ES100 Final Presentation

FSAE Aerodynamics Team

03.27.2025
CAPSTONE PRESENTATION

PRESENTATORS: Oliver Murcko and Steff Jones

What motivated this project:

- FSAE (Formula SAE) is a global engineering competition where university students design, build, and race small formula-style cars.
- Teams are judged on design, cost, and performance.
- It allows students to foster engineering, teamwork, and innovation skills.

- Pave the way for future generations of Harvard engineering students to improve their skills

Problem Statement

IMPORTANCE:	Harvard’s inaugural FSAE Team needs an Aero Package
COMPLEXITY:	Costly, Advanced Skills, Difficulty
GOALS:	Downforce > 500N / Drag < 1.5 / and Weight < 15kg

Existing Solutions:

UC Berkeley

3rd overall in the FSAE League.

Texas A&M

National Record for Total Points.

Used their REAL 20XX car for parts.

Ohio State

1st place out of 107 teams in FSAE.

Accessed their CAD files to learn.

Purdue

8th place out of 107 teams in FSAE.

Design Technical Specifications:

- F1 = Drag Increase: Maximum 300N drag Increase.
- F2 = Downforce: Minimum 500N downforce.

- C1 = Drag Coefficient: Desired **drag coefficient** of < 1.5
- C2 = Lift Coefficient: Desired **lift coefficient** of -2

- W1 = Maximum Weight (car): 200kg
- W2 = Maximum Weight (aero): 15kg

Design Technical Specifications:

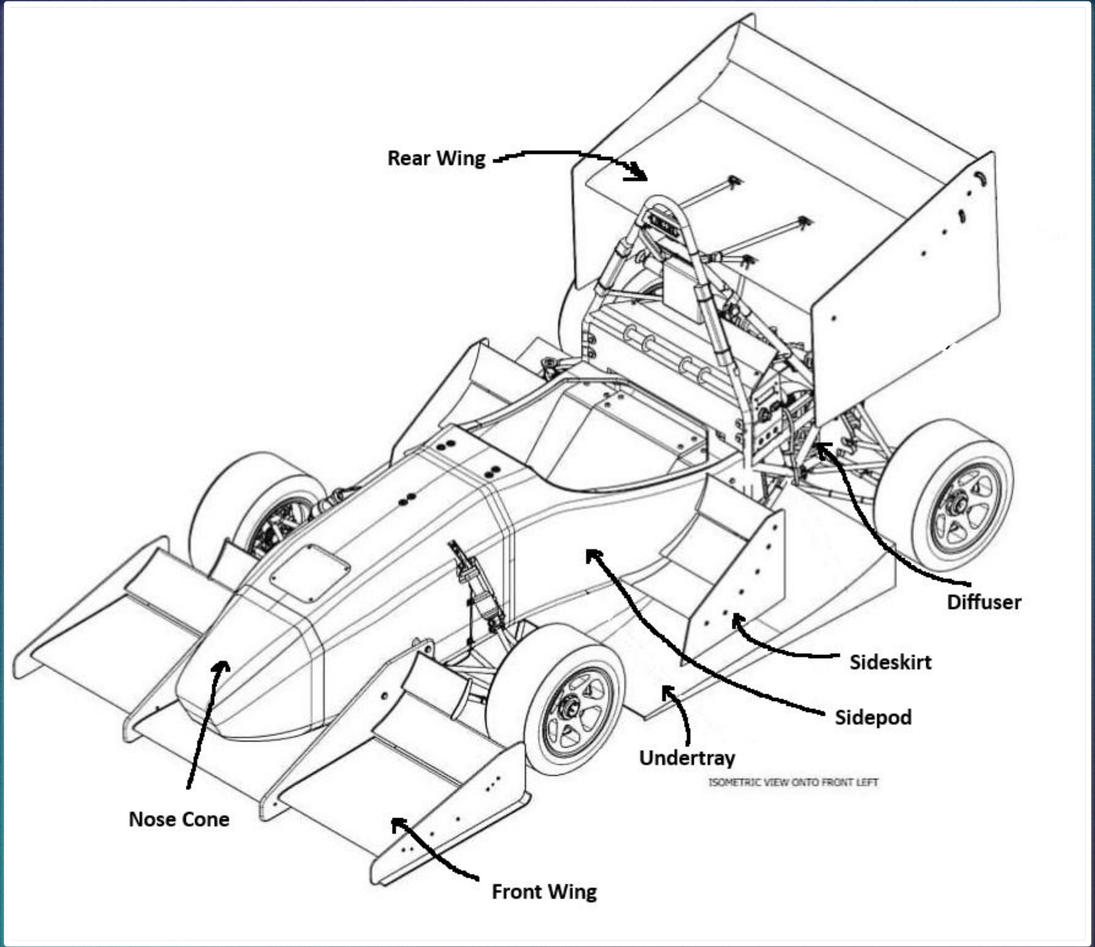
- L1 = Front Wing Length: **Maximum allowable length** in front of **700mm**.
- L2 = Rear Wing Length: **Maximum allowable length** in rear of **250mm**.

- H1 = Rear Wing Height: **Maximum allowable height** upward of **1200mm**.
- H2 = Ground Clearance: **Maximum clearance** of **90mm**.

- P1 = Pressure Distribution: **50/50 pressure distribution** front/back.
- IT1 = Front Wing capable of **withstanding 1kN of impact.**
    - During tests, there is a high likelihood of hitting a cone.

The Design Phase

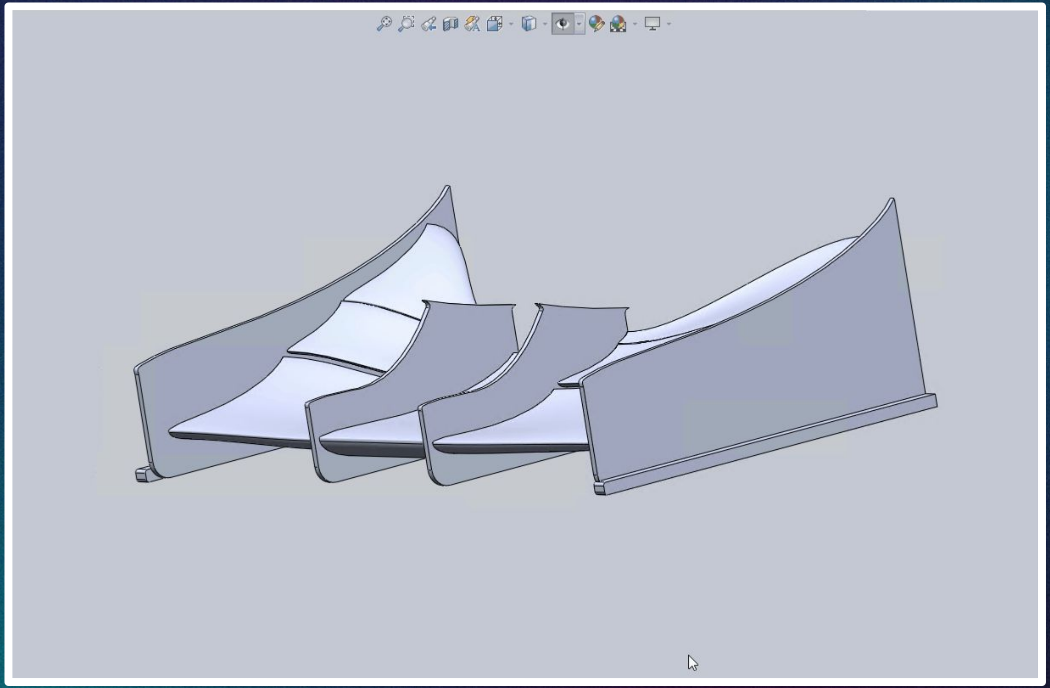
Fall Semester Recap



Designed and tested **7 different Aero Components.**

Worked from **Front to Back** for Aerodynamic consistency.

At least **3 Iterations** per component.



#1

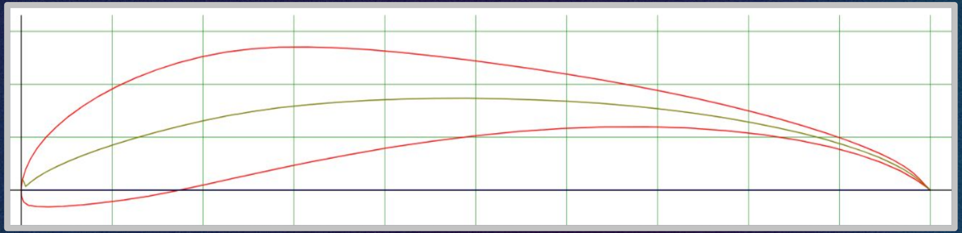
The Front Wing

Serves as **1st point of contact.**

Generates **downforce**, improves **aerodynamics**, balances car stability and **cornering grip**.

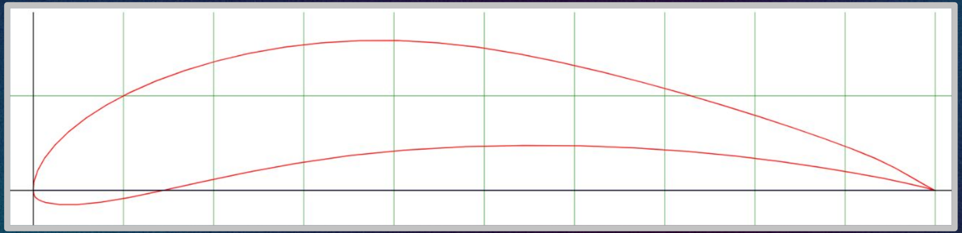
Features:

- Multi-tiered design: 8°, 15° and 30°
- Endplates to channel vertices
- Angled airfoils to control airflow



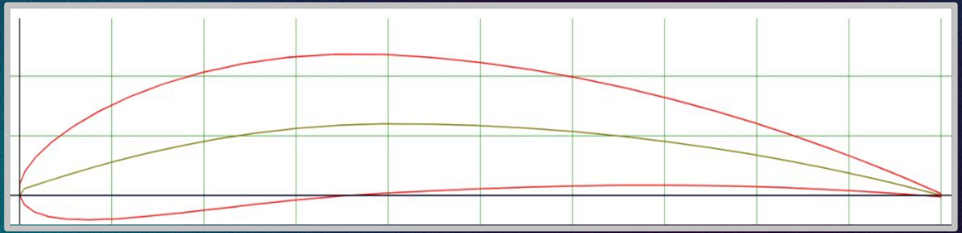
S1223

Max C_L/C_D at **2** degrees of **33.1**



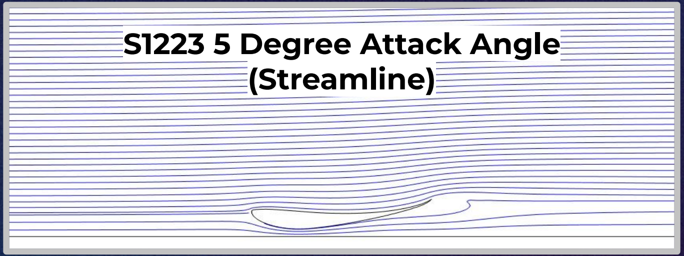
E423

Max C_L/C_D at **7** degrees of **6**



NC6412

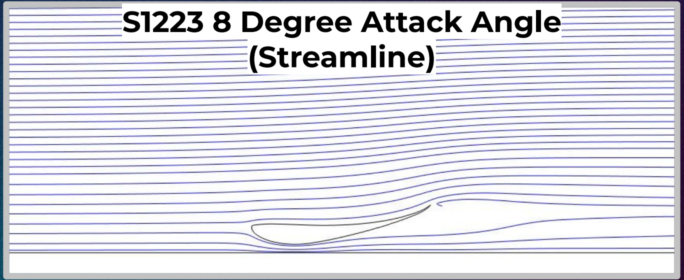
Max C_L/C_D at **3.75** degrees of **9.8**



Max Velocity = **45.6m/s**

Max Pressure = **180 Pa** **(at tip)**

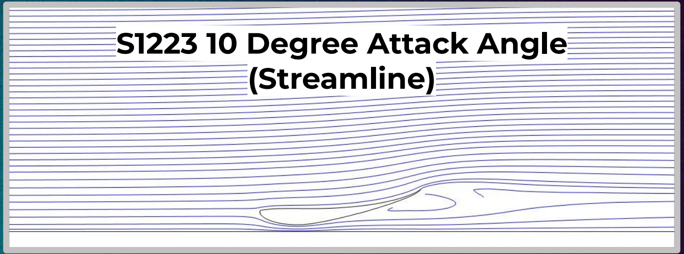
Min Pressure = **-1140 Pa** **(beneath)**



