FEEG6013 Group Design Project

Aerodynamics and model development of a Formula Student car

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GDP Group 15

2024

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Meet our team

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Group leader

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Project manager

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Mechanical lead

Arjun Sidhu
Manufacturing lead

Yong Hua Tang
Aerodynamics lead

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Introduction

What is **Formula Student** (FS) UK?

- Open-wheel race car design competition between universities.
- Tight and technical track layouts.
- Strict rules and regulations to design within FS2024 rules.

Competitive Baseline

SUFST Stag 9

- SCL: 3.573
- SCD: 1.638
- Efficiency: 2.181

(CFD Data From SUFST)

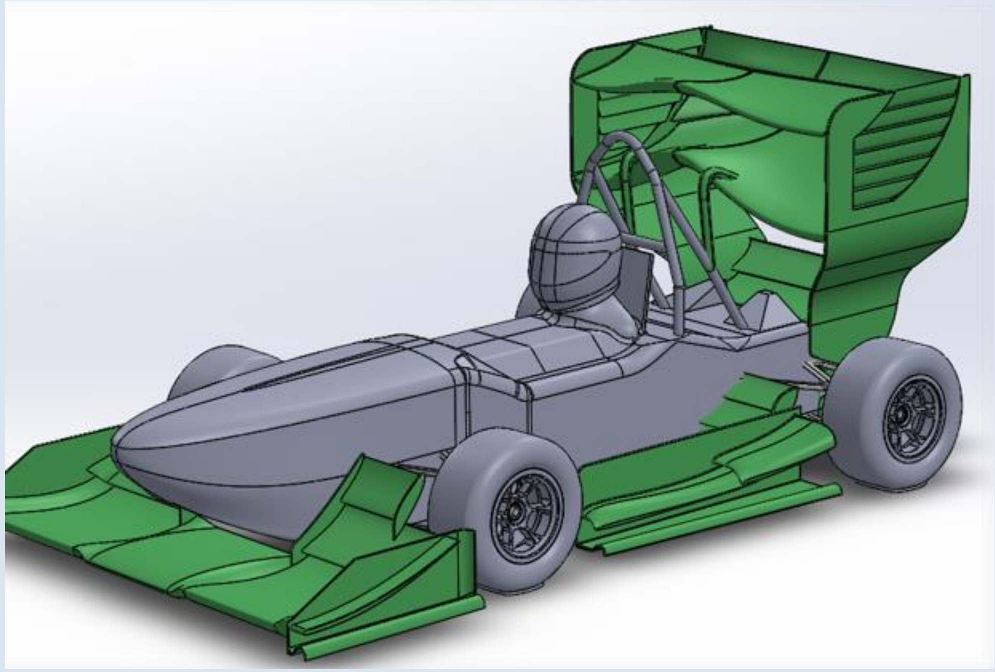
Lap Times (Simulated)

- Skid Pad: 5.543 s
- UoS Long: 72.983 s

SUFST car at competition

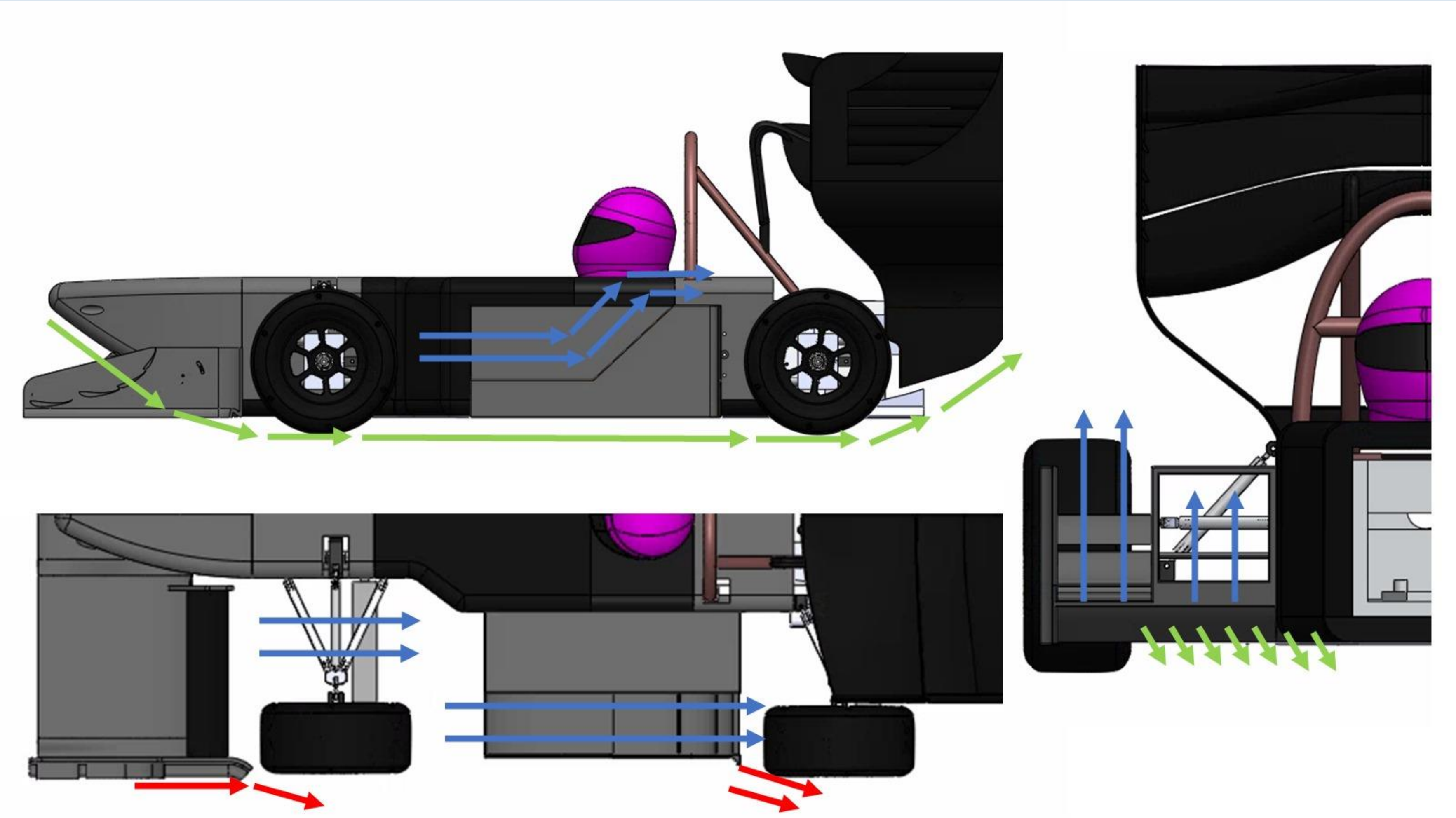
Introduction

- **Design brief**: Generate an aerodynamic package for an FS car and manufacture a 40% scale model for wind tunnel testing.
- **22-23 GDP** final model:
  - Last year's model was very strong **aerodynamically**.
  - **Suspension** design and mechanism have room for improvement.
  - Lack of **cooling** capacity.



2022-23 GDP final model

Flow Concept



Flow influenced by the wings

Flow under the car

Flow along suspension, bodywork and sidepods

Contents

Main Aims & Objectives

Aims:

To improve the aerodynamic performance of an FS car with an electric powertrain and to retrofit the previous wind tunnel model ensuring increased consistency and reliability in testing.

Objectives:

- Design a **suspension system** that allows for both wheels-on and wheels-off testing with ease.
- Development of **aero package** (front wing, rear wing and cooling) which is within 90 % of the lift and drag values of 2023 model and within 0.5 s per lap
- Perform CFD and FEA analysis for validation
- Design and manufacture a **modular wind tunnel model** that is sustainable and operable in the R J Mitchell Wind Tunnel.

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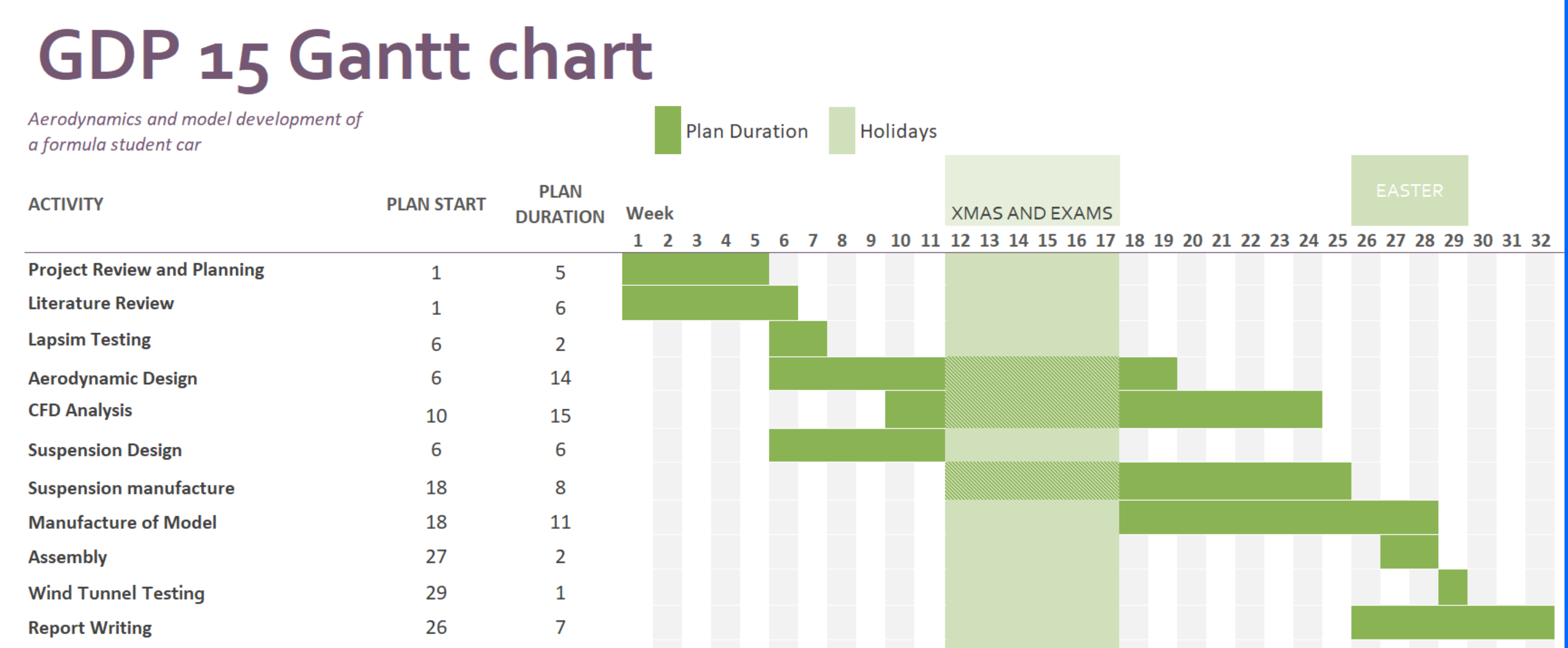
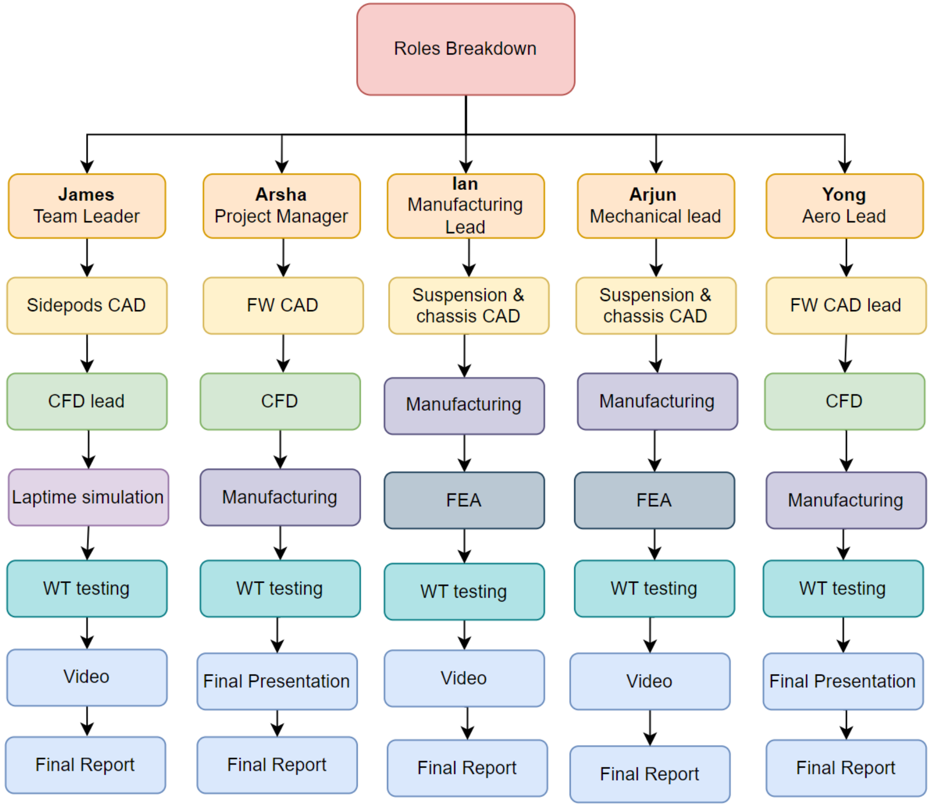
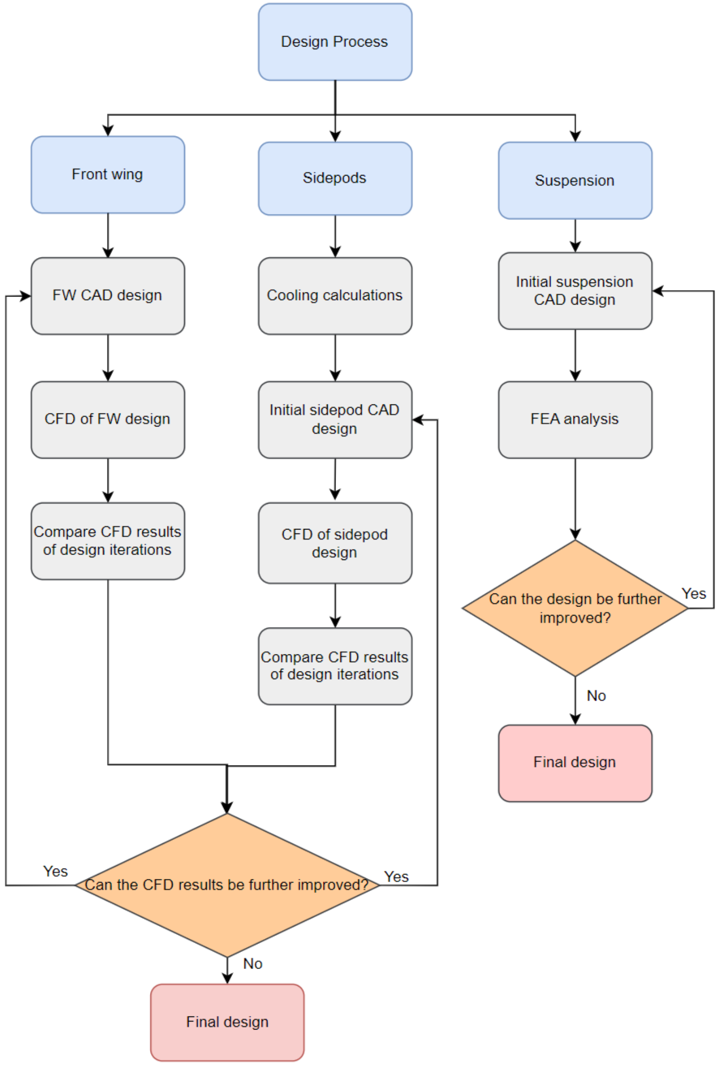
Project Structure



