AEROPAC Spring 2019 Newsletter

Photo: Curt von Delius PHX4

President's Pad   Jim Green

Greetings, fellow AEROPAC members.

The equipment trailer has been getting some much-needed repairs, thanks to Tony, Becky, Evan and Peter. I'll save the details for the article in this newsletter.

The playa is pretty wet this year and MUDROCK is iffy. We will get updates as we get closer to MUDROCK

The BLM says that they will be controlling the Access Permits this year for the Burning Man closure period. I don't have all of the details yet.

Breaking news: It is with heavy heart that I must cancel MUDROCK. We have only cancelled MUDROCK one time before. This year there is quite a bit of water where we launch.

Thanks to James and Janet Flenner for the recon!

What's Inside
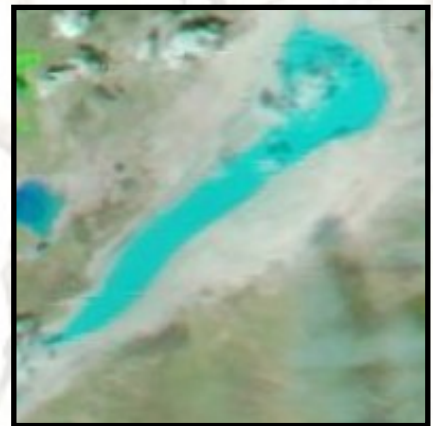
Black Rock launch site

Left: Photos from James and Janet Flenner's flyby— June 12

Above: From https:// worldview.earthdata.nasa.gov

Apr 13, May 13, June 12 respectively

AEROPACers Star in "Savage Builds" Wheel of Death Episode

William Walby assisted Adam Savage with the propulsion of a prototype "Junior" Panjamtrum. The actual Panjamtrum (above) was a WWII British ill-fated experimental weapon designed to blow away German obstacles on the D-Day beaches of Normandy

A number of other AEROPAC members and other rocketeers supported this project—Becky, Jim, Tony, and Skip Meier (not sure Skip is an AEROPAC member).

The portion of episode (Season 1 Episode 2) which features William can be seen at: https://www.youtube.com/watch?v=cGcbLapgbxE

The full episode can be viewed on the Discovery Channel. Check your provider for details.

BLM Chooses Alternative D For Burning Man

Per AEROPAC Prefect Jim Green, "the BLM has chosen Alternative D which is the same as last year's BM Event with no population increase. BLM will add stipulations to their permit requiring 3rd party security, dumpsters and barriers at the event entrances. The final EIS is on the BLM site at: https://eplanning.blm.gov/epl-front-office/eplanning/planAndProjectSite.do?methodName=dispatchToPatternPage&currentPageId=139649

The stipulations are in Appendix E Mitigation measures (which starts on page 101 of the part 2 section).

BLM also wants to control the Access Permits that we used in the past couple of years for our access to the playa during the closure period. They have not yet spelled out how the playa access process will work."

Interesting note: In an article in the Sacramento Bee on Friday, June 21, reporter Michael McGough, citing the BLM EIS, states that drug screening could start at all entrances as soon as this year.

As McGough points out "For some of its participants, drug screenings at Burning Man would pretty much defeat the purpose of the 9½-day event."

| Public Health and Safety | PHS-1 | At all portals of entry into the Event, beginning approximately 14 days before Labor Day, BLM ~~BRC~~ will ~~be required to contract a BLM-approved, independent,~~ contract third-party, private security to screen vehicles and participants, vendors and contractors, and staff and volunteers entering the Event. Third-party, private security will report ~~Closure Order violations, to include weapons and illegal drugs,~~ banned or illegal contraband or significant concerns directly to law enforcement as violations are observed so that law enforcement can respond. ~~Third-party, private security will provide an Event summary report to the BLM within 30 days of the end of the Event.~~ *Corresponding monitoring measure: PHS-1* |

According to McGough, a BLM spokesperson told the Reno Gazette-Journal that the drug screening could go into effect at this year's event, which runs Aug. 25 to Sept. 2, or in 2020.

Per McGough, Marnee Benson, who is Burning Man Project's associate director of government affairs, seemed to indicate in a post she wrote for the Burning Man Journal prior to the impact statement that major changes would not be instituted at this year's event. "We've been assured by BLM that the Record of Decision will be issued in mid-July, in time for our 2019 permit to be issued, and we're planning for NO major changes for this year's event," Benson wrote. "We understand that any major changes from the EIS may be contingent on population or other factors and could be phased in starting in 2020."

In a tribute to the 50th anniversary of Apollo 11's historic flight, join us in celebrating this magnificent machine by flying your own Saturn V! The challenge is to have (at minimum) 50 Saturn V flights over the course of the ARLISS - XPRS launch week.

Basic rules;

Any size Saturn V can participate

You may fly your Saturn V as many times as you like to help the challenge succeed.

Does not have to be scale or highly detailed - just identifiable as a Saturn V (especially from the pad)

Each Saturn V launch announcement will also announce what number the flight is.

Drag racing other Saturn Vs will be encouraged!

Though (right now) there's no award - extra points will be given for;

Number of flights by the same Saturn V

Night launch

Highest recorded altitude (altimeter data required)

Scale detail

Being #50

Here are a few sources for Saturn V models out there

Estes

Apogee Rockets (currently sold out)

Flis Kits

Dr. Zooch

If you want a fun challenge make a Lego or Paper Saturn V

Flying Lego Saturn V

Folded Paper Saturn V

Smaller Paper Saturn V

If you have a 3D Printer (or access to one) and want to build a Saturn V from 'scratch' - here's a great set of parts. These aren't "kits", they're key parts - you'll need to hone your rocket building skills to complete the bird.

Estes BT 80 Size

Estes BT 60 Sized (remix of the BT-80) (work in progress)

Estes BT-50 Sized (remix of the remix) (work in progress)

6" airframe (work in progress)

If you plan to fly your Saturn V in this challenge and would like to have it added to the Tribute Gallery upload the images here!

Club Trailer Gets Off Season Makeover   Peter Clay

As many of you know, our club trailer was showing its age in many ways. The floor was getting worn out (sagging and with a few holes in it) and it had a lot of surface rust, just about everywhere, and some of the lights were no longer working. Well….

We rented a storage locker, emptied the trailer and brought it to my place in Petaluma to begin restoration.

First task was to remove the shelving and the floor. Once the floor was out, Jim and Becky spent hours grinding and wire brushing off all of the rust. Meanwhile Tony made and installed new supports into the trailer frame. While all of this was going on the door frames were also freed of rust. Once the rust removal was completed, the main frame and door frames were painted, new seals for the doors and new running lights were installed. Tony even added some "Bling" by way of some Aluminum Diamond Plate siding running down the sides of the trailer. The trailer looks amazing and should be good to go for the next 15 years!!
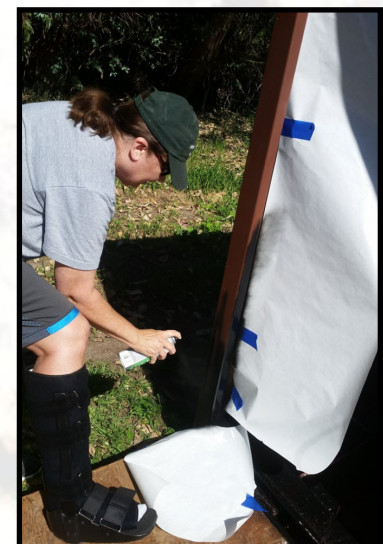
All photos courtesy of Peter Clay

A huge Thank you is owed to Jim and Becky Green, Tony Alcocer, Evan Curtis, Steve Wigfield and Gene Engelgau for their help and HARD work in this endeavor.

