Association of Experimental Rocketry of the Pacific
TRIPOLI Rocketry Association, Inc. Prefecture No. 23
Volume 26 Issue 1
June 2020

AEROPAC Spring 2020 Newsletter

Photo by Phoenix 4, courtesy of Curt Von Delius

President's Pad

Greetings fellow AEROPAC members. MUDROCK is go for launch!

COVID-19 safety rules will be in effect.

Individuals over 60 years old and/or with compromised immune systems or underlying health conditions should consider the risks of attending a launch even when observing any and all precautions, and use their best judgment. They may want to adopt more protective measures than outlined here, such as wearing masks and gloves. Or they may choose to isolate themselves from the activity.

With launches of 10 or fewer participants, individuals should maintain a 6-foot distance from each other at all times.

What's Inside

No group of up to 10 individuals should be closer than 25 feet to another group. Each individual in each group of 10 individuals should maintain the 6 foot separation distance from one another.

We will provide hand sanitizer and disinfectant wipes for use after touching any community-handled equipment such as launch controllers, launch pads and igniter clips.

Vendors will allow no more than one individual in a vendor's trailer at a time. Vendors will use hand sanitizer or disinfectant wipes when handling product for sale to a consumer.

Individuals displaying ANY symptoms such as cough, fever, tightness of chest, or if they have been exposed to anyone who has tested positive for COVID-19, should avoid attending launches for at least 14 days after their symptoms cease or after exposure to the individual who tests positive, assuming they do not acquire any symptoms themselves.

Use of masks may be required of all participants as needed. Hand washing station s will be next to the porta-potties. Porta-potties also have hand sanitizer dispensers inside.

Each person is responsible for bringing and preparing their own food.

Each person is responsible for providing their own transportation.

Camping/sleeping is limited to groups of the same household.

We will continue to monitor the CDC guidelines and abide by those guidelines as well as any national, state, or local restrictions in effect.

Be sure to carry a mask with you so that you can put it on if you can't maintain a 6 foot distance from people such as: Taking your rocket to or visiting RSO/LCO

- Visiting registration
- Visiting vendors
- Visiting other camps
- Take advantage of the space that we have to keep some distance between camps.

Try to stay out of the nearby towns as much as possible. I'm sure that they don't want to worry about a bunch of outsiders infecting them.

Let's show that we know how to conduct a rocket launch safely in these pandemic times.

Jim Green

XPRS Loft Duration / Extreme Altitude Continues!

The AEROPAC Board of Directors has approved the AEROPAC Newsletter Staff as the new Coordinators of the XPRS Loft Duration / Extreme Altitude contest succeeding the Paris family after their many years of excellent management. AEROPAC is also the new sponsor of the contest.

With this change there will be several minor changes in the contest rules beginning in 2020.

Note: Any flight made during the week of ARLISS / XPRS is qualified to enter.

Loft duration: Is focused on flyers 17 yrs and younger and encompasses motor classes A through G.

Objective: To keep a rocket in the air as long as possible. Flights are timed from launch to touchdown. Rocket must be presented to LCO or RSO after each flight for inspection. To qualify, the rocket must be in a re-flyable condition or returned to that status with minor field repairs. Detached fins or non-deployment of recovery mechanism disqualifies a flight (unless rocket is designed as a "tumble recovery").

Contestant must present contest form to LSO or RSO prior to each flight.

LCO or RSO must note the "loft duration" time on contest form and participant (or responsible parent) must insure that the contest form is filled out and returned to contest box prior to 4 p.m. Saturday.

Clusters or staged rockets will be considered based on total impulse of all motors.

Note: LCO and / or RSO cooperation for timing and inspection will be required.

Awards: For each motor class, certificates are given for 1st, 2nd and 3rd place with a trophy awarded to the first place contestant.

Extreme Altitude: Focused on motor classes H through O as well as a Two-Stage category (any flight comprised of HP rocket motors in the booster and sustainer).

Note: All rockets and / or motors meeting TRA safety requirements, including experimental motors and / or rockets are encouraged to participate.

Clustered rockets will be considered based on total impulse of all motors.

Flyers must be TRA or NAR certified for motor class they are entering. TMP or NAR Jr Level 1 flyers must meet all the requirements of those programs with awards presented to the under 18 yr old participant.

Objective: To fly as high as possible with a successful recovery (including recovering within the FAA Waiver in effect at the time of the flight). For all flights (including the booster and sustainer on two-stage flights) any damage must be limited to the same criteria as a TRA certification flight. Non-deployment of recovery mechanism disqualifies a flight including the booster on two-stage flights.

Flight Data requirements: The highest recorded altitude from a "brand name" altimeter or flight computer must be entered on flight contest form and submitted in the contest box prior to 4pm on Saturday.

Note: Contest Co-ordinator(s) may ask to review altimeter / flight computer data if obvious questions arise, e.g. a clear data "outlier" or suspect data recorded by device. For example, a K to K two stage flight that has a recorded altitude of 100k ft. Otherwise, data submitted by each flyer is accepted on the honor system. Decisions by contest Coordinator are final but appealable.

Awards: For each motor class, certificates are given for 1st, 2nd and 3rd place with a trophy awarded to the first place contestant.


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Length: 55.44" (1,408mm)
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Total impulse: 22,223 N-sec (4,996 lb.-sec)
Burn time: 4.4 sec
Peak thrust: 1,461 lbs. (6,499 N)
Delay time: N/A (plugged)
Propellant wt.: 9,779 grams (21.56 lb.)
Loaded wt.: 15,345 grams (33.83 lb.)
Photo by Nadine © 2018
AEROTECH/QUEST DIVISION,
www.aerotech-rocketry.com

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Tribute to James Marino

David Raimondi

I went to my first LUNAR meeting in January 2004 with a mission: I wanted to learn more about High Power Rocketry, and how to get certified to fly larger rockets. I was told to ask James Marino about the process, and after the LUNAR meeting, I went looking for him. James was a big man, about 5 feet 10 inches tall, with a big afro and a booming, deep gravelly voice (which was awesome when he was LCO). We talked about my plans, and he asked what kind of rocket I was building, and he told me about Tripoli Central California (TCC) and when / where the next launch was. We agreed to meet at that next launch a couple weeks away, so he could help me begin my journey to High Power Level 1 Certification.

At the TCC launch, our families met for the first time. I introduced my wife Laura and two kids Steven and Christopher; and James introduced his wife Laura and daughter Rose. With wives of the same name and Christopher with a couple rockets clutched in his hands, a bond between the two families formed, that still exists to this day.

James reviewed the rocket, and watched me build my first HP motor, and when I had the rocket ready to fly; James pointed me to the Range Head. My flight was a text book flight and I was certified Level 1 on the first try - must have been all that good advice. James congratulated me with a firm handshake and the famous words .....“Welcome to High Power, remember mortgage before motors.” That was James’ signature line after a successful Cert flight. After my flight, James turned to Christopher (age 5) and gave him the same attention that I received. The families celebrated all his flights with the same gusto. We rounded off the day with James introducing us to his rocket buddies at the launch, Lee Teicheira, and the entire TCC staff.

James assisted many of us on certification day. This was his last certification on Feb 1, 2020 at LUNAR

In the early days, I was asking James so many questions about HP rocketry that James said he was going to start charging me for the answers. James was working on his L3 project at the time, and that started a whole month of talking about electronics and where buy them. James recommended a GWiz MC, so of course I picked up a GWiz MC from Rob Briody (co-owner of GWiz). I loved learning to fly dual deployment with a master like James.

