S4: WiFi Stu
Satellites for
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by Ken Biba
Director of Eduction, AeroPac

S4: Small Satellites for Secondary Students

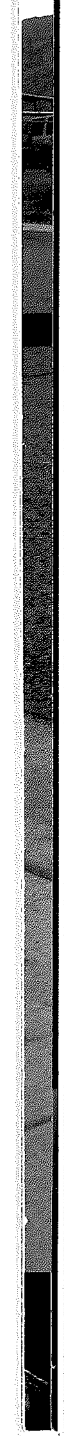
S4 was created by Dr. Lynn Cominsky and her talented science education team at Sonoma State University sponsored by NASA[1]. It extends to secondary students the inspiration for STEM education of the university level ARLISS (A Rocket Launch for International Student Satellites) program[2,3] in building smart robots and science payloads. It is an elegant example of extending the Internet of Things to science, students, and space[4]. AeroPac[5] is proud to be a partner with Dr. Cominsky and her team in bringing S4 to fruition.

S4 leverages the success of the NAR's TARC (Team America Rocketry Challenge) in using the physics of rocketry to inspire STEM by extending student activities to true science payloads that allow experiments to be designed and implemented using intelligent sensors. The payloads are programmed to collect data—data that can then be analyzed to provide a better understanding of the physical phenomena being measured. It enables students to do science at an accessible cost for the capability.

Small satellites owe their existence to the ideas and passion of Professor Bob Twiggs, then at Stanford University (and today at Moorehead State University), for his invention of the CanSat—the first student satellite. The CanSat idea—of being able to include the functionality of a "real" satellite in something the size of soft drink can and flown by small hobby sounding rockets by amateurs—was the genesis of ARLISS 15 years ago, other CanSat programs, and CubeSats (nano cubical satellites that are 100 mm on a side). We now see LEO CubeSat programs being crowd funded on KickStarter, venture financed CubeSat companies being started, CanSat sized payloads being flown to 30-50 kilometers on ARLISS Xtreme airframes, and the creation of new CanSat derived education programs such as S4 and PocketQubes[6] (femto cubical satellites that are 1/8 the size of CubeSats—50 mm on a side).

The S4 Satellite Payload

The core of S4 leverages the success of the Arduino[7] computing platform. Arduino is based on open source hardware and software delivering a sophisticated set of tools to create robots and science experiments. S4 is an Arduino platform that includes basic data collection hardware and software for GPS positioning, three-axis acceleration, three-axis magnetometer, barometric pressure, humidity, and temperature. The exemplar S4 payload software logs these data at 1 Hz to both a local microSD card and also via WiFi telemetry to the ground.



A 3" airframe rocket designed to carry an S4 payload to 800 feet on a G80, and much higher on H and I motors.