Project Structure

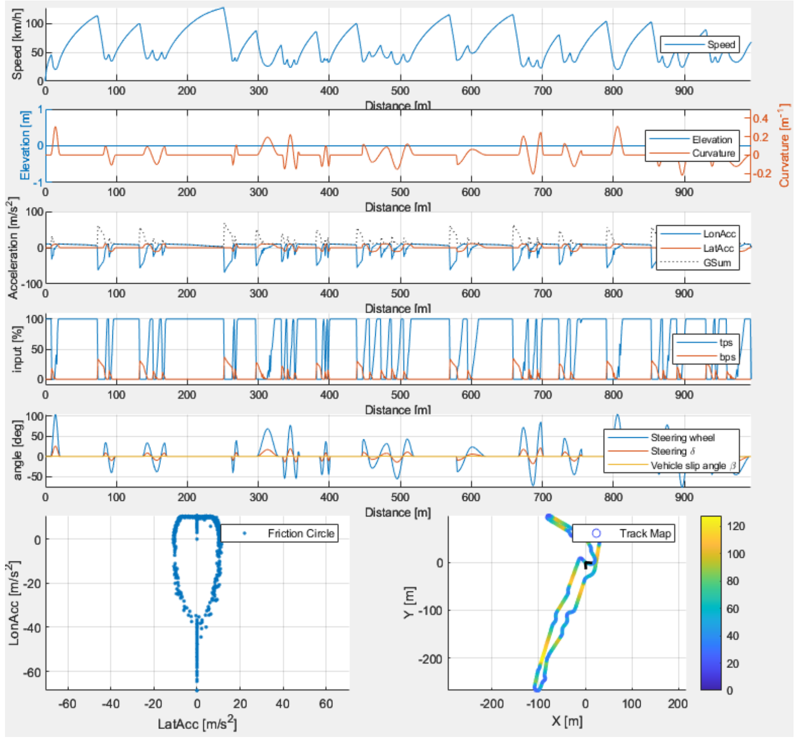




Contents

Design validation – Lap time simulation

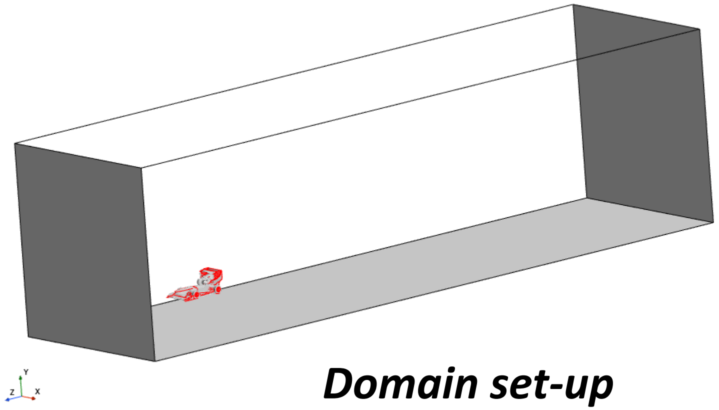
- Lap time simulation helps aerodynamic improvement and cooling modelling.
- OpenLAP MATLAB program was used.
- Designed for use with an ICE powered car not a BEV.
- Lap time output was 69.091 s.
- SUFST Stag 9: 72.983s.



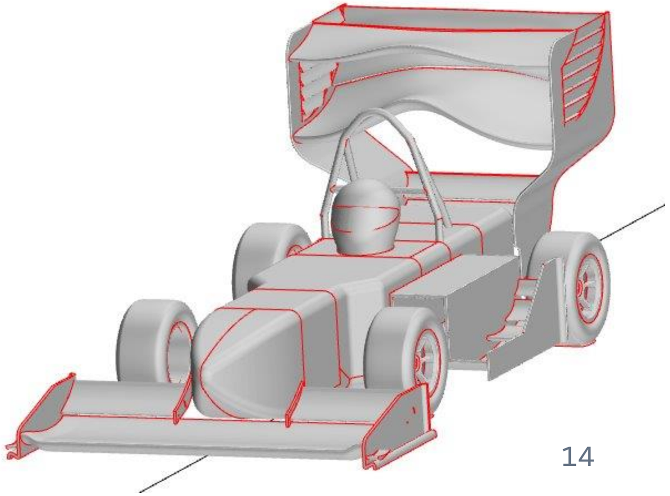
OpenLAP lapsim output

Design validation – CFD

- Aero package design iterations were validated using CFD.
- STAR-CCM+ and IRIDIS HPC was used.
- CFD data was recorded in a table for comparison and data analysis.
- Flow visualisation allowed detection of separation and areas for improvement.

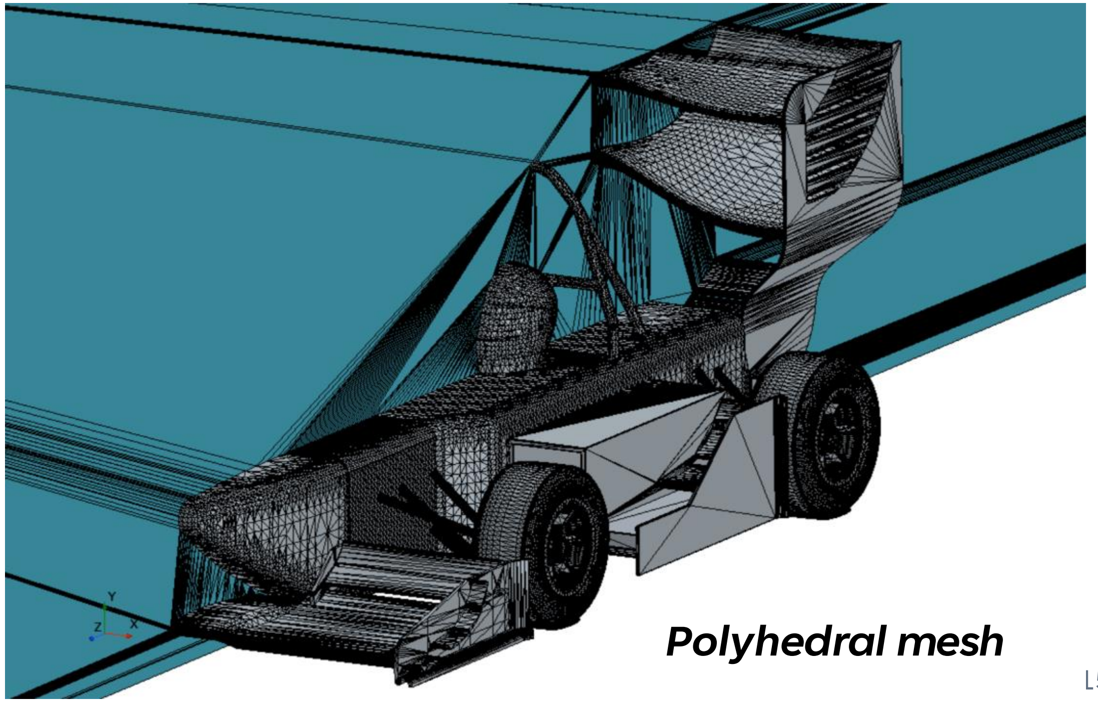


Domain set-up



Design validation - CFD

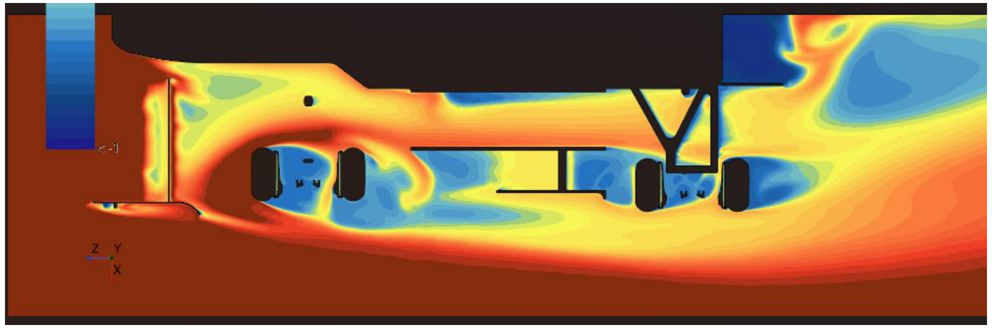
- **Meshing**: Polyhedral option selected for complex car geometry and faster computation.
- **Turbulence models**: RANS turbulence models preferred for stability and quick convergence. Chose k-ω model for accurate near-wall flow resolution and boundary separation prediction.
- **Domain setup**: velocity inlet, moving ground, rotating wheels mirroring real car conditions.
- **Mesh**: Base mesh size set to 0.03 m, generating a 53 million cell mesh. Meshing reduced from 16 hours (120 cores on HPC) to 12 hours, saving time and energy.



Polyhedral mesh

Design validation - CFD

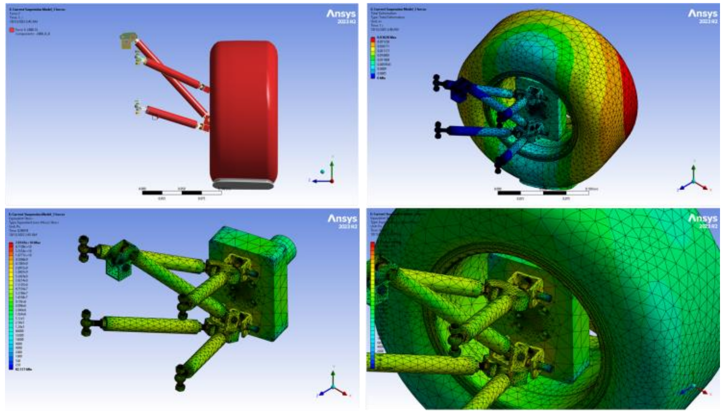
- Simulation **converged** around 3000 iterations.
- **Post-processing** script created from scratch to output Cp, CpT, Velocity, and Vorticity planar slices, along with force measurements to CSV file.
- Force results analysed over the final 1000 iterations due to RANS solver usage for non-steady state solution.



CpT-Y plot

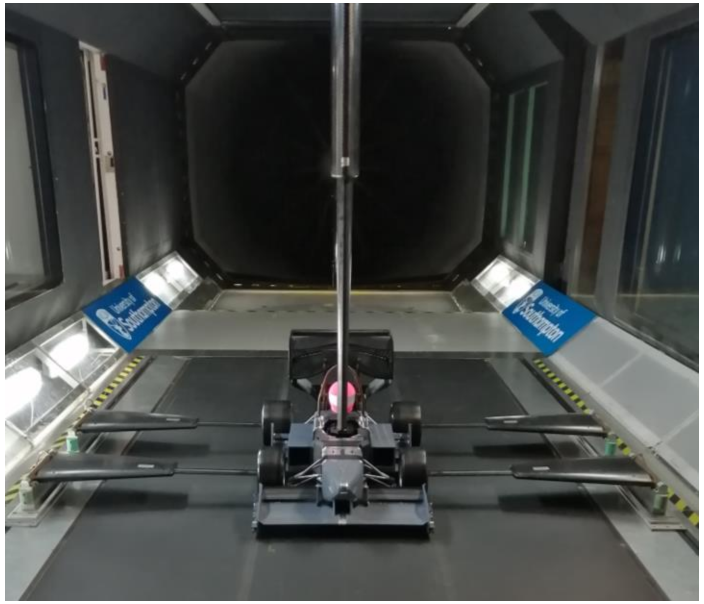
Design validation – FEA Analysis

- FEA with ANSYS assessed suspension and FW design integrity.
- It identified stress distribution and deformation under fixed loads.
- Pinpointed weak points for targeted design adjustments.
- Detailed simulations optimised durability, structural integrity, and performance.
- Tetrahedral mesh with 0.025m mesh size used.
- Force values obtained from CFD simulations.



Design validation – Wind Tunnel

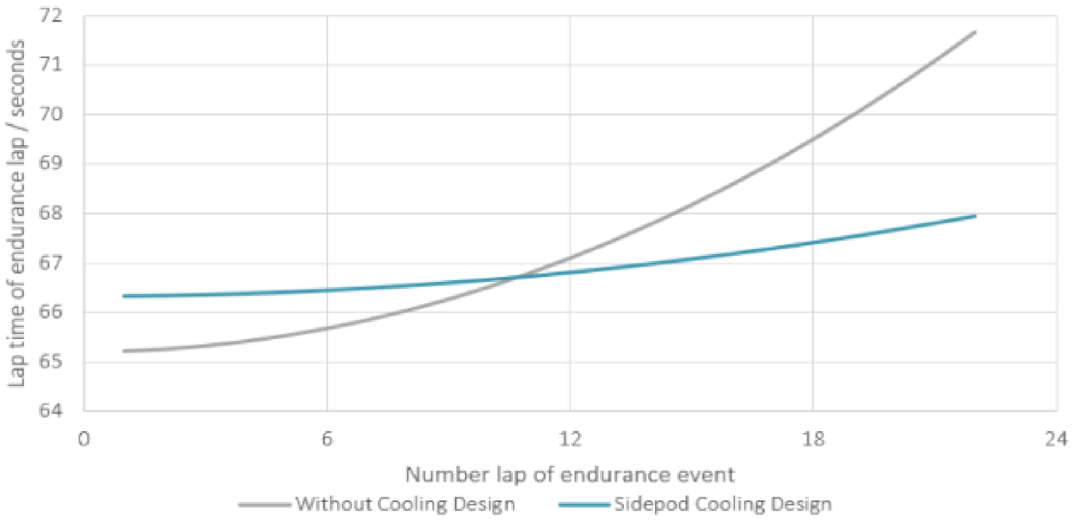
- Acquire aerodynamic package performance with a 40% scaled model.
- Cross-validates accuracy of CFD simulations.
- Allows for real-world testing of design improvements.
- Enhances confidence in aerodynamic performance predictions.