In his never ending quest for knowledge, James was always willing to try new ideas and techniques. He had many test flights perfecting his craft before getting his Level 3 in 2005. With his vast knowledge and experience, he was soon nominated to the NAR L3 Certification Committee (L3CC). When James would walk to the range head, normally a short walk, it would take James upwards of an hour due to all the people he would stop and talk with, or all the people that would stop him. By this time James was quickly becoming a Legend in his own time. There wasn't a question he couldn't answer about High Power Rockets, electronics, making HP motors, and Ham Equipment. If you had a question involving HP rocketry, James knew the answer.

James was enthusiastic when I started building my Quantum Leap II, a two stage rocket for my Level 2 project, and I consulted with him a lot. The first time I flew the Quantum Leap at Black Rock, James was all over it. He helped get the rocket on the pad and chased the rocket down the playa about 3 miles away. Every time I went to fly the Quantum Leap rocket, James was there helping with the flight. Whether working as the LCO, launching Estes rockets or giving much needed advice, James' passion for rocketry, his family, friends and life was infectious.

At Black Rock launches, James, Steve Kendall, Lee and my family would all line up behind Richard & Laura Hagen's motorhome. We dubbed ourselves the "East Enders." With three wives named Laura, there had to be some way to label them. Laura Hagen was known as Laura #1, James' wife was Laura #2, and my wife was Laura #3. Together we survived the heat, the dust, the wind storms, and too much food/wine. It was a wonderful time.

OCTOBER SKIES 2004 – Experimental Day
Photos by Gary W. Walker

James was good at baiting and pushing myself and others to bigger and faster rockets. James loved to make motors and his favorite propellant was Wimpy Red. He would come to an AeroPac launch with a fresh stash of motors, and like a mad scientist, (afro and all), would announce to his friends what motor they were going to be flying. James would bring a rocket or two to a launch, but it was all about the motors for him. If James was always pushing to go bigger and faster you were in...whether you realized it or not.

At the AeroPac XPRS launch in 2005, James once again brought some motors to share. One motor was specifically made for a new rocket that I just finished building, Ridiculous Speed. The motor was affectionately called the "Yard Stick". This was a 54mm motor 1 yard long with Wimpy Red from end to end. The last couple grains were stepped in hopes that the motor would not explode. Now earlier at the launch, Steve Kendall flew his Competitor-4 higher than James or I had ever reached.   We all celebrated with Steve's Famous ribs while Steve lovingly teased us about reaching the highest altitude of the group. On the last day of the launch, rocket met the Yard Stick, a JPS (James Propulsion System) EX L1771 Wimpy Red motor. The weight of the motor was 3 times the weight of the rocket. Dubbed the "Three Frame Wonder" (the rocket was only in the video for three frames) it took off so fast that it was gone in 3/60th of a second. As I stared up into the sky wondering if my rocket still existed, I could hear James laughing hysterically and asking Steve Kendall "Was it good for you?"… (Steve replied, "Well, was it good for me? …. NO.")

After catching up to James in cert level, he grabbed me and invited me to be a flyer for the ARLISS program. ARLISS was James' favorite launch of the year. He loved working with the students from around the world. We would work together to make sure that our rockets were ready when Becky Green would come around with an ARLISS Team wanting a flight. James and I would wrestle with the M1419 motor casing, clean it up with a new propellant load and get both rockets ready to fly again in a couple hours. They were long, but glorious days.

Monday morning at ARLISS 2018. James knows he is going to fly a bunch of student projects on the beautiful Aerotech M1419. That always makes ARLISS flyers happy and James is beaming! L to R: Dave Raimondi, Jim Green, James, Dick Jackson and Becky Green

Beyond rockets, James was an astronomer owning and building several telescopes. One of my prize possessions is the telescope he made me which I still use frequently. James generously provided the mirror for a new telescope to a college in the central valley. The telescope will be named after Bruce Orvis who passed away about 10 years ago. Bruce Orvis agreed to let the LUNAR rocket club use the Snow Ranch lands for a High Power launch site in the wet season.

James with a group of students prior to one of his many ARLISS flights

James was an amazing friend. He leaves behind his wife Laura (#2), his daughter Rose, and all of his rocket buddies, and friends. If someone needed help, James was ready to help! James never turned anyone away. I think by now, James has formed a rocket club in Heaven. He is having fun and laughs with the rocketeers that have preceded us, and he is waiting for us to join him when our time comes. By then James might have the formula for Unobtainium Red to pass around.

James: you are a brother, and I really miss you.

LUNAR Rocket Club, High Power Coordinator, and Past President

AeroPac, ARLISS flyer,ommittee Member

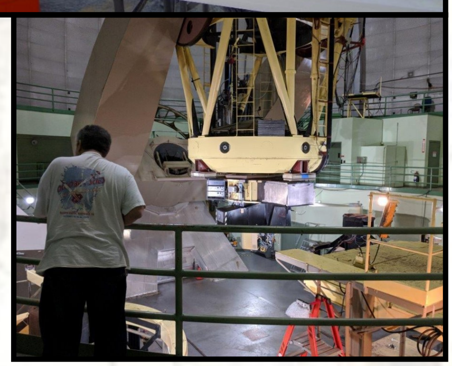
NAR / TRA L3, NAR L3CC / TRA TAP

A Last Gift by Ken Biba

I will miss his huge laugh and his common sense.

As a member of the ARLISS Extreme team James added the basic mechanical skills that some of us, like me, lacked.

But he did something extraordinary just before he died.



We have been struggling for a few years with an interstage problem as we tried to build one that was simple yet coped with changes of temperature, material and the tolerance changes in part sizes that seem acceptable on the ground but are devastating at Mach 1.

He suggested a fix in the week before he died. I think it I will work. We will only know at Mach 1. Thank you, bro, for that last gift.

Marino LCO sound bites: https://www.dropbox.com/s/m34yf5xrycgq7ff/Moonshot.m4a?dl=0 (Thanks Gary Rosenfield)

https://www.dropbox.com/s/hkdpbdv9xwd8l80/Oh%20Baby%21.m4a?dl=0 (Thanks Gary Lech)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AEROPAC Challenges ROC to Night Launch Spectacular !

Inspired by ROC's spectacular "Sparky" night launch drag at last year's XPRS is challenging ROC (Rocketry Club of California) to a night launch show at XPRS 2020. Hopefully, Derek Jameson will create some more sparky motors for ROC and Jim Green will create the required motors (in 38 and 54mm) in Unicorn Farts propel-lant. What form this takes – a group drag races, individual drag races, etc. is TBA. Clearly there is a limit to how many rockets can be launched at one time and safety concerns as well.

Bottom line: Night launches are awesome, night launches with "Sparky" motors are REALLY spectacular, night launches with multiple rockets with sparky motors launched simultaneously are OOTW (OUT Of This WORLD!

