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Active Rear Wing System for the Morgan Plus Four

Group Design Project (ACHA5014)

Group 2

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1 Introduction (AC)

During this project, we have been tasked with the conception and design of a fully active rear wing system for the Morgan Plus Four. The aim is to develop a system that dynamically adjusts to optimise aerodynamic performance, providing both downforce for enhanced cornering stability and reduced drag for improved top speed. The project covers every aspect of this system, from the selection of a wing profile to the design of mounting systems, control systems, and the creation of the code to manage its functionality. Additionally, we will conduct simulations to predict lap times, comparing base runs and the final iteration data to evaluate improvements in lap time on a virtual version of Llandow and Pembrey Circuits.

To ensure efficiency and a high-quality outcome, the team has been divided into specialised departments, with each group focusing on different areas of the design and development process. This structured approach enables us to work collaboratively while maintaining a focus on producing the best-engineered solution.

The design process is constrained by several regulations, which we carefully reviewed and analysed to ensure compliance. Notably, we paid particular attention to regulations regarding the maximum mass, size, and points of movement for the rear wing. These regulatory constraints shaped our design decisions, pushing us to innovate within the established limits. By interpreting specific wording in the regulations, we identified opportunities to optimise the wing's performance without violating any rules.

The rear wing plays a critical role in a vehicle's aerodynamic performance, particularly in track-specific applications, where downforce and stability during cornering are vital. However, these benefits come at the expense of increased drag, which can reduce top speed. The active rear wing system we are designing aims to address this issue by adjusting the wing's position based on real-time data, thereby enhancing performance for various track conditions. By dynamically adjusting the wing's angle and vertical position, we hope to optimise both downforce and drag in different racing scenarios, making it a valuable addition to the Morgan Plus Four.

During this project, we followed the project lifecycle structure, ensuring that each phase was systematically approached, from initial research and design to prototyping, testing, and final iterations. This structured approach ensures that the system is both functional and efficient, delivering a solution that adheres to the project's requirements and regulations while pushing the boundaries of engineering innovation.

2 Initiation (AC)

There are multiple key steps to this project all shown in the flow chart below. Once the group had read the design brief and regulations, the first 2 meetings consisted mainly of brainstorming and the gathering of baseline data to create the first ideas. The designs will then be developed through various simulation processes, testing and further research before concluding on a final design, and then producing a scale prototype to portray the final concept.

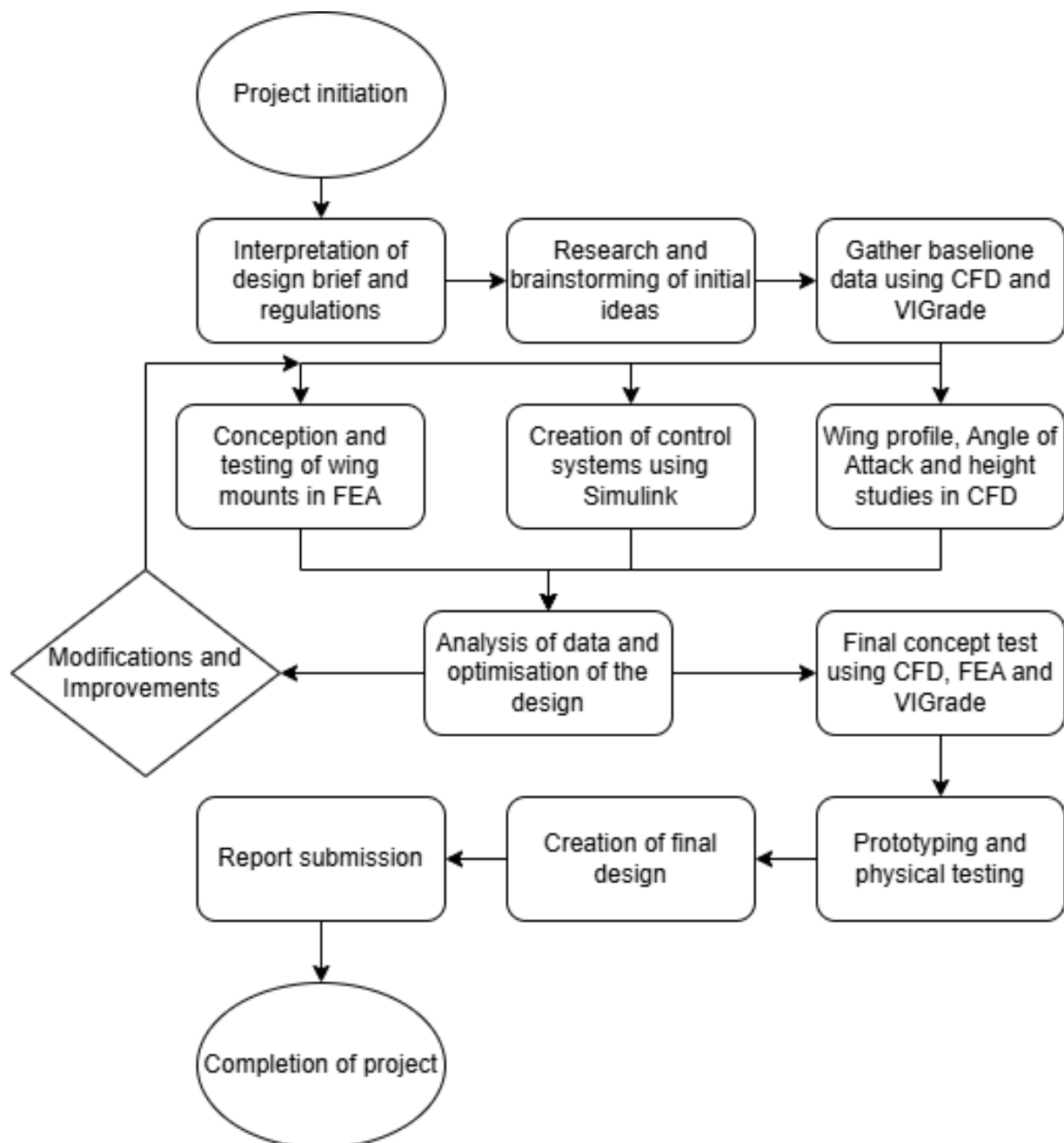


Figure 1 - Flow Chart of the main steps in the project

2.1 Aims and Objectives (AC)

2.1.1 Aims

1. **Design and Develop an Active Rear Wing System**

To design a functional active rear wing system that optimises aerodynamic performance through adjustable movement, improving downforce and reducing drag based on vehicle speed and conditions.

2. **Maximise Aerodynamic Efficiency**

To maximise aerodynamic efficiency by manipulating the wing's angle of attack and vertical position, ensuring optimal airflow for both high-speed and low-speed configurations, in compliance with regulatory constraints.

3. **Ensure Compliance with Regulations**

To ensure the active rear wing system complies with all relevant regulations, including mass, size, movement limitations, and other performance-related guidelines, while exploiting any ambiguities within the regulatory framework for performance gains.

4. **Minimise Weight and Cost**

To design the system with a focus on weight reduction and cost efficiency, adhering to the maximum mass constraint of 60kg and the theoretical budget of £10,000, while utilising university facilities to avoid labour costs.

5. **Optimise System Functionality and Reliability**

To develop a reliable and functional system that performs consistently over time, including the integration of sensors, actuators, and control systems for seamless wing adjustments during vehicle operation.

6. **Incorporate Simulation and Control Systems for Enhanced Performance**

To integrate virtual lap time data analysis from the simulation team and develop an activation mechanism designed by the Mechatronics and control systems team, ensuring the active rear wing dynamically adapts to different racing conditions and enhances vehicle performance.

2.1.2 Objectives

1. **Conduct Comprehensive Research and Feasibility Study**

- Perform a detailed review of regulations, vehicle specifications, and existing active wing systems.

- Identify potential design solutions based on aerodynamics, control systems, and available materials.
- 2. Create a Preliminary Design Concept**
- Develop an initial design concept for the active rear wing, including key components (wing profile, actuation mechanisms, materials, sensors).
 - Define the system's points of movement and determine the necessary adjustments to ensure optimal performance.
- 3. Develop and Analyse Aerodynamic Simulations**
- Use CFD (Computational Fluid Dynamics) to simulate airflow over the wing in different configurations and speeds.
 - Analyse the performance of the wing at different angles of attack and vertical positions, identifying the most effective configurations.
- 4. Collaborate with the Simulation Team**
- Work with the simulation team to gather virtual lap time data, using the data to refine the aerodynamic design of the wing.
 - Incorporate insights from virtual testing to continuously improve the performance of the wing system under various racing conditions.
- 5. Design and Prototype Actuation Mechanisms**
- Design the actuation system to allow the wing to adjust both vertically and change angle of attack.
 - Collaborate with the Mechatronics and control systems team to ensure the wing's activation is seamless, reliable, and responsive.
- 6. Prototype Testing and Evaluation**
- Build a physical prototype of the active rear wing system.
 - Conduct wind tunnel testing to validate the CFD simulations and assess the system's aerodynamic performance.
 - Test the actuation system for reliability, response time, and durability under various conditions.
- 7. Final Design Refinement**
- Refine the design based on testing feedback, focusing on optimisation of aerodynamic performance, weight reduction, and cost efficiency.

- Ensure the system meets all regulatory requirements, including the maximum mass, structural integrity, and movement constraints.

8. Prepare Technical Documentation and Presentations

- Document all design iterations, testing procedures, and results.
- Prepare a comprehensive technical report, including design justifications, performance data, and compliance with regulations.
- Create a final presentation summarising the project's outcomes and showcasing the developed active rear wing system.

2.2 Roles and Responsibilities (AC)

Table 1 - Table showing the roles and responsibilities of each group member

Name	Roles	Responsibilities
Alexander Cook	Project Manager Mechanical design	• Overseeing the proper running of the team. • Facilitating communication. • Keeping the team on schedule. • Preparing the report and presentations • Designing of the wing mounts for the structural team to conduct FEA. • Conception of the activation linkages incorporated within the wing mounts.
Nathan Evans	Aerodynamics	• Selection of the wing profile. • Angle of attack study to conclude on the working window of the wing. • Development of the wing profile, including winglets and end plates.
Oliver Wilson	Aerodynamics	• Conduct height studies to determine the ideal height and vertical displacement of the wing assembly. • Collect and provide the aerodynamic data to simulation for lap time testing.
Dylan Brierley	Simulation	• Acquisition of baseline data in VI-Grade. • Running updated simulations using data from the aerodynamic studies. • Providing feedback to the aerodynamics team, helping to optimize the design. • Gain overall vehicle performance.
Alex White	Mechatronics and Control Systems	• Designing Simulink code to control the working scale model • Creating the circuitry and mechatronics to display the concept of the active rear wing.

Scott Holden	Mechatronics and Control Systems	• Researching suitable mechatronics for the full-scale design. • Providing dimensions for the design and incorporation of the mechatronics into the mounts.
Matthew Stark	Structural and Materials	• Researching all suitable materials for the mounts and wing profile. • Helping with the decision of most suitable material.
Conor Jenkins	Structural and Materials	• Conducting Finite Element Analysis of the wing mount designs and scale model • Communicating results to the Mechanical Design team to improve the wing mount designs.

2.3 Project constraints (AC)

The project has been established with a range of constraints that must be carefully adhered to throughout the design process. A maximum budget of £10,000 has been set, although this applies solely to the theoretical design, as it is assumed that production will take place using the university's facilities, thereby eliminating any labour costs. In addition to financial limitations, the final full-scale design must not exceed a total mass of 60kg, ensuring that weight remains a key consideration in both material selection and structural design.

Further constraints arise from the size of the wind tunnel, meaning that appropriate scaling must be determined to ensure accurate and representative testing. Beyond these physical and financial limitations, the project is also governed by a strict time constraint, with a total duration of 25 weeks in which all stages, from initial concept development through to final evaluation must be completed. Alongside these factors, the design must comply with a set of regulations, which will influence various aspects of the development process.

3 Planning (AC)

3.1 Gantt Chart (AC)

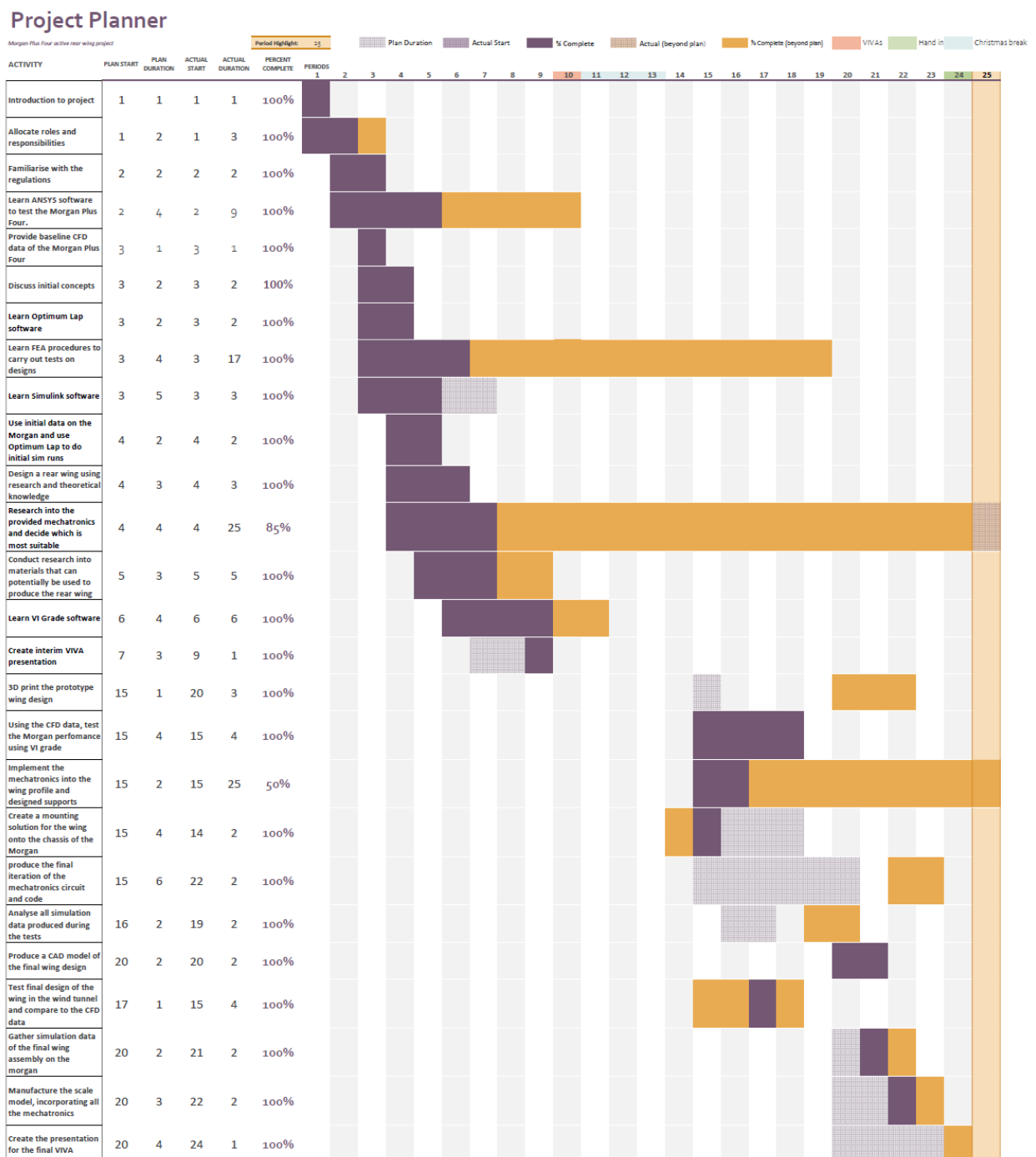


Figure 2 - Group Gantt Chart

3.2 Gateways and Milestones (AC)

During the first two meetings the group planned out the project gateways and milestones, dates were then associated to each of them to ensure the project ran smoothly and stuck to the strict timeline.

Table 2 - Table showing the Gateways and Milestones of the project

Gateways	Milestones	Associated planned completion dates
	Given the technical brief on the assigned project	30/09/2024
	Assignment of all roles within the project	07/10/2024
Familiarise group members with ANSYS software	Completed Baseline CFD simulation on the Morgan to gain data for vehicle simulation.	10/10/2024
Familiarise group members with VIGrade and OptimumLap software	Completed vehicle simulation test of the Morgan on a track to attain baseline performance.	27/10/24
Produce a series of rear wing concepts on CAD through research and analysis. Complete CFD analysis.	Finalised rear wing concept designed on CAD	17/11/2024
Analyse the performance of the rear wing concepts and conclude which concept provides the best confidence	Complete CFD of the chosen wing profile	24/11/2024
Produce PowerPoint consisting of the required research and work conducted throughout the project	Interim VIVA	10/12/2024 or 11/12/2024
Discuss mounting solutions/ concepts. Using FEA determine which produces the greatest strength to weight ratio.	Run FEA on the chosen wing profile and mounts	01/12/2025
Implement the final concept of the rear wing onto the Morgan model and complete CFD to gain data on the aerodynamic performance.	Attain data/ results of the chosen wing profile on the Morgan Plus Four.	30/01/2025
Using CAD files produced	Produce a prototype to test in the wind tunnel	09/02/2025
Decide on what mechatronics will be used and how they will be implemented.	Complete a wind tunnel test of the rear wing concept. Use the data gathered from the test and compare against CFD results.	16/02/2025
Implementing simulation data into the control system coding	Finalise control system	27/02/2025
Using the CAD files produced, convert the files to STL file and import into 3D printing software ready for printing.	Develop prototype and manufacture using additive manufacturing processes.	16/03/2025
Produce PowerPoint summarising the research and work completed throughout the project.	Final VIVA	01/04/2025 or 02/04/2025
	Upload final write up document	30/03/2025 @ 10pm

4 Execution

4.1 Initial concepts (AC)

Over the first two to three meetings the team conducted brainstorming like sessions, looking at varying design ideas along with studying the regulations to produce proposals for the design and incorporation of the wing, mounts and mechatronics that would be both legal and of maximum efficiency.

Focusing on the regulations we searched for 'loopholes' to help push the boundaries and increase the effectiveness of the active rear wing. We directed our attention to the wording in Section 5 of the regulations when discussing the vertical position of the wing profile to insure clean airflow over its surface.

The regulations state:

Positioning:

- The wing must not project higher than the maximum roofline of the vehicle when viewed from a side orientation at **static ride height**.

Emphasising on the 'static ride height' stated in this phrase we concluded that once a vehicle is in motion, the ride height is consistently changing with every bump, change of velocity and direction. This is all due to the Morgan being fitted with suspension and therefore the chassis moving separately to the axle and once moving the ride height is no longer considered static. This would allow us, once the Morgan is in motion, to extend the wing mounts vertically beyond its maximum roofline and allow the wing profile to sit in uninterrupted, clean flowing air above the car.

Actuation Points:

- The wing can be actuated by no more than 2 physical actuation points.

The regulations state that the wing may feature two points of movement. However, it is unclear whether this applies per axis or in general. The lack of detailed definition opens the door for more flexibility in design. Our approach is to implement movement along two axes: one axis to tilt the wing at varying degrees along its length, and the second to move the wing vertically. The vertical movement would allow the wing to rise for better performance, or lower behind the vehicle to reduce drag for maximum speed configurations.

Endplates:

- End plates are acceptable and may be developed for aerodynamic performance improvement.

- End plates must fit within a bounding box no larger than 310mm longitudinally, 250mm vertically, 12mm laterally relative to the vehicle orientation.

Further into the design process, the concept of winglets was introduced. Inspired by aircraft wing designs, this would alter the profile of the wing at different angles and therefore are not considered to be an endplate. The regulations permit the use of endplates but restricts the size, and using winglets would be considered a legal modification, as they are an extension to the wing profile and would be considered as a twisted wing configuration which is permitted within the regulations. This helps change the aerodynamic characteristics of the wing in a controlled and regulated manner. This design element allows us to optimise airflow at the wing's ends, improving overall aerodynamic performance.

4.2 Aerodynamics (NE)

4.2.1 Introduction (NE)

This report outlines the aerodynamic development undertaken as part of a group design project focused on implementing an active rear wing for the Morgan Plus Four. Due to the vehicle's inefficient aerodynamic profile—characterised by a high drag coefficient and minimal downforce—the project aimed to research, test, and optimise wing designs to enhance performance. A wing study was conducted using both Computational Fluid Dynamics (CFD) and wind tunnel testing to assess lift, drag, and efficiency across various aerofoil profiles and angles of attack (AOA). These results guided the design of an actively controlled rear wing intended to improve aerodynamic balance, reduce drag, and increase downforce under high-speed or braking conditions. The report presents the methodology, data analysis, and further development required to meet these objectives within a realistic engineering context.



Figure 3 Shows the Morgan Plus Four used throughout the project to apply the active rear wing system.

4.2.2 Wing Study - Research (NE)

The wing study forms the foundation of the active rear wing system by providing essential insight into how different profiles behave across varying angles of attack. This understanding is key to making informed design decisions. Given the Morgan Plus Four's high drag and limited downforce, aerodynamic optimisation is vital for achieving stable and effective performance improvements.

Table 3 As this project is heavily reliant on aerodynamic performance research into a range of wing profiles was conducted.

Aerofoil	Key Features	Advantages	Disadvantages	Figure
Selig 1223 (S1223) (occamsracers 2023)	High-lift, gradual stall, high drag at high AOA, used in motorsport and UAVs.	Gradual stall behaviour, high lift at low Reynolds numbers.	High drag at high AOA, reducing efficiency.	
Eppler 420 (E420) (occamsracers 2023)	Balanced lift-to-drag, moderate lift, low drag, good stall behaviour.	Balanced lift-to-drag ratio, good stall behaviour, low drag.	Moderate lift, not as high as extreme high-lift aerofoils.	

Church Hollinger (CH-10) (occamsracers 2023)	Motorsport-oriented, high downforce, lower drag, delayed flow separation.	High downforce, lower drag than extreme high-lift aerofoils, delayed flow separation.	Not as high-lift as extreme profiles like S1223.	
Wortmann FX 74-CL5-140	Good lift-to-drag ratio, stable aerodynamic performance, efficiency-focused.	Good lift-to-drag efficiency, stable aerodynamic performance.	Prioritizes efficiency over pure lift generation.	
NACA 6412 (MD. Safayet Hossain, Muhammad Ferdous Raiyan et al. 2014)	Symmetric, moderate camber, stable and predictable.	Stable and predictable performance due to symmetry.	Less lift compared to cambered aerofoils.	
NACA 4412	Higher lift than NACA 6412, early stall, increased drag at high AOA.	Good balance between lift and efficiency.	Early stall characteristics, increased drag at high AOA.	

4.2.3 Method of Experiment (NE)

4.2.3.1 Wing Study/Angle of Attack Investigation (NE)

Prior to CFD and wind tunnel testing it was important to ensure the same scale was used all throughout the study. When conducting wind tunnel testing or CFD simulations, matching the Reynolds (Re) Number is vital, failing to match Reynolds number can lead to incorrect aerodynamic predictions, affecting lift, drag, stall characteristics, and flow separation. Due to the size and limitations of the wind tunnel there were some constraints.

4.2.3.2 Wind tunnel Size (NE)

Due to the shape and size constraints of the wind tunnel, the wing model was limited to a span of 180 mm and a chord length of 193.75 mm (1:16 of full-scale wing). While the initial objective was to match Reynolds numbers with the full-scale concept, this was not achievable within the tunnel's capabilities. As a result, the decision was made to maximise the model size without strict adherence to Reynolds scaling. This approach improved force measurement resolution and reduced sensitivity to surface imperfections. Larger models also better replicate full-scale aerodynamic behaviour, particularly in relation to stall and flow separation. Blockage limits were carefully considered to minimise distortion of flow patterns and avoid overestimation of lift and drag or inaccurate pressure distribution.

4.2.3.3 Max Velocity (NE)

The wind tunnel is limited to 25m/s. When matching Re numbers, velocity can be increased to do so.

With the setup provided, the Re number for Full scale and wind tunnel is not possible without decreasing the size of the wing. When decreasing the wingspan/size it can influence the accuracy of the results. Additionally, the density of the fluid can be increased. This is typically done using water.

4.2.4 Computational Fluid Dynamics – Wing/Angle of Attack Study (NE)

1. Using Aerofoil tools select the coordinates to produce a 3D part in SolidWorks and convert it to a STEP file.
2. Using ANSYS R2021 set the workspace shown on the right. Geometry is used to create the domain. Linked with that is Fluent with meshing to solve the model. Results are then used to complete post analysis.
3. Using SpaceClaim prepare the domain for the meshing.
4. Label all faces in the domain to ensure boundary conditions can be applied correctly. Figure 21 illustrates the labeled domain.
5. Fluent with Meshing – Ensure the geometry has been imported. Begin by applying mesh size for Wing, Body of influence, domain and then create mesh.
6. Ensure the geometry has been described and that boundary conditions have been selected correctly.

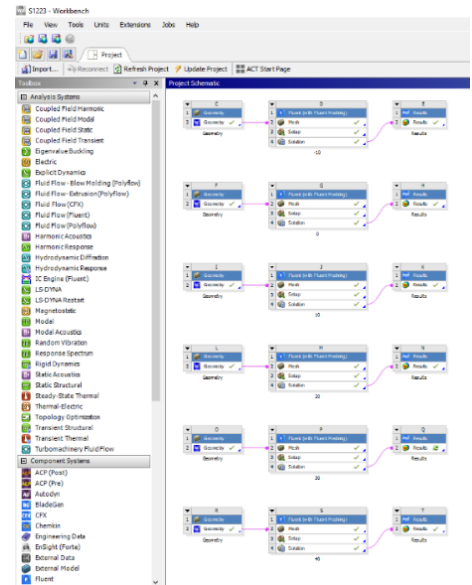


Figure 4 ANSYS R21 workspace layout for the wing study.

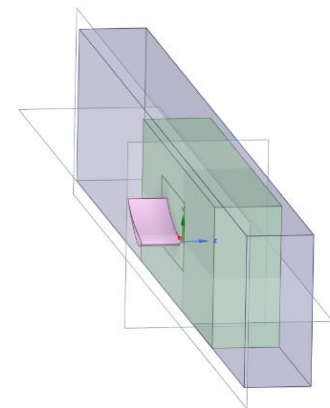


Figure 5 Shows the wind tunnel (half) replicated in CFD ready to be meshed. As the wing is symmetrical the results will be the same for half the model, this therefore reduces solving time.

Table 4 Shows the Mesh dimensions used throughout the wing study. The mesh size was

Face/ Body of Influence	Mesh Size
Wing	0.001
Inner BOI	0.01
Outer BOI	0.02
Maximum/ Domain	0.03

Boundary Layers	3
-----------------	---

7. Apply 3 boundary layers to the wing to represent the real world and create Polyhedra.



Figure 6 Shows the Polyhedra computed and ready to be solved in Fluent.

8. Solution – Ensure turbulence model selected is K-epsilon, Realizable and Non-Equilibrium Wall functions. This turbulence model was selected as a good balance between accuracy and efficiency. As the AOA increases K-omega SST is used to solve for lift and drag whilst providing a more accurate flow separation point (Ali, Hussain et al. 2024).
9. Once the solution has converged, ensure that methods have been changed from Standard and First order to Second order to improve accuracy of results.
10. Using results, analyse and produce visual graphics as seen below.