Max Velocity = **45.9m/s**

Max Pressure = **190 Pa** **(at tip)**

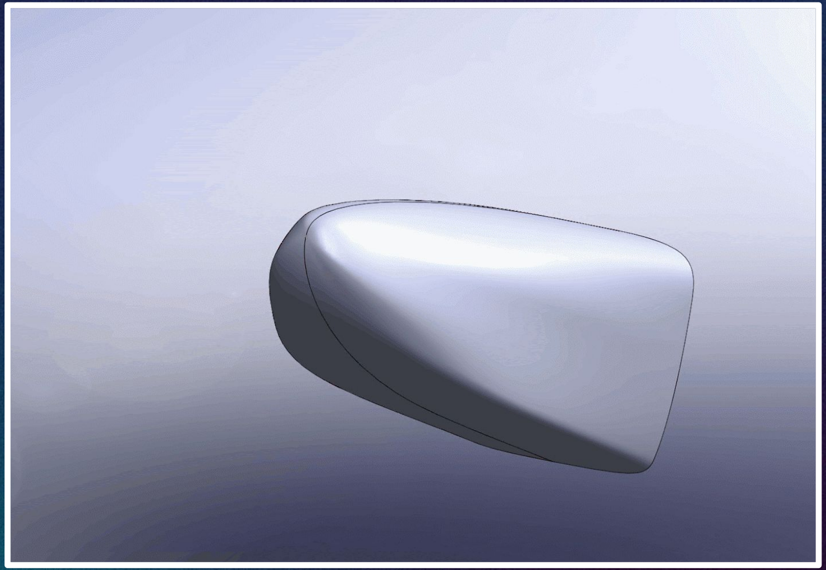
Min Pressure = **-1140 Pa** **(beneath)**

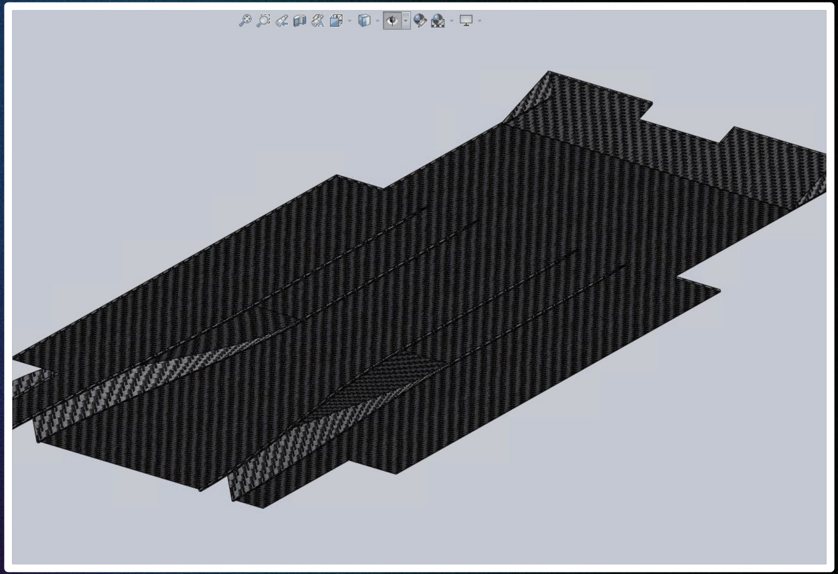


Max Velocity = **45.0m/s**

Max Pressure = **200 Pa** **(at tip)**

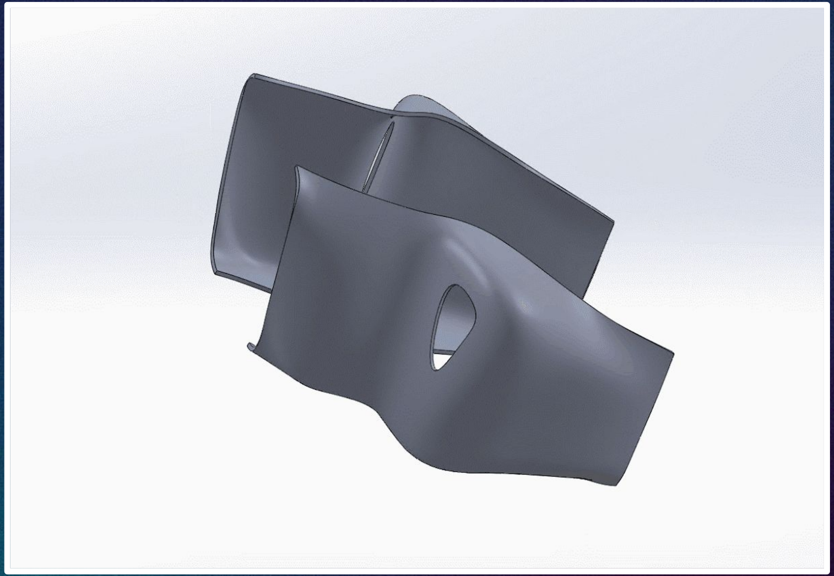
Min Pressure = **-1090 Pa** **(beneath)**

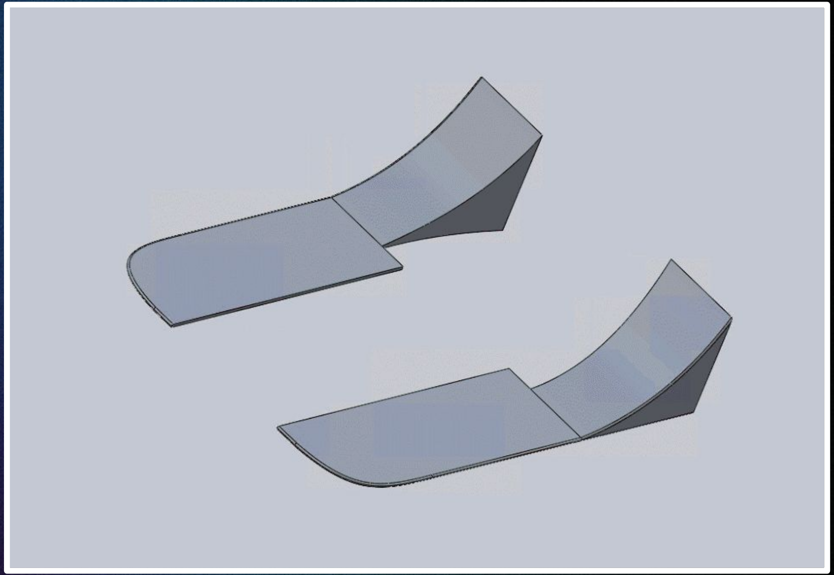




#2 : Nose Cone

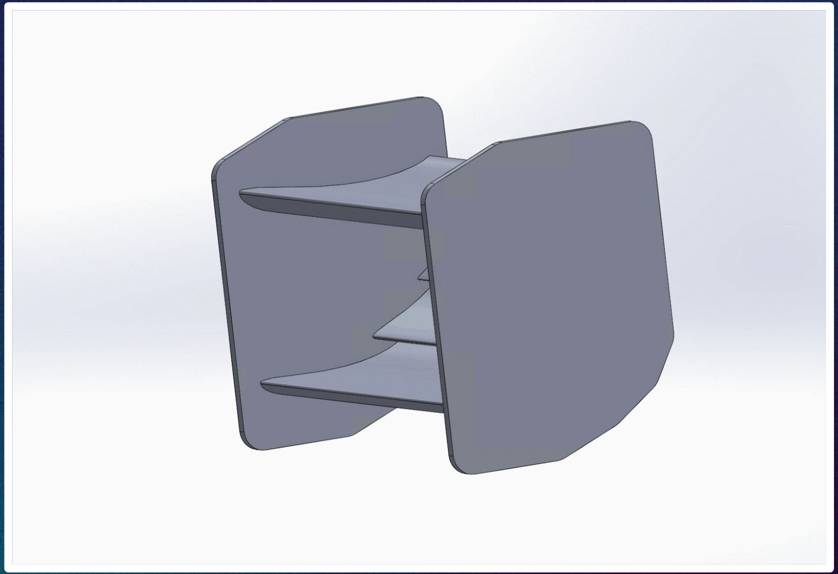
#3 : Undertray

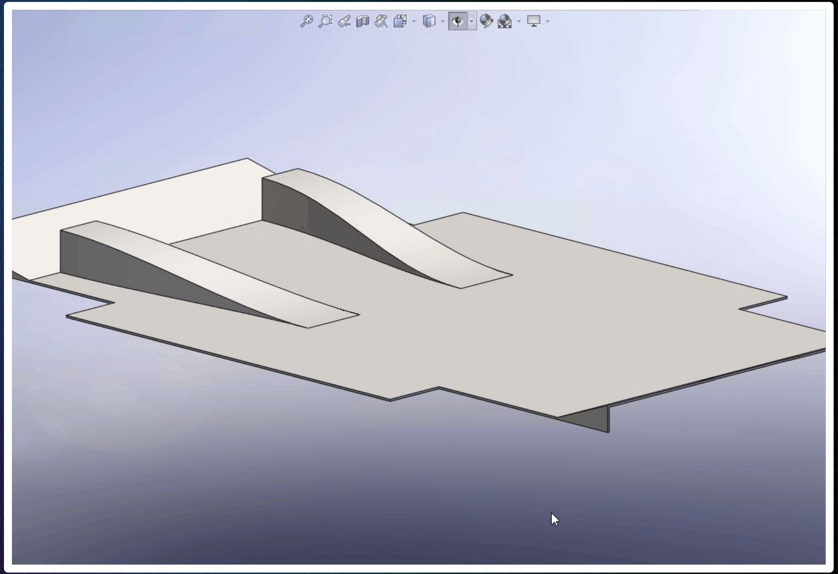




#4 : Side Pods

#5 : Side Skirts

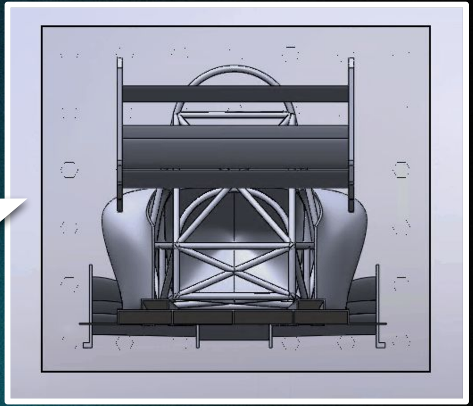




#6 : Rear Wing

#7 : Rear Diffuser

Airflow Analysis



Vortices created by front wing push air beneath the car **to the undertray**

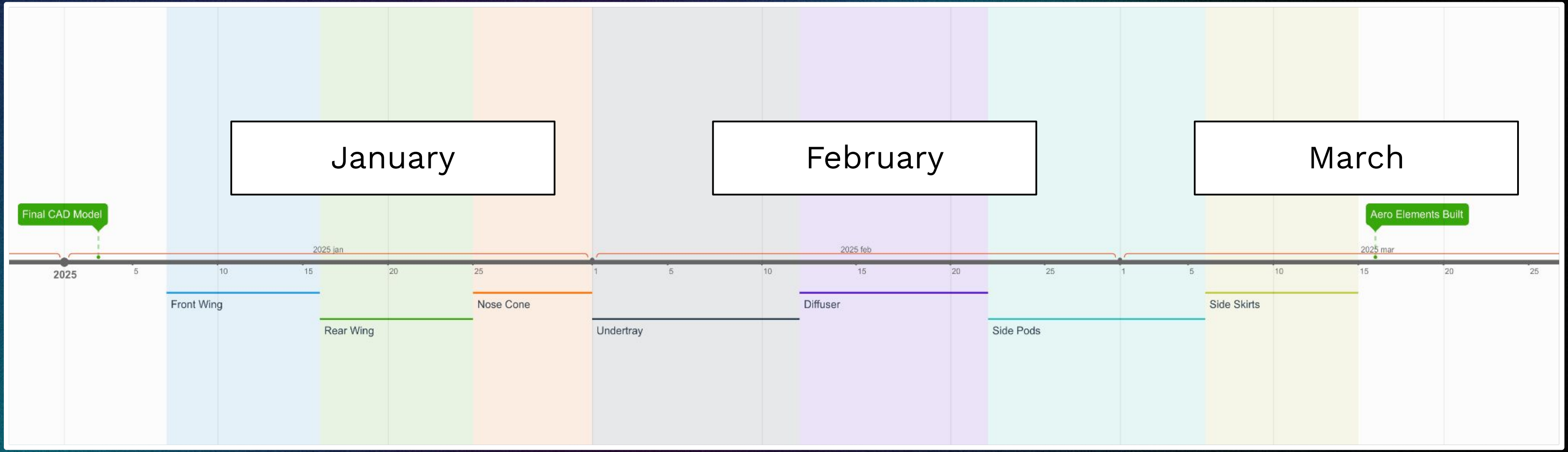
Airflow **pushed upward** behind the car to clear **dirty air** coming **from the engine exhaust**

The Build Phase

Spring Semester Recap

Timeline Changes:

Original timeline:



5-10 days per individual component.
Fully completed by **March 15th**.

