Ardusat Space Program: Training the next generation of Satellite Scientists and Engineers

Ben Peters
Ardusat
341 S Main St, Suite 111, Salt Lake City, UT 84111; 802-365-1778
ben@ardusat.com

ABSTRACT

Huge reductions in the cost of access to space has provided the opportunities for new groups from university labs to commercial startups to produce small satellites and participate in the new space revolution. Ardusat expands this democratization trend to almost 200 participating K-12 schools by running programs building cubesat models with consumer engineering hardware in the classroom, then using these skills to design and implement real space experiments run on Spire Global's constellation of 3U cubesats on a shared sensor payload platform.

The hands-on classroom component combined with the experiment on a real orbiting satellite enables a huge number of new students from diverse and non traditional backgrounds with an authentic space experience that leaves them excited about working in science and technology and starts them down the path of becoming the next generation of satellite scientists and engineers.

INTRODUCTION

One of the biggest changes caused by the plummeting price of launching small satellites is the democratization of access to space. In addition to enabling myriad commercial ventures, this has also sparked university engineering departments around the world to offer innovative education experiences centered around building small satellites, inspiring countless engineering students. Despite the incredible reductions in launching costs, however, they still remain far too high to be affordable for the vast majority of primary schools, and are even prohibitive for colleges and universities to pursue as supplementary curriculum or projects.

Ardusat has been working on extending access to space to a much wider educational audience by providing primary school students with engaging space science and engineering curriculum and activities culminating in experiments on actual satellites in orbit for a small fraction of the cost and complexity of a full-blown small satellite lab. Ardusat is able to achieve these cost reductions by structuring classroom exercises and design projects around inexpensive consumer hardware analogs to real satellite flight hardware, then renting out access to an educational sensor payload flying on Spire Global, Inc's 3U commercial cubesats for the culminating experiment experience, allowing data collection and interaction with a real satellite without forcing schools to pay launch fees.

Ardusat is currently working with almost 200 schools to help them launch their School Space Program. Students at each of these schools learn a variety of electrical engineering and programming skills in the context of small satellite systems and graduate having performed an actual scientific experiment on a real satellite in orbit. At the very least, this provides an excellent framework and motivation for learning these technical skills; for many students it opens their eyes to nascent possibilities in the space industry and launches them on a path to becoming the part of the next generation of satellite scientists and engineers.

OVERVIEW OF THE ARDUSAT SPACE PROGRAM

The first part of the Ardusat Space Program is centered around building up a model "cubesat" from constituent parts, one system at a time. Although this model cubesat is not made of actual flight hardware, each system is a simplified analog of a system in a real satellite, and the project allows students to get a hands on learning experience without the cost of real, low-volume flight hardware. Along with each satellite system, optional curriculum components provide exercises which allow interested classes and/or students to learn more about the science underlying the system they are working on; these curriculum exercises allow the project to be seamlessly integrated into existing science classes that need to teach to established science standards. By choosing which optional curriculum modules to teach, schools have flexibility to implement their Space Program in a piecemeal fashion if they don't have the free time in their science classes to teach the entire unit. A detailed description of each of the systems in the model cubesat is provided later in this paper.

After schools have completed the components they have elected to build of their model cubesats, the second part of the Ardusat Space Program consists of a High Altitude Balloon (HAB) launch. Although not every school in the program performs a HAB launch due to the cost, time investment, and technical knowledge required, Ardusat encourages schools that have the resources and teachers willing to take on the challenge to look into the HAB as it provides an excellent "near space" experience for students with more of a hands-on component than their later space experiment does. One lower-complexity alternative that some member schools opt for instead of a HAB is to do a tethered balloon launch. A tethered balloon involves building a similar payload to a full HAB, but doesn't require tracking infrastructure to be as sophisticated, and doesn't require the same investment in ensuring recoverability and clear air space (both of which can limit launch locations and times). No matter what a school opts for, this portion of the Space Program serves as a "readiness" test to integrate the technical skills learned in the first portion of the program and prepare for the space experiment.

The final portion of the Ardusat Space Program has schools run a real experiment on a satellite in orbit. Ardusat is the exclusive educational partner of Spire Global, Inc, which flies a constellation of 3U cubesats gathering weather and commercial ship and airplane tracking data. This enables schools working with Ardusat to run experiments on an educational sensor payload in orbit without paying the prohibitively high launch costs or taking on the historically significant risk of inoperable cubesats post deployment.

DEMO CUBESAT SYSTEM MODULES

The goal of the Ardusat model cubesat is to use inexpensive consumer hardware to introduce a subset of the engineering concepts and skills required to build a fully functional cubesat. This approach leverages the success, wide adoption, and incredible online learning resources available for hobbyist platforms such as Arduino microcontrollers and XBee radios to control costs and reduce complexity to remain approachable to our target market, at the cost of some modeling fidelity.