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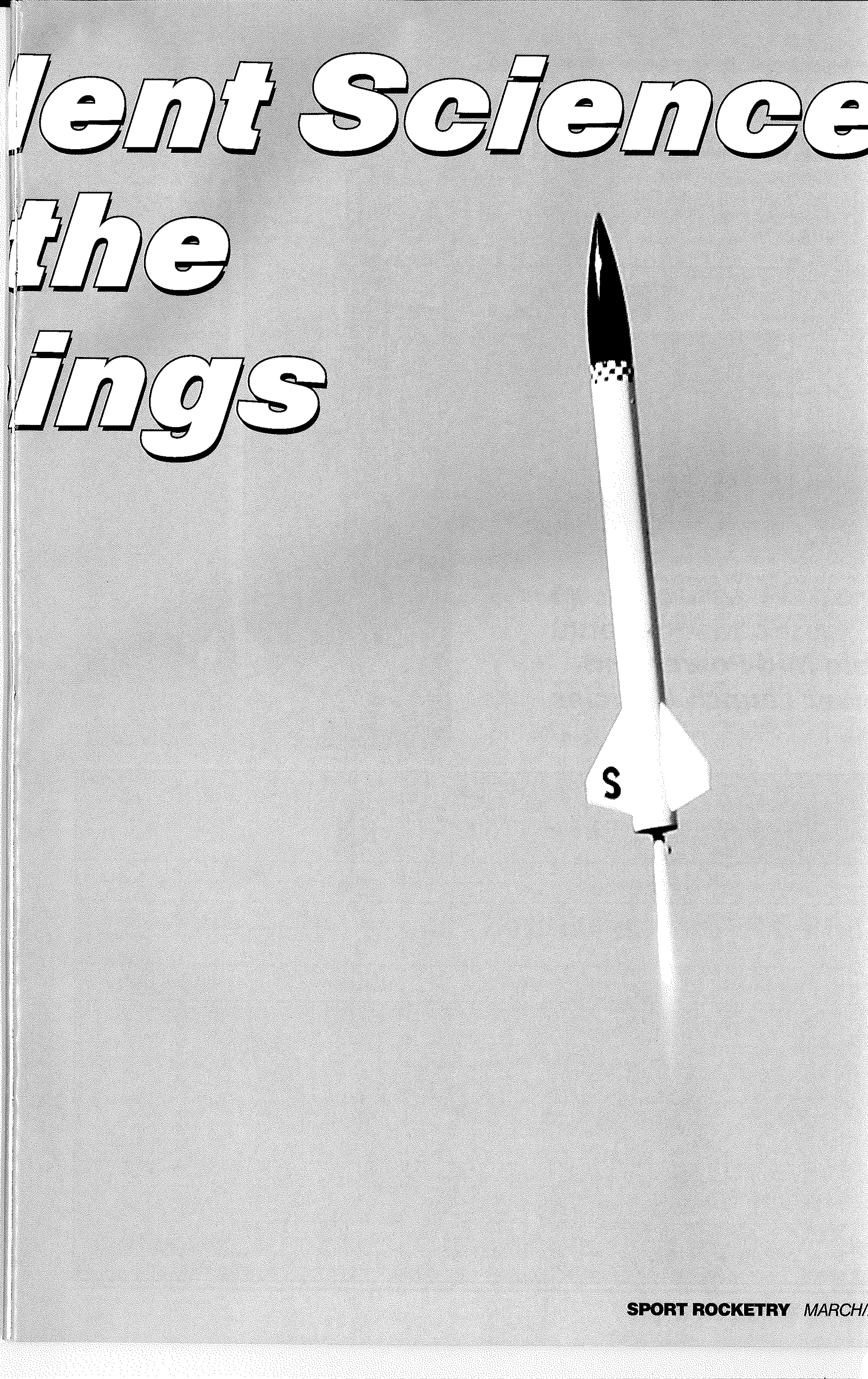
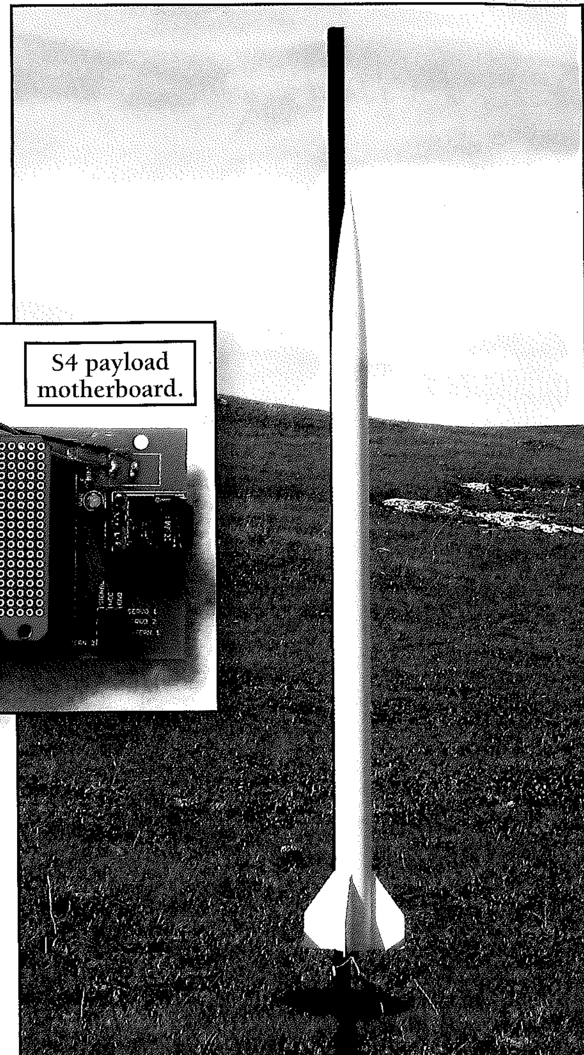
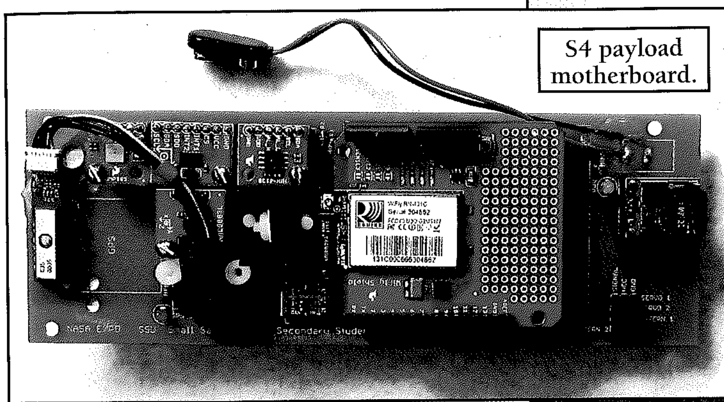


