- COMPOSITE -
ROCKET FINS

In this paper, I explore my ongoing journey of discovery, experimentation, and application of composite materials in crafting rocket components. Specifically, I describe my experiences within the ESL -1 Rocket of ESO (Estaca Space Odyssey) at my engineering school, where we endeavor to continually push the boundaries of aerospace engineering through innovative approaches and hands-on experience.

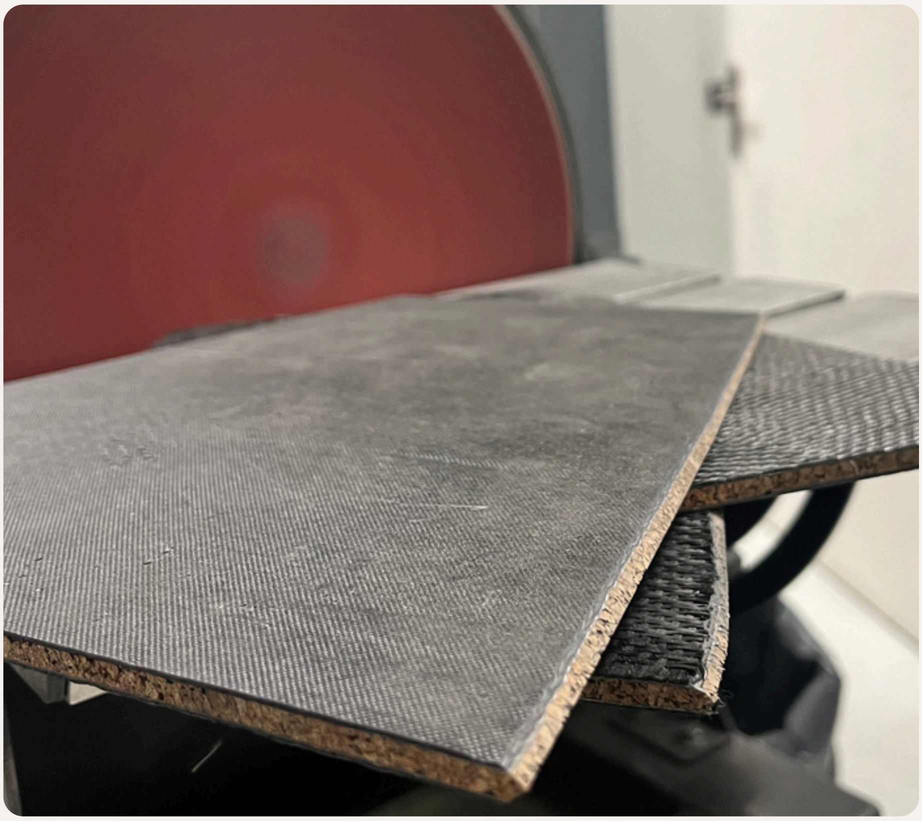

figure 1- Composite Sandwich of the rockets first scaled prototype

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Composite materials, commonly referred to as composites, represent a pivotal innovation in material science, characterized by their unique composition derived from the mixing of two or more constituent materials with diffenrent chemical or physical properties. Unlike traditional mixtures or solid solutions, composites retain the distinctiveness of their constituent elements within the finished structure.
The origins of composite materials trace back to ancient Egypt, where rudimentary composites such as straw and mud were combined to create bricks for building construction.

Today, the domain of composite materials presents a diverse applications, ranging from fiber-reinforced polymers like carbon-fiber-reinforced polymers and glass-reinforced plastic to thermoplastic and thermoset composites. Thermoset polymer matrices, for instance, often incorporate aramid fiber and carbon fiber within an epoxy resin matrix, showcasing the versatility and adaptability of composite materials in modern engineering.

This paper embarks on an exploration of composite materials, diving into their contemporary classifications, and practical applications, within the context of rocketry and aerospace engineering.
Furthermore, we will examine the optimization of viscoelastic damping materials for specific composite applications, highlighting their importance in enhancing structural integrity and performance in demanding environments.

Material Evaluation and Documentation

Embarking on the journey of working with composite materials presented a challenge, particularly given my initial lack of experience. While online tutorials provided a foundational understanding, I was driven by a desire to conduct firsthand comparisons and evaluations of composite layups using the available tools. Inspired by resources such as Alex Burkan's Composite YouTube series, I endeavored to replicate and expand upon these comparisons, even experimenting with combinations of carbon fiber and fiberglass.

Resources like Jim Jarvis's illustrated guide to carbon fiber and instructional channels such as BPS Space and Xyla Foxlin on YouTube refined my techniques for intricate layups, including the critical tip-to-tip assembly. The culmination of these efforts resulted in a series of rigorous tests, where parameters such as height, weight, flexion, and hardness were meticulously measured and evaluated.