Requirements to participate:

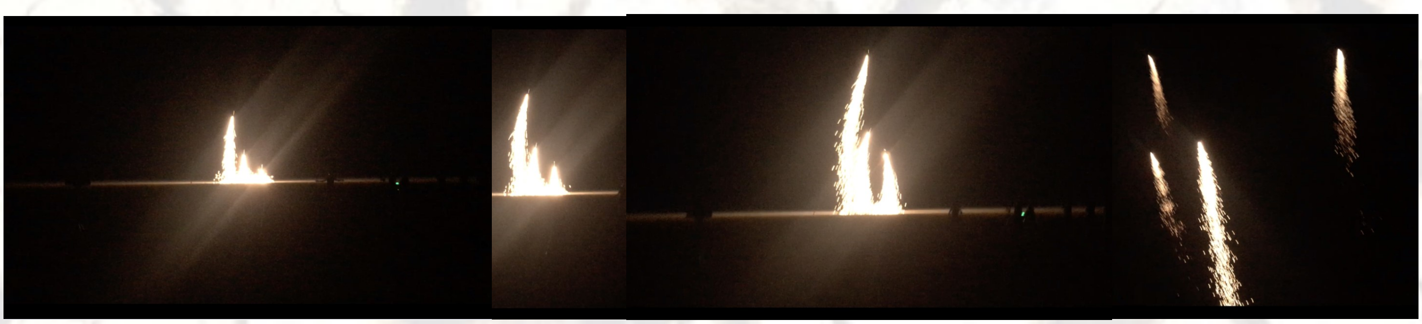
- Must be at least a TRA Level 2 certified flier
- Have a 38mm or 54mm night launch rocket (or one that can be converted)

  Note: The more lights you can put on your rocket the better. Battery powered strip LEDs work great, flashers, colors make them even better
- Your rocket has electronic deployment (only apogee needed) because these motors will have no ejection charges. Note: Electronic deployment is not required for night launches in general.
- Will be attending XPRS this year on Saturday night
- Willing to fly an ass kicking Unicorn Fart Jim Green "Special" propellant motor
- Want to be part of something really cool

Start getting your rocket ready to fly now or build a new one while you probably have some spare time.

There is a limited amount of Unicorn Fart motors available so reserve your motor now!

Potential Unicorn Fart night launch demos flights at MUDROCK and / or AERONAUT

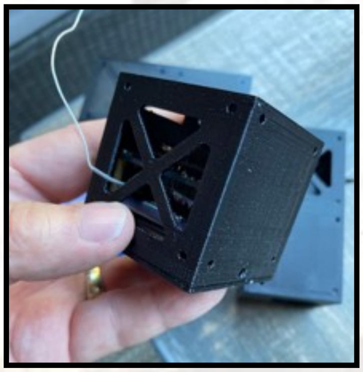


ARLISS Lite: Mid to High Power 3D Printed High Performance Airframes for Small Satellites

Ken Biba

I am fascinated with building space robots and satellites. As a long time part of the ARLISS team - flying student robot satellites - building my own robots to explore what my rocket's experience has been and to learn more in lieu of being an astronaut - is high on my list of good things. I have been working for the past five years on moving the ARLISS experience to a less expensive and more accessible platform than just advanced L2 and L3 class rockets. The product of that is S4 - Small Satellites for Secondary Students - that replaces legacy soda can sized CanSats with 50mm PocketQubes. Nominally motivated for high school students, but there is much exploration power in a compact form factor for any age.

Making the satellites small and in a standard package size has a bunch of advantages. One of the most important is increasing the range of missions possible with this satellite platform. For rockets, packing more function in a smaller mass and volume is almost always a good thing. PocketQubes with commercial electronics can operate in LEO, but also allow flights on a small rocket in parks as a logical extension of TARC but with more focus on science, robots and payloads.

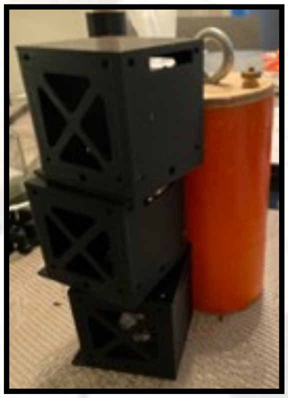


ARLISS

ARLISS Classic 75mm and 150mm airframes on K and M motors can carry a large number of these satellites to above 10k' AGL, and ARLISS Extreme can reach well above 100k'.

But I wanted to lower the entry point - so that mid-power and entry high-power could execute new missions to lower altitudes at more launch locations. 2020 S4 PocketQubes on these new ARLISS Lite airframes extend possible S4 mission opportunities on a very wide range of platforms - ranging from park flights on E30 motors to ~750', to sounding rocket flights halfway to the Karman Line, and a good baseline for the extensions to get to LEO on a rideshare on a commercial launcher.

I designed a family of small rockets based on a single continuous piece of fiberglass airframe tubing but with almost all the remaining parts 3D printed to support single S4 satellite flights on motors of 24mm, 29mm, 38mm and 54mm as well the existing capabilities for multi-S4 satellite flights on existing ARLISS K, M and Extreme airframes. They can be assembled with screws and CA.



The goal of these smaller airframes is to provide low cost, high performance mission platforms for S4 to increase ease of use and the range of possible missions. The availability of 3D printed rocket parts allows us to make creating advanced airframes easier and lower cost. And for students, far more interesting since they can print, modify, and customize the airframes. A big step up from paper and balsa wood.

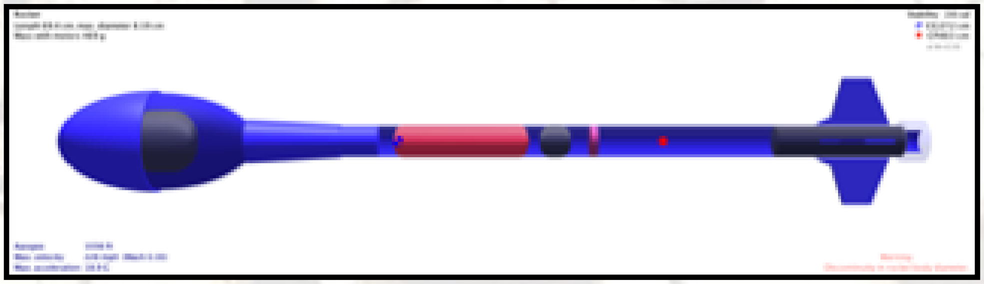
In this paper, I'll focus the low end of this range - the 24mm and 29mm - that yield an expected range of performance from 750' AGL on an E30 motor to over 3k' AGL on an I200. A companion paper will look at the adapters accommodating classic ARLISS K and M airframes to S4 PocketQubes. One of the fortuitous aspects of the PocketQube format is that it fits in the deployment carriers that were classically used for legacy soda can sized CanSats - a 75mm coupler. Three 1P S4 PocketQubes can fit in the space of one legacy CanSat - potentially cutting the cost per mission by 2/3rds. All of these airframes, today, are for captive carry missions - in which the S4 is recovered still within the payload nosecone rather than independently deployed.

