Concept Design and Development of 30kg Microsatellite HIBARI for Demonstration of Variable Shape Attitude Control

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ABSTRACT

We are developing a 30kg class microsatellite "HIBARI". The main technical missions for HIBARI is demonstration a novel attitude control method called "Variable Shape Attitude Control (VSAC)" proposed by Matunaga, Tokyo Institute of Technology. This VSAC is based on an idea to utilize a reaction torque generated by changing the shape of satellites, for example driving solar array paddles by actuators. HIBARI is planned to be launched within a few years under "Innovative Satellite Technology Demonstration Program" led by Japan Aerospace Exploration Agency (JAXA). We designed the concept of HIBARI and describes those in this paper. Specifically, we confirmed the validity of the mission and system, and selected equipment based on radiation tolerance tests and orbital results in the past. Currently we are making Breadboard Model and checking its operation. We plan to develop Engineering Model and Proto-Fright model and conduct various ground tests this year, and proceed to Fright Model next year.

INTRODUCTION

In recent years, with the advancement of performance and miniaturization of devices, the micro/nano satellites and CubeSats have become higher specs, and their missions have diversified. However, there are limitations in performance due to size and power constraints. In particular, it is an attitude control system and an optical system. This is because of the difficulties to mount Control Moment Gyro (CMG), thrusters and large aperture lenses. In addition, the attitude stability against disturbance is lower than that of large satellites in terms of moment of inertia. In this manner, there is a limit to the requirements that can be met by micro/nano satellites and CubeSats at present, and new systems for those are needed to achieve further advancement. Matsunaga, Tokyo Institute of Technology focused on changing the shape of the satellite, and proposed a novel method of attitude and orbit control.[1,2,3] And we are currently developing a technical mission satellite HIBARI that demonstrates this control method.[4,5] This satellite is planned to be launched within a few years by the Epsilon Launch Vehicle under the "Innovative Satellite Technology Demonstration Program" led by Japan Aerospace Exploration Agency (JAXA).

The significance of changing the shape of the satellite can be roughly divided into two. The first is that attitude control is feasible using the counter torque associated with changing the shape of satellites, for example driving solar array paddles by actuators. This attitude control is called variable shape attitude control (VSAC). Figure 1 shows this concept. Since this method changes the relative position of a part of the system, it has been shown that attitude maneuver can be made quickly and energy-efficiently compared to Reaction Wheel (RW) and CMG.

The second significance is that trajectory and attitude control using external force and external force torque such as solar radiation pressure and aerodynamic force can be performed by adjusting the projection area by shape change. For example, the orbital velocity can be finely adjusted and the phase can be controlled by changing the aerodynamic force in a low earth orbit. In addition, external force torque can be generated in the desired direction by the satellite shape, and it can be used for angular momentum desaturation such as RW.

The driving object for variable shape of this satellite is a solar array paddle that efficiently applies the EPS system to attitude control. In this manner, the satellites enable to save space and power by realizing multiple functions with one actuator, leading to cost reduction and high specs of them. Although mission of this HIBARI is demonstration of this control method, in HIBARI project, we aim to conduct an astronomical observation for transient object of gravitational wave sources. This paper describes the mission outline, system, and development status of the HIBARI.

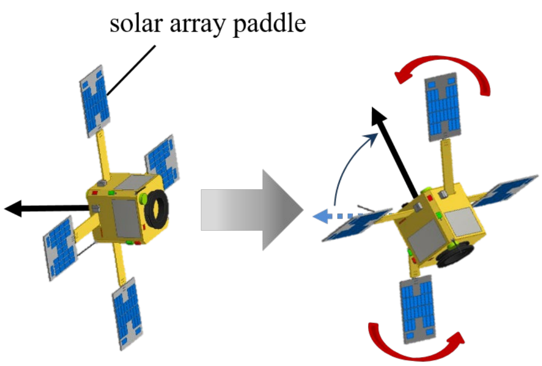

Figure 1: Concept of VSAC

MISSION

As mentioned above, the significance of changing the shape of the satellite is twofold. This time, we focused on VSAC and defined the success criteria as shown in Table 1. In the minimum success, the motor drives the paddle to actively change the shape of the satellite, thereby confirming that the attitude changes. Highly accurate STT and gyro sensor are used to confirm this attitude change.

In full success, we confirm the agility of VSAC. The performance target is 40deg / 20sec. This is equivalent to CMG used for agile maneuver, which is referred to the one mounted on 50kg class microsatellites.