Importantly, findings from online research I conducted revealed significant insights into the comparative strengths and characteristics of carbon fiber and fiberglass:

- Strength: On average, carbon fiber exhibits over 20% greater strength than the highest-grade fiberglass.
- Rigidity: The tensile modulus of carbon fiber is approximately four times that of fiberglass on average.
- Weight: Despite their inherent strength, both carbon fiber and fiberglass are remarkably lightweight compared to metals like steel and aluminum. On average, carbon fiber is approximately 15% lighter than fiberglass.
- Thermal Expansion: Both fibers possess thermal expansion coefficients close to neutrality.
- Corrosion Resistance: Both materials demonstrate high resistance to corrosion and chemical abrasions.
- Cost: The manufacturing process for carbon fiber is notably more complex, with fewer established manufacturers in the industry. As a result, fiberglass generally incurs lower production costs.

figure 2: Testing Samples For Base plates

The exploration of composite materials demanded a methodical approach, involving the fabrication of numerous samples. These varied in factors such as fiber orientation (0° and 45°), fiber composition (fiberglass or carbon fiber), number of layers. A change in epoxy (old barrels to new different resins and hardneres) gave me great results. I also tested different base material for a composite sandwich layup. In materials science, a sandwich-structured composite is a special class of composite materials that is fabricated by attaching two thin-but-stiff skins to a lightweight-but-thick core. The core material is normally of low strength, but its greater thickness provides the sandwich composite with high bending stiffness with overall low density. Our core material final choice is cork which is impregnated with epoxy making the sandwich great in compression resistance.

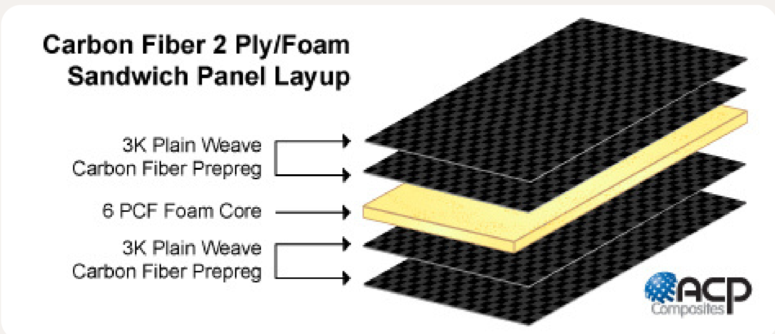

figure 3: Carbon Fiber Sandwich Panel Layup

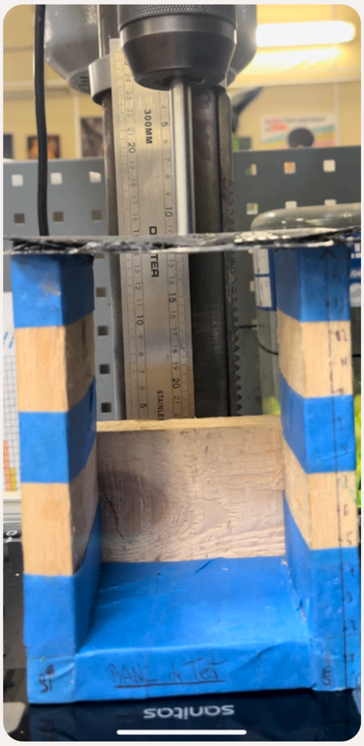

figure 4: Testing Platform

The testing platform employed in this study comprises a U-shaped wooden frame positioned atop a scale. Adjacent to the frame, a ruler calibrated in millimeters and a camera are strategically aligned with the tested sample to ensure precise measurement and data recording. This setup enables the accurate capture of load data and deformation in millimeters during the testing process, facilitating detailed analysis in post-treatment on a Excel spreadsheet.

Each sample configuration, representing variations in fiber orientation, composition, layering, and sandwich layup, is subjected to testing on this platform. Given the destructive nature of the tests, the platform serves to delineate the limits of the composite sandwich configuration.

The plotted results below depict various sample configurations: FdV0 (Fibre de Verre à 0°), C0 (Carbon Fiber à 0°), C45 (Carbon Fiber à 45°), and L (Liège, 4.5mm d'épaisseur). Among them, the layout of C0//C45//FdV0///L///FdV0//C45//C0 emerged as optimal, showcasing superior performance. This configuration has a mass of 4.5g/cm², a thickness of 5.53mm, and a maximum resistance of 125 kg per 1 cm² corresponding to approximately 1226.25 Newtons of force. Even though another sample managed to resist 140kg, the C0//C45//FdV0///L///FdV0//C45//C0 layout demonstrated the best overall compromises, with a carbon fiber outer layer, the tip-to-tip layup will be more chemically bonded.

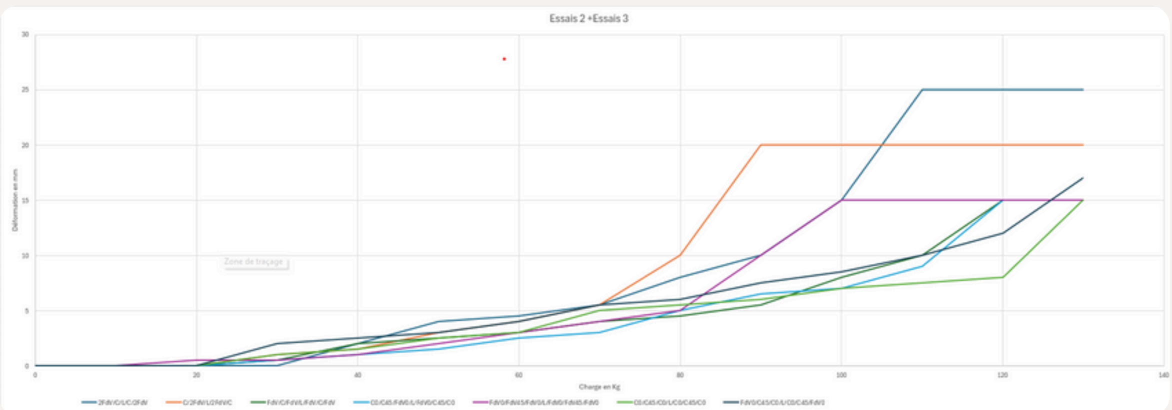

figure 5: Testing Platform results plotted (flexion(mm)/load(Kg))

