NJ Space Grant Support of Princeton University's NanoSat Program

2019-20 Report

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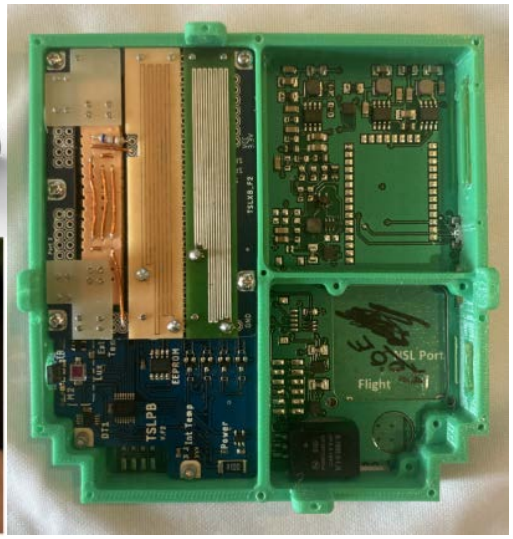
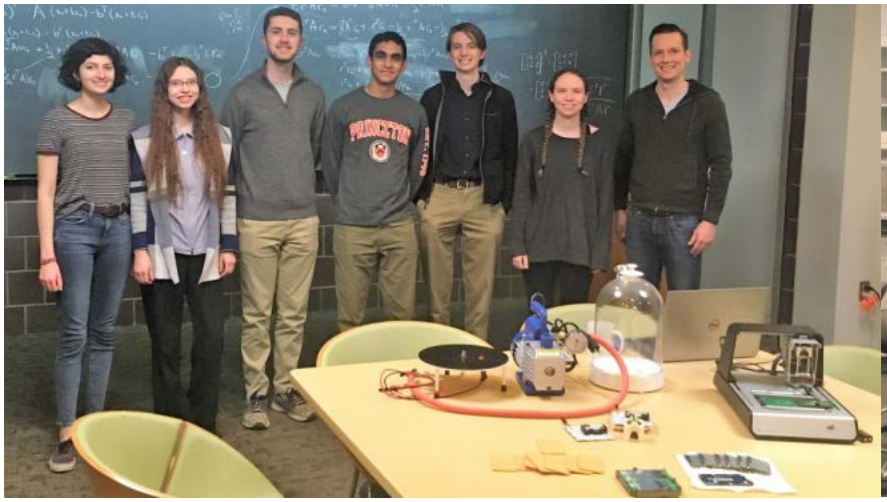
Princeton University's undergrad NanoSat program (and local high school ThinSat STEM outreach program) were generously supported by the NJ Space Grant in 2019 and 2020. The following were some of our highlighted accomplishments that were well-supported during this period of performance. Curricular framework of each project is color-coded as follows:

- **green**=Senior Thesis
- **blue**=for-credit Independent Work semester (junior/senior)
- **orange**=SPRE summer internship (freshman/sophomore)
- **purple**=extracurricular
- **red**=local high school STEM outreach