The S4 payload sends real-time telemetry to a server computer on the ground using IEEE 802.11 wireless networking—commonly called WiFi. Since the S4 telemetry protocol is based on the Internet standard IP protocols, and the server software based on Java, this server can be local to the launch site or be located anywhere on the Internet.

The S4 payload consists of an open source motherboard in which an Arduino, a WiFi communications shield, and individual sensor breakout boards construct a complete payload.





S4 payload motherboard.

The S4 payload can be powered from a single 9V alkaline battery.

Since the hardware and software are open source, different new sensors are easily added—actuators, gyro, radiation, dust, gas, and others not yet imagined. SparkFun[8] and AdaFruit[9] are but two of the open source hardware vendors providing sensors and platforms.

The complete package of Arduino software for the payload and Java based server software for Mac OSX, Microsoft Windows, and Linux can be downloaded from the project web site[10].

Since the WiFi telemetry link is based in the Internet's standard IP protocols, the server can be anywhere on the Internet.

Accessible Mid-Power and High-Power Launch Vehicles

The S4 payload fits in a variety of mid and high power rockets (and teth-

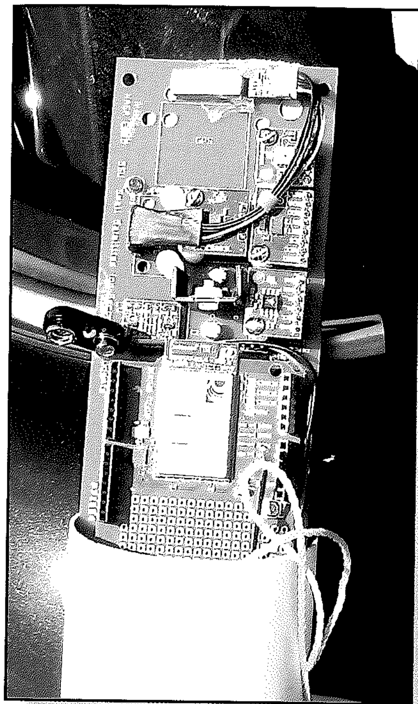
S4 Motherboard	S4 uses a custom motherboard that can be obtained from Sonoma or can be printed independently. It provides power, mounting and connectivity to the Arduino, the WiFly shield and the sensor breakout boards	http://s4.sonoma.edu/?page_id=169
Arduino Uno	S4 is based on s standard Arduino Uno	https://www.sparkfun.com/products/11021
Barometric and temperature sensor	BMP085 barometer and temperature breakout board	https://www.sparkfun.com/products/11824
3D Accelerometer	Triple axis ADXL345 accelerometer breakout board	https://www.sparkfun.com/products/9836
3D Magnetometer	Triple axis magnetometer breakout board	https://www.sparkfun.com/products/10619
Humidity and temperature	Humidity and temperature sensor breakout boad	https://www.sparkfun.com/products/11295
GPS	uBlox GPS breakout board designed for high dynamic environments like rocket flight	https://www.sparkfun.com/products/11571
WiFi shield	An IEEE 802.11b/g WiFi shield for the Arduino. Provides the basic Internet IP radio telemetry capability	https://www.sparkfun.com/products/9954
SD card data logger	OpenLog data logger that logs sensor readings to a standard FAT32 formatted microSD card.	https://www.sparkfun.com/products/9530

ered balloons) and can deliver useful rocket flights to 800 feet on an F motor, to mile high flights on an I motor, to two miles high on an ARLISS K or M airframe.

Tony Alcocer, the President of AeroPac, created a custom designed 3" airframe with 29mm motor mount for the S4 payload. Designed to fly to 800 feet on a G80. Built to HPR standards, it can fly much higher on H and I motors.

Some commercial 2.5", 3", and 4" airframes fit the payload as well. I use an off the shelf AeroTech IQSY Tomahawk kit whose 2.5" airframe and payload bay is a perfect fit for the payload.

The S4 payload can also fly in a standard ARLISS K or M airframe to about 10,000 feet AGL. An ARLISS K will fly one S4 payload at a time on a K550. While ARLISS M payloads are mostly today one-kilogram Open-Class autonomous robots, the original ARLISS M launched three CanSat sized payload as a three satellite cluster launcher. Could someone imagine designing an experiment for connecting three S4 collaborating payloads at once over WiFi?



