Design and Manufacture of an Open-Hardware University Rocket Airframe using Carbon Fiber

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Introduction

Portland State Aerospace Society (PSAS) is an interdisciplinary group of aerospace enthusiasts with the long term goal of putting a cubesat into orbit. The Launch Vehicle 3 (LV3) airframe is a test platform to develop technologies for the group's eventual 100 km launch, replacing the LV2 platform. Like all PSAS projects, this design is completely open-source, with all design, testing, and documentation available on GitHub (see below).

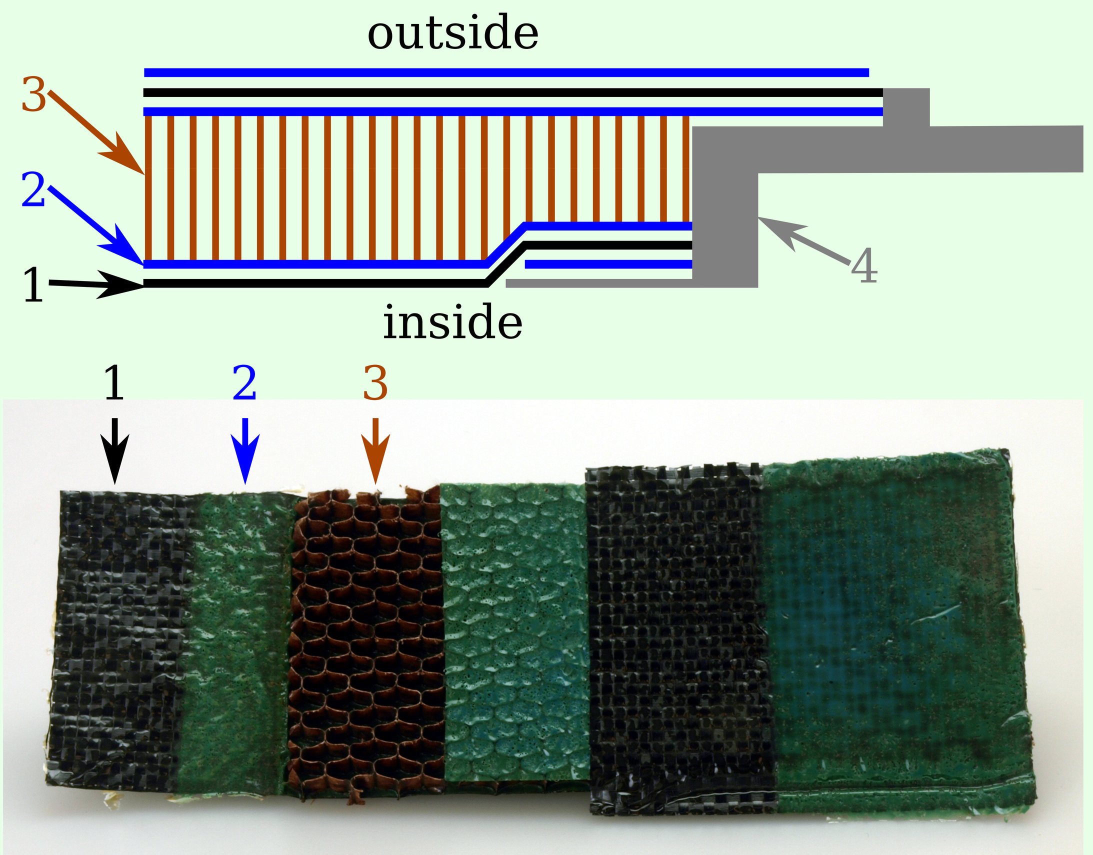

Figure: The sandwich design used throughout the airframe. Carbon fiber plies (1) are separated by a core (3) and bonded with structural adhesive (2), terminating in an aluminum ring (4).

Sandwich Design

Unlike other amateur rocket airframes which use cardboard or many-layered composite walls, LV3 uses a sandwich design (see left). This provides a strong, rigid structure without the excessive weight of many composite plies.

Single sheets of carbon fiber are strong and rigid under in-plane loading, but bend easily. Sandwiching carbon fiber around a lightweight core creates a structure that is rigid in bending, using only two sheets of carbon fiber. This reduces the weight of the airframe by about 80%, relative to the previous LV2 design which used an aluminum frame with a fiberglass shell.

These layers are formed around a cylindrical aluminum mandrel and compacted using heat-shrink tape. Aluminum coupling rings are co-molded to the part.

Sandwich designs are commonly used in large, low-curvature parts, but the outer radius of LV3 is only 3.3 inches. So, the honeycomb core (see left) must be over-expanded along the axis of the rocket, to conform to this tight curvature.

Materials and Surface Finish

The carbon fiber layers are pre-impregnated with epoxy and bonded to a Nomex® honeycomb core using structural adhesive and cured at 350 °F. They are left with many cells lacking epoxy (see bottom right). This decreases the strength an durability of the outer layer, while increasing drag.