Scope Reduction: Full Aero → Front Wing Only

: Cost per component **exceeded available funds.**

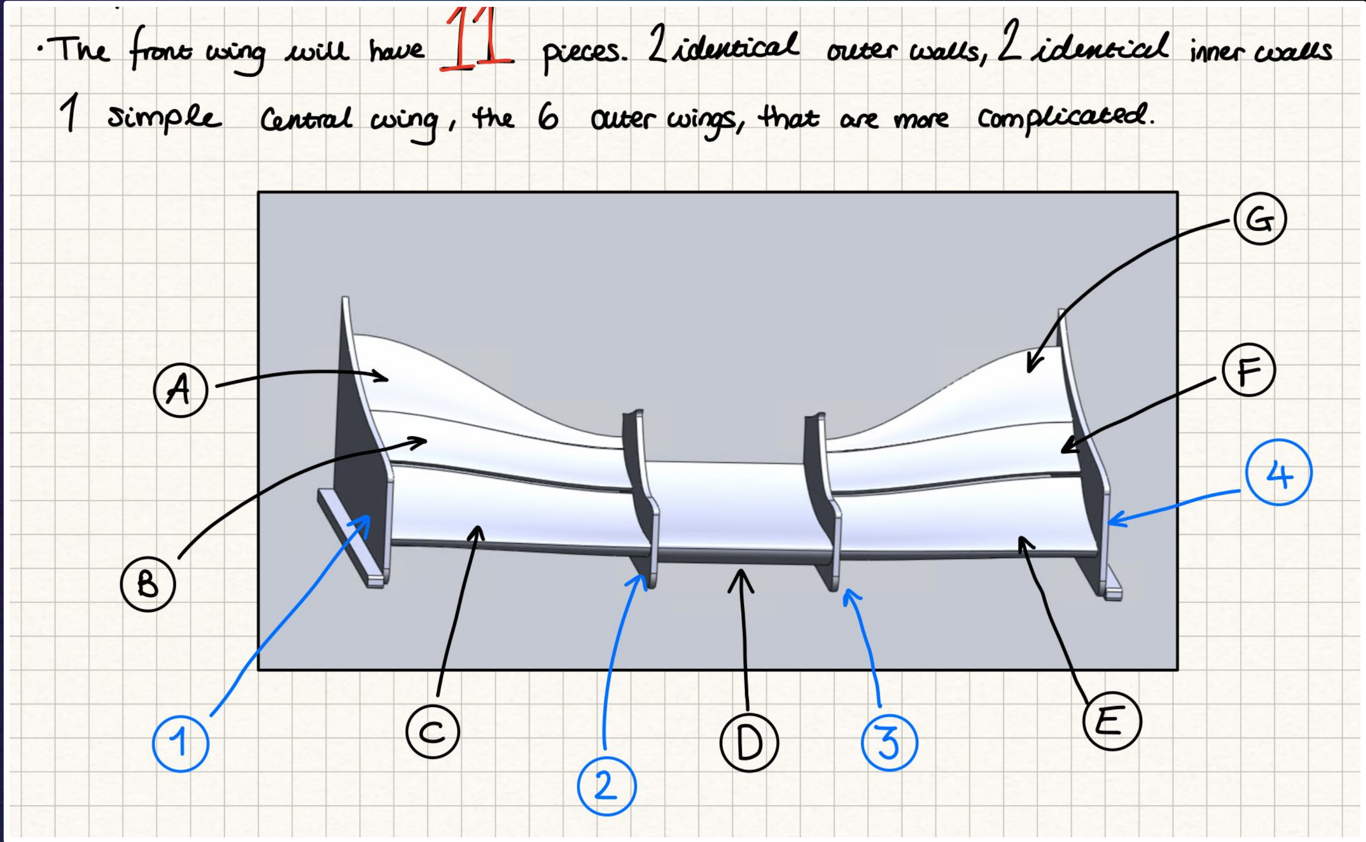
: Manufacturing each part was **highly time-intensive.**

: **Limited Technical Resources** available to us.

The Plan:

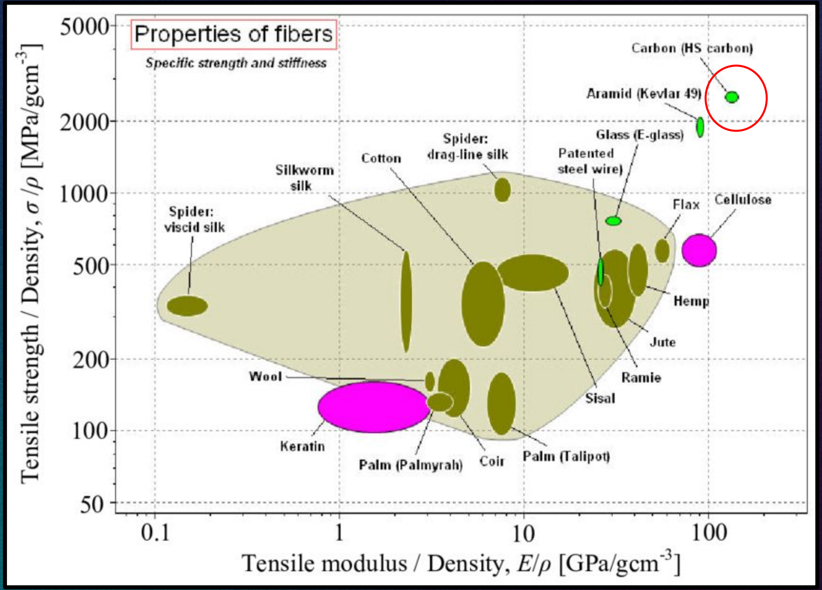
11 Components
- 7 Wings
- 4 Walls

Methods
- CNC cutting for the wings
- Sandwich structure for the walls



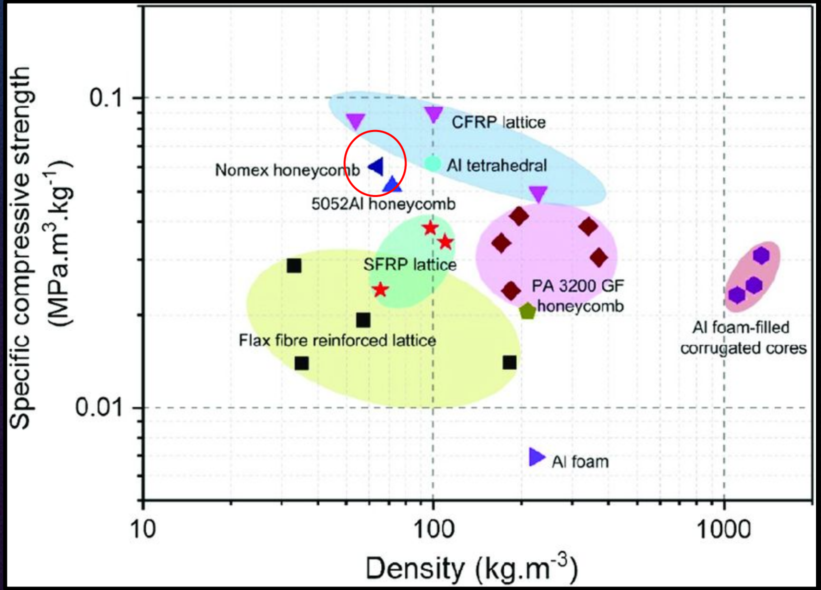
Material Selection:

Why Carbon Fiber:



Extremely strong and stiff for their weight

Why NOMEX core:



Low-density, strong-in-compression core

Wing Fabrication Process (3D Geometry)

- We needed to make **7 unique airfoils**
- Have to be the **exact shape** of our designs
- **Provide support and contours** for CF layups while the resin is curing
- Must work with **West System epoxy resins** (no dissolving and heat resistant)
- **Cannot be 3D printed** due to larger sizes of the wings
- How do we make these shapes to satisfy all of the requirements?

Wing Fabrication Process (3D Geometry)

- Use **dense foam** to create foam cores of each airfoil
- Use **4x4 foot CNC machine** in the woodshop to mill them out
- Create **custom molds** to achieve high accuracy
- Developed a 3-step **milling procedure** with custom molds for each airfoil
- Used **¼ inch flat end mill** for general material removal
- Used **¼ inch ball end mill** for precise contour operations

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Material Selection (foams)

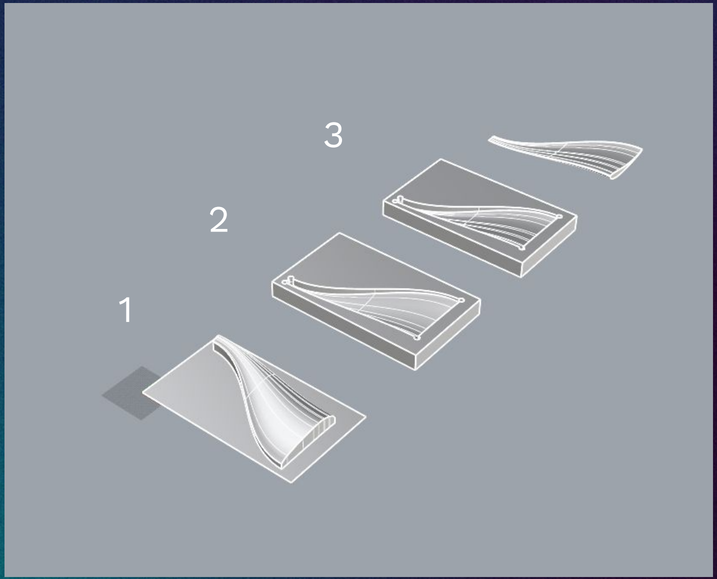
EPS (Expanded Polystyrene):

- Coarse-grained
- Permeable
- Inexpensive

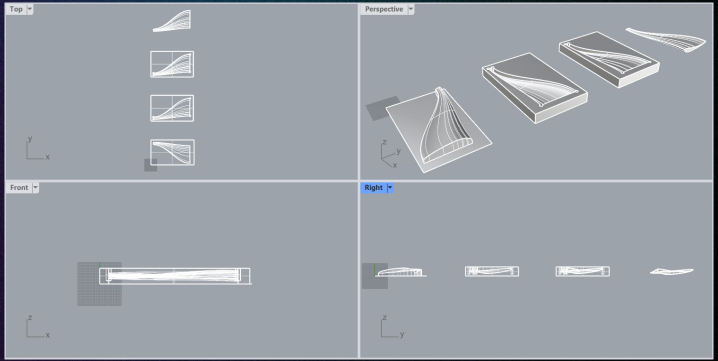
XPS (Extruded Polystyrene):

- High density & compressive strength
- Impermeable
- More expensive

Wing Fabrication Process (3-step procedure overview)

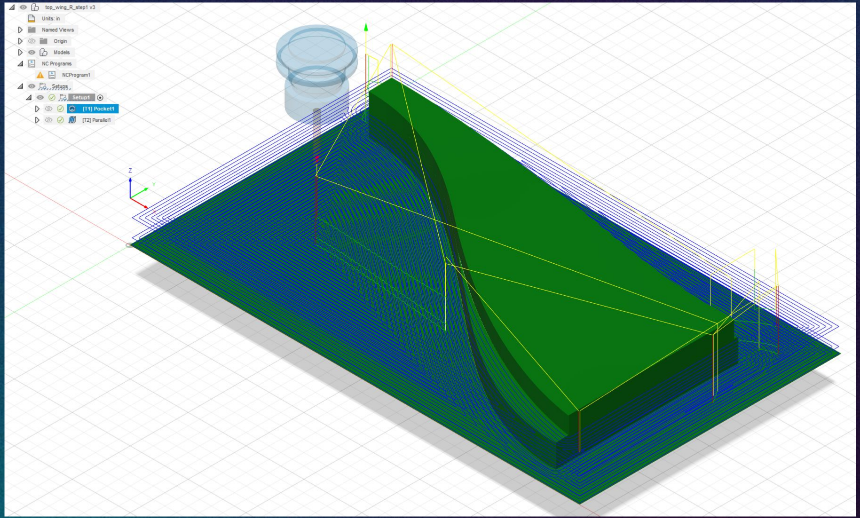


1. Create a **positive (male)** mold (foam #1)
2. Create a **negative (female)** mold (foam #2)
3. **Combine foams #1 and #2** and mill out the other side of the wing