Battery and cooling

- BEVs experience a decrease in power output over time due to factors like state of charge (SOC) and battery temperature.
- Battery temperature increases over the race distance, resulting in a steeper drop in SOC and higher energy consumption.
- Cooling systems are important for maintaining battery temperature and optimising power output.

Radiator model



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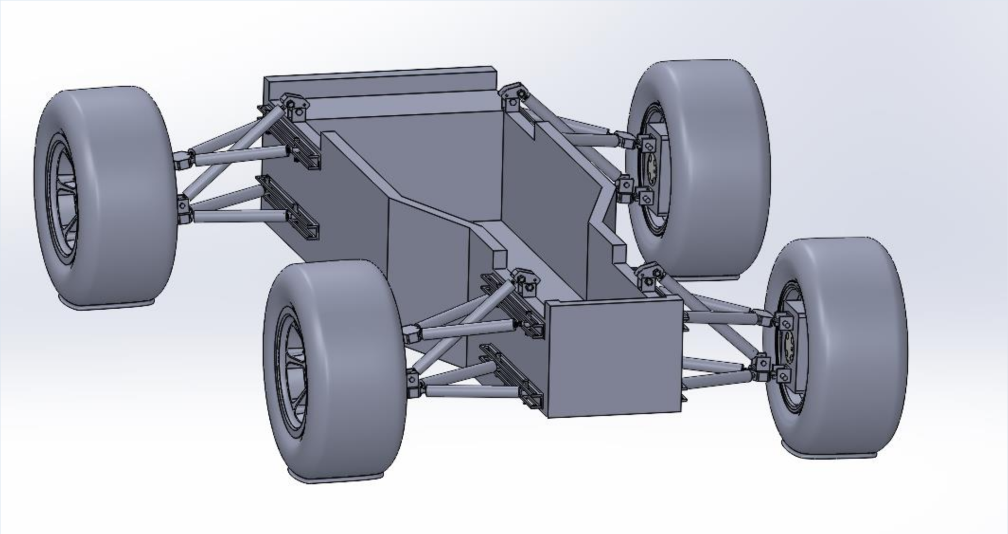
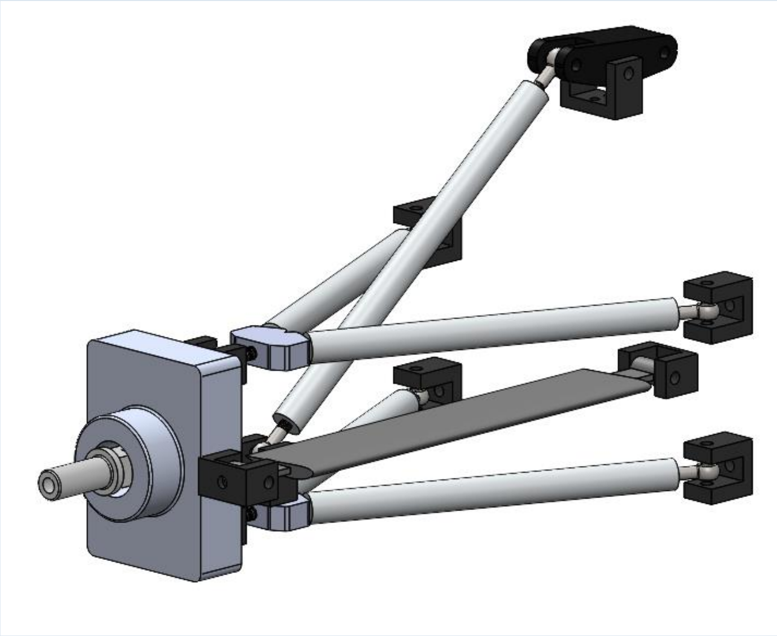
Suspension System Design

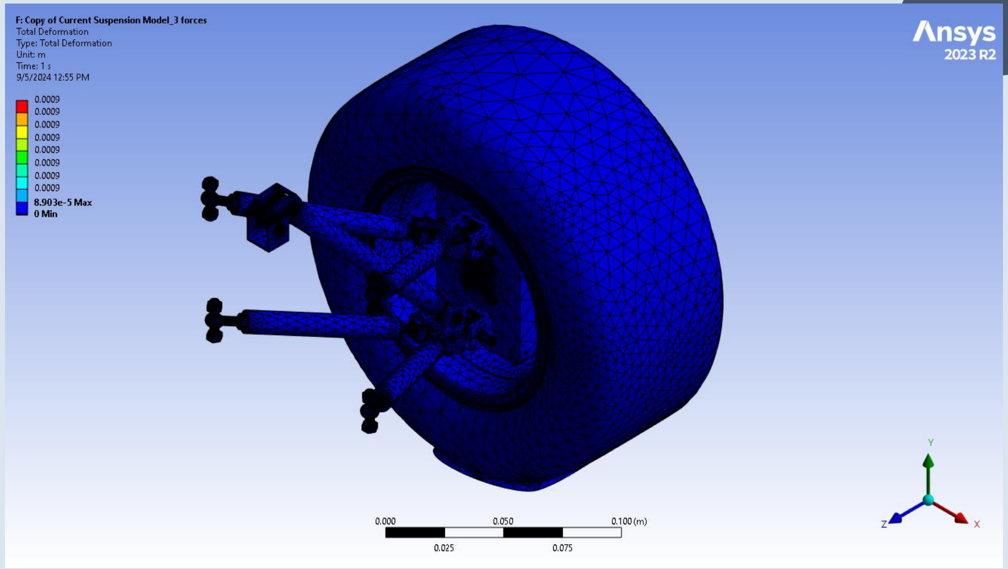
- A pushrod suspension concept was used.
- Final suspension system comprised five primary components: upright, two wishbones, push rod, and rocker.
- Push rod design absorbed system vibrations without damage.

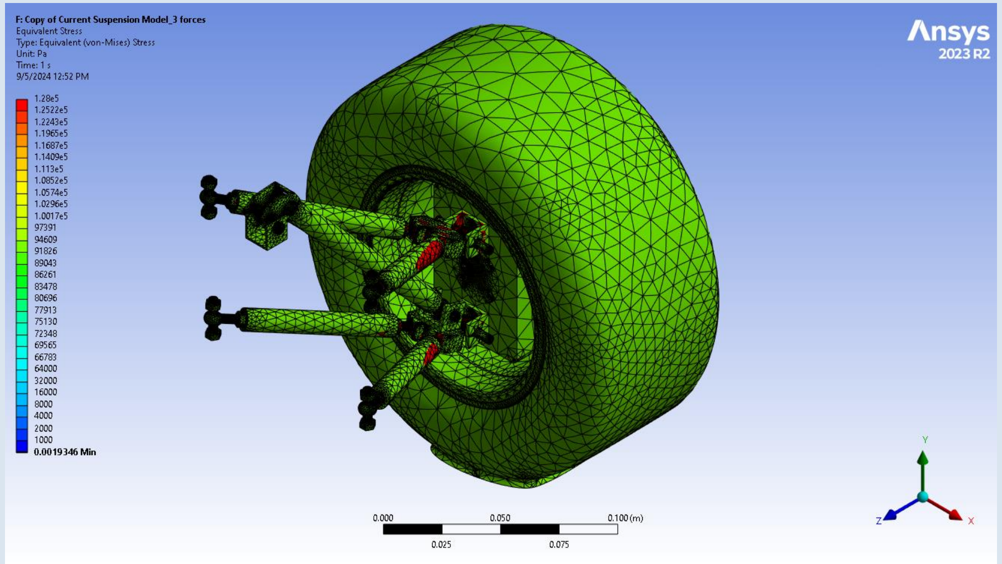




Suspension System FEA

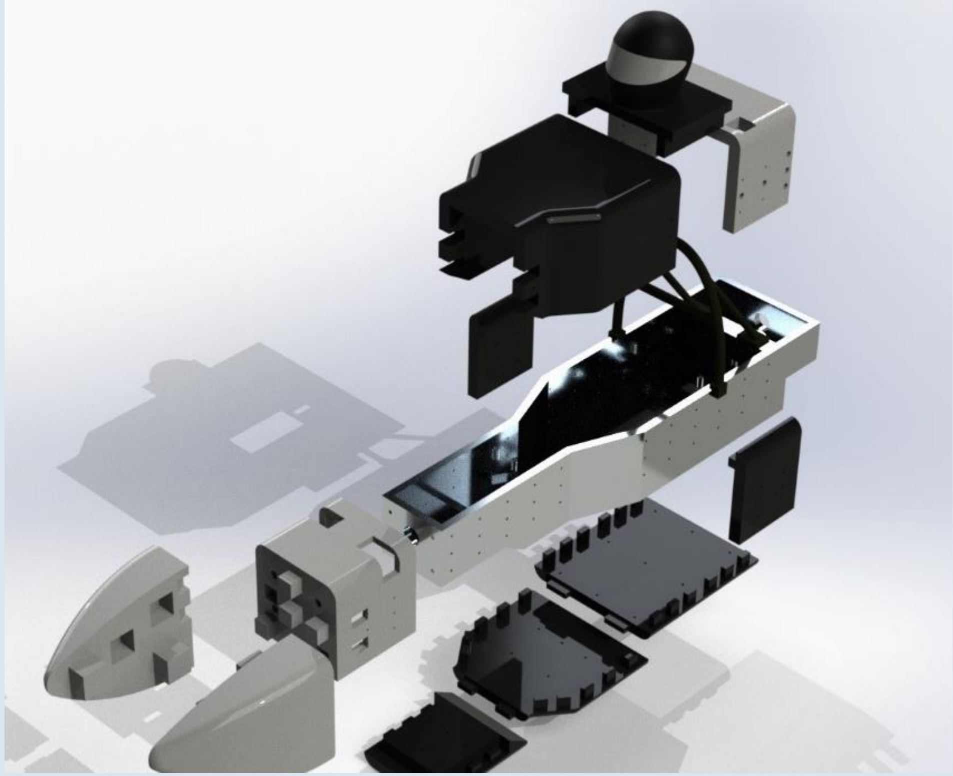
- FEA studies conducted throughout suspension design process.
- Provided stress distribution modelling, deformation analysis, and prediction of failure points.
- Adjustments made to material thickness to enhance component strength.



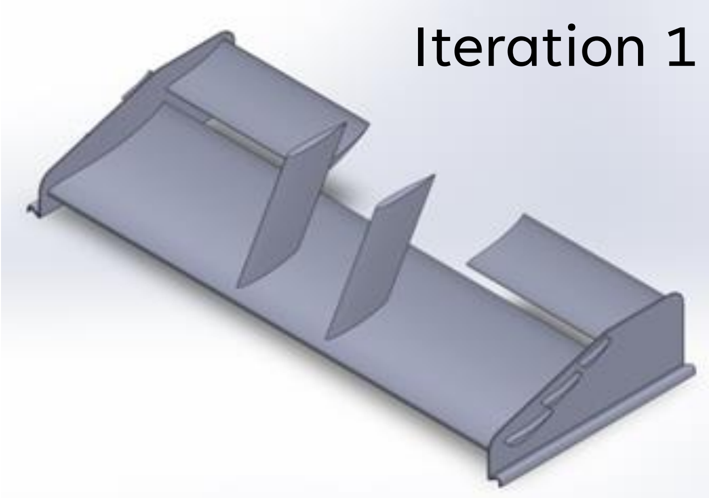


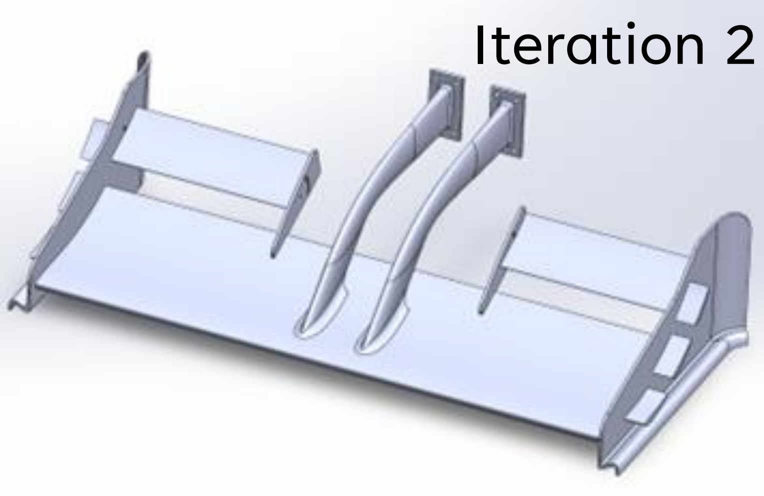
Bodywork

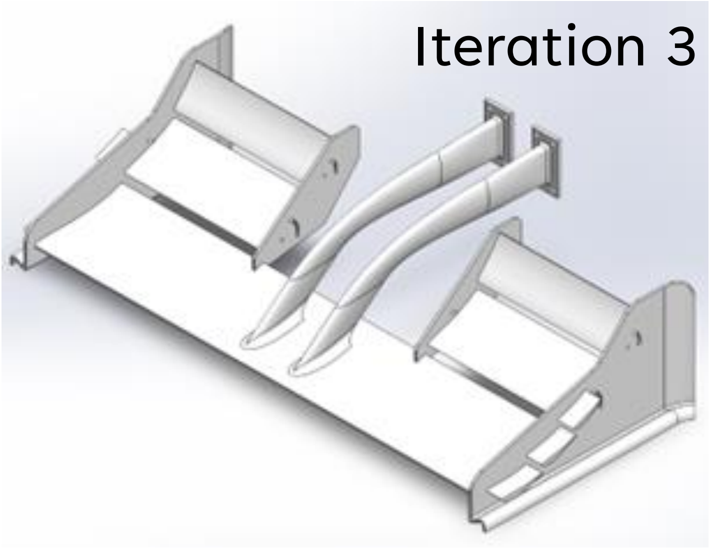
- Redesigned bodywork aimed to reduce drag and facilitate easy mounting of aerodynamic parts and suspension.
- New design composed of **fewer pieces** to streamline assembly process.
- Designed as **shell** to fully encapsulate metal spine
- Pieces **friction fitted** together and bolted directly to metal spine for added strength.
- CFD simulations indicated significant **decrease in drag** coefficient from previous year's design.