All photos courtesy of Peter Clay

Trailer Re-organization, New speaker System

Saturday, June 1, a number of AER-OPACER's met at John Coker's workshop to re-organize the trailer, test batteries, configure a new speaker system, empty the old bins, toss unneeded equipment and load the new bins.

Jim Green, Gene Engelau, Peter Clay, Evan Curtis, James Sampayan, Jonathan DuBose and Fred Radford
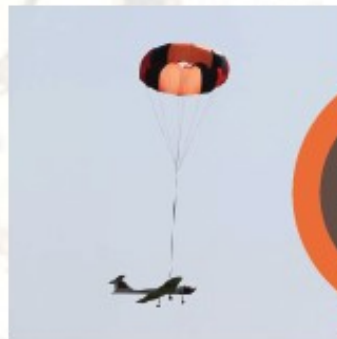
Thunda Down Unda 2019

Launching Rockets in Australia: No Worries, Mate!   Charlie Savoie

Part 1: Just Getting There is an Adventure!

I left Cedar City, Utah at about 9 a.m. on Monday morning enroute to pick up Gary Rosenfield on the way to Las Vegas as we began the journey to our first rocket launch in the outback. After arriving at McCarran International in Vegas we flew 2 and a half hours to Vancouver, B.C. and tried our best to burn 5 hours at the airport there. Luckily, they had some duty-free shopping to take advantage of, at which time I realized everything was infused with maple syrup. I think I saw maple-syrup-infused maple syrup but I can't be entirely sure. Soon enough, probably around 11 p.m., we boarded the 787 Dream-liner and began the 14-hour flight over the Pacific Ocean as we headed to Brisbane, Australia. We touched down at about 8 a.m. local time. It was now Wednesday and we were on the other side of the world.

After going through customs and jumping through a few other hoops after landing, I did some quick stretching and I could feel my body returning to its almost normal dimensions. We then headed to the shuttle bus hub and eventually boarded the one that would get us to the correct rental car facility.

The rental price was great while booking online so of course I was a bit suspicious. I pulled back on the expectations just in case but it wasn't too bad overall; no, we didn't want the insurance but thanks. This discussion went back and forth far too long before the representative finally accepted that she would not get the sale. Not today.

The all white Hyundai Accent waited for us outside where we marked up the inspection checklist with all sorts of marks. Nothing serious, mostly scratched and chipped paint. I got into the right side of the car where the steering wheel was as I prepared for the ultimate driving experience. As a bonus this Accent came fully equipped with a stick shift that you got to use with your left hand. But the real learning experience came from the biggest challenge of them all: trying to use your turn signal without using the windshield wipers.

It seems simple enough but the turn signal and the wiper handles are on opposite sides when you're down under. It wasn't crucial to our operation and the locals say it's easy to identify tourists based on the cleanliness of your windshield. I did this in error at least 50 times and if someone said it was 100 times I wouldn't even argue. Windshield was spotless though!

From Brisbane we drove pretty much directly west, almost causing an accident about 4 times or so.
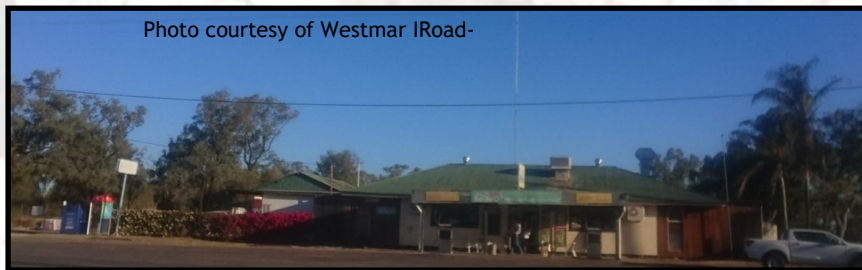
Photo courtesy of Westmar IRoad-

Photo courtesy of Charlie Savoie

Westmar Roadhouse and Charlie posing with a giant prickly pear, an introduced invasive species

in the background the eventual desolation became obvious. We were soon on a 2-way highway headed to the soon-to-be-famous Westmar Roadhouse where our accommodations would be waiting for us. 5 hours later we arrived at what would become to be known as "Bruno's of the Outback."

The Roadhouse was a conglomerate of necessities located on a corner of two highways. Two gas pumps sat out front where we didn't have to pay before we pumped the Accent full of gas. What kind of a society had we found ourselves in? Apparently a society where they just trust you to pay for your gas after you have pumped it.

After walking up 3 steps we opened the single-glass door and were inside of a convenience store/diner hybrid. This is also where we were to check in. The guy behind the counter seemed surprised that we had reservations for this particular weekend. This weekend was booked for the local police as they had to monitor an event 20 km in the other direction and this had been an annual event for many years. We nervously waited as he searched the book for our names and dates. "There you are", he said pointing into the book. A few minutes later we had the key to our room and we were all set. It was still daylight out and we wanted to get out to the range, if only for a short time.

Before heading out we unlocked the sliding glass door to our room and slowly walked in. Each room was its own building consisting of a small bathroom and a room with 2 beds, TV and mini fridge. On top of the fridge sat instant coffee and tea next to a hot plate along with a large bottle of water and some sugar packs. Inside the mini fridge was a small carton of milk to ensure your beverage of choice was perfect. We quickly dropped our bags off, hopped in the Accent and headed to the launch site, which was only about a 20 km drive from the roadhouse.

We passed a couple of flattened kangaroos while driving down the highway before arriving to the entrance of the launch site. A full-scale Iris with the Thunda 2019 logo was displayed horizontally on the left side of the road, signaling our turn-in to the launch site.

The site was located on a farm, and after following a winding dirt road for a few minutes we passed the campsite on the left and found a nice shady spot to park under.

The Beginnings of High Power Rocketry

Highlights of Gary Rosenfield's Talk at Thunda Down Unda

At the Thunda Down Under Saturday evening banquet and awards ceremony AeroTech's Gary Rosenfield gave a presentation called "The Beginnings of High Power Rocketry", primarily about the commercial propellant aspect, from his perspective. A summary of the highlight follows.

After thanking the Thunda organizers, several important information sources were acknowledged:

- Chris Pearson of North Coast Rocketry, who is a historian of high-power rocketry and provided additional information about Irv Wait

- Lee & Betty Piester (more on these folks below)

- Former NAR president J. Pat Miller on the entry of NAR into HP rocketry

- Irv Wait – Considered to be the father of the modern composite propellant hobby motors. Worked professionally at Thiokol and Hercules powder. In 1966 His company, Rocket Development Corporation (RDC), created static test equipment and also developed the first APCP motors available to rocketeers – the Enerjet-8 selling for $2.75 (quite expensive in the hobby then). This motor was the equivalent of an AT E20 performance.

  http://www.ninfinger.org/rockets/catalogs/enerjet/enerjet8.html

- Lee & Betty Piester created Centuri Engineering Company in 1961, developed larger kits for the more powerful motors and bought RDC from Irv Wait who went back to the professional commercial rocket motor industry. The RDC "Ignitrite" evolved into the Centuri "Sure-Shot" igniter.