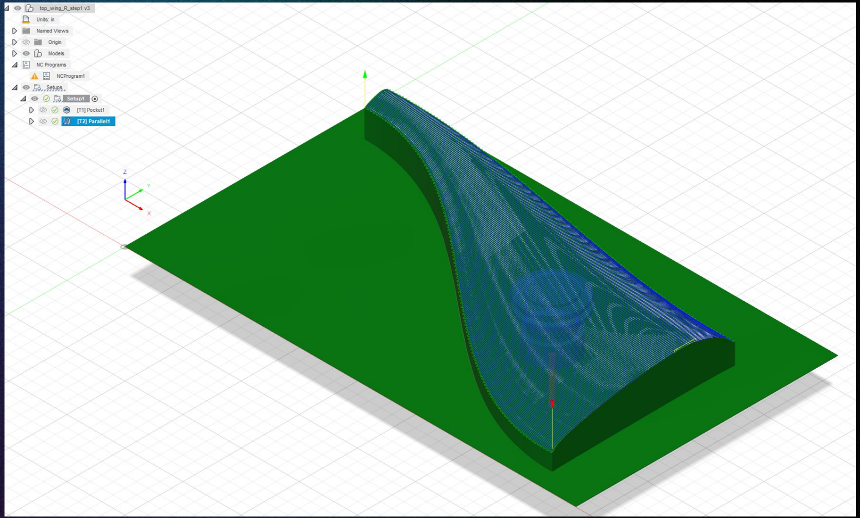


Wing Fabrication Process (Milling Operations)

Top Wing Right Side - Step 1



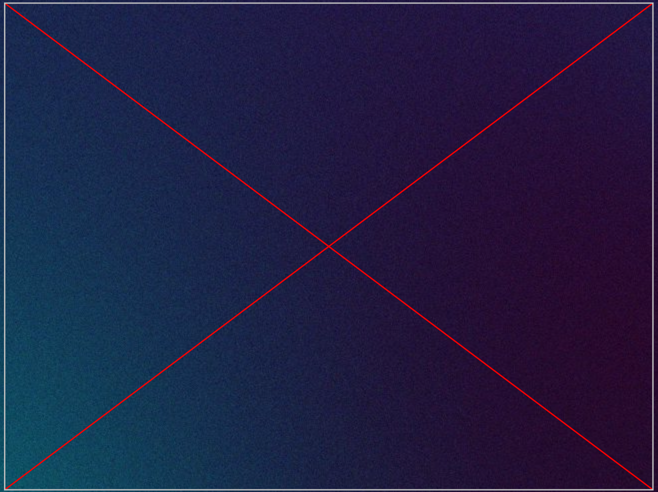
Pocket (flat end mill)



Parallel pass (ball end mill)

Wing Fabrication Process (Milling Operations)

Top Wing Right Side - Step 1

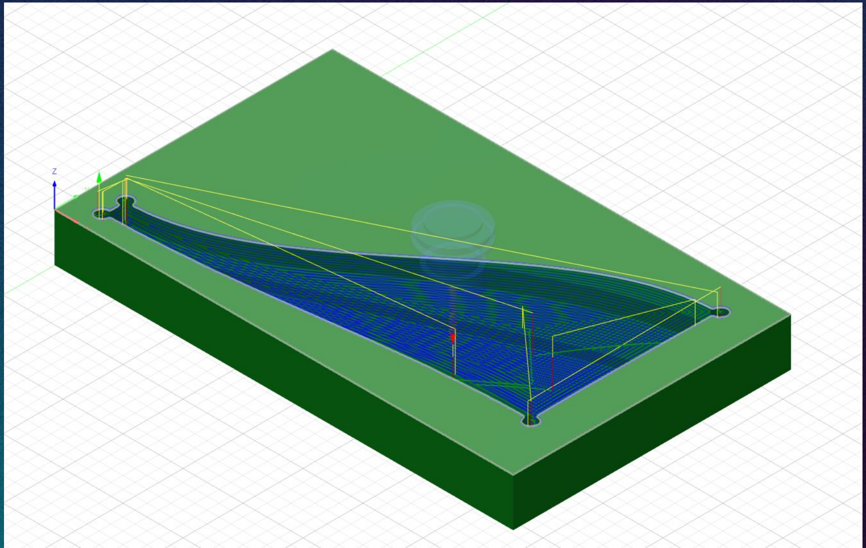


Pocket (flat end mill)

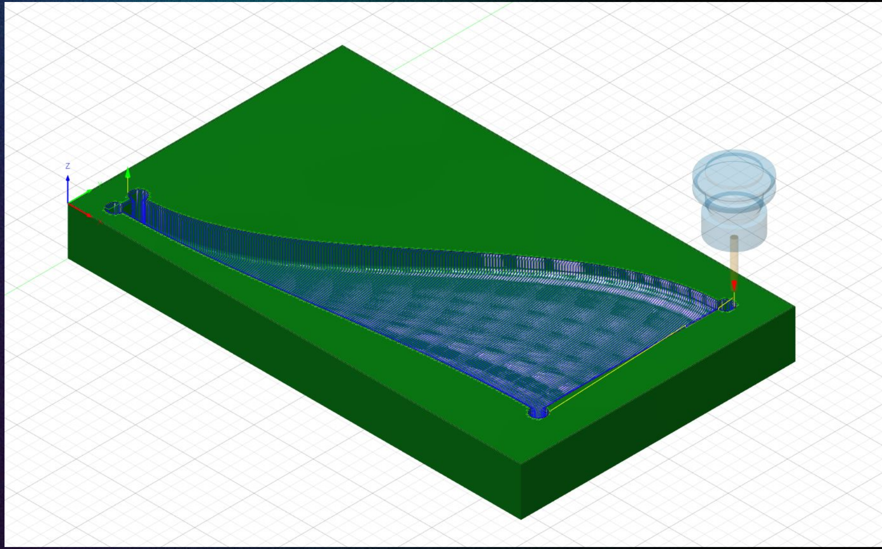
Parallel pass (ball end mill)

Wing Fabrication Process (Milling Operations)

Top Wing Right Side - Step 2



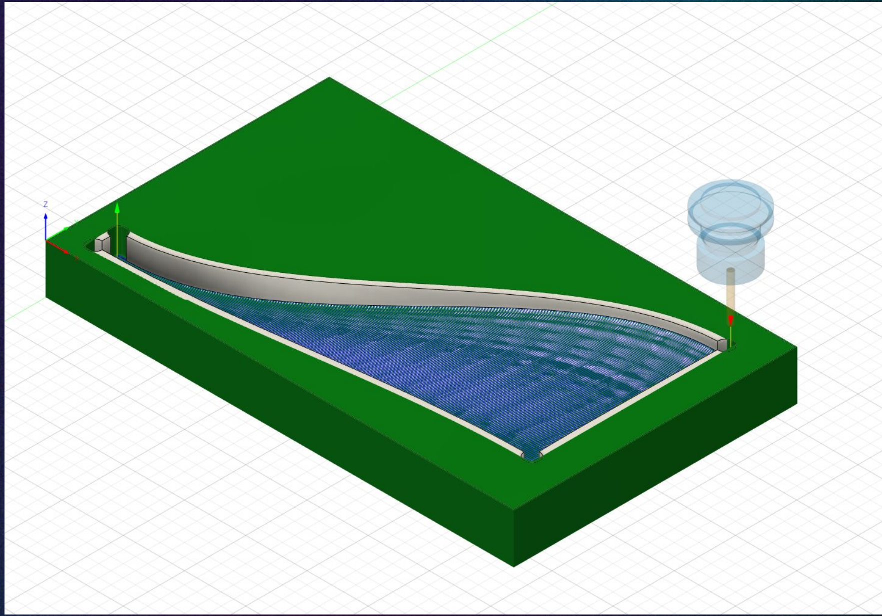
Pocket (flat end mill)



Parallel pass (ball end mill)

Wing Fabrication Process (Milling Operations)

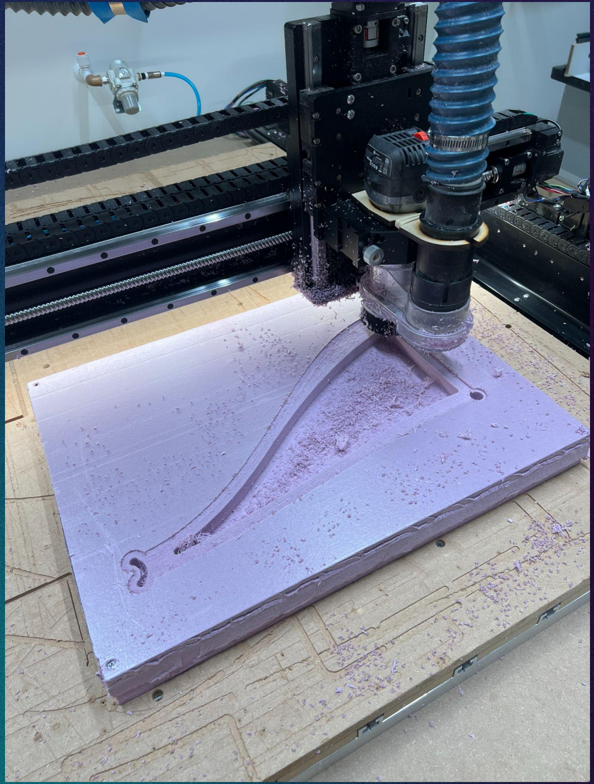
Top Wing Right Side - Step 3

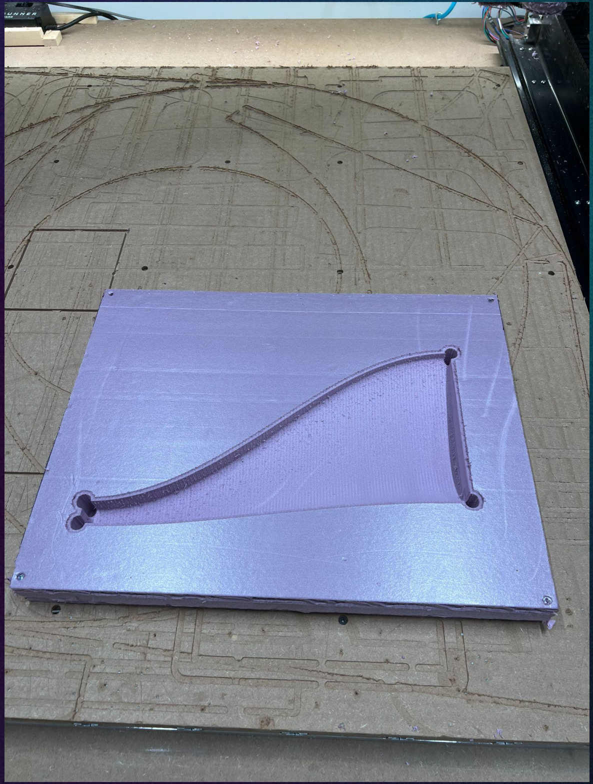


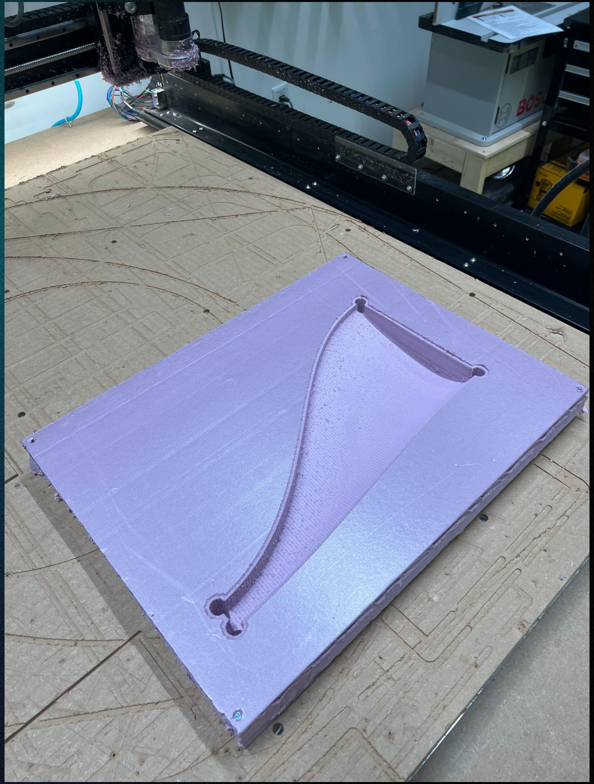
Parallel pass only

Wing Fabrication Process (Step 1)

