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


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## Introduction

The amateur and university rocketry communities are rapidly reaching higher altitudes with more sophisticated rockets. However, most groups are still using heavy airframes made of metal or fiberglass. Commercial off-the-shelf airframes are either too expensive for low-budget university groups or too small to use as a platform for high altitude experiments. A capstone team of mechanical engineering seniors at Portland State University has developed a low-weight, modular carbon fiber airframe as an open-hardware technology for university rocketry. This project continues the work of a 2014 capstone team, who developed a carbon fiber layup process with promising results. This will enable low-budget groups like the Portland State Aerospace Society to explore high

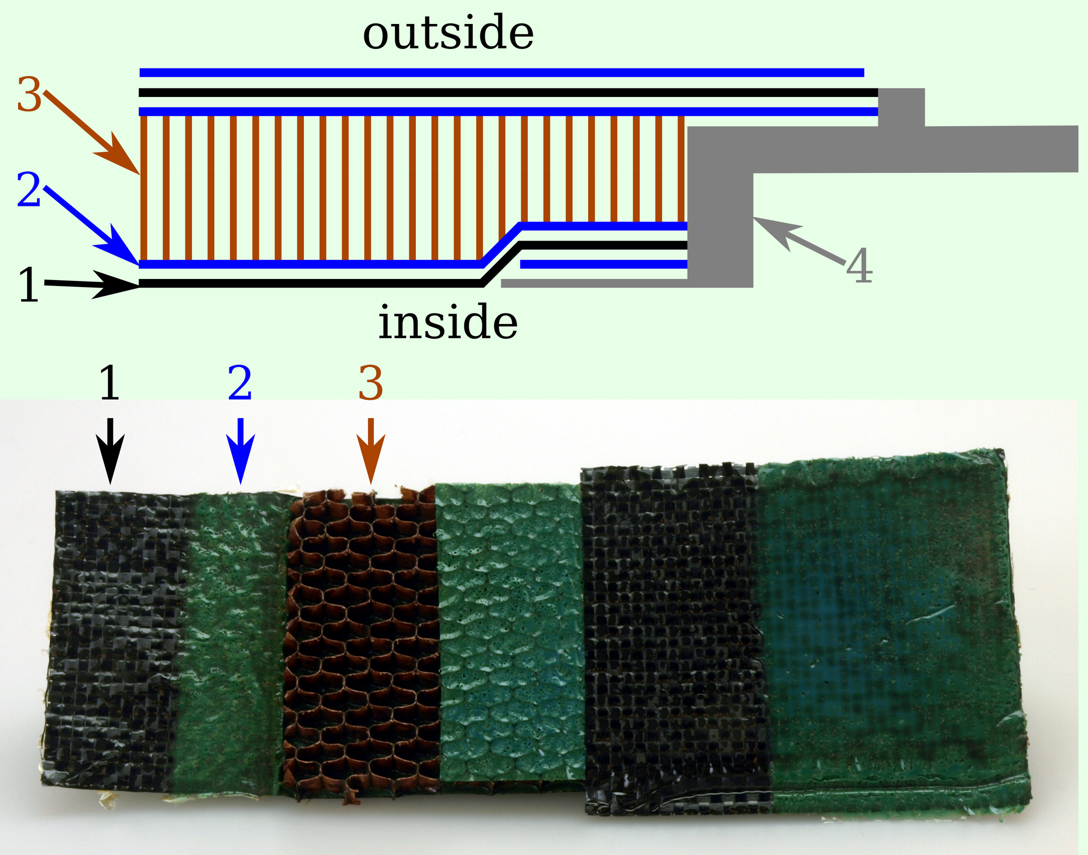


**Figure:** The sandwich design used through-out the airframe. Carbon fiber plies (1) are separated by a core (3) and bonded with structural adhesive (2), terminating in an aluminum ring (4).

## Sandwich Design

The majority of the LV3 airframe uses a sandwich shell composed of CF\nomenclature{CF}{Carbon Fiber} faces surrounding an aramid honeycomb core (see figure \ref{fig:moduleDiagram}). This provides a rigid structure while minimizing weight. Single sheets of carbon fiber are rigid when subjected to in-plane loading, and very flexible in bending. Meanwhile, the core is flexible in bending, and rigid under out-of-plane loading. When laminated together, these form a plate which is rigid in all loading conditions. The core material separates the rigid CF faces, greatly increasing the second moment of inertia of the plate. There is much more to the theory of sandwich plates and beams, but that is outside the scope of this paper.

The body of the airframe is composed of modular cylindrical sections using this sandwich design with aluminum coupling rings co-molded to each end.Each module can hold avionics, experiments, or other equipment with six tapped holes around the inside of the female coupling ring. For the radio module, fiberglass takes the place of the CF to allow radio transparency.

