Recent Activities of Sounding Rocket and Ballooning in Japan*

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Abstract: In ISAS/JAXA, sounding rockets and stratospheric balloons are used for various scientific and engineering objectives. Recent flight experiments made use of sounding rockets and balloons in Japan are summarized in this paper. Also presented are research and development activities toward the future sounding rocket is also introduced.
Key Words: Sounding Rocket, Stratospheric Ballooning, Flight experiment, Upper atmosphere research

1. Introduction

In Japan, the Institute of Space and Astronautical Science (ISAS) is one of major department of in Japan Aerospace Exploration Agency (JAXA) and continues to promote space science program as a leading center of the inter-university research institutes, taking advantage of flight opportunities by science satellites, sounding rockets and balloons. The sounding rockets and the balloons are used for various scientific and engineering objectives such as studies of thermospheric, ionospheric, magnetospheric physics, astrophysics, microgravity experiment, demonstration of various instrument and technique, and advanced engineering experiments.
ISAS has a character of an inter-university research institute as mentioned, and is run in cooperation with scientists and engineers across the nation. Proposals of experiments by sounding rockets and balloons are solicited from science community, and selections of rocket and balloon experiments are made by committees comprising about equal numbers of internal and external members. Approved projects are then implemented with the collaboration of scientists and engineers, again both inside and outside ISAS.
International cooperation for researches by sounding rocket and balloons is also important in the field of scientific and engineering studies. Japanese sounding rocket and balloons have been launched from not only in domestic site but also in overseas range for observations impossible in the Japan area. In addition, by gathering together mutual technologies and experiences, we can conduct more fruitful observations. Through the combination with the national researchers and the cooperation with international organizations, ISAS will keep its own flight opportunities and be able to obtain many new scientific findings[1-3].

2. Sounding rocket programs

We are operating three types of the sounding rocket S-310, S-520 and SS-520 as shown in Fig 2.1. One or two are launched annually from the Uchinoura Space Center. ISAS sounding rockets have

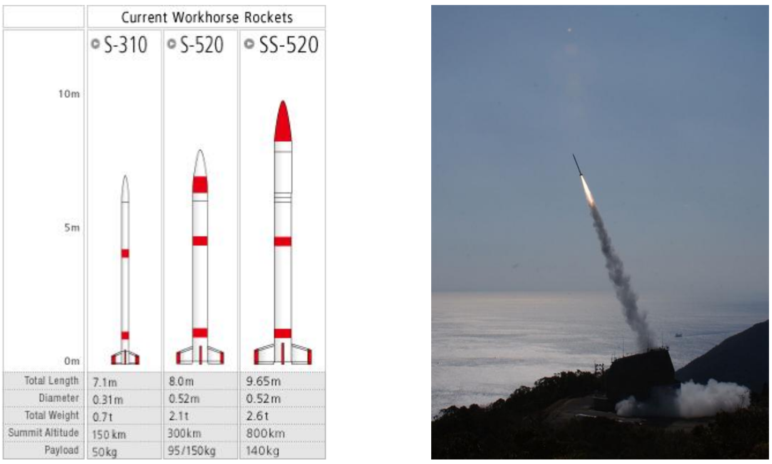

Fig. 2.1 Sounding rockets in ISAS.

been contributing to astrophysical observation, upper atmospheric studies, space plasma physics, etc. The ISAS engineering team is developing new flying-vehicle systems, including propulsion systems, attitude control systems, and re-entry, recovery and navigation technology. Sounding rockets are also used in microgravity experiments for material and life sciences. Offering quick response to planning, implementation and results of experiments, sounding rockets also show excellent flexibility in function and performance confirmation tests of the new observation instruments and technical elements that are expected to be loaded on future satellites and space explorers. Sounding rocket experiments in ISAS from 2013 to 2015 are summarized in Fig 2.1. Typical experiment of these activities are summarized in the following subsections.[4)]

