SSC21-S1-14

RAISE-2 for Agile On-Orbit Demonstration of Innovative Satellite Technologies: Program Strategy, Mission Definition, and Preliminary Design

Yuki Tsutsui, Kentaro Nishi, Yasuyuki Takahashi, Matsuaki Kato,
Tsuyoshi Toriumi, Yutaka Kaneko, Takanori Iwata
Japan Aerospace Exploration Agency
2-1-1 Sengen, Tsukubashi, Ibaraki, JAPAN; +81-70-1170-3369
tsutsui.yuki@jaxa.jp

ABSTRACT

The Japan Aerospace Exploration Agency (JAXA) has provided the second demonstration opportunity of the Innovative Satellite Technology Demonstration Program. In this second mission, JAXA develops the Rapid Innovative Payload Demonstration Satellite-2 (RAISE-2) that carries six components and parts as on-orbit demonstration themes. This paper presents an overview of the RAISE-2's demonstration themes, mission definition including standard platform specifications, results of Phase-A study and preliminary design.

INTRODUCTION

Since 2015, The Japan Aerospace Exploration Agency (JAXA) has been implementing a program to demonstrate on-orbit innovative satellite technologies for parts, components, and satellites developed by industries, universities, and government institutions.[1] Under this Innovative Satellite Technology Demonstration Program, a fleet of small satellites including microsatellites and CubeSats for on-orbit demonstration of satellite technologies, is launched every two years. The flagship of its second fleet is the Rapid Innovative Payload Demonstration Satellite-2 (RAISE-2), which is also called the small demonstration satellite-2.

The JAXA's System Technology Unit (STU) started concept study of RAISE-2 in early 2019 and completed pre-Phase A and Phase A studies including mission definition, conceptual design, project formulation, system definition and preliminary design in early 2020. RAISE-2 is now under development and testing of proto-flight models for this year's launch.

This paper first presents the program strategy for development and operations of a series of small demonstration satellites. Then, we show the results of mission definition and preliminary design for RAISE-2.

PROGRAM STRATEGY

JAXA has developed a program strategy including a program roadmap for the entire Innovative Satellite Technology Demonstration Program, including not only the satellite specifications but also the development process and the procurement process, in order to better reflect the purpose of the program as well as the development of RAISE-2. The three-part strategy is shown below.

a) To aim to establish a satellite bus platform with standardized interfaces to demonstration devices

We expect that this will clarify the interface with the demonstration themes, reduce the cost of design and verification of the interface, and shorten the development schedule by reducing the development risk. The following technical and process challenges are to be solved step by step in the implementation.

1. Technical Challenges

Definition of the standard satellite bus system (100 kg class, 200 kg class) and the capability to be provided to the mission.

- ✓ Definition: body-mounted SAP, nominal attitude of earth-pointing, orbital altitude range, LST range, standard interface with payloads, etc.
- ✓ Capabilities: communication system, downlink capacity, field of view, power supply, attitude change capability, operation pattern, etc.

2. Process Challenges

The proposal process for the 1st and 2nd projects was put out for public solicitation from the viewpoint of incorporating non-space technologies and institutions, and the process was to adjust the details after the selection. However, the maturity level of each applicant is different, and the situation is not consistent with the standardization.

As one of the solutions for this, it is desirable for this program to have a two-stage public solicitation process, where at the first stage, the selection including potential candidates is performed, and then, the details of the demonstration experiment and the compatibility with the standard bus I/F are discussed with the candidates between the first and second stages. At the second stage the selection is made, based on the current criterion that consists of significance and value of the mission and the compatibility with the standard bus I/F.

b) To establish a standard satellite bus and launch it continuously, aiming to be ready to implement this program through service procurement.

The service procurement here means that JAXA does not procure the development and operation of satellites and ground systems but procures the services to provide on-orbit demonstration data. By this procuring services, JAXA's resources in the development phase of this program will be allocated to the front-heavy activities and the company side will be matured. In addition, we will consider transferring the on-orbit technology demonstration using the standard bus to an external organization in the future. There are following contractual issues to be considered for the realization of the program, which will be discussed during the program execution.

- ✓ Concept of risk-bearing and risk-hedging methods
- ✓ Concept of payment in service procurement

c) To aim to increase its value as a demonstration environment by improvement of the bus capability as a small satellite.

In order to achieve this goal, we will identify and promote R&D items to improve the on-orbit technology demonstration capability of the satellite bus while standardizing the satellite bus system of the program. In the future, we aim to bring this satellite into a small satellite system comparable to other competitive services.