For extra success, we will target 40deg/10sec, which doubles the agility of full success. We also demonstrate attitude control using non-holonomic properties. With non-holonomic properties, before and after attitude change, the angular momentum is preserved at 0 and the satellite shape does not change, but the attitude can be changed from point of view of the inertial system. For example, by driving the paddle in order as shown in Figure 2, the attitude can be changed without changing the satellite shape. Arbitrary three-axis maneuver is possible by using this method. In addition, as a control performance, we set the attitude stability as a target. This is for astronomical observation missions that require agility and high stability in the next project. The numerical value is set to 300arcsec/10sec in consideration of the specifications of the attitude determination system. First, the stability is evaluated only with VSAC, and then it is evaluated combining with RW. Telephoto camera is also used to evaluate stability in addition to STT and gyro sensor. Stars are captured by this camera, and a minute attitude change is detected by the shake and extension of the stars image.

Furthermore, for extra success, we set trajectory / attitude control demonstration by external force, which is the second of the significance of satellite shape variable. However, these are done after the VSAC experiment is over. GPS information is used to evaluate trajectory changes.

Table 1: Success criteria

Level	Mission
Min.	• Confirmation of attitude change by variable shape function
Full	• performance evaluation of VSAC ○ target agility: 40deg/20sec
Extra	• performance evaluation of VSAC ○ target agility: 40deg/10sec ○ target stability: 300arcsec /10sec • confirmation of attitude control using non-holonomicity • confirmation of trajectory / attitude change with controlled atmospheric resistance

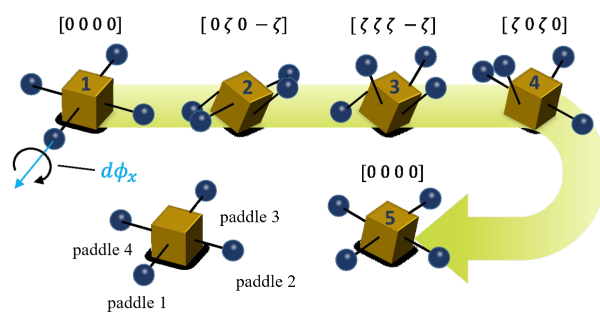

Figure 2: Non-holonomic Attitude Control

Figure 3 shows the mode transition of HIBARI, and Table 2 shows the equipment used by mode. The satellite first enters critical mode after rocket release. Figure 4 shows sequence of this mode. First, MTQ is used to reduce the angular velocity at the time of rocket discharge, and then the satellite body is stable in the spin state to point the sun direction. The spin stable state is maintained until the power stabilizes, and each device such as communication and cameras is checked out followed by deploying the paddles. The paddles are deployed one by one, which is confirmed by each wide-angle camera on the side panel of the satellite. The spin stable solar pointing control by this MTQ is assumed to be the nominal mode of HIBARI. However, the nominal mode after RW driving is 3-axis stable sun pointing by it.

In the mission mode, VSAC experiments are conducted. At first, we confirm the agility, stability and non-holonomicity of extra success with only VSAC. After that, we start driving RW and evaluate attitude control using VSAC and RW together. These experiments are performed in the shade to ensure the accuracy of STT.

When a power shortage or unexpected attitude is detected during the nominal or mission mode, the system enters the safe mode with no control to minimize power consumption. And the main CDH performs processing according to the error and copes with the problem by switching to the critical mode again.