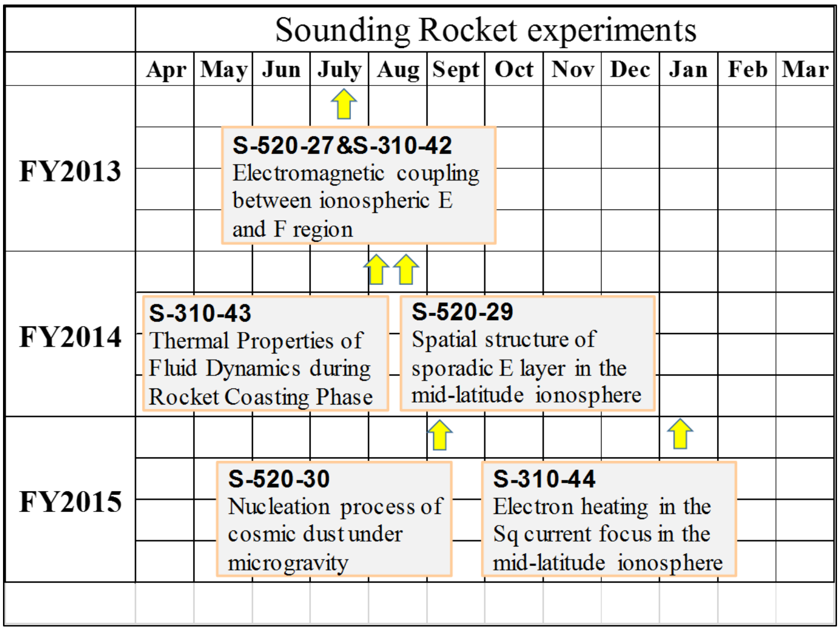

Fig. 2.2. Recent sounding rocket experiments in ISAS

2.1. S-520-27 and S-310-42 sounding rocket experiment for a study of E-F region coupling

There exist several kinds of disturbance in the ionosphere. Simulation by Yokoyama et al. (2009) suggests electro-magnetic coupling between the ionospheric E and F region. This simulation indicates that after the seed of initial perturbation and rotational shear wind is initially set in the E region, the perturbation is developed in the F region. So, the objective of this experiment was to elucidate generation mechanism of F region perturbation such as MS-TID by conducting comprehensive observation of the electromagnetic coupling between E and F regions.

In order to investigate the E and F region coupling, we planned to launch two sounding rockets. One rocket was used to observe plasma parameters in the F region, and another rocket was to investigate E

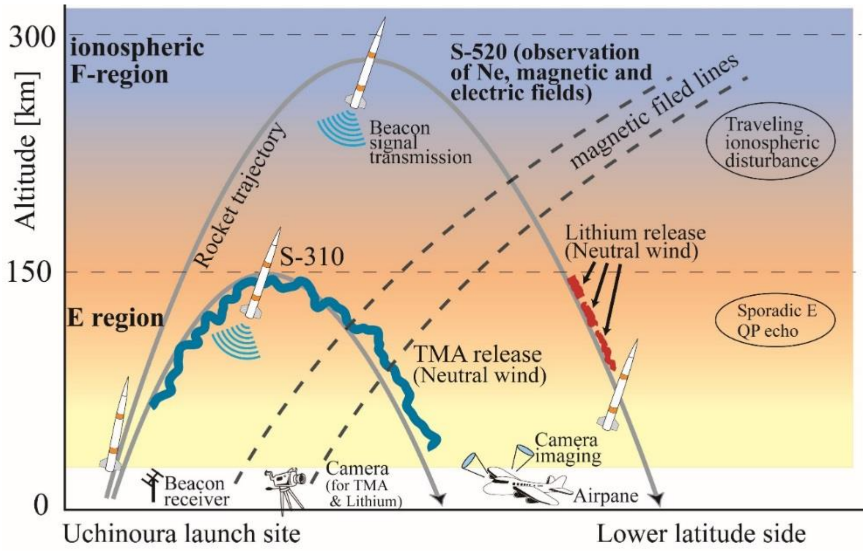

Fig 2.1.1. S-520-27&S-310-42 experiment for a study of E-F region coupling

region. In this experiment, difficult problem was how we can find neutral wind information at higher altitude at night. We have developed Lithium Ejection System by which we can estimate neutral wind by taking continuous images of Lithium vapor emission by sun light. However, this technique cannot be used at night. We decided to use moon light instead of sunlight. In this way, we carried out a comprehensive measurement of plasma, neutrals, electric and magnetic field in the E and F region.
S-520-27 and S-310-42 were launched at 23:00 JST and 23:57 JST on July 20, 2013, respectively. Fig. 2.1.2 shows TWA released from S-310-42 to estimate neutral wind. In the first part of the trajectory, the density is smaller, electric field direction is north-east and its amplitude is larger. In the second half, the density is larger, and the electric field is smaller. This result is consistent with assumption that Perkins instability is responsible for MS-TID. We also succeeded to estimate neutral wind from Lithium release and TMA release.