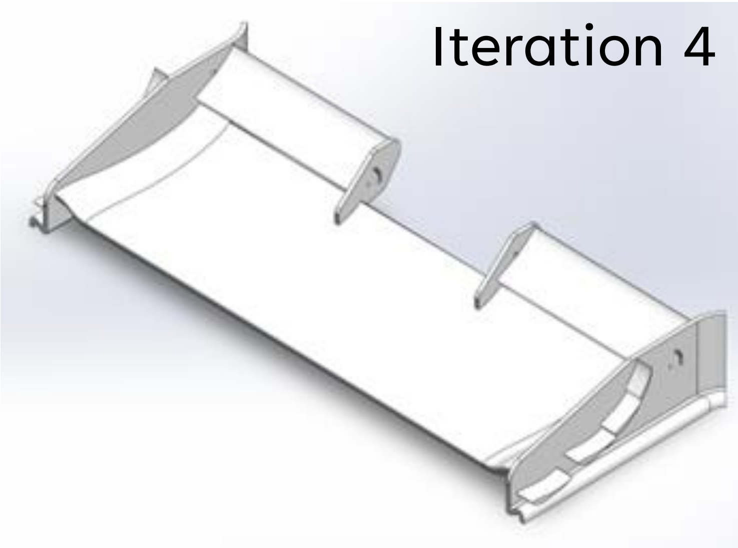


Front Wing design iterations

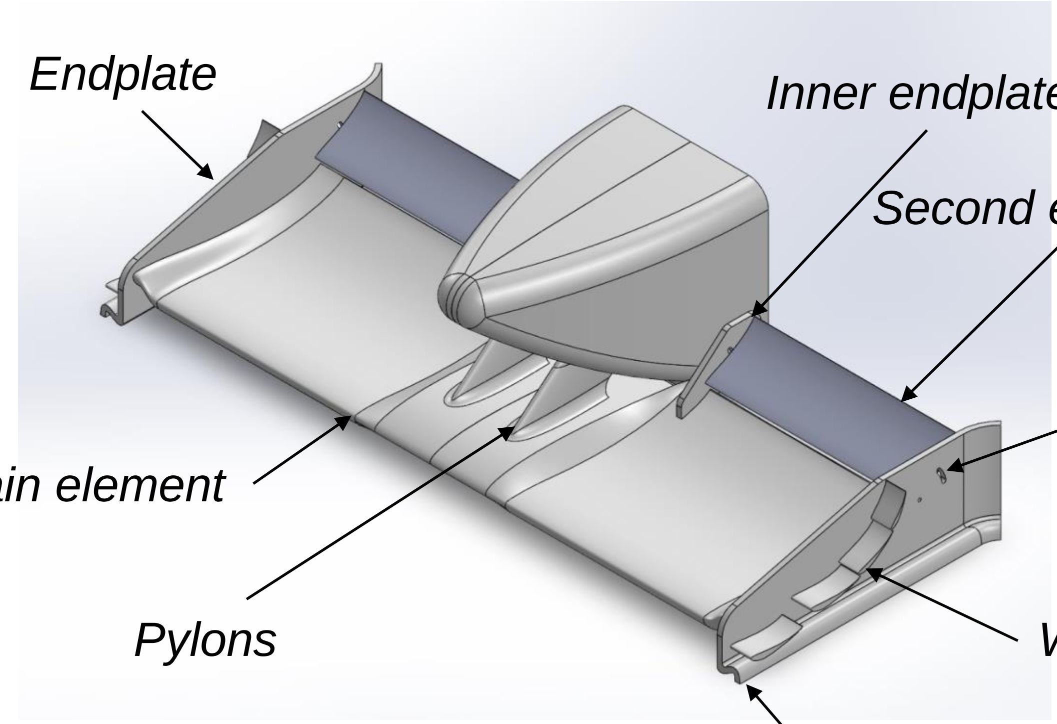


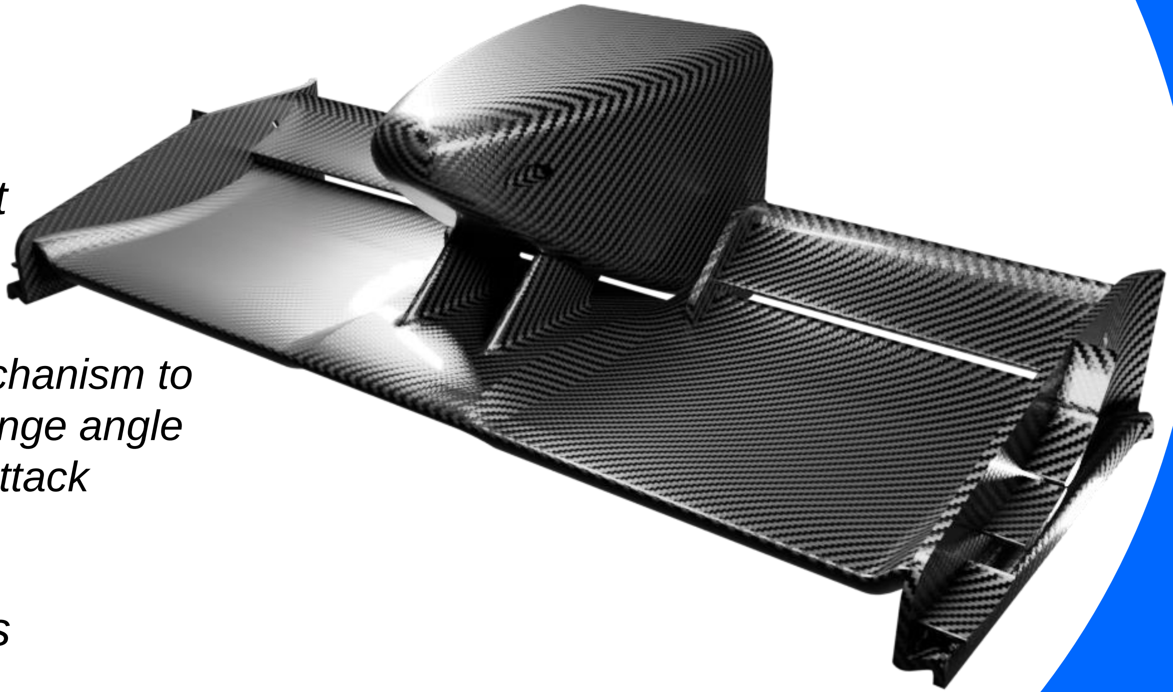






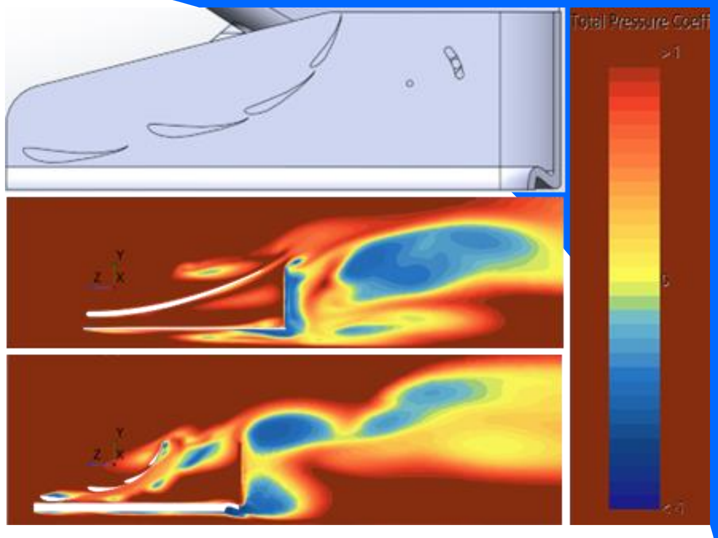
Front Wing Final design

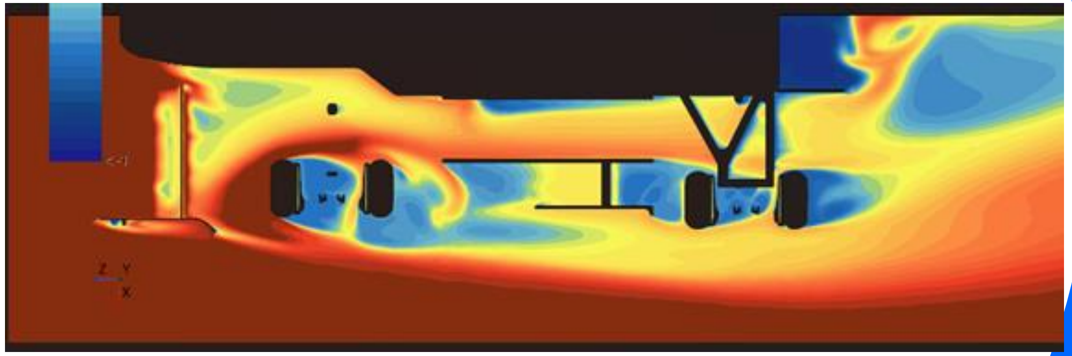


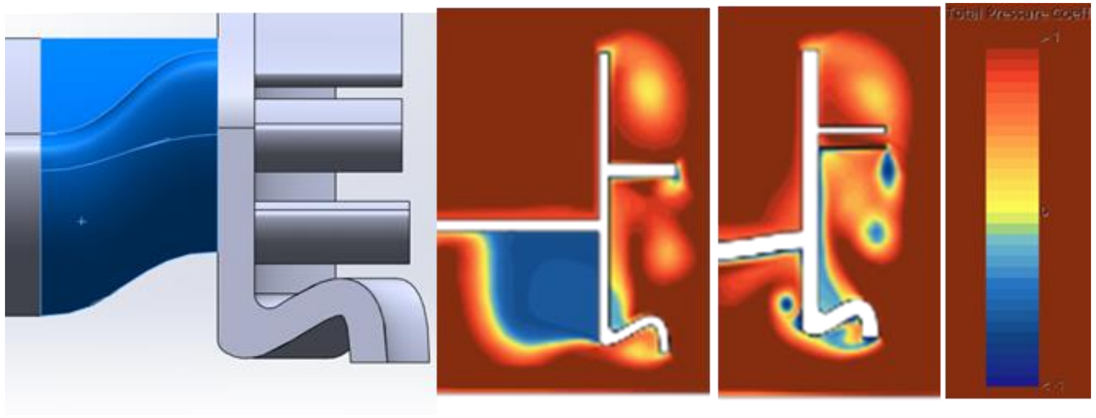


Front wing CFD

- Curved endplates direct the airflow outwards.
- Lofting the main element reduces separation near endplates.
- Winglets rather than canard reduces aerodynamic loss.

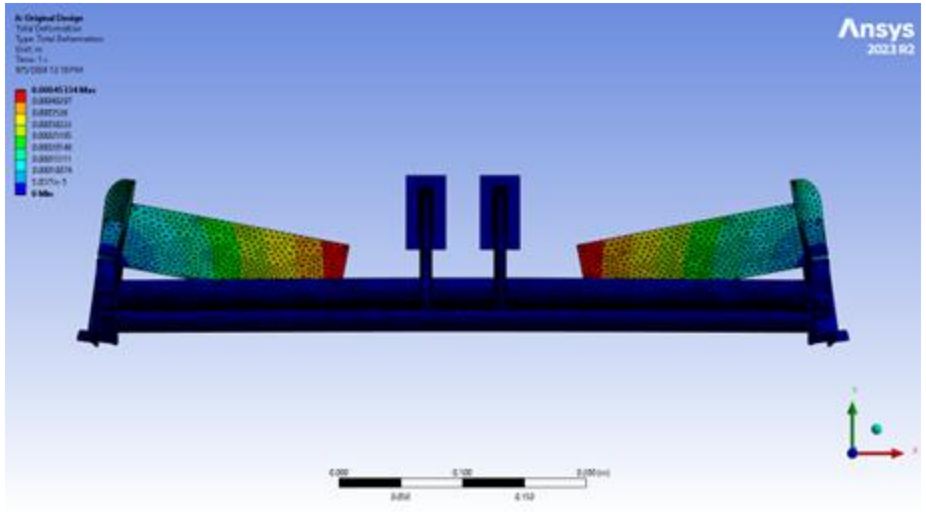


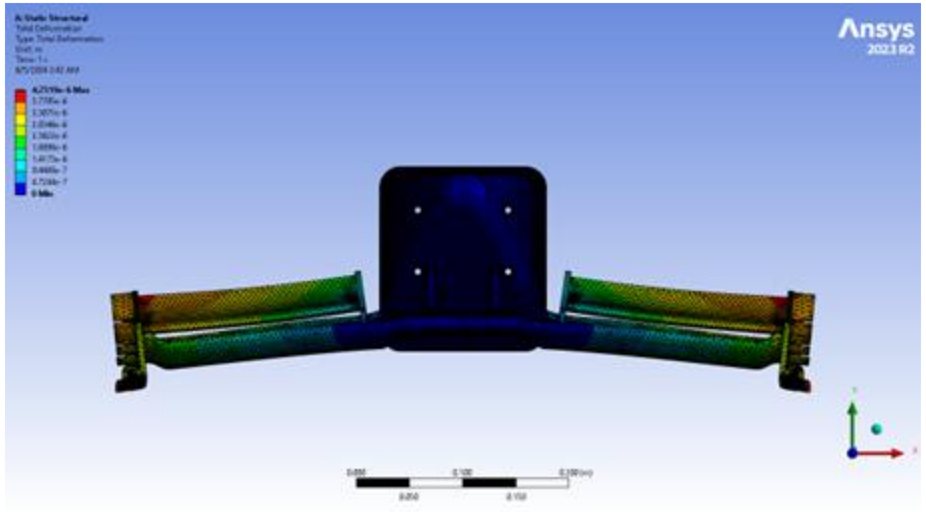




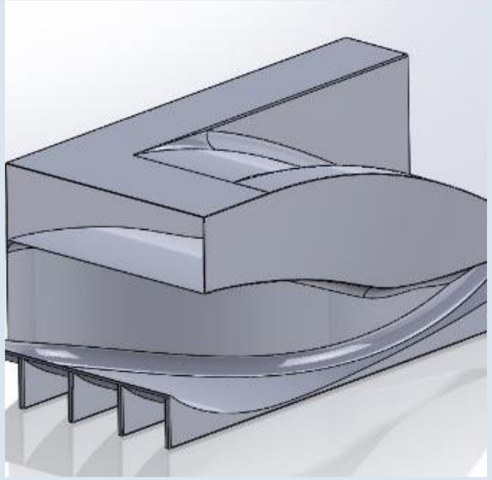
Front wing FEA

- FEA studies conducted throughout FW design process.
- Inner endplates added to FW design after FEA analysis