Airframe Design

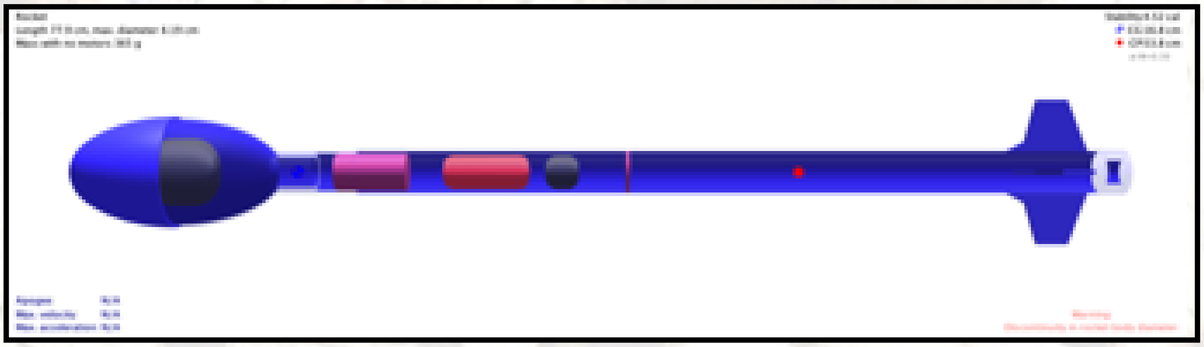
S4 is an affordable satellite, with an entry level 3D printed satellite with as little as $50 in parts, ranging to more complex satellites with many advanced sensors over $300. I wanted to get the best mission profile (and altitude) for the least cost in motors. With about a ~75mm cross section, almost all flights on modest size motors will be subsonic. And subsonic airframe performance is largely based on subsonic drag

Subsonic drag, unlike transonic and supersonic drag, is based on linear fluid flow across the surface area of the airframe - more surface area, the more drag for a given airframe cross section. My experience with optimized egg carrying and bowling ball rockets taught me that the best altitude would come from a basic design of a payload carrying nosecone mounted on a stick-like booster airframe containing recovery and motor. Since these are not going to extreme altitudes, and most S4 configurations carry integral LoRa+GPS tracking telemetry, I decided to standardize on a simple apogee parachute recovery .

This same planform also works well with egg carriers and other payload carriers and with 3D printed parts, easily customized. The basic design then is to have a streamlined nosecone as a payload bay to carry the S4 satellite. As with all subsonic rockets, the best nosecone design is to minimize surface area for a given cross section - so a basic elliptical shape works well for the nosecone.



This payload nosecone is then mounted to an avionics bay, the subsequent assembly then fits into a long standard fiberglass airframe tube (available from many rocket component vendors). A fin can and motor retention at the aft end of the rocket completes the design.



While being optimized for drag minimization and altitude optimization on a given motor is a good thing, the challenge of this planform is how to launch it. Conventional launch rail placement on the airframe body won't fit around the nosecone. Mounting the rail guides on some kind of standoff works, but increases drag and lowers performance after launch. The solution was to create a fly away launch system that incorporates the rail standoffs - and is discarded after launch maintaining the clean drag characteristics of the airframe. In the past, implementing this design would be complex, time consuming and just plain painful. Shaping the components of the nosecone and fin can would be much work - and likely not available off the shelf. 3D printing these components changes that challenge entirely.

3D Printing

Starting in 3D printing can be a bit challenging for a mechanically challenged software guy like me. So I

I started inexpensively with a highly online rated, inexpensive $300 printer. I soon discovered that rather than a tool to build things, maintaining and tuning the 3D printer became a new hobby in its own right. Further, this low end printer only printed one material - PLA - with rather fragile strength (for rockets) and a less than ambitious thermal envelope when considering points of drag and heating like nosecones, fins and motor retention. I gave up - donated my startup printer - and stepped up to a much more capable printer - the Dremel 3D45. While more expensive, it delivered three great things:

- Largely plug and play usage, even with almost 24x7 usage. I could use it as a tool rather than as its own hobby.

Tool	Purpose
Thingiverse	Website devoted to open source sharing of made things. A wonderful resource for discovering things that other folks made and share, that can either be used as they are, or imported and hacked to become part of a new thing.

OpenSCAD	An open source design tool that provides configurable components from programmable libraries. For example, the configurable fin can allows design of a wide range of 3D printed fin cans. When these are then printed at high density in a strong, high temperature material (ecoABS, PETG or nylon) we have a strong custom designed fin can.
TinkerCAD	Free AutoCAD introductory web based 3D design tool. Just enough capability for the vast majority of current projects. Imports and exports .stl design files.
Simplify3D	Third party software that imports an .stl design, the desired quality of the print (draft or final), the specifications for your printer and chosen material, and outputs a 3D printer file directing the specific print.

- A wider range of materials past PLA - EcoABS (Dremel's version of a healthier ABS based on a strengthened PLA), PETG, TPU and nylon. Materials that could build rocket parts that will survive into the transonic range and heftier motors.

- Internet connection so colleagues and students could share the printer and witness the print process thru its network build camera. Perfect as a resource for my high school teams

One surprise was discovering the robust infrastructure of 3D printing tools comprising the complete rocket design and building work flow.

I want to specially call out specific OpenSCAD libraries heavily used in these rocket projects. They've done the double whammy of both dramatically improving design quality while also decreasing the effort.

Purpose	Author	Web Link
Configurable fin can	Gary Crowell Sr	https://www.thingiverse.com/thing:3133682
29mm motor retention (resized for 24mm and 38mm)	wardy89	https://www.thingiverse.com/thing:3691731
Configurable centering ring and bulkheads	Gary Crowell Sr	https://www.thingiverse.com/thing:3145280
Configurable transitions	Gary Crowell Sr	https://www.thingiverse.com/thing:3104666
Fly away rail guide	plainolddave	https://www.thingiverse.com/thing:3706482

What is even more cool is that the authors of these libraries come from three continents - a wider scope even than my "local" rocketry clubs AeroPac and LUNAR.

Gary Crowell has recently added an OpenSCAD library for standoffs - that likely could be an alternative launch solution over the more complex, but less draggy, fly away rail guide system. I am considering using it to create standoffs for my bowling ball rockets.

A key choice in 3D printing rocket components is strength of materials. Low end printers have only one choice - PLA. PLA has limited strength and temperature resistance - particularly as we move above low power designs. The parts in PLA are just too fragile and heat sensitive. More robust materials like enhanced PLA, ABS, PETG, TPU and nylon are better alternatives. All of these require a printer with an ability for a higher extruder nozzle temperature and build bed that is heated.

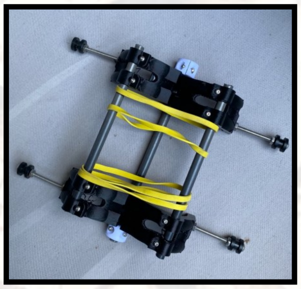
One downside to the Dremel printer is a custom filament spool that while convenient (hands-free RFID setting of filament specific printer settings!) is also pricey. Convenience triumphs price at the moment but generic filaments replacing Dremel's branding versions would likely work as well.

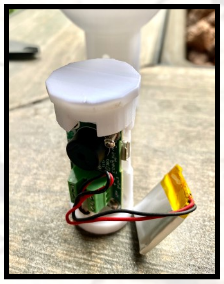
I have found good success in using Dremel's ECO-ABS (an enhanced PLA with the temperature and strength properties of ABS) and PETG. The ECO-ABS gives an esthetically more finished product, but the PETG seems more robust. The Dremel 3D45 also allows for using nylon filament - which has even better strength and temperature characteristics - but is a bit fussier to print with and the finished prints need a bit more manual touchup.

Making It So

All these single S4 airframes share a common nosecone design by my collaborator and long time ARLISS team member Paul Hopkins. A basic elliptical shape, it has enough room for a single 1P S4 satellite. The nosecone has a 29mm shank that requires a transition for all airframes other than 29mm. Gary Crowell's great OpenSCAD library for transitions solved those design needs. PETG or EcoABS are my preferred choices of materials. The base of the nosecone includes provision for an avionics sled secured with a twist of the wrist. The designed avionics sled is for an Altus Metrum EasyMini - but any small avionics package can fit. The fin can is a four fin, subsonic design with a personally pleasing esthetic using the Gary Crowell's OpenSCAD library.