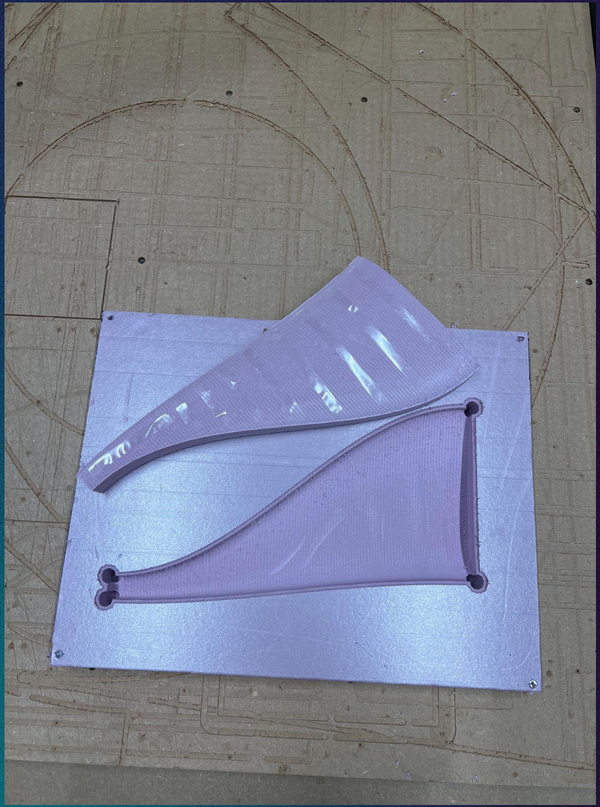
Wing Fabrication Process (Step 2)

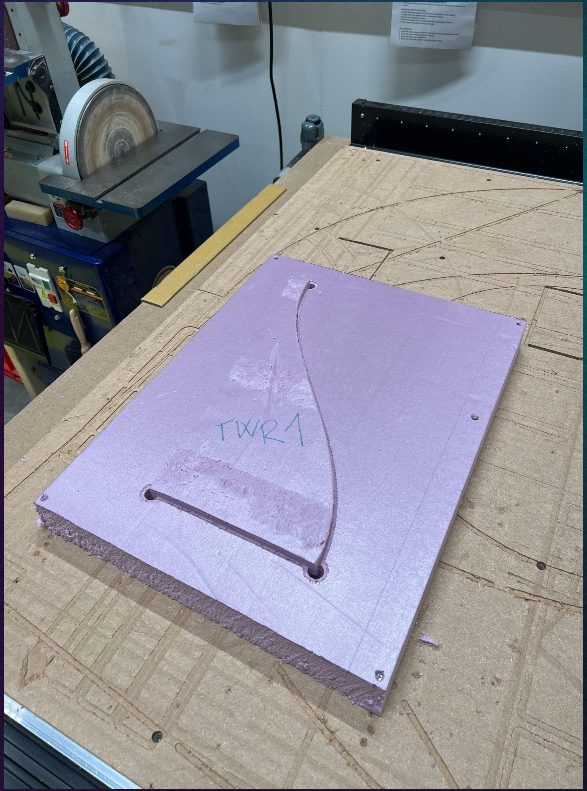






Wing Fabrication Process (Step 3)





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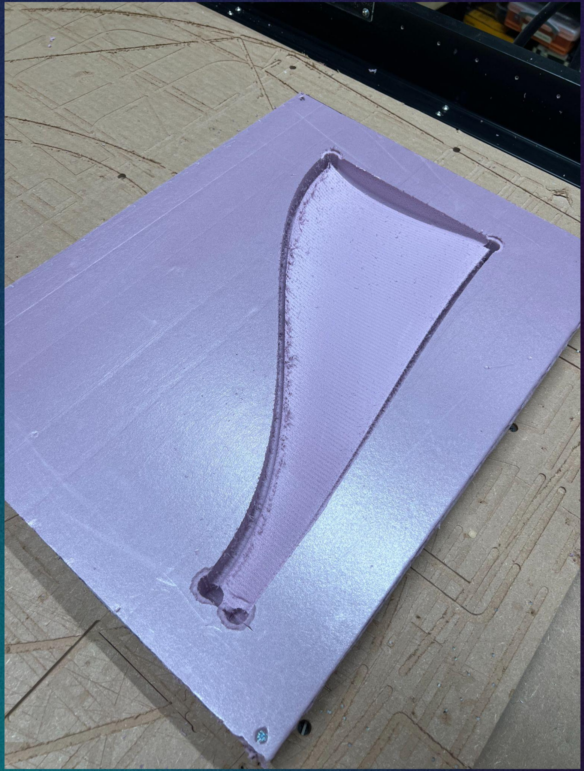
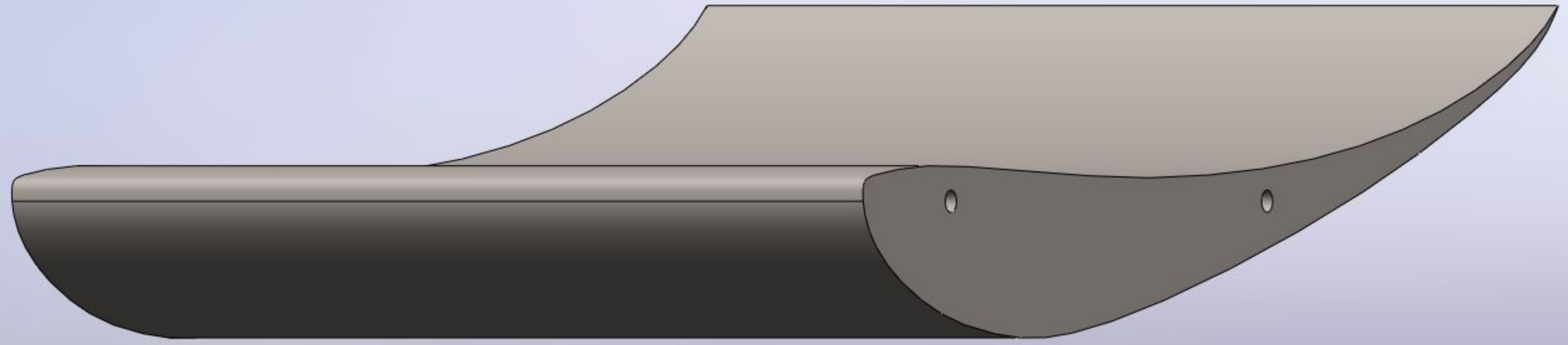
Wing Fabrication Process (Final Foam Airfoil)



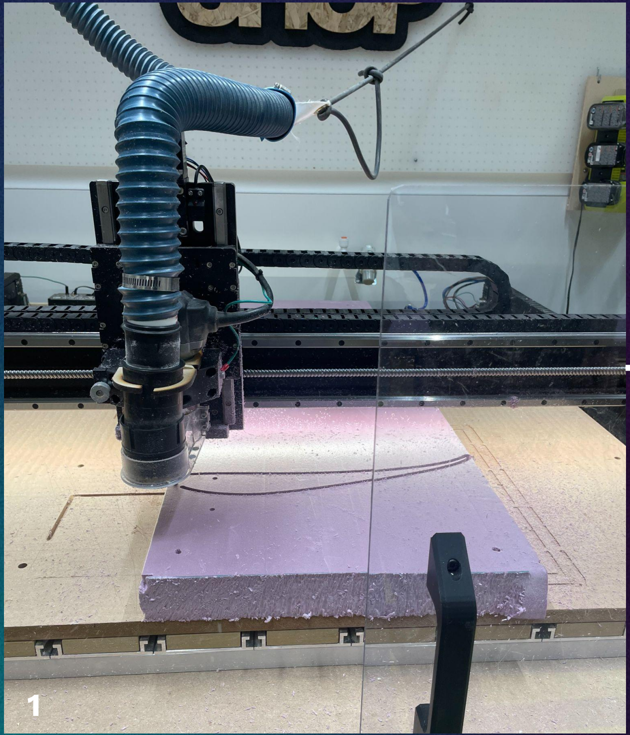
Wing Fabrication Process (Future Improvements)

- **Better tail finish (paper thin)?**
  - Use higher density foams
  - Decrease the cutting feed rate
- **Better surface finish?**
  - Decrease stepover for parallel passes
  - Experiment with 3-flute and 5-flute mills
  - Conventional vs. Climb passes (currently using both)
- **Better tolerances?**
  - Mill down the CNC bed for a flat base
  - Use a CNC machine with automatic tool changes (z-axis problems)

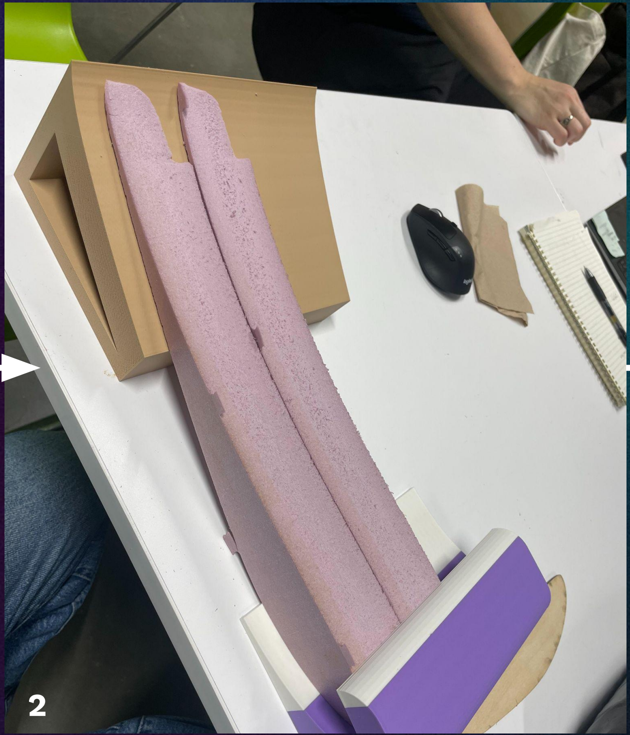
The **Center** Wing



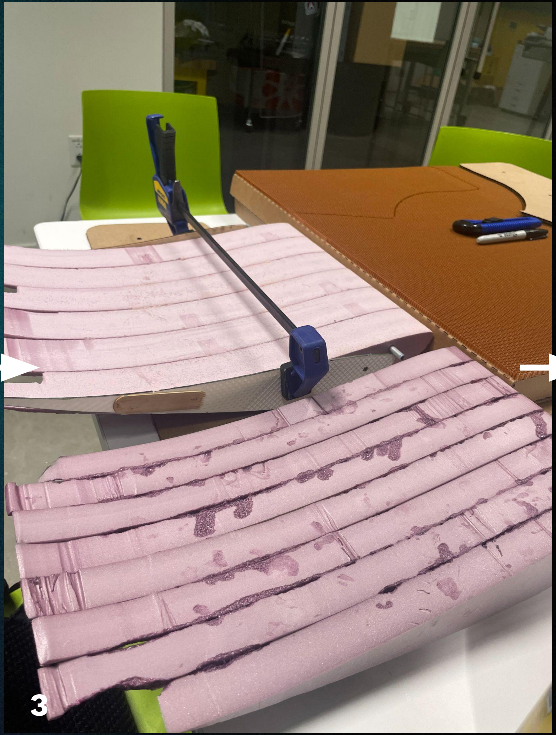
Constructing the **Main Wing**:



CNC 6 Identical Airfoils



Join Them

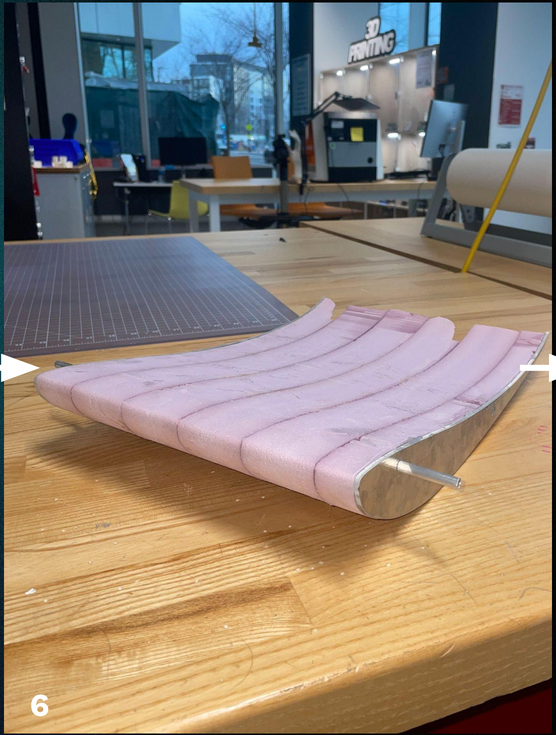


Polystyrene Foam Spray

Constructing the **Main Wing**:

Cut to Correct **Size**

Metal to Foam **Glue**



Almost Final Product

:Finalised **Main Wing**

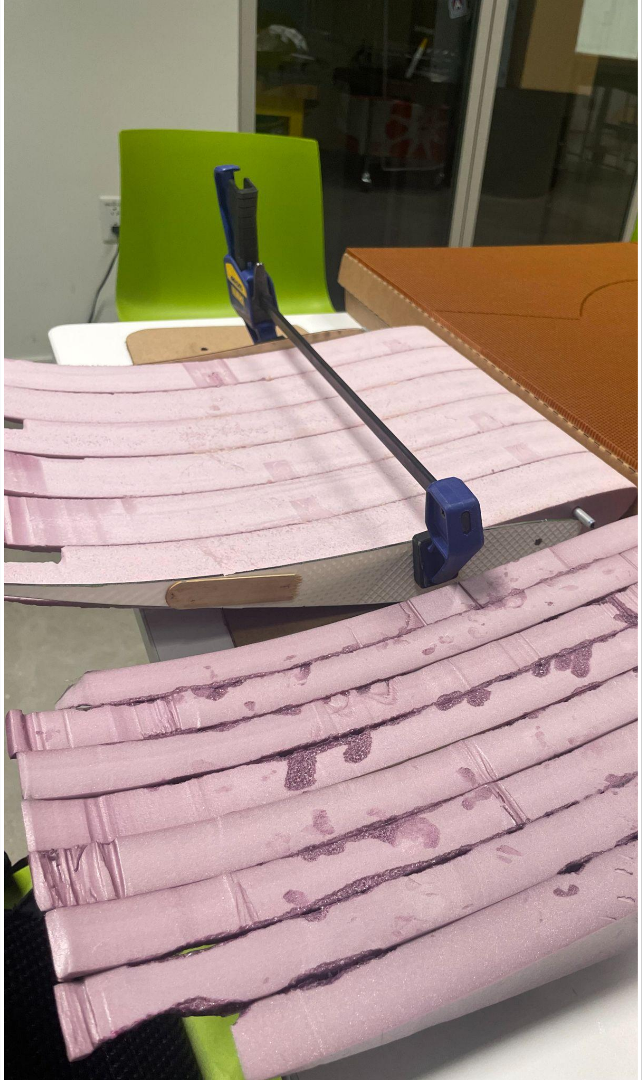
Adaptations to the **Main Wing**:

Adaptations:

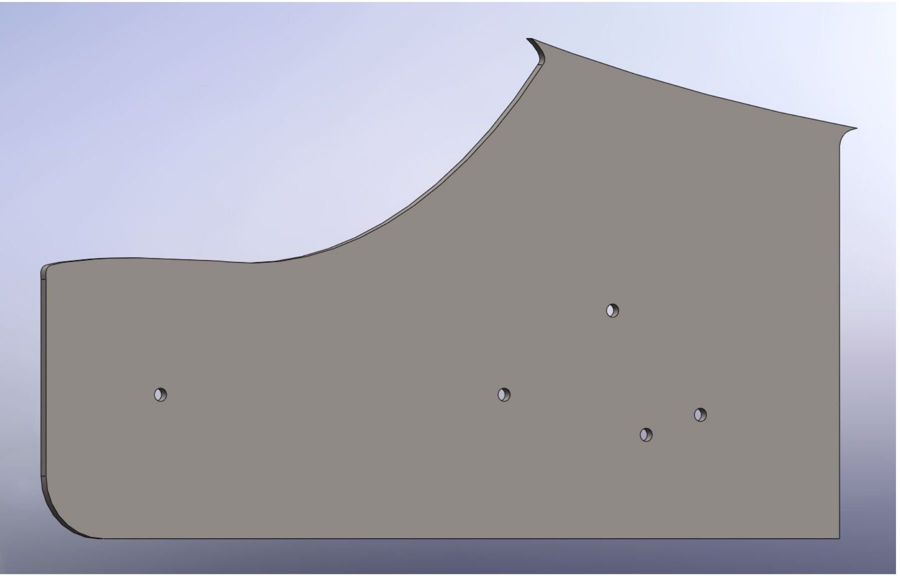
Switched from **Wire Cutter** to **CNC.**

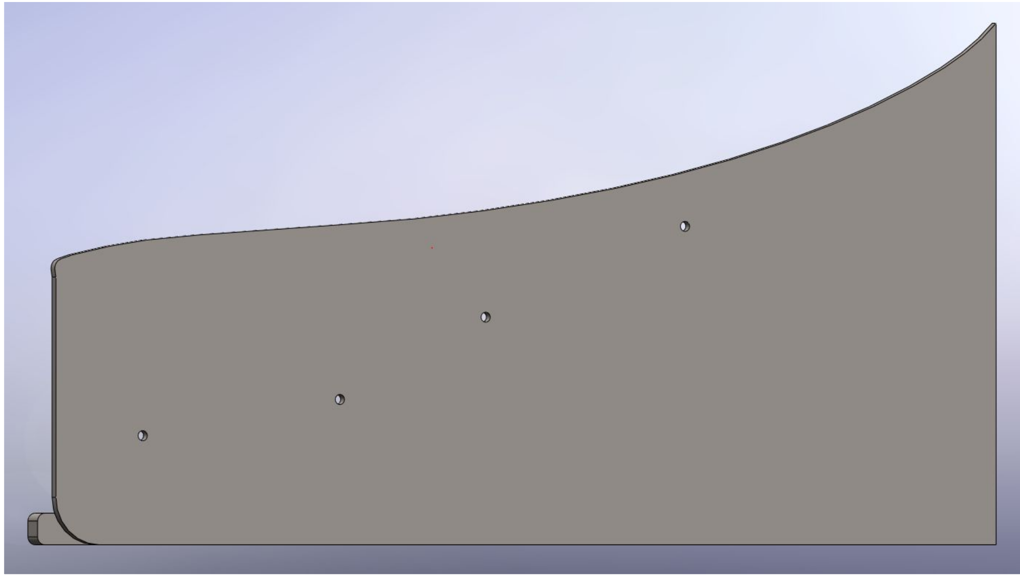
Replaced foam-foam **adhesive** to a more **foam suitable** option.

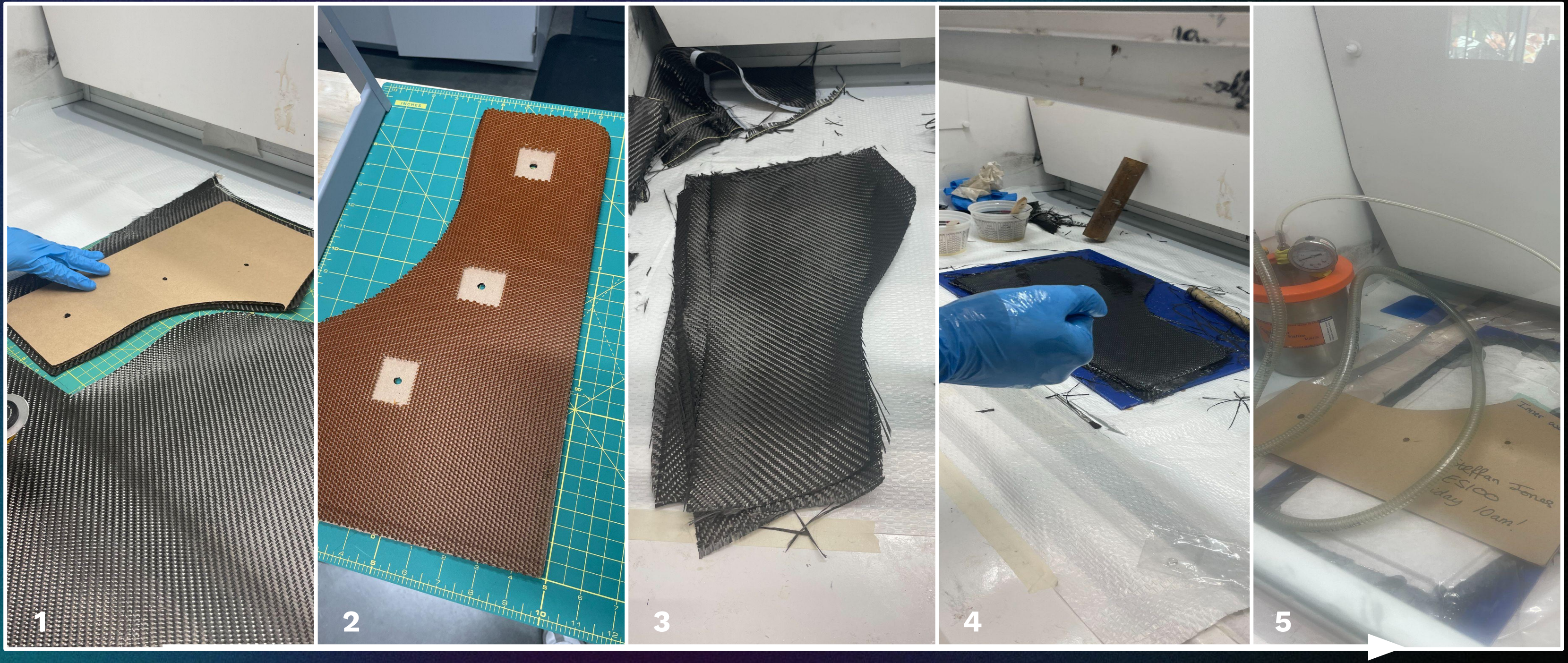
Attached **Aluminium Profiles** to the ends using Gorilla Epoxy Structural Adhesive.



Inner and **Outer** Walls







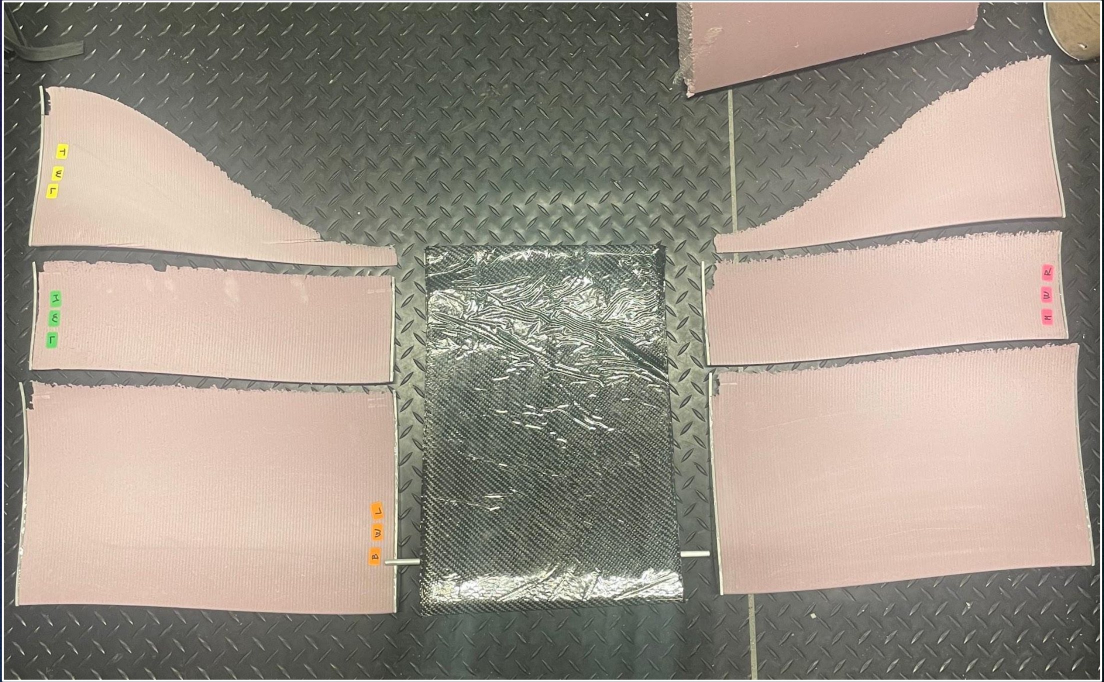
Constructing the **Inner and Outer Walls:**