Frame

The Ardusat demo cubesat frame comes from the original 1U ArduSat CAD files, slightly modified for ease of construction with off the shelf connection hardware and 3D printed materials. Students can use building the frame as a project to learn the basics of 3D design software and important new prototyping tools such as 3D printers and laser cutters. The cubesat frame consists of 4 pieces which are usually printed by students using ABS plastic, then assembled using plastic hardware. Internal plexiglass plates are cut using a laser cutter to mount circuit boards for the subsystems. This eliminates the need for custom PCB design and allows students to customize or make substitutions for any of the subsystems with off the shelf breakout boards if desired. Ardusat publishes the CAD files for this adapted cubesat frame online free of charge.

Onboard Computer

The onboard "computer" of the demo cubesat is an Arduino Uno-derived microcontroller (at the time of this writing, most kits were using the Spark Fun Red Board). Arduinos are one of the most popular beginner microcontroller platforms in the world, and students in the Ardusat Space Program benefit greatly from the wealth of information and tutorials found in the online Arduino ecosystem. Depending on the focus and goals of the students and teacher implementing the program, the Arduino microcontroller can be used as an entire introduction to programming, with students starting out with simple "blinking light" exercises, experimenting with control flow concepts, and binary data types before diving into more advanced concepts such as analog and digital sensors, I2C communication, serial and other networking protocols. Other programs may choose to put less emphasis on programming and use slightly modified versions of example programs to monitor payload sensors and other cubesat systems and communicate with the computer, rather than doing a deep dive and writing their own. In this latter case, the focus of the school's program is typically directed toward payload sensors or space science exploration rather than learning programming.

The OBC is connected to an external SD card controller to enable persistent data logging and make more memory available. This connection can either be via a serial bus "echoed" by the SD card controller for a simple write-only interface that is easily debugged with an attached computer, or using FAT16 drivers that support R/W as well as rudimentary filesystem operations, but require a much larger chunk of the Arduino's available memory.

Ardusat has a second cubesat OBC option using a Raspberry Pi 32 bit ARM SOC running Linux. The Pi is one of the most popular SOCs available in the hobbyist/"maker" community at this point in time, and thus has a similarly large community and world of online tutorials as the Arduino. However, in much of the K-12 educational community, the increased complexity of running headless Linux compared to a programmable microcontroller makes it a less attractive option. Nevertheless it is an important alternative for groups that are interested in more sophisticated OBC use cases.

Power System

The power system of the cubesat consists of some hobbyist solar panels connected to a simple charge controller and a lithium ion battery. This configuration allows for the monitoring of the charging current and a few other charging parameters via analog I/O on the Arduino OBC. The Ardusat Space Program uses the power system as a jumping off point for a number of lessons on electricity, including its generation and importance to modern society, in addition to the discussion of power systems in real cubesats.

Radios

Students have several radio options for their model cubesats, but the most common is an XBee radio (based on IEEE 802.15.4). These hobbyist radios are relatively inexpensive, and support a variety of configurations, from simple point to point communication to more complicated mesh networks. In some cases students build their own antennas as an introduction to soldering and the basics of RF, then do a scavenger hunt using handheld receivers and their homemade antennas to find a point radio source. The Xbee radios support configuration via AT commands, or a GUI-based tool to make this easier. In cases where better radio performance is desired (live streaming from a high altitude balloon, for example), 900 mhz radios are used to easily achieve ranges of 40+ miles line of sight. One of these 900 mhz options has open source firmware, which provides an opportunity for interested students to do a deep dive into radio technology. Students are also encouraged to design their own antennas and experiment with antenna orientation and its effect on radio performance as part of their exploration of radio technology. The radio modules can also be a jumping off point for lessons teaching about the electromagnetic spectrum.

Sensor Payload

The sensor payload on the demo cubesat is a replica of the sensor board currently flying on Spire's "Lemur-2" class 3U cubesats, with slight modifications to the connectors to make them more classroom friendly. It contains the following sensors, all communicating over I2C:

- LSM303 Accelerometer/Magnetometer
- L3GD20 Gyroscope
- TSL2561 Luminosity
- TSL2591 HDR Luminosity
- ISL29125 RGB Light
- TCS34725 RGB Light
- MLX90614 IR Temperature
- TMP102 Ambient Temperature
- ML8511 UV Light
- SI1132 UV/Luminosity

These sensors are all relatively common in the maker community, and have well-vetted open source drivers and example programs for students to play with. Ardusat provides a SDK for the Arduino microcontroller that contains drivers for each of these sensors, enabling students to easily hook the sensor payload to the Arduino OBC and gather scientific data from their classroom environment while they learn about the physical quantities they can measure in preparation for designing their own real space experiment. When they are ready, students can use this code written with the Ardusat SDK as the basis of their experiment to be uploaded to the Spire satellites to gather data.

