ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

DEVELOPMENT OF SPACE BOOM FOR MICRO-SATELLITE: DESIGN OF HINGE AND DYNAMICS OF BOOM

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Abstract

The paper describes design and dynamics of a space boom for a 50 kg-class micro-satellite, code-named as SOHLA-1. The length of the boom is 425 mm and the mass 279 g. The paper reports mainly the development of deployable hinge and arm of the space boom, and the corresponding dynamics and vibration test. Function of the hinge is to deploy the arm and make final rock after deployment. Aim of the paper is to demonstrate how vibration test was vital in developing a space boom to be installed in a real micro-satellite. As the satellite is a kind of piggy-back satellite, the overall dimensions are restricted within a cubic space of 0.5 m x 0.5 m x 0.5 m. The geometrical restriction eventually gives a hard constraint in designing the space boom to support a magnetic sensor and a monitor micro-camera of 100 g. The most interesting point of development of the present boom comes to the fact that designing, machining, assembling and testing should be done by university students throughout development process. Firstly, a conceptual design of the boom is described. Every part of the boom was machined by NC machines operated by students to make a bread-board model (BBM). Deployment test showed that the design was basically well done. However vibration test of the boom BBM revealed some ill-designed aspects of the model. The design was revised to have an engineering model (EM). The boom EM was subjected to qualification test on a shaker bed. The test results suggested some refinements to be done for proto-type model (PM).

INTRODUCTION

A group of medium and small-sized industrial enterprises over Higashi-Osaka Area in Japan organized a challenging association called “SOHLA”, Space Oriented Higashi-Osaka Leading Association, to develop civilian and possibly commercial micro-satellite. JAXA, the Japan Aerospace Exploration Agency, supported SOHLA and transfered its micro-satellite technology [1, 2, 3] to SOHLA, on the condition that the technology could be transfer also to some universities to enhance technical education and thus foster creative engineers. Thus SOHLA-1 project is on one hand a student-based project [4].

The first phase of the SOHLA project started in 2004 to develop a 50 kg-class micro-satellite “SOHLA-1”. The primary mission of SOHLA-1 is to master how to develop a micro-satellite, having its master model “Micro-LabSat” developed by NASDA (at present JAXA) and launched in 2002. SOHLA-1 is a piggyback satellite, which is planned to be launched as a secondary payload by a Japanese heavy launcher H-IIA in 2007. Main specifications of SOHLA-1 are as follows; Dimensions/maximum volume: W500 x D500 x H500 mm, Mass: 50 kg +10 kg, Orbit: Sun-synchronous orbit, Altitude: 700 km. Two booms are planned to be installed in the micro-satellite, one for a magnetic sensor and the other for a monitor camera. Figure 1 shows an image of SOHLA-1 in service in space.

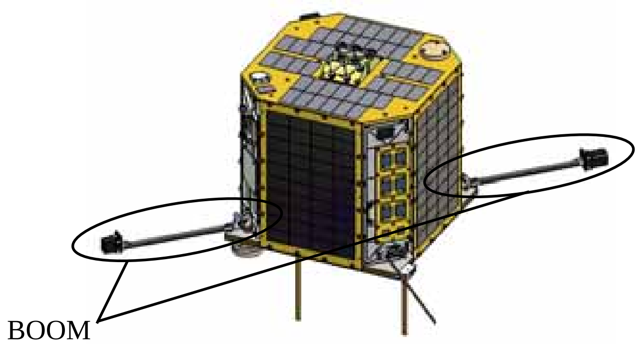

Figure 1 – Image of SOHLA-1

A team of students at Ryukoku University has been responsible to developing the booms to be installed in SOHLA-1.The most interesting aspect of the present development of the booms is that, including designing, machining, assembling, and qualification testing et, everything throughout the development of the boom shall be done by undergraduate and master-level students at Department of Mechanical and Systems Engineering, Ryukoku University, under the guidance and technical advices given by JAXA. Students machined all components by their hands at Digital Creation Hall in Ryukoku University. In this sense the present booms can be called exactly a hand-made space boom. As to verification testing, deployment test, vibration testing and thermal vacuum test are included, together with vibration and thermal simulation by using NASTRAN and related soft-ware.