I intend to test the Young Modulus (E in MPa) of our composite sandwich using a specialized test stand designed for conducting dog bone tensile tests. These tests are pivotal for evaluating the material's tensile strength and deformation behavior. The dog bone-shaped samples feature wider shoulders at each end and a narrower gauge section in between, inducing stress concentration during tensile loading. Observing where the sample ruptures, whether in the midsection or at the ends, provides critical insights into the material's performance. Determining the Young Modulus is particularly significant as it enables precise calculations for structural analyses, such as flutter, essential for building solid rocket fins.

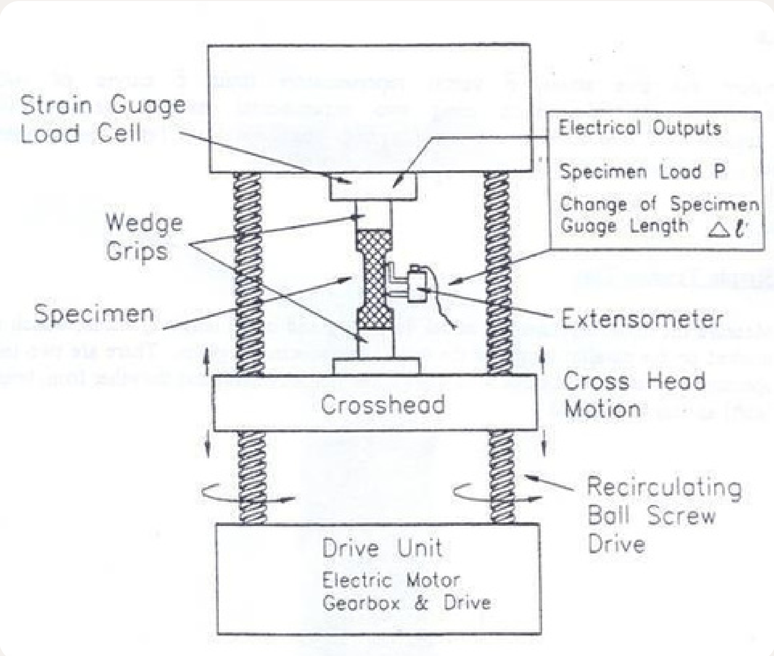

figure 6: Testing Platform for Young Modulous experimental approximation

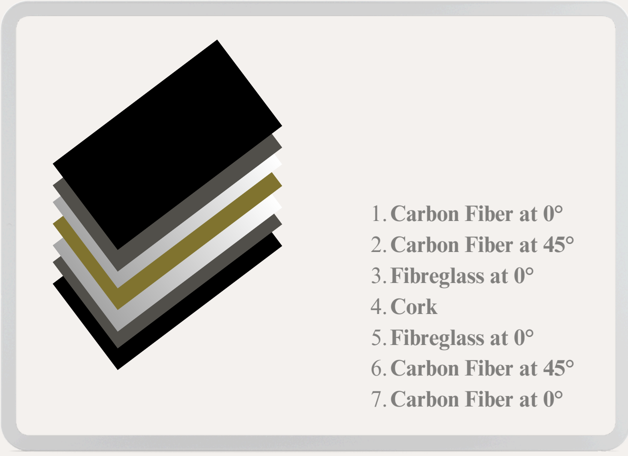

figure 7: Final configuration for the first base plate prototype

For the central panel of our ailerons, located at the heart of the "Tip to Tip" structure, we have chosen a promising sandwich composite configuration based on the results of our preliminary tests. This configuration above includes the choice of materials as well as the orientation of the fibers. We created a panel approximately 30 cm wide and 80 cm long, then cut out the shape of the ailerons from this panel. The ailerons have a trapezoidal shape and their number has been limited to three in order to minimize aerodynamic drag.

figure 8: first base plate prototype

figure 9: Matching fins

We trimmed the excess material so that all of the fins resemble each other as closely as possible. Our priority is to ensure that all three fins match each other before precisely matching the CAD files. In the picture below, we can see the leading and trailing edges that were roughly sanded at a 45° angle using a wheel grinder.

In this picture, we can see the rough leading edges and a cross section of the composite sandwich. The layers of carbon fiber and cork are visible. It is important to note that the cork must be fully saturated with resin to prevent the carbon fiber and fiberglass from delaminating (we can see a bit of that on the bottom of the plate here below).

