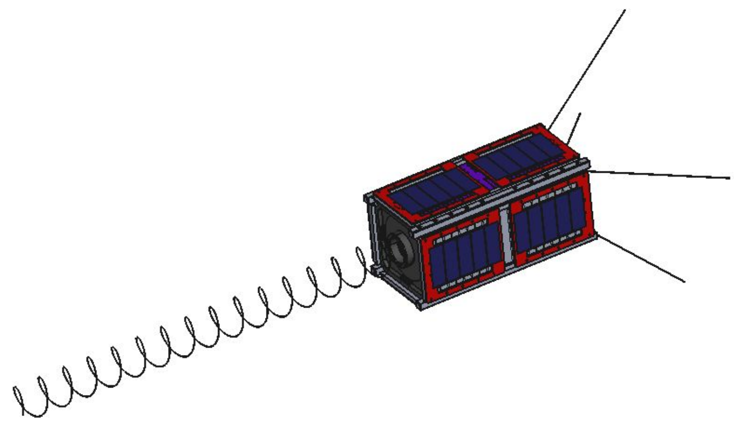
OreSat Structural Design: The Design, Build, and Test of a 2U CubeSat

An application for the Oregon Space Grant Consortium
2017-2018 Undergraduate Team Experience Award Program



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Faculty Advisor
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Date of Submission: 2017-11-10

Project Description

We propose to design, build, and test the mechanical structure and critical deployable components of Oregon's first satellite, OreSat.

OreSat is a CubeSat with a 2U form factor that will be deployed into low earth orbit in late 2019 as part of the NASA CubeSat Launch Initiative. OreSat's primary mission is to connect Oregon K-12 students through space-based STEM outreach. OreSat will be transmitting live video from space. Oregon students will receive the signal with hand-built, hand-held radio receivers pointed at the satellite. OreSat's secondary mission is to survey of the global coverage of high altitude cirrus clouds using an inexpensive and innovative camera and filter system from Dr. Greg Bothun at the University of Oregon.

This project will also function as a senior capstone, fulfilling graduation requirements in the Portland State University Department of Mechanical and Materials Engineering.

Our team will focus on three critical mechanical subsystems of OreSat:

1. **Satellite structure.** OreSat must be able to survive rigorous vibration, extreme temperatures and vacuum of low-Earth orbit while remaining as lightweight as possible.
2. **Critical deployable structures.** OreSat has two deployable structures that are critical to mission success: the 70 cm (430 MHz) omnidirectional radio antenna and the S band (2.4 GHz) high gain helical antenna. Both antennas must be stored within the standard CubeSat volume while stored, and then deploy after the CubeSat is launched.
3. **Safety critical deployment and inhibit switches.** Required by both the CubeSat Design Specification (CDS) and NASA integrators, the deployment and inhibit switches shut down OreSat while it's in the CubeSat deployer mechanism.

This project will progress through three distinct phases:

1. Research

Our team will begin by thoroughly analyzing existing solutions to the design challenges we are facing. This begins with researching and analyzing CubeSat requirements, such as the CubeSat Developers Specification and the dozens of NASA launch services requirements documents. Then we will research CubeSat papers that describe their mechanical systems, being careful to pay attention to missions with some on-orbit success. We can learn from the strengths and weaknesses of these existing satellites. Finally, we'll look at commercial off the shelf systems to try and understand the current state of the art. From this research we will pull together a Preliminary Design Specification (PDS).

2. Design

The design process for the structure, deployment systems, and the inhibit switches will be an interwoven effort among the team to ensure successful integration between the subsystems.

Key design challenges for the aluminum structure include: maximizing usable space on each circuit board; minimizing mass in order to fit within the design restraints; optimizing thermal properties to assist heat transfer from key components; ensuring ease of access and assembly while iterating and testing electrical components; and meeting structural demands during launch and deployment. Extensive work will be required to ensure proper integration with the deployable antennas and inhibit switches. Further design work will strive to improve ease of manufacture of the structure. As an open-source and open-hardware team, we endeavor to make our designs manufacturable by third parties without access to prohibitively expensive equipment whenever possible.