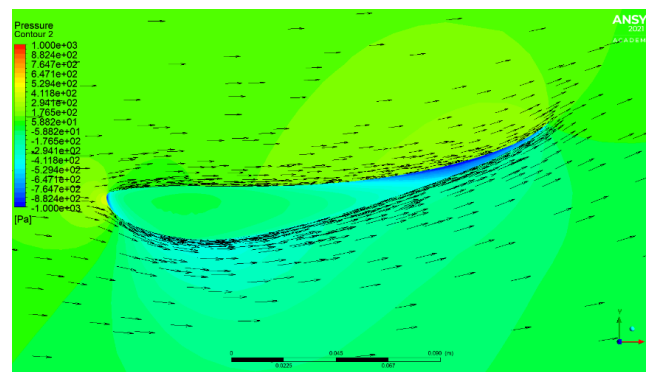


Figure 3 Shows the S1223 post solution with pressure contours and vectors to show the direction of airflow around the surfaces of the wing.

4.3 Wind Tunnel Testing – Wing/Angle of Attack Study (NE)

Wind tunnel tests were conducted throughout this project to validate the results produced from CFD. Through the results produced by CFD certain wing profiles were chosen. The profiles chosen to produce and test were; S1223, Eppler 420, CH-10.

1. 3D Print chosen wing profiles and bracketry required to mount wings within the wind tunnel.
2. Mount the wing in the wind tunnel, ensuring it is secure and there is no debris within the tunnel.
3. Using the voltage dial adjust until the fan is at the correct operating speed (20m/s). An Anemometer is used to measure the velocity of air passing through the tunnel.
4. Once the wing and fan have adjusted to testing conditions. Adjust the lift needle to provide a datum for testing (Lift force = 200g).
5. Adjust the AOA every 5 degrees and take note of Lift and drag force.

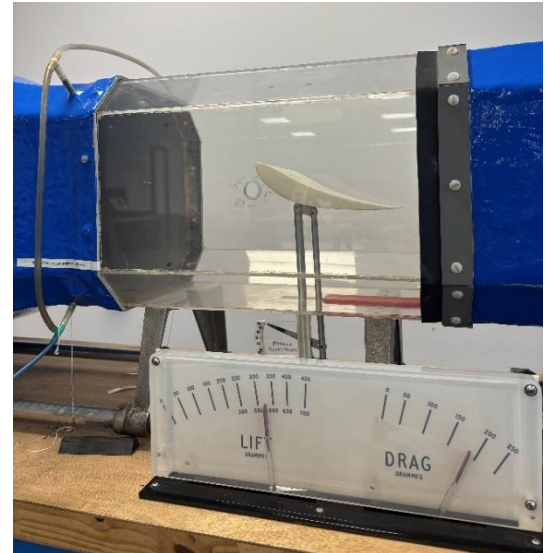


Figure 4 Eppler 420 being tested at -20 degrees.

4.3.1 Raw Data (NE)

4.3.1.1 Wind Tunnel Measure Results (NE)

Table 3 S1233 measured wind tunnel results.

Wing Tunnel Data - S1233				
AOA	Measured Lift Force (G)	Measured Drag Force (G)	Lift Force Data (G)	Drag Force Data (G)
-20	390	190	190	190
-15	470	145	270	145
-10	375	125	175	125
-5	255	120	55	120
0	200	110	0	110
5	-105	155	-105	155
10	-10	200	-210	200
15	5	260	-195	260
20	20	300	-180	300

Table 4 Eppler 420 measured wind tunnel results.

Wing Tunnel Data – E420				
AOA	Measured Lift Force (G)	Measured Drag Force (G)	Lift Force Data (G)	Drag Force Data (G)
-20	550	180	350	180
-15	545	155	345	155
-10	425	135	225	135
-5	320	120	120	120
0	200	120	0	120

5	125	160	-75	160
10	15	200	-185	200
15	30	255	-170	255
20	130	300	-70	300

Table 5 CH-10 measured wind tunnel results.

Wing Tunnel Data – CH-10				
AOA	Measured Lift Force (G)	Measured Drag Force (G)	Lift Force Data (G)	Drag Force Data (G)
-20	500	160	300	160
-15	475	125	275	125
-10	380	105	180	105
-5	285	90	85	90
0	200	100	0	100
5	75	140	-125	140
10	-15	175	-215	175
15	-100	275	-300	275
20	-30	330	-170	330

4.3.2 Results/Data (NE)

4.3.2.1 Wind Tunnel – Data (NE)

Table 6 Shows the wind tunnel data for the S1223.

Wing Tunnel Data - CH-10												
AOA	Lift Force Measured (G)	Measured Drag Force (G)	Lift Force Data (G)	Drag Force Data (G)	Lift Force (kg)	Drag Force (kg)	Lift Force (N)	Drag Force (N)	Lift Coefficient	Drag Coefficient	Inverse Lift	Efficiency
-20	500	160	300	160	0.3	0.16	2.94	1.57	0.21	0.12	-0.21	-1.80
-15	475	125	275	125	0.275	0.13	2.70	1.23	-0.20	0.09	0.20	2.16
-10	380	105	180	105	0.18	0.11	1.77	1.03	-0.27	0.08	0.27	3.47
-5	285	90	85	90	0.085	0.09	0.83	0.88	-0.34	0.07	0.34	5.11
0	200	100	0	100	0	0.10	0.00	0.98	-0.40	0.07	0.40	5.44
5	75	140	-125	140	-0.125	0.14	-1.23	1.37	-0.49	0.10	0.49	4.78
10	-15	175	-215	175	-0.215	0.18	-2.11	1.72	-0.56	0.13	0.56	4.34
15	-100	275	-300	275	-0.3	0.28	-2.94	2.70	-0.62	0.20	0.62	3.07
20	-30	330	-170	330	-0.17	0.33	-1.67	3.24	-0.53	0.24	0.53	2.17

Table 7 Shows the wind tunnel data for the Eppler 420.

Wing Tunnel Data - S1233												
AOA	Measured Lift Force (G)	Measured Drag Force (G)	Lift Force Data (G)	Drag Force Data (G)	Lift Force (kg)	Drag Force (kg)	Lift Force (N)	Drag Force (N)	Lift Coefficient	Drag Coefficient	Inverse Lift	Efficiency
-20	390	190	190	190	0.19	0.19	1.87	1.86	0.39	0.39	-0.39	-1.01
-15	470	145	270	145	0.27	0.145	2.66	1.42	0.15	0.30	-0.15	-0.51
-10	375	125	175	125	0.175	0.125	1.72	1.23	-0.04	0.26	0.04	0.16
-5	255	120	55	120	0.055	0.12	0.54	1.18	-0.29	0.24	0.29	1.18
0	200	110	0	110	0	0.11	0.00	1.08	-0.40	0.22	0.40	1.78
5	-105	155	-105	155	-0.105	0.155	-1.03	1.52	-0.61	0.32	0.61	1.93
10	-10	200	-210	200	-0.21	0.2	-2.07	1.96	-0.83	0.41	0.83	2.03
15	5	260	-195	260	-0.195	0.26	-1.92	2.55	-0.80	0.53	0.80	1.51
20	20	300	-180	300	-0.18	0.3	-1.77	2.94	-0.77	0.61	0.77	1.26

Table 8 Shows the wind tunnel data for the CH-10.

Wing Tunnel Data - Eppler 420												
AOA	Measured Lift Force (G)	Measured Drag Force (G)	Lift Force Data (G)	Drag Force Data (G)	Lift Force (kg)	Drag Force (kg)	Lift Force (N)	Drag Force (N)	Lift Coefficient	Drag Coefficient	Inverse Lift	Efficiency
-20	550	180	350	180	0.35	0.18	3.44	1.77	0.32	0.37	-0.32	-0.87
-15	545	155	345	155	0.345	0.155	3.40	1.52	0.31	0.32	-0.31	-0.98
-10	425	135	225	135	0.225	0.135	2.21	1.32	0.06	0.28	-0.06	-0.22
-5	320	120	120	120	0.12	0.12	1.18	1.18	-0.15	0.24	0.15	0.61
0	200	120	0	120	0	0.12	0.00	1.18	-0.40	0.24	0.40	1.63
5	125	160	-75	160	-0.075	0.16	-0.74	1.57	-0.55	0.33	0.55	1.68
10	15	200	-185	200	-0.185	0.2	-1.82	1.96	-0.78	0.41	0.78	1.91
15	30	255	-170	255	-0.17	0.255	-1.67	2.50	-0.75	0.52	0.75	1.44
20	130	300	-70	300	-0.07	0.3	-0.69	2.94	-0.54	0.61	0.54	0.88

Table 9 Wing dimensions used to calculate lift and drag coefficient.

	mm	Meter
Cord Length:	193.75	0.19375
Span:	180	0.18

Equation 1 shows the equations that were used to convert the forces acting on the wing surface to coefficients throughout wind tunnel testing.

$$C_L = \frac{\text{Lift Force (N)}}{\frac{1}{2} \times \rho V^2 \text{Area (M)}}$$

$$C_D = \frac{\text{Drag Force (N)}}{\frac{1}{2} \times \rho V^2 \text{Area (M)}}$$

$$\text{Efficiency} = \frac{C_L}{C_D}$$

4.3.2.2 Computational Fluid Dynamics (CFD) – Data (NE)

Table 10 Selig 1223 CFD results.

Selig 1223						
AOA	Lift Coefficient	Drag Coefficient	Force produced by lift (N)	Force produced by Drag (N)	Inverse Lift Coefficient	Efficiency
-20	0.33	0.41	2.10	1.94	-0.33	-0.82
-10	-0.05	0.22	-0.31	0.79	0.05	0.21
0	-0.49	0.22	-3.24	0.81	0.49	2.20
10	-1.02	0.37	-6.68	1.76	1.02	2.76
20	-0.80	0.58	-10.36	3.64	0.80	1.38

Table 11 Eppler 420 CFD results.

Eppler 240						
AOA	Lift Coefficient	Drag Coefficient	Force produced by lift (N)	Force produced by Drag (N)	Inverse of Lift Coefficient	Efficiency
-20	0.33	0.31	2.07	1.96	-0.33	-1.06
-10	0.03	0.23	0.19	1.44	-0.03	-0.13
0	-0.42	0.19	-2.82	0.76	0.42	2.22
10	-0.93	0.30	-6.09	1.61	0.93	3.09
20	-0.59	0.55	-9.86	3.48	0.59	1.06

Table 12 CH-10 CFD results.

CH-10						
AOA	Lift Coefficient	Drag Coefficient	Force produced by lift (N)	Force produced by Drag (N)	Inverse Lift Coefficient	Efficiency
-20	0.32	0.15	2.03	1.97	-0.32	-2.09
-10	-0.24	0.11	0.02	0.93	0.24	2.09
0	-0.44	0.08	-2.95	0.75	0.44	5.22
10	-0.64	0.17	-6.25	1.62	0.64	3.76
20	-0.58	0.29	-9.71	3.39	0.58	1.98

4.3.3 Analysis (NE)

4.3.3.1 Wing study – Data/results (NE)

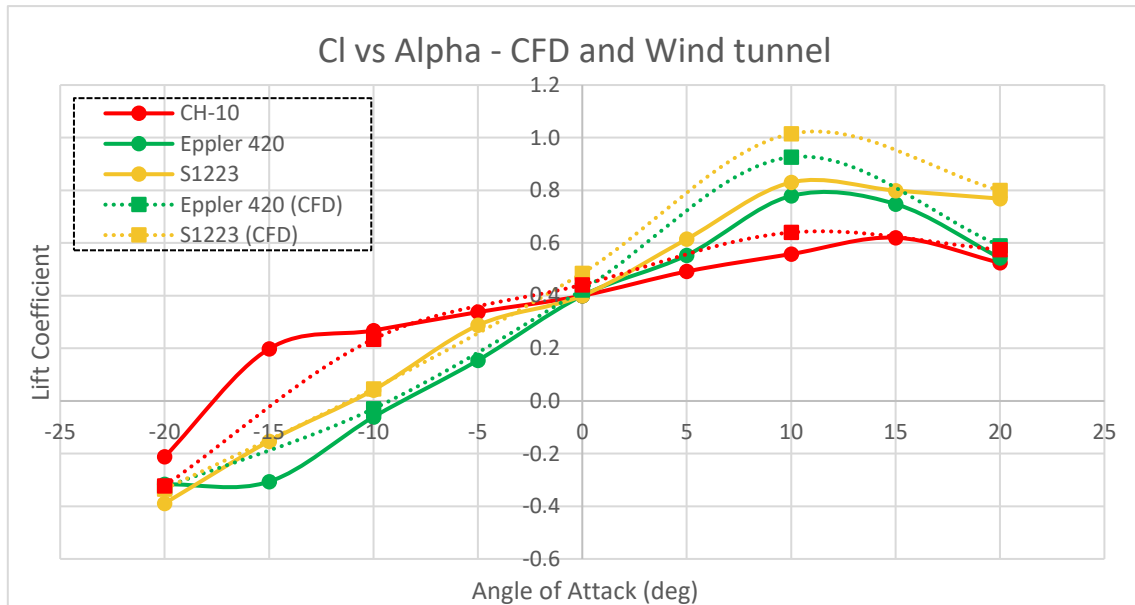


Figure 5 Shows the Lift Coefficient against AOA calculated through CFD and wind tunnel testing for S1223, Eppler 420 and CH-10.

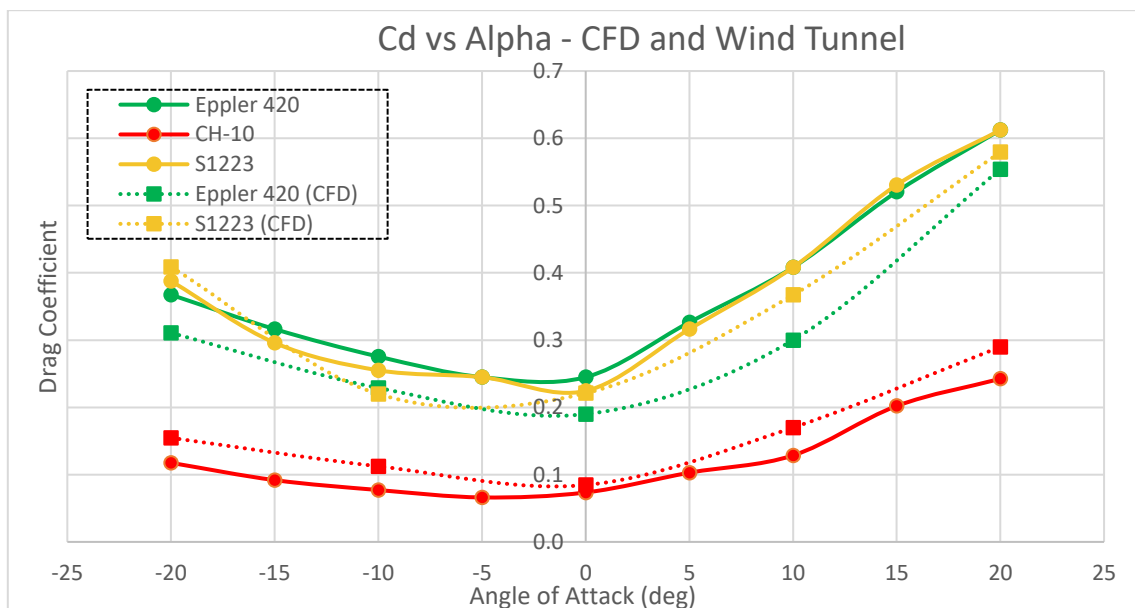


Figure 6 Shows the Drag Coefficient against AOA calculated through CFD and wind tunnel testing for S1223, Eppler 420 and CH-10.

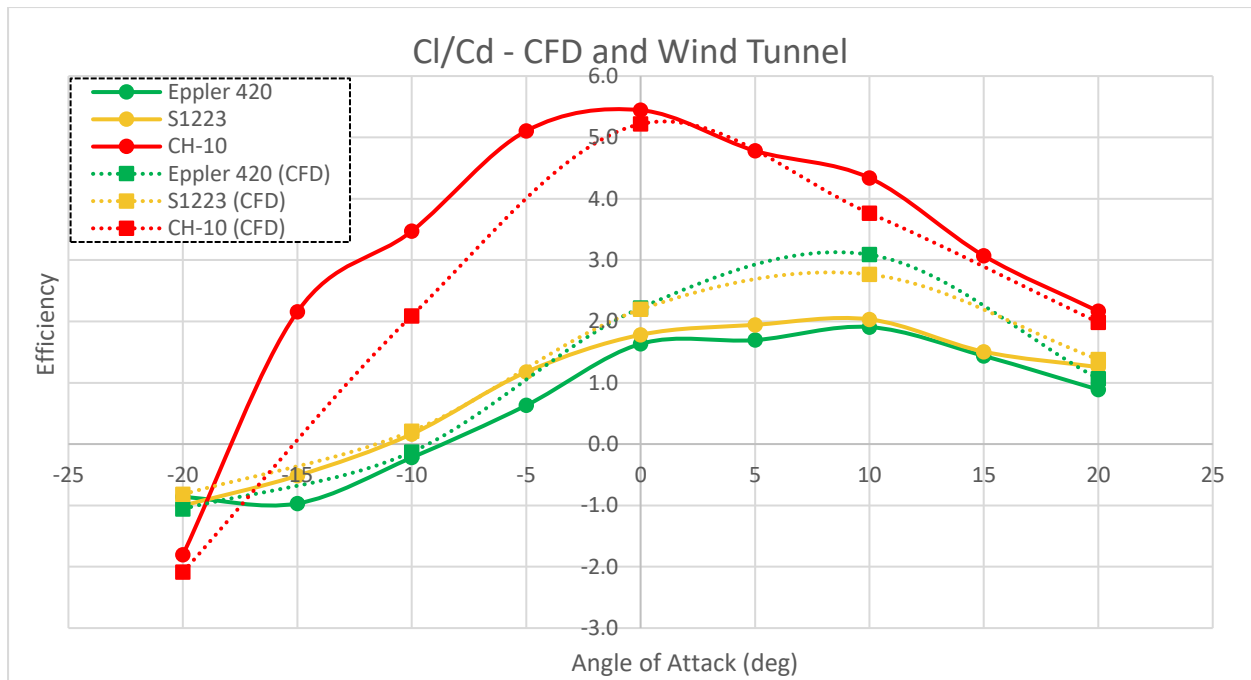


Figure 7 Shows the Efficiency against AOA calculated through CFD and wind tunnel testing for S1223, Eppler 420 and CH-10.

Figure 5 shows that as AOA increases so does lift coefficient until wing stall. There are distinct regions on the graph. The linear region shows the lift coefficient increasing with AOA. The Non-linear region – pre stall, between 7° and 12° degrees shows lift coefficient increasing however it is not linear, this shows flow separation has begun. Flow separation is caused by the boundary layer detaching from the surface of the wing, this is due to the adverse pressure gradient which increases drag and decreases lift therefore effecting the efficiency of the wing (Marcelo Dasliva 2023, Glenn Research Center, Tom Benson 2021).

The wing profiles tested have low Reynolds (Re) numbers this allows for laminar flow across the wing. Whilst there are many advantages to a low Re wing profile it does increase the effects of flow separation. Laminar boundary layers are more susceptible to flow separation due to their low momentum and lack of turbulent mixing. When faced with an adverse pressure gradient, the laminar flow often lacks the energy to remain attached to the surface, resulting in earlier separation and reduced lift. On the other hand, higher Re number causes turbulent air to form, this has a higher resistance caused by viscous forces, but this turbulence can energise the flow and therefore delay wing stall.

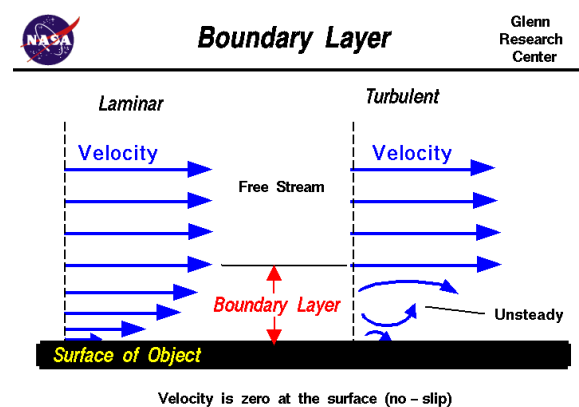


Figure 8 Shows a diagram regarding the effects of Laminar and turbulent airflow over and object for a boundary layer (Glenn Research Center, Tom Benson 2021).

The post-stall region, between 12° and 20° AOA, indicates that the wing has exceeded its critical stall point and passed its maximum lift coefficient. Although the wing continues to generate lift, drag increases exponentially beyond this point. As a result, aerodynamic efficiency declines, and the wing no longer provides performance. This behaviour is illustrated in Figure 7.

CH-10 wind tunnel shows a very similar trend to the CFD with an outlier at 15 degrees. The steady increase of lift coefficient throughout the linear region shows that the wing profile is stable. Furthermore, throughout the post stall stage lift coefficient decreases gradually. Overall, the results gathered from both CFD, and wind tunnel show a similar trend.

Eppler 420 shows a steeper gradient compared to the CH-10. The wind tunnel results show a similar trend to CFD with an outlier at 15 degrees like CH-10 wind tunnel results. However, unlike the CH-10 and the S1223 the post stall region- gradient is more aggressive compared to the CH-10, this shows that the wing is unstable.

The Eppler 420 exhibits a steeper lift curve compared to the CH-10. Wind tunnel results show a similar trend to the CFD data, with a notable outlier at 15 degrees, similar in the CH-10 results. However, unlike both the CH-10 and S1223, the post-stall gradient of the Eppler 420 is considerably more aggressive, indicating that the wing is less stable in this region. Additionally, Figure 7 demonstrates that the Eppler 420 is the least efficient of the three wing profiles.

Figure 5 shows that the S1223 produces the highest lift while being the second most efficient wing profile overall. It follows a similar lift gradient to the Eppler 420 but generates greater downforce with a comparable level of drag. However, unlike the Eppler 420, the post-stall region is less aggressive and closely resembles the CH-10. These results suggest that the S1223 combines characteristics from both profiles, offering strong performance with a more gradual and predictable stall. This makes it a more stable and reliable option for aerodynamic optimisation.

Overall, the S1223 offers the strongest aerodynamic performance of the profiles tested. The linear region in Figure 5 demonstrates a consistent increase in lift across the range of AOA. While its drag coefficient is comparable to that of the Eppler 420 in figure 6, it produces significantly more lift. The post-stall behaviour is stable and gradual, indicating a predictable stall, which is beneficial for vehicle dynamics and handling. Although it is not the most efficient aerofoil, the S1223 represents a well-balanced compromise, combining favourable aspects of all the profiles tested.

4.3.3.2 Result Validation (NE)

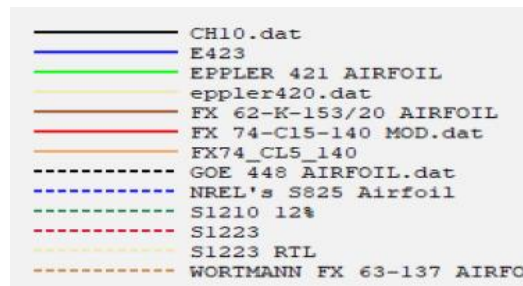


Figure 9 Shows a legend of for the different wing profiles researched in 'Aerodynamic and bending analysis of low-speed airfoils at high Reynolds number (Chhari, Raj et al. 2023).

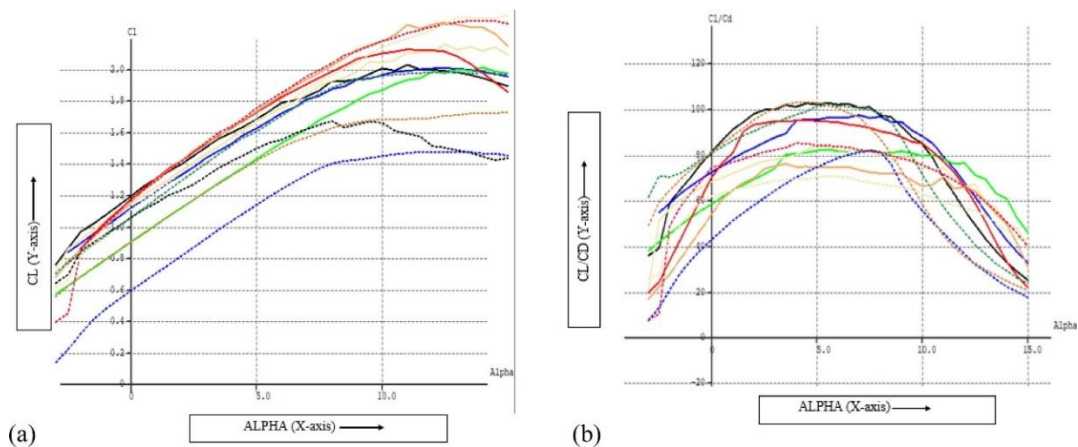


Figure 10 Shows C_L vs Alpha and C_L/C_D vs Alpha graphs gathered in Chhari, K, Raj, U., Galav, A, Dhillon, L, Tiwari P, & Singh, J.P. (2023) 'Aerodynamic and bending analysis of low-speed airfoils at high Reynolds number'.

The study focused on the aerodynamic performance and structural bending characteristics of selected wing profiles, though it was carried out under different testing conditions. As a result, the values obtained differ from those in this report; however, the results remain comparable in terms of overall trends and behaviour.

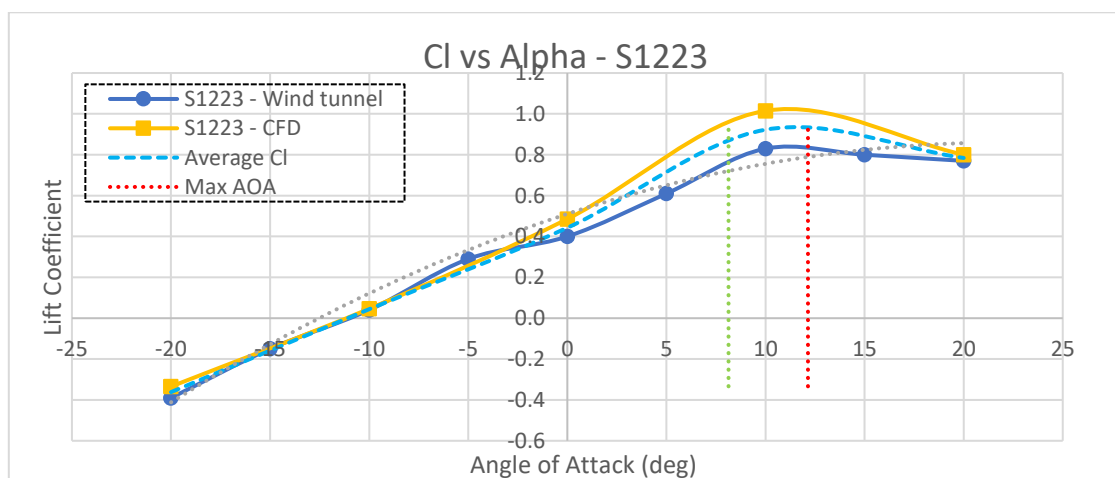


Figure 11 Shows the results for the S1223 through Wind tunnel and CFD testing. The max AOA is 12.15 degrees with max efficiency being at 8.13 degrees.