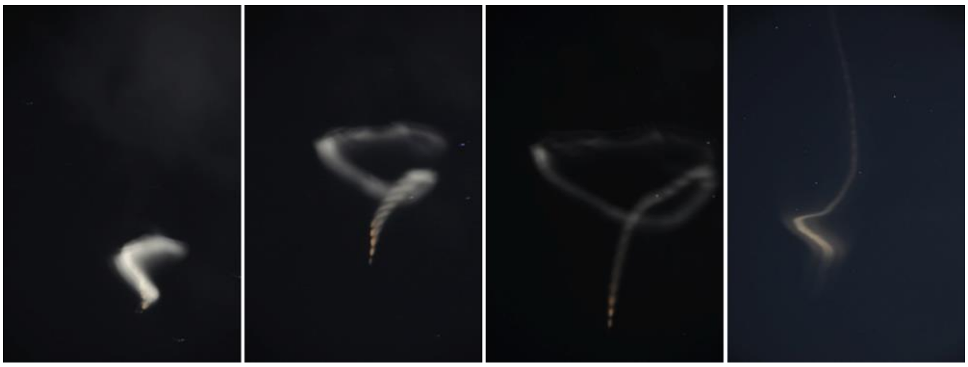

Fig 2.1.2 Estimation of neutral wind from TMA release.

2.2 S-310-43 experiment for a study of thermal properties of fluid dynamics during rocket coasting phase

The objective of this campaign is to observe thermo-fluid dynamics of cryogenic two-phase flow and phase-change heat transfer during the rocket coasting phase in order to improve cryogenic design and analysis technique of cryogenic propulsion system. Test sections of shape similar to turbo-pump LN2 was employed instead of LOX. Boiling of LN2 inside the test sections and the transition of flow regimes from gas/liquid two-phase flow to liquid mono-phase flow were visualized. The temperature, pressure and void fractions of each channel were also measured

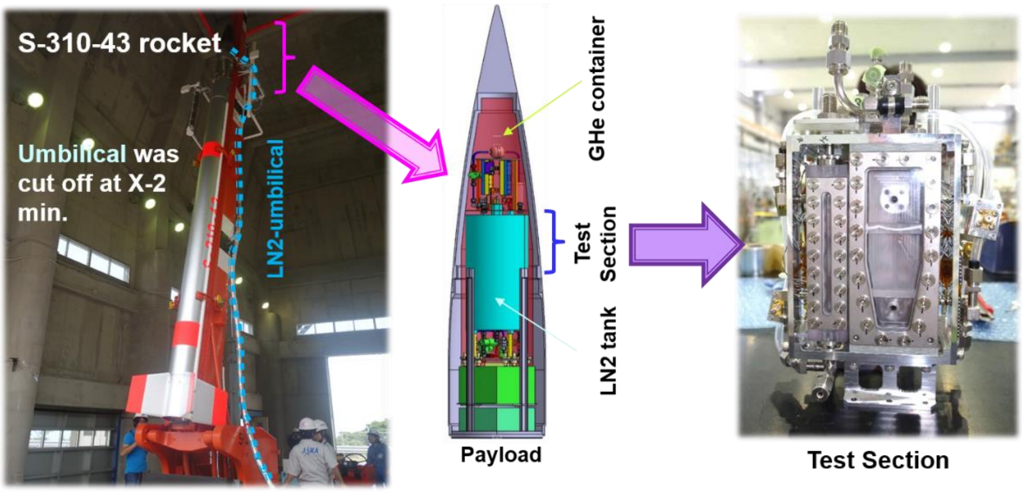

Fig 2.2.1. S-310-43 rocket and test section.

It was confirmed that the two-phase flow in the complex channel could wet the heat transfer surfaces more easily due to μ gravity, and that more uniform chill-down effect could be obtained. However, in the fluid system with complex geometry, behavior of two-phase flow under the condition of low Weber number and Bond number should not be considered as homogeneous mixture flow, but as unsteady free-surface flow.

