SWARM-EX CubeSat Design

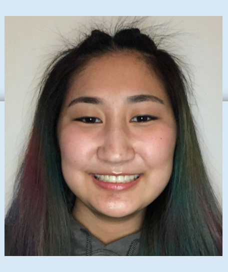
SWARM-EX is a NSF funded satellite mission across six institutions: CU Boulder, Stanford University, Georgia Institute of Technology, University of South Alabama, Western Michigan University and Olin College of Engineering.

Anargyros Kriezis
OLIN COLLEGE OF ENGINEERING

Celvi Lisy
OLIN COLLEGE OF ENGINEERING

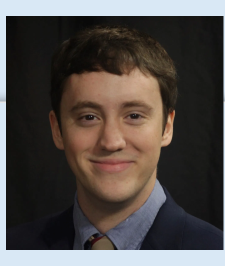
Rohil Agarwal
OLIN COLLEGE OF ENGINEERING

Emanuele Costantino
UNIVERSITY OF COLORADO BOULDER



Berwin Lan
OLIN COLLEGE OF ENGINEERING

David Fitzpatrick
UNIVERSITY OF COLORADO BOULDER



Brodie Wallace
UNIVERSITY OF COLORADO BOULDER

Tigey Jewell-Alibhai
OLIN COLLEGE OF ENGINEERING

Whitney Q. Lohmeyer
OLIN COLLEGE OF ENGINEERING

Scott Palo
UNIVERSITY OF COLORADO BOULDER

Poster Presentation

Mission Overview

SWARM-EX seeks to address outstanding aeronomy and space weather questions using constellations of 6-12 formation-flying CubeSats. The SWARM-EX pathfinder mission, supported by the National Science Foundation, uses three 3U CubeSats to demonstrate the key control and communication technologies that will enable the proposed SWARM-EX missions with larger constellations. This presentation summarizes the analysis of the structural and thermal loads, that will be performed using finite element analysis techniques, that will be experienced during the orbital lifetime and launch of the SWARM-EX satellites.

CubeSat Design

SWARM-EX aims to be a CubeSat platform for various instrument payloads, as required by the science needs of different university and institutional missions. The satellite bus was designed with a 0.5U payload bay and capabilities that can support a variety of experiments.

The satellite components are categorized in five groups: Payload, Power & Data, Antennas & Radios, OGNC (Orbit Guidance Navigation and Control), and Structures.

Payload:

The payload section of the SWARM-EX pathfinder satellite houses two sensors, a Langmuir Probe and a FIPEX (Flux-Φ-Probe-Experiment), as well as the electronics required to operate them. As stated earlier, there is a 0.5U allocation for the payload subsystem. This is in addition to the tuna can volume on one of the 1U faces of the spacecraft, which has dimensions of 88 mm in diameter and 46 mm in height. This payload section is designed with the ability to accommodate the different experiments that future SWARM-EX missions will require.

Power & Data:

The CubeSat power source consists of three solar panels (with a total of 23 cells) that charge the 6 lithium ion batteries. The power is regulated through the EPS (Electronic Power System) board. The data processing takes place at the CDH (Command and Data Handling) board. Both the EPS and CDH circuit boards are part of the board bus and connect to the backplane board, to which all the components of the CubeSat connect.

Antennas & Radios:

The SWARM-EX satellites each have four different radio/antenna systems to successfully complete their mission. Telemetry and commands are sent and received through the UHF antenna and radio, while the data from the science payload is downlinked in X-band frequencies. Each satellite is also equipped with a GPS patch and radio to support its OGNC operations, attitude determination/control, and the science mission. A Globalstar radio is also included to provide backup communications soon after deployment and in the case of UHF communication loss.

OGNC:

The CubeSat utilizes the Blue Canyon Technologies ADCS (Attitude Determination and Control System) XACT-15 to achieve its science and formation flying goals. The XACT-15 system is an integrated unit containing three reaction wheels and three magnetorquers. Two external sun sensors are placed on the nadir- and zenith-facing sides to ensure continuous coverage. A 0.5U cold gas thruster provides the necessary delta-v for formation flying maneuvers.