The directional antenna will benefit from the shape-memory effect of nickel-titanium alloys. If stowed in its austenite phase as a compressed helix, the antenna could pack tightly into its provisioned volume during stowage, launch, and deployment from the International Space Station. Once in orbit and exposed to the low-temperatures, the helix would undergo transition to its martensite phase and expand into its full helical shape. The omnidirectional array will either rely on a hinged deployment mechanism or simple elastic deformation depending on design decisions to be made during cross-disciplinary meetings. Working with the electrical engineers, we will determine which approach will best meet their needs without sacrificing mechanical reliability and robustness.

The output of the design stage will be a complete CAD model, along with 3D printed prototypes.

3. Build and Test

Using Agile methods taught to us in our engineering classes, we will attempt a series of short design-build-test "sprints" that will allow us to quickly discover mistakes in our thinking, and allow us to focus on actual test results rather than simulations.

We imagine that the structure will be machined out of aluminum and anodized to meet the requirements of the CubeSat Design Specifications. We plan to have parts machined at ProtoLabs, which does quickturns of CNC'd aluminum parts in just 5 days. If we choose nitinol as the material for the S band helical antenna, then we will reach out to our contacts at NASA’s Glenn Research Center who specialize in shape-memory alloys.

Once built, all the systems will be rigorously tested. We will conduct exhaustive mechanical tests on the structure, antenna deployment mechanisms, and inhibit switches. The systems will be put on a vibration table which sweeps through the relevant frequencies to test the response to launch conditions. A thermal vacuum chamber will test the structure’s readiness to be deployed into the low Earth orbit environment. We even have permission to work with the research team at the Portland State University’s Dryden Drop Tower to simulate a microgravity environment for deployment mechanism tests.

Throughout the design-build-test process, we will also research reliability statistics to be able to help us answer the statistical reliability of our systems based on their testing.

Please see Table 1 for our proposed timeline.

Table 1: Project plan, with Key Milestones and Deliverables (12/01/17 - 06/29/18)

12/01 - 12/31	Preliminary research and CAD work; 3D prints
01/01 - 01/31	First prototype structure send to Protolabs. Create vibration jig for Element vibration table. Vibration testing and analysis on prototype structure. CAD revision of prototype structure. Tests of antenna deployment systems and inhibit switches.
02/01 - 02/28	Further antenna testing, including first thermal vacuum deployment tests. Second prototype structure to Protolabs.
03/01 - 03/31	Vibration tests on second prototype structure with full system: antenna deployment mechanisms, inhibit switches, and full assortment of PCBAs.
04/01 - 04/30	Statistical tests on the antenna deployment mechanism. Further vibration testing on the full system. **Critical Design Review (CDR) of the system.**
05/01 - 05/31	Final CAD updates. Final system tests. Final flight structure to Protolabs Begin documentation.
06/01 - 06/29	Build flight systems. Final documentation; graduate!

Scholarly Aspects and Educational Objectives

The OreSat structural design project will give our team the opportunity to create a complete, ready-to-use CubeSat for its mission to low Earth orbit. As a part of a larger interdisciplinary project that is building OreSat, the design process will offer the team valuable collaboration experience with people outside of mechanical engineering, developing communication skills directly applicable to real-world work environments.

The unique opportunity to work on a system that will be deployed into space will also require us to consider factors beyond the scope of most capstone projects. Successful completion of the project will further our education in a number of disciplines such as: heat transfer and thermal analysis for structural design; material science and statistical analysis for antenna deployment; integration and specification handling with the deployment switches.

Expected Outcomes

This project will serve as the senior capstone project for five mechanical engineering students at Portland State University.