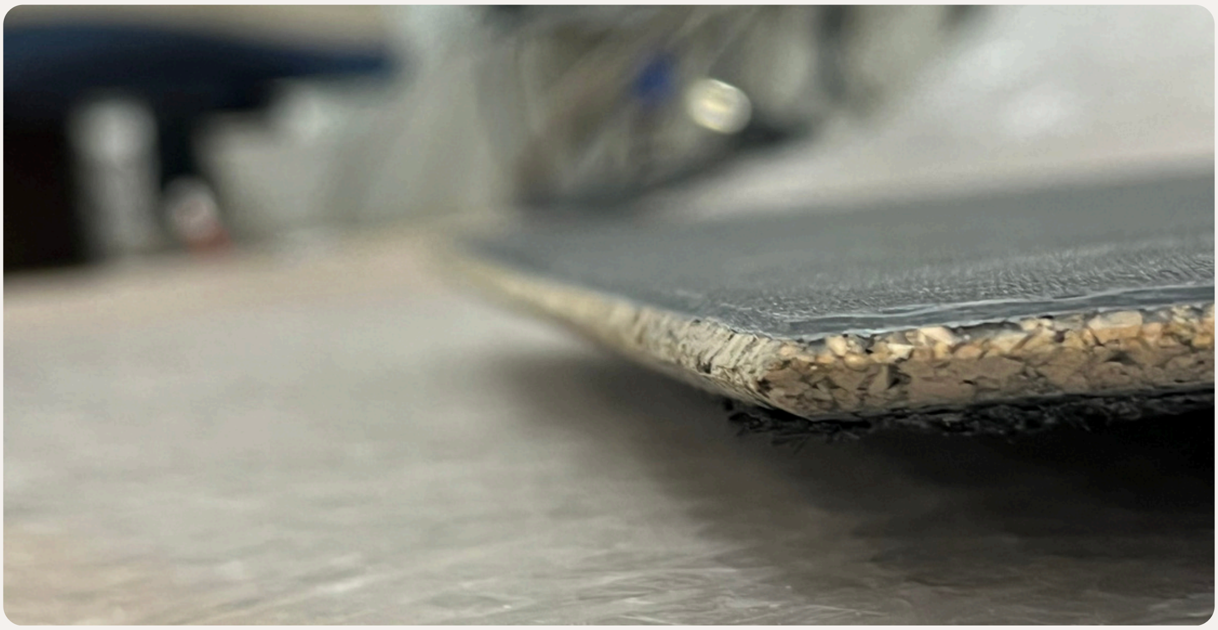

figure 10: Trailing edges

Fins Alignment Procedure
and
Mounting Technique

Proper fin alignment is crucial for the stability and performance of a rocket during flight. Fins provide stability by generating lift and preventing the rocket from tumbling or veering off course. If the fins are not aligned correctly, the rocket may experience instability, reduced performance, and even catastrophic failure. Misaligned fins can cause the rocket to spin or wobble, which can lead to uneven airflow and increased drag. This can result in reduced altitude, decreased speed, and an unpredictable flight path. In addition, misaligned fins can cause structural failure due to uneven stress distribution on the airframe. Therefore, it is essential to ensure that the fins are properly aligned and securely attached to the rocket body to achieve optimal performance and safety during flight. For small rockets fin jigs are easily built with a 3D printer, here is a typical exaple for aligning fins:

figure 11: Fin alignement example

Fins Alignment Procedure and Mounting Technique

For our specific use case, most of the fin jig examples available online were not suitable because our rockets diameter was too big (205mm). We had to get creative and think outside the box to design a fin jig that would allow us to place the fins perfectly, be reusable, use minimal plastic, and have fewer pieces. After building a first prototype that failed due to an incorrect internal diameter, I realized that using screws added unnecessary complexity to the design. Therefore, I decided to create a "puzzle fitted" fin jig that would eliminate the need for screws. Before printing the entire jig, I printed three small prototypes to test the fitting and tolerances of the puzzle link. After conducting these tests, I determined that a 0.3mm space between the male and female parts provided the best fit.

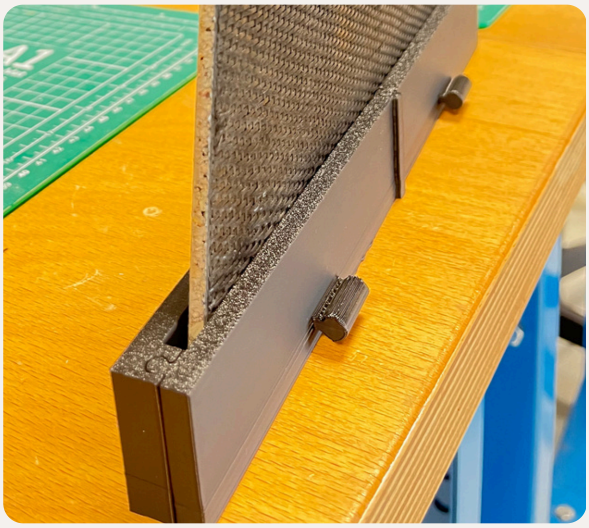

figure 12: Puzzle Link

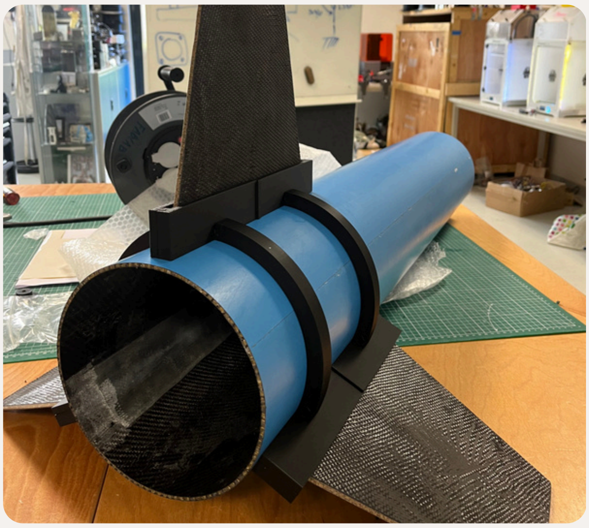

figure 13: Fin jig

Once the fins fit properly in the fin jig, we thoroughly sand the section of the tube where the fins will be attached. After sanding, we apply a thin layer of thickened epoxy that dries in only 5 minutes to the bottom of the fins. We then slide the fins into the fin jig to glue them to the tube, here the epoxy is used solely for alignment and not for structural support. After the epoxy has dried and the fins are securely in place, we remove the fin jig and begin filleting the sides of the fins. To ensure consistency in the size of the fillets, we use popsicle sticks as a reference, as they are roughly the size that we need.