DEFINITION OF BOOM

Boom is defined as a deployable beam to support a mission component apart from the main body of a satellite. Figure 2 depicts a conceptual sketch of booms.

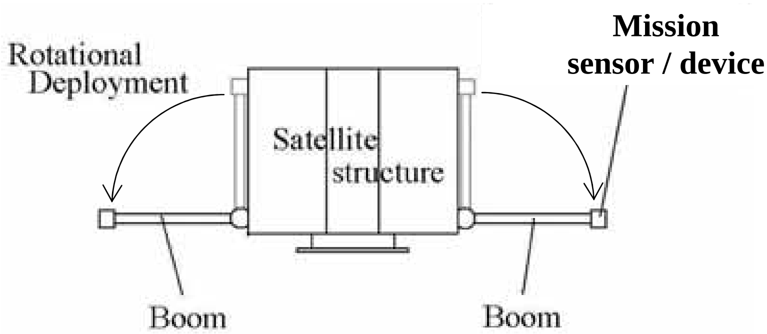

Figure 2 – Conceptual sketch of booms

A boom must be harnessed and locked firmly during launching (launch-lock). On orbit, the boom is released to deploy and latched finally to support a mission device apart from the satellite. Thus the main elements of a boom are a hinge, an arm and a pin-puller. Figure 3 shows the components of the boom. It is noted that the satellite is so small that there are inevitably severe geometrical constraints in designing the boom.

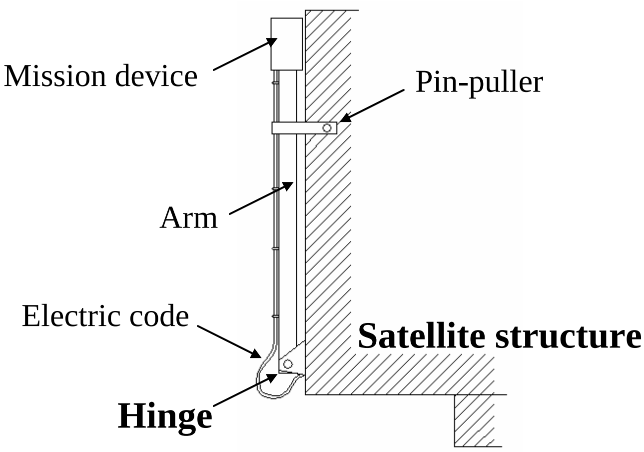

Figure 3 – Elements of boom

FLOW OF DEVELOPMENT

Figure 4 shows a flow-chart of development of the space boom. Starting from Bread board model (BBM), an engineering model (EM) was designed to conduct many engineering verification tests mainly on vibration test. Currently, proto-type model is under development followed by a flight model to be launched in space.

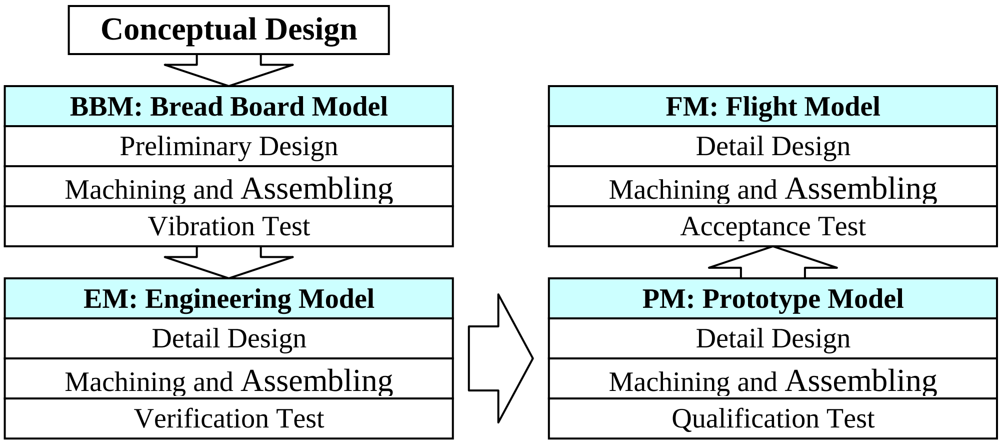

Figure 4 – Flow of development

REQUIREMENTS AND CONSTRAINTS

Primary and secondary requirements are as follows:

Primary requirements;

1) Reliable launch-lock
2) Reliable release, deployment and final latch

Secondary requirements;

1) Low impact to the satellite body after deployment
2) Light-weightedness
3) Synchronous deployment of two booms
4) Survivability under mechanical environment during launch
5) Survivability under space environment, e.g. thermal environment
6) Accurate deployment angle

There are geometrical constraints to the boom as follows:

1) Boom in launch-lock configuration can be settled inside the maximum volume of 0.5 x 0.5 x 0.5 m.
2) Boom should not interfere in the satellite body.