Adaptations:

Introduced a **Mylar film.**

Improved **Vacuum seal apparatus.**

Adaptations to the **Inner and Outer Walls**:



All **7** Front Wings

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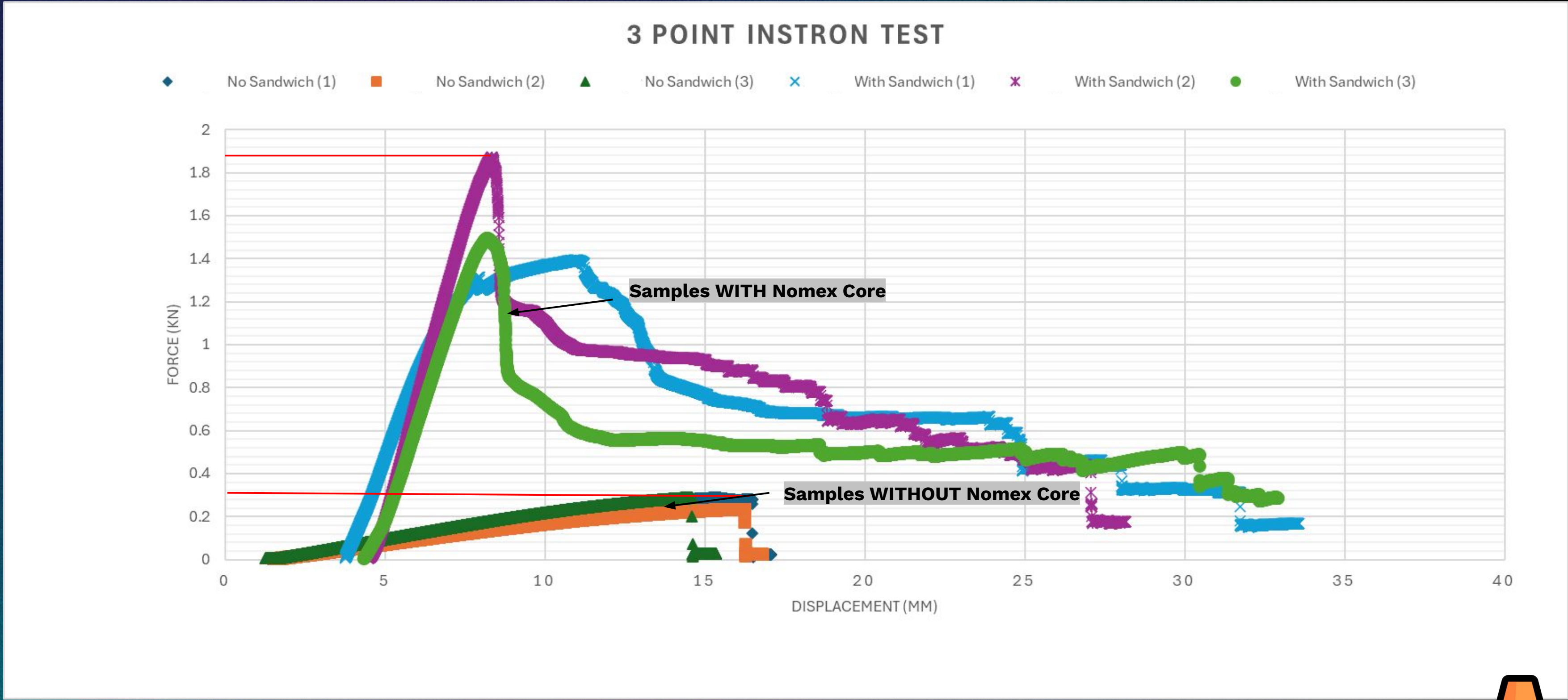
What skills were crucial to this project:

Physical Skills:
1. Shapeoko 4x4 CNC
2. Carbon Fibre Layups
3. Waterjet Cutting
4. Laser Cutting
5. Wire Cutting

Technical Skills:
1. Solidworks
2. ANSYS Fluent
3. SimScale
4. Rhino
5. Autodesk Fusion
6. COMSOL

The Testing Phase

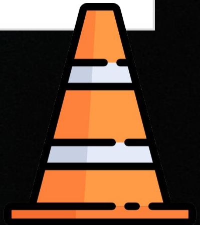
Instron Testing and Wind Tunnel Tests

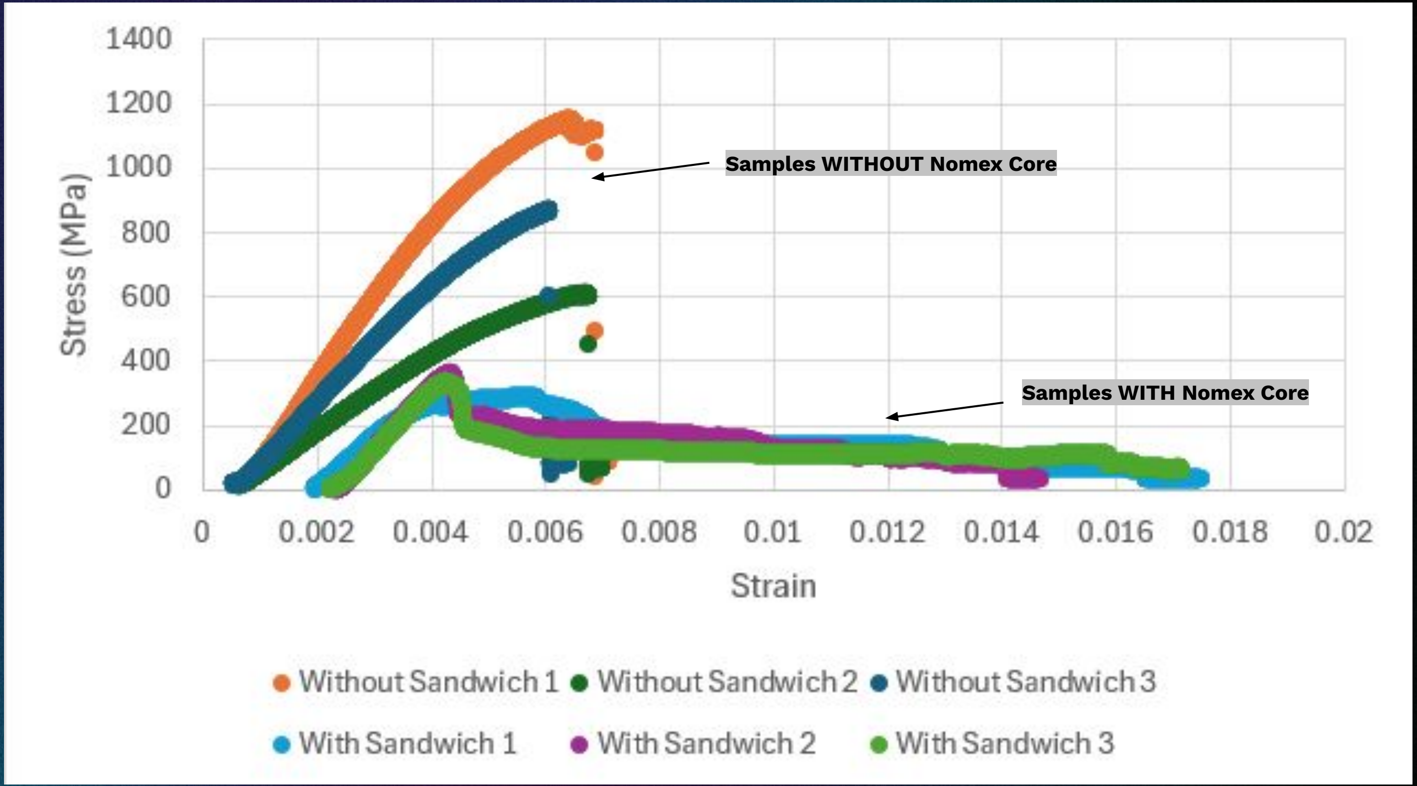


Our Instron **Results**:

6 Samples, 3 WITH sandwich, 3 WITHOUT Sandwich

Hitting a Traffic Cone, will it survive?





Our Instron **Results**:

6 Samples, 3 WITH sandwich, 3 WITHOUT Sandwich

Hitting a Traffic Cone, will it survive?

Peak **Load** (Max Force) Comparison:

The Sandwich samples reached significantly higher peak forces

- **Sandwich samples** = around **1.8 kN and 1.5 kN.**
- **Non-sandwich samples** = around **0.25–0.35 kN.**

This suggests that:

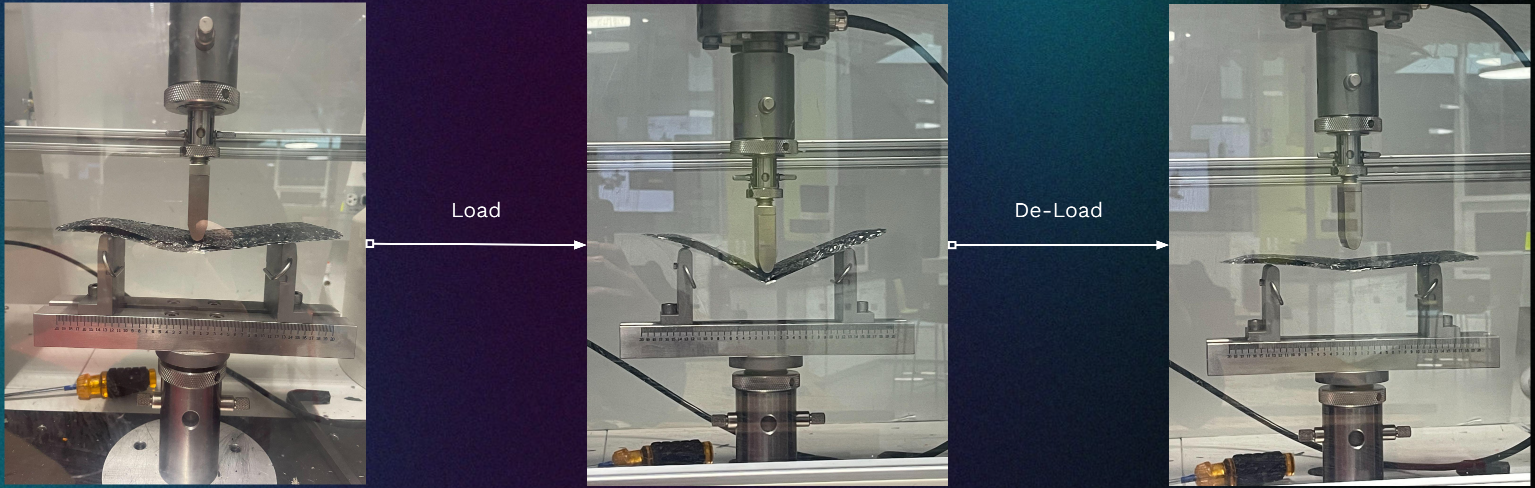
Adding a Nomex core drastically improves load-bearing capacity, due to increased bending stiffness (moment of inertia).

Post-Failure Behaviour Comparison:

The Sandwich samples exhibited safer failure patterns

- **Sandwich samples** have **Gradual Load Decay**
  - The Nomex Core attributes
- **Non-sandwich samples** have **sharp drop to zero.**

The sandwich specimens exhibit characteristic of tougher or more damage-tolerant composite structures.



Considerations in our Instron Test:

Resin caused variation in width:

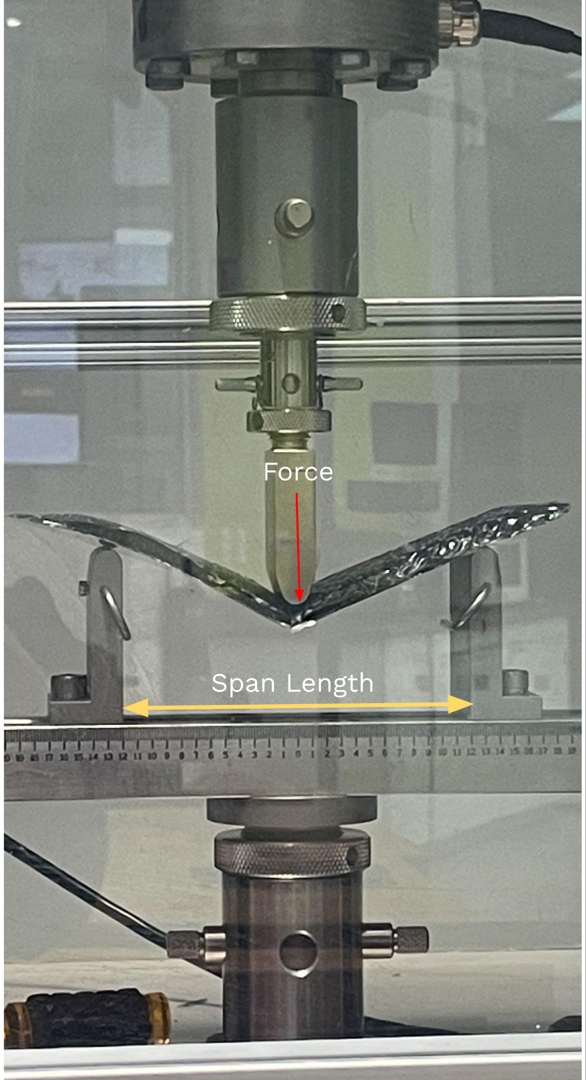
- Carbon Fibre was same width, but resin caused deviation.