Not Limited to Rockets—Balloons Too!

The S4 payload is not limited to rockets—it can work in a number of places as an experimental platform. Tethered balloons. Bicycles. Automobiles. Walking. Anyplace the telemetry link can extend to and the payload can fit. And even beyond, since the payload records data to its microSD card in the event that the telemetry link is lost.

Connecting the Payload to the Internet

One of the unique features of the S4 payload is using WiFi and IP protocols for telemetry from the sky to the ground. The payload contains the client WiFi radio and IP protocols—it connects to a ground station that provides telemetry storage, display, and retrieval.

The S4 payload has a very capable WiFi client that implements the IEEE 802.11b radio that directly communicates to an S4 ground station, and in addition it implements the Internet standard IP and TCP protocols used to carry telemetry transmissions.

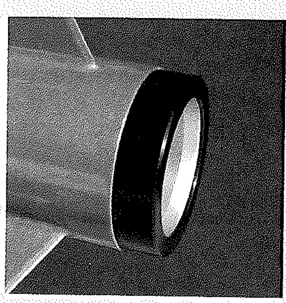
There are two examples of a base station: the AeroPac Virtual Classroom which can track payloads to much higher altitudes and which we use at Black Rock for ARLISS and ARLISS Xtreme flights; and the Virtual Classroom-Lite for individual or smaller school projects.

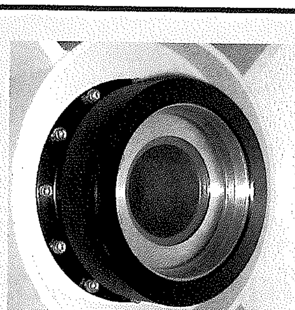
The use of WiFi and the IP protocol suite for telemetry means that unlike many custom or proprietary telemetry links, S4 experiments can become a full participant in the Internet—anywhere on the Internet.

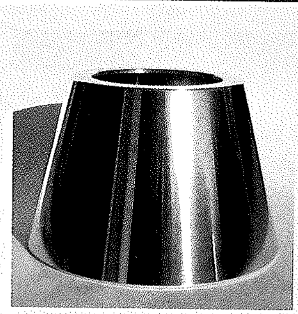
Open Source, Platform Independent Server

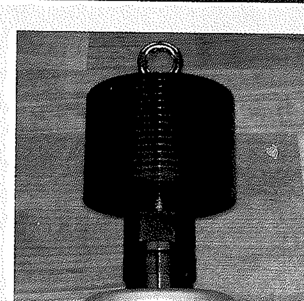
The S4 payload is designed to connect to a standard Windows, Mac OSX, or Linux computer as a server. The server computer for S4 is a standard laptop computer with Java and MySQL based data storage, retrieval, and presentation software. The server computer can be attached to the ground station via either wired Ethernet or the WiFI telemetry network itself.