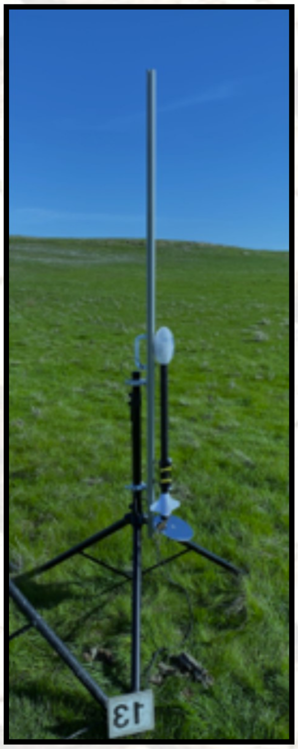
Motor retention also based on a Thingiverse 29mm design, scaled down for the 24mm version and up for 38mm and 54mm versions. PETG or nylon, with better thermal envelopes are my choice for the printing material.





I used the OpenSCAD bulkhead library to design a simple recovery retention bulkhead - held in place by M2 screws with an M3 forged eyebolt. EcoABS and PETG looks to be best for this. A small nylon parachute and kevlar cord harness completes the recovery design. I found a tested fly away rail guide design on Thingiverse by plainolddave. Unfortunately, the smallest pre-designed size was for a 38mm body tube. And further, made no accommodation for a nosecone of larger diameter than the airframe. I scaled the design for both 24mm and 29mm designs and further modified the design using a long metric stainless steel screw as a rail guide standoff to accommodate the payload nosecone. The designs successfully flew and printing in PETG resulted in robust, reusable performance.

And here we have the complete package of integrated rocket with integrated S4 satellite, with fly away rail guide mounted on a (partially) 3D printed 1010 rail launcher.



OpenRocket simulations show a useful range of performance - for both the 24mm and 29mm variants. The 24mm version is simulated with motor delay, the 29mm version uses an avionics apogee deployment. Missions with altitudes ranging from under 800' to over 3000' with accelerations from 10G to over 40G work.

Motor	Airframe	Altitude (feet AGL)	Max Velocity (mph)	Max Acceleration (G)
E30-7	24mm	767'	166	10.1
F39-6	24mm	964'	200	12.3
F72-5	24mm	1377'	296	20
F50	29mm	1488'	282	15.1
G80	29mm	2312'	453	20.8
H70	29mm	3056'	456	19.4
I200	29mm	3367'	663	41.4

Future

There are some obvious extensions to be thought about. These are all for captive carry missions … can we extend the design to allow for active S4 deployment so that the S4 can execute independent missions? Does it make sense to extend the nosecone to carry a 2P S4?

Documentation https://github.com/kenbiba/ARLISSLite

S4 2020 - PocketQubes are the New CanSats

Technology and Program Overview

Ken Biba[1], AeroPac, TRA 4968 L3 TAP, NAR 84610 L3
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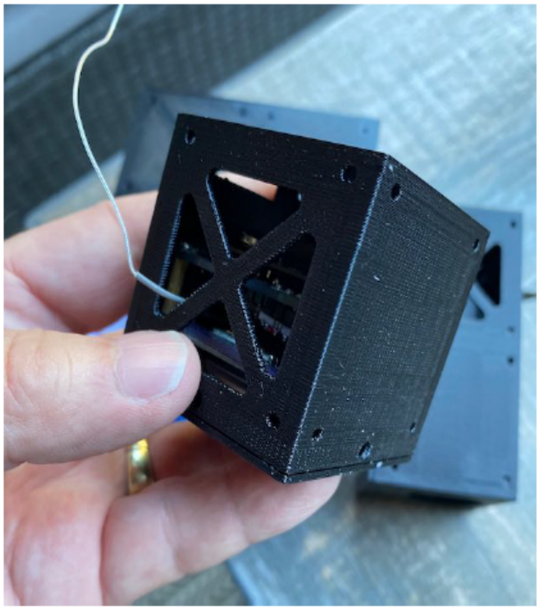
April 2020



Twenty years ago Prof. Bob Twiggs revolutionized aerospace education by launching small satellites the size of soft drink cans on amateur rockets to short circuit the satellite development cycle. In a heartbeat, these CanSats morphed into CubeSats (10 cm cubes) leading the way for Moore's Law to drop the cost of satellite access to LEO. My colleagues at the AeroPac rocket club in California, colleagues at the University of Tokyo led by Prof. Shinichi Nakasuka and Stanford University led by Prof. Twiggs created ARLISS - A Rocket Launch for International Student Satellites - in the Black Rock Desert of Nevada in 1999. The world's first CanSat launch.

Ten years later, Prof. Twiggs created PocketQubes (5 cm cubes), downsizing CubeSats by almost a factor of 10, changing the scale factor of small satellites again. And the opportunity for changing the paradigm for aerospace education and the satellite development cycle yet again.

PocketQubes are the new CanSats … and S4 (Small Satellites for Secondary Students) is the program to create that new baseline of small, low cost, open source educational satellites on sounding rockets and HABs that lead the way to small satellites in space. S4 was originally a 2014 NASA funded, Sonoma State University (led by Dr. Lynn Cominsky) executed, program for secondary students based on the ARLISS idea of small educational sub-orbital satellites. S4 in 2020, now as an AeroPac/ARLISS program, has adopted the PocketQube form factor to not only replace CanSats for use in student missions on rockets and HABs but also to aspirationally plan for LEO missions. Open source, 3D printed - it is available to all as a baseline to create a new platform for aerospace education.

And perhaps help open space to a whole new generation.

Background

The S4 (Small Satellites for Secondary Students) student satellite system is an opportunity to do science experiments as rocket and balloon 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[7] concept of science rocket payloads to secondary students. The NASA sponsored Rising Data[8] 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[9], 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[10]) 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.

- Atmosphere science measuring aerosols, dust, radioactive residue, organic compounds, lightning, temperature, pressure, humidity, gas content;
- Measurement of ground and vegetation using visible and infrared light imaging and image processing;
- 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[11] via parachute or mechanically actuated recovery like steerable parasails or parawings with autonomous guidance;
- Cosmic gamma ray spectrometer analysis in the exosphere. Gamma ray spectrometer analysis as rockets and balloons pass thru the jet stream.

Each 2020 S4 satellite payload is inspired by the new standard PocketQube picosatellite format (in the 1p format, 5x5x5 cm and ~100gm, and in a 2p format - 5x5x10 cm and ~200gm) - 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 $300. Core data collection loops can exceed 20 Hz, with multi sensor collection loops delivering 5

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[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. CubeSats are now the standard for modern small satellites - educational, commercial and government. PocketQubes 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] ARLISS - A Rocket Launch for International Student Satellites. www.arliss.org

Hz. Future ARM processor enhancements and improved I/O bus rates can imagine higher sensor speeds and multiprocessor configurations.

Each S4 satellite is configured in a 3D printed package (usually ABS).

S4 collects data locally on the satellite in non-volatile flash memory and/or micro-SD card. 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. They can communicate locally at high speed via peer-to-peer WiFi.