Figure 5 sketches an enveloped space allowed to the present booms.

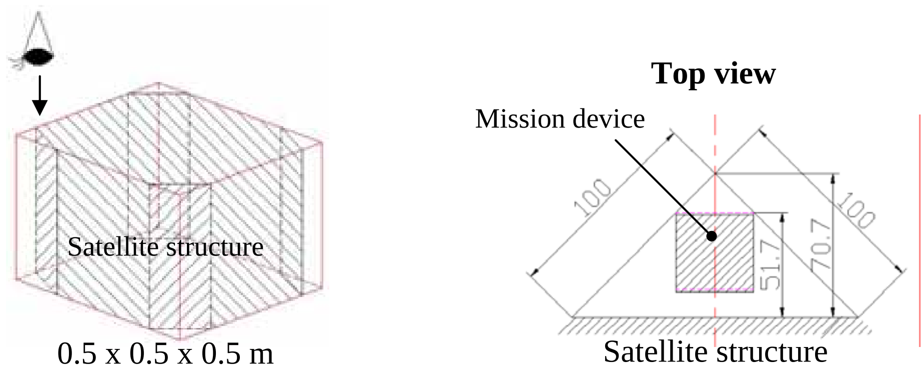

Figure 5 – Allowable envelope for boom

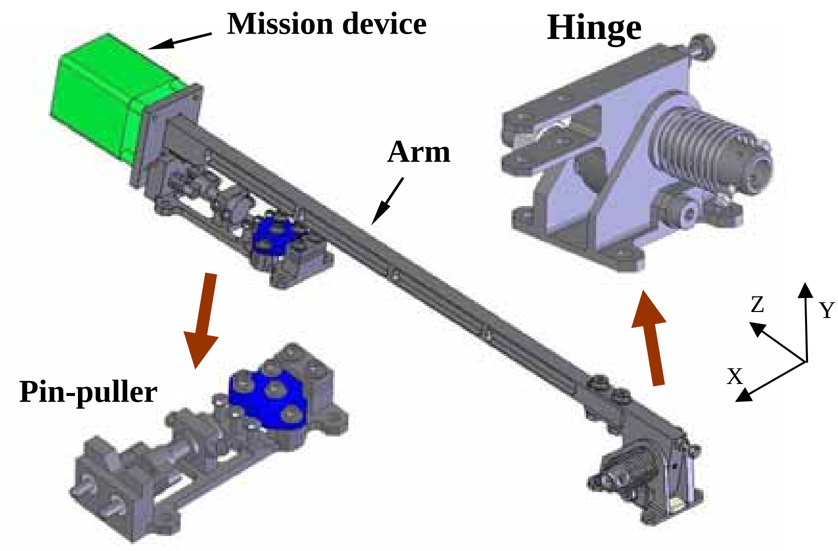

Figure 6 – Exploded view of boom EM.

DESIGN OF HINGE EM

The hinge is accommodated with an elastic rotational spring as an actuator to deploy the arm. Final latch after deployment is done by using a lock-pin which is realized by a spring-plunger available on commercial market. A PTFE (polytetrafluoro ethylene) bush is used for space lubrication.

A rubber stopper with high damping ability was installed to reduce impact of the arm end to the body. Figure 7 shows photographs of the hinge EM. Figure 8 shows a photograph of the boom EM in launch-locked configuration.

The main specifications of the boom EM are as follows; Mass of the boom: 279 g, Mass of the mission component: 100 g, Size: L0.425 x B0.073 x H0.050 m.

