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

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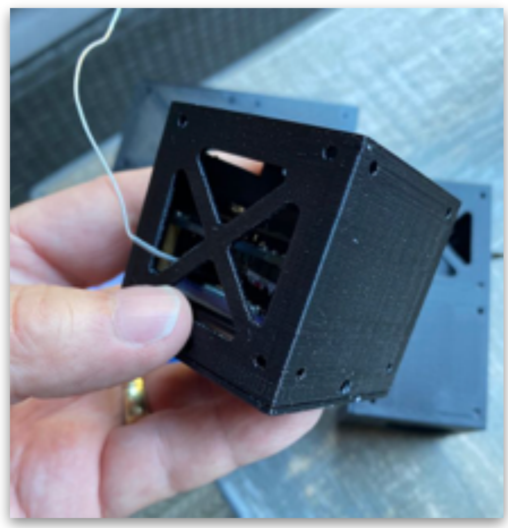
I am fascinated with building space robots and satellites. As a long time part of the ARLISS team - flying student robot satellites - building my own robots to explore what my rocket's experience has been and to learn more in lieu of being an astronaut - is high on my list of good things. I have been 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.

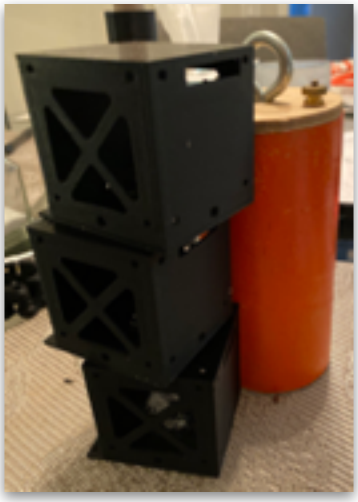


ARLISS Classic 75mm and 150mm airframes on K and M motors can carry a large number of these satellites to above 10k' AGL, and ARLISS Extreme can reach well above 100k'.

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.

[1] Thanks to Paul Hopkins for his collaboration on the 3D printed packages for S4 and for the design of the ARLISS Lite payload nosecone.



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

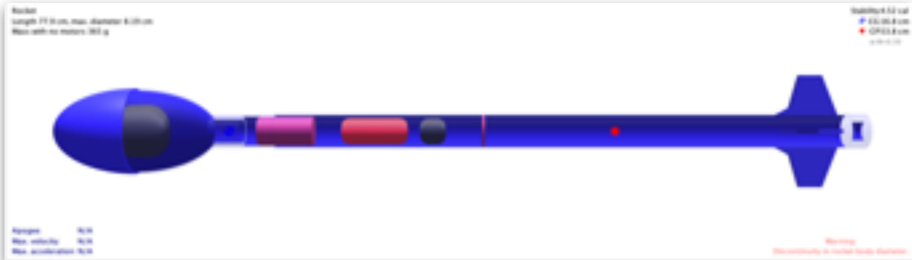
S4 is an affordable satellite, with an entry level 3D printed satellite with as little as $50 in parts ranging to more complex satellites with many advanced sensors over $300. I wanted to get the best mission profile (and altitude) for the least cost in motors. With about a ~75mm cross section, almost 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 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 improved 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.

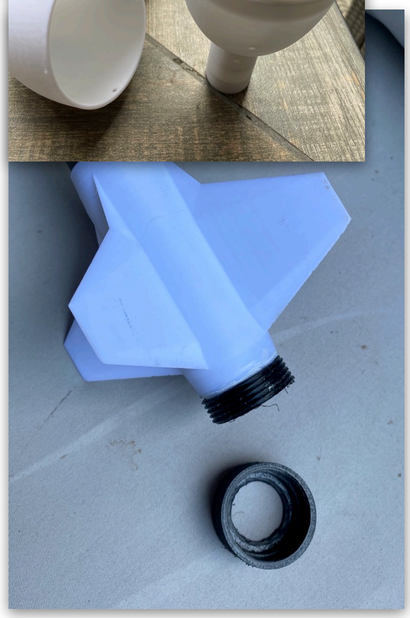
A key choice in 3D printing rocket components is strength of materials. Low end printers have only one choice - PLA. PLA has limited strength and temperature resistance - particularly as we move above low power designs. The parts in PLA are just too fragile and heat sensitive. More robust materials like 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.

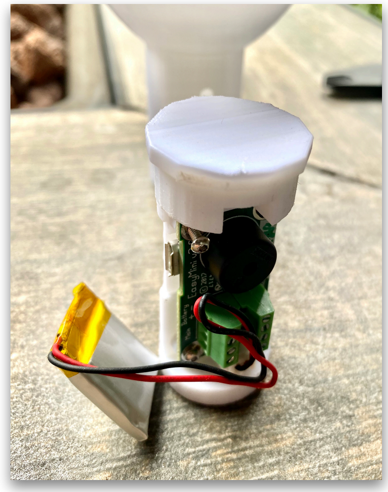
I have found good success in using Dremel's ECO-ABS (an enhanced PLA with the temperature and strength properties of ABS) and PETG. The ECO-ABS gives an esthetically more finished product, but the PETG seems more robust. The Dremel 3D45 also allows for using nylon filament - which has even better strength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



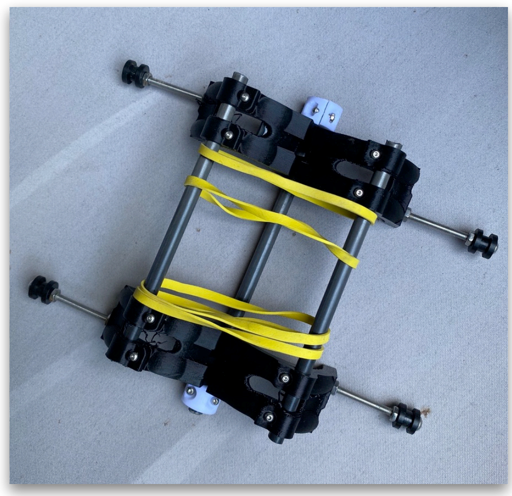
great OpenSCAD library for transitions solved those design needs.   PETG or EcoABS are my preferred choices of materials.



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

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

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.

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