Other key individuals in early development of composite propellant hobby motors:

- John Rahkonen of Pro-Dyne,

- George Roos of FSI,

- Scott Dixon of Vulcan Systems,

- Mark Mayhle of SSRS/Crown,

- Frank Kosdon,

- Randy Sobczak & John Krell of Plasmajet,

- Jerry Irvine of U.S. Rockets

Photo courtesy of Charles Savoie

Gary Rosenfield addressing Thunda crowd

Key points in Gary's timeline:

Early 70s - Gary attends monthly launches at Anaheim / Angel Stadium. Some city Parks and Recreation Departments would actually promoted and supported the hobby and a "Mr. Anderson" of Placentia Parks and Rec drives Gary and several rocket club members to a Lucerne Dry Lake launch.

1971 - Gary and brother Bobby discover Enerjet motors, buy several and fly them at Lucerne. Gary is totally hooked on composite rocket motors.   "I remember watching that first flight and I was totally hooked after that. The rocket took off like something out of a "Roadrunner" cartoon—just a puff of smoke from the igniter, a loud hiss and it was gone!." Progresses to multi-stage and clustered Enerjet

Enerjet E-24-7
Posted by Chris Michielssen

Present day Q-jet motors carries some Enerjet DNA

motors, meets Jerry Irvine (US Rockets) and Randy Sobczak and John Krell (Plasmajet).

1972 Enerjet catalog: http://rocketryretrospection.blogspot.com/2016/10/1972-enerjet-catalogue.html

Flies a 3 stage Cineroc Enerjet powered rocket to 7k' at Lucerne

Starts first business, Composite Dynamics and sells plans to modify the Cineroc into a "Mini-Cineroc". Also sold plans to reproduce a three-motor cluster rocket called the "2250" that Enerjet sold to commercial customers in the early 1970's.

1972 – Attends NARAM 14 in Seattle and meets Larry Brown of Enerjet. Lots of cool Enerjet flights including a 3 cluster of F67 Enerjets

1973 - Attends NARAM 15 in Columbus, OH. Scott Dixon of Vulcan Systems static tests a 1-1/2" diameter by 1-foot long motor with translucent propellant. This test was "really exciting" and further piques interest in composite motors.

Decides to make his own motors after Centauri makes decision to shut down Enerjet division. Meets "BJ" Humphries member of the Pacific Rocket Society (PRS) and the Reaction Research Society at Anaheim Stadium.   BJ Introduces him to Bill Sprague who supplies him first sample of ammonium perchlorate (AP).

September 25, 1973 – After reading every book on rocketry and propellant in exixtence, Gary manufactures and static tests his first composite propellant, 29mm x 5" with AP and polyester boat resin mixed at 3:1. "One of the most exciting experiences of my life." Successfully flies a similar motor in a Enerjet 1340 rocket.

Enerjet 1340 Rocket

Shortly thereafter, in first business transaction, sells some motors through a hobby shop.

1974 – Attends NARAM 16 in Manassas, VA – Meets Mark Mayhle who started Small Sounding

Rocket Systems (or SSRS, and later called Crown Rocket Technology), demoed several Composite

Dynamics motors there and also flew a 3-cluster of FSI F100s in a 2250

Meets John Davis, engineer at Hughes Aircraft, who was flying some high performance FSI "Thunderbolt" motors. John joined Composite Dynamics a few years later.

Enlists in US Air Force, stationed at Nellis near Las Vegas for 3.5 years. Continues intense experimentation on propellants with John Davis, flying up to 3" M class motors at Lucerne. Begins selling F and G motors using same technology.

While in Las Vegas, participated with John in the NAR-sponsored testing that eventually resulted in the

Department of Transportation (DOT) granting DOT-E 7887, an exemption that allowed the shipment of limited quantities of model rocket motors as flammable solids.

One of first to manufacture commercial rocket motors using Hydroxyl-Terminated Polybutadiene (HTPB).

Partnership with John Davis key in evolution – learned what TO do / NOT to do, variety of propellant manufacturing techniques, tooling methods and how to source chemicals and materials.

Considers these motors as first direct descendants of modern HP motors.

1977 – Attends Smoke Creek launches. The Rocket Research Institute (RRI) headed by Chuck Piper was flying large steel rockets using potassium perchlorate and asphalt propellant ("GALCIT"). Ray Goodson also involved, and he eventually influenced the group to switch to aluminum airframes and AP composite propellants.

Mike and Richard Morris and Roger Johnson flew their "Helix 1", a very large rocket using model rocket construction techniques and a cluster of about 84 Composite Dynamics 24mm F40 Motors! Ray Goodson tested his first fully-slotted and "C-slot" composite motors.

Helix rocket—look closely, that is cluster of 84 F40 motors!

Photos on this page are from http://www.rimworld.com/tripoligerlach/downloads/2014-04-04.pdf

1980 - Decides to sell interest in company to John due to "difficulties" in relationship and the need to provide a steady income to growing family. Hired at Bermite, a defense contractor making motors for the Sidewinder missile, among others, as a "junior engineer" probably because of experience with HTPB pro-pellant. Company was using an older "CTPB" poly-butadiene binder with an epoxy curative. Helped develop Bermite's version of the reduced smoke Side-winder. Worked for Dr. Claude Merrill who had been head of the Rocket Propulsion Lab at Edwards AFB which proved to be "one of the most valuable experi-ences of my life." 1980 Composite Dynamics Catalog http://www.ninfinger.org/rockets/catalogs/cd80/cd80.pdf

Korey Kline / Gary Rosenfield with their motors

Forms idea to start a new hobby rocket motor company and AeroTech is born, immediately developing the design and manufacturing principles that were even-tually incorporated into AeroTech products, including some strategic ideas that had been rejected by John, like the paper casting tubes still used today. Gained a large portion of technical knowledge from experiences with John Davis and Dr. Merrill. The rest by learning on his own through various means. Discovered that a lot of techniques and materials, which were good for military use, were not applicable for hobby use. Some military ingredients, delivering superior performance, were far too expensive for hobby rocketry.

This period was mainly one of R & D for AeroTech, Bermite work taking priority.

1982 - Joined Aerojet Tactical Systems in Sacramento, California until 1984. Responsible for technical

assistance and process improvement in all phases of propellant and liner manufacturing operations for a number of missile programs such as Minuteman, Peacekeeper, Harpoon, Hawk, Standard Missile and Sidewinder.

Experience at Aerojet shows there isn't a lot of large scale production of propellant that was useful for AeroTech products.

1984 – Left Aerojet to focus on AeroTech and expand product offering and along and with Vulcan Systems in Colorado, AeroTech brought out essentially the first commercial high-power hobby motors that were widely available in the U.S..

The first AeroTech motors used machined graphite nozzles made on a screw machine run by Korey Kline who later formed Hypertek.

Develops a line of low thrust motors to accommodate the then common, not very robust rockets. The 54mm I65, J100 and J125 moonburners. These motors were a big success for AeroTech, the I65 now released in a DMS configuration.

1985 – Co-founds Industrial Solid Propulsion (ISP), Inc. with Dan Meyer (a NAR member and fellow Aerojet employee) as a separate business to design and manufacture composite propellant rocket motors for aerospace, military and industrial applications. Moved operation to Las Vegas.

1986 – Approached by Lee Piester to form a new company (to be called Enertek) that would manufacture and sell a complete line of mid-power (E through G) motors, rockets and ground support equipment. Company develops prototypes and sales / marketing materials and generates $600k through a hobby industry show. Initial promisers of capital failed to produce and effort fails. AeroTech purchases Enertek assets in a voluntary liquidation.

