The Spacecraft Challenge:
A Student Satellite Program Accelerator

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ABSTRACT

Brigham Young University's first smallsat project, like many university smallsat projects, faced significant personnel challenges. The time required for inexperienced undergraduates to become contributing team members, combined with moderate turnover, caused overruns in the budget and schedule. To find and train future team members for employment, the student team formed a club and instituted a peer-mentored, introductory-level challenge to design, build, and fly a miniature, fully-functional model spacecraft, in one semester. At very low cost, two annual rounds of the challenge provided more than 30 students with full-cycle, design-to-flight engineering experience. Leveraging this introductory experience, many participants have now contributed to more advanced smallsat projects. We describe the low-cost project and implementation of the challenge format along with recommendations for starting similar programs at other schools.

INTRODUCTION

In establishing a new small satellite program at Brigham Young University (BYU), we found recruiting, training, and keeping undergraduate students challenging. BYU was awarded an Undergraduate Student Instrument Program (USIP) grant for 2016-2018 through NASA's Office of Education and Science Mission Directorate and an Educational Launch of Nanosatellites (ELaNa XX) opportunity through NASA Launch Services Program. Award timing and a USIP requirement that only undergraduate students contribute to the project made it difficult to find students to lead the team and develop custom CubeSat subsystems. New undergraduate students required significant training to begin contributing. Combined with turnover typical for undergraduate students, this delayed the project, making it difficult to iterate on the design before satellite delivery deadlines.

To find and train future members of the satellite team, the student team leaders started the BYU Spacecraft Club and developed the Spacecraft Challenge for new students to design, build, and launch a femtosatellite-sized model spacecraft on a model rocket, collect sensor data in-flight, and transmit the data to ground in real time, all in one semester. The challenge format is inspired by the X-Prize, and a cash prize is provided to participants who successfully complete the task[1]. The challenge provides students an overview of the spacecraft design process and an introduction to the basic skills needed in satellite development, mentored by CubeSat team members. Following challenge completion, intermediate-level opportunities are available for participants to further prepare to work on a CubeSat mission by specializing on the subsystem of their choice.

The Spacecraft Challenge has helped many students become more involved in their engineering programs through hands-on application of the principles they study. In the first and second years, the challenge has drawn an average of about one hundred applicants per year. About a quarter of these students complete the challenge and many of them have gone on to participate in intermediate challenges and on the CubeSat team. In this paper, we describe the Spacecraft Challenge, its educational impact, and its usefulness for developing a university space program.

CHALLENGE REQUIREMENTS

The core of the challenge is to design, build, and fly a model spacecraft (nicknamed a "femtosat", inspired by the KickSat Project[2]). It incorporates many typical elements of a satellite system: computer, sensor, radio, and battery system. Teams of two or three students must learn enough about each of these subsystems to integrate all components together. They design the spacecraft as a single module Printed Circuit Board (PCB). Once completed, the model spacecraft must be able to communicate with a ground station, transmitting meaningful data during launch aboard a model rocket. A picture of a model spacecraft from this previous year is shown below.

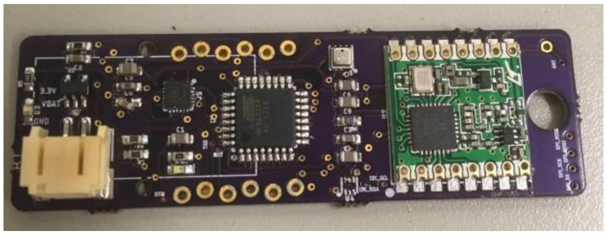


Figure 1: A "Femtosat"

LEARNING OBJECTIVES

The purpose of the Spacecraft Challenge is to teach students and prepare them to be spacecraft engineers. Through the course of the challenge, students should develop a high-level understanding of the function of spacecraft systems, learn to complete a long-term project, and develop technical skills and experience needed in spacecraft development. Students should learn about satellite systems. What role does each component play? We expect students with a big-picture understanding of the entire satellite system to be better system and subsystem engineers. Participants should also learn how to complete a long-duration project (several months). This objective requires students learn to coordinate time and effort, and work with a team to accomplish their goals.

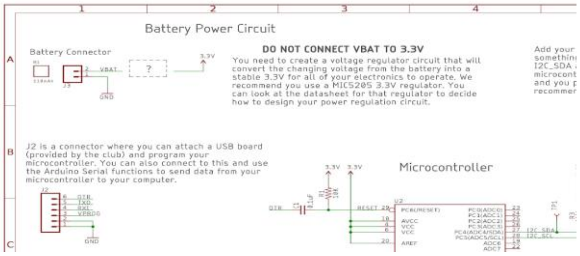
Students are also expected to learn many technical skills that will help in building spacecraft. Through the course of the challenge, participants learn how to consider mission requirements, design electrical circuits and PCBs, solder, program embedded electronics, and debug an integrated system. These skills allow students to contribute to follow-on spacecraft projects.

FROM DESIGN TO LAUNCH

The Spacecraft Challenge involves everything from designing the PCB, to assembling and testing the boards, to writing the flight software. After team formation, students get to work. To reduce fabrication delays, students first design the spacecraft's PCB. Before ordering, mentors review designs for any obvious errors. While waiting for PCBs, students develop flight software by breadboarding an Arduino with the corresponding sensor breakout boards. After PCBs are fabricated, students hand-populate surface mount components and program the model spacecraft. At the end of the semester, teams' submissions are placed in a model rocket and launched a thousand feet into the air. During flight, the model spacecraft collect and transmit sensor data, which is received by a portable ground station and later provided to the students for processing.