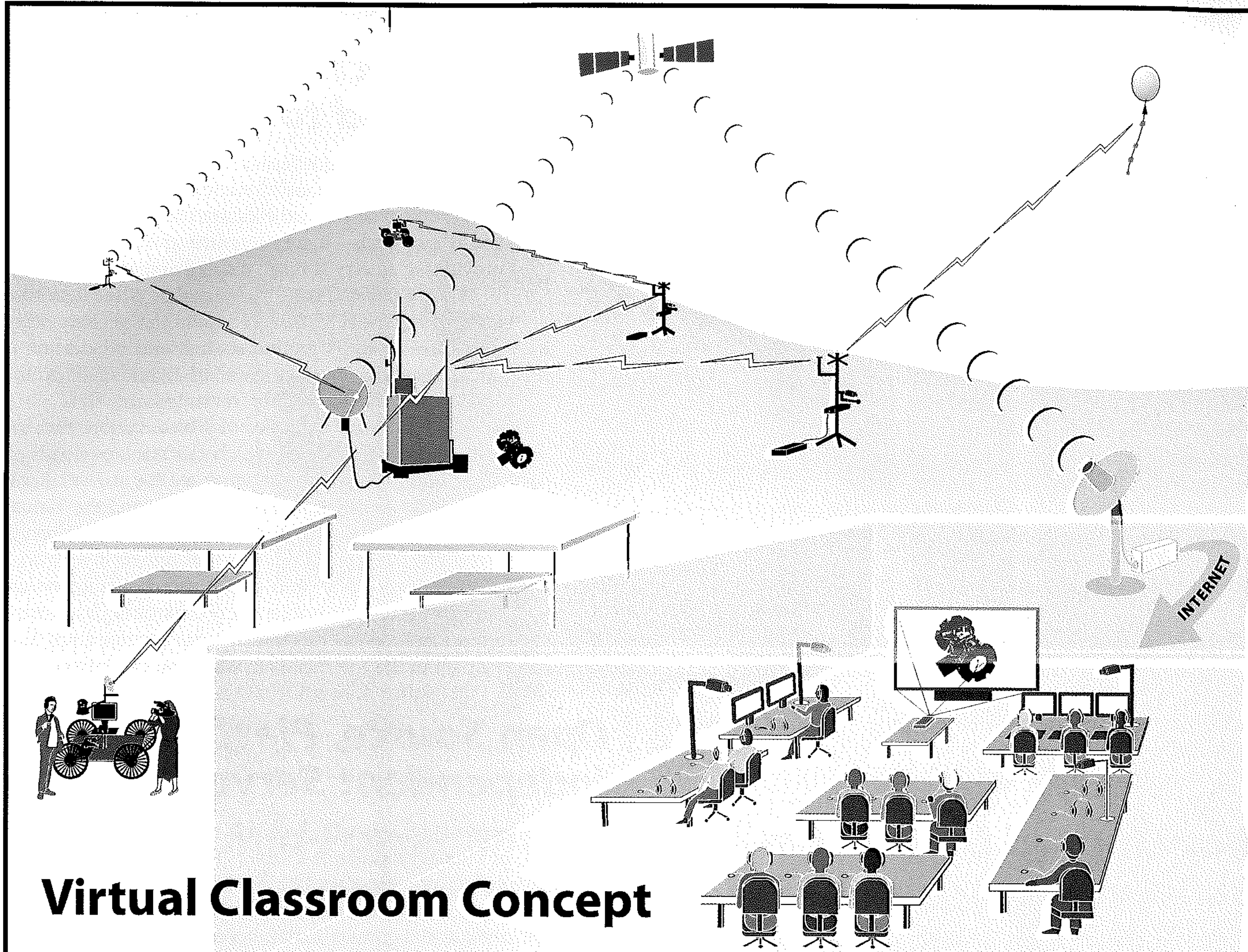
S4 uses the Internet UDP protocol to transmit telemetry from the payload to a local S4 ground station, where it is locally stored for safety and redundancy. The local S4 server instance can optionally forward this telemetry to another instance of the ground station server anywhere on the Internet.











Virtual Classroom: The Internet Everywhere

Bob Twiggs recognized that CanSats are often flown in places that are hard to get to and make collaboration difficult. The Virtual Classroom (inspired by Professor Twiggs's concept) is an integrated wireless network system to provide a distributed, near real-time electronic collaborative environment that allows video, audio, CanSat telemetry data, and participation by a worldwide community of participants in physically remote locations. For example, all of the student members of a robotic satellite team may not be able to be at the launch and recovery site. The Virtual Classroom provides all members of these teams with a broadband Internet connection to view and participate in these experiments with many of the tools that on-site experimenters might not have on site because some tools might be impractical to bring to the remote site.

The Virtual Classroom is used for the ARLISS student satellite program at Black Rock, Nevada. The Virtual Classroom provides real-time streaming video, audio, social media, and telemetry support for people, payloads, and airframes. This system was designed for ARLISS and the Black Rock desert and very high altitude flights to 30 km and higher.

The Virtual Classroom implements an S4 ground station with particularly good antennas enabling telemetry communications to extended altitudes.

Virtual Classroom Lite: The Internet Mostly Everywhere

For most users of the S4 system, the ARLISS Virtual Classroom will not be available or is simply too much capability. The S4 Lite ground station uses medium distance WiF to fit this need—with coverage to about 4,000 feet AGL with the Phase 1 payload and perhaps as high as 10,000 feet with the Phase 2 payload. This can also complement the high performance system by providing pad local coverage. It is based on using IEEE 802.11b for the Phase 1 S4 and 802.1n for more advanced projects using 802.11n for Phase 2 payload.

The VC Lite consists of a modern, high power IEEE 802.11b/g/n WiFI router[11] with multiple antennas to provide full coverage during different phases of the rocket flight. A circularly polarized high gain patch "sky" antenna[12] points up for zenith coverage complemented by a whip "ground" antenna that provides horizontal ground coverage to both server and payload. The high power of the Amped radio (600 mW) coupled with the high gain of the antennas give extraordinary telemetry coverage even with the low power payload WiFi radio.

S4 Lite Ground Station.