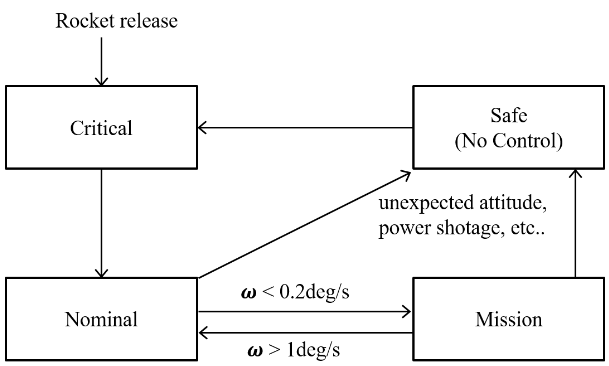

Figure 3: Attitude Control Mode Transition

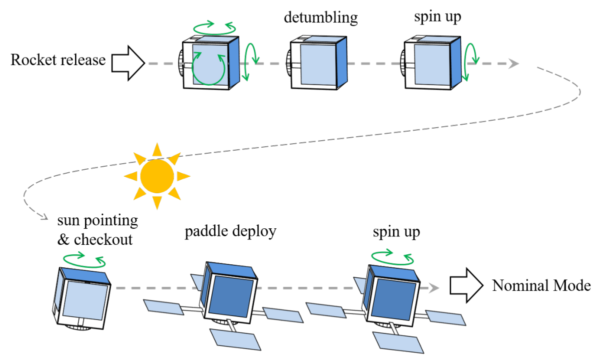

Figure 4: Sequence of Critical Mode

SYSTEM

In this section the system of HIBARI and each subsystem are described. The subsystems include CDH (Command & Data Handling), COMM (Communication), ADCS (Attitude Determination & Control System), EPS (Electric Power System), Camera system, and Structure & Thermal. The system diagram is shown in Figure 5.

A microcontroller showing 'each subsystem CDH' in Figure 5 is prepared in each subsystem to monitor the system, and the main CDH monitors the microcontrollers. This is to reduce the load on the main CDH and improve the reliability of each subsystem. For each CDH, microcontrollers are selected due to the high radiation tolerance.

Figure 6 shows the overview of HIBARI. The satellite sizes 450 × 450 × 500 mm, which can envelop in the Epsilon Launch Vehicle. The mass of the satellite bus unit is 25 kg. The satellite has 4 paddle units and this is 2.5 kg per one.

Table 2: Equipment Used for Each Mode

Mode		Sensor					Actuator		
		SAS (Sun Sensor)	GAS (Geomagnetic Sensor)	Gyro	STT (Star Tracker)	GPSR (GPS Receiver)	MTQ (Magnetic Toruque)	RW (Reaction Wheel)	Paddle
Critical	Detumbling		○	○			○		
	Spin up		○	○			○		
Nominal	① sun-pointing with MTQ spin-stabilization	○	○	○		○	○		
	② sun-pointing with RW 3 axis-stabilization	○	○	○	○	○		○	
Mission	① VSAC	○	○	○	○	○			○
	② VSAC + RW	○	○	○	○	○		○	○
Safe		○	○	○					