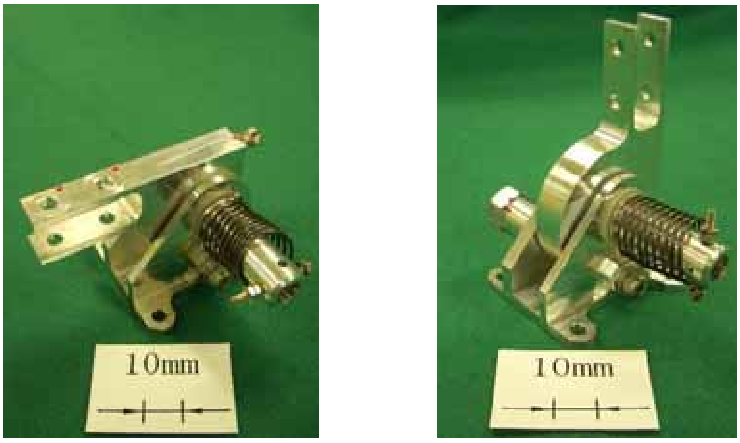

Figure 7 – Photograph of hinge EM

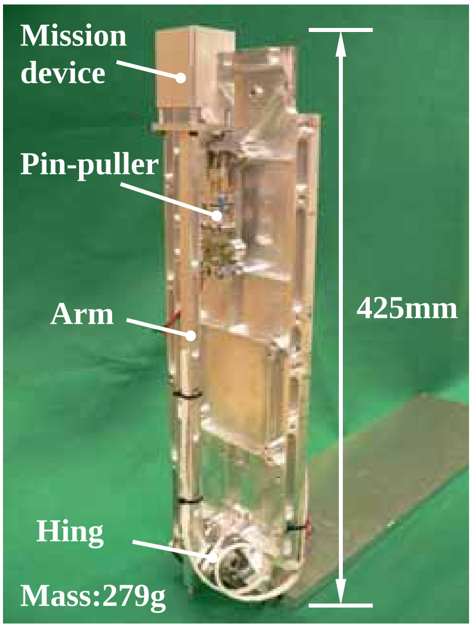

Figure 8 – Photograph of the boom EM

VIBRATION TESTING

Vibration testing was conducted to investigate dynamics of the boom having a dummy mass for a mission component. Mass of the component was assumed to be 100 g. It is noted that the boom has its weakest stiffness in *x* direction (refer to Figure 6). So the vibration testing in *x* direction is described in this context. Table 1 shows the observed eigen-frequencies of the boom in three different excitation patterns.

Table 1 – Observed eigen-frequencies of the boom EM

	Twist mode 1 [Hz]	Bend mode 1 [Hz]	Bend mode 2 [Hz]
Pre-low-level random	118.7	143.7	378.1
Random	96.9	112.5	330.0
Post-low-level random	103.1	156.3	375.0

The severest response was observed at the mission component to show the maximum acceleration of 82 G at 100 Hz in both random and sinusoidal excitations. The conditions for sinusoidal excitation input were as follows; frequency range: 5~100 Hz, acceleration level: 24 G. The vibration testing revealed many necessary refinements of the boom, especially it was suggested that the stiffness of the boom elements should be increased.

DEPLOYMENT TEST

Deployment test was conducted in the university laboratory to confirm the deployment dynamic characteristics. How to cancel the effect of the gravity is the key for ground-test of space components. Arm of the boom EM was hold in horizontal plane by a thread of 3 m and the other end of the thread was fixed with a counter balance weight. Figure 9 depicts a concept of cancelling gravity for the deployment test. Figure 10 shows the test configurations.