figure 14: Sanding

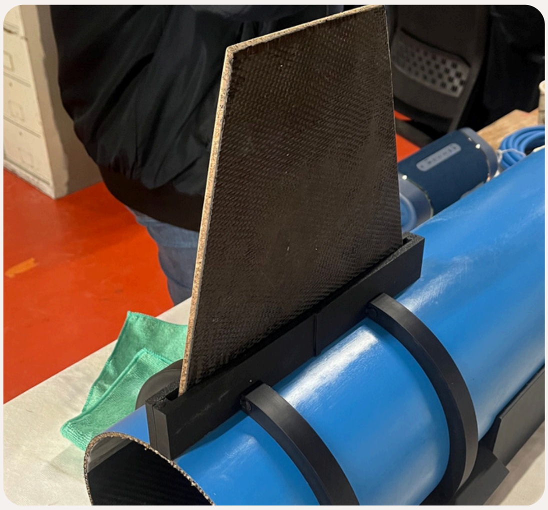

figure 15: Sticking on the fins

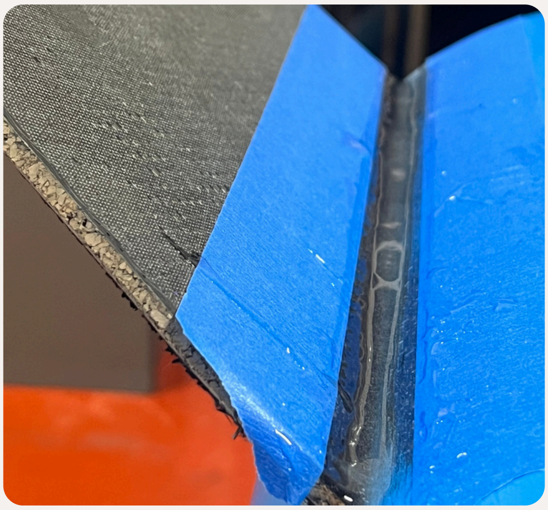

figure 16: filitting the fins

Looking back on this prototype, there are several changes I would make for the next iteration. Firstly, instead of just sanding the strip of the tube where the fins will be glued, I would sand the entire fin section of the tube to remove the blue paint and prepare the surface for adhesion. This would also make the process easier as it is more difficult to sand the tube once the fins are already attached. Secondly, I would ensure that the tube is placed on a level surface before filleting the fins. Even though the epoxy is thick, it can still spread unevenly if the tube is not levelled, resulting in an uneven fillet. Finally, I would explore cheaper alternatives to the 5-minute epoxy used for filleting, as it is quite expensive at 9.50€ for just two fillets. Anyway here is the fin section before the “tip to tip” layup.