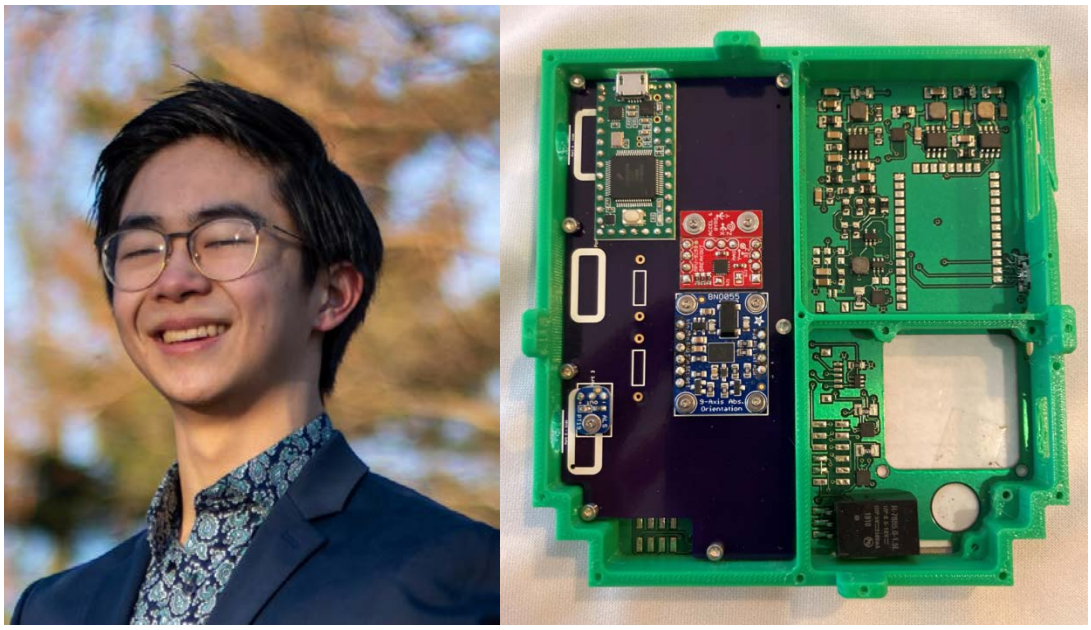
1. ThinSats

a. **ProtoSat:** a 9-student (freshman and sophomore) undergrad extracurricular team completed the mission design, detail design, fabrication and test of Princeton's first-ever student nanosat (a ThinSat), manifested for orbital launch as a rideshare on NASA's NG-15 Antares/Cygnus resupply mission to the ISS this Feb 20! The ThinSat (called "ProtoSat") will be the first-ever exposure of several student-level circuit prototyping methods (Voltera PCB printing, CNC PCB engraving, and even a solderless breadboard) to a full space environment, thereby proving their space qualification and increasing their TRL, for the benefit of academic nanosat programs worldwide.

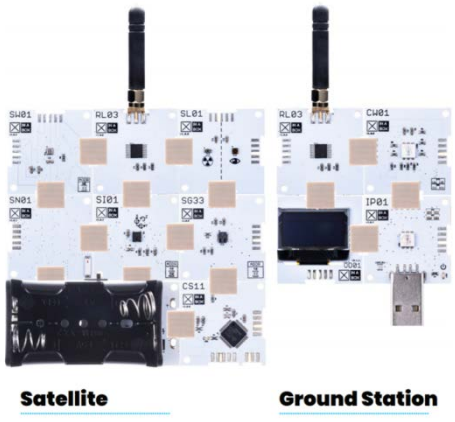




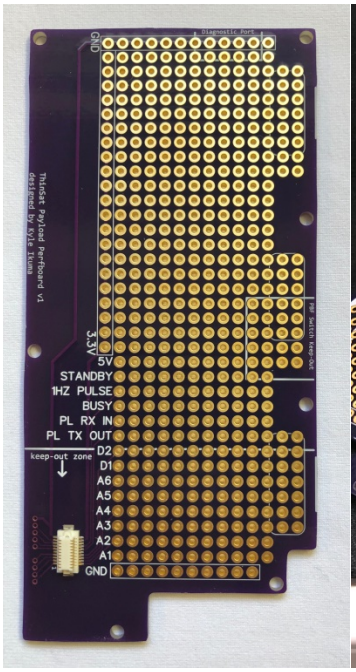
b. **MEMSat**: during the 2021 “covid summer”, entirely from his bedroom(!), then-freshman intern Kyle Ikuma (’23) completed the design, fabrication & test of MEMSat, which will also launch into orbit on Feb 20! MEMSat will be the first comparative on-orbit test of the zero-G performance of 3 different microelectromechanical (MEMS) inertial measurement units (IMUs) popular in the nanosat community, but never before compared side-by-side in a space environment.