This is solved by adding a layer of structural adhesive over the carbon fiber (see bottom left). This fills in any dry cells and protects the carbon fiber from damage. It can also be sanded to improve the surface finish, decreasing the surface feature size by a factor of 50.

These materials were donated by Boeing and Pacific Coast Composites after they expired for use in human-rated vehicles, and could not have been afforded otherwise.

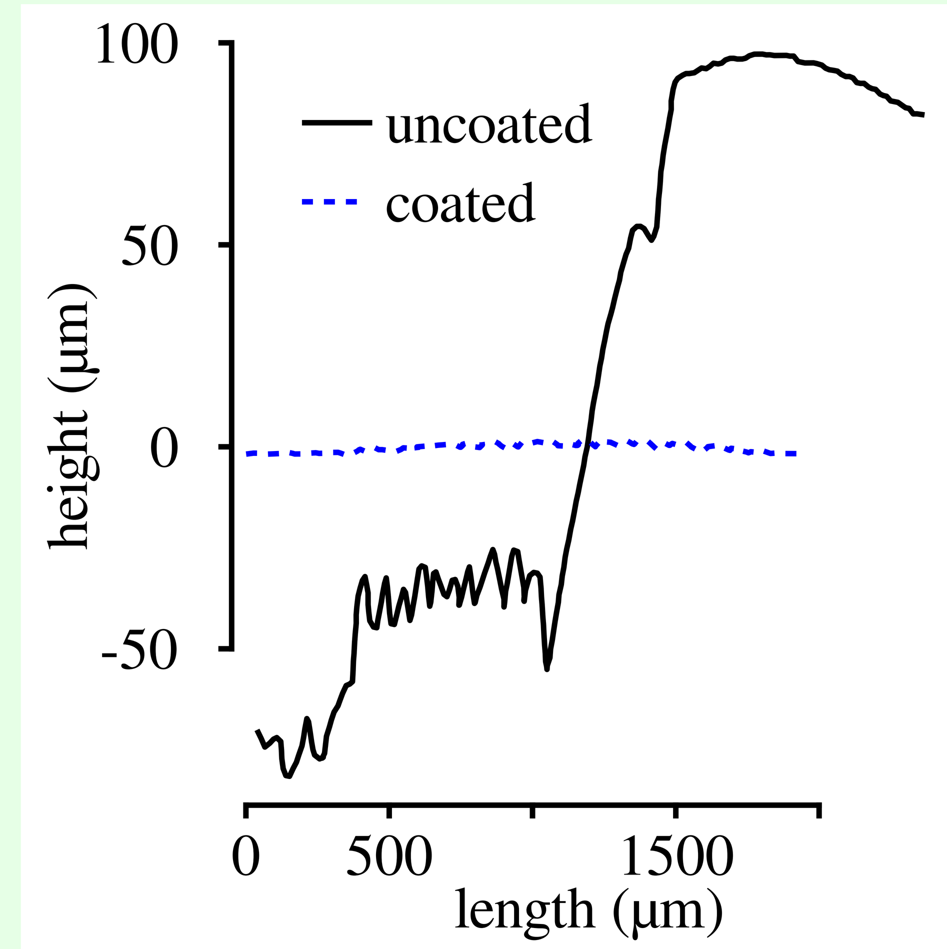

Figure: Surface roughness profiles of coated (dashed blue) and uncoated (black) coupons.

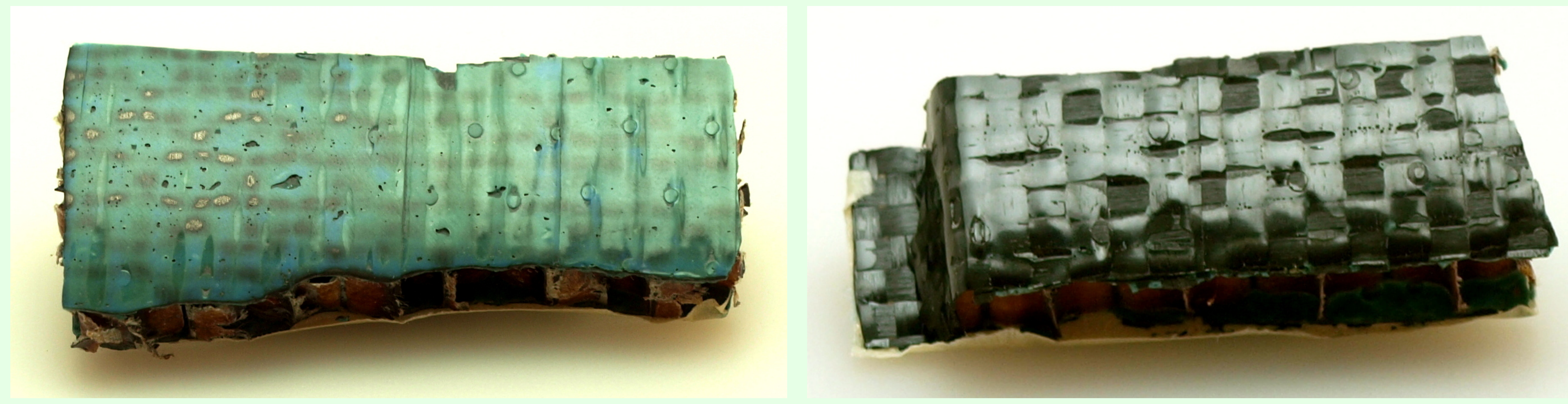

Figure: A partly polished coupon with adhesive surfacing (left), and a coupon with no adhesive surfacing (right). The coated coupon has only been polished on the left side.