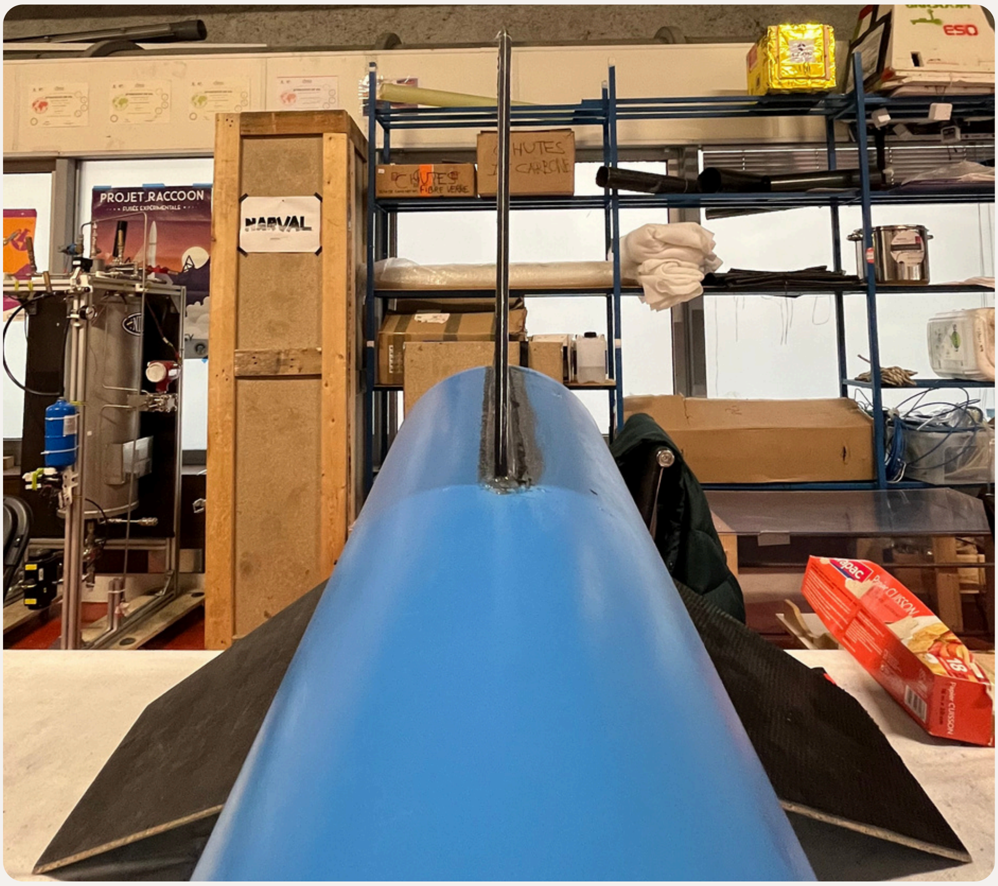

figure 17: Fins before tip to tip

Fins Alignment Procedure and Mounting Technique

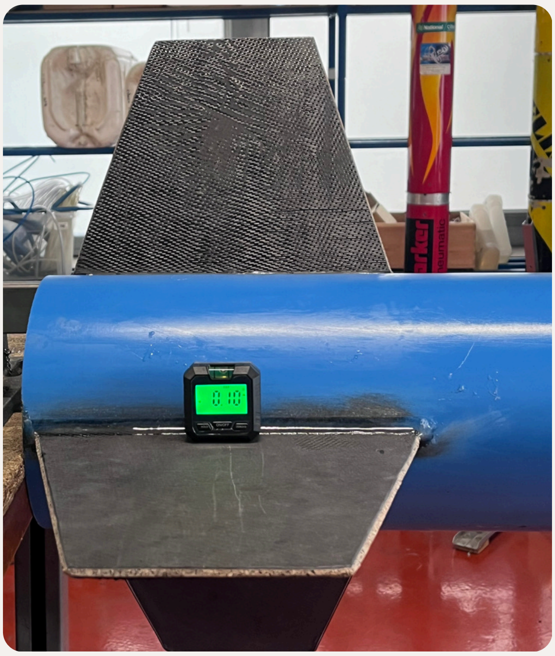

figure 18: minimum misalignment

figure 19: maximum misalignment

Regarding alignment, the most critical parameter is roll alignment. We can see that the minimum misalignment is 0.1°, and the maximum is 0.69°. This issue can be attributed to the slit in the fin jig being too large and not tight enough, allowing for some movement of the fins. As this is only a prototype, we can easily address this issue in the final product by reducing the size of the slit or adding some form of securing mechanism to hold the fins in place more tightly.

While the competition rules allow for up to 1° of misalignment in this direction, we strive to achieve the minimum possible misalignment to reduce roll and drag.

Integration of Metal Leading and Trailing Edges

Protecting the trailing and leading edges of the rocket is crucial as they are exposed to high-speed airflows that can potentially damage the cork and compromise the aerodynamic performance of the fins (on the microscopic level). To address this issue, two possible solutions were considered. The first one, which is more realistic, involves covering the edges with carbon fiber during the tip-to-tip process. This solution is relatively easy to implement but may not be aesthetically pleasing and can be challenging to achieve consistent edges across all three fins. The second option, which can be seen below, is to use metal trailing edges that fit perfectly with the angles sanded earlier. This option provides a more streamlined and professional look while also ensuring that the edges are well-protected. Ultimately, we decided to go with the second option as it offered better protection and aesthetics for our rocket.

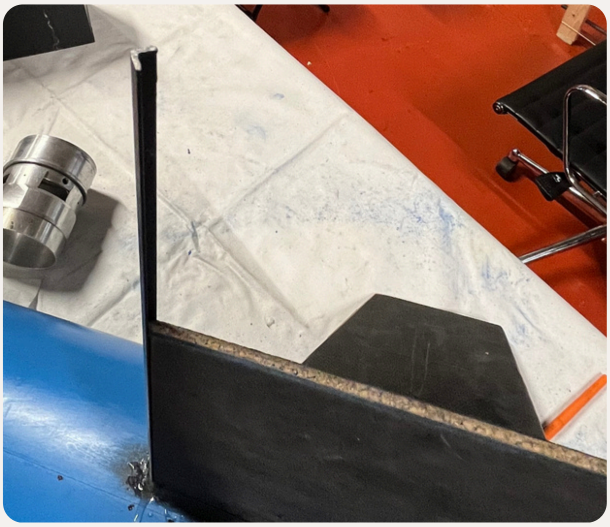

figure 20: L (5x5mm)