The ground station should be placed at the base of the launch pad adjacent to the rocket containing the payload. The whip antenna covers the ground and the patch antenna the sky. The AP will pick the best antenna with the strongest signal. It is powered by small 5 Ah 12V gel cell battery that provides a full day of launch usage.

The router is configured to provide compatibility between the VC Lite and the VC networks. It provides a fixed IP address for the server (192.168.2.27) and provides DHCP services to the client devices—the S4 payloads. Both clients and the server connect to the wireless network with the SSID of "Telemetry." Connecting this router to a wide area connection to the Internet (perhaps via a wireless cellular router) allows access to the IP telemetry from anywhere the Internet goes.

The router and the two antennas are mounted on a standard camera tripod with the sky antenna pointed up and the ground antenna attached directly to the router. Mounting both antennas a few feet off the ground significantly improves radio range. The sky antenna conveniently has a mounting hole for a standard camera screw attachment.

Flight Experience

Let's look a sample rocket flight flown during the July 2013 inaugural S4 program with teachers and educators at the ROC launch in Southern California. The payload was flown on a 3" airframe on a small H motor to about 1200 feet. Plotting the GPS data in Google Earth gives a good picture of the flight.

The GPS sensor gives a very precise report on altitude and we can use the barometric pressure sensor to plot atmospheric pressure as compared to altitude during the 210 second flight. The data clearly show the change in pressure with altitude during the flight and gives that introduction to the study of the atmosphere (see data plots on next pages).

Looking at the altitude and the humidity together shows a more complex correlation between altitude and humidity.

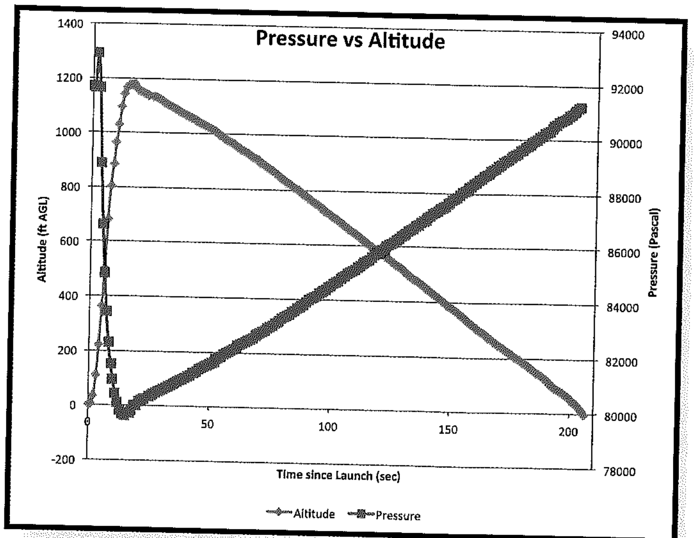
The 3D accelerometers show us the major flight events of launch and recovery deployment as well showing the effects of atmospheric drag, slowing the rocket as it coasts after motor burnout to apogee.

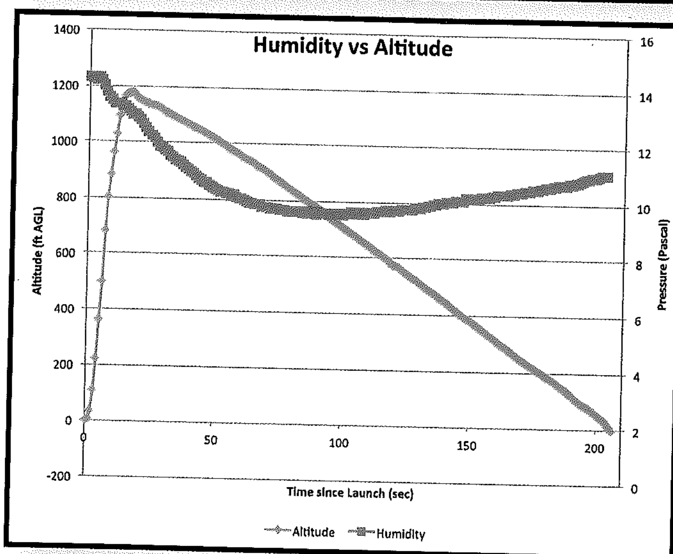
The 3D magnetometer not only measures the magnitude of the Earth's magnetic field, but by measuring in all three axes the field strength of the Earth's magnetic field can be used to give insights into the orientation of the rocket during flight—the amount of spin during ascent and the tumbling after recovery.

