Intelligent Space Systems Laboratory
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Optimal Design Methodology Emphasizing Surface Equipment Placement Applied to 6U CubeSats

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Paper Number : SSC24-P3-13

Wednesday, August 7
Weekday Poster Session 3
9:00am to 12:30pm

Abstract

In recent years, the number of launches of nano-satellites, which have the advantage of being developed in a short period of time, has increased rapidly. However, several issues need to be addressed to maximize the benefits of nano-satellites. One of them is that theoretical methods have not been widely applied to the placement of equipment on satellites. Therefore, this paper proposes an "Optimal Design Methodology Emphasizing Surface Equipment Placement Applied to 6U CubeSats". It details the design and development of two 6U CubeSats using this method, along with the results and lessons learned.

Method

This method used for the design of the two CubeSats is very effective for the design of CubeSats due to their characteristics of densely packed equipment. The generalized flow of this method is described below.

Step1. Determine satellite size and onboard equipment.

Examples of components with requirements for placement of equipment on the satellite surface are shown in Table 1.

Step2. Eliminate placement options that are not feasible.

Reduce the number of options, except for those that can be easily eliminated, e.g., STT and SAP do not face the same direction.

Step3. Evaluate power, observable time, observation view angle, etc., with a narrowed-down pattern.

Calculate viewing angles and power generation only for candidates that cannot be easily determined, i.e., limited patterns.

Table 1. Examples of equipment placement requirements

Subsystems	Components	Requirements
Attitude Control System	STT (Star Tracker)	Not facing the sun or earth in the observation posture
Electrical Power System	SAP (Solar Array Paddles (Panels))	Sun pointed
Communication System	Antenna	Xband-ANT must point in the same direction as one of the Sband-ANTs Tx and Rx mounted at least 2 sets each on opposite sides
Mission Equipment	Telescope Thruster	Earth pointed STT opening and thruster not on the same surface

Use case

In our laboratory, we applied it to two 6U CubeSats. SPHERE-1 EYE, developed in collaboration with Sony Group Corporation and JAXA, is equipped with a camera designed and developed by Sony Group Corporation. It aims to capture images and videos of the Earth and celestial bodies from orbit. It was assembled in July 2022 and launched in January 2023 aboard a Falcon 9 rocket.
ONGLAISAT(ONboard Globe-Looking And Imaging SATellite) was developed in collaboration with TASA(Taiwan Space Agency), carrying a TDI(Time Delay Integration) camera for technology demonstration. The assembly of the flight model has been completed, and it is scheduled for launch within the year. These CubeSats were designed with the goal of creating a common bus system. The coordinate axes were determined as shown in Figure 1.