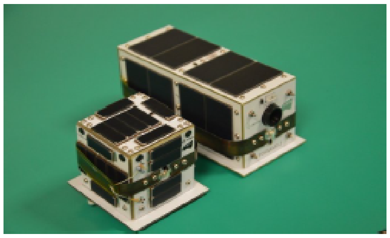
The system is extensible and new sensors can be added to each S4 satellite for new and different missions. Users can make use of the default sensors and mission programming or add new sensors and programming.

S4 satellites are designed to be flown on rockets as small as TARC size rockets or drones that fly a 1p S4 payload on E 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[12] or to be deployed at apogee on a recovery device (such as a parachute) for independent recovery and descent[13]. The 3D printed PocketQube format allows for an incremental transition to an ultimate space capable packaging suitable for LEO deployment.

S4 changes the scale of small student payloads. Because we can now fly many more satellites per airframe, we dramatically reduce the cost of each mission - dividing the recurring cost of the motor by the number of satellites. In large ARLISS M configurations, this is almost a 20x reduction in per mission cost! But with single payload missions on mid-power rockets, introductory missions to 1k+ are are reduced in cost to small 10s of dollars, using carrier rockets largely 3D printed.

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.

Multiple PocketQubes have successfully been deployed to LEO, beginning with the 2P $50Sat[14] in 2013 that pioneered single chip FSK radios. In November 2019, the 1P FOSSASat developed by high school students in Spain, reached LEO and successfully demonstrated single chip LoRa/RTTY spread spectrum radio communication to ground.



Missions

Science is about the journey of iteratively 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.

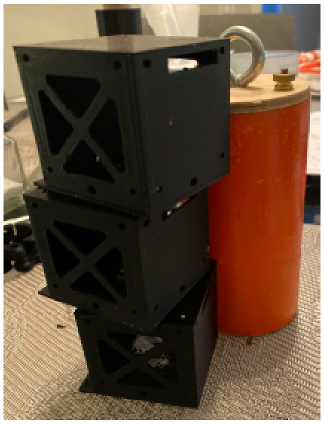
S4 leverages four amazing recent innovations in citizen science:

- Low cost sounding rockets and high altitude balloons,

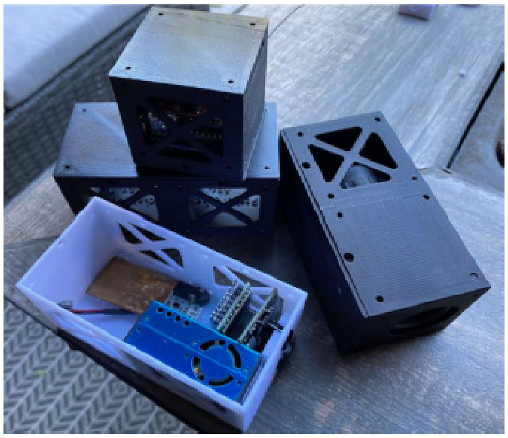
[12] To be recovered with the rocket or ballon that launched them.

[13] Standard ARLISS CanSat deployment - independent PocketQube recovery under parachute, parawing or … whatever.

[14] http://50dollarsat.info



•Robots and low cost environmental sensors,
•3D printing of both packages and airframes,
•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 a 1P PocketQube at low altitude, and a more complex 2P PocketQube to the stratosphere. Different sensor suites might be better suited for younger learners and simpler missions (say middle school) while missions with spectrometers and GPS might be better suited for more sophisticated learners and more complex missions (say advanced high school). In the picture to the right, we can see four configurations of S4: a basic 1P sitting on 2P package, a 2P configured with a gamma radiation sensor, a particulate matter spectrometer, a video camera and IR imager, and a 2P configured with a small telescope with video camera. As we can see on the left, three 1P satellites can fit in the space previously taken by one classic CanSat.

Since S4 is in the standard PocketQube format we can imagine, with appropriate modifications, extending these missions to LEO.

An S4 PocketQube has a rich portfolio of (optionally) configured 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 the S4 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) (1 Hz)
- AS7265 18 channel 410-940 nm near-UV to near-IR light spectrometer
- Beta, x-ray and gamma radiation spectrometer < 1 MeV
- 32x24 pixel 60 degree infrared imaging sensor,
- Visible light imaging camera (optionally removable IR filter for multispectral imaging)[15].

It is configured as a 3D printed ABS 50mm 1p (or 1.5p or 2p) package for either captive flight or independent deployment for parachute recovery. It weights about ~50-200 grams depending on sensor configuration. Spread spectrum wireless telemetry allows for independent tracked recovery. Additional sensors can be configured on standard extension busses (I2C, serial, 1-Wire, SPI, DIO). Open source data collection and telemetry software is Arduino/C++ based.

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

Some Simple Missions

Simple S4 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

More Complex Missions

A rocket based mission to 30k' can take advantage of the rich portfolio of S4'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 several S4s 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 rocket 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
Can we detect vegetation and changes with vegetation with season and water content?		

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 desktop/laptop dashboard downloads mission data from the satellite and displays.

This package is written in C/C++ and is hosted on the standard Arduino IDE.

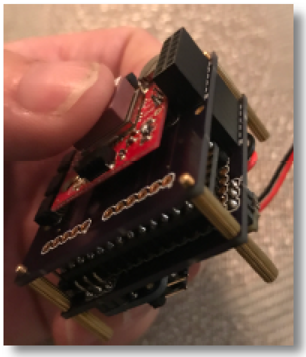
The S4 hardware also supports Python for users that prefer to port the mission software to that environment.

The S4 mission software is open source and available for modification and improvement.

S4 Hardware Platform

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

Platform	Package	Processor	Data Storage	Communications	Sensor Capacity	Scope
S4	1p, 1.5p, 2p PocketQube, 3D printed ABS plastic	ARM Cortex M0 or M4 C/C++	22 MB Flash, microSD card	LoRa telemetry	< 10	Standard Arduino platform with local storage, telemetry and substantial sensor capacity.

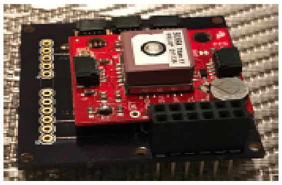
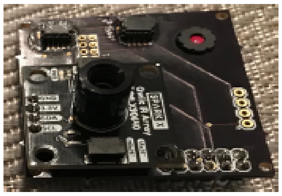


S4 is based on an enhanced processor platform - the ARM Cortex M4 - the Adafruit ItsyBitsy M4 Express. It adds the baseline S4 sensors: flight capable GPS (capable to 80 km altitude), 3d accelerometer, 3d gyro, 3d magnetometer, temperature, atmospheric pressure, battery voltage, equivalent CO² concentration, TVOC, humidity, UV+IR+visible light intensity, and an 18 channel 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. It is programmed with the Arduino IDE and the standard S4 mission software.

The S4 is based on the standard PocketQube 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 commercially available daughterboard sensors designed for the science mission in mind.

There is room for one or more boards of standard PocketQube size within the S4 1p package depending of component height. Such boards could contain additional sensors or perhaps stepper motors to control a deployable parawing 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 imaging sensor, the particulate matter sensor, the multispectral imaging sensors or the radiation sensor can be packaged in a 2p configuration.

	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 multispectral 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.

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

Both the Imaging Board and the particulate matter sensor are designed to mounted to the aft outer side of the 1P package to face downward as S4 is deployed for parachute or parawing recovery.

The S4 package is a 3D printed 5x5x5 cm plastic enclosure designed to hold the core processor+memory, baseline sensors, battery, antennas, and additional sensors.