1988 – Introduces first line of "effects" propellant – White Lightning following pioneer Scott Dixon of Vulcan Systems who introduced "Smokey Sam" (developed at China Lake Naval Weapons Center) and red "Hellfire" propellant. White Lightning is still AeroTech's most popular propellant.

1989 – AeroTech began to design and develop a line of mid-power rocket kits, ground support equipment, igniters and propellant formulations for the model rocket market. These products were designed to be easy-to-assemble and with large-rocket adult appeal.

Also in 1989, at NARAM-31, G. Harry Stine and Pat Miller orchestrate the internally controversial entry of NAR into the world of High Power Rocketry. Years later Jim Barrowman (think "stability") thanked Pat . "You saved the hobby and the NAR, Patrick. Thank you."

1990 – AeroTech introduces the Reloadable Motor System (RMS) under the ISP trademark. Previously all motors were "single use". The development of RMS sprang from man-rated parachute extraction systems for light aircraft. RMS was a breakthrough and highly controversial technology in the beginning and consisted of a reusable aluminum alloy motor casing and separate solid propellant "reload kits". The use of metal and the idea of "reloading" a motor had been generally frowned upon.

AeroTech feels RMS will be successful by delivering lower costs per flight and that rocketeers would find assembling the kits interesting. Encouraged to deliver RMS by father of BALLS, Steve Buck.

RMS first demo'ed at Black Rock in 1990 and first sold at LDRS that year. RMS takes rocketry to a whole new level by significantly reducing cost per flight. Interestingly, advances in designs, materials and assembly techniques have once again made single-use high power motors popular with flyers for many applications, at a slightly higher cost per flight than reload kits but requiring no hardware cost.

RMS takes AeroTech's share of market from 50/50 with Vulcan to 90%. Vulcan and Scott Dixon release a bogus video decrying the dangers of reloadable motors. This creates havoc at AeroTech and problems with the DOT and Consumer Product Safety Commission. In the end, AeroTech is cleared and granted special permit to ship larger motors and reloads economically as 1.4 C.

1993/94 – AeroTech, at the request of Frank Uroda of PML, designs and delivers a K1050 to power Dr. Soren's probe destroyer and earns screen credits for Star Trek: Generations

1994 – Until now the US Dept of Justice's Alcohol, Tobacco, Firearms Bureau (ATF) position on APCP was as long as it was used for propulsion it was exempt from their regulations. Now ATF decides propellant needs to be regulated resulting in manufacturers, dealers and consumers having to comply with all the purchasing and storage regulations that applied to low explosives restricting and discouraging sales. This leads to expansion of hybrid motors, but due to the complexity and equipment requirements hybrids present a host of issues for the average flyer.

Where Did the Motor Diameters Come From?

29mm or 1-1/8" diameter originated from Coaster/Mini-Max/Enerjet motors. 38mm or 1-1/2" diameter was first produced by Scott Dixon of Vulcan Systems in the late '80s. 54mm or 2-1/8" diameter is related to the 2" motors that were originally produced by John Davis and Gary and used in 2-1/8" airframes. Eventually we started making motors in the 2-1/8" airframe tubing and that became the standard.

98mm diameter motors were first produced by AeroTech in the late 1980s and were designed to fit LOC Precision 4" tubing. 75mm or 3" diameter motors were first suggested by Karl Baumann (and later by Dave McVeigh) as an intermediate size between 54 and 98mm diameter, and were sized to fit 3" tubing.

2001 – Fire destroys AeroTech propellant and motor manufacturing facilities in Las Vegas. Ellis Mountain manufactures propellant grains in interim and first shipments from new plant in Cedar City, Utah made in April, 2003. This period of limited supply for AeroTech leads to the rise of Cesaroni and AMW and to the growth of the "EX" side of the hobby.

2000 - 2009 - NAR and Tripoli filed a lawsuit in federal court regarding ATFs alleged unlawful regulation of APCP as an explosive. The protracted legal action was finally decided in 2009 when federal Judge Reggie Walton ruled in favor of Tripoli and the NAR. The long overreach of ATF regulation of our hobby was finally over! This also resulted in the rapid decrease of hybrid motors' presence at launches.
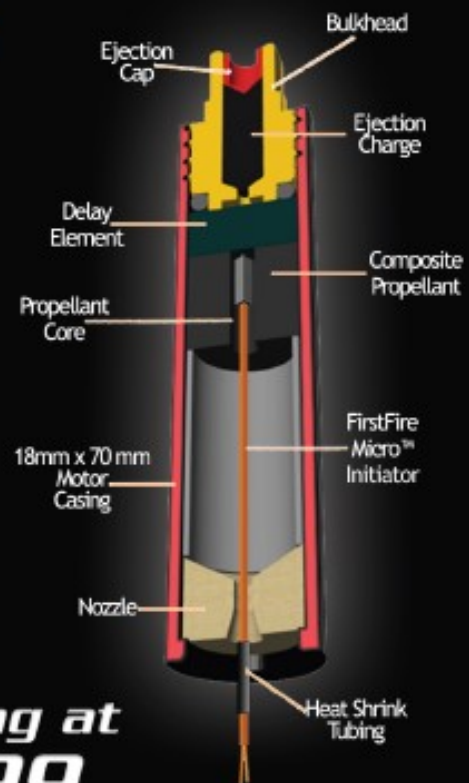
S4: Small Satellites for Secondary Students

Ken Biba[1], AeroPac, TRA 4968 L3 TAP, NAR 84610 L3

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All photos courtesy of the author

Technology and Program Overview

The S4 (Small Satellites for Secondary Students) student satellite system is an opportunity to do science experiments as rocket and balloon science payloads targeted to middle and high school students - but also useful to a much wider range of curious learners. It is based on over 20 years of the international ARLISS[2] program of university and high school student payloads that invented CanSats[3], CubeSats[4] and autonomous recovery satellite robots. It uses the PocketQube[5] format for small satellites that is the inevitable successor to CubeSats and CanSats via Moore's Law. S4 began in 2014[6] with the work of Dr. Lynn Cominsky of Sonoma State University, funded by NASA, in collaboration with AeroPac, creating science curriculum extending the ARLISS concept to secondary students. The NASA sponsored Rising Data[7] program extended the concept to STEM training for community college students.