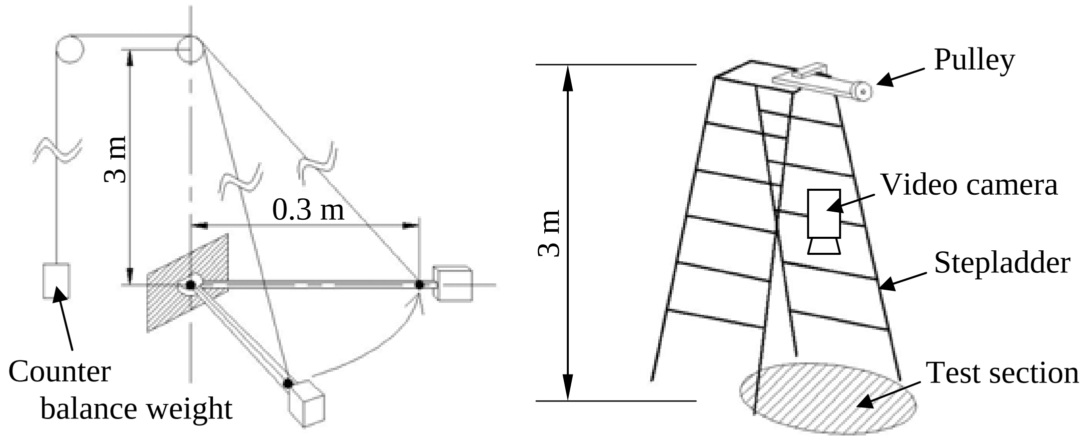

Figure 9 – Conceptual sketch of deployment test

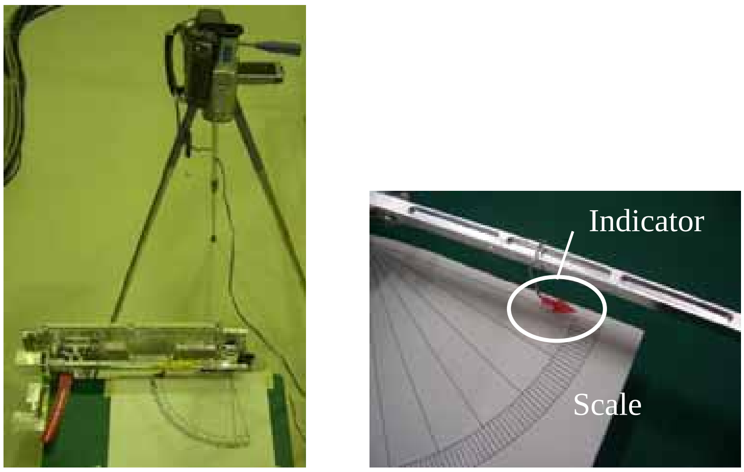

Figure 10 –Configurations of deployment test

Equation of deployment motion of the boom is given by

$$I\ddot{\varphi} + c\dot{\varphi} + k\varphi = k\left(\frac{\pi}{2} + \alpha_0\right) - T_D \tag{1}$$

where φ is the angle of deployment, I the moment of inertia of the arm system, c the rotational damping coefficient at the hinge, k the rotational spring constant of the hinge, α_0 the initial angle of rotation for the arm, T_D torque due to dry friction at the hinge. Figure 11 shows the comparison of the test results and the simulation to have a good qualitative character of deployment.

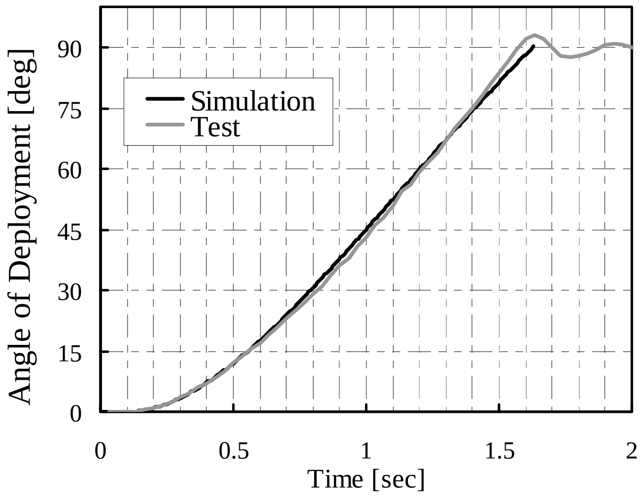

Figure 11 – Deployment motion

CONCLUDING REMARKS

Overview of student-based development of a space boom to be installed in a 50 kg-class micro-satellite, SOHLA-1, has been described. Engineering model (EM) of the boom was subjected to vibration testing to reveal the dynamics of the boom system. The vibration testing suggested a lot of refinements to be made for designing a proto-type model (PM) of the boom. The design of the boom PM was completed and machined. It is going to be subjected to qualification tests, including vibration testing, thermal vacuum test, spin test and so on. These development phases made us to ready for entering flight model (FM) development. The boom FM is scheduled to be completed in December, 2006.

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