The core S4 electronics are expected to space capable for short missions to LEO. It is anticipated that the plastic PocketQube form factor can be upgraded to WindForm - a 3D printed space capable material and format[16].

Standard Expansion Interface

S4 defines four external sensor interfaces, each defined a simple four wire interface using SparkFun's QWiiC[17] 4 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 used in the S4 Mission Software.

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 following table represents sensors that can fit in the package, have supported drivers, 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.

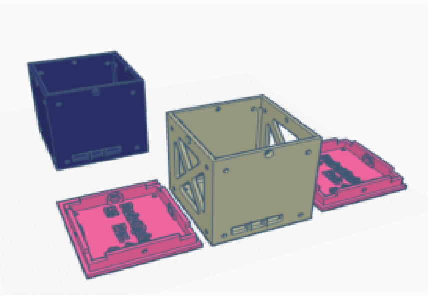
16 Windform has already been flown in LEO. http://www.windform.com

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

Measurement	Sensor	Description/Link	S4Qube S	S4Qube 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		√
Ambient UV light	Vishay VEML6070	https://www.adafruit.com/product/2899	√	
CO^2	AMS CSS811	Equivalent CO^2 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		√

Measurement	Sensor	Description/Link	S4Qube S	S4Qube O
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		√

Package



S4 has a physical package in nominal 50mm PocketQube format supporting standard 42mm PCBs. It can be extended to 2P and 3P configurations. It is nominally 3D printed in ABS for most missions. With a digital design, details can changed for a specific mission.

The S4 system adds lower power rocket solution with largely 3D printed parts for nosecone payload shrouds, fin cans, motor retention and recovery retention.

Communications and Telemetry

An emerging wireless standard for the Internet of things, LoRa[18], is used as the S4 basis for inexpensive, long range, low power S4 telemetry service in either the 430-480 MHz or 902-928 MHz bands in the Americas. LoRa is based on a 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 communication to LEO has 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[19] Arduino communications library to provide the basic protocol structure.

[18] https://www.lora-alliance.org/What-Is-LoRa/Technology

[19] http://www.airspayce.com/mikem/arduino/RadioHead/

The basic S4 ground station is an S4 PocketQube 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.

Mission Modes

S4 can be flown in a range of vehicles, ranging from small mid-power rockets, to high power sounding rockets to high altitude balloons and aspirationally to LEO. These vehicles deliver mission profiles that work in a local park under 1500' to sounding rocket missions at Black Rock or SpacePort America in the continental US.

3D printing allows us to design aerodynamically efficient airframes that get the most altitude for the least motor power - and the money to pay for propellant. Driving the cost down is a good thing.

Captive and Deployed

S4 missions anticipate both captive and deployed S4 satellites. Smaller missions carry one 1P satellite, large airframes can carry up to 18 1P or the equivalent.

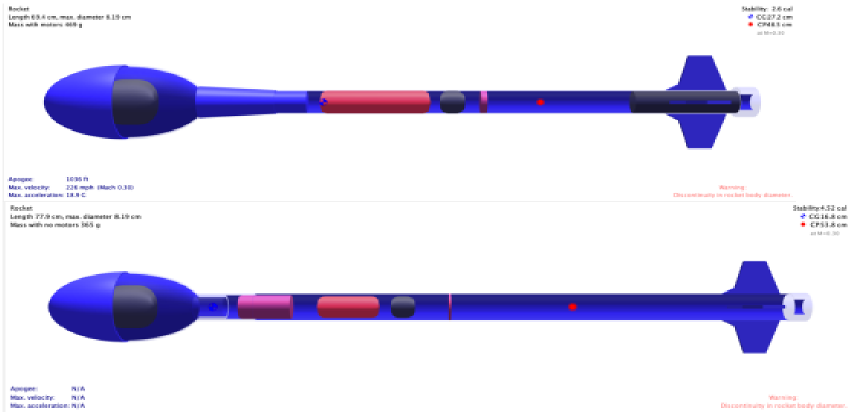
Captive satellites remain within the launch vehicle and rely on the launch vehicle's recovery mechanism for safe return. It is anticipated that the launch vehicle will provide means for access to the external world (air vents, imaging windows, etc) sufficient for the missions of the captive payload satellites.

Deployed satellites are deployed right after launch vehicle apogee in the classic ARLISS manner, and deploy their own recovery and descent mechanism. This mechanism can be a wide variety of safe mechanism - some passive like parachutes or streamers, some active like parawings.

Park Mission

A park mission is envisioned as a captive S4 flight flown on a mid-power airframe on an E thru G motor to 1-2k' AGL. Archetypal 24mm and 29mm airframes have been designed and tested for these missions. Each of these airframes uses 3D printed parts for a nosecone payload carrier, fin can, fly away launch assembly, motor retainer and recovery anchor. The baseline 24mm airframe is anticipated to use chemical motor delay, while the 29mm uses off-the-shelf commercial avionics for deployment. Both flight regimes are subsonic and the rocket planforms are optimized for subsonic drag.

The 24mm airframe can carry a nominal 1P S4 PocketQube to ~750'AGL on E30 or ~1000 on an F24 motor. The 29mm airframe can carry a nominal 1P S4 PocketQube to ~1500'AGL on an F50 to ~3000'+ AGL on an I200.

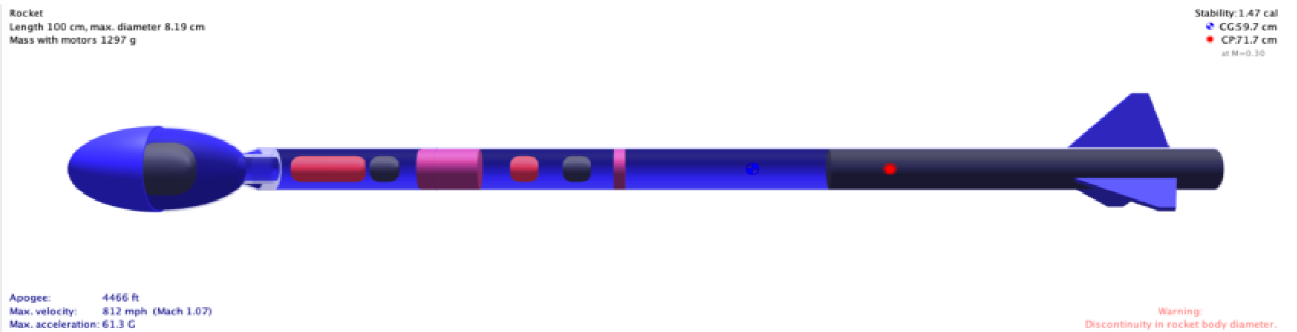


Small Sounding Rocket Mission

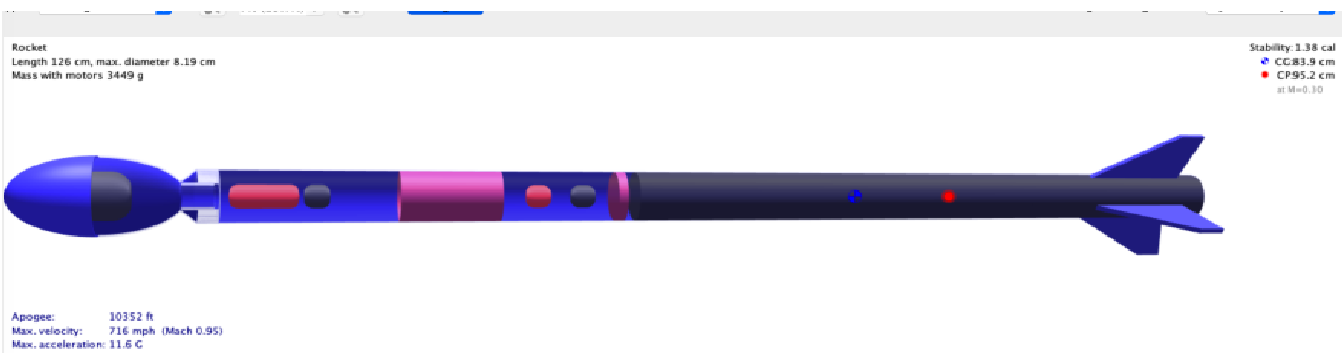
A small sounding rocket mission captive carries a single S4 satellite payload altitudes under 10k' AGL. Much real science can be done in this domain, particularly on the atmosphere and ground imaging as well as supersonic flight dynamics.