MISSION DEFINITION

Demonstration Themes

RAISE-2 has its role of carrying six components of demonstration themes to low Earth orbit (LEO) and providing suitable environment and operations for their on-orbit demonstrations. Table 1 lists the six of demonstration themes. These themes were proposed to and selected through the program committee.

Table 1: Demonstration Themes

Name (acronyum)	Institution
COTS micro-processor board SPRESSENSE™ for Space (SPR)[2]	Sony Semiconductor Solutions Corporation
Closed-loop Interference Fiber Optic Gyroscope (I-FOG)[3]	Tamagawa Seiki Co., LTD
3D-printed Antenna (3D-ANT)[4]	Mitsubishi Electric Corp.
Advanced Thermal Control Device (ATCD)[5]	Tohoku University
MEMS Advanced Redundant Inertial Navigation system (MARIN)[6]	JAXA
Small Star Tracker Amanogi Star Compass (ASC)[7]	Amanogi Corp.

Mission Preconditions

Major preconditions of the RAISE-2 mission are listed in Table xx. This 110kg satellite with a rectangular parallelopiped shape of 0.75 to 1 m sides will be launched into a Sun-synchronous orbit of 560 km altitude in JFY(Japanese Fiscal Year) 2021, and will be operated over 13 months. RAISE-2's predecessor in the Innovative Satellite Technology Demonstration Program is RAPIS-1, the Rapid Innovative Payload Demonstration Satellite-1, which was a 200 kg satellite launched in January 2019. Due to this mass and size difference, RAISE-2 is designed as a new satellite.

Table 2: Mission Assumptions

Item	Assumption
Launch date	FY2021 (Planned)
Launch vehicle	Epsilon Rocket
Orbit	560km Sun-synchronous orbit Local Sun Time: 9:30
Mission period	Commissioning phase: 1 month Operation phase: 12 months
Fairing Envelope	1m, 0.75m, 1m (at launch)
Mass Limit	110kg

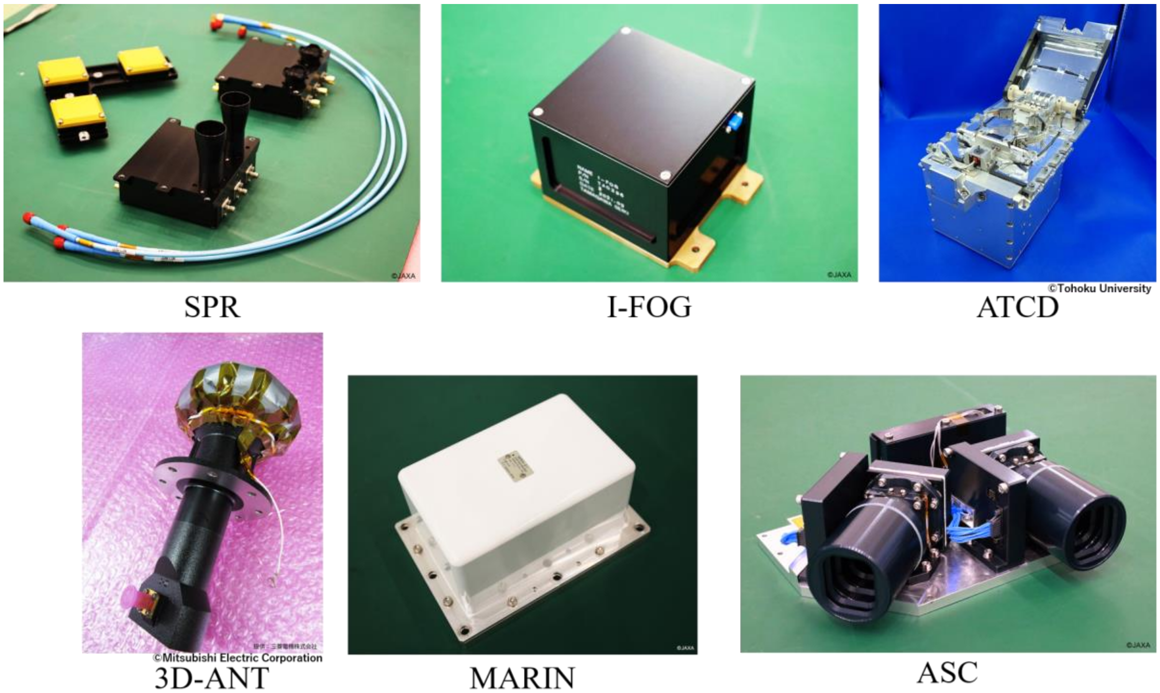

Figure 1: Demonstration Components

(https://www.kenkai.jaxa.jp/kakushin/kakushin02.html)