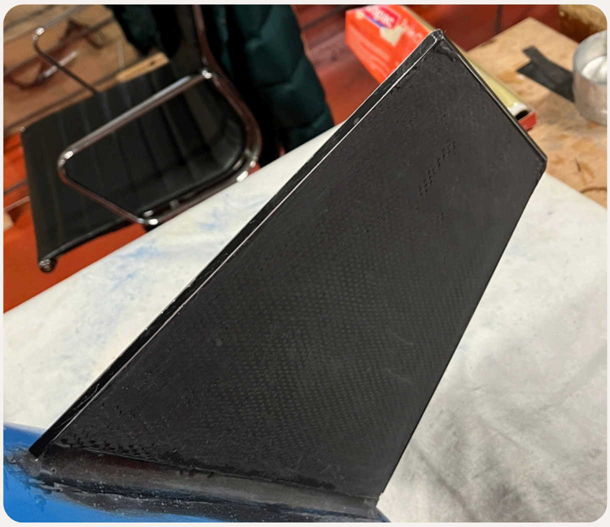

figure 21: metal edges

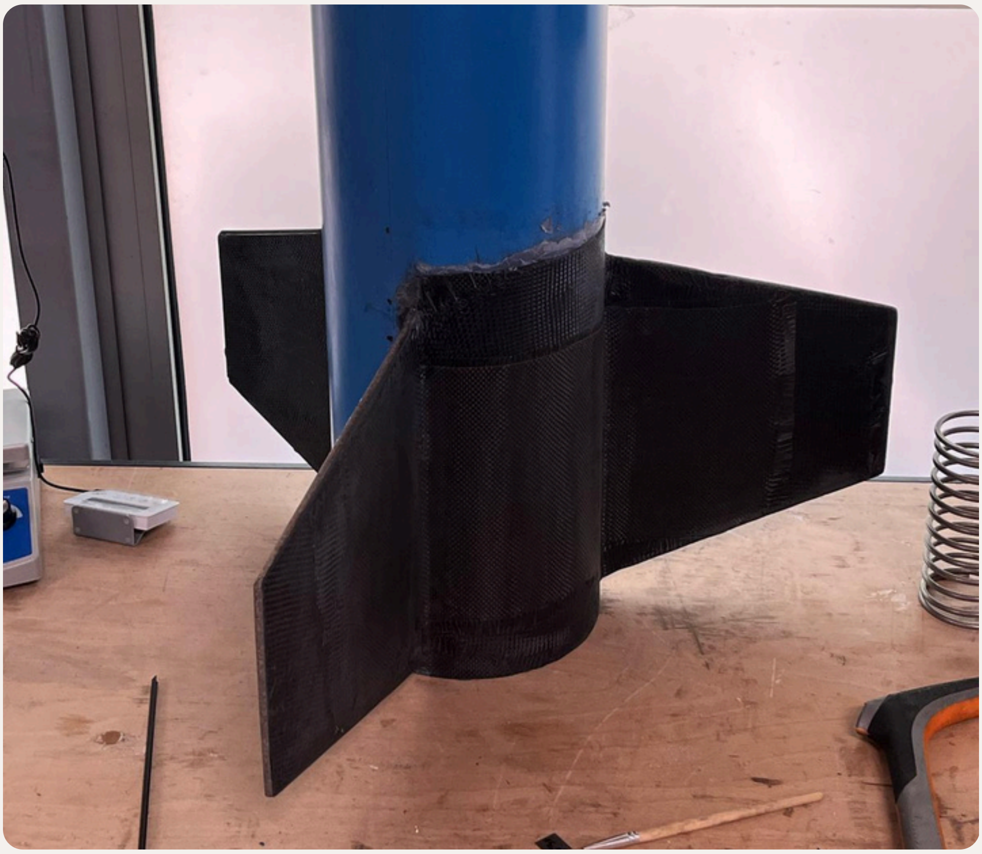

figure 22: Tip to Tip

Here's an illustration of the inaugural "Tip to tip" wet layup procedure I executed on this prototype, where the carbon fiber plies extend from one fin's extremity to the other fin's end. The term "wet layup" signifies that no accelerated curing mechanism was employed for the epoxy resin. For this prototype, I applied three distinct plies: the first at 0°, the second at 45°, and the final at 0° orientation. Regrettably, due to limited carbon fiber inventory, the fiber sheets didn't perfectly conform to the fin's contour, but rather resembled rectangular shapes.

After allowing the layup to cure, I meticulously sanded it using a sequence of 80, 120, 240, and 480 grit sandpaper. Following the removal of carbon dust with isopropanol and lint-free wipes, I introduced a thin epoxy resin coating, which I subsequently wiped with a paper tissue. Previously, I had experimented with a paintbrush application, but despite achieving a high-gloss finish, under specific lighting conditions, it exhibited surface irregularities and micro-voids. The paper tissue technique yields a less glossy finish but ensures a more consistent texture and superior aesthetics.

Note: assurez-vous que tous les composants nécessaires sont présents et que vous disposez de suffisamment de temps pour effectuer le travail (il est préférable d'être plusieurs pour répartir les tâches et éviter d'être débordé). La résine doit sécher pendant au moins 24 heures et doit être mélangée avec le durcisseur pendant au moins 4 minutes.

Équipements de protection individuelle (EPI):

- Travaillez dans une pièce bien ventilée ou, si possible, à l'extérieur.
- Pour la manipulation de la résine : portez une blouse (la résine est quasi-impossible à enlever des vêtements), un masque ou un respirateur, et des gants à usage unique en nitrile ou en latex.
- Pour le ponçage et la découpe : portez des gants (pour éviter les échardes de carbone), des lunettes de protection (surtout lors de la découpe), et une blouse (pour éviter les poussières sur vos vêtements).