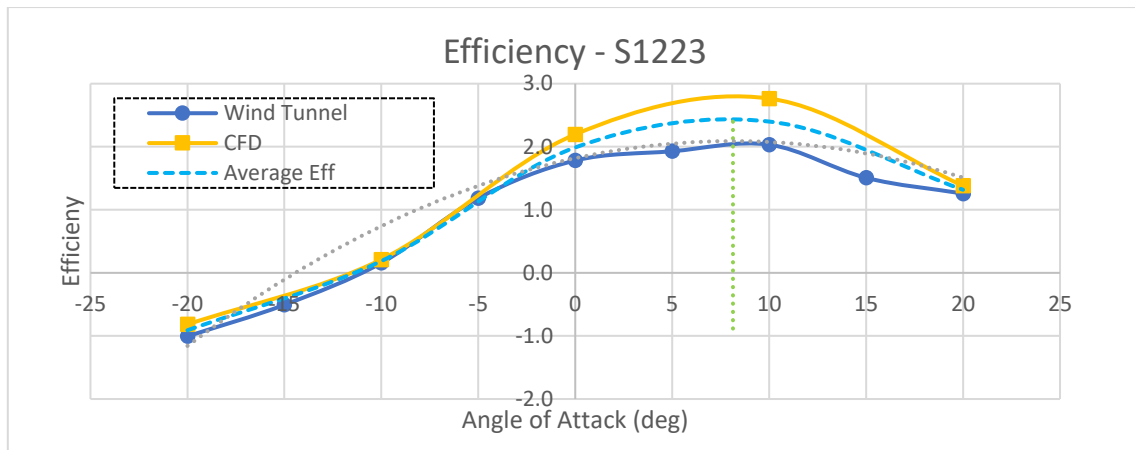


Figure 12 Shows the efficiency of the S1223. At 8 degrees AOA is when the wing is producing the most lift to drag ratio.

Table 13 Shows the percentage difference between wind tunnel and CFD testing from the study conducted.

Percentage Difference (%)	
Lift	7.31
Drag	3.63
Efficiency	11.69

Comparing Figures 5 and 10a, both show similar trends in C_l vs AOA, with the wing stalling between 12° and 15° . During wind tunnel testing, lift force was measured using a gauge with 50-gram increments, this will not capture accurate force readings. This limitation is reflected in Table 13, where the percentage difference between CFD and experimental results ranges from 3.63% to 11.69%. According to research on turbulence models by Ali and Hussain, the percentage differences in drag coefficient shown in Table 13 demonstrate good correlation, considering the models applied. However, the variation in lift is considered too large, particularly when compared to real-world testing data. Through the turbulence model research an error margin of approximately 6% was observed. The resolution of the wind tunnel measuring equipment may have amplified the discrepancy between CFD and experimental results, particularly in lift measurements.

To improve the accuracy pressure taps could have been utilised. This would have given a better understanding of the flow behaviour especially around stall regions. Additionally, finer increments with the force gauges can be implemented. Using this combination of measuring devices would have decreased the percentage difference in results from CFD and wind tunnel.

Efficiency with the methodology of CFD process could be increased. An AOA study was conducted where all the selected wing profiles were testing from -20 to 60 degrees. This was not necessary as these tests were not scale whilst the data could be extrapolated the Re Number was not able to be matched and therefore the data could not be converted to the full-scale wing.

4.3.4 Development (NE)

When developing the rear wing the aim was to improve efficiency and reduce drag. An AOA study was conducted on the developed wing profile to attain general force, lift and drag coefficients. Furthermore, a height study was conducted, this aimed to attain the optimal height of the wing. Oliver Wilson conducted an initial height study. To ensure a fair test the same methodology was applied.

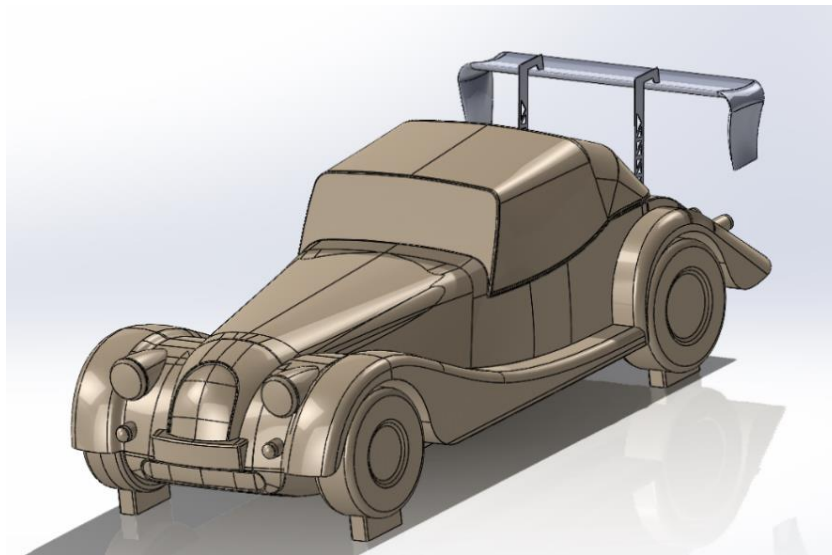


Figure 13 Shows the developed wing implemented to the Morgan Model.

Table 14 Shows union jack matrix for Lift Coefficient produced from the height study tests.

Lift Coefficient		Angle of Attack (Degree)				
		-10	-5	0	5	10
Height (mm)	900	0.14		0.15		-0.02
	1100		0.06	-0.04	-0.14	
	1300	0.11		-0.03		-0.14

Table 15 Shows a union jack matrix for Drag Coefficient produced from the height study tests.

Drag Coefficient		Angle of Attack (Degree)				
		-10	-5	0	5	10
Height (mm)	900	0.38		0.42		0.43
	1100		0.42	0.42	0.43	
	1300	0.34		0.37		0.39

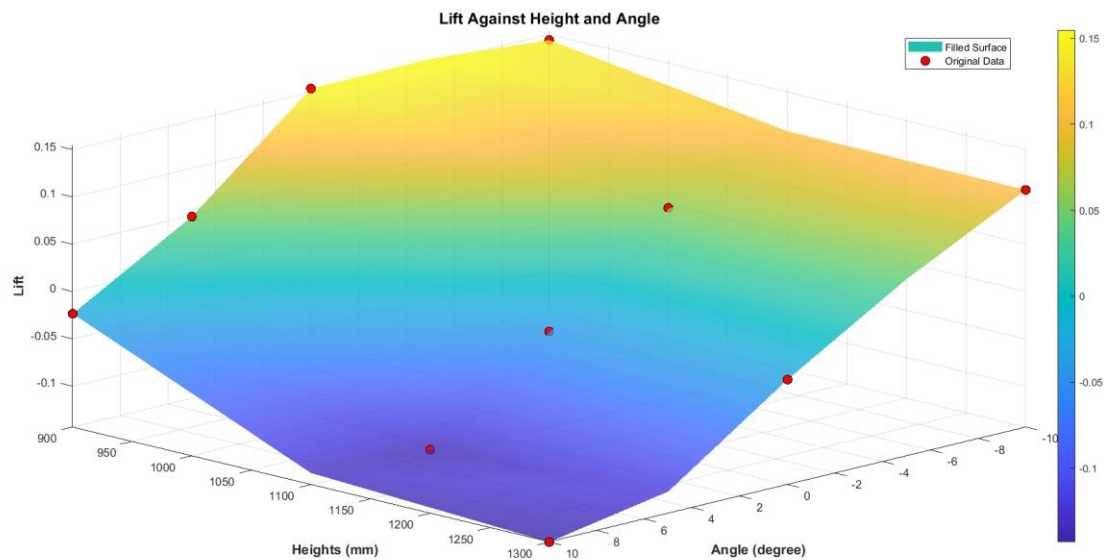


Figure 14 Shows the developed wings Lift coefficient in respect of Height and AOA using the union jack matrix.

Compared to the baseline and the results produced through the initial height study, there is an overall decrease in lift and drag. The drag coefficient has decreased by 0.1 at 1300mm. Figure 14 illustrates that the downforce increases with changes in height and angle of attack. However, there is no measurable difference in lift between the wing at 1100 mm and 5°, and that at 1300 mm and 10°. As such, raising the wing to 1300 mm offers no clear aerodynamic benefit in terms of downforce. Notably though, the drag coefficient is lowest at 1300 mm. This design concept is influenced by practices in the aeronautical industry, where winglets are used to reduce drag by partially recovering the energy lost through wing tip vortices (Marcelo DaSilva, 2023). Elevating the wing effectively increases the aspect ratio without extending the span. This approach can improve fuel efficiency and overall vehicle stability. Therefore, the combination of the S1223 profile and winglet concept theoretically enhances both aerodynamic efficiency and handling characteristics.

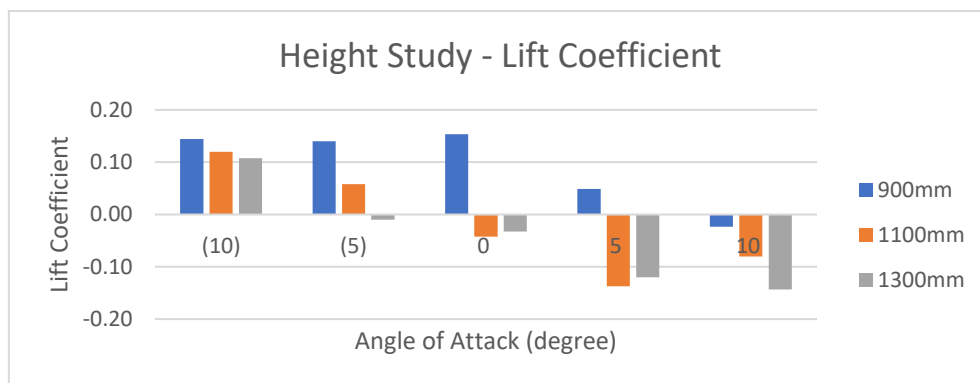


Figure 15 Shows the trend between increase in height of the rear wing and angle of attack.

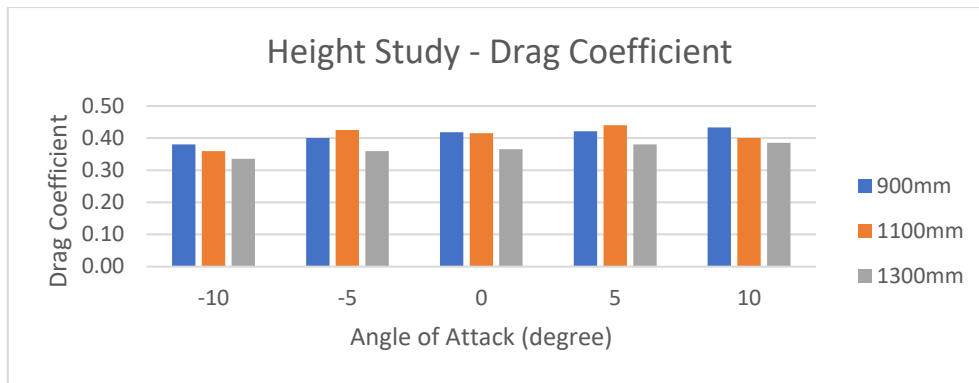


Figure 16 Shows the relation between height increasing and angle of attack.

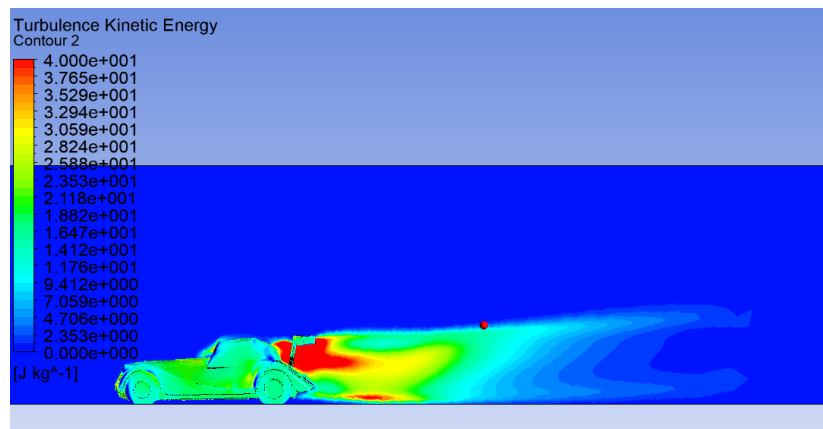


Figure 17 Shows the Turbulence Kinetic Energy for the initial concept.

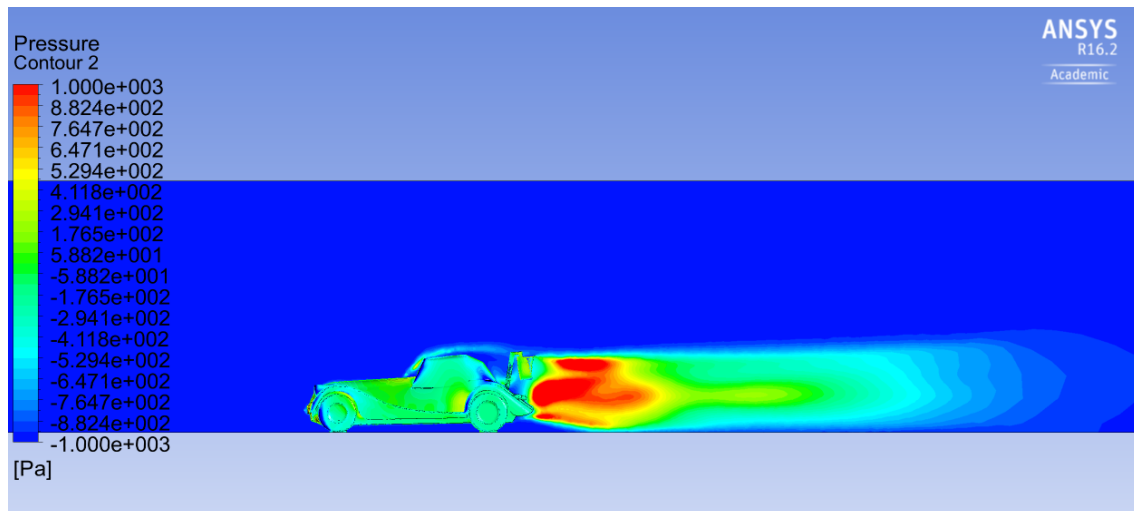


Figure 18 Shows the Turbulence Kinetic Energy for the developed concept using the same scale as Figure 17 as Max 40 J/kg.

The Turbulent Kinetic Energy (TKE) contour shows in Figure 17 a highly turbulent region immediately behind the rear wing, indicating substantial vortex formation and wake unsteadiness. This turbulence persists downstream, with elevated energy levels extending over 1–2 body lengths, suggesting inefficient pressure recovery and significant pressure drag. The turbulent structures

generated by the rear wing may be interacting with the wake from the roof and underbody, increasing overall flow complexity. Reducing this wake turbulence through improved endplate design, wing placement, or diffuser interaction could significantly reduce drag and improve rear-end stability.

The developed wing concept reveals a significant reduction in wake turbulence behind the vehicle.

The initial concept produced peak TKE values exceeding 133.4 J/kg, with a wide, disorganised wake extending well beyond one vehicle lengths.

This suggests substantial pressure drag and instability in the rear flow. In contrast, the developed wing reduced peak TKE to 82.12 J/kg and showed a more coherent wake. The improved flow attachment and vortex control indicate a more stable downforce generation, contributing to overall performance gains for the Morgan Plus Four.

4.3.5 Further Work (NE)

4.3.5.1 Mounting system (NE)

The mounting system should be redesigned so the winglets serve as the primary supports. Underside mounting disrupts airflow and reduces efficiency, whereas end-mounted supports preserve clean flow beneath the wing and improve aerodynamic performance.

4.3.6 Conclusion (NE)

Overall, research was conducted into several wing profiles, assessed through CFD and wind tunnel testing. Each underwent an angle of attack study to evaluate lift and efficiency. The CH-10, Eppler 420, and S1223 were selected, manufactured, and tested, with results compared to CFD data. To further improve performance, a developed wing featuring winglets was introduced. A height study revealed this concept produced lower lift and drag than the initial design, with the winglets reducing drag by improving flow behaviour and increasing effective aspect ratio.

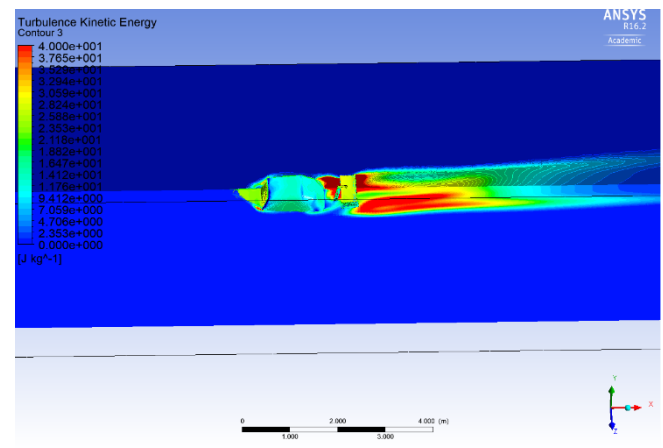


Figure 19 Shows Turbulence Kinetic Energy plot of the initial rear wing concept. There is reduced aerodynamic efficiency due to ineffective flow and vortex control at the wing tips.

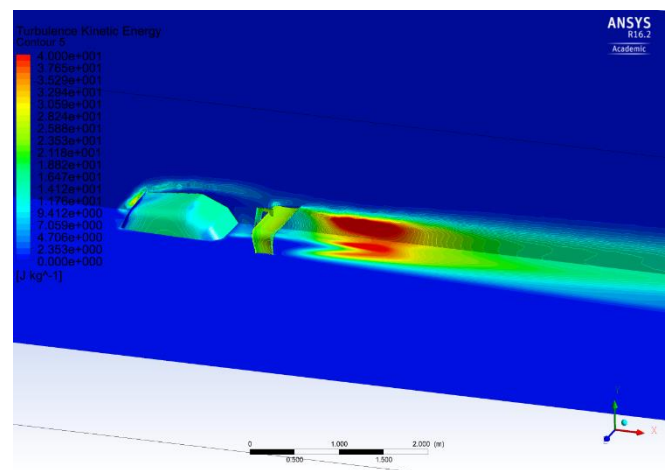


Figure 20 Turbulence Kinetic Energy (TKE) plot of the developed rear wing concept, compact, well-controlled turbulent wake with reduced lateral spread and faster dissipation, indicating improved vortex management and reduced drag.

4.4 Aerodynamic Development (OW)

4.4.1 Introduction (OW)

The aim of the project is to produce a functioning active rear wing that helps increase performance of the morgan +4. The area of study around aerodynamics is critical for the successful implementation for the rear wing as it is heavily dependent on aerodynamic optimisation.

To improve the performance of the car will require design and development based mostly on CAD (SolidWorks) and using CFD(Ansys) to test the designs and analyse data. Applying various concepts such as Bernoulli's principle, boundary layers and flow separation to the CFD results to help design a wing to improve lap times.

The work will also reference Nathan Evans results and finding to help inform design decisions mainly focusing on wing selection and correlation with wind tunnel data.

4.4.2 Methodology (OW)

The design of development

For the baseline run of the morgan full car runs the Wind Tunnel has been set up in a way that allows the car to be simulated in free stream air giving the most accurate results. The layout of the tunnel consists of the following named sections shown in Figure (21). The floor is set to moving in the set up and with the walls surrounding the car excluding the in and out let's will be a mirror of the floor. This will allow for more accurate boundary interactions as the whole tunnel is moving like it would in real world situations.

The body of influence is made around the model at a finer mesh, using 0.1m mesh size. A body of influence is used to refine the mesh to smaller sizes around the geometry in the wind tunnel allowing for closer meshing and more accurate results whilst still having an effective solve.

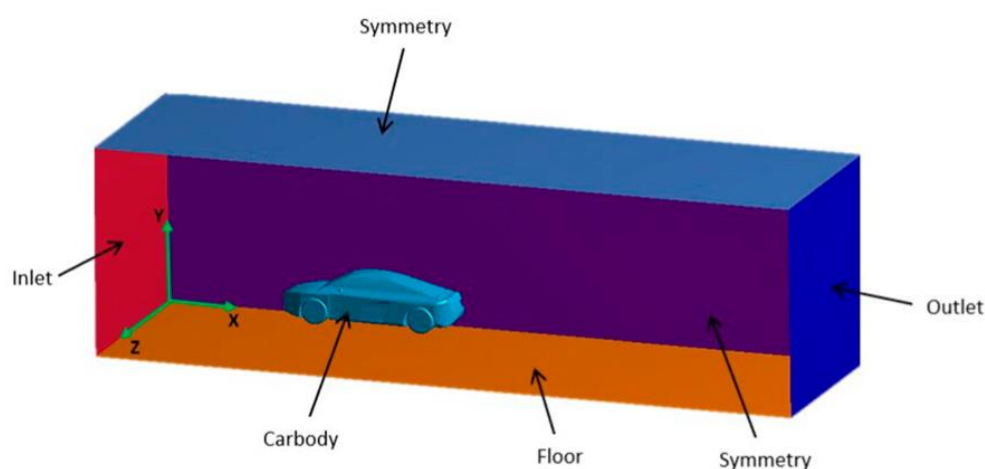


Figure 21- Wind tunnel setup (Zavala, 2023)

Dimensions: 4

☐ H1	20 m
☐ H2	40 m
☐ V3	4 m
☐ V4	0.56 m

Figure 22- Tunnel dimension for baseline Run

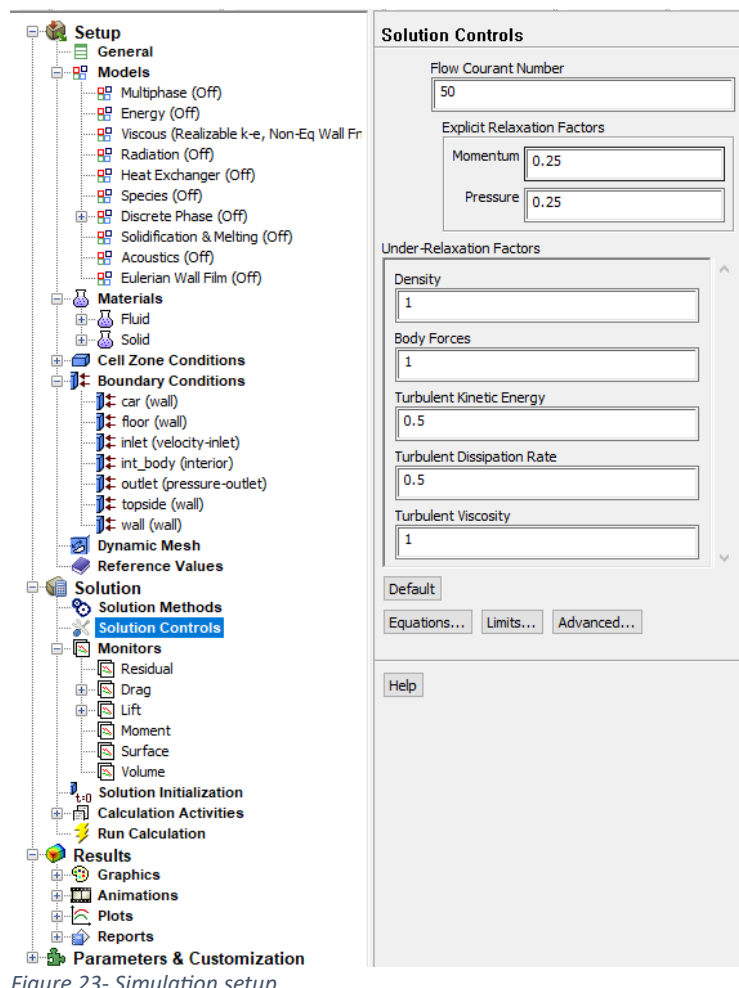


Figure 23- Simulation setup

The type of simulation done was a non-equilibrium wall function, this method was suggested as it computes quicker and is easier to setup whilst giving good results, more accurate models can be used but are more difficult to set up and optimise.

To ensure consistent and reliable results during testing, all setup parameters remain constant throughout each run. This includes factors such as airspeed and environmental conditions, among others. By keeping these variables unchanged, the data gathered can be directly compared across different test runs, allowing for a clearer analysis of how changes in the wing configuration or other

design aspects influence aerodynamic performance. This consistency is crucial for accurately assessing the effects of each modification without introducing additional variables.

4.4.2.1 Baseline runs- roof up +down (OW)

The aerodynamic impact of roof configuration was tested to understand how airflow interacts with the car. Using the same wind tunnel setup, differences in lift (CL) and drag (CD) were measured to guide design decisions.

4.4.3 Wing Testing (OW)

Wing testing used a smaller tunnel to test a selected wing from research that show good characteristics for the intended purpose. The wind tunnel was defined as shown in figure (24); the wing is tested at half size also to increase speed of testing.

Dimensions: 4	
☐ H1	1.5 m
☐ H2	3 m
☐ V3	0.5 m
☐ V4	0.6 m

Figure 24- Tunnel Dimension for isolated wing testing

4.4.3.1 Implementation of wing- Height Study (OW)

A height study was conducted to determine the most efficient wing position, ensuring it operates in clean, high-velocity airflow. Results were shared with the simulation and mechatronics teams to assess structural loads.

The active wing mechanism aims to maximize efficiency by adjusting height, ensuring optimal downforce and minimal drag. Consistent wind tunnel parameters were maintained, with test speeds aligned to the Morgan's average lap velocity 31.754 m/s.

To accelerate data processing, MATLAB was used to interpolate missing test points, creating a matrix for visualizing lift and drag variations. Further research into peak efficiency ranges could improve result accuracy.