Satellite Model

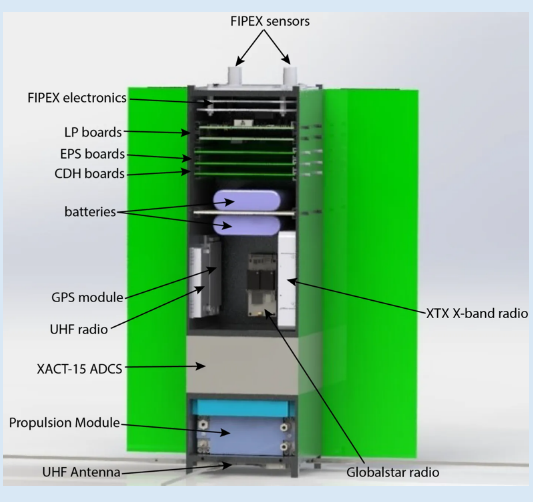


Figure 1: Earth (nadir) facing side of the satellite without the back cover

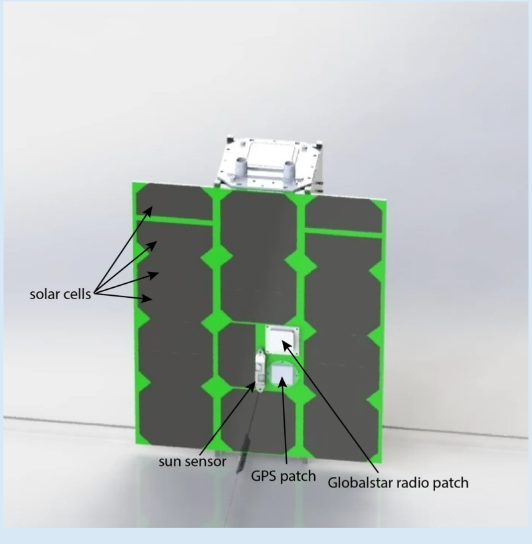


Figure 2: Space (zenith) facing side of the satellite with deployed solar panels

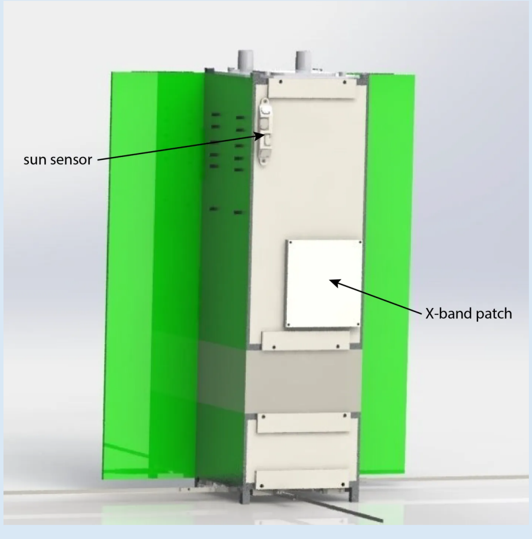


Figure 3: Earth (nadir) facing side of the satellite with back cover

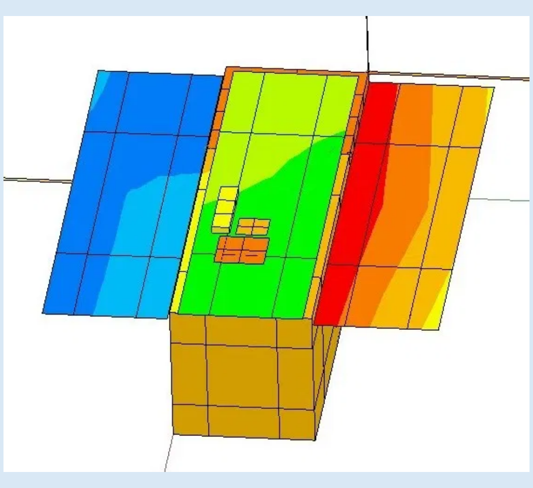


Figure 4: Thermal modeling of the cubesat

Structure & Harnessing:

The structure consists of two sections, the upper and lower modules. As referenced in the satellite model, the upper module includes the science payload bay, the board bus, and all the required radios. The lower module houses the propulsion system and the UHF antenna. The antenna patches, sun sensors, and deployable solar panels are attached on the outside of the structure within the 9mm envelope allowed by the dispenser.

Structural Analysis

The structure has several requirements regarding its launch load, static load, and fundamental frequency. In order to ensure that the structure fulfills these requirements, different analyses need to be run. In order to ensure that the structure can withstand quasi-static loading of 30g (applied independently in each primary axis), has a yield factor of safety of 2.0, and has an ultimate factor of safety of 2.6, a static finite element analysis study will be conducted. Another form of structural analysis that will be performed on the structure is vibration testing in order to ensure that the structure can withstand the vibroacoustic launch environment. Namely, the analysis must show that the structure has a fundamental frequency higher than 100 Hz. Fatigue testing and thermal testing will also be conducted on the structure.

Thermal Analysis

The main objective of the thermal control subsystem (TCS) for SWARM-EX is to keep all the components within their operational/survival temperature ranges for the duration of the mission. SWARM-EX's TCS is primarily passive. Heat is transferred from components to the satellite structure and then rejected into cold space via thermal coating. The external coating has a low solar absorptance to reduce heating from the sun, and a high IR emissivity to reject excess heat dissipated by internal components. The only components with active thermal regulation are the battery packs, which are heated using battery heaters.