The fins use the same sandwich design, with an aluminum frame defining their planform. The center of the frame is filled with core material, and the whole surface is covered in carbon fiber. The leading and trailing edges of the fins are machined out of the aluminum frame. The fins are fins are attached to a module with epoxy fillets, using chopped CF as a filler, and ``tip-to-tip'' CF sheets running from the tip of one fin across the module to the tip of the other fin.The nose cone uses the same coupling ring system as the modules. It is a von K\'arm\'an ogive formed from two molded CF shells. Unlike the rest of the airframe, the nose cone uses a thin shell of two CF sheets, rather than a sandwich design (see section \ref{sec:noseCone} for details). The tip of the nose cone is machined out of aluminum and is removed when assembling the recovery system inside the nose cone.

## Materials

Nearly all of the materials used in the LV3 airframe were donated. The pre-impregnated CF and the structural adhesive were made available after they expired for use in commercial aircraft. Acquiring expired materials from large manufacturers and distributors is the strongly preferred over purchasing them outright or simply using cheaper materials. Distributors are unlikely to offer these materials in quantities appropriate to this type of project, and purchasing them would be outside the budget of many university and amateur groups. Using carbon fiber cloth with painted-on epoxy could change the manufacturing significantly, and would increase the weight of the airframe. Acquiring donations is also a good way for university groups to form industry contacts. It can even become an opportunity to collaborate with other university groups, through the re-donation of excess material.

The CF is a plain weave design that is pre-impregnated with epoxy resin which cures at $\SI{350}{\Far}$.Meanwhile, the adhesive is an epoxy film which cures between $\SI{250}{\Far}$ and $\SI{350}{\Far}$, intended for bonding metals and composites. This allows for co-curing of both materials together. The core material is an over-expanded honeycomb Nomex$^\mathregistered$ mat which bonds well to the adhesive.

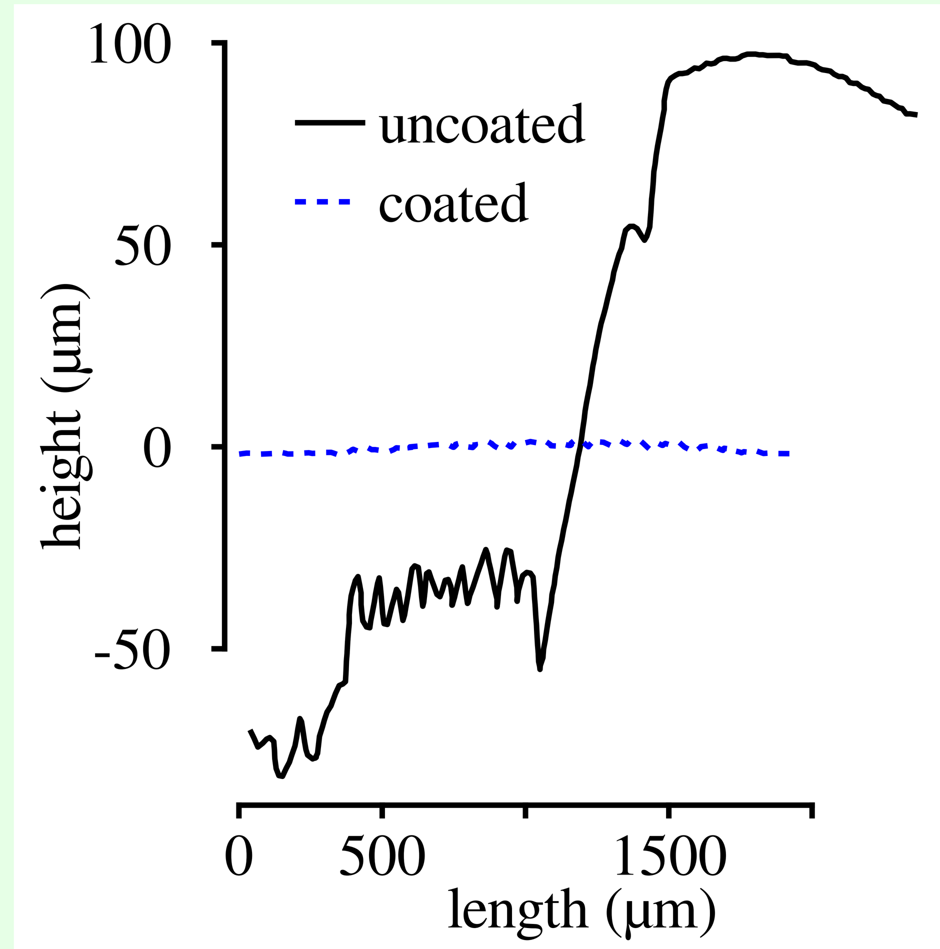


**Figure:** Surface roughness profiles of the coated and polished (dashed blue) and uncoated (solid black) coupons shown below.

**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 (top, female end) with motor-retaining ring, and a crushed fiberglass module (bottom, male end).