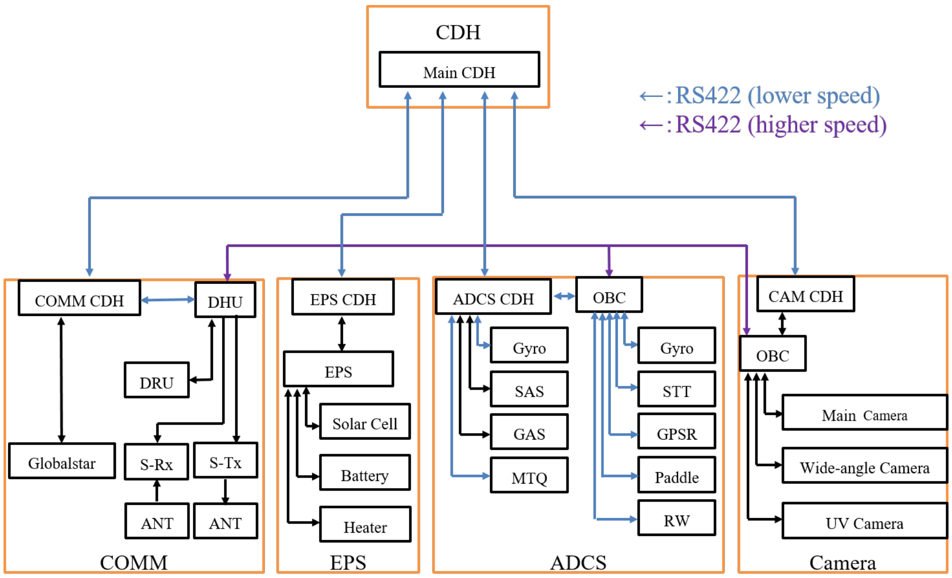

Figure 5: System Diagram

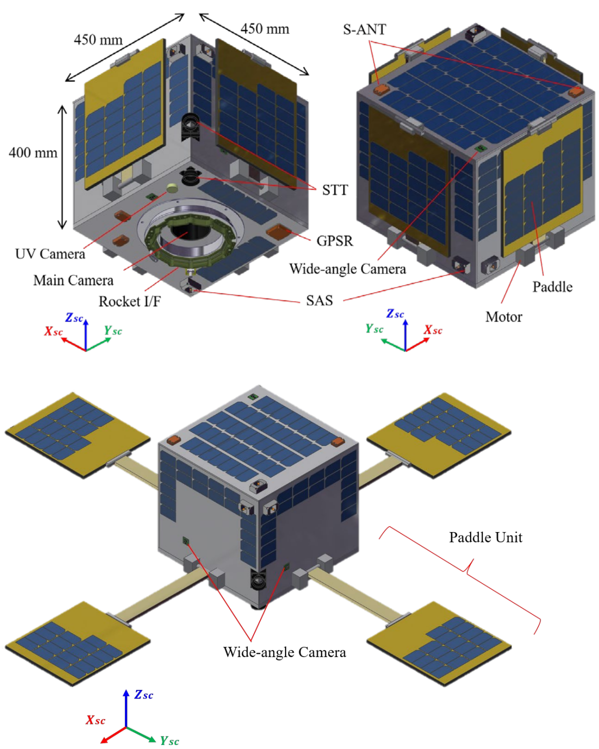

Figure 6: HIBARI Overview

CDH & COMM

The main CDH performs monitoring of each subsystem, management of operation mode, and processing of command / telemetry. When the main CDH detects an error, it switches to the operation mode. It also manages time of satellite, and synchronizes periodically with the CDH of each subsystem.

There are two types of communication devices, S-band and Globalstar communication. The S band is used as a nominal communication system, receiving commands from the ground, and transmitting HK and experimental data to the ground. In order to establish communication with the ground even in any attitude, the satellite is arranged with an antenna that can cover the whole sky, considering the antenna pattern and their location. In addition, the receiver is always turned on so that commands can be received even when emergency. Globalstar is used for demonstration of real-time communication with the ground for next project astronomical observation.

ADCS

The ADCS consists of a coarse attitude system based on high reliability CDH and a fine attitude system based on OBC that can be operated at high speed. The coarse attitude system is used when the reliability is required in the critical mode or the safe mode, or used for backup of the fine attitude system. The fine attitude system is used during missions where accuracy is required. Even if the OBC in fine system freezes, the coarse attitude system functions as a backup, and it is designed to be able to reboot the OBC.

Also, although the data in ADCS is primarily processed as telemetry via CDH, a higher speed communication line is separately prepared (purple line in Figure 5), which can flow directly to the COMM system in order to transmit a huge amount of data at the mission period.

EPS

EPS manages the power of the system. Table 3 shows the power consumption by each mode. The orbit is a sun synchronized orbit with altitude of 500 km and 60 minutes of sunshine. Based on this table, solar cells are arranged so that sufficient power can be generated when they are directed to the sun, and the power balance become positive regardless of the satellite attitude in the safe mode. In addition, a 160Wh battery is mounted so that power is not depleted during the initial critical mode until sun pointing and during missions. In addition, EPS detects the over current of CDH of each subsystem, and is responsible for power off and reboot.

Table 3: power consumption

	power consumption [W]					
	Detumbling/ Spin up	Nominal ①	Nominal ②	mission ①	mission ②	safe
CDH & COMM	5.3	5.3	5.3	5.3	5.3	5.3
ADCS	3.1	8.3	10.8	22.6	23.7	2.7
EPS	1.1	1.1	1.1	1.1	1.1	1.1
Camera	0	4.2	4.2	8.2	8.2	0
Total	9.5	18.9	21.4	37.2	38.3	9.2

Camera

Camera System has three kinds of cameras, a Main Camera, Wide-angle Cameras, and a UV Camera. Table 4 summarizes each Field of View (FoV), number of mounted, and usage. The Main camera is used for observation of the earth and astronomical objects at nominal mode. Also, during the stable attitude control mission, this camera is used to capture stars and evaluate stability. The wide-angle camera is mounted on each of the six panels of the satellite and take images of paddle deployment and drive. this camera is also used as a 3-axis attitude determination earth sensor by taking the edge of the earth. We are developing and on-orbit demonstration of a 3-axis attitude determination earth sensor using this wide-angle camera and image identification technology.[7-10] The UV camera is demonstrated on-orbit for the future observation missions gravitational wave source.

Since the Camera system also has a large amount of data, a separate higher speed communication line is prepared.

Table 3: specifications of Camera System

Camera	FoV[deg × deg]	Number	Usage
Main	8.2×5.4	1	• observation of the earth and astronomical objects • evaluation of attitude stability
Wide-angle	62.2×48.4	6	• capture paddle deployment and drive • determination of 3-axis attitude by using as earth sensor
UV	8.4×6.4	1	• Demonstration for future observation missions

Structure & Thermal

The thermal structure system is designed to meet the arrangement requirement and heat requirement of each component and vibration requirement at the rocket launch. Also, the paddles should be designed to meet the agility requirements of VSAC experiments. For this purpose, it is necessary to increase the moment of inertia of the paddles, for example, by lengthening the paddles or increasing the mass of paddles. In HIBARI, the paddle length is increased by using a hinge and the weight of the tip is added to increase the inertia of the paddle. The paddle deploying sequence is shown in Figure 7. The paddle is first deployed 180 degrees by spring hinges and fully deployed by motors. Also, the power line of the paddles is routed with a margin enough to drive the paddles.