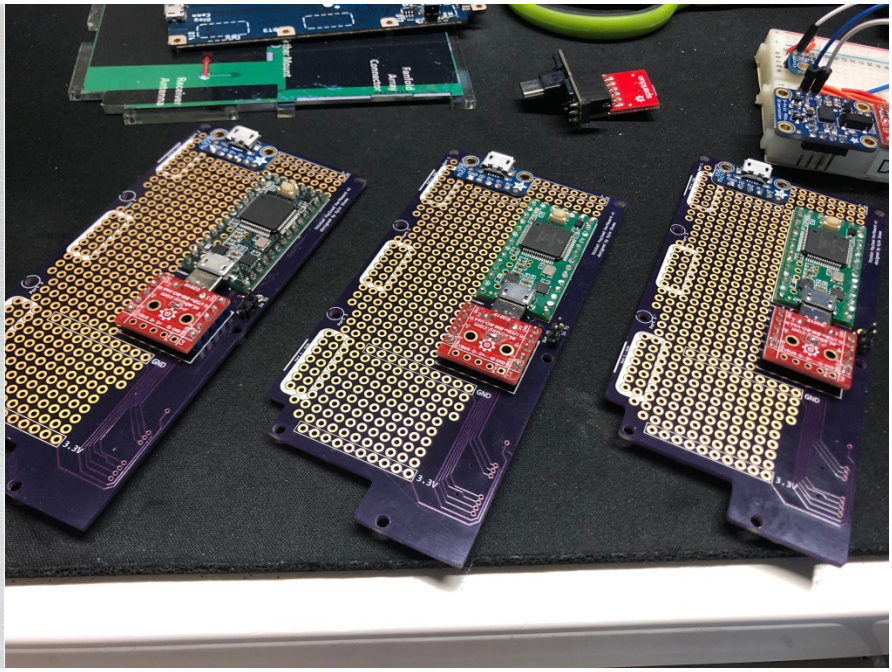


c. **Local high school ThinSat outreach**: we mentored our local ThinSat partner high schools (Princeton High School, Princeton Day School & Montgomery High School) through prototyping their first science payloads (using modular, click-together, Arduino-programmed xChip electronics), test-launching these payloads via local low-altitude balloon launches and remote (in Indiana) stratospheric balloon and drone launches, and finally integrating final payloads into their ThinSats for orbital launch alongside ours on Feb 20!



d. **ThinSat Development Aids**: as another part of Kyle Ikuma's remote summer nanosat internship during covid, he designed and fabricated several different breadboard/perfboard template payloads, for use in lowering the bar to entry to development of more custom ThinSat payloads (i.e., beyond the basic click-together xChips), not only for our university ThinSat students, but also for our local partner high school ThinSat teams, and perhaps for rollout nationwide someday for the whole ThinSat program.