Synergy

Team-Advisor Collaborative Learning

Dr. Gerald Recktenwald will act as the team advisor. His interest in heat transfer will guide our efforts in thermal analysis of the structural components of the satellite and possibly in the activation of the shape-memory alloy used in the directional antenna. His expertise in numerical analysis will aid the team as it deals with nonlinear analysis of the shape-memory alloy as well as data collection and statistical analysis of the deployment mechanisms' reliability. As a professor he has always stressed the importance of interdisciplinary work and communication with the customer; as such he will assist with the integration of our team's mechanical systems and help ensure that we meet the requirements of OreSat and the CubeSat Developers Specification.

Our team will benefit from the fact that Dr. Recktenwald happens to be the professor in charge of organizing and facilitating all senior capstones. He will ensure that our team maximizes educational outcomes and satisfies the needs of the customer. There are a lot of engineering challenges associated with this project and his well-rounded background will facilitate in our learning throughout the design process.

Leveraging Opportunities for Funding or Further Research

This project will deliver key components of OreSat - Oregon's first satellite. As a result, it will enable all of the opportunities that OreSat will bring to Oregon STEM education. Oregon high school students involved in building ground stations, and talking directly with their own nanosatellite, will be encouraged to pursue STEM fields including aerospace. The survey of high-altitude cirrus clouds will contribute to the understanding of the planet and can be used by climate scientists to improve climate models. Finally, as an open-source project, OreSat itself will enable other universities in the US and around the world to participate in CubeSat design by leveraging our easy-to-use, modular system.

The project will serve as a mechanical engineering capstone for the five members of the team. As a research and design project it will further our understanding of materials science, structural analysis, heat transfer, statistical analysis, and interdisciplinary teamwork.

Aerospace Relevancy

The CubeSat nanosatellite form factor has become a celebrated and encouraged standard throughout almost all NASA directorates, ranging from the NASA Education Mission Directorate to the the Space Technology Mission Directorate (STMD). Even OreSat's ride to space, the CubeSat Launch Initiative, is "an integrated cross agency collaborative effort led by NASA's Human Exploration and Operations (HEO) Mission Directorate to streamline and prioritize ride share and deployment opportunities of CubeSats".

Our structure, deployables and inhibit switches project is particularly relevant to the **Space Technology Mission Directorate (STMD)** because of our focus on reducing the cost and complexity of space systems. Our simple to build, open source CubeSat structures will help forward the state of the art for CubeSat systems.

OreSat's primary mission of live video from space to Oregon high schools is particularly relevant to the **NASA Education Directorate.** OreSat was accepted into the CubeSat Launch Initiative because of our dramatic impact on STEM education in the state of Oregon. Our systems have the ability to enable a space-based STEM outreach to all high schools in our state, which we are personally very excited about.

Finally, OreSat's secondary mission of high altitude cirrus cloud observation has direct relevance to the **NASA Science Mission Directory (SMD).** The high gain antenna deployment mechanism we're designing and building will directly enable the transmission of high bandwidth science data from OreSat's CirrusFluxCam science subsystem.

Budget

This budget includes materials and services necessary to prototype OreSat's structural systems. It also includes in-kind services and donations that we will procure in order to meet the 1.5x matching requirement.

Qty	Description	Vendor	Cost Ea.	Ext. Cost	Ext. Donation
1	SLA and FDM 3D prints	EPL	$1,000.00	$1,000.00	
1	First OreSat prototype structure	Protolabs	$1,600.00	$1,600.00	
1	Second OreSat prototype structure	Protolabs	$1,600.00	$1,600.00	
1	Flight model OreSat structure	Protolabs	$1,600.00	$1,600.00	
1	Misc Hardware for structure and antenna molds	McMaster Carr	$1,000.00	$1,000.00	
1	Nitinol and Beryllium Copper wire	Aviva Metals	$250.00	$250.00	
39	Dr. Recktenwald's time (1 hr/wk)	PSU ECE Department	$104.80		$4,125.00
43	Rob Melchione's time (~ 2 hr/wk)	G7 Aerospace	$150.00		$6,450.00
	TOTAL			$7,050.00	$10,575.00
				Match ratio:	1.50