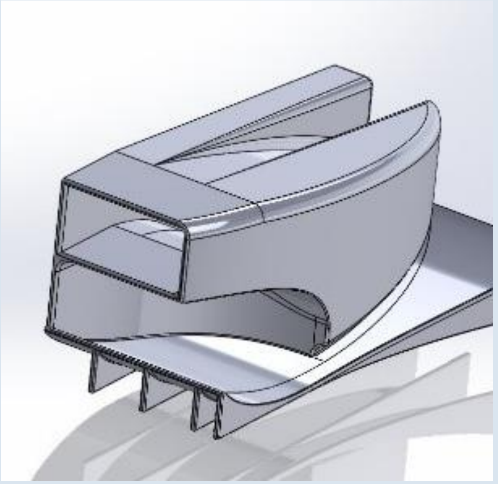




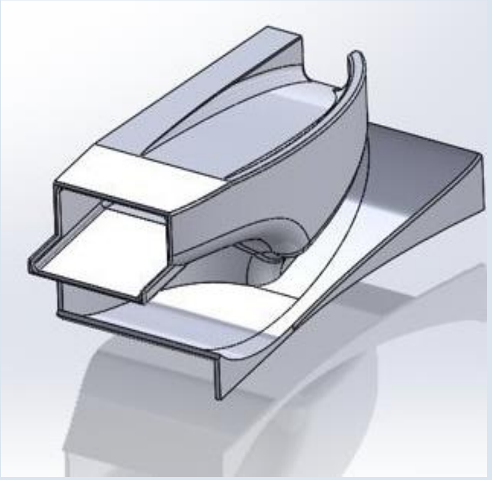
Sidepods design iterations



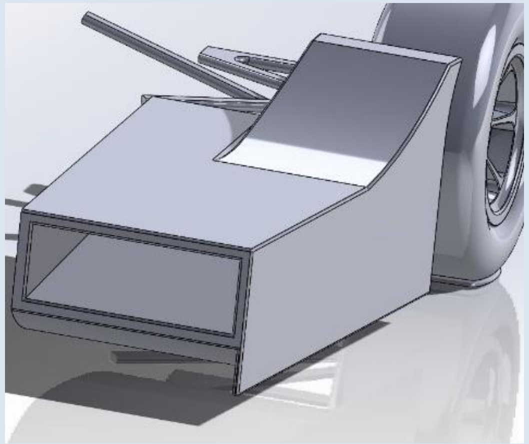
Iteration 1



Iteration 2



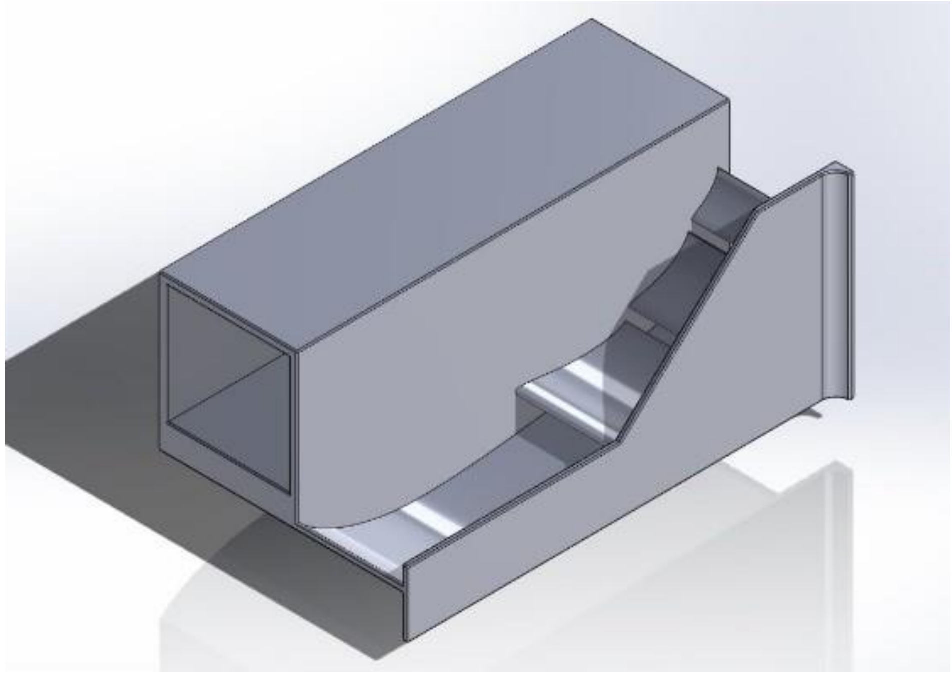
Iteration 3



Iteration 4: Low drag design

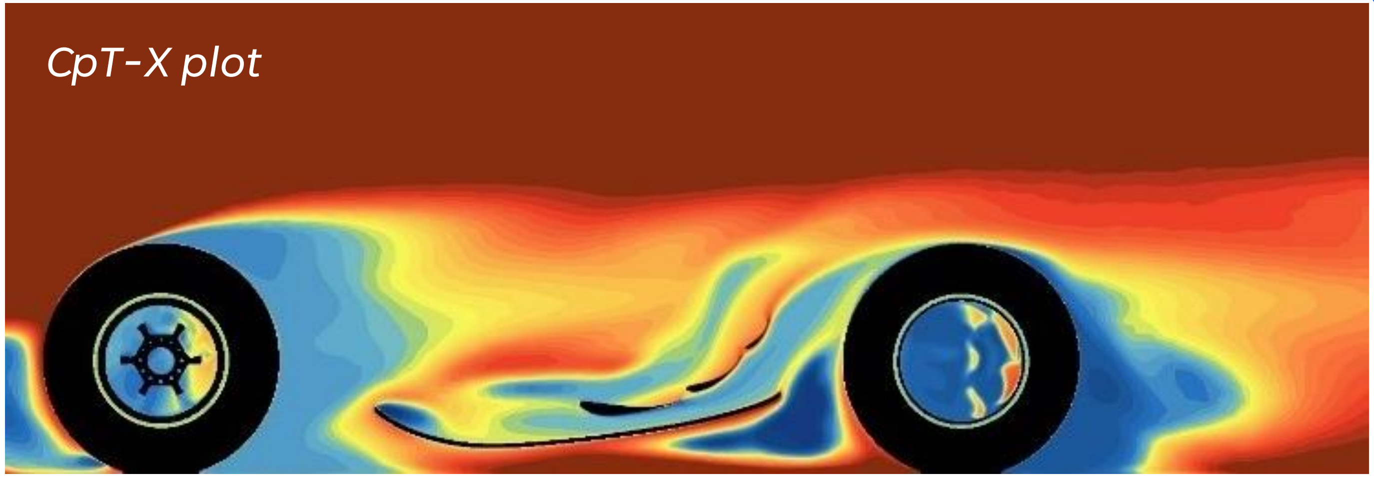
Sidepods final design

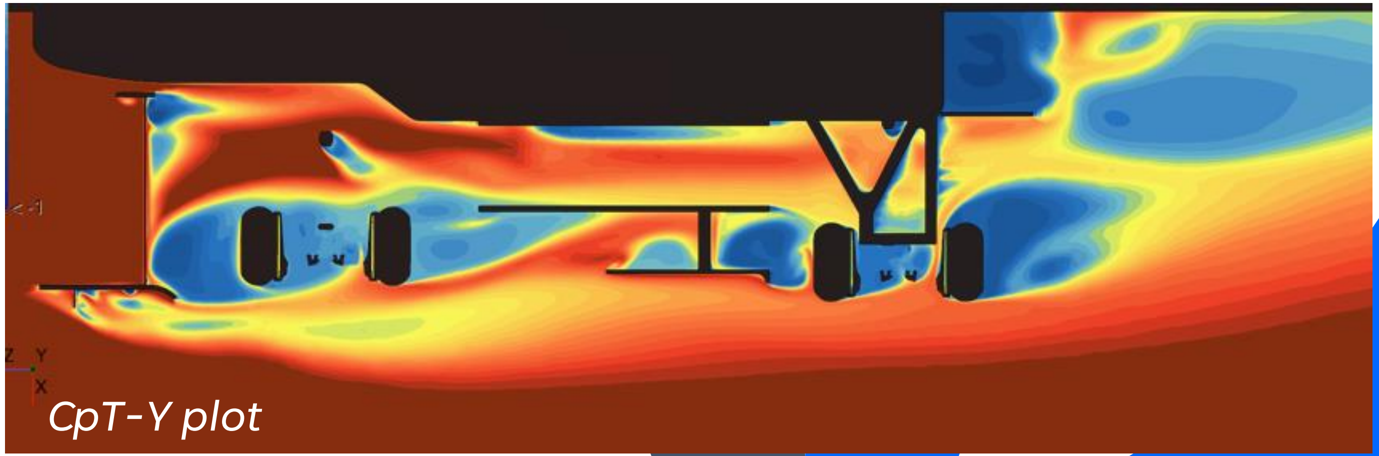
- Aims to increase downforce.
- Utilises ground effect design, with added aerofoils outboard of sidepod inlet.
- Reduced exhaust area of sidepod to accelerate flow toward diffuser and widen aerofoil span.
- Increased drag and decreased downforce contrary to expectations.



Sidepods CFD

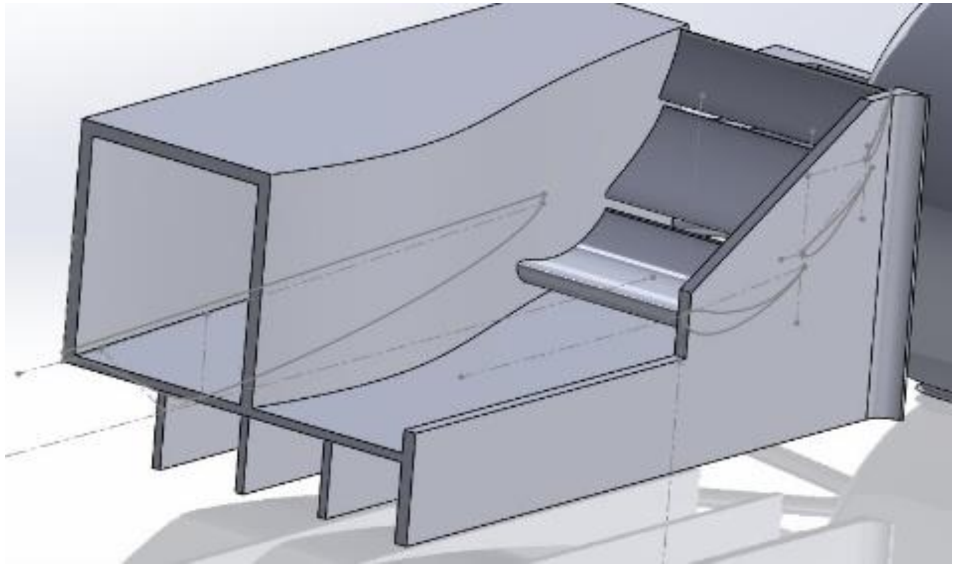
- Generates lots of downforce with aerofoils
- Produce upwash near the rear wheel.
- Separation near curved leading edge.





Attempted improvements

- Reduced exhaust area of sidepod to accelerate flow toward diffuser and widen aerofoil span.
- Less aggressive floor edge.
- Strakes to straighten the flow.
- Increased drag and decreased downforce contrary to expectations.



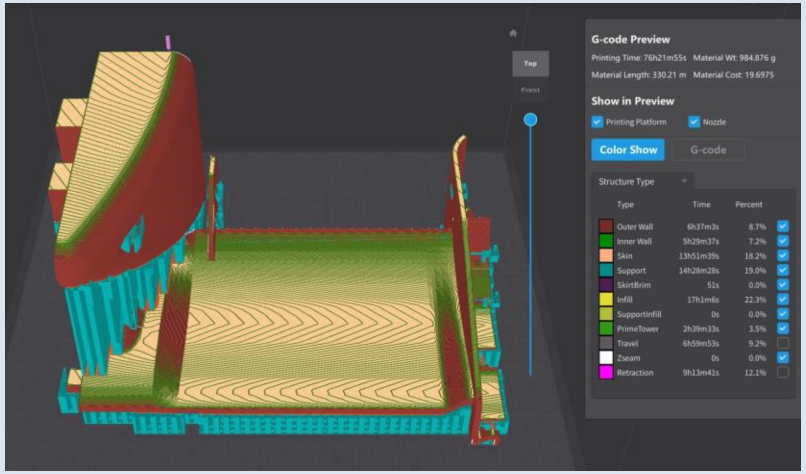
Contents

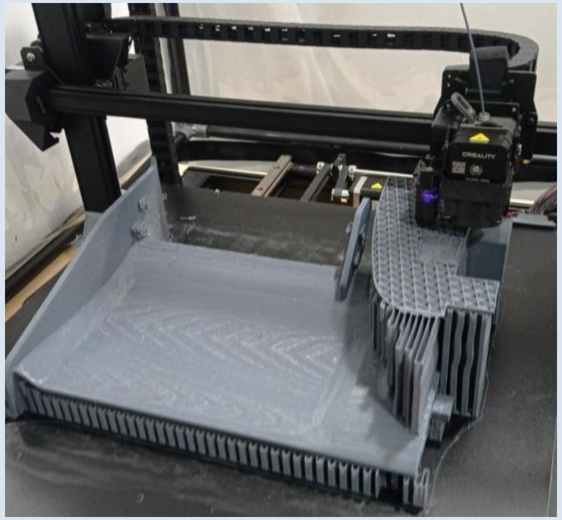
Manufacturing: 3D Printing

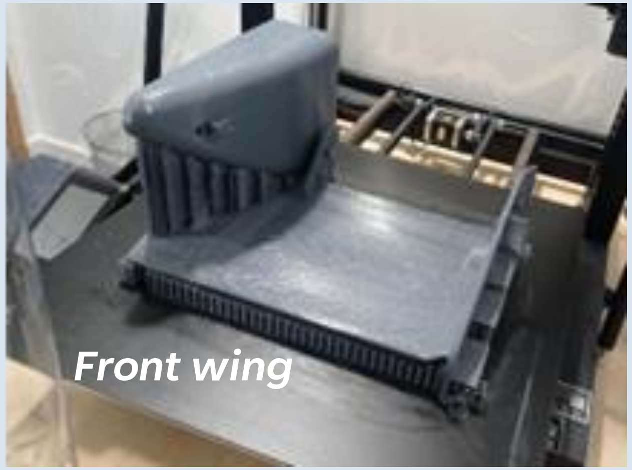
- The process of 3D printing was employed for manufacturing the bodywork, FW, and sidepods.
- PETG opted over PLA for higher strength and flexibility.
- Creality CR-M4 3D printer with 450mm x 450mm x 470mm build volume used.
- Printer equipped with 0.4mm nozzle for 1.75mm diameter filaments.