The **S4 vision** is to imagine a progression of science experiments rooted in missions on the ground or on small rockets such as TARC[8], progressing to missions to a few thousand meters on high power hobby rockets (like ARLISS), extending to sounding rocket or high altitude balloon missions to tens of kilometers high in stratosphere and exosphere (like ARLISS Extreme[9]) and eventually to PocketQube missions deployed into Low Earth Orbit. Each step challenges student imagination and abilities with an incremental increase in scope, risk and cost - based on a common platform. The wide range of sensors and extensibility of the S4 system allow for missions in the atmosphere or the ground (and eventually space!) that are largely only limited by the learner's imagination and are tantalizing close to the capabilities of Star Trek's tricorder.
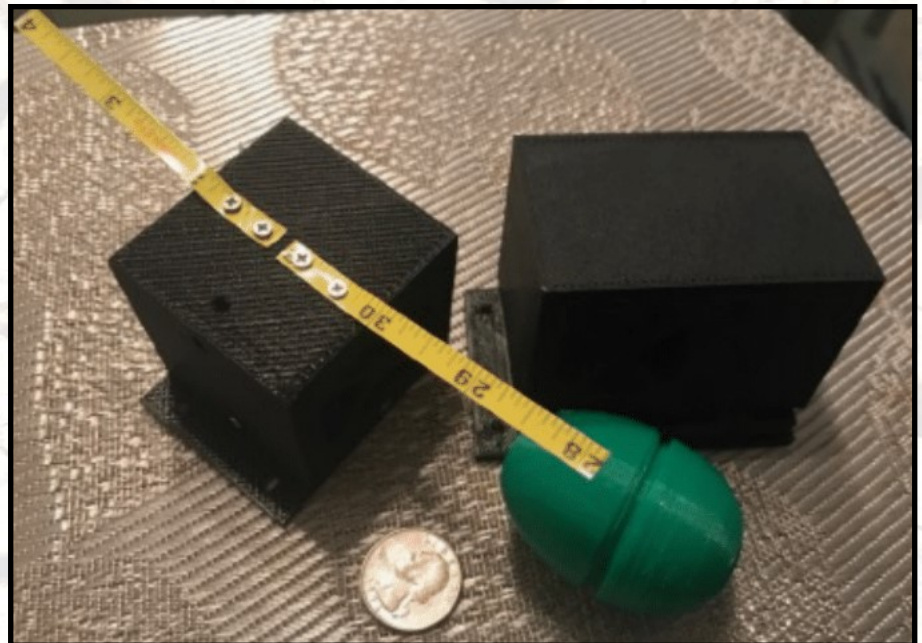
ARLISS 2019 S4 Overview

- Atmosphere science measuring aerosols, dust, radioactive residue, organic compounds, lightning, temperature, pressure, humidity, gas content;
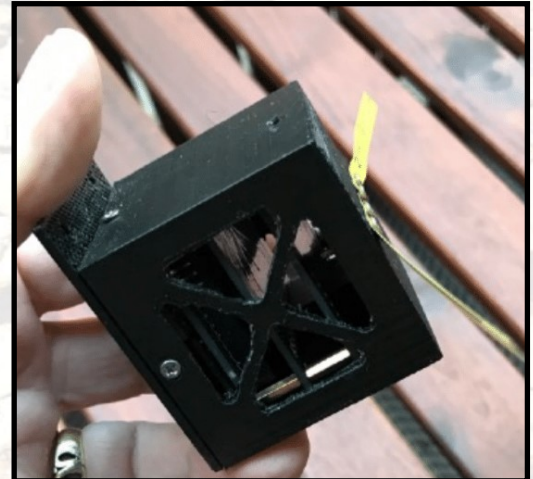
- Vehicle dynamics measuring drag, vehicle orientation, position, trajectory using GPS, accelerometers, gyros, magnetometers, temperature sensors;

- Airframe control for recovery thru servos and/or pyrotechnics;

- Satellite recovery after apogee deployment[10] via parachute or mechanically actuated recovery like steerable parasails or para-wings with autonomous guidance;

- •Cosmic gamma ray spectrometer analysis in the exosphere.

Each 2019 S4 satellite payload is inspired by the new standard PocketQube picosatellite format (in the 1pformat, 5 cm on a side, in the 1.5p format - 5 x 5 x 7.5 cm, ~300 gm) - invented by Professor Bob Twiggs, inventor of CanSats and co-inventor of CubeSats. Each S4 satellite contains a portfolio of sensors and is programmed as an advanced Internet of Things Cortex ARM computer. Configurations with minimal sensors can be as inexpensive as $50, and full-up configurations with multiple sensors and telemetry can reach over$200. Core data collection loops can exceed 20 Hz, with multi sensor collection loops delivering 5-10 Hz.

S4 collects data locally on the satellite in non-volatile flash memory. Higher end S4 payloads can add real time radio telemetry using modern spread spectrum long range radio communications to communicate to ground stations and download real-time telemetry from the mission and track payloads via GPS. The system is extensible and new sensors can be added to each S4 satellite for new and different missions. Users can make use of the default sensors and mission programming or add new sensors and programming

S4 satellites are designed to be flown on rockets as small as TARC rockets or drones that fly a standard hen's egg size payload on F and G motors to 1000' up to high power sounding rockets or balloons that reach the top of the stratosphere. S4 satellites can be configured for either captive flights[11] or to be

to be deployed at apogee on a recovery device (such as a parachute) for independent descent. The PocketQube format allows for an incremental transition to an ultimate space capable packaging suitable for LEO deployment.

The S4 program anticipates rapid technology changes in platforms and sensors and has tried to standardize on common standards for programming language, packaging, communications and sensor interfaces.

Missions

Science is about asking and answering questions about the world we live in. S4 is such a tool to ask questions about the earth and the space the around it using rockets and high altitude balloons as interesting platforms to observe. They provide opportunities to investigate second hand (by our robots and their sensors) deep questions about the earth and its environment.

S4 leverages three amazing recent innovations in citizen science:

- Low cost sounding rockets and high altitude balloons,

- Robots and low cost environmental sensors,

- Internet and data sharing

 S4 is a modular set of tools allowing a range of science missions in different S4 configurations - ranging from a simple one like S4 Egg at low altitude, and a more complex one like S4Qube to the stratosphere. S4 Egg is suited more for younger learners and simpler missions (say middle school) while S4Qube for more sophisticated learners and more complex missions (say advanced high school). These are illustrative not prescriptive.

Since S4 is in the standard PocketQube format we can imagine, with modest modifications, extending these missions to LEO. S4Egg has a relatively simple portfolio of atmosphere sensors with data sampled at 10 Hz:

- Mission time to the millisecond,

- temperature, humidity (water vapor content),

- air pressure,

- eCO2 and

- volatile organic compounds (TVOC) - CO, alcohols, atmospheric pollutants.

It is configured as a 3D printed PLA enclosure in the shape of a hen's egg replacing the payload of a TARC rocket. It weighs ~30 grams and can be thought of as a sensor measuring the basic chemical content of the Earth's atmosphere column.

S4 Qube has a rich portfolio of sensors with most data sampled at 10 Hz:

- GPS position of latitude, longitude and altitude (to 80 km),

- GPS time,

- Battery voltage,

- Mission time to the millisecond,

- Temperature - both internally to S4Qube but also to two external 1-Wire based temperature sensors

- Humidity,

- Air pressure,

- eCO2,

- TVOC - including carbon monoxide

- 3x accelerometer,

- 3x gyroscope,

- 3x magnetometer,

- UV, visible and IR light intensity

- Particulate matter spectrometer(PM1.0, PM2.5, PM5.0) (particle density: .3u, .5u, 1u, 2.5u, 5u, 10u) (1Hz)

- AS7265 18 channel 410-940 nm near-UV to near-IR light spectrometer

- Beta, x-ray and gamma radiation spectrometer < 1 MeV.

It is configured as a 3D printed PLA 50mm 1p cube for either captive flight or independent deployment for parachute recovery. It weights about ~150-200 grams. Spread spectrum wireless telemetry allows fori ndependent tracked recovery. Additional sensors can be configured on standard extension busses (I2C,serial, 1-Wire, DIO).Open source data collection and telemetry software is Arduino/C++ based.

S4Qube has an experimental multispectral imaging sensor cluster combining a low resolution false color visible light camera, coaxial with a thermal imaging camera and an optional spectrometer designed for ground examination. It is hopes that this imaging sensor cluster can be used for false color vegetation and crop analysis[12].

