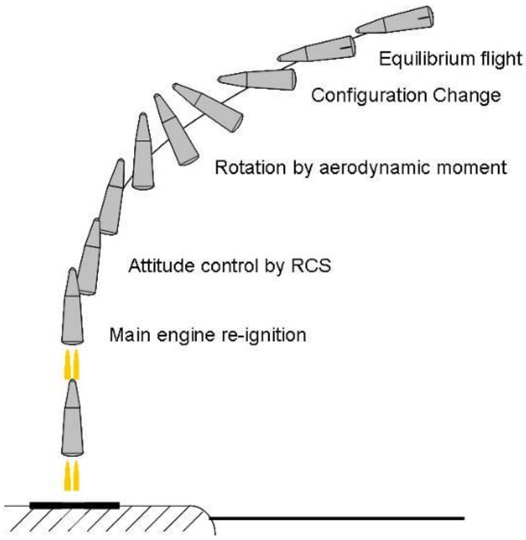

Figure 11. Turnover maneuver.

Figure 12 and 13 shows the possible configuration changes for the turnover maneuver and the aerodynamic change, respectively. If the difference of pitching moment coefficient C_m between maximum and minimum value is large, the angular velocity of the vehicle rotation will be too large to control the sloshing of a liquid fuel in a tank. If the difference of C_m between the equilibrium flight configuration and retracting one is large, moreover, the angular velocity will become large rapidly. From these reasons, such deference of C_m should be minimized by some refinements of the vehicle configurations and the position of a center of gravity.

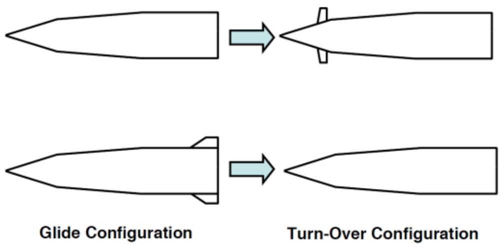

Figure 12. Configuration changes for turnover.

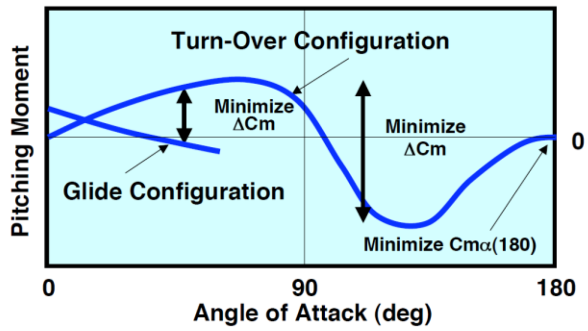

Figure 13. Pitching moment during turnover maneuver.

In order to demonstrate the aerodynamic turnover maneuver, flight experiments by a small scale model gliding from a helicopter is planned. The scale model will be lifted up to about 2,000 m altitude by a helicopter. After a cut-off from a helicopter, the model will glide as keeping the angle of attack at 5-10 deg controlled by tail fins. The model starts the turnover maneuver by configuration change blow 1,000 m altitude. After the turnover maneuver, the pitch and yaw attitude of the model will be controlled by an on-boarded gas jet to maintain the attack angle of 180 deg. The parachute is opened before the landing. Figure 14 shows a preliminary glide test by the small scale model of the reusable sounding rocket from 30m height. [5]

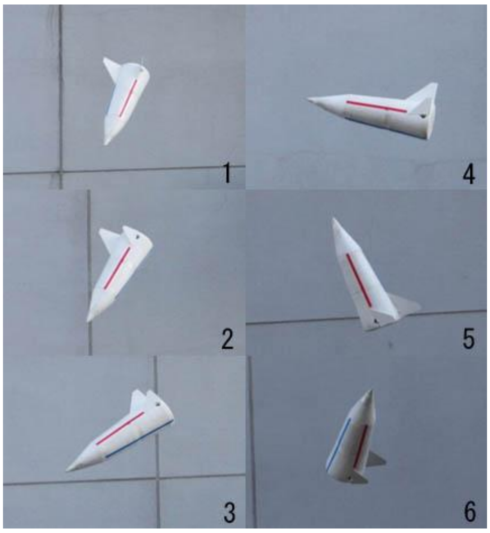

Figure 14. Preliminary glide test for turnover maneuver.

5. SUMMARY

The present system design of the reusable sounding rocket and related technical demonstration studies are summarized. The reusable sounding rocket with unique characteristics such as sampling, repeated daily flight etc will bring the great changes of the scientific observation of atmosphere and micro G experiments, and so on. Such reusable sounding rocket is effective not only for science missions but also for the research and development of the future space transportation systems. These activities will accelerate such studies and lead to the next step. Finally, the plan of technical demonstrations in Phase-A are summarized in Fig. 15.

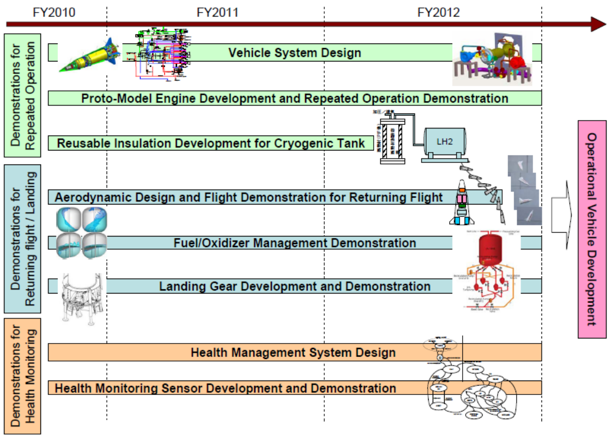

Figure15. Plan of technical demonstrations

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