PHASE-A STUDY

JAXA's phase-A starts with Mission Definition Review (MDR) and ends with System Definition Review (SDR). Between the two reviews, we preform conceptual design, System Requirements Review (SRR), request for proposal to determine a satellite prime contractor, project formulation and preliminary design. In the conceptual design phase, mission feasibility is confirmed and system requirements are derived through conceptual design by JAXA and candidates of satellite prime contractors. In parallel, it is essential to derive and verify interface specifications between demonstration components and satellite platform from the perspectives of mechanical, thermal, electrical, data handling, and mission operations and so on.

Then, in the project formulation phase, JAXA selects one satellite prime developer through RFP process and authorizes project baselines including schedule and budget through SDR and Project Approval Review.

In the following, we show how JAXA has managed this project inthree perspectives:

Stakeholder Communications

One of a challenge on this program is how could JAXA raise their technical maturity of demonstration plans. A reason of this challenge is that this program is set on a high-level context which is to promote new players to join the space industry. So that, the proposers are not always institutions that are well-skilled in developing equipment for space.

To deal with this situation, JAXA has held almost bi-weekly meeting for six of each institution to explain our design standard policy, mission assurance, and systems engineering process. As a result, we reached agreement on the interface conditions that would be sufficient by the time of the MDR.

Through these efforts, we compiled an interface condition document that can be applied in the next project. This will contribute to ensuring a sufficient level of maturity at the time of demonstration theme proposal.

JAXA Coordination

As Japanese space agency, JAXA has a role of maximizing the mission outcomes for domestic industry.

To accomplish this purpose, we had decided to carry out initiatives that will contribute to increasing the value of the program by bringing JAXA's cutting edge technologies into the mission.

As a result of coordination, we have agreed with stakeholders to combine our two innovative technologies in the following.

1. Gallium-Nitride power controller (GaN-BCR)

This performs MHz order power switching, then realize higher power efficiency which means lower power loss, smaller mechanics, and lighter weight. It is planned to be demonstrated by operating with JAXA prepared battery.

2. Variable coding modulation transmitter (VCM)

To improve mission data down link throughput, this transmitter changes to the optimal coding modulation depending on link quality which varies by distance, elevation angle, and climate every moment. It is planned to be demonstrated by operating with 3D-ANT.

Since these new technologies are general-purpose for satellite platforms, they are expected to be used not only for the standard platform of this program but also for future satellites to be developed by JAXA.

Standard Platform Specification

To be clear again, this innovative technology demonstration program provides an opportunity to demonstrate new components proposed by a variety of institutions every two year. However, not only to satisfy with their needs, but also to improve JAXA’s small demonstration satellite platform is essential matter of this mission. For this motivation, we started to establish a strategy of how to command this program on the long-term perspective. In addition, we have refined this strategy and created criteria and policy for standard specifications and development processes for small demonstration satellite series. A summary is given below.

a. Development of standard specifications and policies for small demonstration satellite series: payload electrical/data/mechanical interface, mission operations and design standards.

b. Development of standard development process: full EM testing requirement for components without flight heritage equivalent to this mission, system EM electrical testing requirement involving all components, system STM testing requirement involving all components and so on.

PRELIMINARY DESIGN

System Overview

The following figures and table show results of preliminary design for RAISE-2 system.

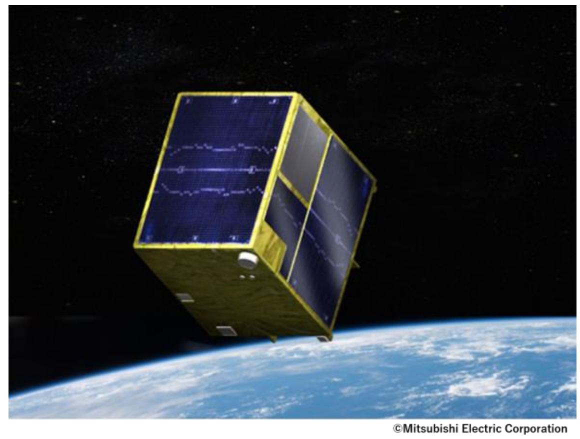

Figure 2: RAISE-2 Overview (1)