S4 Egg Missions

S4 Egg missions are based on questions suitable for middle school science:

Question	Sensor(s)	Study Guide
How do we determine altitude from pressure in the atmosphere? What IS the atmosphere?	Barometer Temperature	Atmosphere
What is humidity? How does water content in the atmosphere change with altitude? Time of year? Location?	Barometer Humidity Temperature	Atmosphere
How does CO2 in atmosphere change with altitude? Time of year? Location? Vegetation?	Barometer Humidity Temperature	Atmosphere
How does pollution from TVOCs change with altitude? Location? Adjacent sources of pollution? What ARE TVOCs? Time of year?	Barometer TVOC	Pollution Organic compounds
How are any of the above related to temperature? To each other?	Temperature	Weather
How do answers to any of the questions change in different locations or at different times or seasons.		Weather
How fast did the rocket go?	Barometer	Physics Atmosphere
How high did the rocket go?	Barometer	Physics Atmosphere

S4Qube Missions

A rocket based mission to 30k' can take advantage of the rich portfolio of S4Qube's sensors to ask many more questions. Such a flight will be supersonic and will pass from the troposphere into the lower edge of the stratosphere, and likely into the jet stream (depending on jet stream and location). On such a flight severalS4Qubes could be flown and multiple questions could be flown from multiple sensors on different subjects.

Question	Sensor	Study Guide
How fast and high? Do GPS and barometer agree?	GPS Barometer	Physics Atmosphere
What was the path of the rocket flight?	GPS	Physics Mapping/visualization
What did the airframe experience? Stress? Temperature? Acceleration?	IMU Temperature GPS	Aerodynamics Strength of materials Physics of rocket flight
What were the physics of the rocket's flight. How much drag was on the rocket. How could you measure it? Did it change with altitude? How?	IMU Barometer Temperature	Aerodynamics Physics Atmosphere
How much energy did the motor put out?	IMU GPS	Design of rocket motors. Chemistry Physics of rocket motors
What did the atmosphere look like during the rocket's flight? What did it consist of? How did it change? Why?	Barometer Temperature Humidity Particulate matter TVOC CO eCO2 Radiation	Composition of the atmosphere How sensors work Aerosols
Did the rocket enter the jet stream? Stratosphere? How could you tell?	GPS Barometer Temperature Pressure	Composition of the atmosphere Jet stream
Does light change with altitude? Why?	Spectrograph GPS Humidity Temperature Particulate matter IMU	Light and atmosphere Light propogation
Is the sky blue? Why? Why not?	Spectrograph Humidity Particulate matter	Physics Atmosphere
Did the rocket find air pollution? What. Why. Where.	Barometer Humidity TVOC Particulate matter Radiation eCO2 CO Pressure Spectrograph	Air pollution Aerosols TVOC CO

Did the rocket see radiation? If so, where could it come from? What kind?	Radiation sensor Particulate matter Humidity Pressure GPS Barometer	Radiation aerosols Nuclear physics Nuclear testing Nuclear plant failures Atmosphere science

Mission Software

S4 is based a common satellite mission software package that includes:

- **Management drivers for each sensor to initialize and collect data from each sensor;**

- **Communications protocols for location telemetry to the ground;**

- **Data collection loop that**

- **polls configured sensors,**

- **periodically saves sensor data to local flash storage,**

- **wirelessly transmits location data to the ground station,**

- **Ground station software to receive location telemetry from mission satellites.**

- **A portable Python dashboard downloads mission data from the satellite**

For S4 Egg and S4 Qube this package is written in C/C++ and is hosted on the standard Arduino IDE. The S4 hardware also support Python for users that prefer to port the mission software to that environment. The S4 mission software is open source and available for modification and improvement.


 S4 Platforms

S4 provides two standard platforms to accommodate different missions. All platforms are powered by a 3.7VLiPo battery sized for the mission and configuration. Small configurations, such as S4Egg are powered by as little as 100 mAh, while more robust configurations require 350+ mAh, each delivering hours of operation.

Platform	Package	Processor	Data Storage	Communications	Sensor Capacity	Scope
S4Egg	3D printed plastic package in hen's egg size, to match TARC payload	ARM Cortex M0+ C/C++	2 MB Flash	None	< 4	Entry level S4 satellite designed to be flown in TARC compatible rockets as a subset of PocketQube
S4Qube	1p PocketQube, 3D printed plastic	ARM Cortex M4 C/C++	22 MB Flash	LoRa telemetry	< 10	Standard Arduino platform with local storage, telemetry and substantial sensor capacity.

S4 Egg is embedded in a 3D printed plastic enclosure, in the shape and volume of a chicken egg - 45mm in diameter. S4Egg is based on Adafruit ItsyBitsy M0Express platform. It provides an Arduino compatible 48 MHz ARM processor with substantial processing, memory, and I/O resources. The S4Egg has a standard baseline sensor suite designed for crowd sourced earth science of atmospheric temperature, humidity, pressure, CO2concentration and TotalVolatile Organic Compound (TVOC) measurement. It has a limited capability for sensor expansion using standard S4 sensor interfaces. It has no baseline telemetry capability and stores mission data locally on 2 MB of flash. The platform includes a serial port, a digital/analog port and an I2C port for sensor expansion.
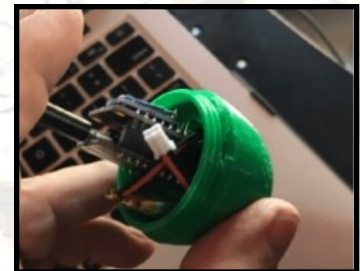

	48MHz Cortex M0+ ARM Processor, 256KB program/32KB SRAM memory, I/O, 2MB flash mission storage, LiPo battery management	https://www.adafruit.com/product/2796	$11.95

S4Egg Sensor board I2C Serial port DIO Environmental	Custom PCB, To be published	~$3.00
Humidity, temperature, atmospheric pressure, equivalent CO2, Total Volatile Organic Compounds sensor	https://www.tindie.com/products/onehorse/air-quality-sensors/	$35.95
150 mAh LiPo battery	https://www.adafruit.com/product/2750	$6.95
3D printed plastic egg enclosure	To be published	~$3.00

S4 Egg is programmed in the C/C++ Arduino environment using the Arduino IDE development environment. The standard S4 mission program can be used to collect data and as a baseline for adding new sensors and experiments. The S4Qube is based on an enhanced processor platform - the ARM CortexM4 - the Adafruit ItsyBitsy M4 Express. It adds the baseline S4Qube sensors: flight capable GPS (capable to 80 km altitude), 3d accelerometer, 3d gyro, 3dmagnetometer, temperature, atmospheric pressure, battery voltage, equivalentCO2concentration, TVOC, humidity, UV+IR+ visible light intensity, and an 18channel light spectrometer from 410-940 nm. The board flash mission memory expands to 22 MB for local recording of sensor data and a LoRa wireless data connection provides for real-time tracking and telemetry. The

platform includes a serial port, a digital/analog port and an I2C port for sensor expansion. Like S4Egg, it is programmed with the Arduino IDE and the standard S4 mission software.
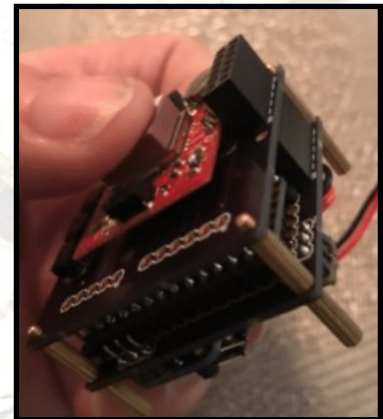
The power of the Cortex M4 adds substantial capabilities to S4 - particularly in the areas of imaging and signal processing with a minimal increase in cost.S4Qube is based on the standard Pocket Qube 42mm square stackable boards with a common inter-board communications and power bus. The basic S4Qube can be assembled from two boards - the Processor, Memory and Telemetry Board and the Sensor Board - outfitted with a set of daughterboard sensors designed for the science mission in mind.
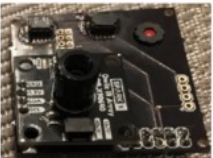
There is room for one or more board of similar size within the S4 1p package depending of component height. Such boards could contain additional sensors or perhaps stepper motors to control a deployable para wing for a controlled, steerable recovery.