Dimensions: 4	
☐ H1	20 m
☐ H2	40 m
☐ V3	4 m
☐ V4	0.56 m

Figure 25- Tunnel Dimensions for height study

4.4.4 Analysis (OW)

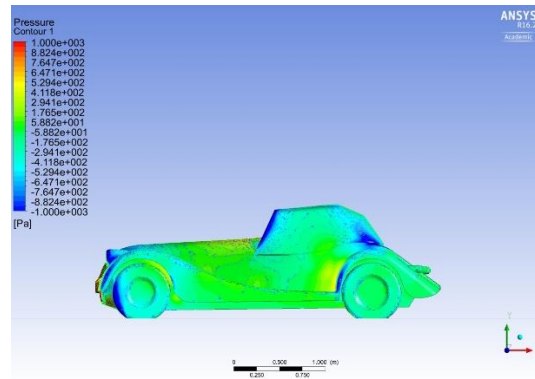


Figure 26-Side view Morgan Pressure plot

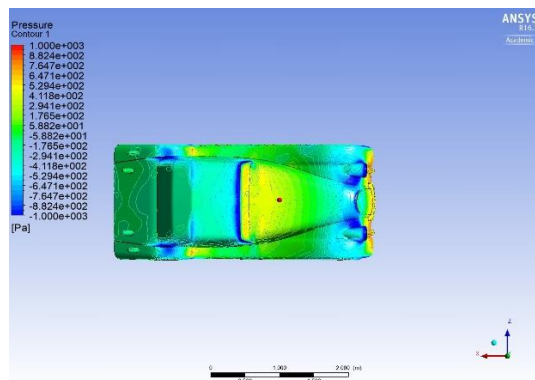


Figure 27-Top view Morgan Pressure plot

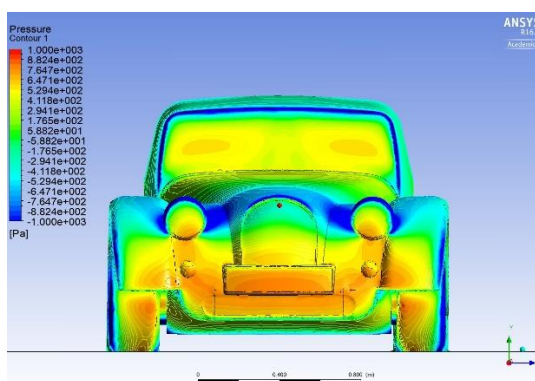


Figure 28-Front view Morgan Pressure plot

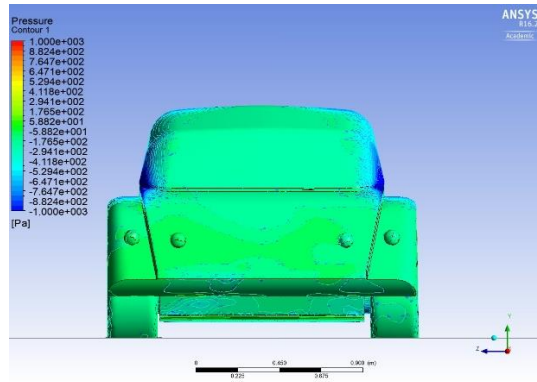


Figure 29-Rear view Morgan Pressure plot

The pressure distribution images of the Morgan +4 reveal key aerodynamic characteristics. Low-pressure (blue) zones indicate regions where air velocity increases, reducing pressure, while high-pressure (red) areas correspond to slower-moving air.

Significant low-pressure regions are observed on the bonnet corners and the roof, indicating areas where lift is generated, which in turn reduces the contact force on the tyres, potentially affecting stability.

At the rear of the car, pressure remains relatively neutral due to the streamlined shape of the Morgan +4. However, along the cockpit sides, airflow wraps around the body, generating turbulent wake structures trailing behind the car. This wake turbulence may contribute to increased drag and instability, which the active wing aims to mitigate.

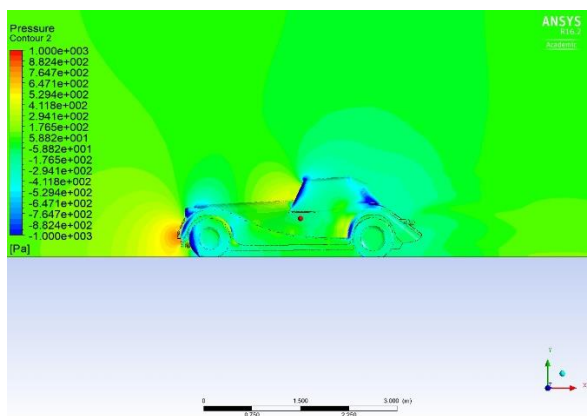


Figure 31-Pressure distribution on wall (roof up)

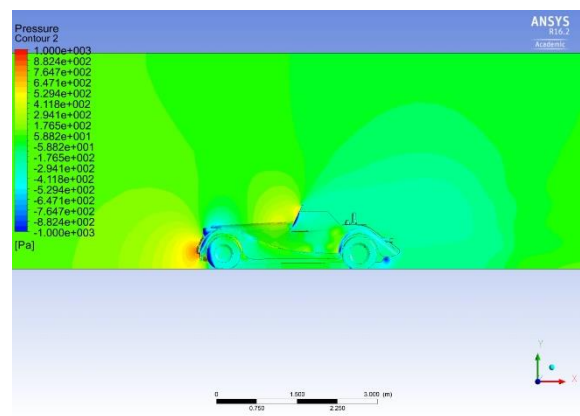
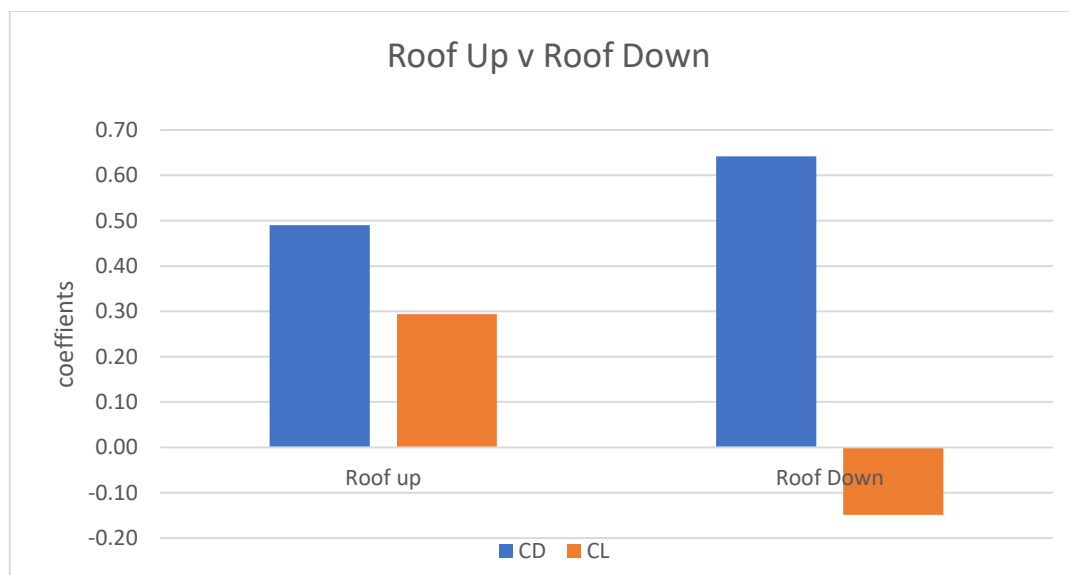


Figure 30-Pressure distribution on wall (roof down)

The images in Figure (30,31) illustrate the pressure distribution differences around the car, particularly highlighting the significant variations in airflow over the roof area. These differences are best demonstrated through turbulence models mapped along the centre plane.

Comparing the roof-up and roof-down configurations, the drag coefficient (CD) and lift coefficient (CL) vary significantly. With the roof down, the car generates negative lift but experiences a substantial increase in drag. Conversely, the roof-up configuration produces higher lift but reduces overall drag, indicating that the roof itself contributes significantly to lift generation.

Based on these findings, the roof-up configuration was selected as the baseline due to its lower drag characteristics. However, the additional lift penalty requires compensation, which will be addressed through the implementation of the active rear wing.



Graph 1 - Lift, Drag Histogram for Baseline Run

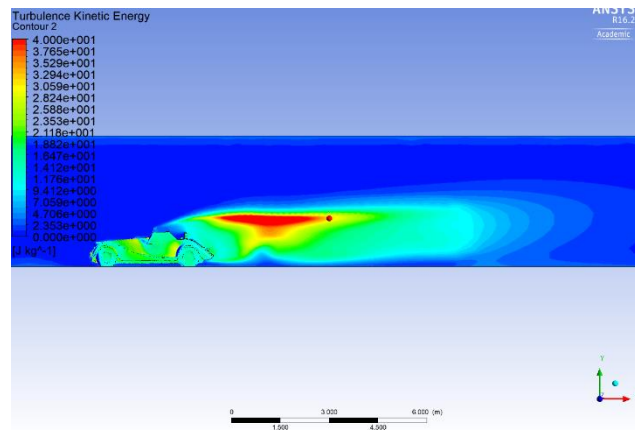


Figure 14 - Turbulence flow (roof down)

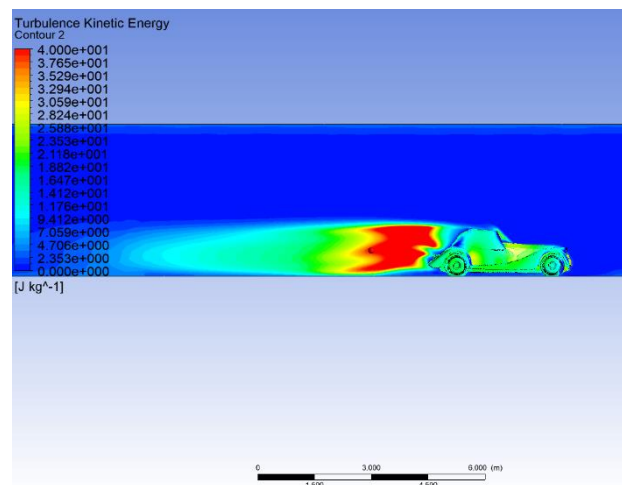


Figure 15-Turbulence flow (roof up)

Understanding the optimal wing placement was a critical part of the research, as it identified areas of clean, high-velocity airflow. The initial design approach aimed to position the wing within this airflow to maximize efficiency. In the roof-up configuration, turbulence was more confined behind the car, meaning the wing required less height adjustment to remain in clean air.

4.4.4.1 Y^+ mesh (OW)

The Y^+ mesh is used to analyse boundary layer resolution, ensuring accurate near-wall flow calculations. It helps refine the meshing process to achieve accurate aerodynamic simulations, particularly in high-gradient regions where flow separation, turbulence, and pressure changes occur.

In this study, the maximum mesh element size mapped is 0.6m, as shown in Figure (32), with bigger mesh sizes being suggested around the high drag area such as the edge of the window, wheel arch, front area of bonnet showing a large. The suggested limits for the Y^+ plus suggests between 30 to 300. The areas in red show a high turbulent region but also show where the mesh could do with being refined for accuracy of boundary layers time to simulate. (xitadel, 2023)

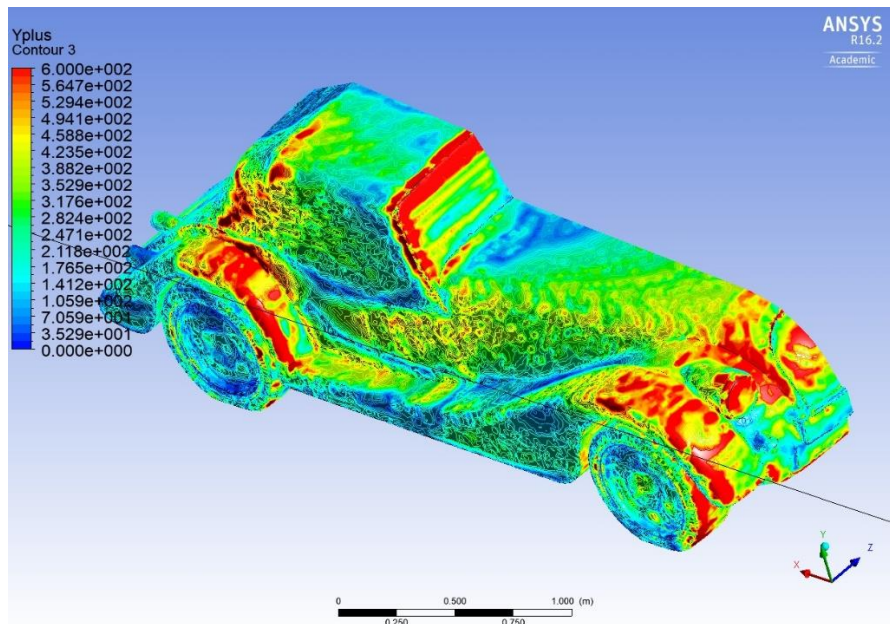


Figure 32- YPlus mesh

4.4.4.2 Wing study data (OW)

Figure 33-Turbulence @10 Deg

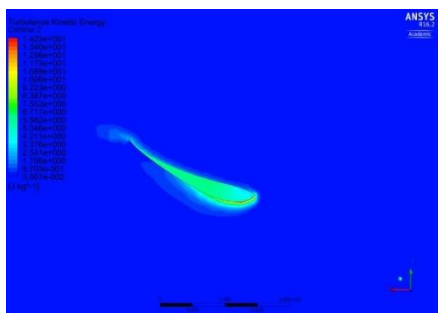


Figure 35- Turbulence @ 30 Deg

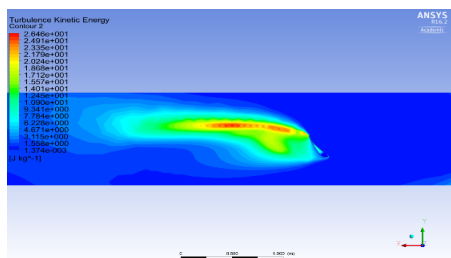


Figure 34-Turbulunce @20 Deg

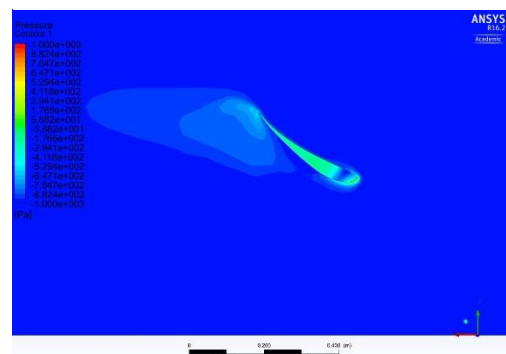
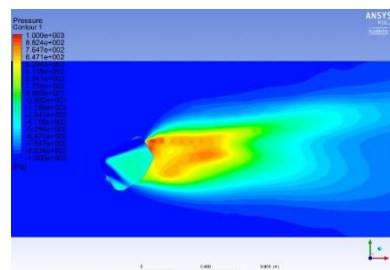


Figure 36- Turbulence @40 Deg

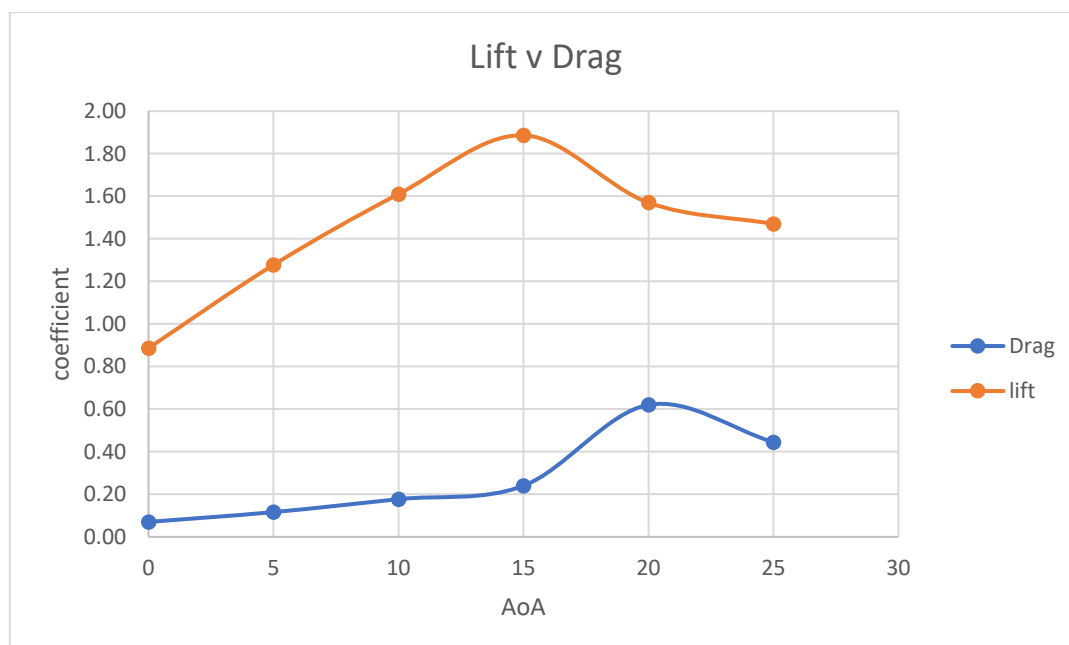


The next test conducted was on the type of wing that would allow for the best performance for the morgan. Using the data from Nathans wing study and research, it was concluded that the s1223 was the best wing shape for application.

The images in Figure (33,34,35,36) show how different angles of attack impact drag on the wing, with higher angles (20-40 degrees) generating turbulence and reducing lift efficiency. The increase in turbulence has a direct effect on the amount of drag produced as the air separates from the lifting surface. With turbulence is lost energy that creates the drag making the wing less effective.

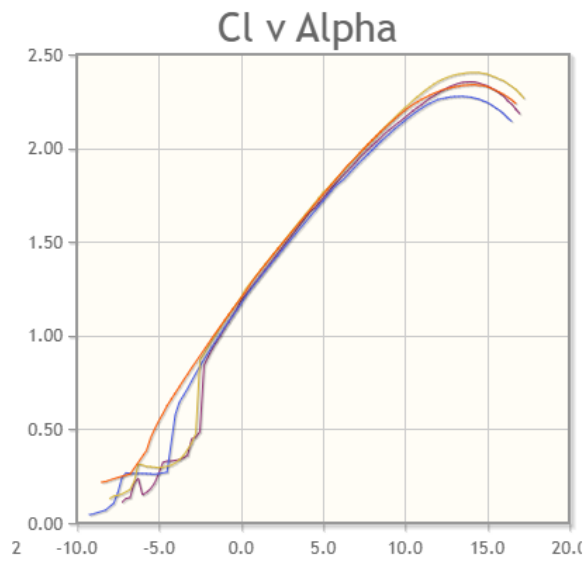
This information is crucial for defining the wing's operational range, especially for its use as an air brake in straight-line braking scenarios. To determine the optimal working range of the S1223 wing shape, testing was conducted in isolation at half-scale in a smaller wind tunnel, allowing comparison of raw data with results from Aerofoil tools.

The graph shows a wing study carried out in isolation with end plates on, taking measurements at every 5 degrees of attack to see where the stall point is so the optimisation of the wing can be achieved.

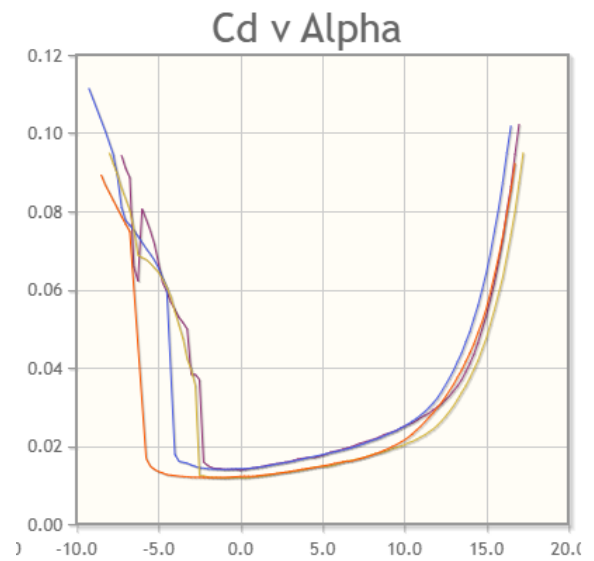


Graph 2 - Plotted Wing Data

The graph from the CFD results suggest that at 15 degrees of angle of attack is the most efficient operating angle. The drag decreases at the 25-degree mark which is an anomaly as at this AOA the drag should only be increasing. As shown in the data this isn't the case, this could be due to meshing inaccuracy or a parameter not being correct when setting up the simulation.



Graph 4 - Lift v Alpha (airfoiltools, 2025)



Graph 3 - Drag v Alpha (airfoiltools, 2025)

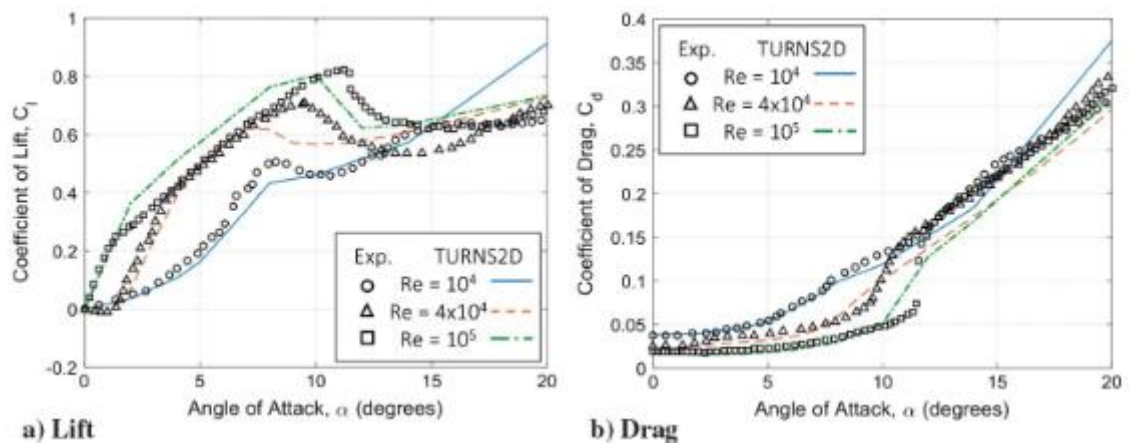


Figure 37-Lift, Drag plots for NACA0012 (Justin Winslow, 2017)

The data above is taken from Airfoil Tools Graph (3,4) that provided the wing profile, the graphs are showing change in lift and drag against angle of attack, the graphs have different trends to the CFD

testing conducted. The Drag increases dramatically between the 10 and 15 Degree where in the test data the drag increases after 15 Degrees, this could be due to the end plates that was also tested on the wing at the same time, the wing would experience less wing tip vortices and help improve the lift characteristics but as seen on the lift graph, the C_L is expected to achieve a higher rate of change to the 10 degree mark with it falling short of the expected lift of $C_L 2.2$. (airfoiltools, 2025)

A study conducted on a different wing demonstrated a similar trend to the CFD analysis, where lift initially decreases but then begins to rise again near the peak, while drag consistently increases. This suggests that, despite differences in numerical values, the overall pattern remains consistent when the Reynolds number is accounted for, thereby increasing confidence in the testing conducted.

Variations in wind tunnel testing setups, such as differences in height, length, turbulence model settings, and growth rates in CFD simulations, contribute to discrepancies in data. To improve correlation between experimental and simulated results, adjusting the Reynolds number in the simulation is a viable approach. The Reynolds number characterizes airflow behaviour and its interaction with the boundary layer. Utilizing the calculation tool in Airfoil Tools to determine the overall Reynolds number for the wing profile in isolation, based on the provided formula, can enhance the accuracy and reliability of the analysis.

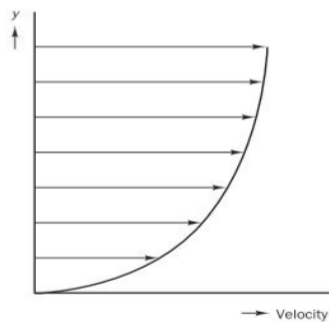


Figure 21- boundary layer (Malalasekera, 2007)

The boundary layer is the friction from air moving over the surface of the car and moving slower than the air above, as shown in figure 21 the slow air at the surface effects the air moving above it. When meshing the wing and car 3 layers of mesh was used to simulate the boundary layer. Making the simulation more accurate when simulating turbulence and separation.

Equation 2-Reynolds Number (airfoiltools, 2025)

$$Re = \frac{\rho v l}{\mu} = \frac{v l}{\nu}$$

Velocity m/s 78.293 mph
 Chord width m 0.98425 ft
 Kinematic Viscosity m²/s 1.529e-4 ft²/s
 Reynolds Number **739,072**

Figure 38-Reynolds Number calculated (airfoiltools, 2025)

As seen in figure 38 the Reynolds number is 739,072 which describes the airflow as laminar in terms state, a study suggests that a low Reynolds number is considered 10^4 to 10^5 suggesting the wing that's been studied was under laminar conditions and is seen as such in results. (Justin Winslow, 2017)

More time spent validating results would enhance the accuracy of the CFD testing. Nathan has performed extensive CFD testing on various wing profiles and attempted to correlate these results with wind tunnel data from the university. However, issues arose due to the mounting methods and the scale of the wind tunnel, making it challenging to obtain accurate data for comparison with the CFD findings.

4.4.4.3 Height study (OW)

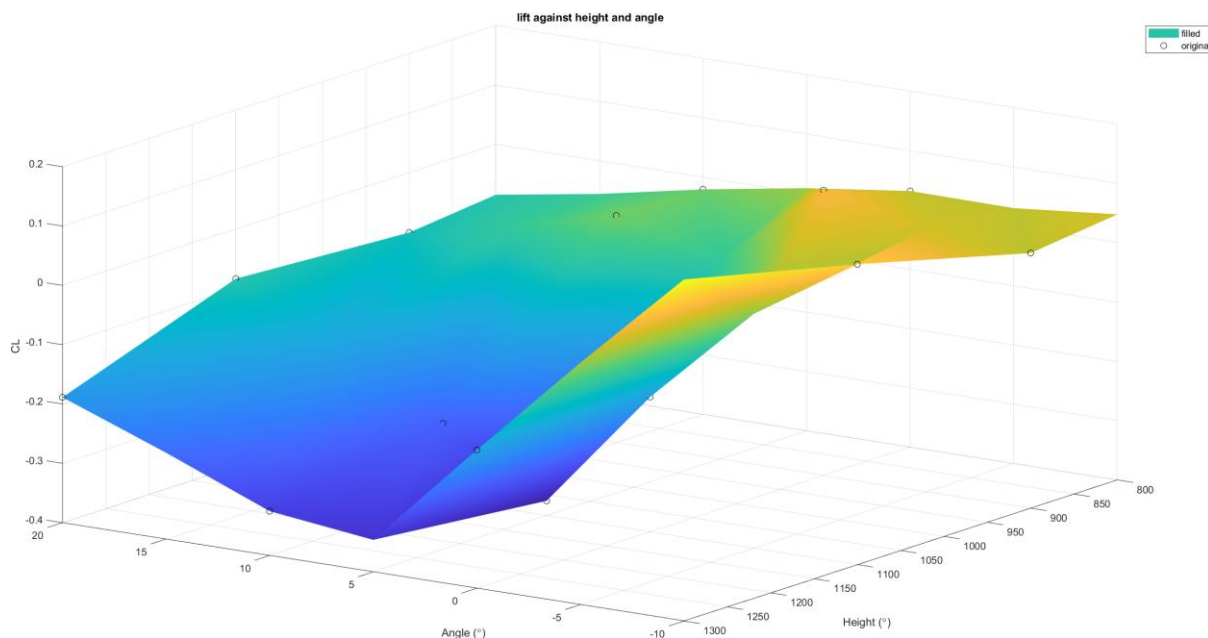
Table 1- Lift Coefficient Height Study

matrix for height study								
lift			31.754m/s					
mm	-15	-10	-5	0	5	10	15	20
800				0.03		-0.02		
900		0.03		0.08		-0.02		-0.10
1100		0.11		-0.17	-0.38	-0.27		-0.08
1300				-0.17		-0.33		-0.19
1500								

Table 2- Drag Coefficient Height Study

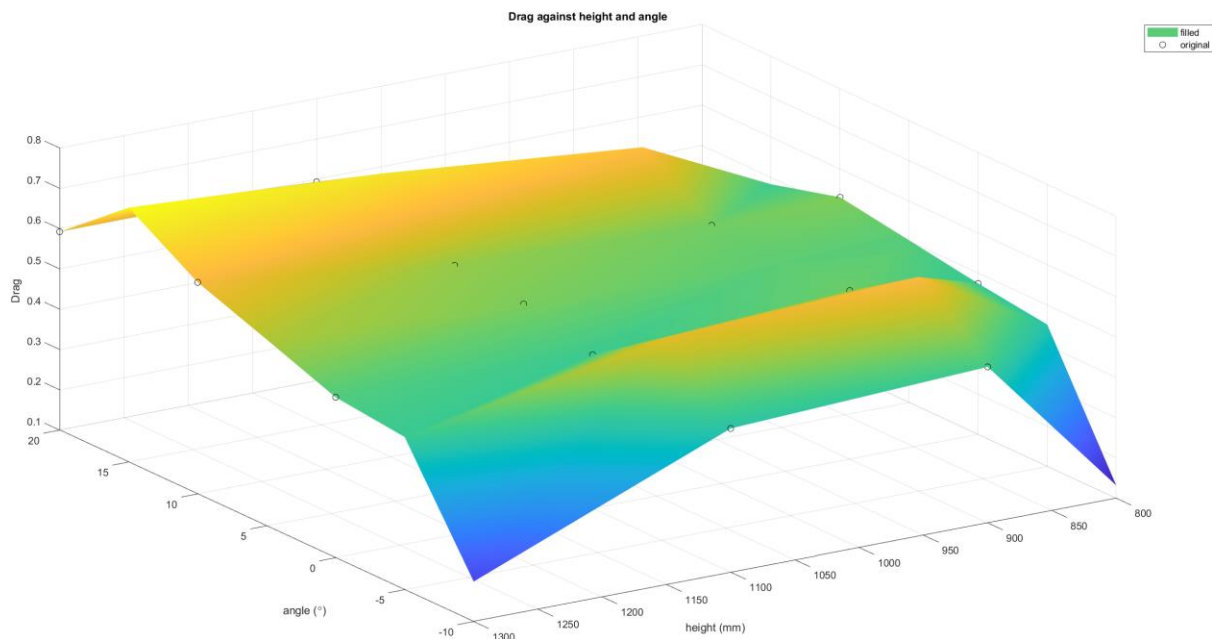
drag			31.754	m/s				
mm	-15	-10	-5	0	5	10	15	20
800				0.47		0.53		
900		0.49		0.52		0.52		0.51
1100		0.46		0.48	0.53	0.54		0.59
1300				0.50		0.62		0.59
1500								

A height study was conducted to determine the optimal working areas for the wing, focusing on its effectiveness in free-stream air. To save time, aerodynamic mapping was done by testing at set angles of attack and using a MATLAB script to fill in the data. This approach provides a rough idea of the wing's behaviour at different heights and angles, enabling more focused research into highly efficient areas for further refinement.