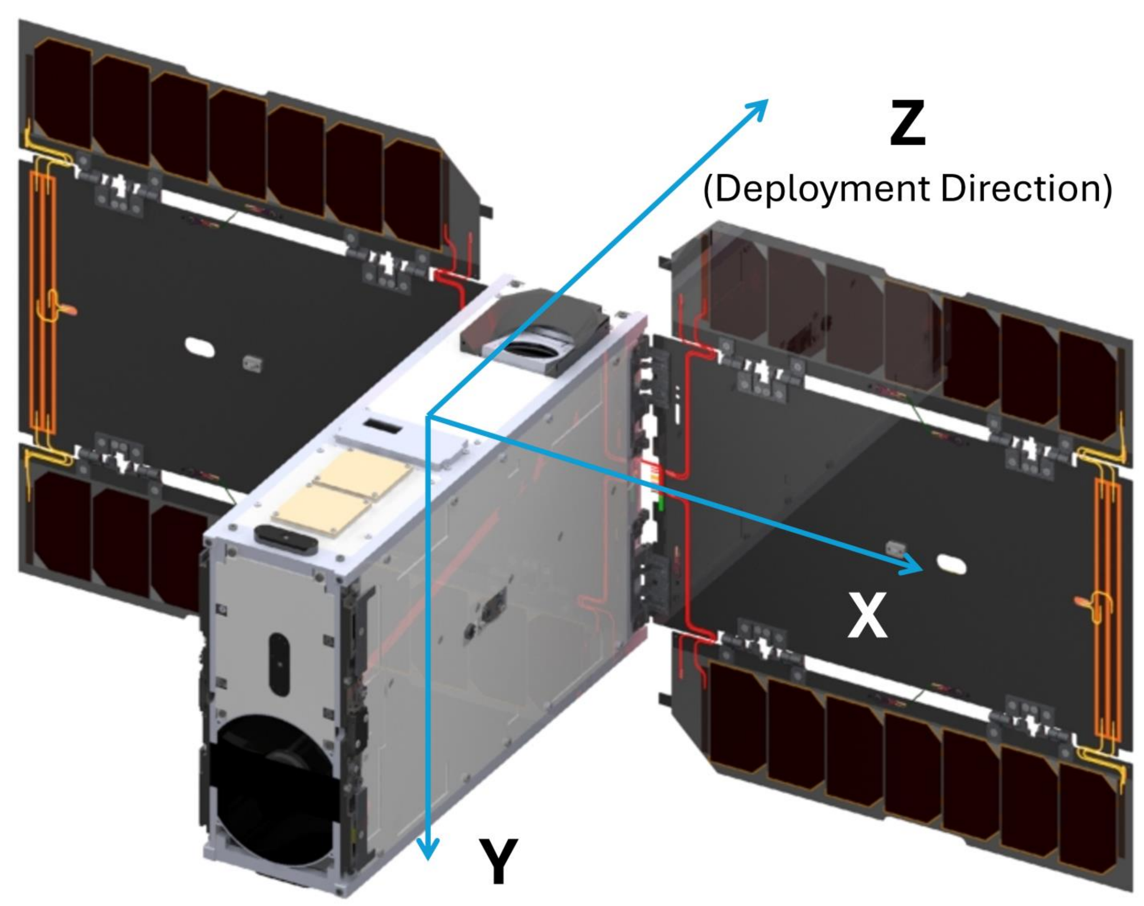

Figure 1. Coordinate System Definitions (ONGLAISAT)

The requirements for each component are given in the example shown in Table 1.
Possible candidates for the placement of major equipment are listed below.

- Main SAP direction (3 patterns)
- Main Antenna direction (3 patterns)
- STT direction (2 patterns)
- Thruster direction (2 patterns)

The possible combinations of choices result in 3 × 3 × 2 × 2 = 36 configurations. The mission possible time, etc., was estimated from the power and viewing angle calculations in Step 3 and organized on a matrix basis as shown in Table 2. Each letter is used to identify each candidate. By narrowing down the candidates and performing the calculations, two satellite designs were designed while saving labor for the optimal design.

Table 2. Candidate matrix of placement solutions

Design Matrix	Thruster(t)		PY(t)			PZ(t)		
Antenna(a)	STT(stt)	SAP(sap)	MY(sap)	PY(sap)	PZ(sap)	MY(sap)	PY(sap)	PZ(sap)
MY(a)	MY(stt)		A×	B×	B×	A×	B×	B×
	PZ(stt)		D× E○	D△ E△	A×	D× E×	D△ E×	A×
MZ(a)	MY(stt)		A×	C×	C×	A×	C×	C×
	PZ(stt)		C×	C×	A×	C×	C×	A×
PY(a)	MY(stt)		A×	D× E△	D○ E×	A×	D× E×	D○ E△
	PZ(stt)		D△ E○	D× E△	A×	D△ E×	D× E×	A×

Discussion

- For a 6U or smaller CubeSat, with a narrower distance between devices, it was shown that if the number of surface devices exceeds a certain number, it is possible to design a satellite that can operate in orbit by arranging the devices in this way.
- A company was created to manufacture and sell 6U CubeSats designed using this method as a general-purpose bus.
- For small satellites weighing 30 kg or more, even if the component mounting surface is determined, there is a large degree of freedom in how the components are arranged, making layout difficult using this method alone.
- The early positioning of the spacecraft's equipment is usually done "manually" by a group of system engineers heavily based on their experience.
- The process takes time, so once a feasible design is found, it becomes the baseline, limiting broader exploration and possibly leading to suboptimal or later-modified designs.

Lessons Learned

- SPHERE-1 EYE is still in orbit and operating with no critical problems.
- The number of candidates was reduced to some extent by placement alone, which reduced the number of iteration engineers had to estimate possible shooting areas and power generation when further narrowing down the candidates.
- There is still the challenge that estimates still need to be done by engineers over time.

Future Work

- The Master thesis is concerned with the creation of a tool that automatically outputs solutions for several configurations of the equipment configuration of a 30-100 kg rectangular-shaped satellite and the necessary formulations.
- That tool optimizes the center of gravity, ease of assembly, and placement of heat-generating components as evaluation functions.