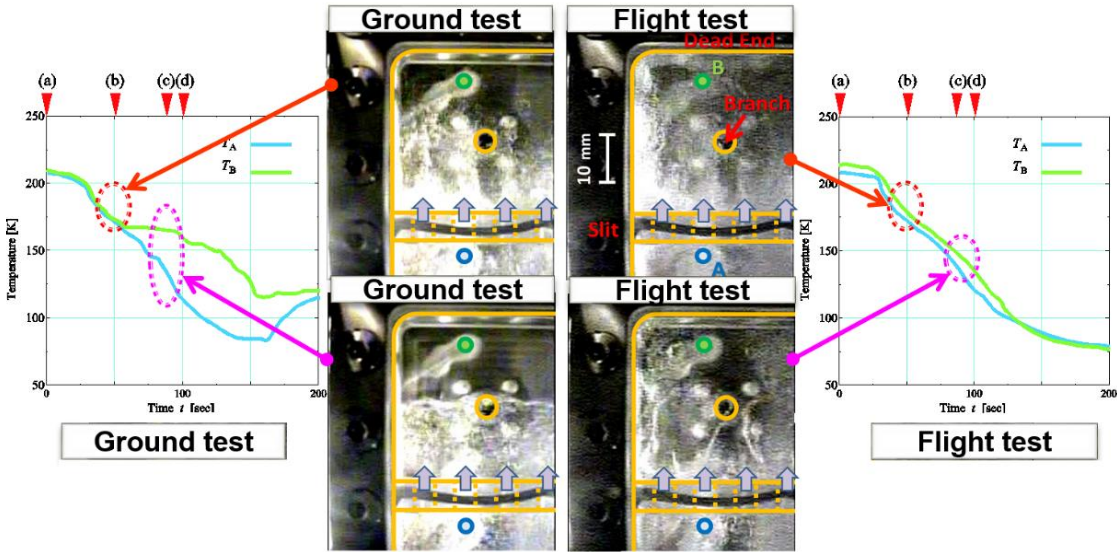

Fig 2.2.2. Gas/liquid nitrogen two-phase flow in test section and temperature histories.

3. Scientific balloon programs

In ISAS, scientific observation balloons have been used in space and earth observation as the only flight vehicle that can stay for extended periods in an altitudinal region higher than aircrafts reach and lower than satellites. Scientific balloons provide opportunities for scientific observations such as cosmic observations and atmospheric observations, and also space engineering demonstrations such as micro-gravity experiments and flight system demonstrations. A helium-gas-filled balloon made of thin polyethylene film can float a payload into the stratosphere. Because of the loose restrictions on the size and weight of the payload, many challenging experiments with state-of-the-art equipment have been conducted. Recovered equipment can be upgraded for subsequent flight opportunities to obtain further scientific achievements. Scientific balloons brought up both scientists and equipment pioneering new space science. Two balloon experiment campaigns per year are planned as annual domestic balloon activities, and several heavy balloons and high altitude thin balloons are launched in those campaigns. From 1971 to 2007, more than 400 heavy balloons have been launched from Sanriku, Iwate. From 2008, domestic balloon campaigns are being carried out at Taiki, Hokkaido. Flights circumnavigating the South Pole have been conducted as long duration flights, and southern sky observations are being carried out by the Japan-Brazil international collaboration. Typical balloon experiment of these activities are summarized in the following subsections.[5)]

Fig 3.1. ISAS scientific balloon release from Taiki Aerospace Research Field (TARF).

3.1 Scientific balloon experiment B16-01: High altitude flight test for Mars probe airplane

ISAS/JAXA conducted a balloon release of the scientific balloon experiment on June 12, 2016, aiming at a high-altitude flight test for a Mars probe airplane. To achieve a Mars probe airplane, it is imperative to perform aerodynamic design of the plane to fit it for flight in the very thin atmosphere of one hundredth compared to that on the Earth. This experiment was conducted at a high altitude where the Mars' atmospheric density was simulated to acquire aerodynamic data for the plane. The balloon was released at 3:33 a.m. on the 12th from the Taiki Aerospace Research Field. The balloon entered in a state of horizontal floating at an altitude of 36 km over the Pacific Ocean some 45 km east from the Taiki Field at two hours and 25 minutes after its release. At 6:20 a.m., a radio command was sent to detach the test plane. Four minutes later, the balloon and a control instrument were also detached by the command, and they landed softly on the ocean about 35 km east from the Taiki Field. They were recovered by a boat at 7:04 a.m. Concerning the flight test for a Mars probe airplane, the various data acquired from this flight test will be analyzed to incorporate the analysis results into future Mars probe airplane designs.