An example of such a board could contain the interesting the AS3935 lightning sensor for mapping distance to storm fronts at altitude. Some sensors - like the particulate matter sensor, the experimental multispectral imaging board or the radiation sensor can be packaged externally - mounted to the aft side of the package.

Some sensors - like the particulate matter sensor, the experimental multispectral imaging board or the radiation sensor can be packaged externally - mounted to the aft side of the package.

S4 Processor, Memory, Telemetry Board		Custom, open source	
	120 MHz Cortex M4 w/ hardware floating point processor, 512k program flash, 192k SRAM, I/O, 2 MB flash memory mission storage	https://www.adafruit.com/product/3800	$14.95
	LoRa telemetry radio	SPI, u.FL antenna	
	20 MB expanded mission memory	SPI	
	LiPo battery + management	Solar cell recharging	
	Connectors	1Wire bus S4 Power S4 bus	
S4 Sensor Board		Custom, open source	~$3
	Sensors	I2C Mediatek GPS, I2C VEML6070 UV sensor, I2C visible + IR sensor, I2C spectrometer, I2C eCO2+TVOC+temperature+pressure+humidity, I2C acceleration+rotation+magnetometer, I2C MSLaltitude Particulate matter PMS- 5003 spectrometer is connected on a QWIIC serial port. Gamma ray X100-7 radiation spectrometer is connected on a QWIIC DIO port.	
	Connectors	QWIIC I2C, Serial, DIO S4 Bus	
S4 Imaging Board (Experimental)		Custom, open source	~$3
	Sensors	640x480 false color serial .jpeg Thermal 32x24 image	
	Connectors	QWIIC I2C, Serial S4 Bus	
3D printed 1p and 1.5p PocketQube enclosures		To be published	~$3

The third board - the Imaging Board - is experimental. It integrates two imaging sensors to investigate multi spectral imaging. The first sensor is a simple visible light sensor with the color filters changed to allow capture of the near-infrared. This allows assessment of ability of plants to process sugar. The second sensor is a thermal imaging camera. The board allows for the optional integration of an additional light spectrometer for experiments in ground imaging for vegetation analysis.

Both the Imaging Board and the particulate matter sensor are designed to mounted to the aft outer side of the1p package to face downward as S4 is deployed for parachute or para wing recovery.S4Qube is a 3D printed 5x5x5 cm plastic enclosure designed to hold the core processor+memory, base line sensors, battery, antennas, and additional sensors. S4Qube can be flown on standard HPR airframes on Gthru O motors as a captive payload or can be deployed for independent recovery under parachute. The core S4 electronics are expected to space capable for short missions to LEO. It is anticipated that the plastic Pocket Qube form factor can be upgraded to a 3D printed space capable material and format.

Standard Expansion Interface

S4 defines three external sensor interfaces, each defined a simple four wire interface using SparkFun's QWIIC134 pin connector, providing power and data interfaces from sensors to the processor. SparkFun uses QWIIC just for I2C, but S4 extends it to add a serial port as well as a digital/analog port but adopting a common common miniaturized polarized connector. Standard Arduino C/C++ sensor libraries are shared betweenS4Egg and S4Qube in the S4 Mission Software.

Type	Pins
Serial	3.3v, Tx, Rx, GND
I2C	3.3v, SDA, SCL, GND
Digital/Analog (D/A)	3.3v, Digital I/O, Analog I/O/PWM, GND

All of the S4 platforms also support an internal SPI peripheral interface, generally limited to communications and internal storage peripherals and not generally supported as an external sensor interface.

Sensors

The S4 system uses an open ended collection of sensors, on standard hardware interfaces, to measure position, light, dust, chemistry, atmosphere, radiation and multispectral imaging. The same sensor interfaces are used by all platforms. The following table represents sensors that can fit in the package, have supported drivers for at least one S4platform, and are believed to collect useful data during rocket or balloon flight. Tested drivers for these are contained in the S4 Mission Software. The list is under continual review as flight experience is accumulated and as new sensors are available and missions are imagined.

Measurement	Sensor	Description/Link	S4Egg		S4Qube	
			s	o	s	o
Time	Mediatek XA110 GPS	.5 sec with 2 Hz refresh rate. https://www.sparkfun.com/products/14414	√	√		
Location	Mediatek XA110 GPS	3m RMS horizontal precision. https://www.sparkfun.com/products/14414	√	√		
Geometric Altitude	Mediatek XA110 GPS	10m RMS vertical precision. https://www.sparkfun.com/products/14414	√	√		
Ambient atmospheric pressure	Measurement Specialties MS5611	Rated to 0 Pa pressure. Over 100k' MSL altitude https://www.tindie.com/products/onehorse/lsm9ds1ms5611-breakout-board/		√		
	Bosch BME280	30,000Pa to 110,000Pa ~30k' MSL altitude https://www.tindie.com/products/onehorse/air-quality-sensors/	√	√		
Ambient atmospheric temperature	Measurement Specialties MS5611	https://www.tindie.com/products/onehorse/lsm9ds1ms5611-breakout-board/		√		
	Bosch BME280	-40C to 85C https://www.tindie.com/products/onehorse/air-quality-sensors/	√	√		
	Microchip MCP9808	High precision external temperature https://www.adafruit.com/product/1782		√	√	
Acceleration	ST LSM9DS1	3D acceleration sensor. Up to 16gs. Software absolute position: roll, pitch, yaw. https://www.tindie.com/products/onehorse/lsm9ds1ms5611-breakout-board/	√	√		
Magnetic field	ST LSM9DS1	3D magnetic field sensor. Software absolute position: roll, pitch, yaw. https://www.tindie.com/products/onehorse/lsm9ds1ms5611-breakout-board/	√	√		
Rotation	ST LSM9DS1	3D gyro, rotation sensor. Software absolute position: roll, pitch, yaw. https://www.tindie.com/products/onehorse/lsm9ds1ms5611-breakout-board/	√	√		
Ambient IR light	AMS-TAOS TSL2591	https://www.adafruit.com/product/1980		√	√	
Ambient Visible light	AMS-TAOS TSL2591	https://www.adafruit.com/product/1980		√	√	