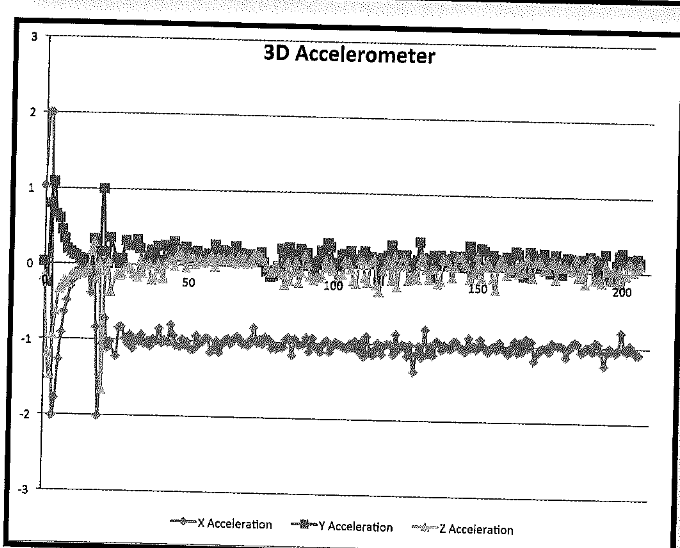
The openness of the Arduino platform allows not only these standard sensors, but also new sensors for measuring radiation, gas concentration, temperature, and imagery to be added to provide a platform for Earth and Space science investigation.

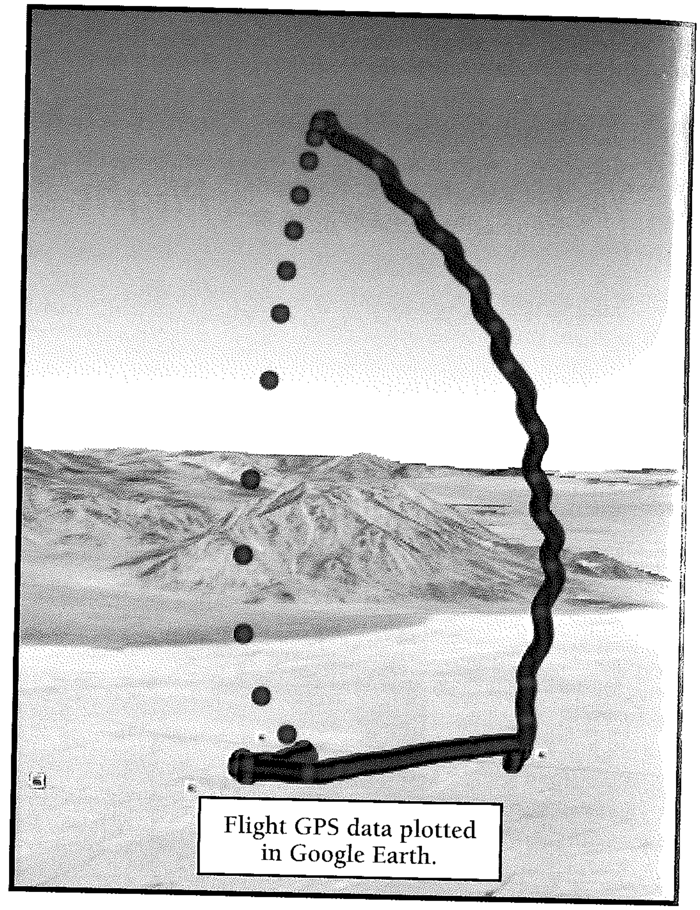
A Rapidly Progressing Platform

Just like Arduino, open source hardware, and the Internet, the fundamental S4 capabilities are rapidly moving forward.









Flight GPS data plotted in Google Earth.

An upgraded, Phase 2, hardware and software S4 platform is being constructed from an Arduino Yun[13] and the Adafruit 10DOF sensor board[14]. This upgrade in the hardware for the payload has a number of benefits:

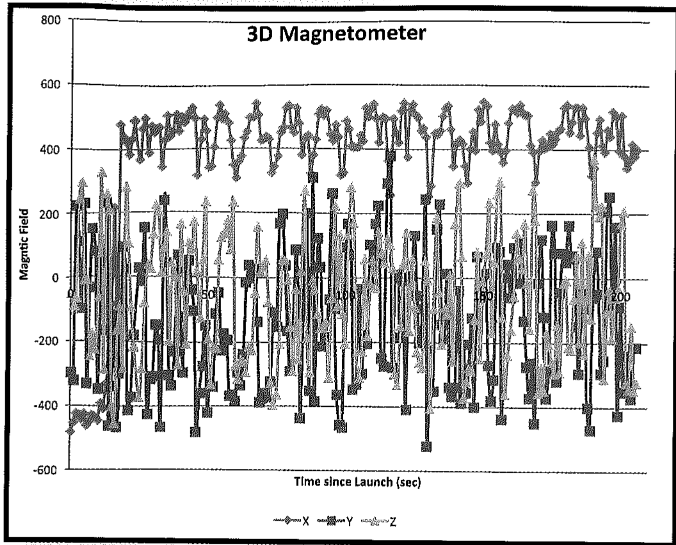
- A better WiFi data link with support for the more recent IEEE 802.11n wireless standard and five times the transmitter power
- Extends the sensors of the S4 to include 3D gyroscopes thus including all the fundamental components to build a complete inertial management unit
- Replaces the custom motherboard with a standard Arduino prototype shield reducing the complexity of getting hardware design started.

Illustrating the rapid progress of open source systems, this modest Phase 2 upgrade substantially increases the capabilities of the S4 payload just about a year after the first S4 release, and about halves the price and size while maintaining the basic Arduino and Internet platform.

The use of open source standards—Arduino and WiFi—makes the S4 payload not just a one time project, but a living platform that can expand with student ambitions and capabilities.

S4: The Step after TARC

S4 is that next step after TARC, extending the value of rocketry not just to aerospace education but to the fundamental skills of STEM. TARC introduces students to the science of astrodynamics, team collaboration, and basic physics. S4 then extends that platform to using rocketry and balloons to explore the Earth and its atmosphere by creating science satellite payloads that can explore. And because it is a standard platform, the solutions can be shared and extended among teams. It provides not just a vehicle for do-



ing something fun, but a vehicle to collaborate with other students and teachers. And being based on the Internet, S4 encourages that collaboration to be anywhere the Internet extends.

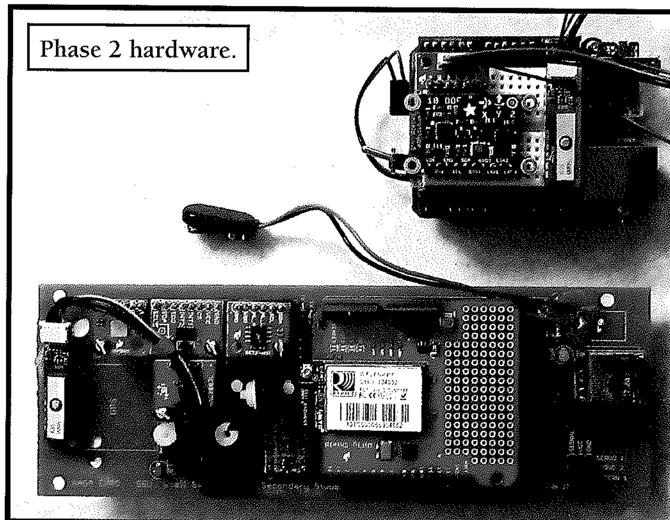
The NAR has just designed just that link—between the rocketry of TARC and the payloads of university level ARLISS. The NAR has chosen to fund the S4 payload hardware and the launch costs for an ARLISS K flight at Black Rock for five of the best TARC teams. The top twenty-five TARC teams will be invited to make proposals from which the ARLISS team will select five. These teams will be invited to design experiments using S4 to be flown at Black Rock. The teams can be physically present to fly their payloads, or, can participate remotely by telemetry across the Internet. Or both!

Summary

S4 is just beginning of connecting the rocketry, STEM, and the Internet. Interested hobbyists, students, and teachers can learn more about the program on the website or by contacting the S4 team directly (Dr. Lynn Cominsky: lynnc@universe.sonoma.edu) or the author (Ken Biba: kenbiba@me.com).

Notes

1. http://s4.sonoma.edu
2. http://arliss.org
3. *Sport Rocketry*, January/February 2014, pg. 6
4. http://www.youtube.com/watch?v=eAfH1QC7VFQ&feature=youtu.be
5. AeroPac is the oldest rocketry club flying from Nevada's Black Rock Desert and is a California non-profit educational corporation. ARLISS and S4 are two of the rocketry education programs that AeroPac supports.
6. http://pocketqub.org
7. www.arduino.org
8. www.sparkfun.com
9. www.adafruit.com
10. http://s4.sonoma.edu/?page_id=167
11. http://www.ampedwireless.com/products/r10000.html
12. http://www.l-com.com/wireless-antenna-24-ghz-8-dbi-lh-circular-polarized-patch-antenna-4ft-rp-sma-plug-connector
13. www.sparkfun.com/products/12053
14. www.adafruit.com/products/1714


Phase 2 hardware.