Guidance/Stabilization

This is one important subsystem that is currently missing from Ardusat cubesat kits in program classrooms, however Ardusat has talked with some of the schools about putting together a simple 1-axis pointing control system using off-the-shelf components as an engineering and beginning control theory lesson. In the future, Ardusat looks forward to integrating a 3-D reaction wheel control system with cubesat kits so that advanced students can have a taste of this deeply important and challenging topic.

HIGH ALTITUDE BALLOON FLIGHT

After students have familiarized themselves with the cubesat systems in the process of building their demo hardware, Ardusat encourages schools to look into the feasibility of launching a high altitude balloon as a (relatively) inexpensive, hands-on, "near space" experience. Schools are provided with numerous online resources on HABs based on previous experiences, and have a variety of recommendations for the specialized systems required for successful balloon flight and payload recovery. In some cases Ardusat has even traveled on site to assist with the balloon operations.

When properly conducted, HAB flights can easily reach altitudes in excess of 100,000 feet, which is high enough to capture stunning pictures and video showing the curvature of Earth and the blackness of space while recording data on properties of the upper atmosphere. Unlike the code-and-data based experiments on the Spire satellites, HABs also allow the students to physically construct their own payload, giving them a uniquely memorable experience.

HAB Communication Systems

In addition to the model cubesat hardware described earlier, a typical school's HAB payload requires some extra communication systems to aid in the recovery process. At a minimum, Ardusat advises some form of satellite communication system that can send a "breadcrumb" with telemetry data periodically. The simplest option is the integrated SPOT rescue/tracking beacon, originally designed for outdoors sports enthusiasts. This device sends out position and tracking data below 60,000 feet which is viewable in SPOT's online portal. It has the advantage of being self powered, ruggedly built, and ready to use out of the box; however some groups prefer to use a custom built solution consisting of an external GPS module attached to the payload OBC, which reads position data, then constructs a data payload for transmission using a RockBLOCK satellite modem to communicate on the Iridium communication satellite network. These data packets then require some additional server side processing to be useful, but configuring this system is a valuable learning experience, and allows a limited amount of live sensor data to be streamed along with telemetry for live tracking on the ground.

Some schools fly 900 mhz radios in addition the satellite communication system to stream live data as long as line of sight can be maintained between a ground-based antenna and the HAB. These radios have displayed excellent performance with continuous data transmission to above 100,000 feet and over 40 miles downrange.

Ardusat encourages schools to fly cameras on their HABs, since the pictures and video taken from the edge of space are stunning. These cameras can be a completely self contained unit such as a GoPro, which is configured to either take continuous video or a sequence of still shots and operates entirely autonomously from the OBC. Another option is to use a more hobbyist friendly camera such as the Hack HD, which also saves media to an onboard memory card, but can be controlled using a wire interface from the OBC.

SPACE EXPERIMENTS

As a culminating experience, Ardusat Space Program students can run their very own experiment on Spire's satellites. The satellites typically fly in a nadir-pointing orientation with the sensor board pointing toward Earth. By the time they have run a space experiment, students have done enough classroom exercises that they have some understanding of both the technology and science involved on the real cubesat, at least at a high level. This helps inform their hypothesis development and helps them design creative experiments.

The sensor board on the Lemur-2 class satellites is very similar to the sensor board described in the "System Modules" section above, with the addition of a few more expensive sensors including a MLX90621 64 pixel thermopile array and a RD3024 Geiger counter. This sensor board is connected to a 32 bit ARM-based OBC via a dedicated, multiplexed I2C bus. C code written by the students and tested in the classroom on Arduinos can be compiled and linked against a proprietary Ardusat-written shared library emulating the Arduino API, resulting in a binary that can run on the satellite's OBC to query payload sensors and store data for download to Earth. Many schools that have more of an emphasis on science than programming in their programs opt for the "no-code" option which specifies the sensors to log, logging start time, frequency, and a few other parameters, then gets scheduled on the satellite's OBC without the need for any custom code at all.

EXAMPLE IMPLEMENTATION OF THE ARDUSAT SPACE PROGRAM

Cache Valley Makers

One case study of the Ardusat Space Program in action can be found with the Cache Valley Makers after school group of young women, organized by Kevin Reeve in Logan, UT. Over the course of Fall 2015, these young women, aged between 10 and 16, began learning engineering technology by building up a model cubesat for use as the payload for a high altitude balloon flight in November 2015. The group started out with an exploration of radio technology, building their own radial antennas and learning how to solder in the process. This paved the way for a scavenger hunt activity searching for a radio beacon source, which was later repeated during the actual HAB flight to conduct the final pinpoint search for the payload after landing.