Two archetypal airframes have been designed and tested both using the same payload nosecone and upgraded versions of the fly away launch system. Both use avionics for recovery. With this nosecone shape both are high drag and the flight regime is large subsonic.

The 38mm airframe can captive carry a 1P S4 to ~2000' AGL on a G80 up to ~5000' AGL on a J570.



The 54 mm airframe can captive carry a 1P S4 to ~2500' AGL on an I200, and reach as far as ~10k' AGL on a K250.



ARLISS K Mission

ARLISS K is one of the two workhorse rocket designs for the ARLISS program. There are variants, the specific airframe depicted is the author's version - customized for S4 missions. An ARLISS K, regardless of individual variance, is always an airframe with a 12" 75mm payload bay - originally designed for one CanSat - in an airframe with a 54mm motor mount. The original ARLISS K CanSat mission profile was carry one CanSat to ~9k' AGL on a K550 motor, deploy just after apogee for the satellite to go on with its mission. At current motor prices, the cost of one mission is the cost of one K550 - about $130.

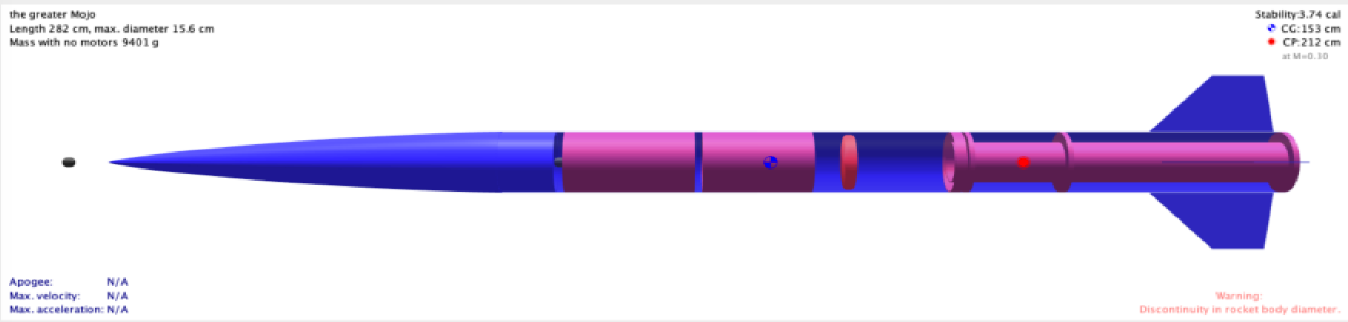
This ARLISS K, optimized for S4 satellites can carry up three 1P satellites for apogee deployment and two more in a nosecone payload bay for captive carry.

This updated S4 ARLISS K reduces the cost of each mission by 5x - to about $25/S4 satellite.

ARLISS M Mission

The ARLISS M airframe has become the workhorse of the ARLISS program. Originally designed to carry 3 standard CanSats in its 12”x6” payload carrier, to be deployed just after apogee, the most popular mission today is to carry one “unlimited” < 1Kg satellite - generally a ComeBack[20] robot to a target 11k’ AGL.

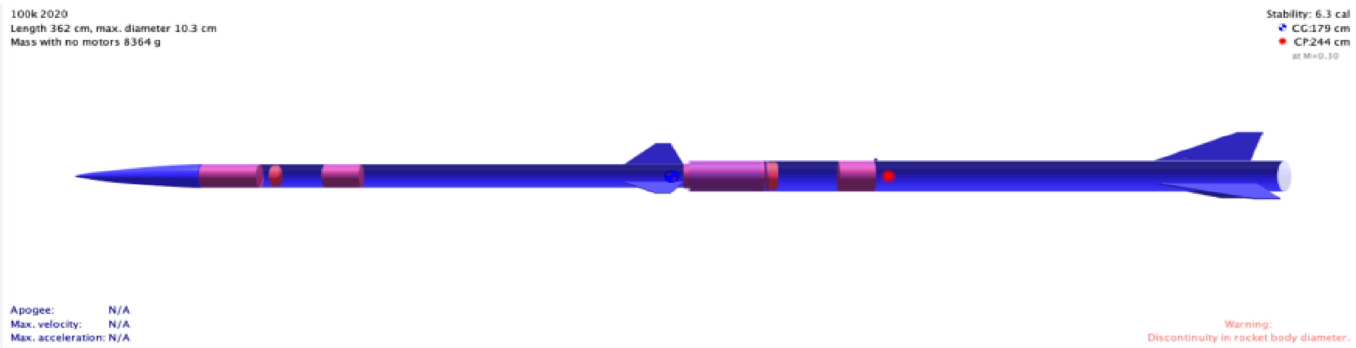
When used for S4 payloads, up to 24P of S4 satellites can be carried between the primary payload carrier, and the nosecone payload bay. These are some mix of both captive and deployable and in a mix of sizes - 1P, 2P and 3P. The more deployable are carried, the fewer satellites can be carried leaving room for recovery gear. Both payload bays have 3D printed inserts specially designed for S4. With 24 satellites, the cost per mission for the typical M1419 motor is under $20.



ARLISS Extreme Mission

20 An ARLISS ComeBack Competition mission independently deploys a satellite just after airframe apogee. Each satellite then deploys the recovery method of choice. Parachute then wheels. Quadcopter. Wings. Parawing. Anything. The project that gets closest to the present GPS coordinates on the Black Rock playa - wins. The most recent winner in 2019, a young woman led team from Japan used a deep learning vision system plus GPS to literally hit the target 2 times in 3 flights - with the third attempt less than a centimeter away.

ARLISS Extreme, while still under development, has been designed to carry 3x 1p S4 payloads as captive payload halfway to the Karman line. Its foundation architecture is the successful Carmack Prize winning flight above 100k' in 2012.



Documentation

S4 is documented at GitHub[21]. 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.

Future Work

Technology changes rapidly, as we are at a wonderful time of innovation. Modern microcomputers, wireless communications, sensors and 3D printing encourage a rapid fail fast development methodology. Updates to the current system are in progress.

- Updated communications to include S4 to S4 communications to enable satellite swarms using LoRa and WiFi. Additional beacon modes as backup in challenging environments like LEO.
- New sensors as they are available.
- New processors and storage.
- Distributed ground stations increasing coverage sharing telemetry via Internet dashboards.

21 https://github.com/kenbiba/S4