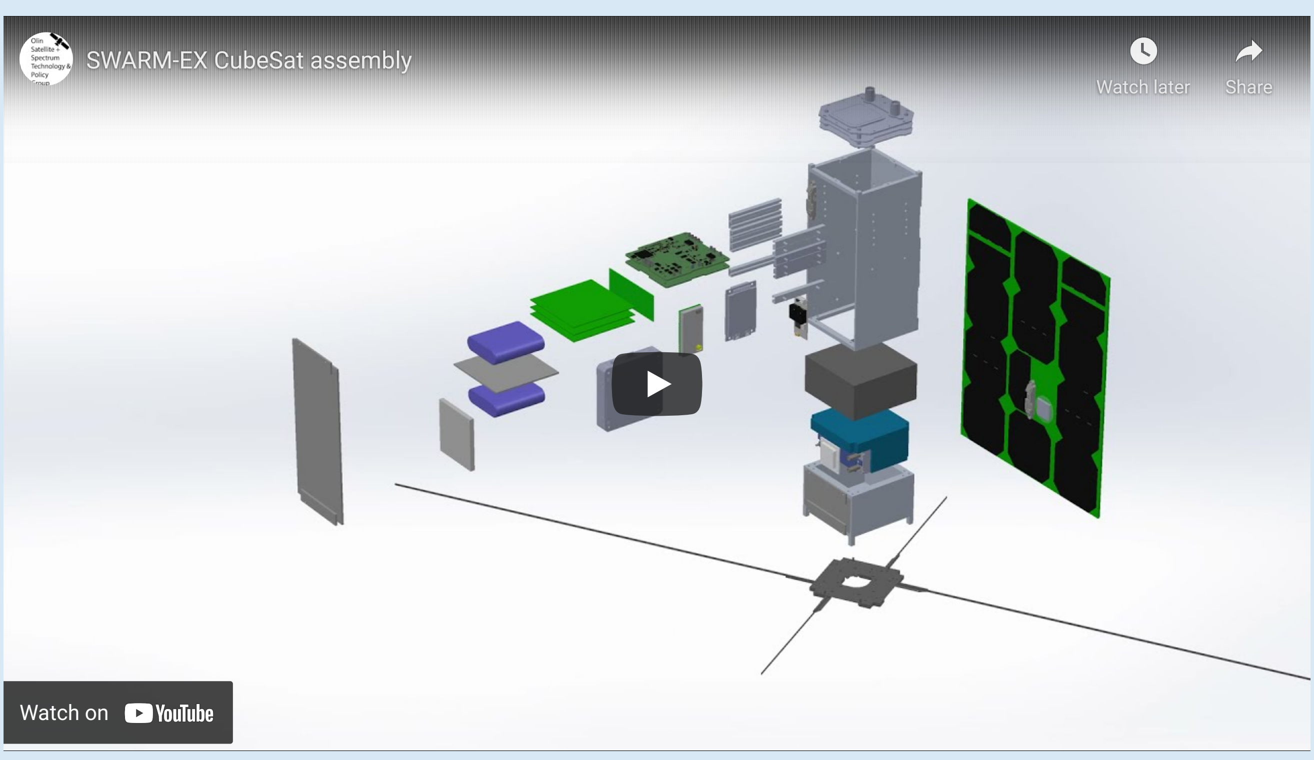
Passive cooling is affordable and lightweight, but may be limited when components are designed to run at high temperatures. The FIPEX instrument used by SWARM-EX has components that must be kept at temperatures between 600 and 700°C while gathering science data. The challenge for the TCS is to ensure that the FIPEX is modeled to a high enough fidelity to ensure that these high temperatures will not heat the other components past their allowed temperatures.

The primary analysis tool used by SWARM-EX's TCS is Thermal Desktop (TD) by C & R Technologies. TD is integrated into AutoCAD's work environment, making it easy to reconstruct the spacecraft, model thermal paths between components, and generate solutions for different space environments. TD has allowed SWARM-EX to predict component temperatures, which in turn allows the team to reevaluate design decisions to ensure that thermal control efforts are successful.

Mission Next Steps

Physical prototyping is underway, with an initial version of the CubeSat composed of 3D-printed components is currently in progress. This will be used for the first fit check of the current version of the assembly. Afterwards, two iterations of the structure will be machined with increasing precision for higher fidelity fit checks, and these iterations will undergo vibration and vacuum chamber testing to ensure structural integrity. In parallel, a FlatSat testing bed is being developed to facilitate systems-level testing between subsystems.

Assembly Animation



Acknowledgements

The SWARM-EX mission was selected and awarded a four-year grant from the National Science Foundation's Ideas Lab. Starting in 2020 the six partnering institutions have worked on different aspects of the project to satisfy its science, engineering and educational goals.