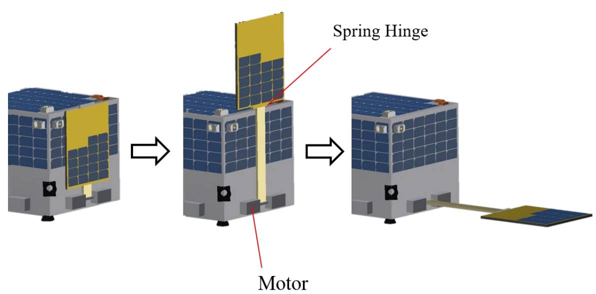

Figure 7: Sequence of Paddle Deploying

DEVELOPMENT PLAN

The development schedule is shown in Figure 7. We are currently developing and testing Breadboard model (BBM). As a next step, we solve problems in BBM except Structure & Thermal system, develop Proto-Fright Model (PFM), and conduct electrical tests and environmental tests with each component. In addition, the operation test of software model for the ADCS system is performed. Structure & Thermal system is planned to manufacture in the stage of Engineering

Model (EM) and carries out a vibration test of the case and paddles. As a test of the paddle driving mechanism, a deployment test and a drive test using an air levitation device are performed.[6] Afterwhile, we perform thermal vacuum tests by combining with the thermal model of each component. Finally, we plan to develop FM and conduct each environmental tests and long-term End to End test.

CONCLUSION

We are developing a 30kg microsatellite “HIBARI”, which demonstrate a novel attitude control method called VSAC. This paper described the mission and concept design of HIBARI. HIBARI is planned to be launched within a few years. Currently in the BBM development phase, we plan to develop PFM this year and FM development next year.

ACKNOWLEDGMENTS

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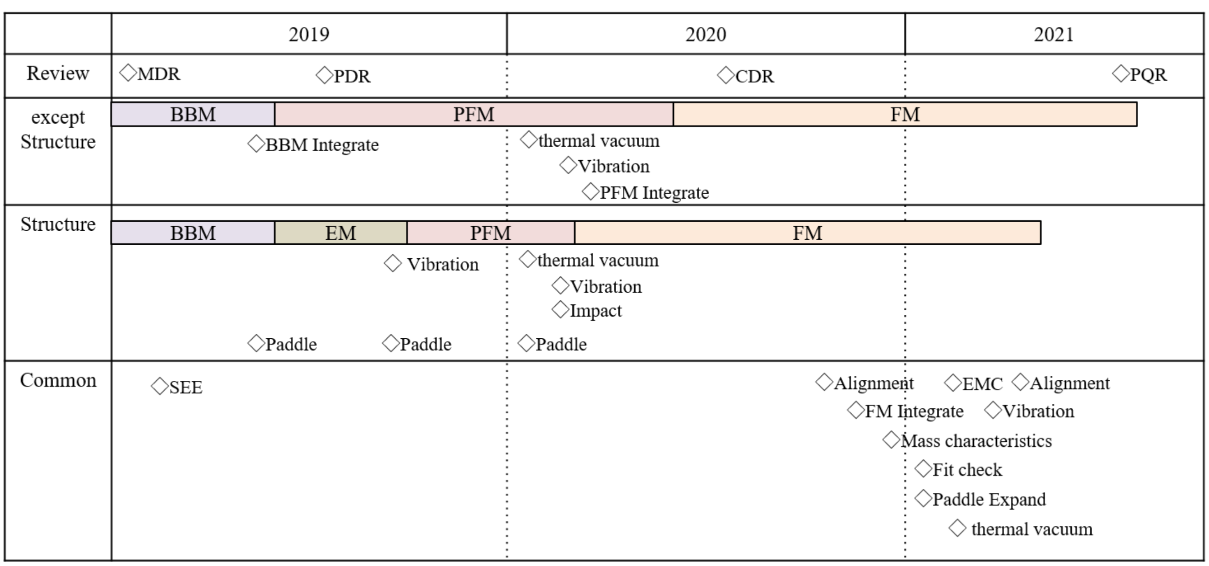

Figure 7: Development schedule

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