Inconsistent Span Length:

- No Sandwich = 12cm span.
- Sandwich = 24cm span.

$$\Delta_{max} \text{ (at point of load)} \; . \; . \; . \; . \; . \; . \; . \; = \frac{P\ell^3}{48EI} \rightarrow EI = \frac{P\ell^3}{48\Delta_{max}}$$

Flexural Rigidity: More Force, Less Deformation (90x)



Wind Tunnel Testing

MIT Wind Tunnel Considerations:

- Open-loop tunnel
- 3x2 foot testing section
- No moving ground
- Maximum velocity 70mph (31.3 m/s)

Possible testing scenario:

- Due to a **small test section**, the front wing would have to be tested at **50% scale**
- Airflow **velocity needs to be adjusted** to get accurate results with a scaled model
- **Reynolds number must be the same** between the scaled model and full sized wing $Re = \frac{\rho v L}{\mu}$

Wind Tunnel Testing

Wind Tunnel Testing Conditions

- **50% scaled** model of front wing
- **v = 16 m/s (full scale)**
- Velocity in the tunnel would then have to be **32 m/s** (71.6 mph)
- Boundary condition with **no moving ground**

With max. wind tunnel speed we could achieve approx. the same Reynolds number!

Challenges

- Poor communication (emails)
  - Testing plans
  - Availability
  - No general guidance
- Surprise MIT facility visit (new info)
- Testing fixture compatibility + availability

$$\frac{\rho v L}{\mu} = \frac{\rho v_{tunnel} L_{sc}}{\mu}, \quad L_{sc} = \frac{L}{2}$$

$$\frac{\rho v L}{\mu} = \frac{\rho v_{tunnel} L}{2\mu}$$

$$vL = \frac{v_{tunnel} L}{2}$$

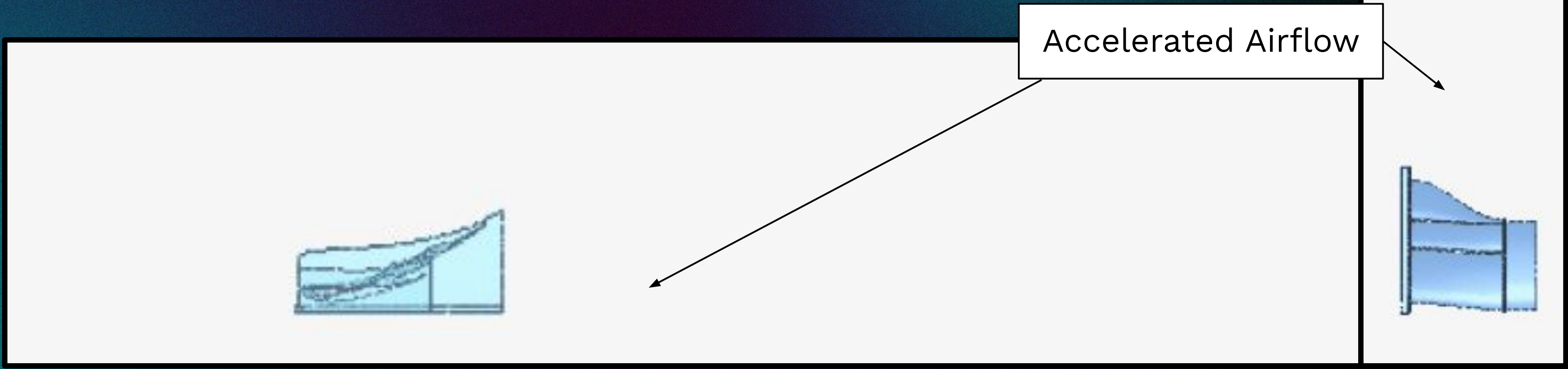
$$v_{tunnel} = 2v$$

SimScale Simulations:

Emulate what we would see from Wind Tunnel Tests

Inlet Velocity = **16m/s**

Outlet Pressure = **101325 Pa**



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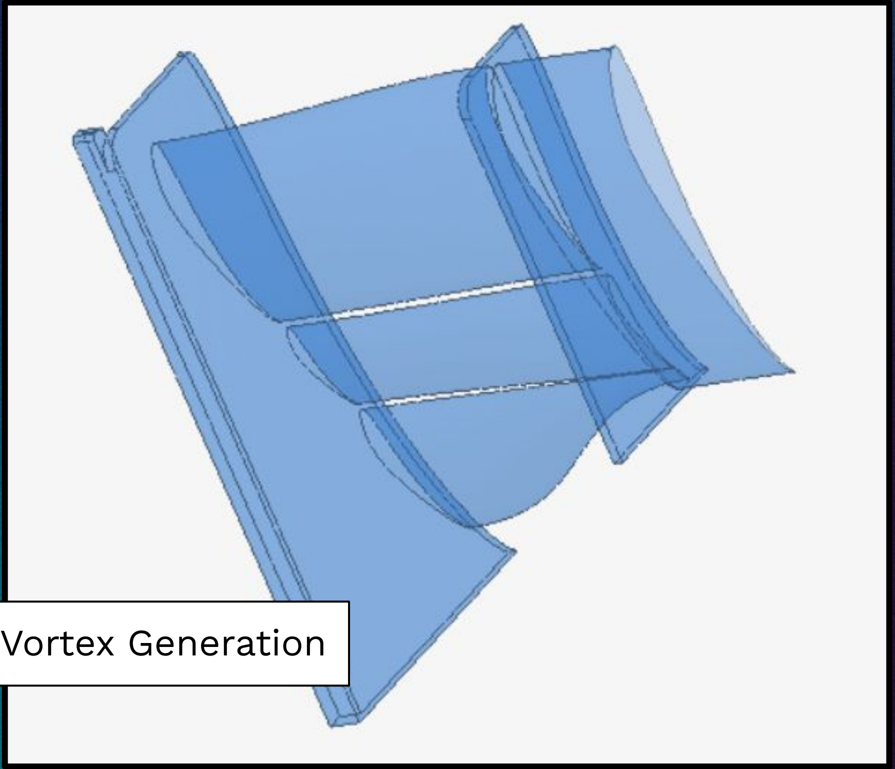
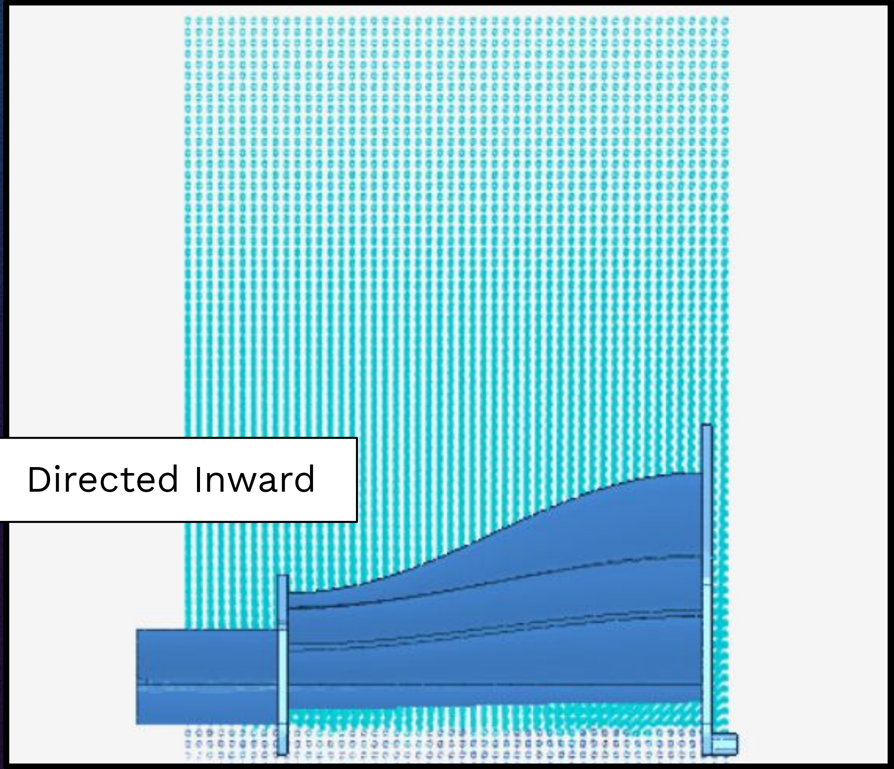
SimScale Simulations:

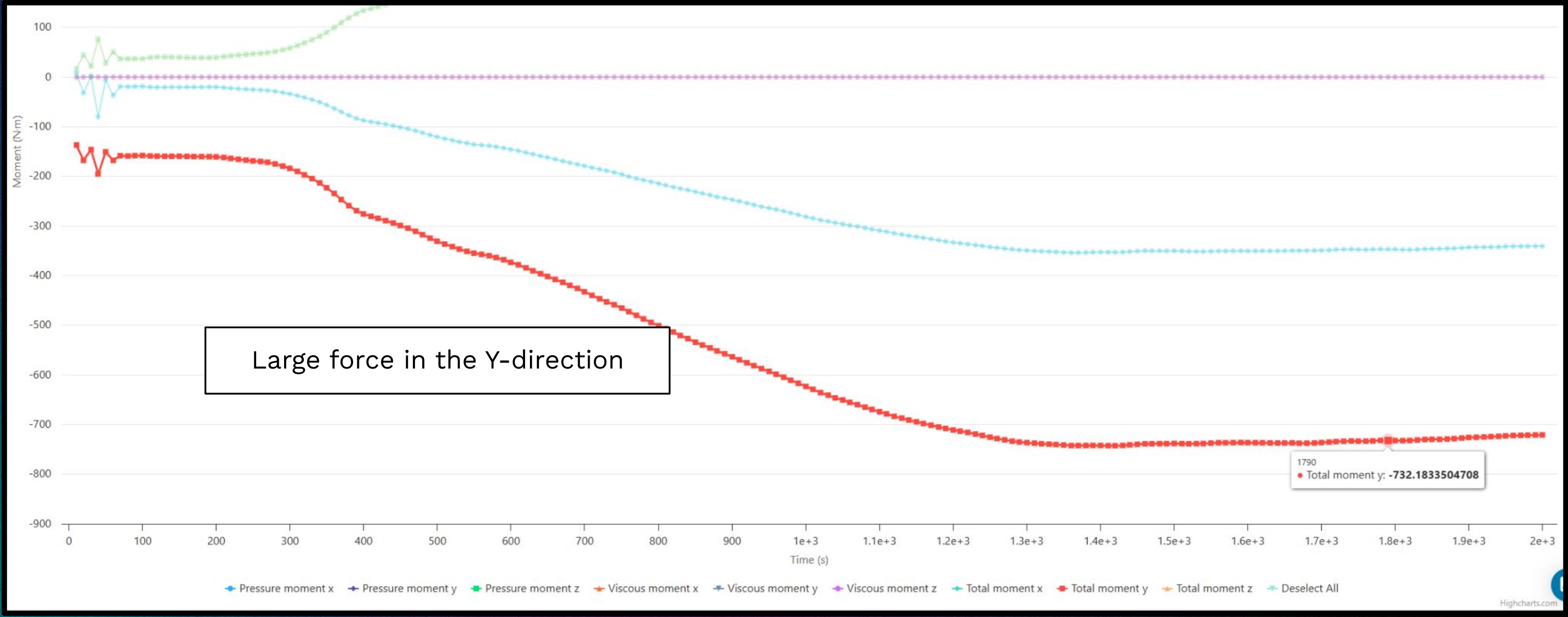


Vortex Generation



Directed Inward

SimScale Simulations:



THANK YOU!!!

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