Figure: A carbon fiber module with a motor-retaining ring (top), and a crushed fiberglass module (bottom).

Modular Design

The airframe is composed of 18 and 24 inch long modules, which couple together via male and female aluminum rings. Large features and experiments can be added in-line, using these modular coupling rings.

The only specialty modules are the radome, which substitutes carbon fiber with fiberglass for radio transparency, and the fin section, which has fins bonded to the outside

Destructive Testing

Rather than yielding like traditional engineering materials, this design "pings" as the most heavily loaded fibers begin to break and sections of core material experience small delaminations from the faces.

Different modules were tested in axial compression and surface-puncture loading. Compressed modules consistently failed in buckling at the coupling ring, well above the service load. However, delaminated modules and modules subjected to puncture loading much weaker (see table). Small samples were also tested in tension, but exceeded the maximum load of the testing equipment.

Strain measurements revealed linear-elastic behavior up until failure (see right). The stress appears to concentrate around the pillars in the coupling rings which transfer the load between modules (see left).

Conclusions

This design represents a significant improvement over typical amateur airframes, bringing university groups closer to a 100 km launch. However, the vulnerability to puncture may reduce long-term reusability.

Table: Failure strengths of modules.

Material	Loading	Pinging Strength	Ultimate Strength
carbon fiber	axial	7×10^3 lb	10×10^3 lb
carbon fiber	puncture	<100 lb	<100 lb
delaminated CF	axial	<100 lb	<100 lb
fiberglass	axial	2×10^3 lb	5×10^3 lb

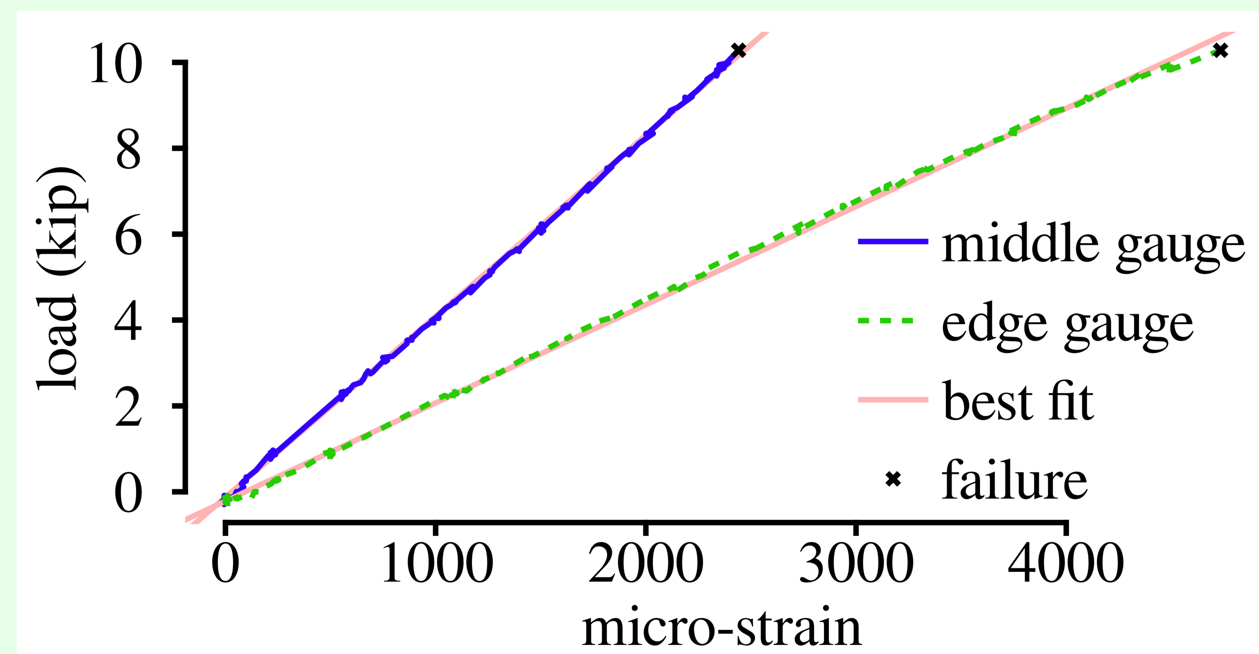

Figure: Load-strain plot for points in the middle of a module (dashed green) and at the point of failure (blue) with best fit lines (pink).

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Project Repository:
`github.com/psas/lv3.0-airframe`

PSAS Website:
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