After the RF unit, the girls began to learn basic programming using the Arduino microcontroller. They broke into pairs, with each pair of girls assigned one of the Ardusat payload sensors to research and learn how to use. The girls soldered their sensor onto a breakout board, then wired it to an Arduino running a program they wrote using the Ardusat SDK to communicate with the sensor. Once they successfully got the sensor up and running, the girls used it to explore their classroom and outdoors, getting a sense for the range of values for that physical quantity found in a familiar environment. Based on this real world experimentation and some online research, each pair of girls presented back to the group and brainstormed some ideas for interesting investigations to make using the sensor on the HAB flight and in a real space experiment, as well as predictions for what they would observe.

At this point, the group decided to work on building their HAB payload instead of getting deeper into the electromagnetic science lessons or some of the other areas that the Ardusat Space Program provides lessons for. They used carbon fiber hunting arrows and posterboard to make a cube-shaped payload box, inside of which they affixed their Arduino. They created a small mounting platform for a sensor payload board to point down toward Earth and programmed the Arduino to read and record data from these sensors to a microSD card. Ardusat provided the group with a pre-built live streaming data unit based on 900 mhz radios featuring a second sensor board and GPS. This radio live streaming was able to get location, telemetry, and sensor data from the HAB payload for the majority of its flight, with reception only failing when the balloon dropped below the mountains to the east of Logan, UT, breaking line of sight with the ground antenna.

The girls filled the balloon themselves on the day of the flight, taking extreme care to avoid contamination of the latex balloon's surface with potentially destructive skin oils or contact with the ground. They all were able to take part in the attachment of the payloads, final flight checks, and enthusiastic countdown to launch. Many of the girls also participated in the chase and eventual capture of the balloon, which involved a long drive, careful planning and monitoring electronic maps, and eventually hiking through the high Utah desert to find the payload.

This experience left the girls excited about working with technology and science. Many of them are continuing to work in the Makerspace, and are extremely interested in pursuing careers in science and technology, including aerospace and small satellites. They are currently working on designing an experiment to use the IR sensors on the Spire satellites to attempt to measure temperatures and cloud cover over the US Rockies to investigate mountain snowpack and learn about the critical role water plays in the ecology of the US West.

Summerland, BC District 67

An elementary school in Summerland, BC decided to participate in the Ardusat Space Program out of excitement about the opportunity to be one of the first schools to run an experiment in space. They got an early version of the demo cubesat kit, and added a custom camera (the Hack HD) in addition to the usual payload. In spring 2016, they successfully ran an experiment on a Spire satellite. Wanting to provide a personal and memorable experience for their students, the teachers involved had each student in their class write a short message. These messages were concatenated into a text file which was uploaded as a kind of virtual "capsule" to the Spire satellite, where it will remain on the main SD card until the satellite eventually deorbits.

In addition to the personal messages, the students collected data from the satellite once every minute over the course of a single orbit. The students then looked up the local time on the surface of the Earth for the location under each data reading, and categorized them into day, night, and dawn/dusk. They then compared these categorizations to the data from the various light sensors to build a simple model of when the satellite appeared to be in eclipse and when it was in sunlight. This led to a discussion of the geometry of the Earth - Sun system, and how eclipses work.

Another group of students used the UV data from the SI1132 to calculate approximate UV Index values, then compared it to conditions found in familiar conditions on Earth, including a sunny summer day at the beach. They concluded that Low Earth Orbit is not a good place to be without a good coat of sunscreen!

CONCLUSION

The Ardusat Space Program uses consumer hardware and access to a shared payload to provide compelling educational space experiences at a dramatically lower cost than has been historically available. This low price tag enables many more students to experience the fruits of the small satellite revolution. If even a small portion of these students are motivated to pursue a career in satellite technology as the result of their school-age experiences, Ardusat will have succeeded in its mission to help democratize access to space and inspire young people. Space technology in turn will benefit from the next generation of scientists and engineers having more diverse and non traditional backgrounds. The focus on consumer hardware and better integration with the rest of the engineering and technology community will hopefully drive these young engineers to more creative solutions that bring down the costs and lower the barriers to entry to space even further in the future.

Acknowledgments

Ardusat would like to thank Spire Global, Inc for their generous partnership, engineering support, and continued enthusiasm for Ardusat's educational mission. Ardusat would also like to thank all the amazing school groups that we have had the privilege of working with; especially those who have allowed us to use their experiences as case studies.