## Modular Design

The body of the airframe is composed of modular cylindrical sections using this sandwich design with aluminum coupling rings co-molded to each end. Each module can hold avionics, experiments, or other equipment with six tapped holes around the inside of the female coupling ring. For the radio module, fiberglass takes the place of the CF to allow radio transparency. The fins use the same sandwich design, with an aluminum frame defining their planform. The center of the frame is filled with core material, and the whole surface is covered in carbon fiber. The leading and trailing edges of the fins are machined out of the aluminum frame. The fins are fins are attached to a module with epoxy fillets, using chopped CF as a filler, and ``tip-to-tip'' CF sheets running from the tip of one fin across the module to the tip of the other

## 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. A carbon fiber module was subjected to compressive loading along its axis. This was done by attaching dummy rings, which emulate a connection to another module, and loading the dummy rings through a flat plate.

The load was slowly increased using a hydraulic press. Similar tests were performed with a fiberglass module, a CF module where the CF layers were delaminated from the core, and a CF module with the load applied laterally

The time and corresponding load at which audible pinging occurred was also recorded. The load was slowly increased using a hydraulic press. Similar tests were performed with a fiberglass module, a CF module where the CF layers were delaminated from the core, and a CF module with the load applied laterally via a 2 inch wide beam, to puncture the module.These results can be seen in table \ref{tab:compression}.In compressive loading, both the CF and fiberglass modules failed through buckling of the

## Conclusions

The nonuniform stress in the compressed CF modules presents an opportunity to compare these results to a finite element model. Due to the required time and lack of immediate benefits, this has not been pursued. The surface finish of this design could be improved by filling the small voids in the adhesive coating. This would not provide much benefit to the LV3 platform, but may be useful in other applications.This design provides a strong, lightweight, low-cost testing platform which will be a significant advantage in PSAS' race towards $\SI{100}{km}$.Any university or amateur groups able to acquire the necessary materials should be able to build similar rockets, reaching much higher altitudes without upgrading to larger motors. It is strongly advised, however, that such

**Table:** Results of destructively testing modules.

| Material | Loading | Pinging Strength | Ultimate Strength |
|---|---|---|---|
| carbon fiber | axial | $7 \times 10^3$ lb | $10 \times 10^3$ lb |
| carbon fiber | puncture | <100 lb | <100 lb |
| delaminated CF | axial | <100 lb | <100 lb |
| fiberglass | axial | $2 \times 10^3$ lb | $5 \times 10^3$ lb |

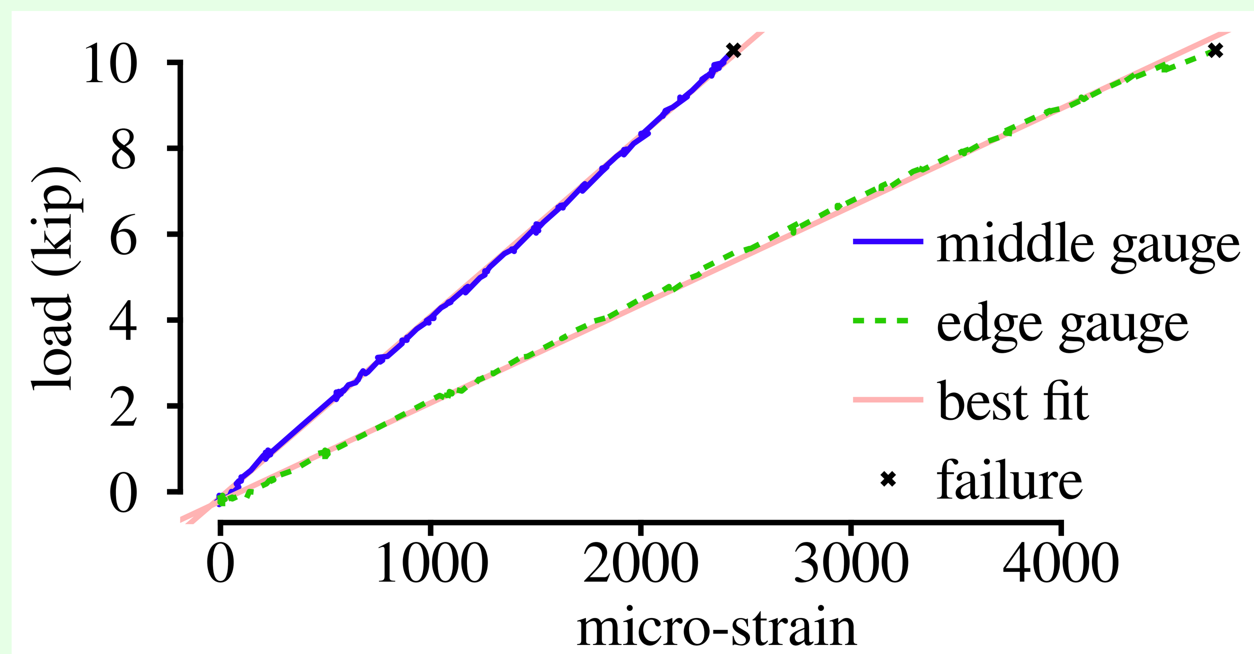


**Figure:** Load-strain plot for points in the middle of a module (dashed green) and at the point of failure (solid blue) with best fit lines (pink).


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For more information, please visit:
`github.com/psas/lv3.0-airframe`
`psas.pdx.edu/`


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