Design

To jumpstart design, we provide a partial schematic PDF of the model spacecraft, that has components such as the microprocessor, and interface headers as a template. A section of the starting schematic is included below. Students learn electronic design and analysis (EDA), by producing their own single-module spacecraft schematic and populating it with the processor, radio, power system, and sensors of their choice using Autodesk Eagle. Students learn to reference component data sheets to design the support circuitry around the various chips.



DO NOT CONNECT VBAT TO 3.3V

You need to create a voltage regulator circuit that will convert the changing voltage from the battery into a stable 3.3V for all of your electronics to operate. We recommend you use a MIC5205 3.3V regulator. You can look at the datasheet for that regulator to decide how to design your power regulation circuit.

J2 is a connector where you can attach a USB board (provided by the club) and program your microcontroller. You can also connect to this and use the Arduino Serial functions to send data from your microcontroller to your computer.

Figure 2: Starting Schematic

All components are suggested, but not required. Teams have the flexibility of substituting any desired components. For more technical information regarding the various components of the model spacecraft, please see Willis et al.[3]

Prior to PCB order, students are required to pass a design review to demonstrate comprehension and catch simple mistakes. Reviewers come from the peer-mentoring team and are expected to have an in-depth understanding of the project in addition to EDA proficiency.

Software

Flight software is developed in an environment that models the design as closely as possible. All parts, including the processor, radio, and sensor, are readily available hobby parts, allowing teams to practice wiring components together using breakout boards. We recommend an Atmega 328P, bootloaded as an Arduino, for the flight processor. This allows students to develop and test flight software using the Arduino Uno and the Arduino IDE. They can then deploy the same software to the final model spacecraft again using the Arduino IDE. The large online support for Arduino is especially valuable for freshmen participants with limited programming experience.

Assembly

Students hand assemble the single-board model spacecraft PCB, learning through-hole and surface mount soldering in the process. We teach a lesson on board assembly and make sure at least one mentor is proficient and available to help students through the process. Perhaps the most educational part of the assembly process is debugging. Students learn tools to isolate, identify, and resolve issues.

Launch

Launch day is an exciting culmination of an extensive extracurricular effort that represents the most challenging, hands-on engineering work many students have done. At this point, they understand the design flow from initial designs to final launch. Ideally, they understand why each step was necessary for the final product.

At the launch site, we perform another communication check between the model spacecraft and the ground station. Teams strap their payloads to the inside of model rockets and start the countdown. After launching a thousand feet into the air and landing, the rockets are immediately recovered. Any data that we collect from the transmission is delivered to the teams for further processing. Teams are required to give a brief report on their data before collecting the prize.

AFTER THE CHALLENGE

Upon completion, students apply their new skills to more advanced projects with less supervision, advancing spacecraft work at BYU. Currently without funding, many are designing low-cost CubeSat subsystems, including star trackers and reaction wheels.

Many students also organize the challenge and mentor participants the following year. They teach lessons, provide guidance, and perform design reviews.

RECOMMENDATIONS FOR OTHER SCHOOLS

If you're interested in starting a similar program, find a group of motivated student organizers and start early. You'll need to advertise, plan the schedule, set up the workspace, acquire prototyping materials and soldering equipment, recruit and train mentors, build a ground station, acquire model rockets for the launch day, find a launch site, and get any necessary site or school approvals for the activity. We recommend all mentors design, build, and fly their own model spacecraft before the program begins. For more technical details regarding the model spacecraft, see Willis et al.[3]

Be aware of the needs of the target. We designed the challenge for new engineering students with little to no technical experience. Needs may vary highly with skill level. For example, high school students may need an entire school year to finish the project.

For those interested in starting programs of their own, we are providing support files on the BYU Spacecraft Group website (http://spacecraft.byu.edu/club/).

FUTURE WORK

One of our goals in the future is to improve retention. Most students that decided to drop out of the challenge felt that they didn't have the needed time. We are hoping to make the challenge more doable by improving the teaching and resources for learning. This requires a delicate balance between providing enough support to succeed but retaining enough challenge to learn.

Participants are given a time restriction of one semester to complete the Spacecraft Challenge, which makes it a one-attempt project. While not ideal, the time required to order a PCB is a major constraint. We have had several teams that did quite well, but didn't notice a design flaw until the week before the launch. The PCBs for the model spacecraft often take several weeks to arrive, so there isn't enough time to reorder. Many teams are able to jerry-rig a solution and still fly, but we are hoping to find ways to iterate designs inside of one semester.

CONCLUSION

Students at Brigham Young University have created and ran the Spacecraft Challenge, a one-semester, peer-mentored project designed to prepare and motivate students as spacecraft engineers. The annual challenge has run for two consecutive years and has provided over thirty students with hands-on skills necessary to spacecraft projects as they design a model spacecraft. These students have gone on to contribute to other spacecraft projects at BYU and help develop the space capabilities at the university.

REFERENCES

1. "History of Xprize." XPRIZE, www.xprize.org/about/about-us.

2. "KickSat," KickSat, kicksat.github.io/.

3. Willis, Jacob, et al. "Femtosats: Elegant Flight Telemetry Payloads For Model Rockets," International Telemetering Conference Proceedings, 2018.