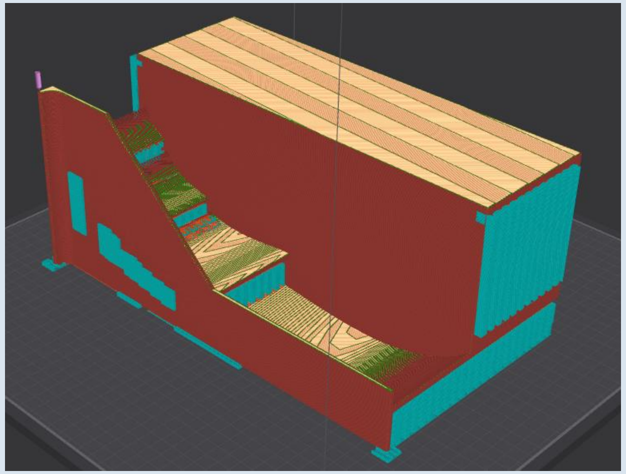
WT 3D Printer

Manufacturing: 3D Printing

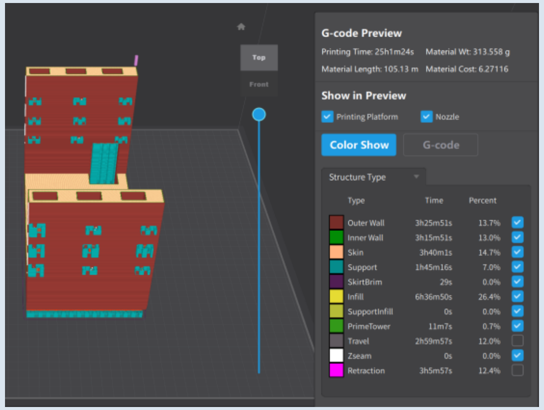


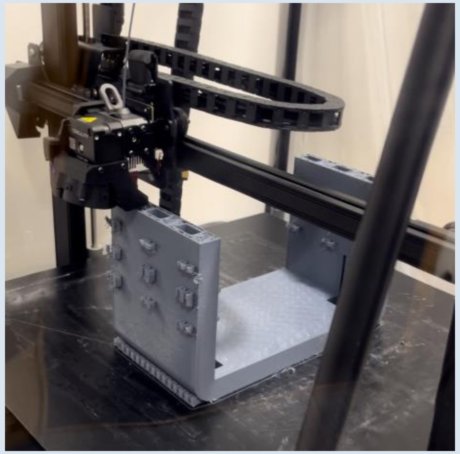




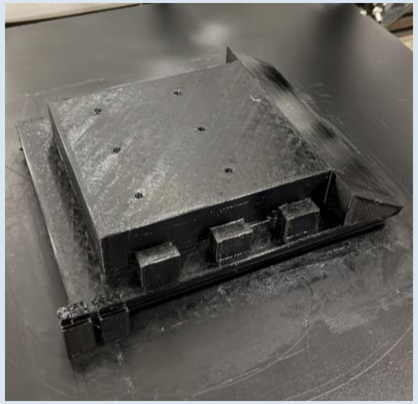


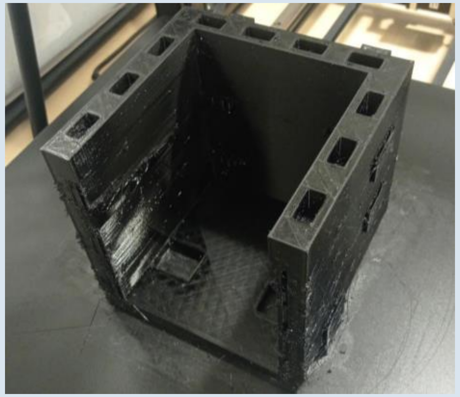
Manufacturing: 3D Printing

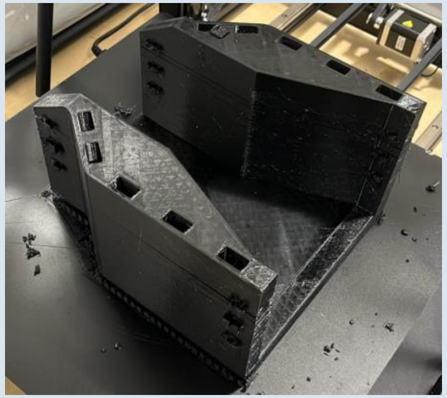




- Adjustments were made to get the bodywork parts to fit
- Aluminium tape was used to seal gaps



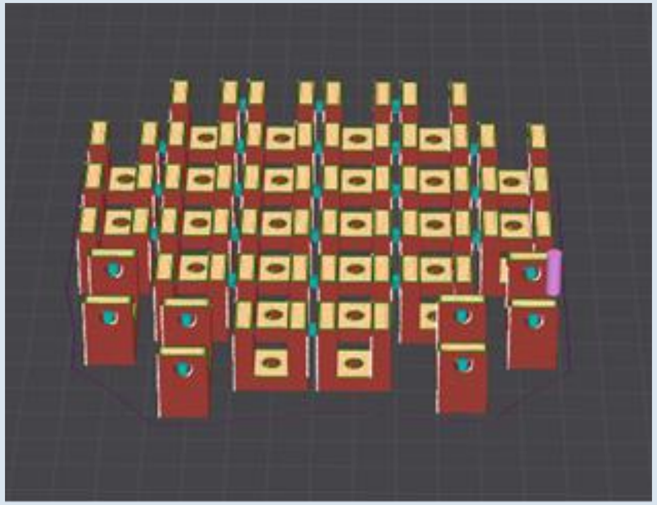




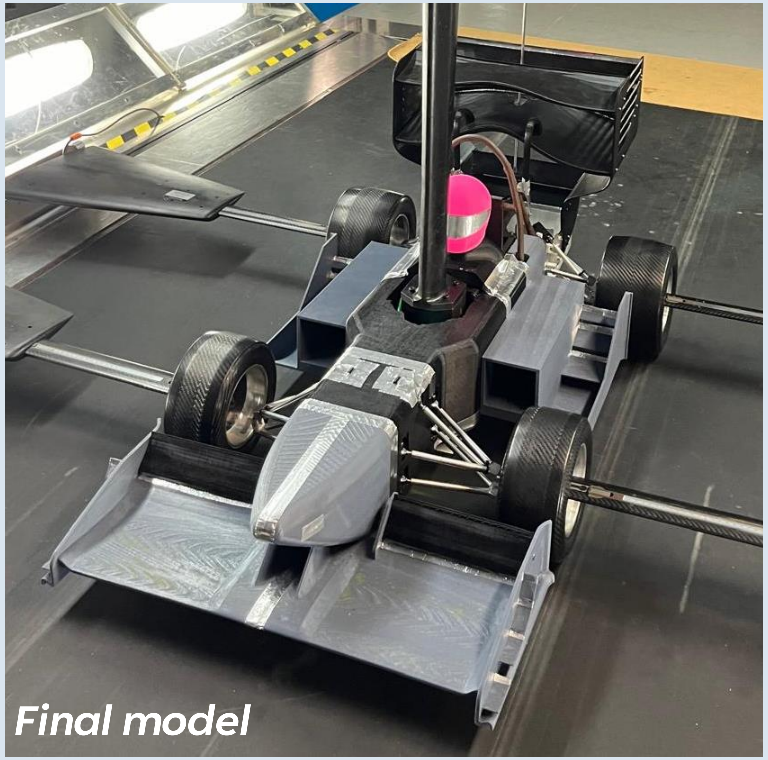
Manufacturing: Suspension

EDMC manufactured Uprights, Wishbones, Pushrods

3D printed suspension mounts



Manufacturing: Assembly



Final model

Cost breakdown

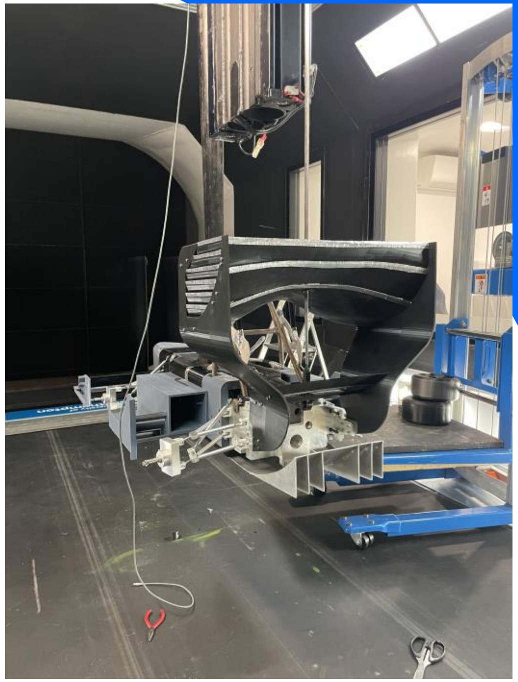
Total budget for project: £ 850

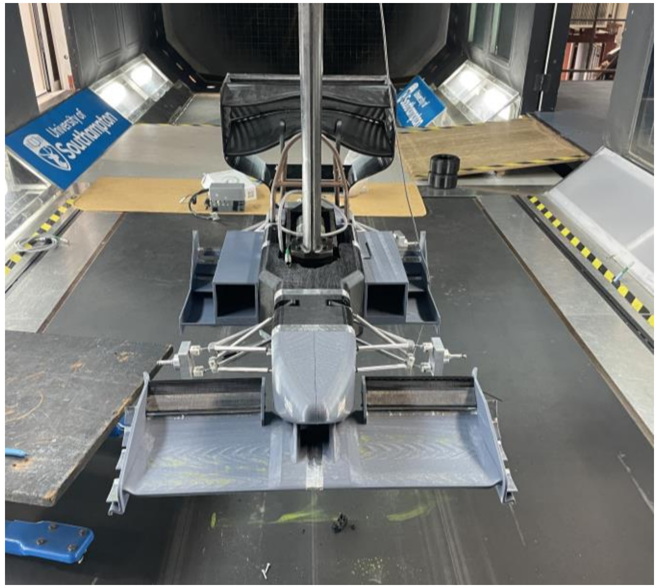
	Proposed budget (£)	Final expenditure (£)
Suspension	150.00	310.36
Bodywork	100.00	154.99
Front Wing	100.00	91.18
Sidepods	75.00	94.42
Total budget/spent	425.00	650.95
Total remaining	425.00	149.05

Contents

Wind Tunnel Testing – Day 1

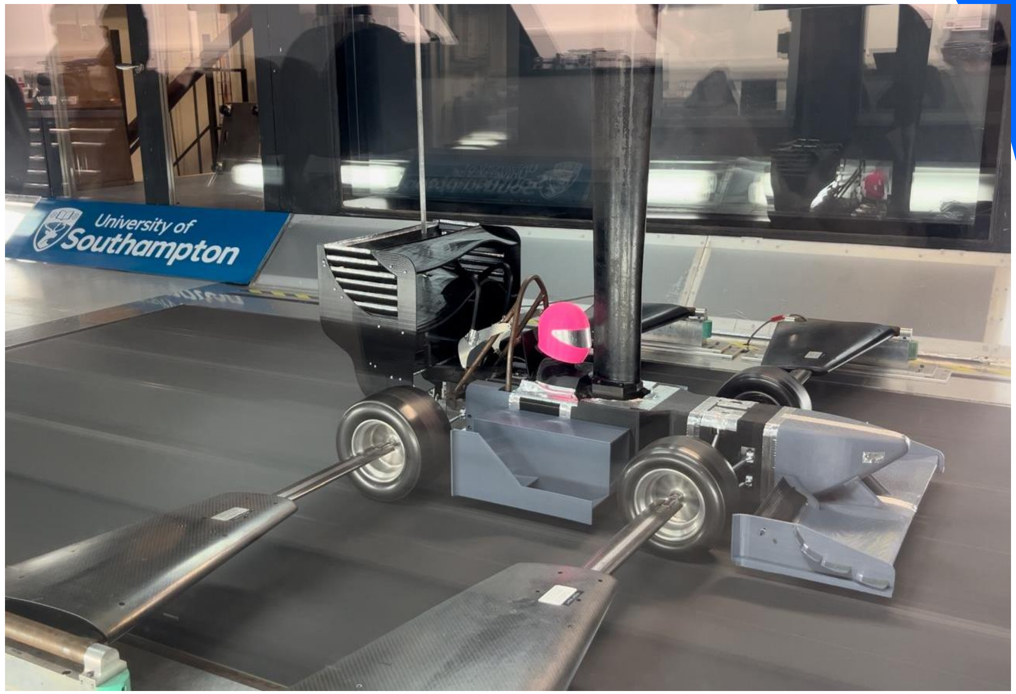
- **Assembly** of model and mounting the model to the balance.
- All parts were 3D printed and assembled before testing.
- **Challenges** faced:
  - Fitting internal balance inside model's spine.
  - Bodywork height required minor modifications for internal balance accommodation.
- Gaps between bodywork pieces sealed with aluminium tape.
- Assembly incomplete by end of day due to modifications for internal balance.





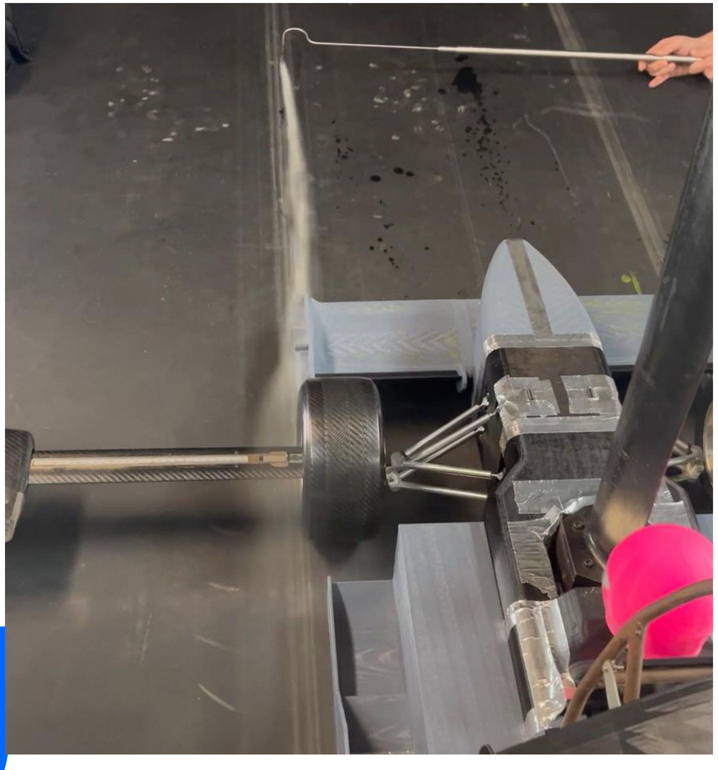
Wind Tunnel Testing – Day 2

- **Assembly** completed.
- **Challenges** faced:
  - Control arms were omitted in suspension design.
  - Lack of control arms would allow wheels to move during testing, affecting data accuracy.
  - **Wheels-off** testing was conducted instead.
- **Tests** conducted:
  - **Heave** test for ride heights 15-45 mm.
  - **Pitch** test for front ride height 25mm, and the rear heights 25-45 mm.
  - Varying **FW angles** from 20-50 degrees, for ride heights 15-45 mm.