Fig 3.1.1. Mars probe airplane and balloon experiment in TARF

3.2 Scientific balloon experiment B16-02: Capturing microorganisms in the stratosphere

The existence of microorganisms in the upper atmosphere (in the stratosphere and mesosphere) has been reported so far through collecting microorganisms. Understanding the kinds of organisms in the upper atmosphere and clarifying their distribution are important to learn about the upper end of the Earth's biosphere. This experiment aimed at capturing microorganisms while the instrument to collect them was detached from the balloon and descending by a parachute.

ISAS/JAXA released a balloon from the Taiki Aerospace Research Field at 3:43 a.m. on June 8, 2016. The balloon used this time is a large-size one with a maximum expansion volume of 15,000 cubic meters (33.5 meters in diameter), and it ascended at a speed of 300 meters/minute. The balloon entered in a state of horizontal floating at an altitude of 28 km over the Pacific Ocean some 35 km east from the Taiki Aerospace Research Field at one hour and 40 minutes after its release. At 5:50 a.m., the balloon and an instrument to collect microorganisms were detached by a radio command and they landed softly on the ocean about 30 km east from the Taiki Field. They were recovered by a boat at 6:28 a.m. Microorganisms and particle specimens corrected in the instrument are to be analyzed.

Fig 3.2.1. Microorganism capturing instrument and balloon experiment in TARF.

3.3 Super-pressure balloon

Development of a balloon to fly at higher altitudes is one of the most attractive challenges for scientific balloon technologies. Since balloons ascending to high altitude need to be extremely light, these balloons are made of a specially developed ultra-thin polyethylene film. A new world record of the highest unmanned balloon altitude of 53 km was established in 2003 by a 3.4 μm-thick balloon. After that, a thinner balloon film with a thickness of 2.8 lm was developed. A 5000 m^3 balloon made with this film was launched successfully in 2004. Now such balloons are utilized for ozone observations in the mesosphere. Super-pressure balloons, slightly pressurized inside, do not shrink even after sunset, so that they continue to float at a constant altitude for up to several months. R&D is currently being undertaken into a structure to minimize the stress on the film and the construction procedure[6].

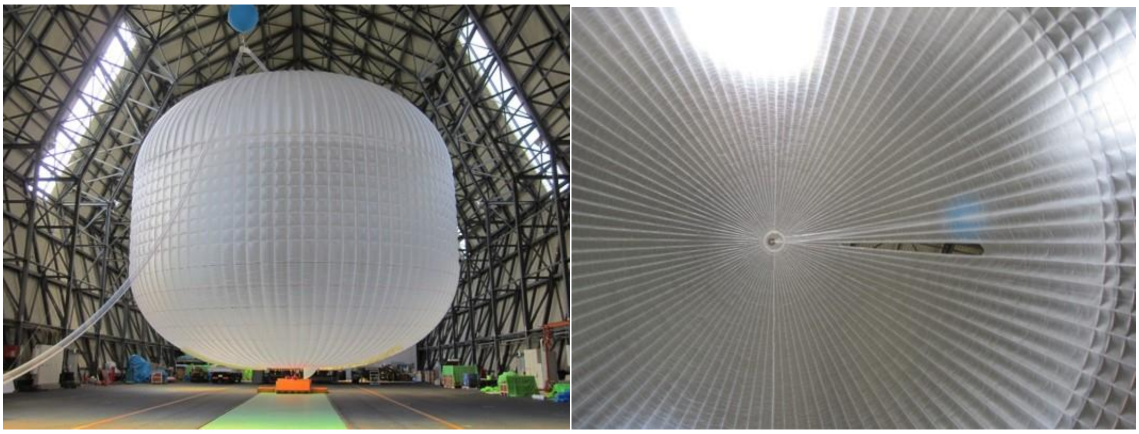

Fig 3.3.1 Super-pressure balloon.

4. Activities toward future sounding rocket

4.1 Small satellite launch by SS-520

To launch a small satellite, SS-520 sounding rocket is advanced in progress now. The original SS-520 is a two-stage solid rocket. The first stage of which comes from the main booster of the S-520 sounding rocket. It has a capability for launching a 140 kg payload to an altitude of about 800 km.
For the launch of a satellite, a third stage solid motor is added atop. The attitude outside the atmosphere in first stage is stabilized by succeeding spinning with tail fins. And before the ignition of second stage, the attitude is utilized in the spinning stabilization and the Rhumb-line control by a gas-jet system to determine the flight direction for the second and third stage flight. For the Rhumb-line control and orbiting a satellite, an advanced on-boad avionics is under development.