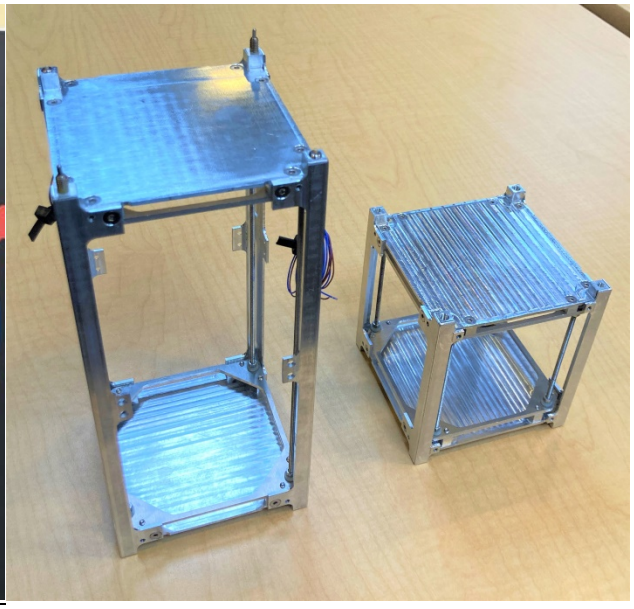


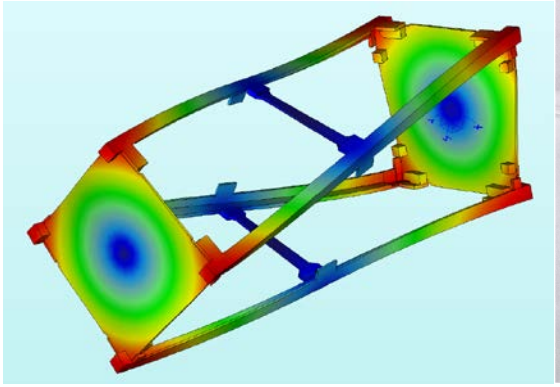
2. CubeSats

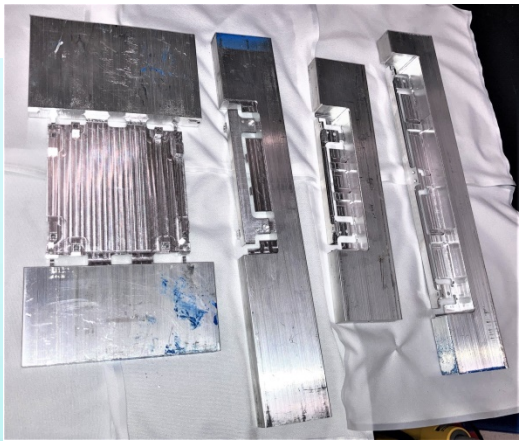
a. **CubeSat Structural Frame (Chassis)**: the design of Princeton's first CubeSat bus began in earnest with Michael Hauge's ('21) design of our first CubeSat structural frame(in both 1U and 2U sizes) as his junior for-credit Independent Work semester project. His project involved:

   i. Implementing a novel power and signal transmission bus along the typical CubeSat stack's threaded rods (to ease CubeSat circuit board design for us and maybe someday more of the CubeSat community).
   ii. Ensuring strict compliance to the CubeSat Design Specification.
   iii. Proving structural qualification of the frame via FEA analysis.
   iv. Generating CNC and waterjet toolpaths for the parts so that future Princeton CubeSat teams can fabricate their frames in-house for a tiny fraction of the cost of a COTS CubeSat frame.

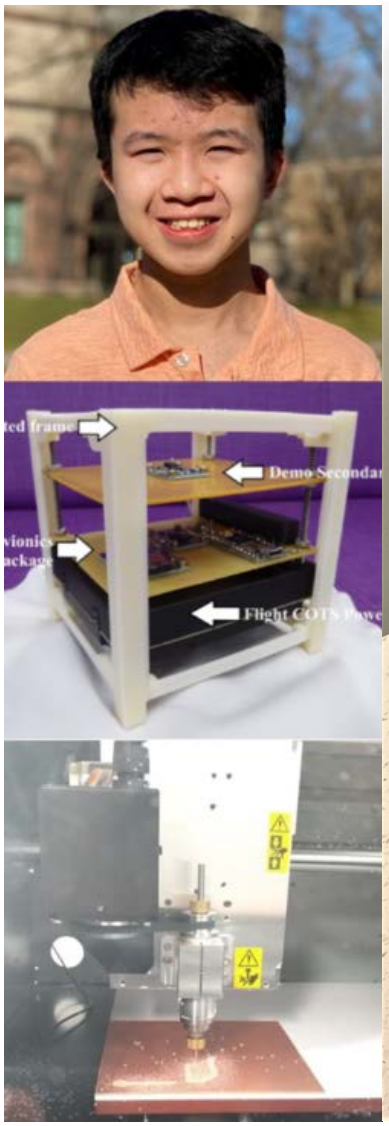
   Michael's project report can be found in Appendix 1.