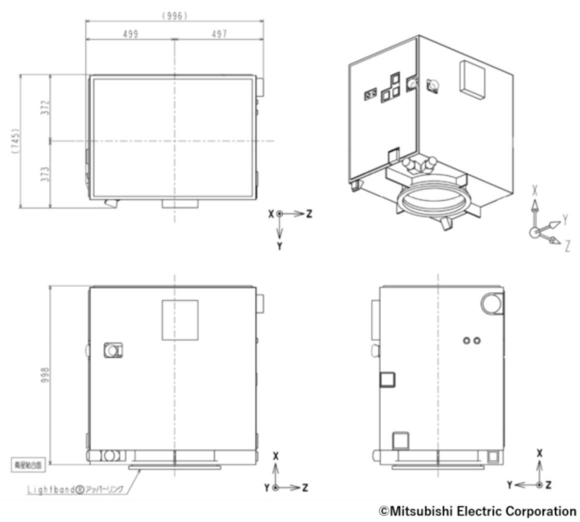

Figure 3: RAISE-2 Overview (2)

Table 3: RAISE-2 Design Results

Item	Assumption
Size	0.996m×0.745m×0.998m
Mass	107.6kg
Power	body mount SAP 215W (BOL) 180W (EOL, minimum β angle)
Attitude	Nominal: 3-axis Earth pointing
Communication	TTC: S-band Mission data downlink: X-band
Thermal Control	Passive and system heater control

Payload Mass Capacity	More than 23kg
Payload Area Capacity	More than 2.5m^2 (footprint)
Payload Data Throughput Capability	More than 900MB/day
Payload Power Interface	5V, 12V, 28V
Payload Signal Interface	RS422, LVDS, 1553B, Spacewire Various analog interfaces

System Analysis

In order to confirm the feasibility of the system specifications in the previous section, a series of system analyses were executed. In this section, we give an overview of these analyses.

a. Orbit Analysis

RAISE-2 is not capable of maintaining its own orbit due to a lack of thrusters. Therefore, the orbit drift by various perturbations becomes significant. It is mainly evaluated by beta angle defined as angle of Sun direction to orbit plane. Orbit analysis conditions and results are shown below.

Table 4: Orbit Analysis Summary

Item	Value
Insertion Orbit Including error	Altitude: 560±10km Inclination: 97.6±0.2deg Local Sun Time: 9:30±10min
Analysis period	13 months
Perturbation	Earth gravity potentials, tidal force, third-body gravity Airforce drag, Solar radiation pressure
Result	Beta angle: 23.2~49.5deg

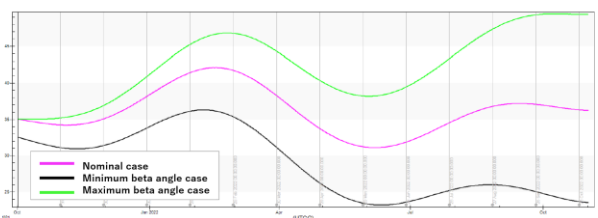

Figure 4: Orbit Analysis

b. Power Analysis

Using the results of the orbit analysis, a power analysis is performed. The main point is to confirm that power balance is satisfied under the most critical conditions whichtake into account the attitude variation and the high-load operation mode. It is confirmed that there is a sufficient margin in the battery capacity, and it recovers completely after a few orbits.

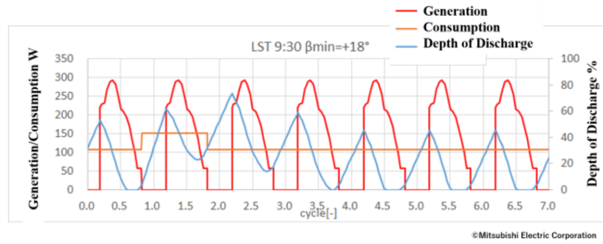

Figure 5: Power Analysis

c. Communication Analysis

We assume that our ground station consists of one domestic primary station and one secondary station as a redundant system. The following figure and table show the results of the coverage analysis with the primary ground station and available communication time.

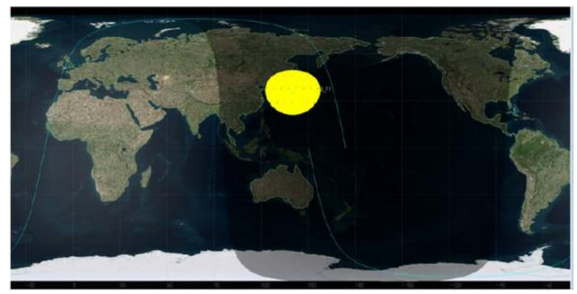

Figure 6: Orbit Analysis

Table 5: Communication Analysis Summary

Item	Value
Average duration/pass (including operational constraints and margin)	408.2 sec
Average number of passes/day	2.77

d. Data Transmission Analysis

In this section, we estimated the required data rate for the amount of data generated by the bus system and the mission system of RAISE-2, based on the results of the communication analysis.