Graph 5 - Lift Plot MATLAB

The Lift graph in Graph (5) presents data filled using a MATLAB script, filling in gaps between angles of attack that hadn't been studied yet. The data shows that at 1100 mm and 5 degrees of angle of attack, the lift coefficient is optimal. This point represents ideal conditions for lateral loading, maximizing grip by putting the most weight on the tires. The testing and data extrapolation indicate the wing's optimal lift performance, aiding in its ideal placement for the desired aerodynamic effect.



Graph 6 -Drag Plot MATLAB

The drag produced by the wing remains relatively stable until higher angles of attack are reached. At 1100 mm, where the wing achieves its highest performance, drag increases slightly, but not significantly compared to lower wing heights. This indicates that the wing operates at peak efficiency in free-stream air, with minimal drag from the wing mounts, helping to optimize aerodynamic performance.

The optimal angle and height for performance have been determined, and now the focus shifts to achieving proper aero balance by analysing the pressure distribution between the car's axles. At peak performance, the balance was found to be outside the recommended range, with only 13% on the front. According to Dylan's simulation data, the ideal range for balance is between 45-60%. Since the current balance lies outside this range, it negatively impacts lap times, suggesting that a reassessment of the design approach is necessary.

4.4.5 Conclusion (OW)

4.4.5.1 *Why the baseline (OW)*

The baseline data that was collected showed the difference between the two models. Being able to make an informed decision and weighing up the aerodynamic characteristics of the morgan was useful to the group in giving direction to the design process and routes that could provide the maximum efficiency to the car.

4.4.5.2 *Why the wing (OW)*

The S1223 aerofoil was selected for its high lift characteristics and smooth stall behaviour, which is important in performance settings to allow for gradual loss of grip. This predictability is vital for the driver, as it minimizes the risk of sudden instability. However, challenges arose when attempting to match the CFD testing results with the provided data, as well as comparing them to external testing. Despite this, the combined efforts of Nathan's real-world testing and CFD simulations provided a reasonable level of confidence in the accuracy of the results. The research indicated that the wing shape was an effective choice, with the profile proving to be a strong option. However, aligning the numerical data with the research results proved to be difficult, and greater attention should have been given to validating the results.

4.4.6 Why selected height (OW)

The initial placement of the wing at 1100mm from the floor appeared optimal, aligning with the original design goals. However, after considering aerodynamic balance, it became clear that the wing's effectiveness resulted in an imbalanced distribution, with only 13% on the front, negatively impacting lap times according to Dylan's simulation data. The focus shifted to optimizing balance by lowering the wing to a position behind the car, discarding the moveable height concept. The goal is to achieve the ideal performance within a single height range, such as 900mm above the floor where the aero balance is at 49% at its peak efficiency.

This aims to reduce the effectiveness of the wing to influence the aero balance less, it also simplifies the design of the mounting structure as it removes the need for movement up or down, as a whole the design philosophy at the beginning was sound and achieved what was intended but worked too good in the end accidentally making the car slower when in use.

Since the design brief specifies only a rear wing and does not mention adjusting other aerodynamic features on the Morgan +4, the focus remains on optimizing the rear downforce. However, if modifying additional features were permitted, the attention would shift to balancing the rear downforce with a front splitter to improve overall aerodynamic efficiency and balancing out the car to improve the lap times.

4.5 Simulation (DB)

4.5.1 Work Content (DB)

I am the sole member of our group's simulation department; therefore, I am responsible for all the track performance analysis of our rear wing and aero improvements. Below is a list of my planned work content to be carried out through the project:

- Learn OptimumLap software.
- Use initial data on the Morgan and OptimumLap to do initial sim runs.
- Learn VI Grade software.
- Using the data produced by the aero department, test the Morgan Plus Four performance using VI Grade software.
- Produce data on the performance of the vehicle. Use this data to assist producing code for the active control system.
- Analyse data produced from the tests.

4.5.2 Research (DB)

4.5.2.1 *Simulation Design Approach (DB)*

Firstly, I spent time researching and understanding the two design approaches, driver out-the-loop and driver in-the-loop simulation (Mercedes AMG F1, 2020).

Driver out-the-loop is based on software using a standard driver model rather than an actual driver. The positives to this are that the driver model is consistent between setup changes therefore eliminating human error on a consistency basis. This also removes logistic issues of trying to schedule a driver or the use of the simulator, allowing for reduced running time. However, driver out the loop is limited to the accuracy of the driver model, as it doesn't involve a real driver therefore inaccuracies with the model can occur.

Driver in-the-loop is based around a real driver testing the car on a simulator, around a track, to evaluate performance. The benefit to this is that you can get realistic times and feedback on how the driveability of the car is affected. This information would be useful for knowing how well the car drives although would be subject to how experienced the driver is at feeling/conveying changes. Another disadvantage is the consistency of the driver between setups as each one will need an out lap and a few flying laps to properly evaluate the change, therefore they would need to stay very consistent between sessions to accurately test the performance difference.

For this project, I have opted for driver out the loop to make session planning easier and to get consistent results from changes to the model or aero.

4.5.2.2 *Simulation Software Use (DB)*

There were three options readily available on campus which were OptimumLap, VI Grade and BPS.

OptimumLap is very basic and is a point mass model sim, meaning that the car is modelled as a solid object moving around a lap to evaluate aero, rather than incorporating brake or suspension factors (OptimumLap, 2019). I used this for some insightful base data for the Morgan.

BPS is the simulator used for driver out the loop and seeing as I chose to use driver in the loop, I didn't opt to use this.

VI Grade is an industry standard simulation software with complex suspension and vehicle parameters (VI Grade, 2016). This is the main software being used for the project with in-depth car modelling required to get an accurate representation of the Morgan's performance.

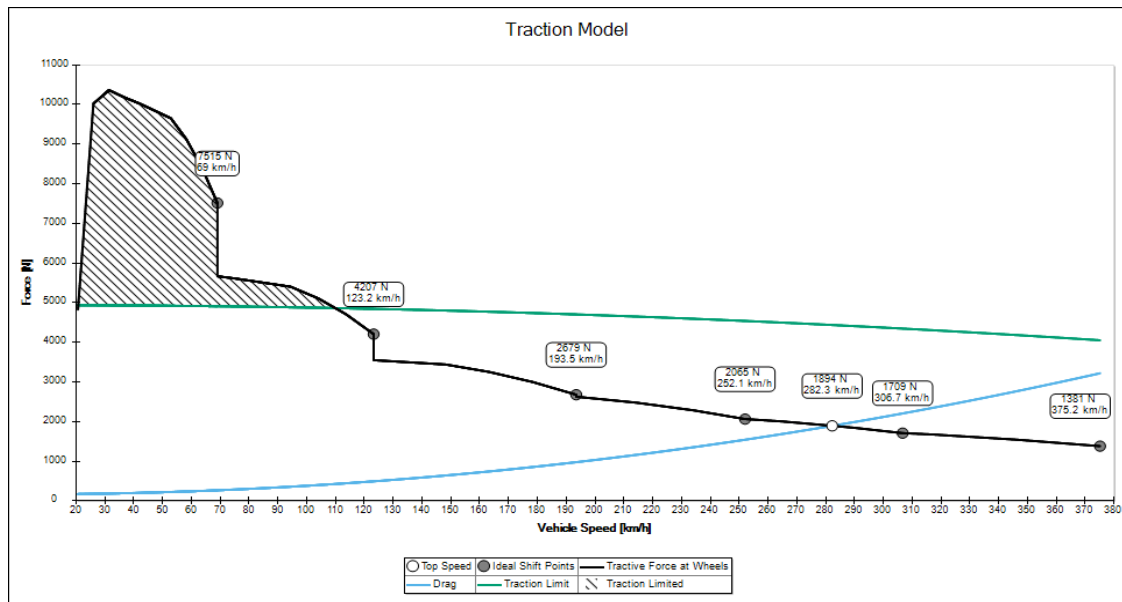
4.5.3 *Testing & Methodology (DB)*

4.5.3.1 *OptimumLap Testing (DB)*

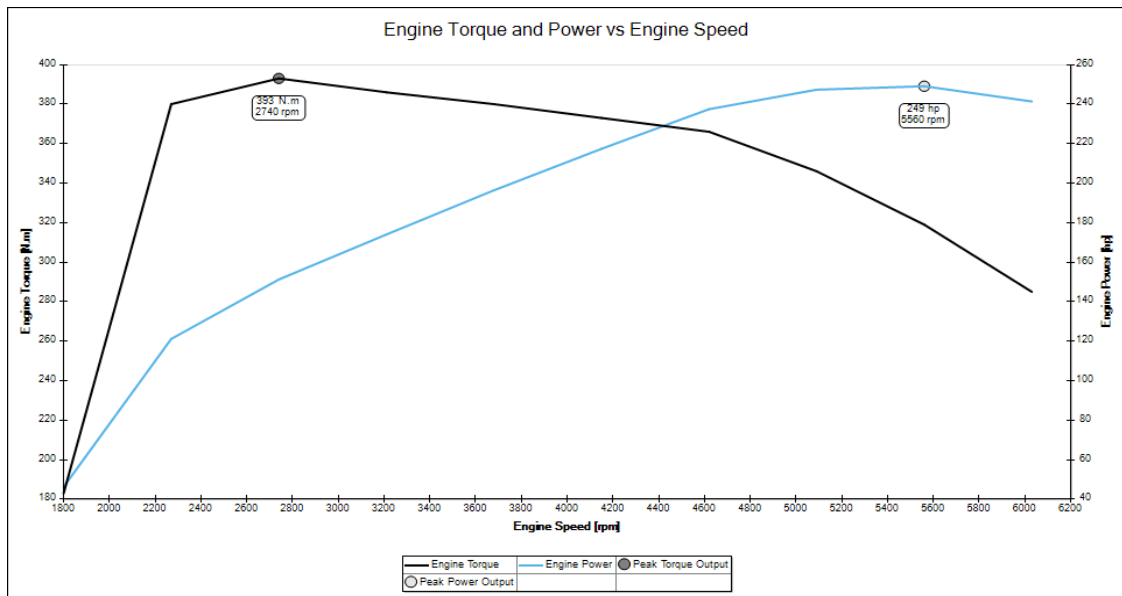
Initially, I began simulating the Morgan through the basic OptimumLap software. The car parameters are largely limited through the low complexity of the software however, I was able to test aero coefficients alongside traction limits to begin investigating performance.

Table 16 - Morgan 6-speed manual OptimumLap data parameters (Morgan, 2024)

Car Data	Figures
Mass	1119kg
Cd (Coefficient of drag)	0.494
Cl (Coefficient of downforce)	0.316
Frontal Area	0.94m ²
Air Density	1.223Kg/m ³
Rolling Radius	0.3135m
Rolling Resistance	0.015
Longitudinal Grip	0.9
Lateral Grip	0.9
Engine Data	
Engine RPM	Torque (Nm)
1800	183
2270	380
2740	393
3210	386
3680	380
4150	373
4620	366
5090	346
5560	319
6030	285
Transmission	
Gear	Ratio
1	3.683
2	2.062
3	1.313
4	1
5	0.809
6	0.677
Final Drive	
Final Drive	2.81
Drive Efficiency	80%



Graph 7 -Traction model graph from OptimumLap



Graph 8 -Torque and power vs engine speed graph from OptimumLap

The 'car data' table shows my data inputs of the manual Morgan in the baseline tests. Above are output graphs from OptimumLap which give a clear overview and basic understanding of what the software will base the test from.

For my initial simulation tests, I decided to run a sweep test of key performance factors like downforce and drag coefficients, along with other appropriate changes to get a good idea of the cars stock performance.

4.5.3.2 VI Grade Testing (DB)

4.5.3.2.1 Aero Balance Study (DB)

I decided to investigate the difference of lap time around Llandow and Pembrey with front and rear aero balance alterations, using an aero map (Remmerie, W. 2019). Since we are designing a rear wing rather than an aero package then I decided to leave the downforce value on the front as stock and only change the rear. Considering that the Morgan produces lift then a reduction in lift coefficient on the rear would result in higher rear balance and vice-versa.

Table 17 - Morgan aero balance table

Aero Balance Rear	Resultant Rear Cd	Resultant Rear Load (N)
60.0%	-0.211	-158.15
57.5%	-0.234	-175.39
55.0%	-0.259	-194.12
52.5%	-0.286	-214.36
50.0%	-0.316	-236.85
47.5%	-0.349	-261.58
45.0%	-0.387	-290.06
42.5%	-0.428	-320.79
40.0%	-0.474	-355.27

This table shows the aero balance adjustments made, along with the effect on the rear load and coefficient of downforce. This was calculated using the aero load equation for a velocity of 130km/h, frontal area of 0.94m² and air density as 1.223kg/m³.

4.5.3.2.2 Comparing Rear Wing Concepts (DB)

The aero department tasked me with comparing their best two wing concepts, with quite a few differences between them. I decided to test both wings on the Morgan static (no movement) and active (moving based on inputs).

The first wing concept was the standard Selig 1223 profile, designed by Ollie. This layout negatively affected the coefficient of drag, increasing it to 0.53 over the stock 0.494. However, it made a large difference to the downforce/lift coefficient going from producing lift from stock of -0.316 to a downforce of 0.38.

The second wing concept was a modified Selig 1223 profile, with added winglets, designed by Nathan. This wing design had improved the overall coefficient of drag to 0.44 and produced a downforce coefficient of 0.14.

4.5.3.2.3 Modelling Active Aero (DB)

To model the active aero in VI Grade I had to utilise the performance modifiers file to scale the preset aero map, which I can make alterations to.

Cornering		
Angle	5	deg
Cd	0.44	
Cl	-0.14	
Drag	329.79	N
Aero Load	104.93	N
Air Brake		
Angle	60	deg
Cd	2.5	
Cl	-0.4	
Drag Scale	568%	
Aero Scale	286%	
DRS		
Angle	-10	deg
Cd	0.34	
Cl	0.11	
Drag Scale	77%	
Aero Scale	-79%	

Figure 39 - Modified Selig 1223 active aero pre-test figures and scaling table

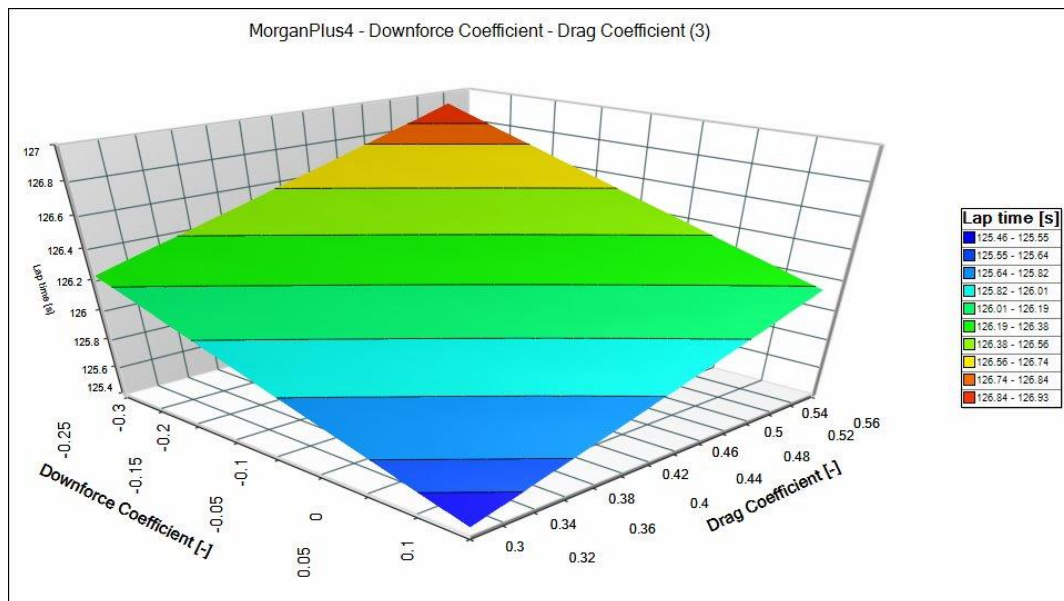
This table displays how I set up the active aero for the modified Selig 1223 concept, using the figures I was given by the aero department. The other wing concept is modelled in the same way, with slight adjustments to the figures to match CFD data. Cornering scales the aero to the map most efficient for downforce, seen in the table as 5 degrees angle. The file then scales the drag and aero up for the air brake, then reduces drag and downforce for the straights. The given data will then be used to test both concepts active.

4.5.3.2.4 Aero Package Test (DB)

While the wing is intended to be bolted on and directly improve the Morgan's performance, we were also keen to analyse what it would be like with an aero package, including our rear wing concepts. Therefore, I also plan to do a brief test with some front aero load input, matching our concept to the optimum balance found in my optimal balance study.

4.5.4 Analysis (DB)

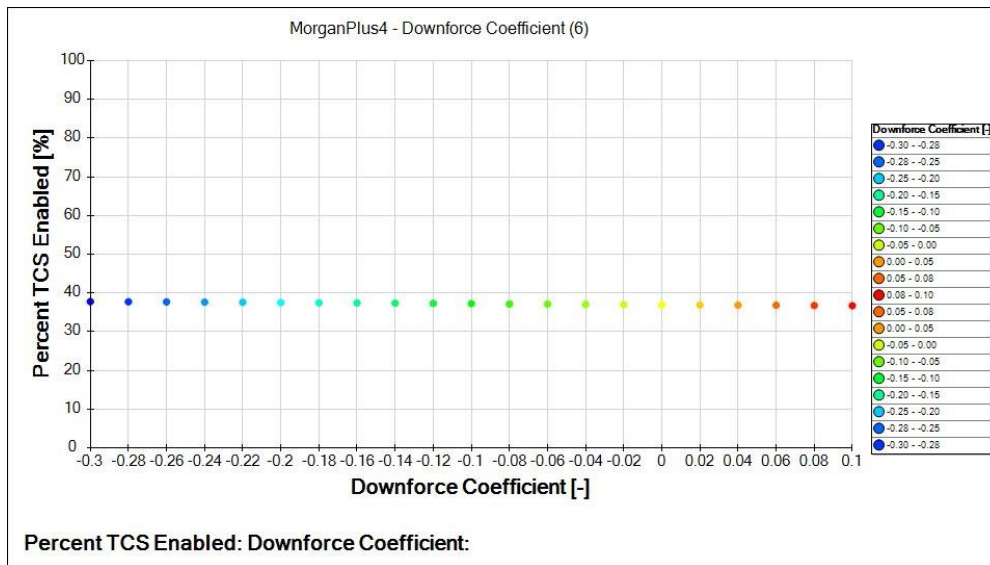
4.5.4.1 Initial Simulation (DB)



Graph 9 - Downforce, drag coefficients against lap time

The figure above shows the difference in lap time, downforce and drag coefficients around Oulton Park International. It was clear that creating downforce (positive coefficient) improved the Morgan's lap by nearly a whole second, over its stock value of -0.316. The drag reduction also improved lap time in a very similar way, although had less of an effect as downforce. As predicted from this data, the aero team will need to create something that adds downforce but doesn't increase drag adversely from its stock value of 0.494.

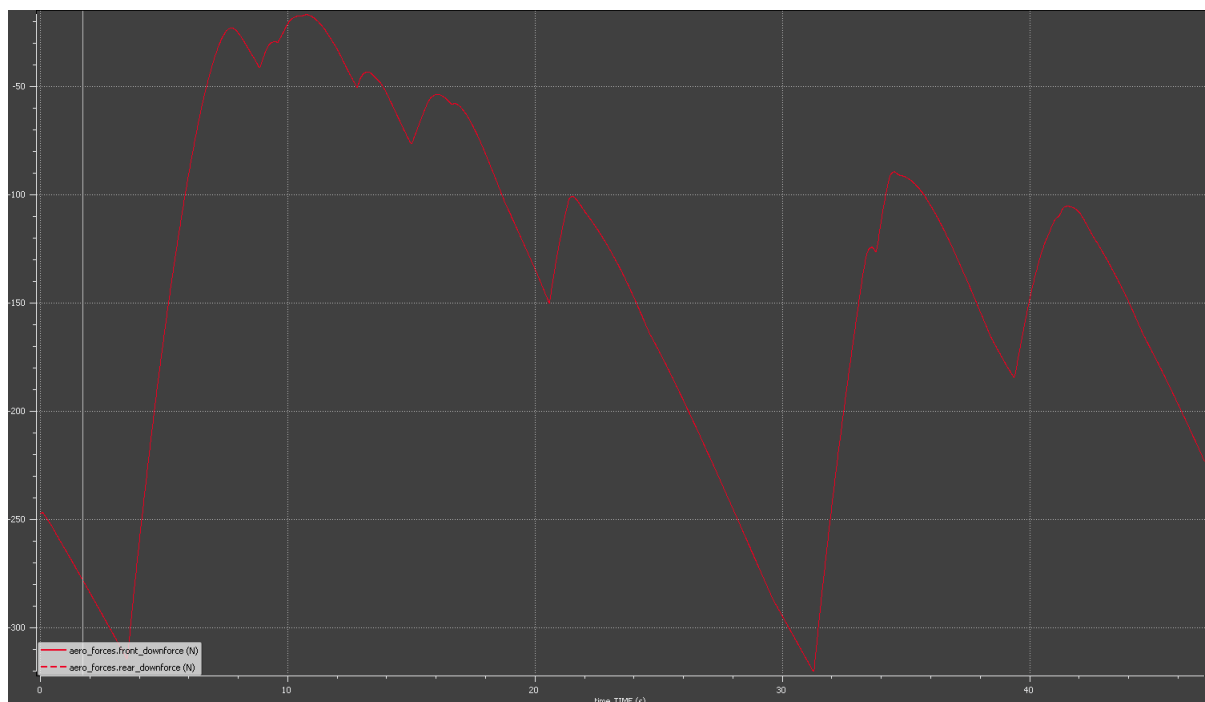
Percent TCS Enabled: 37.786 Downforce Coefficient: -0.300



Graph 10 - Downforce coefficient against traction control percentage

Percent TCS Enabled: 36.724 Downforce Coefficient: 0.100

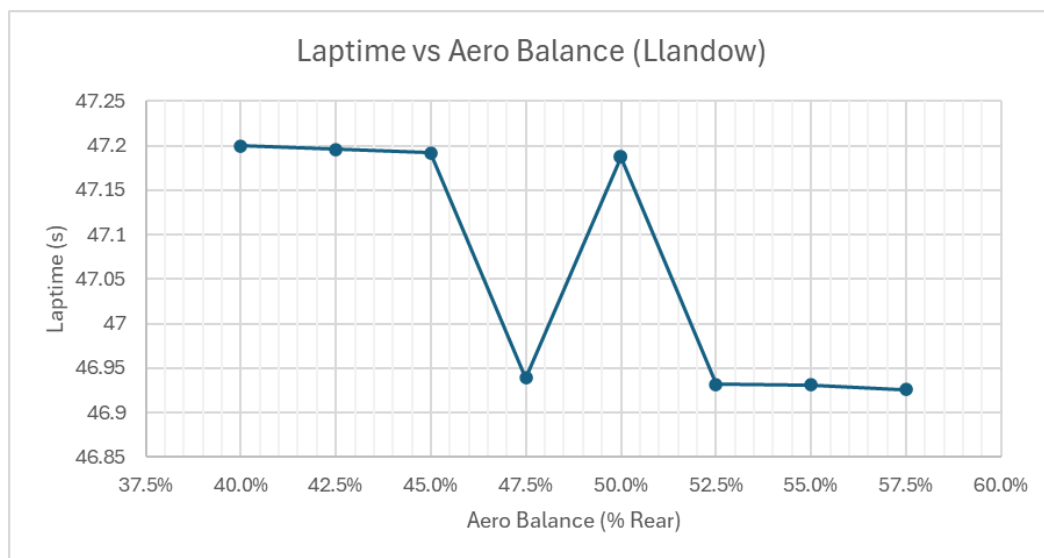
Above is a graph investigating the effect of downforce coefficient increases on the traction control system (TCS) and it measures how much the TCS is enabled over the course of the lap. Less TCS enabled means more grip and better transfer of power to the ground. As shown by the data readouts, at close to the Morgan's stock value the system is enabled over 1% more than at 0.1 coefficient. Therefore, the wing we develop should aim to improve the traction at the rear wheels.



Graph 11 - VI Grade baseline aero forces graph

This graph shows my first output graph from the more complex software, VI Grade, and helps to understand the aero force over the car. The circuit used for this test was Llandow (track map see appendices) which has a mix of slow and fast corners. Shown at the start of the graph, the Morgan has large amounts of lift through the slow first corner, then becomes more neutral at top speed down the back straight.