Team Lead Resume

Calvin Young
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EDUCATION

Bachelor of Science in Mechanical Engineering 01/2015 – 06/2018
Portland State University, Portland, OR

EXPERIENCE

Student Member 02/2016 – Present
Portland State Aerospace Society, Portland, OR

- Refinement of preliminary structural design for educational cubesat
- Design and testing of recovery system educational sounding rocket
- Assistance design of control system for cubesat reaction wheel system

Writing Systems Technician 06/2015 – Present
Hewlett-Packard (Contracting through Syncro Design), Vancouver, WA

- 3D modeling and CAD design of test specimens
- Script writing and process automation for experimental workflow
- Collaboration with systems engineers in design of experiments
- Production of material for sales and marketing teams

Summer Research Intern 06/2017 – 08/2017
NASA Glenn Research Center, Cleveland, OH

- Research and development of spring tire for extraterrestrial rovers
- Created a MATLAB tool to quickly predict tire density
- Refurbished a test rig used to measure tractive performance
- Led STEM outreach tours of the Simulated Lunar Operations facilities

3D Artist / Shipping and Receiving 09/2013 – 03/2015
Outlier Incorporated, Brooklyn, NY

- Computer-generated 3D graphics for commercial media
- Fulfilling and shipping domestic and international orders
- Management of inventory and showroom; coordination with factories

TECHNICAL SKILLS

- Direct solid modeling with PTC Creo
- Freeform modeling and rendering with Blender
- Parametric modeling with SolidWorks
- Statistical analysis in MATLAB and R
- Elementary programming in C++ and Python

Team Member Listing and Experience Profiles

Group Demographics:

- Female Students: 2/5 - 40%
- Underrepresented Minorities: 0/5 - 0%
- Veterans: 0/5 - 0%

Shivani Nadarajah (Mechanical Engineering Undergraduate, PSU)
Undergraduate researcher studying mechanical fatigue due to turbulence in the Wind Energy and Turbulence lab at Portland State, experience with data analysis software (R and MATLAB) and other C-based programming such as Python and JavaScript, manufacturing processes and stress analysis, fluid mechanics with an emphasis on turbulent flow, currently working in quality engineering.

Justin Burris (Mechanical Engineering Undergraduate, PSU)
Experience with Solidworks CAD modelling, additive manufacturing with 3D printers. Experience with machining and manufacturing processes. Time spent with automotive applications.

Calvin Young (Mechanical Engineering Undergraduate, PSU)
Past projects include development and testing of sounding rocket recovery system; assistance in design of reaction wheel control system and preliminary structural design of cubesat. Summer internship research focused on R&D of nitinol spring tires for extraterrestrial rovers. Works with industrial 3D printers and mass-market consumer products. Experience in PTC Creo, SolidWorks, Blender, MATLAB, R, C++, Python.

Paijanne Jones (Mechanical Engineering Undergraduate, PSU)
Certified Computer Aided Drafter and Designer (AutoCAD, Inventor, and Solidworks) with a mechanical and industrial focus. 20 years experience as an architectural and structural designer and drafter. Experience with C++, LISP, and microcontroller programming. Experience in automotive mechanics and engine rebuilds. Currently working as an assistant engineer for a structural and mechanical PE.

John George (Mechanical Engineering Undergraduate, PSU)
5 years of experience in design and production of high purity semiconductor industry products (3D modeling, drafting, precision machining and quality documentation control). Design and manufacturing team member of Portland State Aerospace Society electronic nose cone separation and recovery system. Experience in AutoCAD, Solidworks, Matlab, PTC Mathcad, Arduino, Python.