Matériaux nécessaires pour la fabrication :

- Fibre d'arrachage
- Fibre de verre
- Fibre de carbone
- Résine et durcisseur
- Liège
- Deux plaques en plexiglas (pour la fabrication des ailerons, il est important d'avoir une surface plane et non adhésive)
- Mold release (pour faciliter le démoulage)
- Carton ou une nappe cirée (pour protéger les surfaces de travail)
- Acétone (pour nettoyer les outils)
- Papier de verre de différents grains (pour le ponçage après polymérisation : grain 180, 200, 400, puis ponçage humide avec du grain 800, 1000, 2000)

Outils nécessaires :

- Mètre ruban ou une règle
- Deux verres en plastique (pour peser la résine et le durcisseur séparément, puis les mélanger ensemble)
- Balance de cuisine (enveloppée de film plastique pour éviter les dégâts de résine)
- Bâtonnets en bois (pour le mélange et la création de congés sur les ailerons)
- Raclette en plastique (très importante pour la fabrication des ailerons, une vieille carte en plastique permet de répartir la résine uniformément et de réduire l'excès)
- Rouleau anti-bulles (optionnel)
- Cutter (pour la découpe du liège)
- Ciseaux (pour la découpe des fibres)
- Scotch de masquage (pour faciliter la manipulation des fibres et éviter l'effilochage des zones coupées)
- Feutre (pour indiquer l'orientation des fibres coupées)
- Papier et crayon (pour noter les mélanges et les ratios de masse)
- Pinceau (pour la finition et l'état de surface)
- Éponge (pour le ponçage humide)

En suivant ces consignes de sécurité et en utilisant les bons outils, vous devriez être en mesure de travailler avec des matériaux composites de manière efficace et sûre.

Annex B: Different Shapes

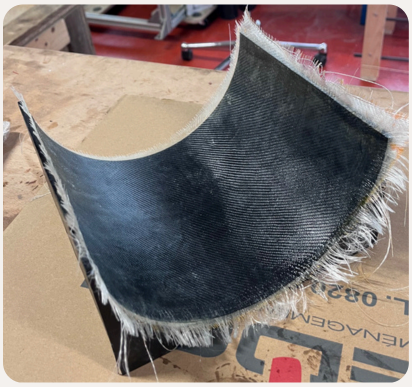
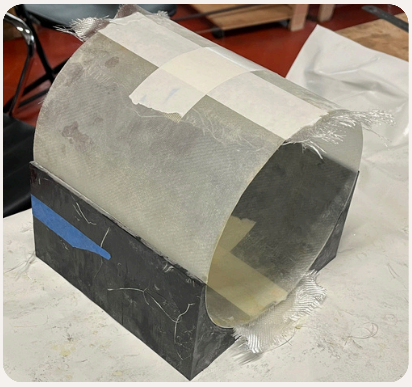


figure 23, 24, 25: Avionics section


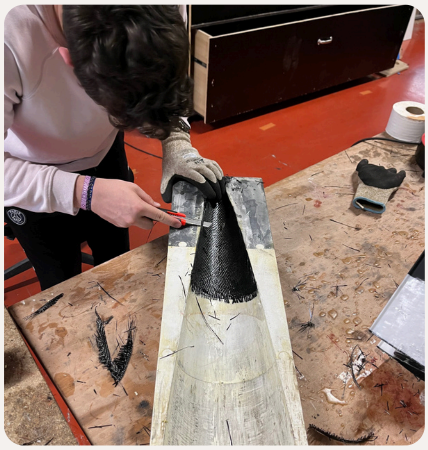

figure 26, 27, 28, 29: Nose cone Build steps



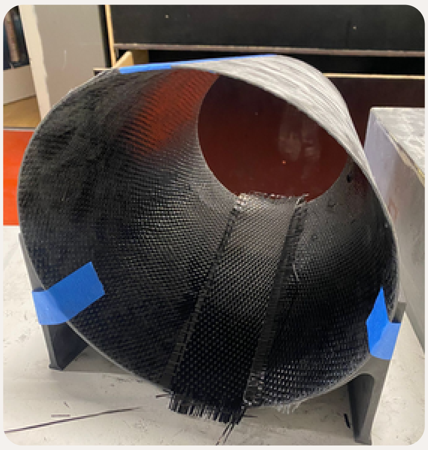

figure 30, 31: Culot

Pour toutes ces formes, la méthode est la même : créez un moule qui correspond exactement au diamètre extérieur de la pièce que vous souhaitez réaliser. Assurez-vous que la surface de contact du moule soit exactement la moitié de la surface extérieure de la pièce que vous voulez fabriquer. Ensuite, disposez les feuilles de fibre sur le moule, je recommande d'utiliser trois couches pour cette étape de la construction. Appliquez la résine et laissez-la durcir.

Une fois que la résine est sèche, ne retirez pas encore les feuilles de fibre du moule. Découpez et poncez les bords des feuilles de fibre pour qu'ils correspondent parfaitement aux bords du moule. Faites attention à ne pas poncer le moule lui-même.

Ensuite, retirez la pièce en composite du moule. Cette pièce n'est que la moitié de la pièce finale, donc répétez les mêmes étapes pour la deuxième moitié.

Une fois que les deux moitiés sont terminées, Scothez les intersections sur l'extérieur de la pièce et disposez quelques feuilles de fibre sur l'intérieur de l'intersection. Je recommande de faire une intersection à la fois, puis d'attendre qu'elle durcisse avant de faire la deuxième intersection. Cependant, vous pouvez faire les deux intersections en même temps si vous êtes suffisamment prudent.

Une fois que la pièce est terminée, vous pouvez ajouter autant de couches intérieures que vous le souhaitez pour atteindre l'épaisseur désirée.