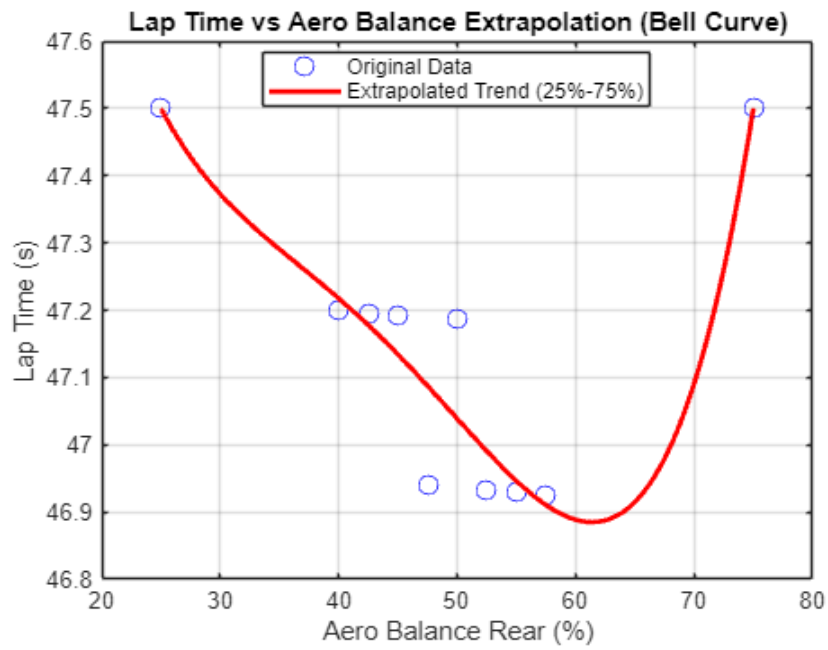
4.5.4.2 Aero Balance Analysis (DB)



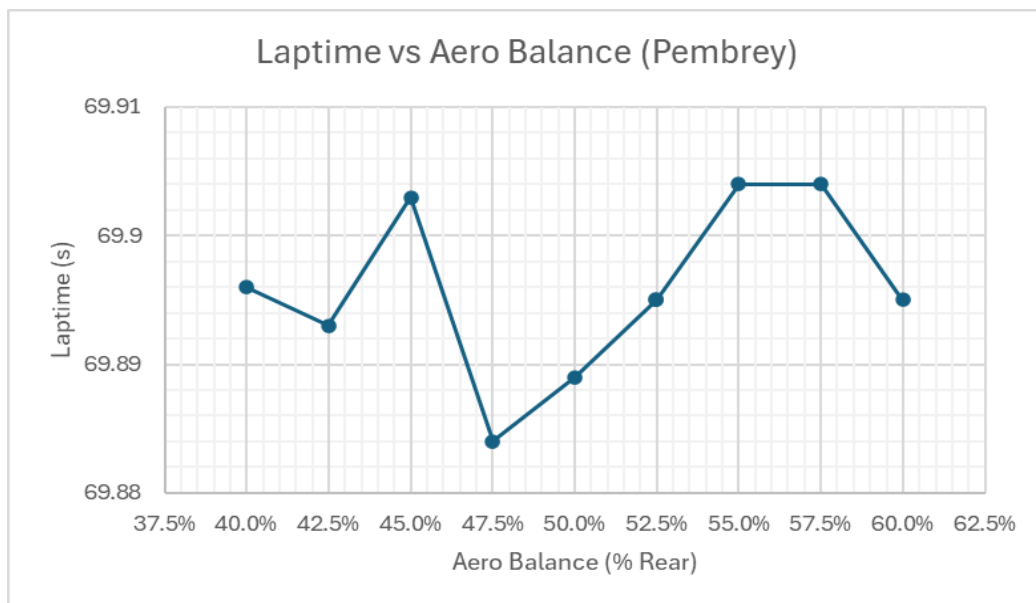
Graph 12 - Llandow aero balance graph

This graph above displays the data from the table of results for the balance test. It's clear to see that 57.5% is the fastest time set across the tested balance figures and overall, there is a trend towards quicker lap time with higher rear bias. There appears to be a spike in the data at the Morgan's stock balance of 50% which is interesting to see that the car seems to be quicker just below or above this balance. However, this could be a data anomaly to do with the simulation software or driver model, therefore it may not be fully representative of performance.

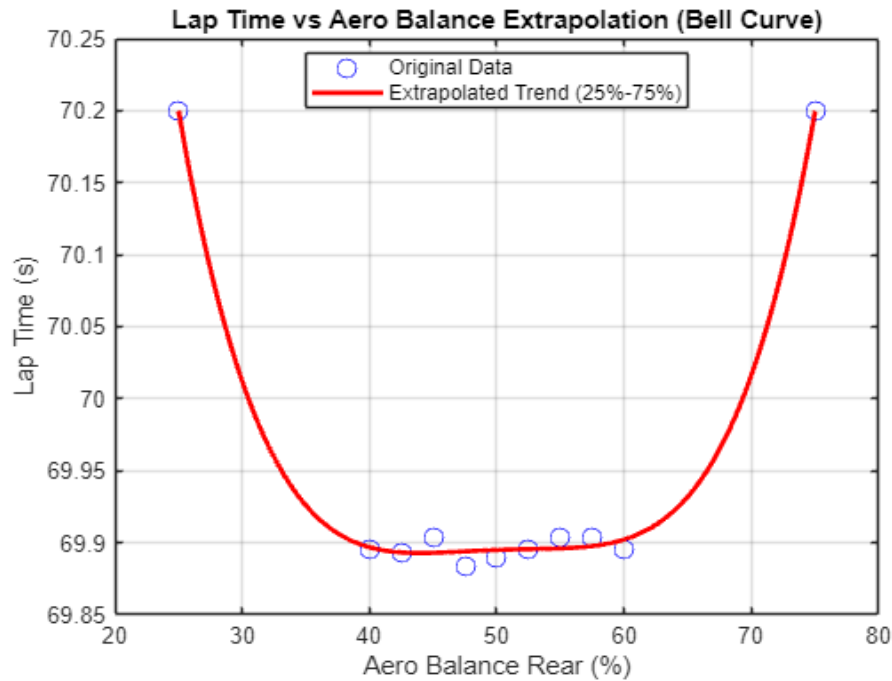
From this test I decided to extrapolate the data to get a full picture of how the car performs at values that weren't tested, including 60% which failed within the software, due to a static equilibrium failure.



Graph 13 - Matlab extrapolation graph for Llandow aero balance analysis



Graph 14 - Pembrey aero balance graph



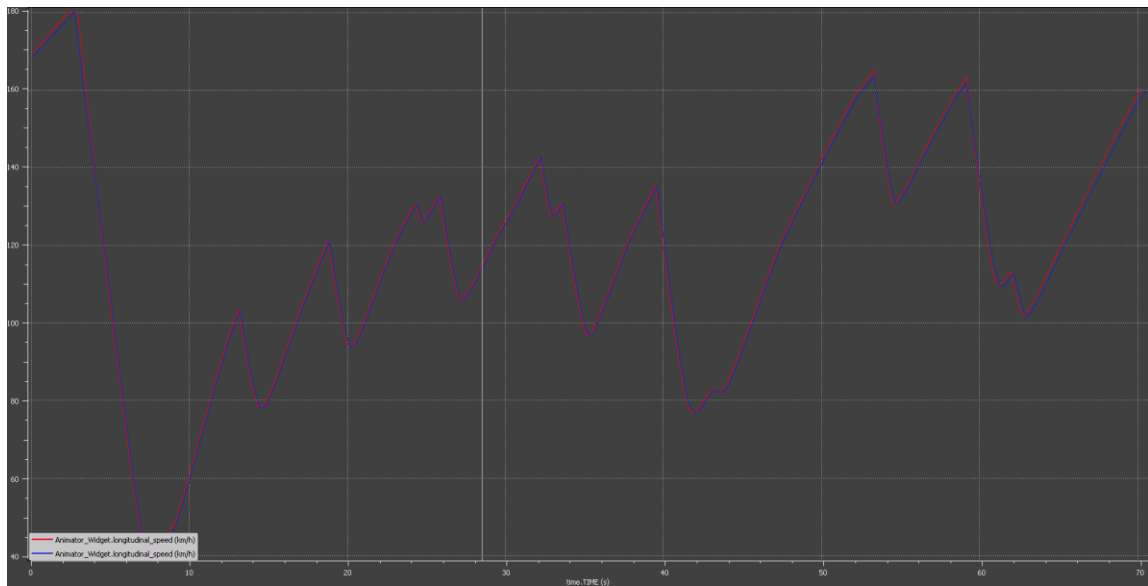
Graph 15 - Matlab extrapolation graph for Pembrey aero balance analysis

The results and extrapolation above show that interestingly, around Pembrey, the Morgan prefers more frontal aero than rear bias (opposite to the Llandow test). This could be due to the nature of the corners requiring more turn in and front grip. However, it was also observed that the changes in balance made very small lap time differences.

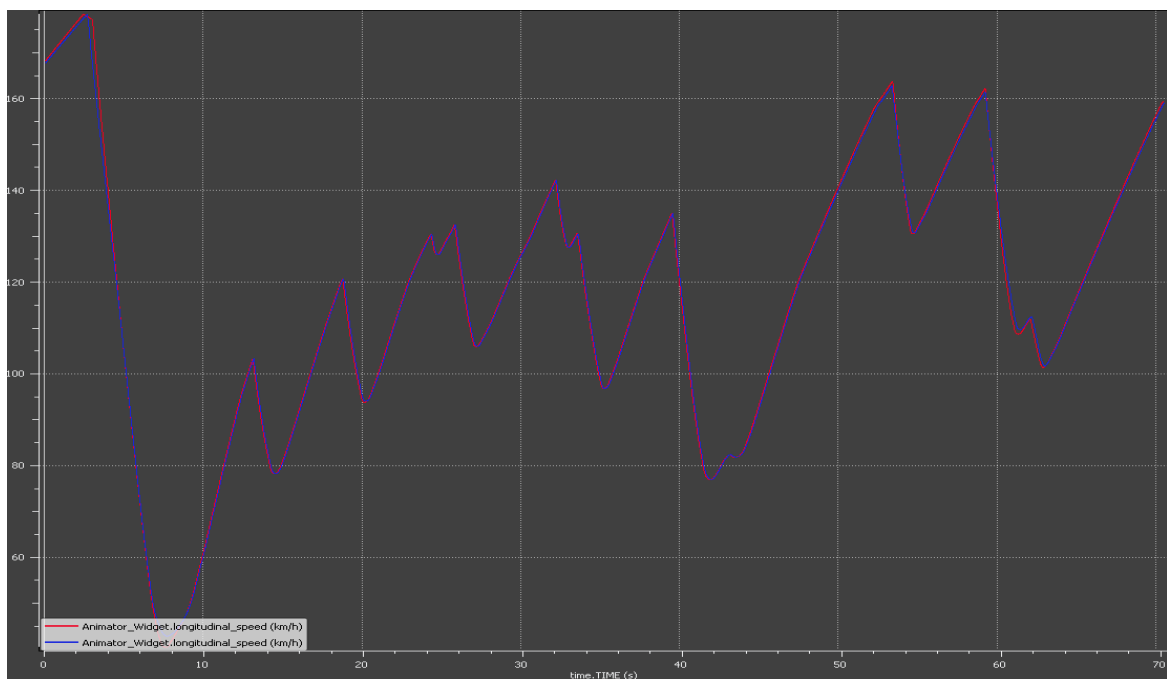
4.5.4.3 Comparing Rear Wing Models (DB)

4.5.4.3.1 Pembrey (DB)

Firstly, I tested the concepts around Pembrey (see appendices) which is a longer, more aerodynamically demanding track than Llandow. Therefore, I felt that the test should include both tracks. I tested the wings active and static which is shown on the graphs, with active in RED and static in BLUE.

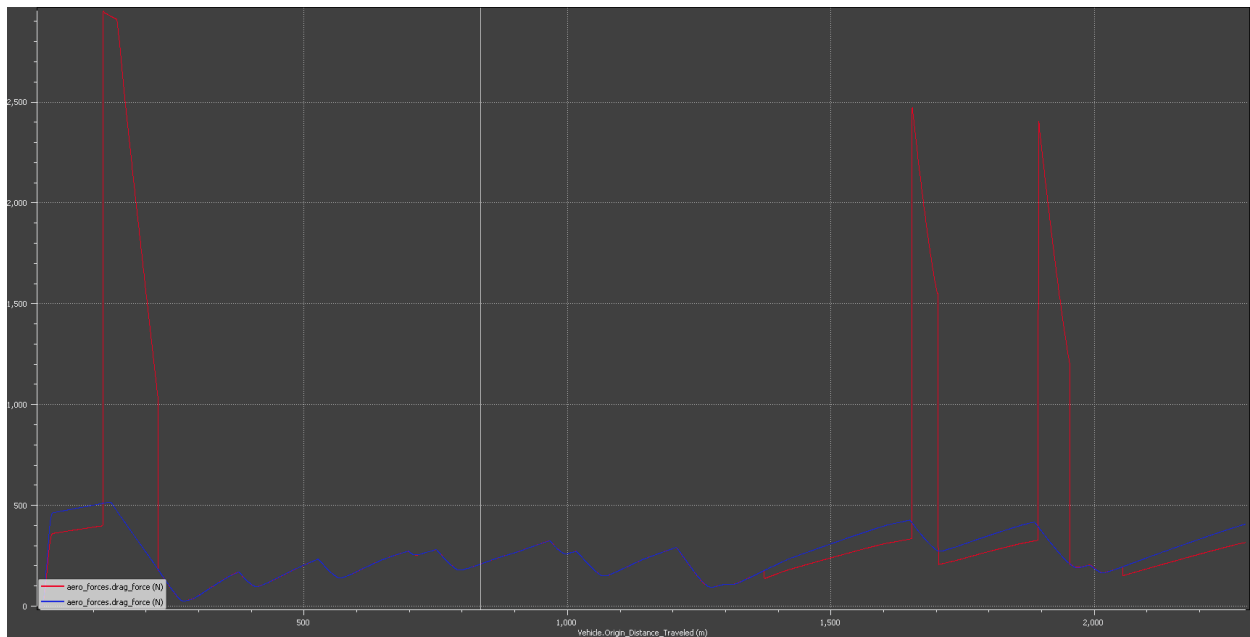


Graph 16 - Modified Selig 1223 speed vs time graph

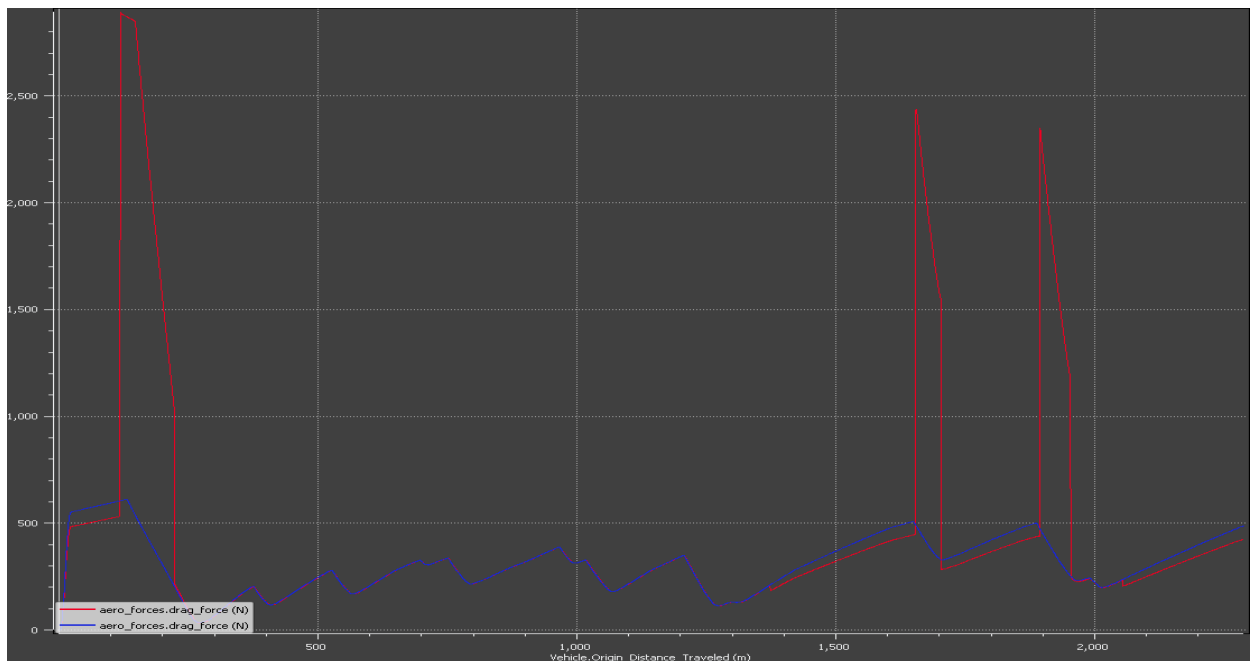


Graph 17 - Standard Selig 1223 speed vs time graph

The speed time graphs above show some of the main differences in the concepts, with the modified profile surpassing 180 km/h compared to the standard which just fell short. This led me to believe that increased drag on the standard Selig was having a large effect on speed.



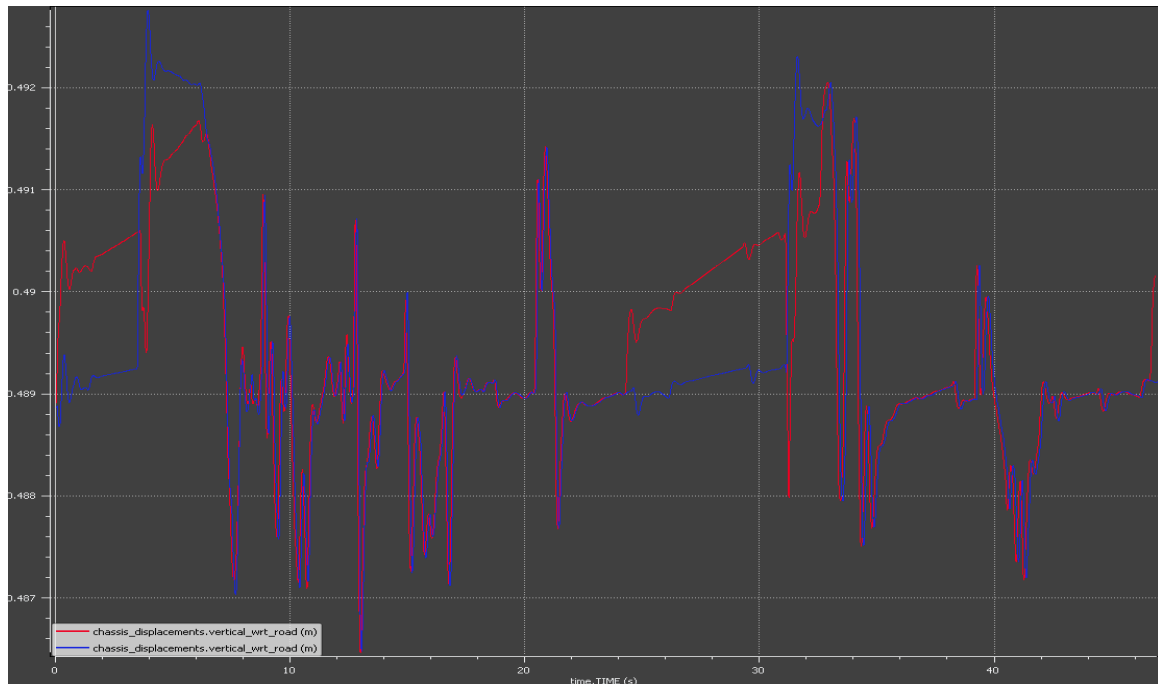
Graph 18 - Modified Selig 1223 drag vs distance graph



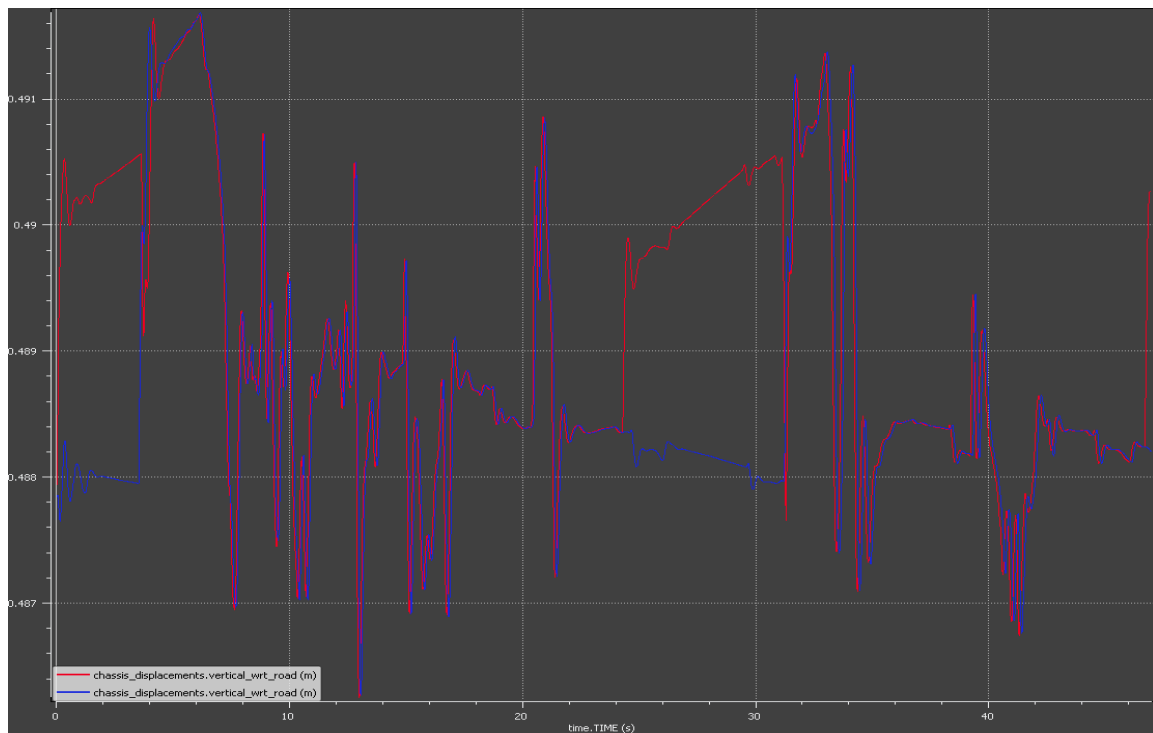
Graph 19 -Standard Selig 1223 drag vs distance graph

These drag graphs clearly highlight the difference, showing that the standard Selig has higher drag on average on the static blue line. However, it is interesting to note that despite lower drag static, once in air brake position, the wings are almost identical.

4.5.4.3.2 Llandow (DB)



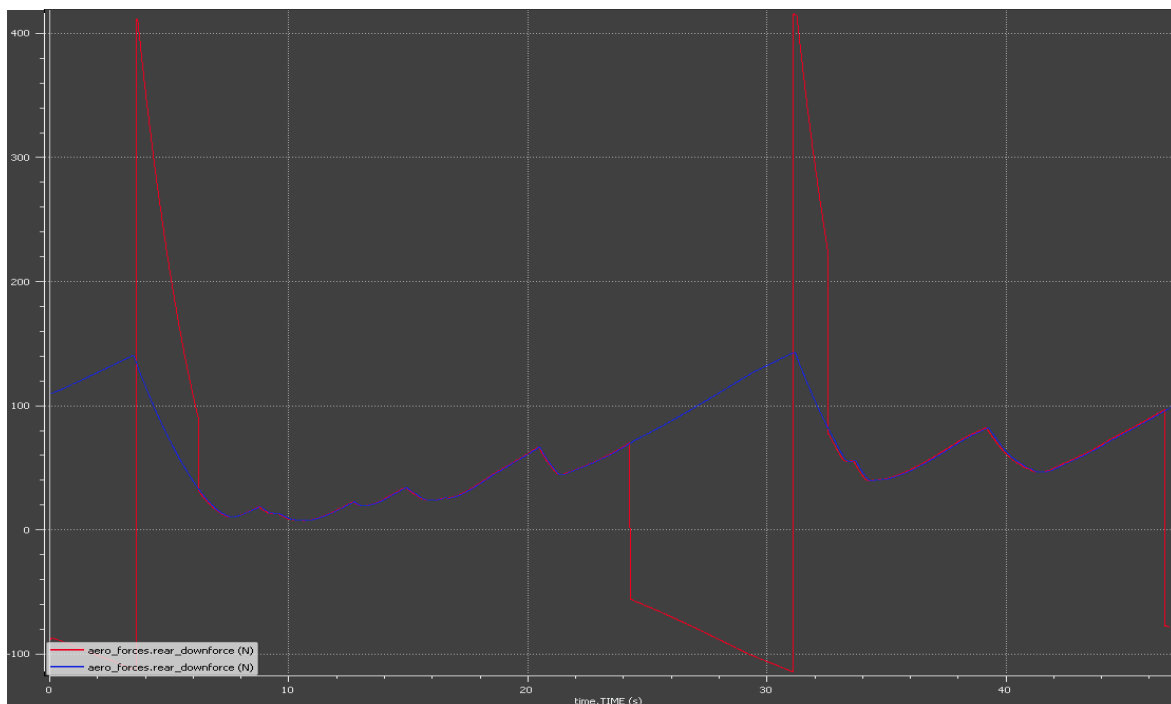
Graph 20 - Modified Selig 1223 ride height vs lap time



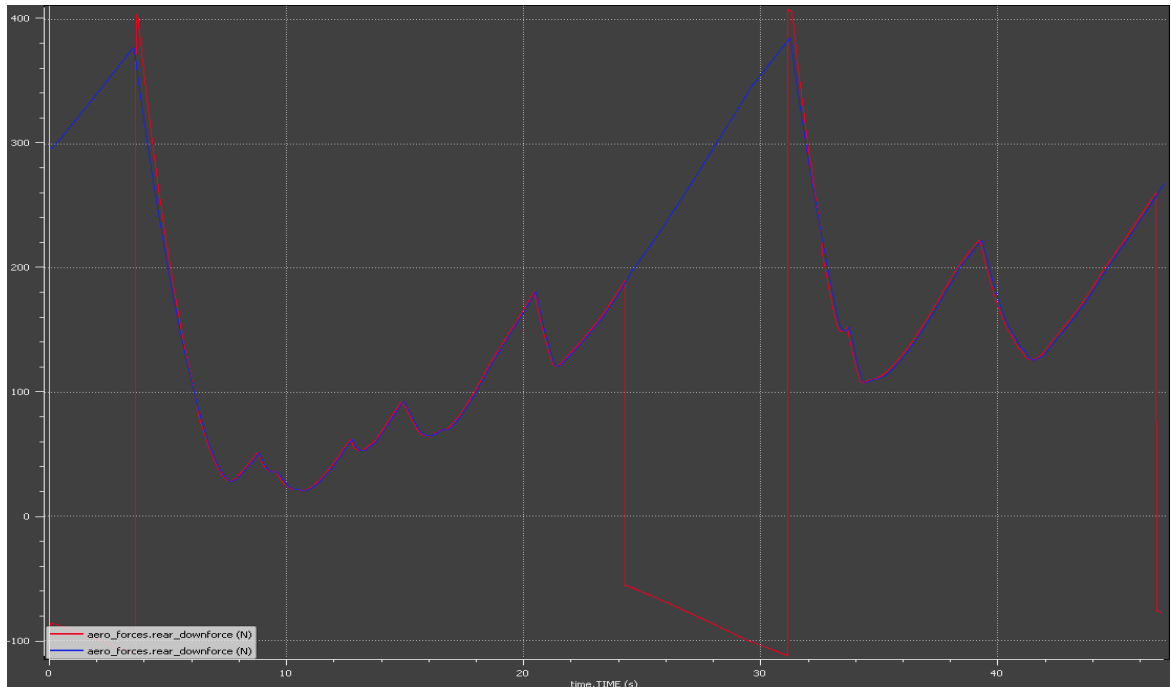
Graph 21 - Standard Selig 1223 ride height vs lap time

These ride height graphs above show the difference in drivability between the concepts, with the modified Selig looking much more manageable. This is due to the active wing providing a good

reduction in how much the ride height variance, which will improve the corner stability and braking. The standard wing varies lots and doesn't improve much when made active.