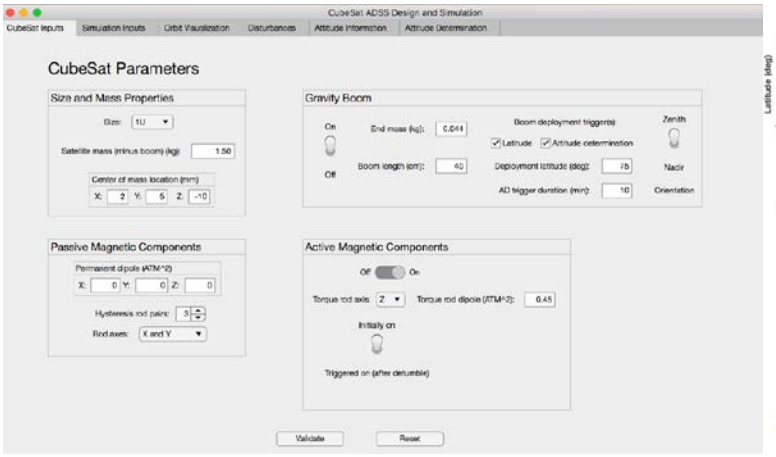


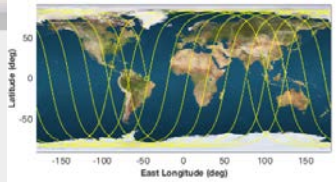
b. **CubeSat Onboard Computer (OBC) and Avionics Suite**: Princeton's CubeSat development program is a bit upside-down with respect to those of other universities: we are most interested in developing an inexpensive, modular, DIY, payload-agnostic CubeSat bus, for use with a wide variety of future missions, rather than designing around a specific science mission or payload right from the start. The first modular subsystem in our "Princeton Bus" was Douglas Chin's ('21) junior Independent Work project: an avionics board with an Arduino onboard computer (OBC), MEMS inertial measurement unit (IMU), and SD card reader for onboard data storage (all seen below in a 3D printed demo CubeSat frame, as well as a 3U-sized prototype of Michael Hauge's frame). We used Douglas' project as an opportunity to learn how to cheaply CNC-mill (engrave) our own circuit boards in-house. Doug's project report can be found in Appendix 2.



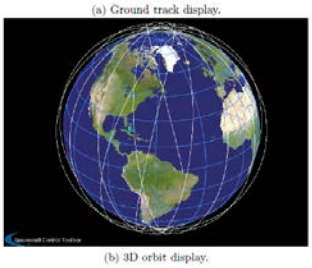
c. All-Passive 3-Axis Attitude Stabilization System (and Simulator) for CubeSats

This year, Michael Hauge is continuing his work in the NanoSat lab via his yearlong senior thesis project, which is the next modular addition to the "Princeton Bus": a novel all-passive 3-axis attitude stabilization system (ADSS). Development of this ADSS requires (as a prerequisite) an advanced orbital dynamics simulator and ADSS sizing tool (more advanced in many ways than even STK's $30K add-on SOLIS attitude control simulation/design tool). This was obviously a thesis-worth project unto itself. Michael finished the simulator development all in only 1 semester, authoring an advanced, GUI-based adaptation of local Princeton Satellite Systems' "CubeSat Control Toolbox" MATLAB libraries. Michael will be spending this—his final—semester designing and assembling the burn-wire deployed gravity boom that he sized with his similar. The ADSS will eventually also include: a horizon sensor, magnetic hysteresis rods (for passive detumbling), and an optional active torque rod. All components will be modularly configurable in the "Princeton Bus." Michael's expansive senior thesis report is excluded herein until completed.

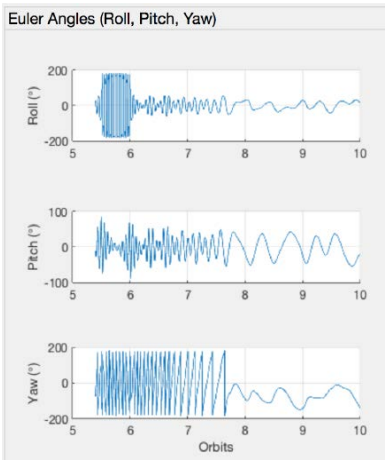


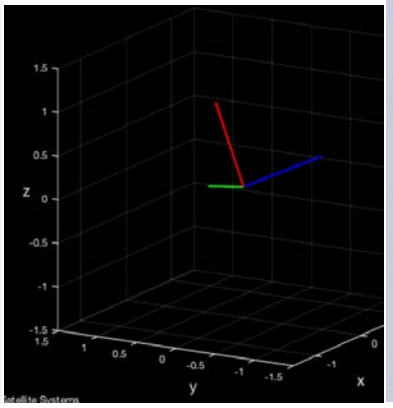


(a) Ground track display.



(b) 3D orbit display.

