Development of Deployable Composite Booms for a Novel Dragsail Payload

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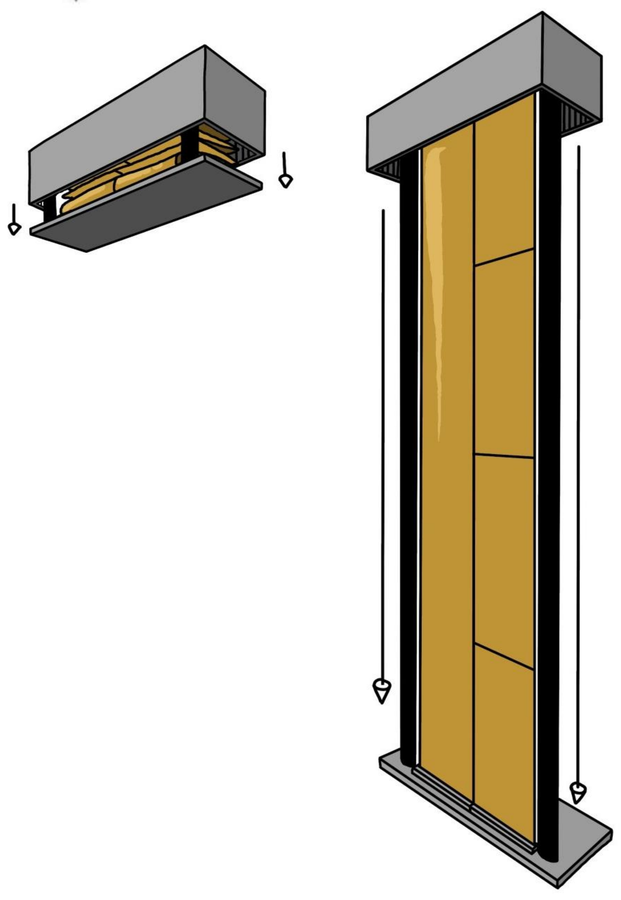


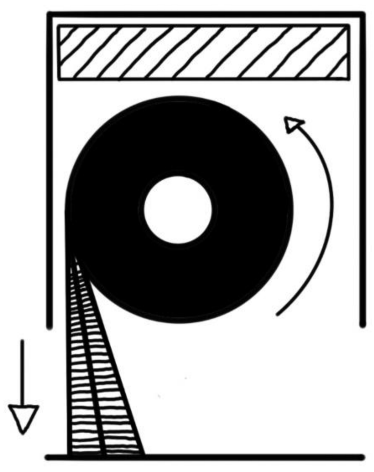
The Rotulus Mission

Rotulus is a novel CubeSat dragsail, currently in development at the University of Birmingham. It is based upon a 3U CubeSat form factor and aims to mitigate growth of space debris in the near-Earth space environment.

Dragsails increase the cross-sectional area of debris objects such as end-of-life satellites, utilising the small amount of atmospheric drag found in low-Earth-orbit (LEO) to achieve deorbit. Traditional dragsails opt for a square configuration, but this can cause issues with stability and system complexity. Rotulus' novel 'scroll-like' configuration (right) aims to reduce design complexity and improve stability through gravity gradient stabilisation.

Introduction

Dragsail deployment will be achieved through the unrolling of two carbon fibre reinforced polymer (CFRP) booms, which will be coiled around a central drum (right) and extended parallel to the sail length.



The aims of the project were as follows:

1. Identify the optimal manufacturing method for production of Rotulus' CFRP booms.
2. Manufacture a suitable boom prototype using low-budget materials.

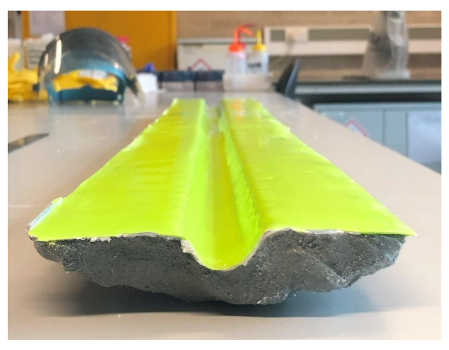
Design drivers

- The available payload volume dictates that the coiled outer diameter shall be no more than 45mm.
- For significantly accelerated deorbit, the booms shall be at least 1m in length.
- The booms shall be manufactured in-house at the University.

Manufacturing method

1. Making the mould

A fibreglass mould was created using an epoxy mould-making kit. A PVC pipe was sawed in half and used as the pattern, ensuring a semicircular cross-sectional geometry.