Graph 22 - Modified Selig 1223 rear downforce vs lap time graph



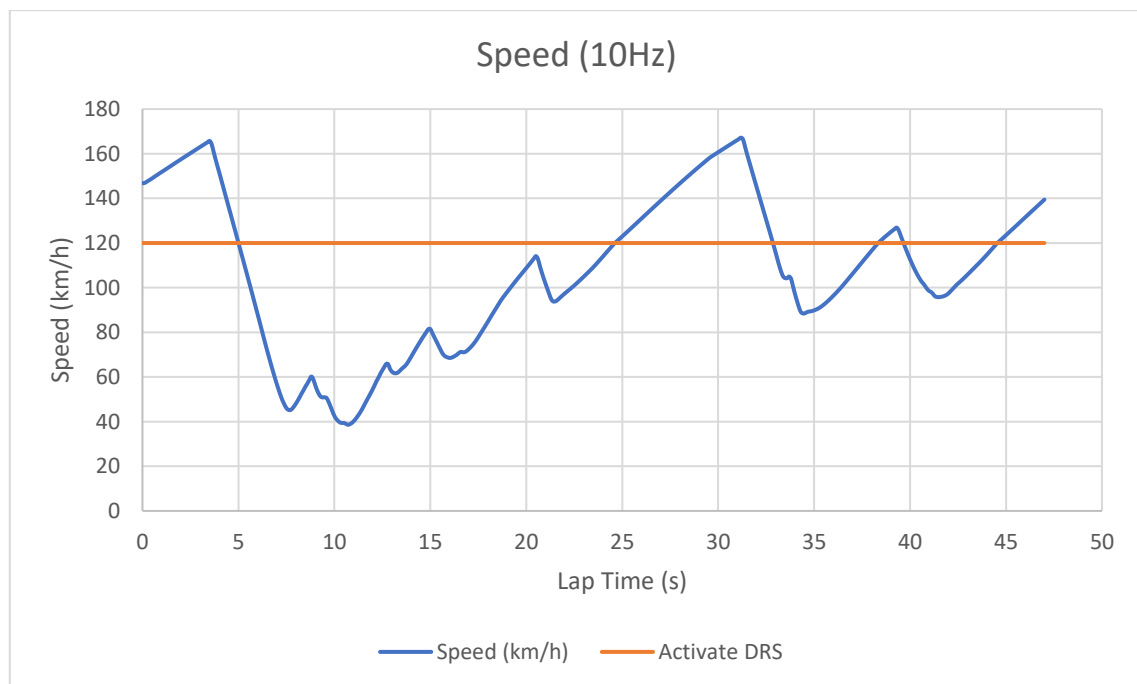
Graph 23 - Standard Selig 1223 rear downforce vs lap time graph

There is a large difference in the above rear downforce graphs as the standard concept produces much more rear downforce. However, with the extra drag and the factors that have negatively

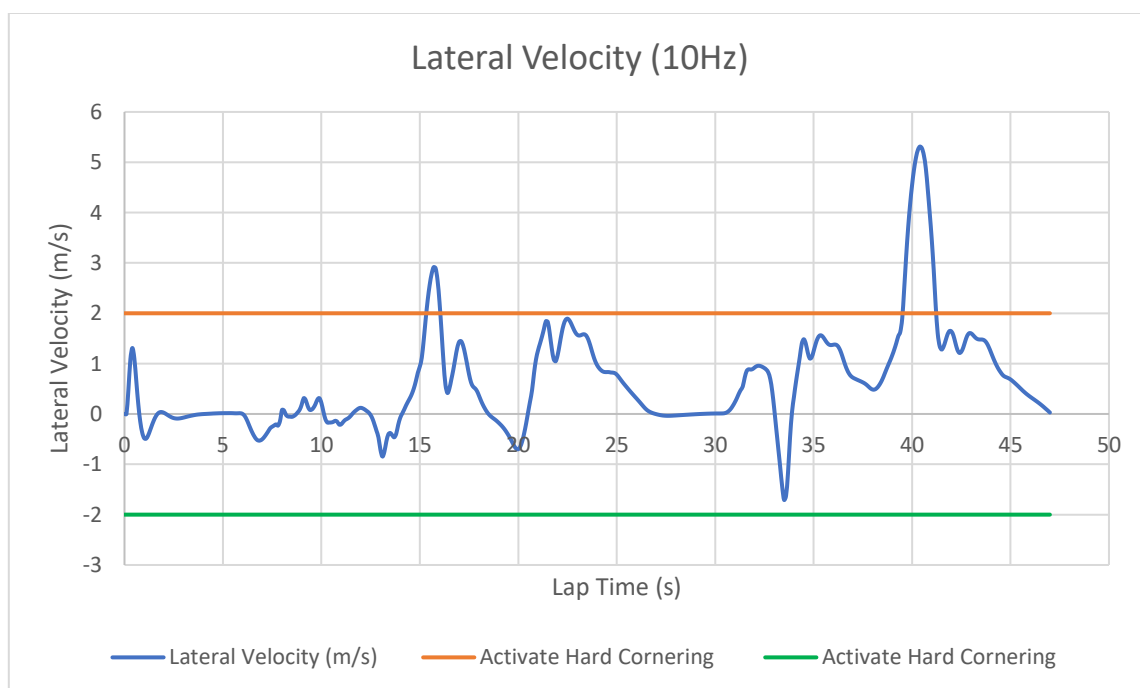
affected the handling including the aero balance being too high on the rear, we planned to use the modified Selig 1223 to do final simulation analysis (Remmerie, W. 2018).

4.5.4.4 Control Systems Development (DB)

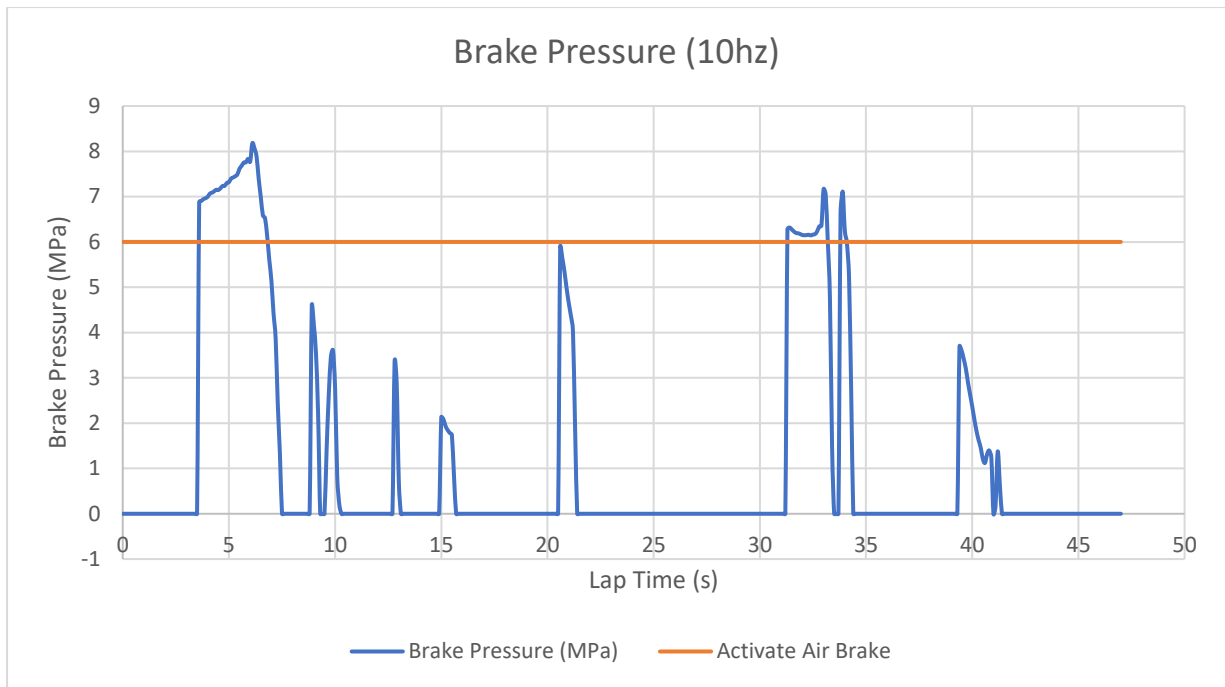
I was also included in providing the control systems department with data of a lap at 10 hertz frequency to be used in the final model to test the movement of the active wing systems. Here are the graphs of the three adaptive inputs:



Graph 24 - Speed vs lap time graph at 10hz



Graph 25 - Lateral velocity vs lap time graph at 10hz



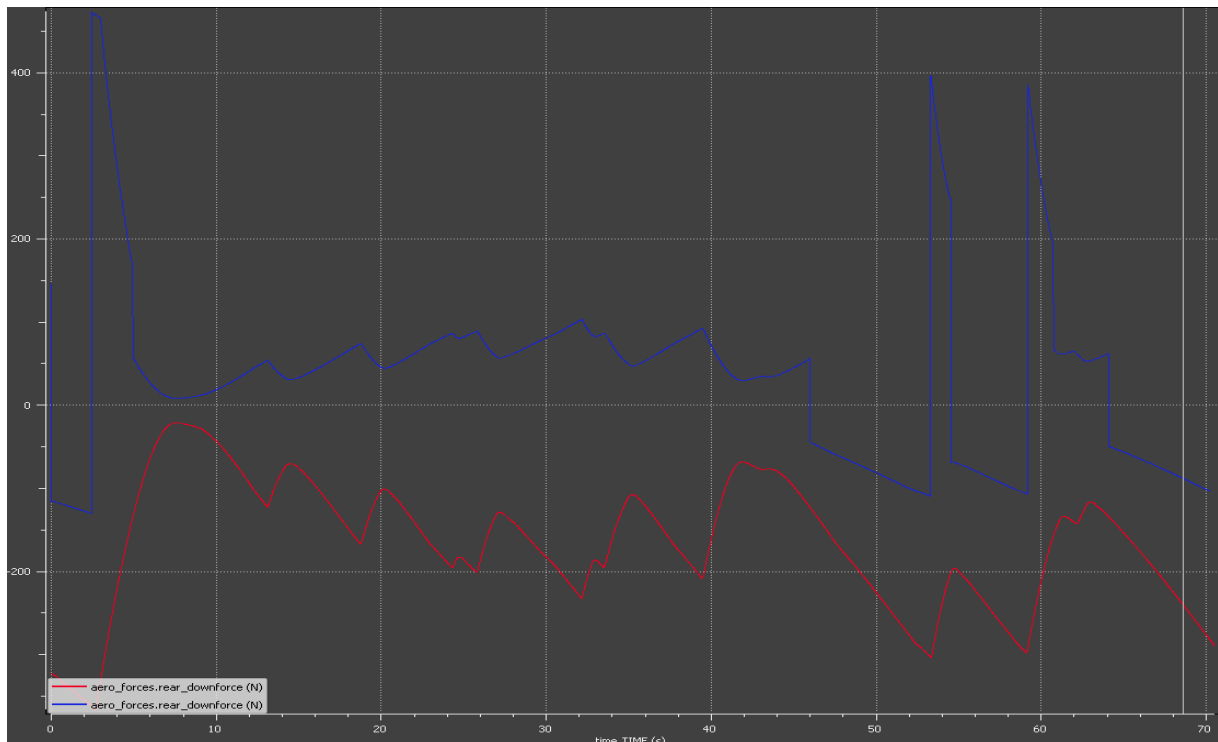
Graph 26 - Brake pressure vs lap time graph at 10hz

Using the drag graph from the Llandow active and static tests I recorded the data for drs, braking and corner scaling points to let the control systems department know the points that the wing should move.

4.5.4.5 Final Simulation Analysis (DB)

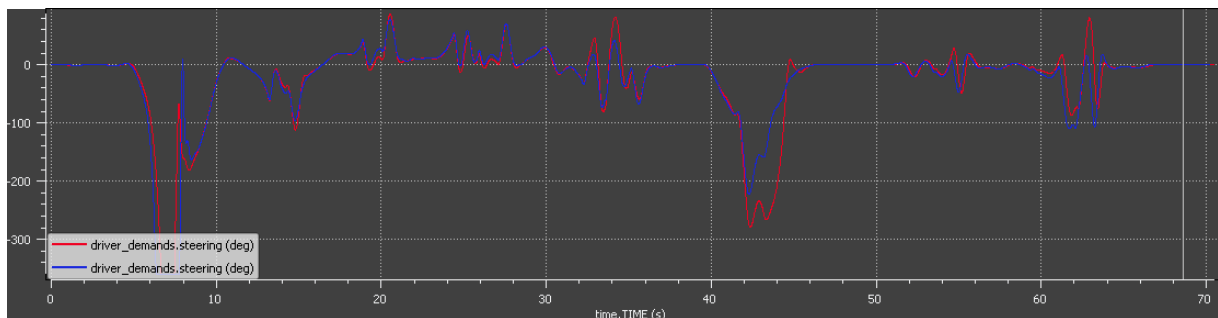
To conclude the rear wing evaluation, I ran simulations on both Pembrey and Llandow for analysis side by side on the same graphs. Our final wing concept solution is displayed in **BLUE** and the stock Morgan in **RED**.

4.5.4.6 Pembrey (DB)



Graph 27 - Rear downforce vs lap time

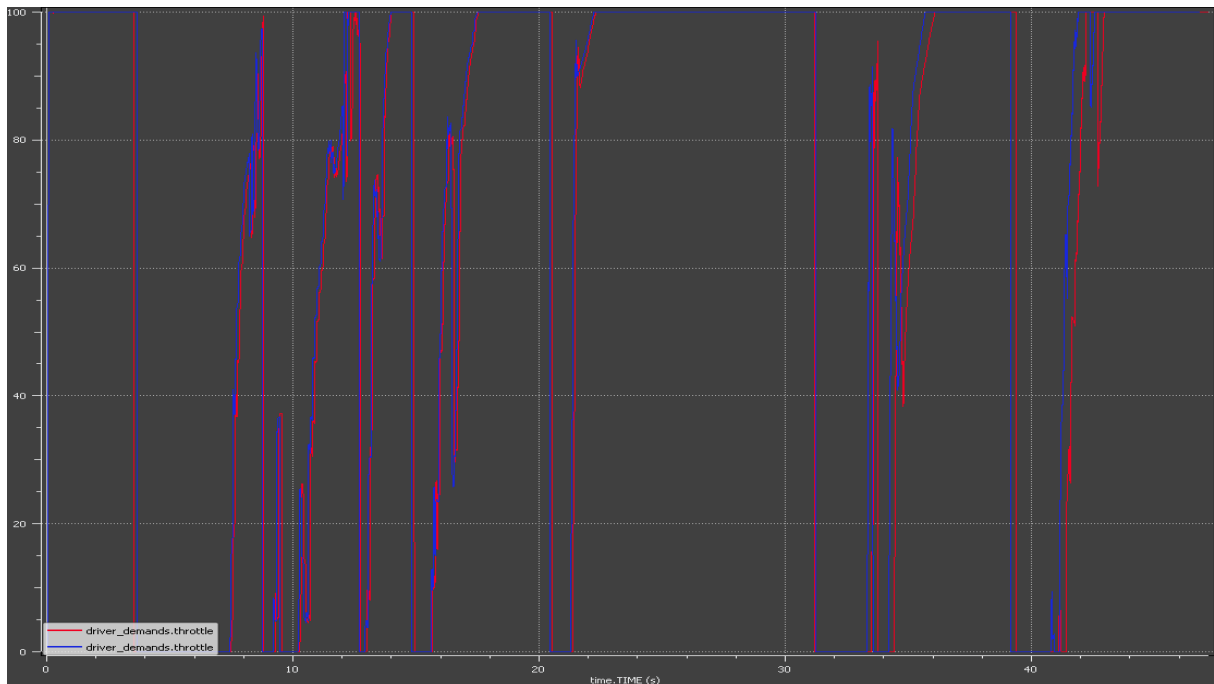
This downforce comparison graph above shows the big improvements made to the Morgan from only the rear wing. From a car producing lift, it now produces downforce at every corner, improving handling overall.



Graph 28 - Steering driver demands vs lap time

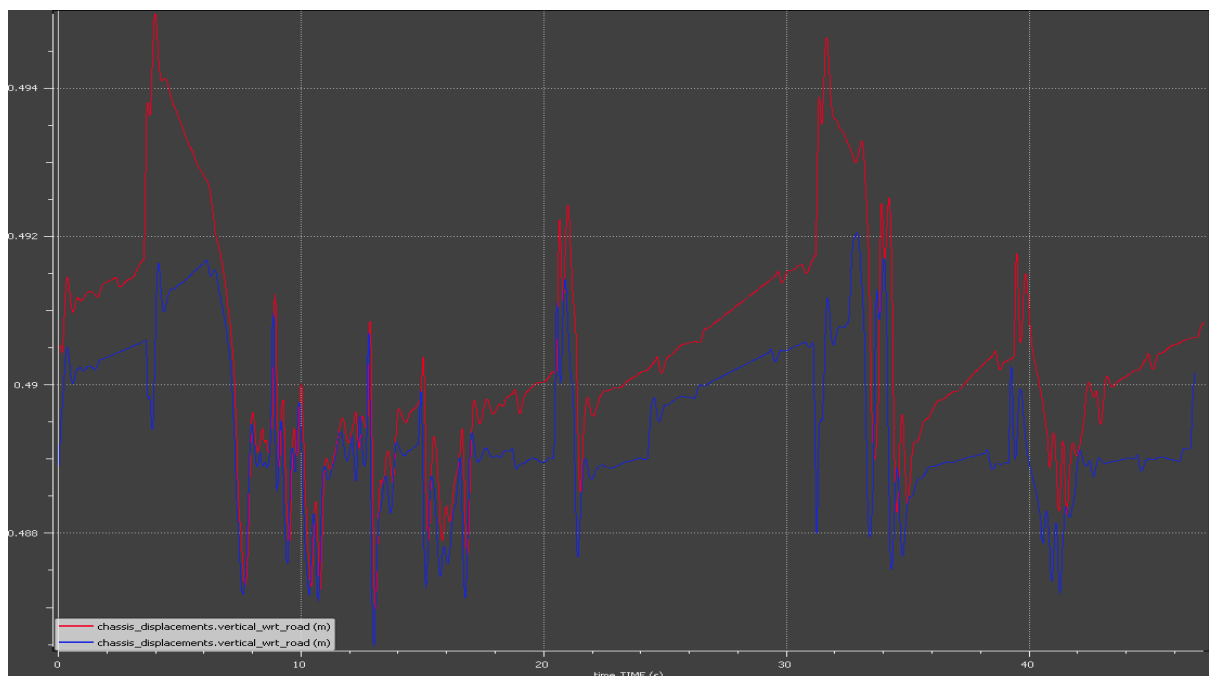
The steering against lap time graph above highlights further the improvements to handling, with a focus on the section of the graph from 30 seconds to 45 seconds. It's clear that the stock Morgan requires more steering and corrections, showing how the car has improved in stability and driveability.

4.5.4.7 Llandow (DB)



Graph 29 - Throttle input vs lap time graph

The above throttle input graph around Llandow displays the improvements to power delivery. The blue line picks up fractionally earlier at every acceleration point, as well as removing the large lift that the stock car experiences into the last corner at around 43 seconds.

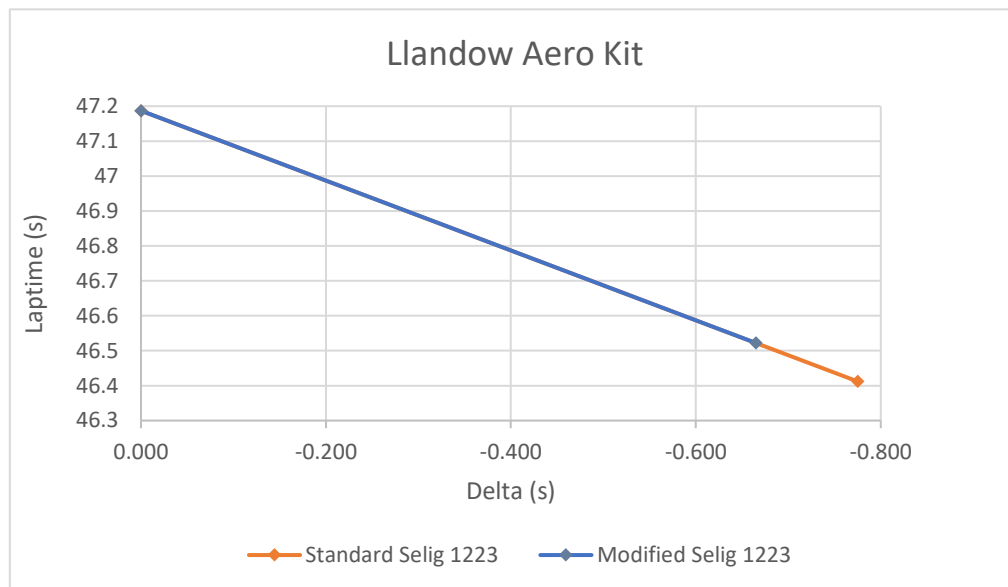


Graph 30 - Ride height vs lap time graph

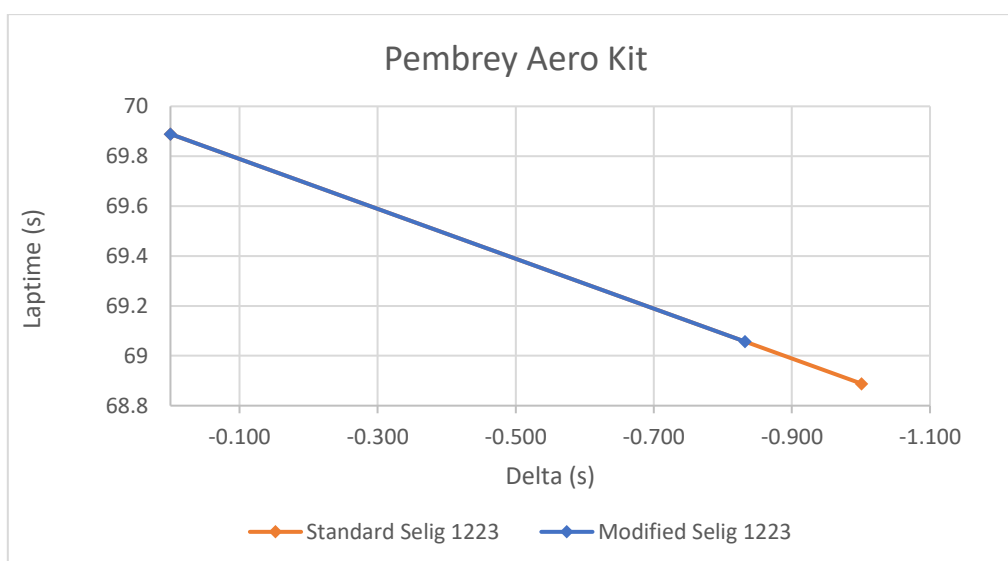
The above ride height graph is a good representation of how the car is more stable due to the ride height varying less. The downforce pushes the car down at high speed rather than lifting, therefore

pitch and roll have been reduced in most areas (Diasinos, S., Barber, T. and Doig, G. 2017). As a result, the car will also be more stable over kerbs, bumps and at high speed with our wing solution.

4.5.4.8 Aero Package Considerations (DB)



Graph 31 - Llandow aero package lap time and delta

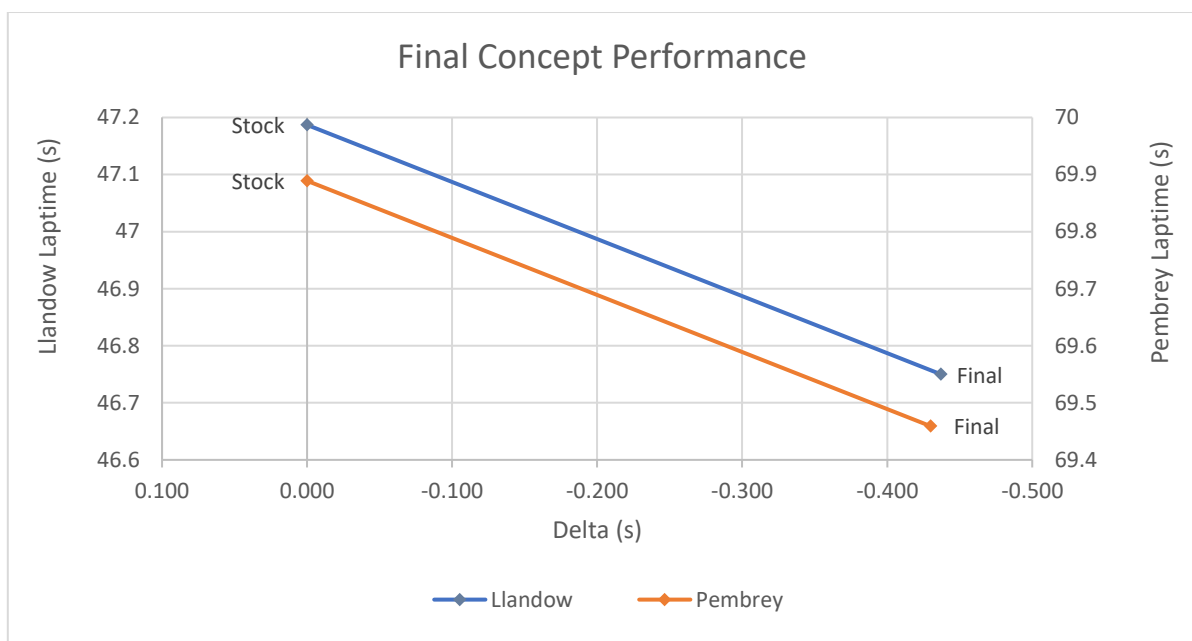


Graph 32 - Llandow aero package lap time and delta

These aero kit graphs show the improvement in lap time with optimal balance of 47.5% rear for Pembrey and 57.5% for Llandow. The balanced standard wing is clearly quicker by over a tenth, but this is because of the aero balance being too rear bias, and these tests confirm that evaluation.