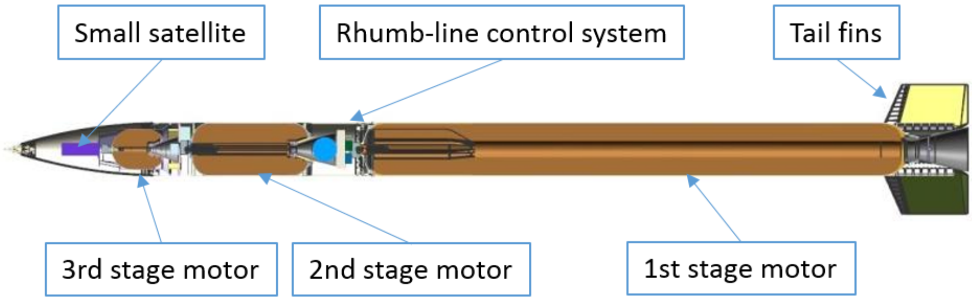

Fig 4.1.1 SS-520 rocket for small satellite launch.

4.2. Activities toward reusable sounding rocket

In ISAS, activities for reusable rocket technology and architecture including flight demonstration by the RVT (Reusable Vehicle Testing, Fig 4.2.1) have performed various progresses in technical areas such as frequent-flight propulsion systems, reusable rocket engines, returning flight and vertical landing techniques and demonstrations, composite cryogenic LH2 tank studies, new architectures for reusable and repeated flights with quick turnaround and so on. Following these basic studies of reusable rocket, mission definition and system requirement synthesis of the reusable sounding rocket are completed. In addition to the technical and performance related issues, its operational aspects and requirements for the frequent and repeated flight were given stressed. Throughout the studies, technical readiness to the reusable rocket technique and for the system synthesis for the reusable sounding rocket vehicle have been conducted. For the sounding rocket's system definition and requirement analysis, research of the flight demand such as the number-of-flight per year and its frequency by the potential user communities. These requirements are from the needs of the middle to upper atmosphere research, studies from micro-gravity community, engineering community which may use this repeated flight opportunity[7].

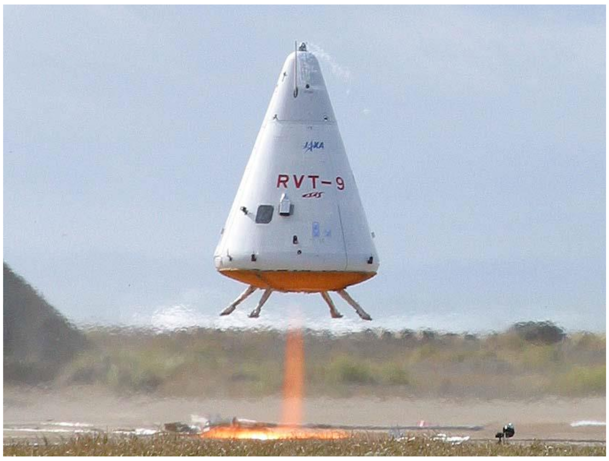

Fig 4.2.1 RVT flight demonstration.

A goal of the proposed vehicle is first to achieve the fully reusable vehicle with enhanced operability, which will demonstrate the benefit of reusability. At the same time, the rocket vehicle is used as a sounding rocket. An easy access to the flight opportunity is quite important for those who wish to use it such as the astrophysicist and researchers of atmosphere. The micro-gravity community is also one of the major potential users of the vehicle. By enhancing the flight operability, a low cost operation of the vehicle will give a good opportunity for these researchers or users, which means the frequent use of the vehicle is expected. The mission definition of the proposed reusable sounding rocket are 1) To achieve 100km in altitude and returns to the launch site, 2) The 100kg payload to be carried, 3) Flight frequency is higher than 10 times per a year, 4) The minimum flight interval is one day, and 5) Operational flight cost should be an order of magnitude less than the existing ISAS sounding rocket.