Table 6: Data Transfer Analysis Summary

Item	Value
Data generation (Bus)	250 MB/day
Data generation (Mission)	350 MB/day
Required data rate	15.6 Mbps

From this analysis, it was confirmed that the link quality could be secured for the X-band communication system. Another link, TTC link of S-band is also confirmed by the similar analysis.

e. Structural Analysis

RAISE-2 is a box-shaped structural model made of aluminum alloy panels and CFRP panels and has some internal deck panels. The launch vehicle imposes interface conditions regarding load conditions and limitation of first-order eigenvalue range. We have confirmed their feasibility to these conditions by FEM structural analysis.

f. Thermal Analysis

For the thermal design of RAISE-2, the panels on each outer surface will be basically insulated with MLI. In addition, some of the surfaces facing the deep space direction have heat radiating surfaces, and these will stabilize the heat balance. As a result of thermal analysis, it was confirmed that all components and parts could be kept within the allowable temperature range. Also, RAISE-2 has a system heater capacity of about 20 W maximum for some cold conditions.

g. Field of View Analysis

RAISE-2 has some components requiring field of view (FoV) required such as star trackers, RF antennas, sun sensor, and so on. Not only bus components but also some of mission components have FoV requirements. We confirmed that RAISE-2 does not have any structures that would block their FoVs, such as deployable paddles, so that each component would have a sufficient field of view. After confirming the feasibility of the system through these analyses, JAXA has completed SDR.

LESSONS LEARNED

From the activities of the RAISE-2 project to date, several Lessons Learned have been derived for the next project. Among them, two key lessons are discussed below.

- ✓ Necessity of clarification regarding interface conditions for demonstration themes:

As mentioned in the section on Phase-A study, in order to complete the coordination with many stakeholders in a limited period of time, we decided to create a standard interface conditions document and apply it to the next project. In fact, this has been utilized in the RAISE-3 project and has been effective in shortening the coordination period.

- ✓ Necessity of MBSE in systems analysis:

In order to carry out a Phase A study for a newly developed satellite in a short period of time, it is necessary to practice systems engineering based on information and ideas without any conflicts or inconsistencies in various analyses and documentation. To deal with this issue, we have been studying the methodology of Model-Based Systems Engineering (MBSE). In the RAISE-3 project, the results of this study are utilized to digitize the development process as a trial phase.

CONCLUSION

In this paper, we have introduced the RAISE-2 mission definition to preliminary design. As a result of those steps, the project has passed a series of reviews and was approved to transfer to an implementation phase. After it completed a series of development tests, the RAISE-2 is now undergoing proto-flight tests and verifications for a launch this year.

REFERENCES

1. Kaneko. Y., et al. “Overview of the Innovative Satellite Technology Demonstration Program”, Proceedings of the 64th Space Sciences and Technology Conference, 3C05, Online, 2020 (in Japense).
2. Ota. Y., et al. “Sony’s SPRESENSE™ with an ultra-low power multicore processor to try a challenge to dive into the space”, Proceedings of the 63th Space Sciences and Technology Conference, 3K08, Tokushima, 2019 (in Japense).
3. Matsumoto. T., et al. “Demonstrations of Closed-loop Interference Fiber Optic Gyroscope on LEO”, Proceedings of the 64th Space Sciences and Technology Conference, 4C08, Online, 2020 (in Japense).
4. Miura. K., et al. “Orbital evaluation plan of 3D-Printed Antenna”, Proceedings of the 64th Space Sciences and Technology Conference, 4C09, Online, 2020 (in Japense).
5. Nagai. H., et al. “On-orbit demonstration of lightweight, powerless high-performance thermal control devices (2)” Proceedings of the 64th Space Sciences and Technology Conference, 4C10, Online, 2020 (in Japense).
6. Komiyama. M., et al. “Study of Orbital Demonstration Plan for Redundant MEMS IMU (MARIN)” Proceedings of the 64th Space Sciences and Technology Conference, 4C11, Online, 2020 (in Japense).
7. Kudo. Y., et al. “Space Verification of Domestic Low-Cost Star Tracker for CubeSat”, Proceedings of the 63th Space Sciences and Technology Conference, 3K10, Tokushima, 2019 (in Japense).