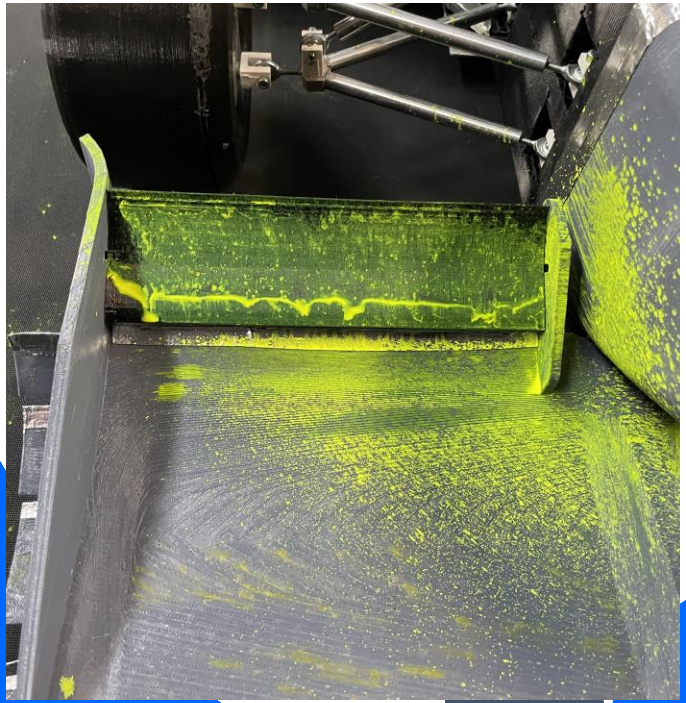
Wind Tunnel Testing – Day 3

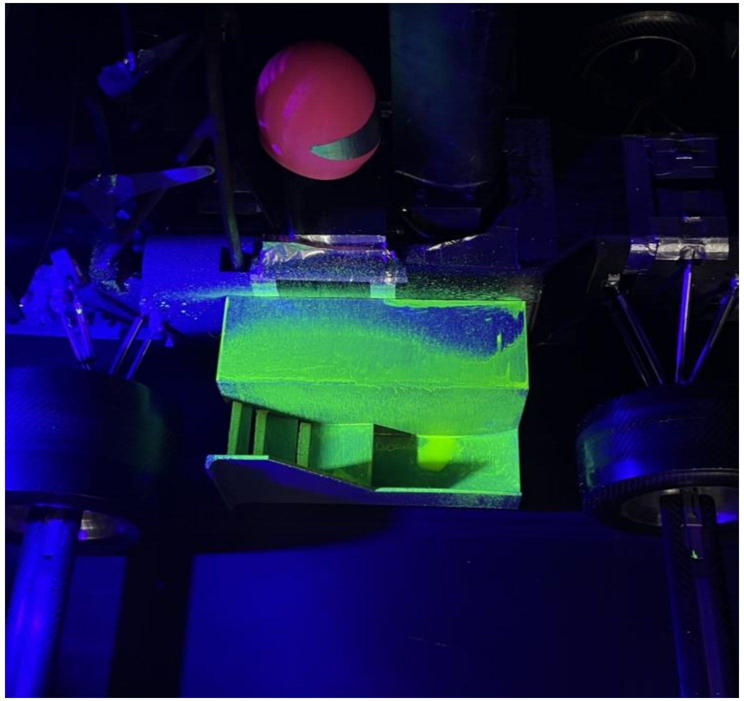
- Smoke visualisation and flow-vis tests conducted.
- A smoke machine fitted with a wand was employed to visualise flow patterns around the model.

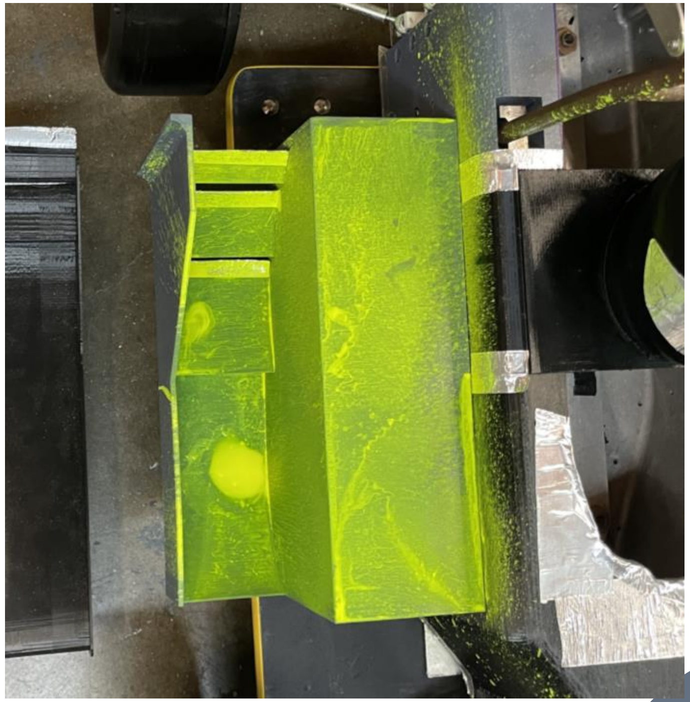


Wind Tunnel Testing – Day 3

- Flow-Vis dye was applied to front wing and sidepods to observe flow direction and boundary layer separation, aided by ultraviolet light.
- However, flow pattern on surface not properly observed due to texture of 3D printed material.

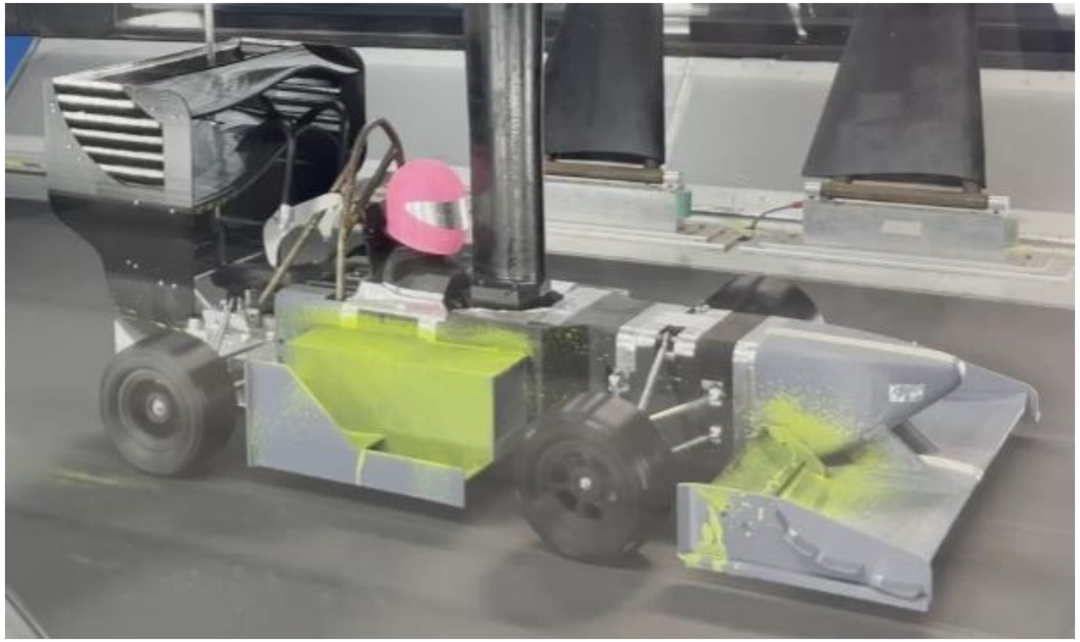






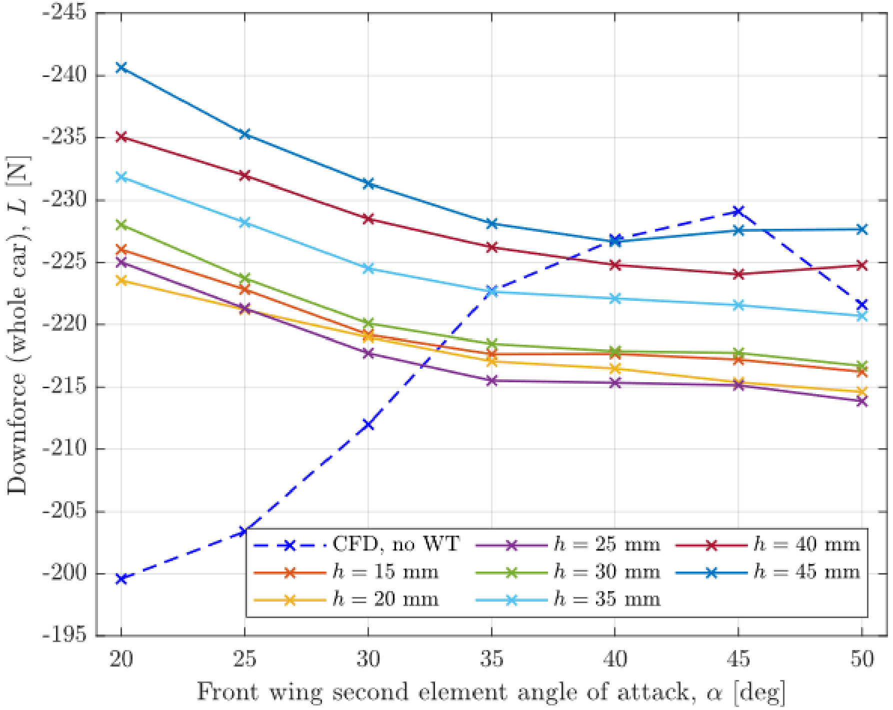
Wind Tunnel Testing – Day 3

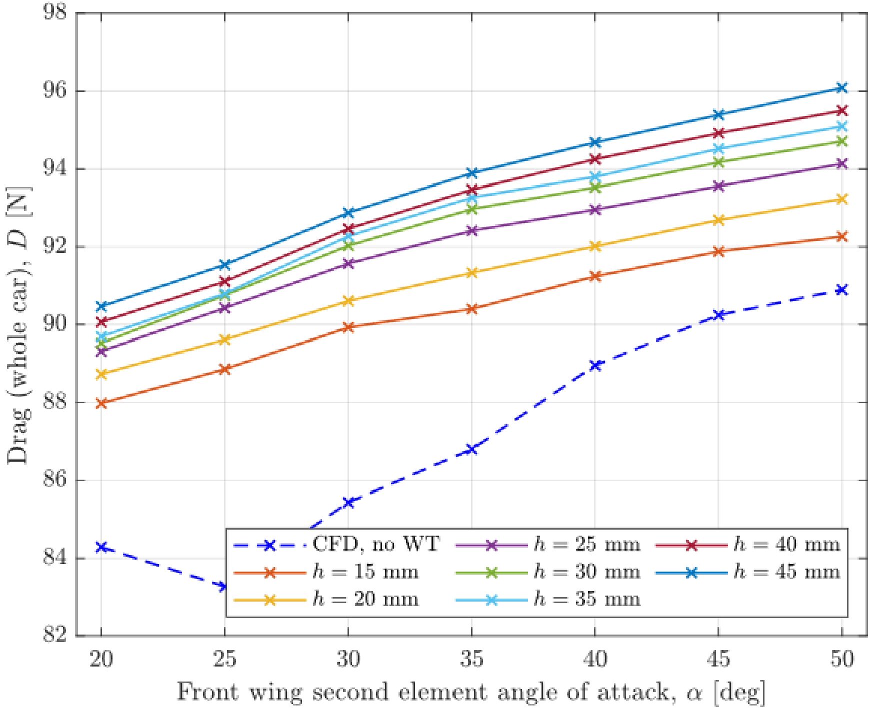
- **Wheels-on** testing conducted at low wind and road speeds.
- Temporary solution devised to lock wheels in place for wheels-on testing.
- Suspension held up throughout testing, validating new design for different ride heights.



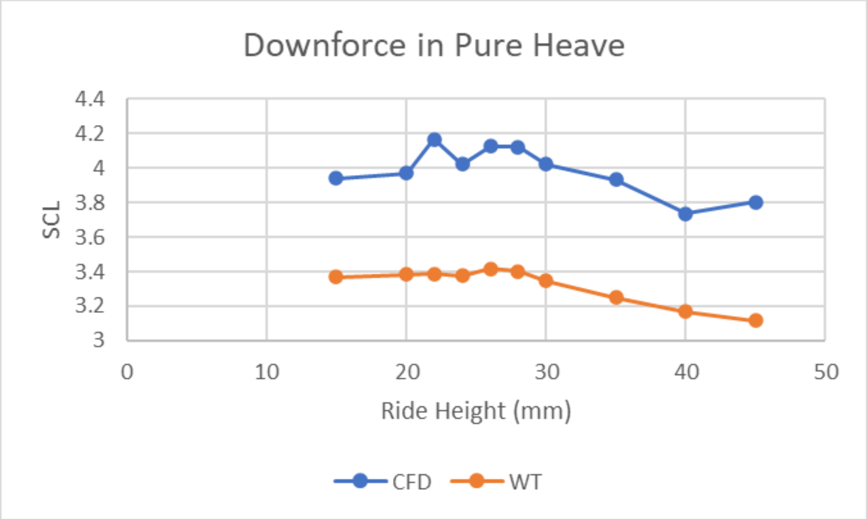
Wind Tunnel Testing - Results

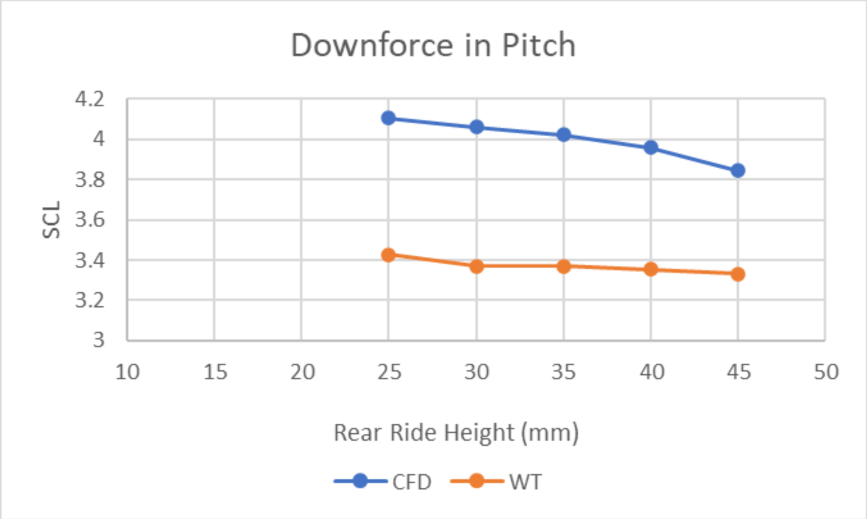
- The wind tunnel results mirrored the CFD findings.
- The drag data exhibited excellent accuracy, with errors as minimal as 0.5% at high velocities.
- The validation affirms the accuracy of our CFD analysis, though there's room for further enhancements.