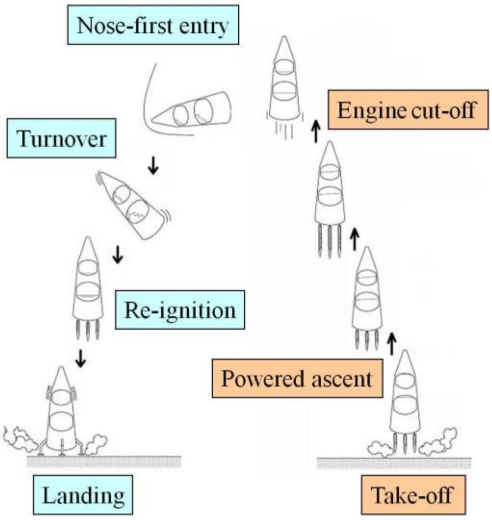

Fig 4.2.2 Typical flight sequence of proposed reusable sounding rocket.

In phase A of the development plan of the proposed reusable sounding rocket, demonstrations of the key and critical technologies to develop the reusable sounding rocket have conducted for engineering verifications of subsystems before the manufacture of flight system. The key technologies are 1) aerodynamic design and flight demonstration for returning flight, 2) fuel/oxidizer management demonstration, 3) landing gear development, 4) reusable engine development and repeated engine operation development, 5) reusable insulation development for cryogenic tank, and 6) health management system construction[8].

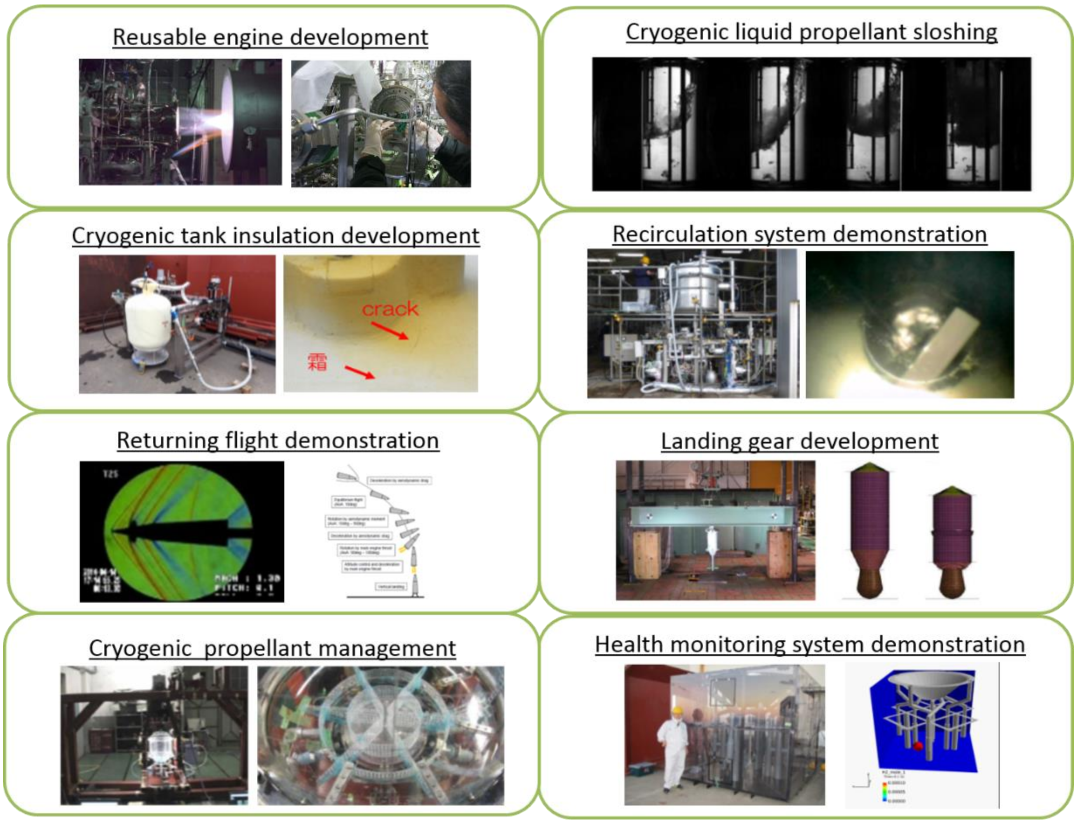

Fig 4.4 Technical demonstrations for reusable sounding rocket.

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