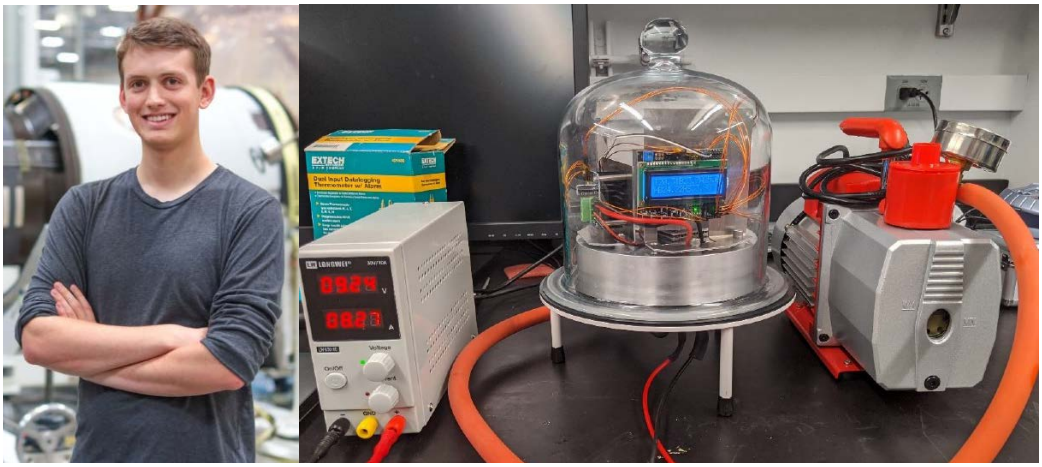




3. DIY NanoSat Environmental Test Facilities

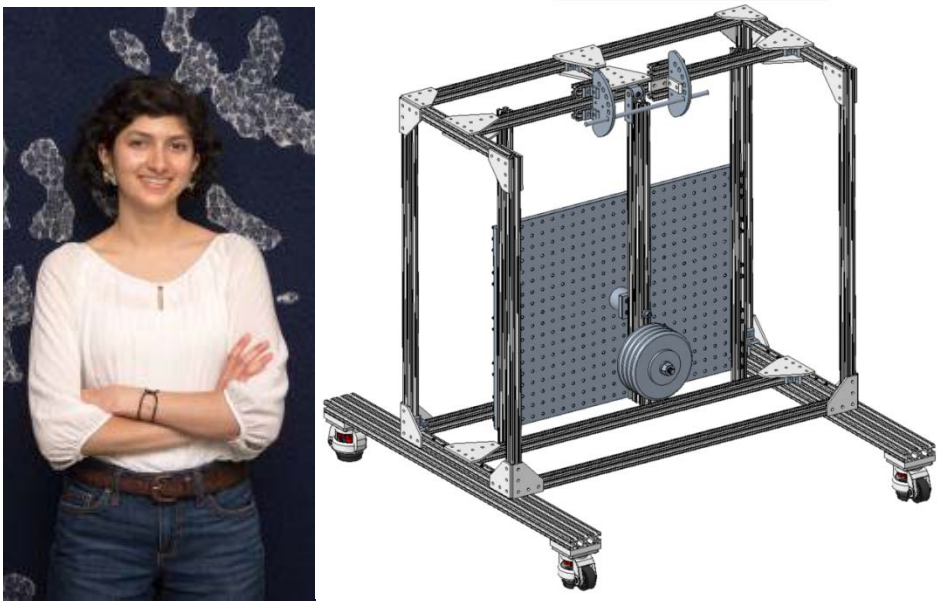
a. NanoSat TVAC Chamber

One of the most unique and favorite aspects of Princeton's nanosat program is our ambitions to outfit an entire miniature in-house spacecraft qualification test facility, all via DIY student projects. As Carter Green's ('20) senior for-credit Independent Work semester project, he designed, built, and tested the world's first sub-$2k, student-safe, zero-cryogen nanosat TVAC chamber, using a COTS educational bell jar, COTS vacuum pump, and thermoelectric Peltier cooler/heater. Carter's project report can be found in Appendix 3.



b. Shock Pendulum Test Fixture

As Shalaka Madge's ('21) summer internship, she designed a miniature shock pendulum test fixture, to simulate a nanosat's launch shock environments. The elegant design awaits another intrepid student to fabricate it, and characterize its producible shock environments.