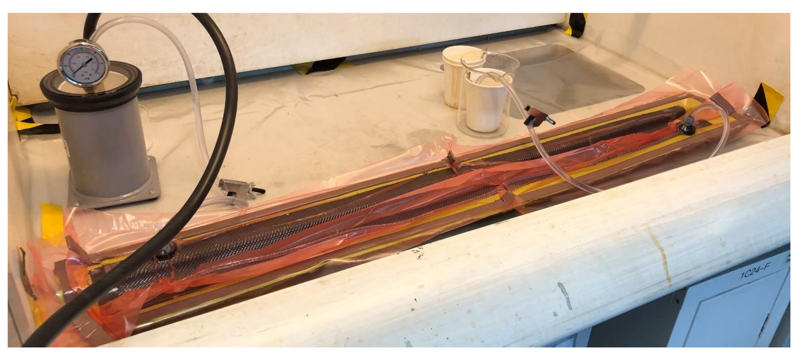
2. Layup

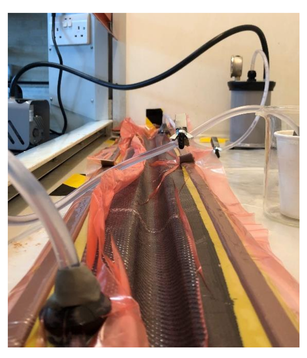
90g 1k plain weave carbon fibre cloth was selected due to its availability, low cost, and low consolidated thickness (0.1 mm)

A [45/45] layup was used, with the 45° plies inducing bistability. The addition of a central 0° unidirectional ply would provide reinforcement and improve creep resistance [1], but this was not possible in this case, due to thickness and budget constraints.

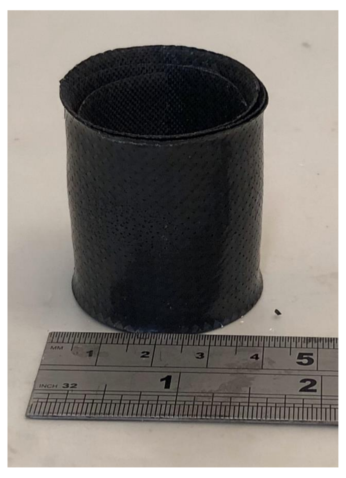
3. Resin infusion

Resin infusion was selected as the optimal manufacturing method, for its ability to produce defect-free parts with excellent mechanical properties. An epoxy infusion resin was chosen due to epoxy systems' heritage aboard space missions and low cost. This was cured at ambient temperature for ease. However, due to the thermal cycling the booms will be exposed to in LEO, an autoclave-cured resin system with superior thermal properties should be used for the flight model.





Manufactured boom prototype



Shown above is the boom prototype, manufactured using the described method. It is a bistable tape-spring structure, meaning there is zero stored strain energy in both the coiled and deployed state. It maintains bending stiffness through its cross-sectional geometry.

Due to issues with inhomogeneous curing of the part, the boom length was reduced from 1 m to 0.45 m. This is thought to be due to insufficient mixing of the resin and hardener.

Shown below are other key parameters of the manufactured boom, compared against those expected from the theory presented in [2].

Parameter	Expected	Manufactured
Thickness	0.20 mm	0.29 mm
Radius of curvature (cross-section)	14 mm	12.5 mm
Subtended angle (cross-section)	180°	135°
Coiling diameter	19.4 mm	28.8 mm
Coiled outer diameter	27.3 mm	37.0 mm

Conclusions & Future work

The prototype boom manufacture was a success overall, demonstrating the university's ability to manufacture a sufficiently compact bistable boom in-house, using resin infusion.

The theoretical model was found to overestimate the boom's compactness, possibly due to the mechanics of bistability.

Ensuring complete mixing of the resin and hardener was identified as a key improvement to make to the process going forward. Other less critical improvements, to make the process easier, were also identified (e.g. the use of spray tack to secure the carbon fibre during layup).

Areas for future work to focus on have been identified as follows:

- Production of a second boom using the improved process to reduce the error between the expected and manufactured parameters.
- Mechanical testing of the boom prototype.
- Optimisation of the boom geometry and layup.
- Investigation into the boom deployer mechanism.

References

[1] Mao, Huina & Shipsha, Anton & Tibert, Gunnar. (2017). Design and Analysis of Laminates for Self-Deployment of Viscoelastic Bistable Tape Springs After Long-Term Stowage. Journal of Applied Mechanics.

[2] Fernandez, Juan. (2017). Advanced Deployable Shell-Based Composite Booms for Small Satellite Structural Applications Including Solar Sails.