Measurement	Sensor	Description/Link	S4Egg		S4Qube	
			s	o	s	o
Ambient UV light	Vishay VEML6070	https://www.adafruit.com/product/2899	√	√		
CO²	AMS CSS811	Equivalent CO² detector - 400-8192 ppm https://www.tindie.com/products/onehorse/air-quality-sensors/	√		√	
TVOC	AMS CSS811	Volatile organic compounds - 0-1187 ppb. Ethane, propane, formaldahyde, others https://www.tindie.com/products/onehorse/air-quality-sensors/	√		√	
Humidity	Bosch BME280	0 - 100% RH, =-3% from 20-80% https://www.tindie.com/products/onehorse/air-quality-sensors/	√		√	
Lightning	AS3935	https://www.sparkfun.com/products/15276				√
Spectrometer	AS7265X	18 channel 410-940nm spectrometer https://www.tindie.com/products/onehorse/compact-as7265x-spectrometer/			√	
Temperature	DS18B20 1-Wire Temp Sensor	Two remote sensors available.				√
	Bosch BME280	40C to 85C https://www.tindie.com/products/onehorse/air-quality-sensors/	√		√	
Camera	Still camera	640x480 still camera. TTL serial interface. https://www.adafruit.com/product/1386 Updated with false color - https://publiclab.org/wiki/near-infrared-camera				√
Particulate matter	PMS 5003	Optical laser dust sensor from .3 micron to 10 micron. https://www.adafruit.com/product/3686				√
Gamma Radiation	First Sensor X100-7	PIN silicon photodiode radiation detector. Detects 0.002-1.0 MeV gamma and X-rays. Detects photon energy. Gamma ray spectrometer https://www.sparkfun.com/products/14209				√
IR imaging sensor	MLX 90640	32x24 array of IR sensors for IR imaging. 55 degree FOV https://www.sparkfun.com/products/14844				√

Communications and Telemetry

An emerging wireless standard for the Internet of things, LoRa, is used as the S4 basis for inexpensive, long[14] range, low power S4 telemetry service in the 902-928 MHz unlicensed band in the Americas. LoRa is based on a variant direct sequence spread spectrum modulation system that provides up to 30 dB of additional radio link budget depending on desired throughput vs range performance

The LoRa radio link can be uniquely software configured to trade off range vs throughput. Low data rate ranges to LEO have been demonstrated. Telemetry speeds range from 100s of b/s ranging to 10s of kb/s are possible with tradeoffs to range. S4 uses the standard RadioHead Arduino communications library to[15] provide the basic protocol structure. S4 uses software tunable LoRa radios in the 902-928 MHz unlicensed band. The basic S4 ground station is an S4Qube with minimal sensors (just a GPS), attached via a USB cable to a host computer forwarding received telemetry to the host. The ground station connects to a USB port on a local laptop for a .csv telemetry data stream. It has a local I2C OLED showing distance and direction to the payload as well forwarding telemetry to host computer for storage.
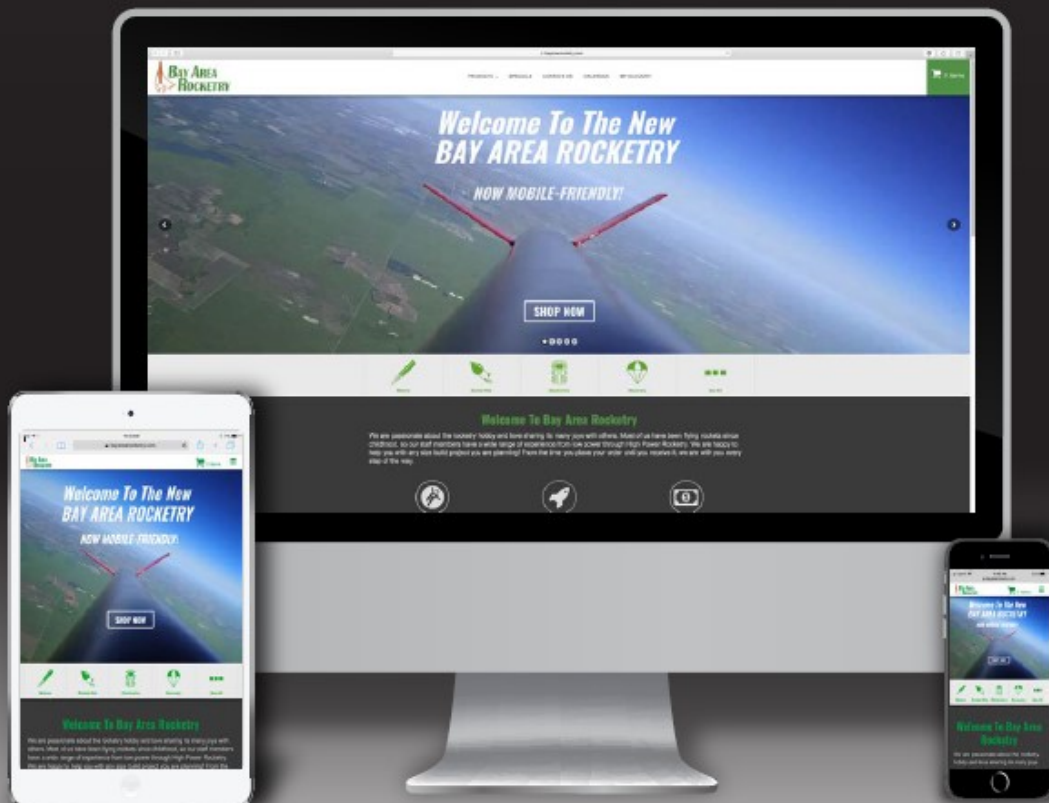
S4 is documented at Hackaday[16] Current software, documentation and the 3D printer package. S4 is open source and freely available to be used by anyone - though attribution is a wonderful thing. We ask that users share missions, new sensors and modifications with the entire S4 community. Contact Ken Biba at kenbiba at icloud.com for more information

1 Thanks to Paul Hopkins for his collaboration on the 3D printed packages.

2 A Rocket Launch for International Student Satellites is an international high school and university competition for autonomous robotic student satellites held for the last 20 years by the AeroPac rocketry club at Black Rock Nevada in collaboration with UNISEC-Global -the worldwide university space engineering university consortium. www.arliss.org.UNISEC-GLOBAL. https://www.dropbox.com/s/dc0szessadhzig/Sport%20Rocketry%20ARLISS%201.2014.pdf?dl=0

3 https://en.wikipedia.org/wiki/CanSat

4 https://en.wikipedia.org/wiki/CubeSat

5 PocketQubes are the successor to CubeSats designed by Professor Bob Twiggs, co-inventor of CubeSats and CanSats. CubeSats5are now the standard for modern small satellites - educational, commercial and government. Pocket Qubes reduce size and weight -reducing the characteristic dimension from 10 cm to 5 cm - recognizing the increase in electronics density of Moore's Law. A number are now in orbit with more on the way. https://en.wikipedia.org/wiki/PocketQube

6 https://www.dropbox.com/s/10g3w2qxc5axnbo/S4%20Student%20Satellite.pdf?dl=0

7 http://lbym.sonoma.edu/RisingData/user/register

8 Team America Rocketry Competition (www.rocketcontest.org) lofting raw egg payloads on mid-power rockets using E thru G motors

9 ARLISS Extreme is a two-stage amateur sounding rocket that can take 600g of PocketQube payload to 40+km on commercial motor as an FAA Class II rocket. https://www.dropbox.com/s/3oml83hwd5okfgd/AeroPac2012100kProgramReport.pdf?dl=0

10 Standard ARLISS CanSat deployment.

11 To be recovered with the rocket or balloon that launched them.

12 https://publiclab.org/notes/warren/12-10-2010/normalized-difference-vegetation-index-nrg-and-landsat-7-bands

13 https://www.sparkfun.com/qwiic

14 https://lora-alliance.org/What-Is-LoRa/Technology

15 http://www.airspayce.com/mikem/arduino/RadioHead/

16 https://hackaday.io/project/22134-student-science-satellites-and-sounding-rockets