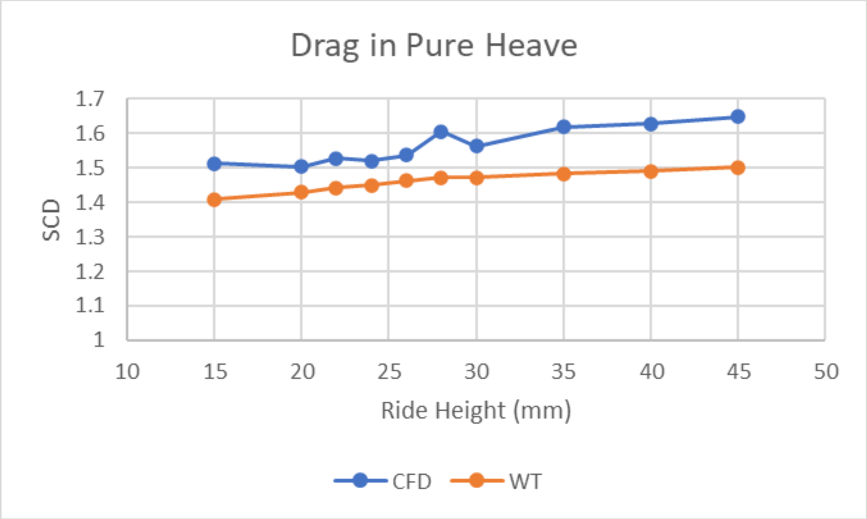


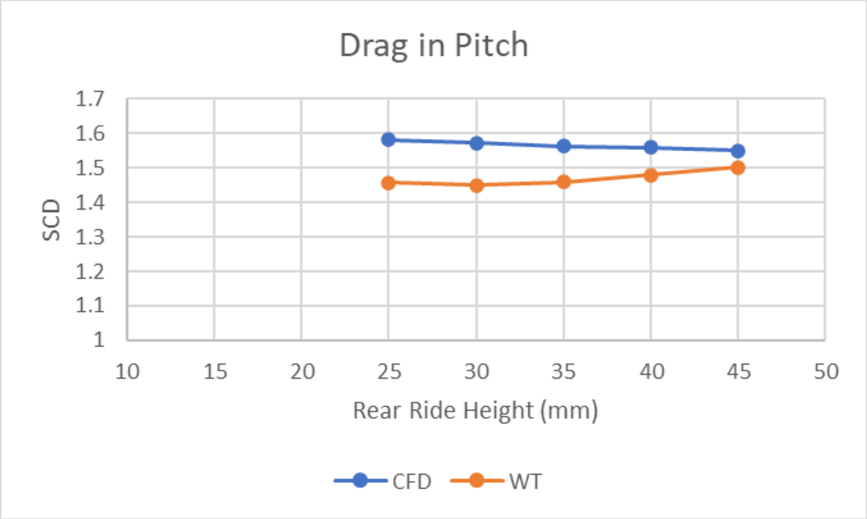


Wind Tunnel Testing - Results





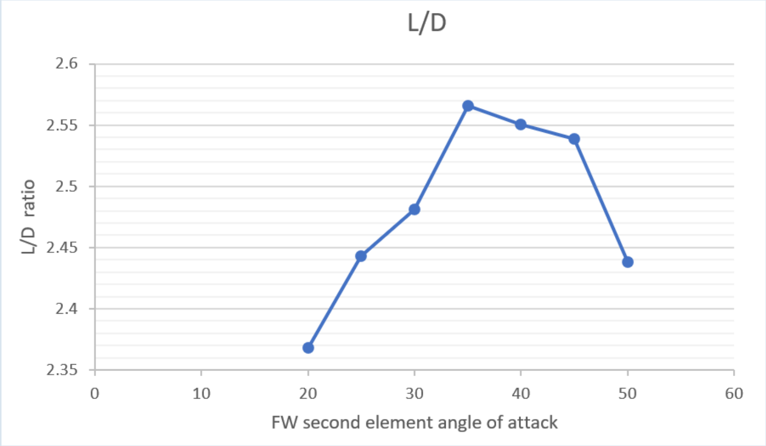




CFD Results

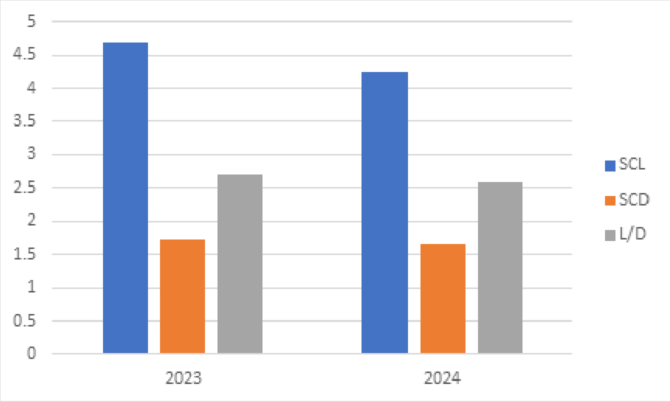
- FW analysis:
  - Highest downforce at 45 degrees.
  - Best L/D at 35 degrees.
  - FW SCL exceeds 2023 model at 45 degrees.

FW second element angle	Lift (N)	Drag (N)	L/D
20	-399.184	168.576	2.36797
25	-406.8	166.538	2.4427
30	-423.986	170.868	2.48136
35	-445.426	173.596	2.56587
40	-453.706	177.914	2.55014
45	-458.232	180.49	2.53883
50	-443.204	181.794	2.43795



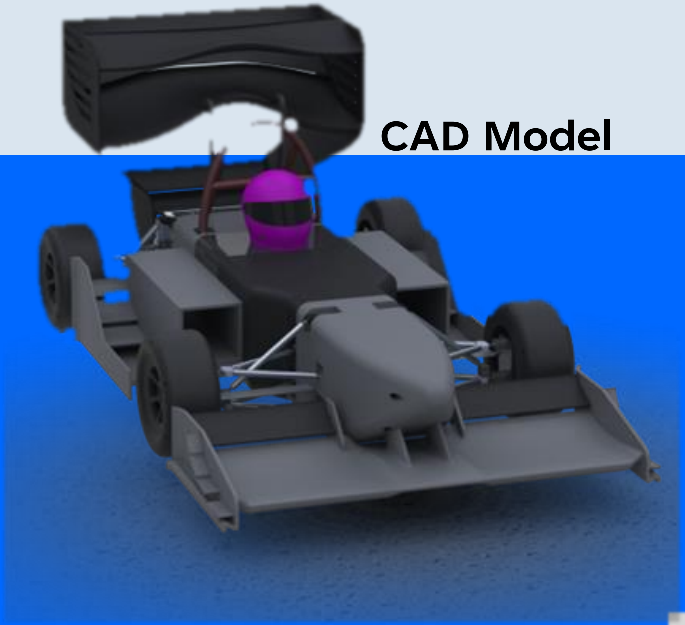
CFD Results

- Whole car:
  - Downforce was 9.75% lower than 2023 model.
  - Drag was 6.09% lower compared to 2023 model.

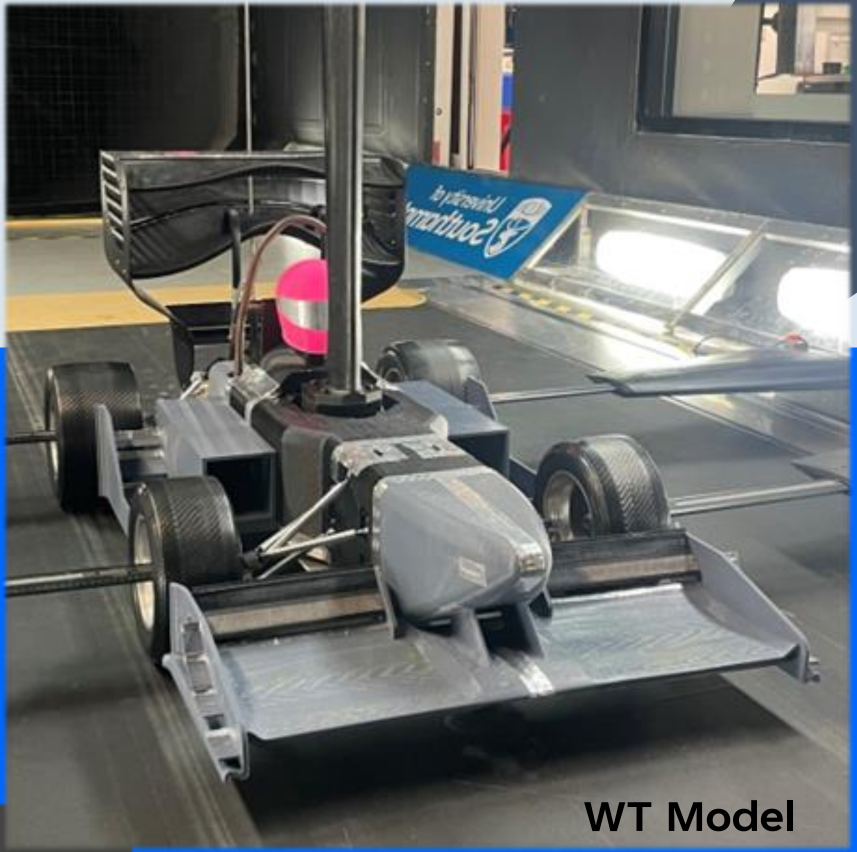


					Whole car		Front wing		Rear wing		Sidepods		Underfloor		Chassis	
Model	Lift (N)	Drag (N)	%FR	L/D	SCL	SCD	SCL	SCD	SCL	SCD	SCL	SCD	SCL	SCD	SCL	SCD
2023	-493.54	184.852	64.858	2.67	-4.634	1.736	-2.098	0.326	-1.758	0.716	-0.748	0.106	-0.696	0.046	0.454	0.344
2024	-445.42	173.596	66.33	2.567	-4.182	1.63	-2.018	0.278	-1.726	0.738	-0.226	0.128	-0.63	0.052	0.264	0.278

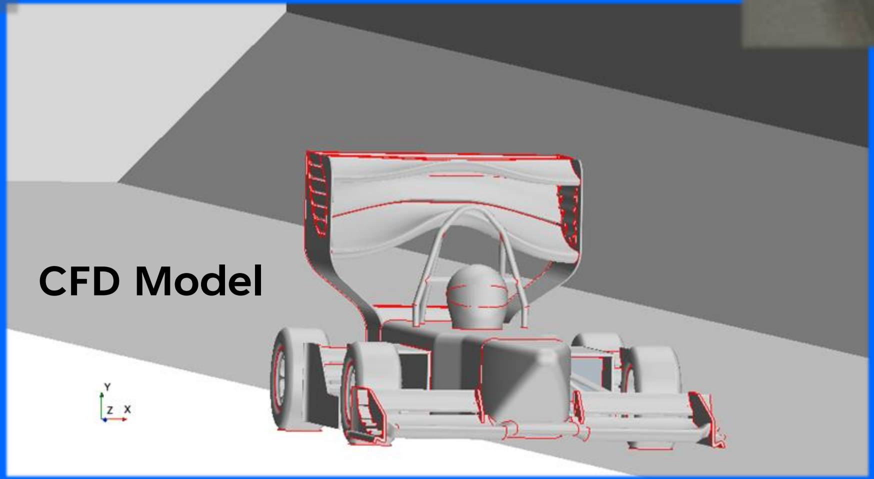
Final Design Proposal



CAD Model



WT Model



CFD Model

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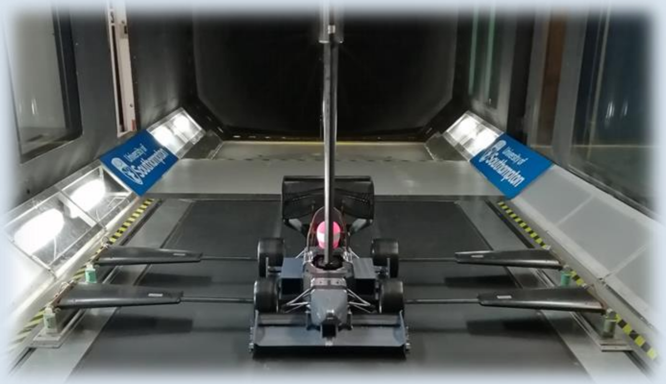
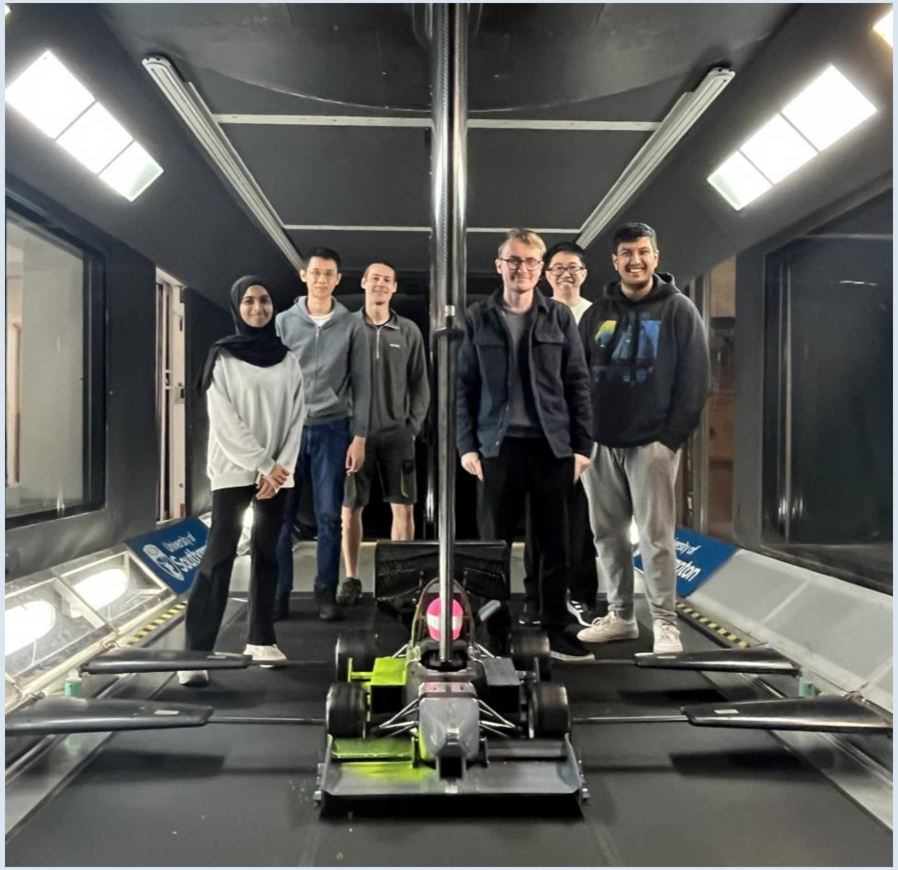
Future Work



- CFD: Vital for validation but faces challenges like run quality and hardware specs.
- Manufacturing: Suggestions include wheel redesign, rear wing enhancement, and surface finish improvements.
- Materials: Explore alternatives like PLA, ABS, CFRP, and titanium alloys for better performance.
- Active suspension: Integration can improve ride dynamics and steering control for accurate simulations.
- Active aerodynamics: Implementing features like turning vanes and DRS offers precise aerodynamic control.

Summary



- Increased robustness and reliability of the WT model while increasing the aerodynamic performance.
- Achieved 90% of the downforce as 2023 model with 6.09% lower drag and produced almost the same lap time.
- Increased cooling capacity by adding sidepods to the model.

Thank you

Q&A