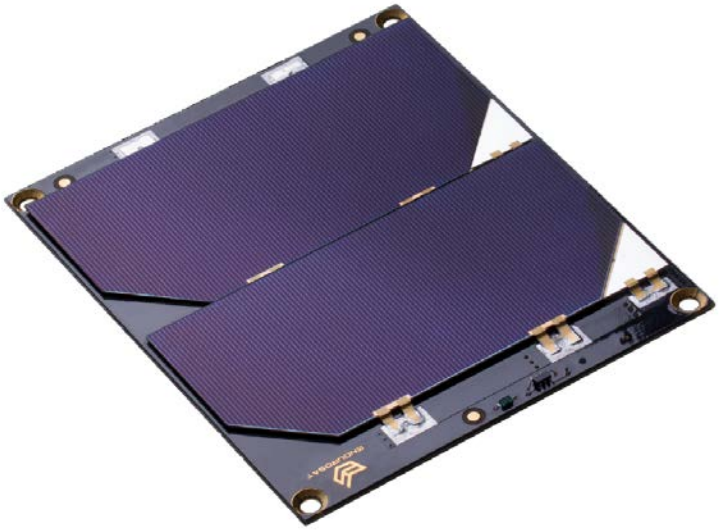


4. Other COTS CubeSat Subsystems

In combination with other funding sources, the Space Grant enabled us to procure the following COTS CubeSat subsystems (which we hope to use as design aids in order to replace with our own inexpensive DIY version soon!):

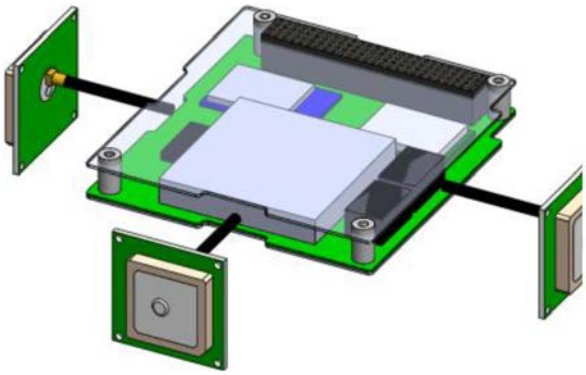
a. EnduroSat EPS Power Subsystem

b. EnduroSat 1U Solar Panel



c. NSL CubeSat Communication & Navigation Subsystem

We are applying funds towards the R&D (and eventual first procurement) of NSL's first-ever GlobalStar radio packaged in a CubeSat form factor (with integral space-unlocked GPS!). This will be the workhorse communication subsystem for the "Princeton Bus."



5. NanoSat Lab Prototyping Tools

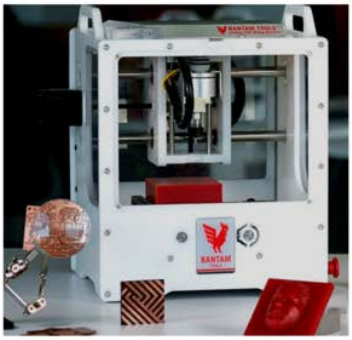
In combination with other funds, the Space Grant has enabled us to keep our nanosat lab outfitted with the latest and greatest rapid-prototyping tools most applicable to in-house nanosat fabrication, including the following:

Roland MDX-540
Tabletop CNC Milling Machine

Wazer Desktop Waterjet

Ultimaker S3
3D Printer

Voltera Desktop Circuit Board Printer



Bantam Desktop Circuit Board Milling Machine

6. Press/Media

a. http://www.towntopics.com/wordpress/2018/11/07/pu-phs-pds-team-up-for-thinsat-satellite-launch-program-experience/
b. https://www.pds.org/school-news/news-post/~post/pds-thinsat-program-announces-student-team-20181031
c. https://princetonol.com/announcement/princeton-day-schoolprinceton-university-partnership-launches-out-of-this-world
d. https://www.youtube.com/watch?v=7TMoRObjmHI
e. https://mae.princeton.edu/about-mae/spotlight/mike-galvin-and-mae-thinsat-orbital-project (same video)
f. https://twitter.com/voltera_io/status/1129403970450001921?lang=en
g. Another university article is being prepared for release (and potential subsequent media/blog coverage) after our Feb 20 ThinSat launch!