4.5.5 Project Review (DB)

To review my simulation role, I was still able to evaluate and analyse the concept wings that the aero department provided me with. The simulation tests delivered logical and comparable data which displayed clear changes and improvements. There were some issues experienced during the project, mainly down to planning the use of co-operating with Simulink. I had initially set my plan to be inclusive of the use of Simulink to model a more detailed active rear wing to improve accuracy and increase possibilities however, there was IT issues related to file permissions on campus. I did attempt to rectify this by applying for a temporary demo license which took too long to be sent by VI Grade, and due to the upcoming deadlines, I had to alter my plans. However, I feel that I worked well with the group, and we came to a good final active rear wing solution which I was able to contribute towards.



Graph 33 - Llandow vs Pembrey final concept performance

4.6 Control Systems and Mechatronics (AW)

To develop the code and the mechatronics for the wing, I utilized model in the loop testing. I know what we require the system to do, automatically change wing angle based on 3 or more inputs, so if I achieve this at a small scale I can verify it works and rectify any bugs before it is implemented into the full-scale wing on a morgan. Model in the loop testing involves testing a controller model at the component or system level within a simulation environment (Cummins, 2024). For the morgan wing this meant creating simulated track data for a vehicle which I can then use as inputs to test my code and hardware.

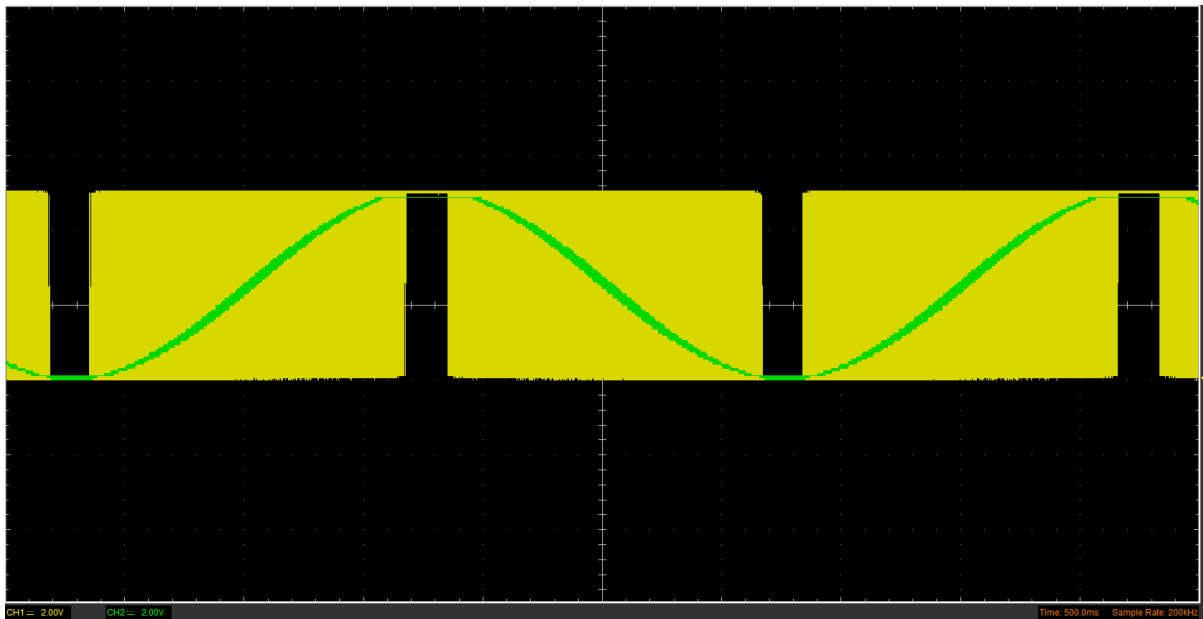
I received simulated data from Dylan in the simulation team created on VI grade, which has been formatted to 10 Hz on a excel document. This could then be brought into a MATLAB code to create track data I could feed into my Arduino to verify if the controller can control the plant as per the requirements (Ni.com, 2024).

4.6.1 Finding the most suitable capacitor (AW)

To convert the PWM signal from the track data into a stable analogue voltage the Arduino can read, you need to use a RC low pass filter. The PWM signal is at 490 Hz on pin 3, 9 and 10 on the Arduino. Therefore, we are using a 10k resistor to set the cutoff frequency to $1/10^{\text{th}}$ of the PWM signal, making it 49 Hz. A lower cutoff frequency is beneficial as it will give a smoother output and increase the response time. Using a 10k resistor also makes the maths easier.

When it came to finding what would be the best capacitor to use to effectively smooth the PWM waveform, I used an oscilloscope and a simple Arduino setup. This involved sending a sine wave input through the Arduino which is connected in a loop to a 10k resistor and a capacitor. I then connected the oscilloscope to the system.

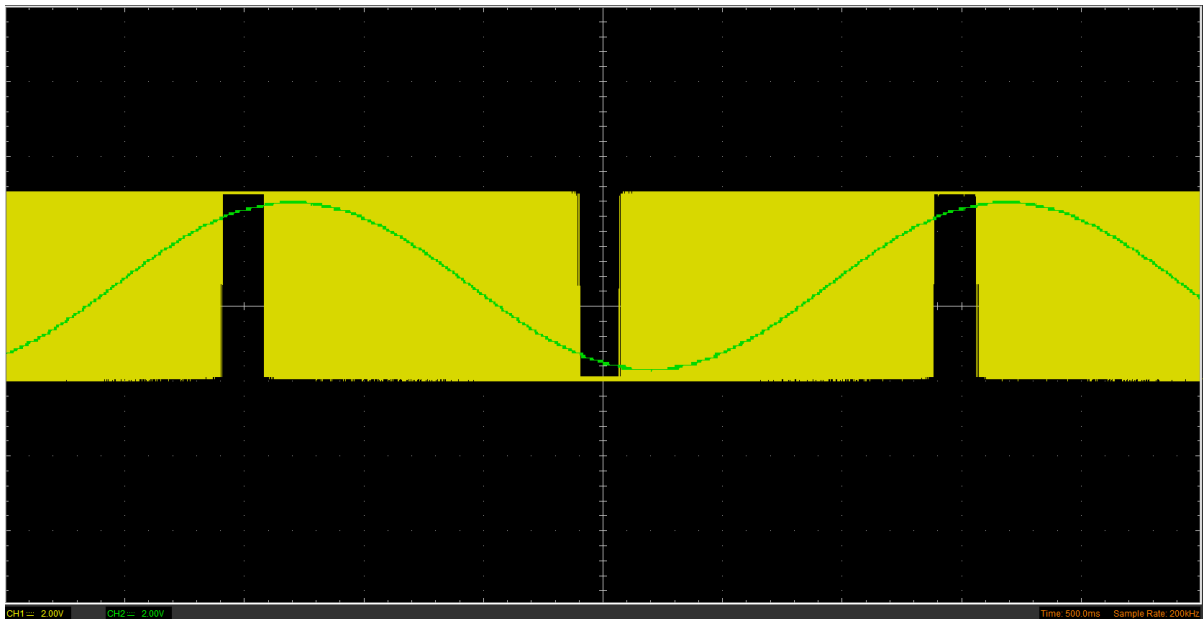
4.6.1.1 1 μ F 50V 10k resistance (AW)



The image above shows a screenshot from the oscilloscope when a 1 μ F 50V capacitor is being used in the system. The yellow section represents the PWM signal, while the green line represents the sine wave being input from the Arduino. For this example and the others, the PWM and the sine wave were set to 2V and the frequency to around 500ms.

From the screen shot above you can see the sine wave is quite thick, this means it has a lot of noise in the signal, likely caused by the cap being too low from the 10k resistor. Noise is variations in voltage or current that are often random, usually of relatively low amplitude and can make the motor randomly glitch (R.Keim, 2018). Also, in the screenshot the peak of the sine wave goes past the top of the PWM signal, this means not all of the 5V range will be utilised, only around 4V instead. However, you can see the peak of the sine wave is exactly in the centre of the PWM signal, this means there is no lag in the system with this capacitor.

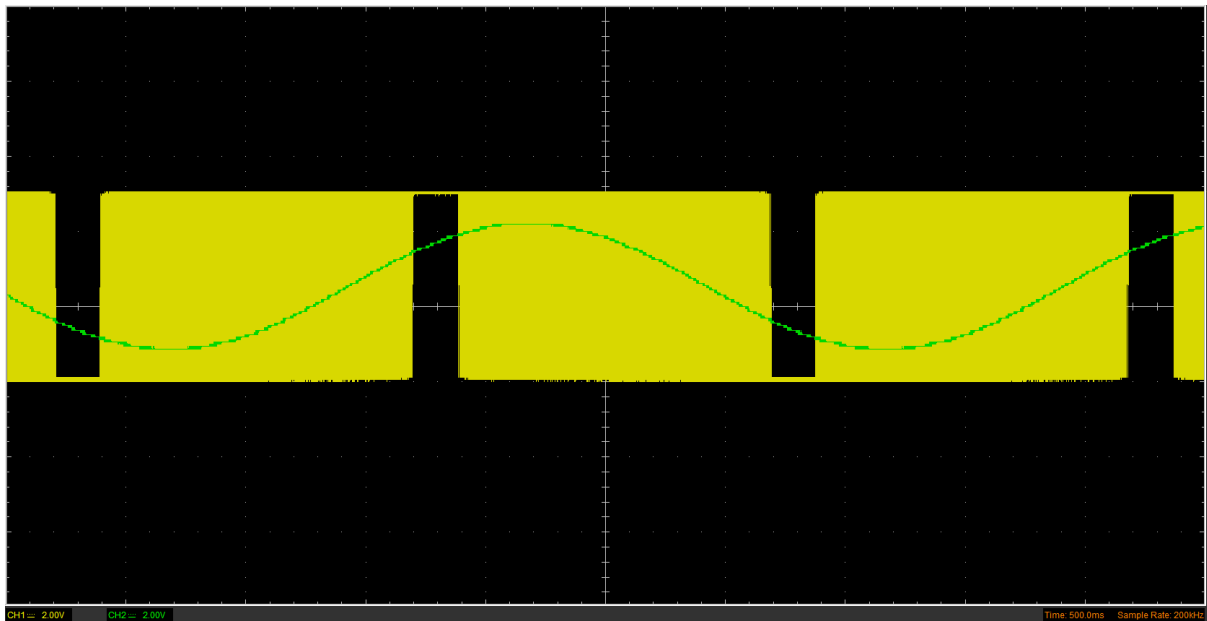
4.6.1.2 22 μ F 16V 10k Resistance (AW)



In this screenshot a 22 μ F 16V capacitor is being used in the system. This is the capacitor that I decided to go with to use on my system. As you can see it doesn't quite reach the top and bottom of the PWM signal, however it is very close, and this means that all of the 5V are being used. The sine wave is very thin meaning there is little to no noise coming from the system, which is ideal as the motor won't receive random unwanted signals.

With this capacitor the sine wave is quite delayed or lagging behind the PWM signal. This is not much of a concern as currently it is only for a simple small-scale model of the wing and as the whole system will be delayed so it won't massively affect the results. If I had more time, I would implement an Arduino digital to analogue converter to my system, this would allow me to adjust the sine wave so that it perfectly sits in between the PWM signal without losing any detail.

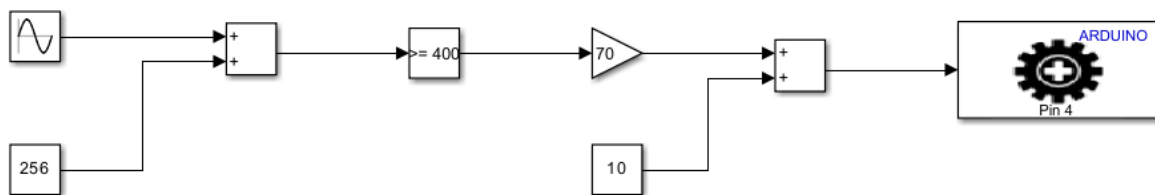
4.6.1.3 47 μ F 10V 10k Resistance (AW)



In this screenshot a 47 μ F 10V capacitor is being used. This is more just to show if the farads are increased too much the sine wave amplitude reduces too much so you miss out on a lot of information being passed through the PWM. It also very delayed.

4.6.2 Simulink development (AW)

4.6.2.1 Simulink code: Using a sine wave to utilise a compare to constant block. (AW)

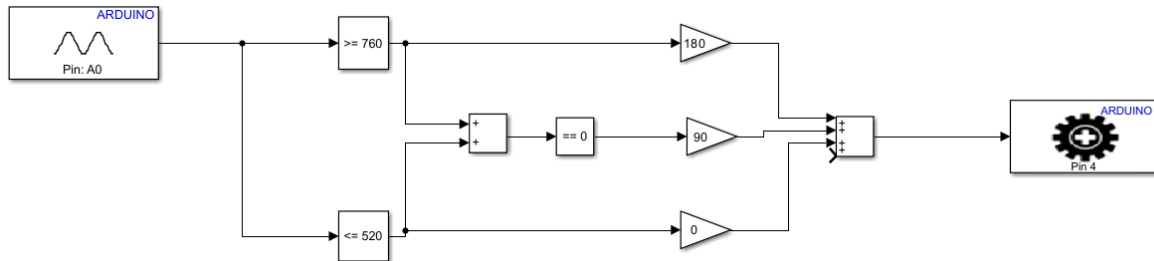


Above in the screenshot you can see a simple Simulink code I created using a sine wave as an input. This allowed me to develop my understanding of signals and Simulink. As sine waves amplitude is equally in the positive and the negative a constant has been added to the sine wave to shift the waves up on the y axis making it positive throughout the whole wave. This came in useful when I had to also adjust the 10-bit input from the Arduino to suit the simulated code.

Because we are using a servo motor which has a range of 180 degrees, it reads inputs as degrees to move not speed to spin. Therefore, if you give it a constant of 10, it will move to 10 degrees from 0 and stay there, not spin at 10mm/s. In this code the wing is being given a constant input of 10

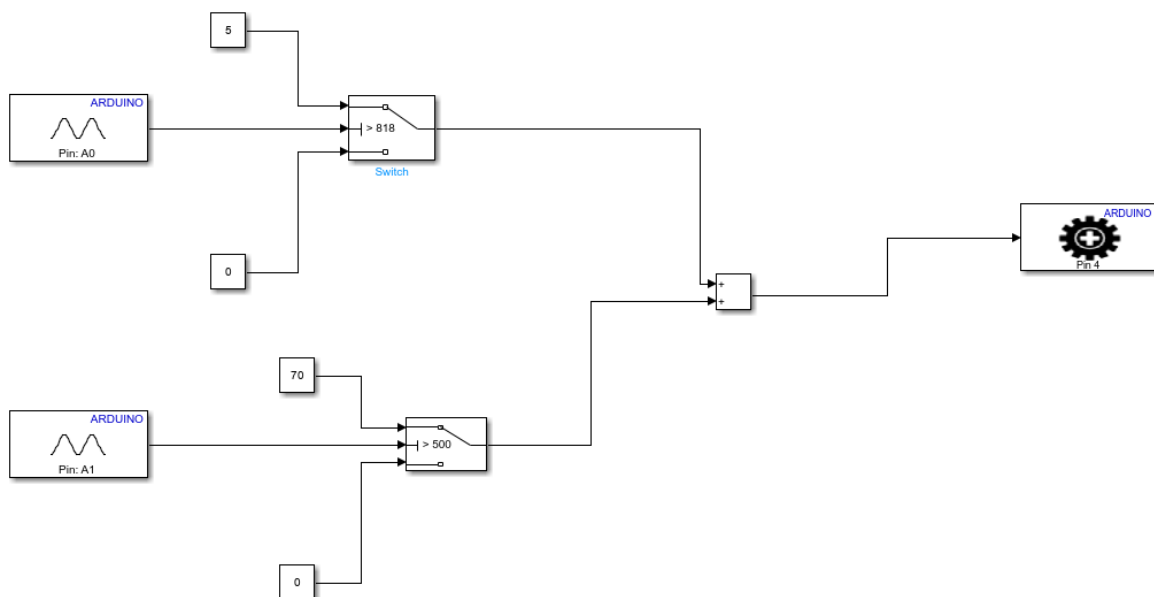
degrees, which will be the starting angle of the wing. The optimum standard angle has been determined by the simulation and aero team but can be easily adjusted on the Simulink code.

4.6.2.2 Simulink code: 3 different angles using compare to constants.



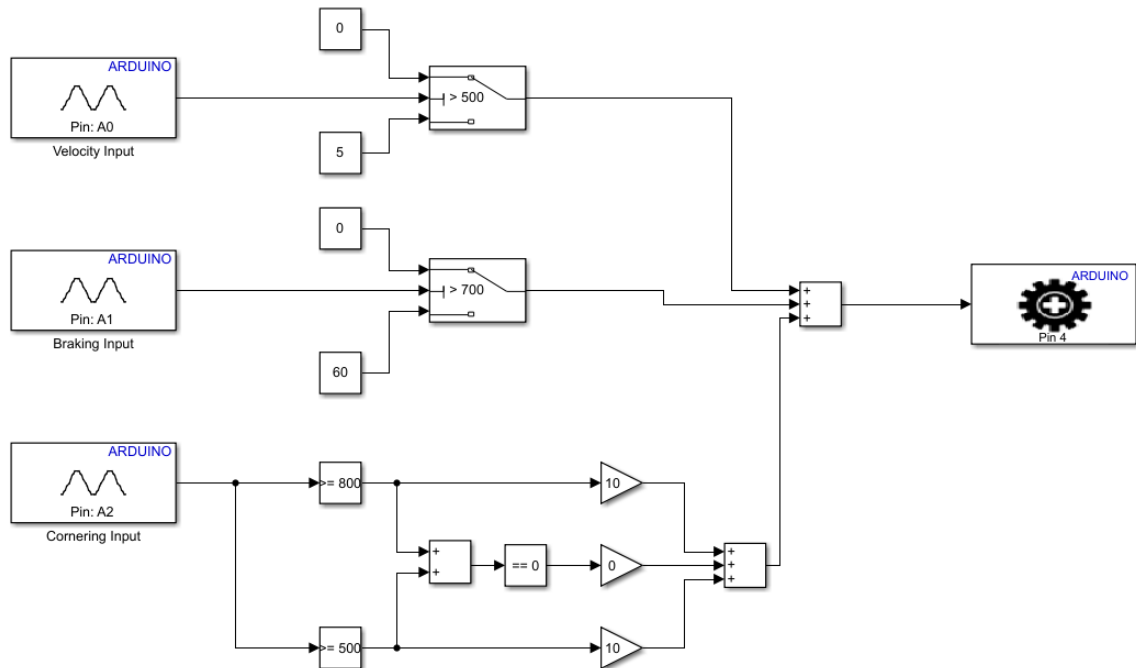
The code above allows for 3 different angles to be produced from a single input from the track data instead of just 2.

4.6.2.3 Simulink code: 2 Arduino inputs using switch blocks over compare to constants (AW)



In this code I was looking at using switch cases over compare to constant blocks and having 2 inputs go into one output. Switch blocks are essentially a more efficient way of have two angles for one input. They give the same result, but with less blocks. When it comes to adding two inputs to one output I just linked the two branches of code with a sum block.

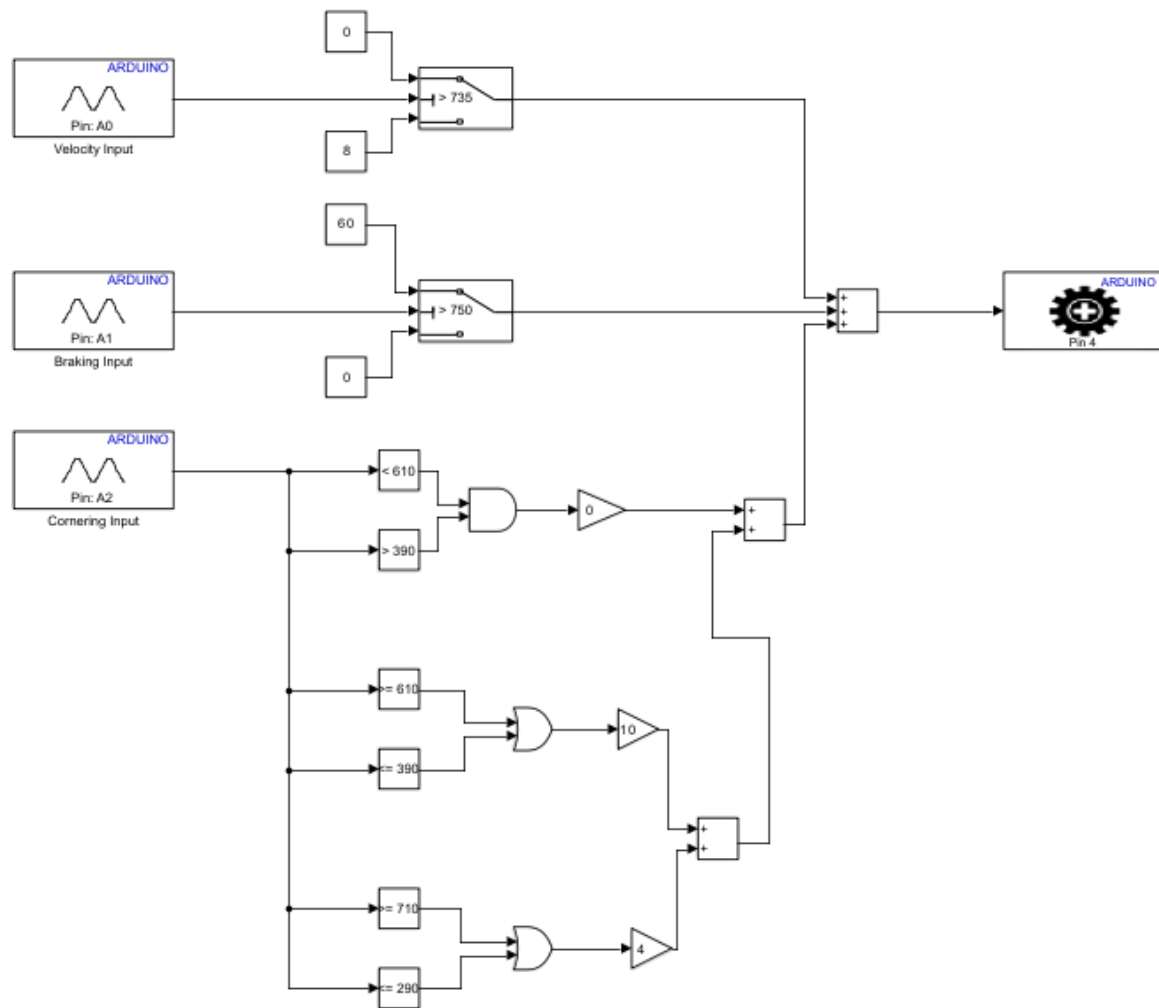
4.6.2.4 Simulink code: 3 inputs with compare to constant blocks and switch blocks for 2 of 3 different angles for each input. (AW)



Above is a more complete variation of how my Simulink code look. I have temporarily added thresholds on when branches will be active just to allow me to confirm it works.

This code has 3 inputs: Velocity, Braking and Cornering. This gives the wing a total of 5 different angles it can move to while going around the track. 0, 5, 10, 20 and 60 degrees. Each branch can give an input of 0 degrees so when they are not active they do not affect the input you want at the time. Because velocity and braking only really need two angles I have utilized switch blocks. 0 degrees is for top speed minimum drag, 5 degrees is the standard angle the wing will be set too, 10 and 20 degrees are for cornering depending on how sharp the corner is, and 60 degrees is for hard braking full drag.

4.6.2.5 Simulink Code: 3 Inputs (AW)

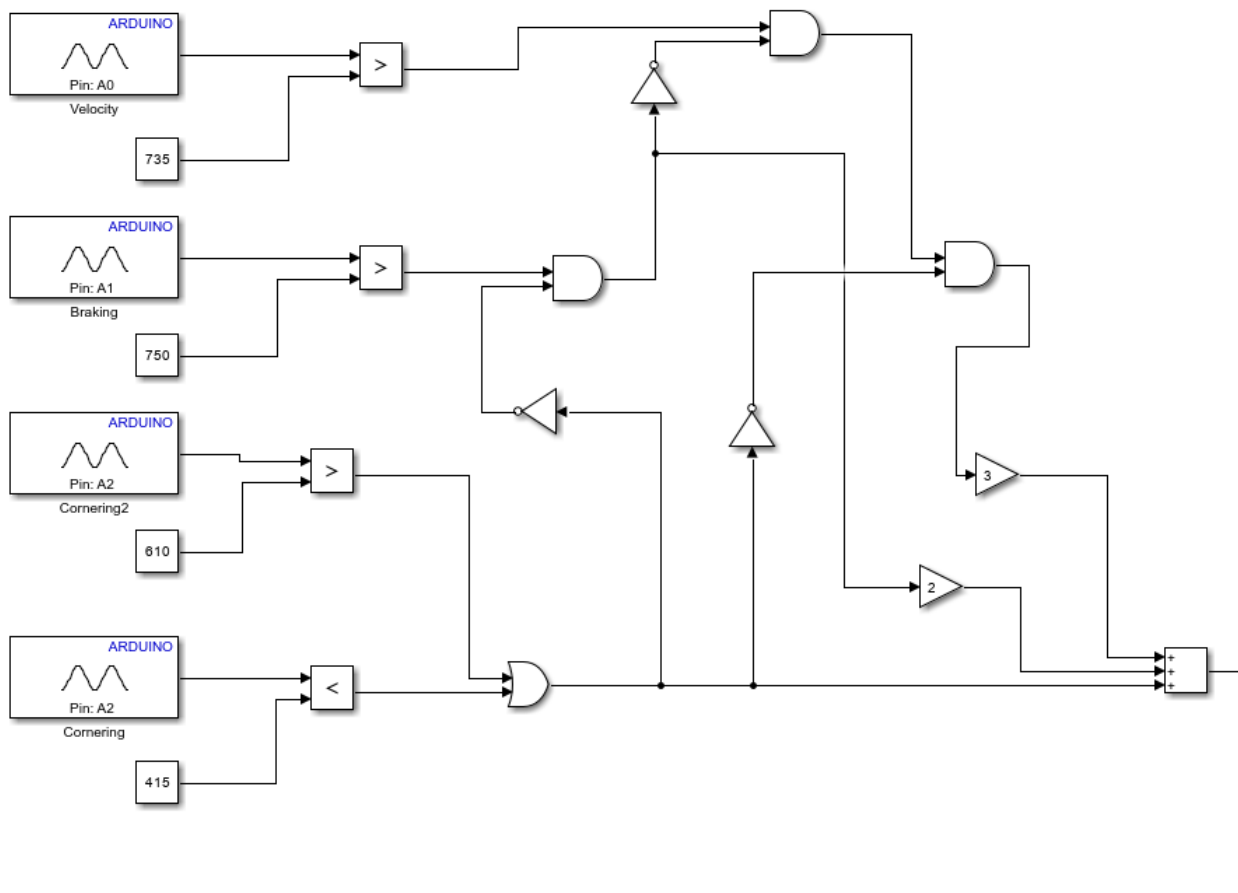


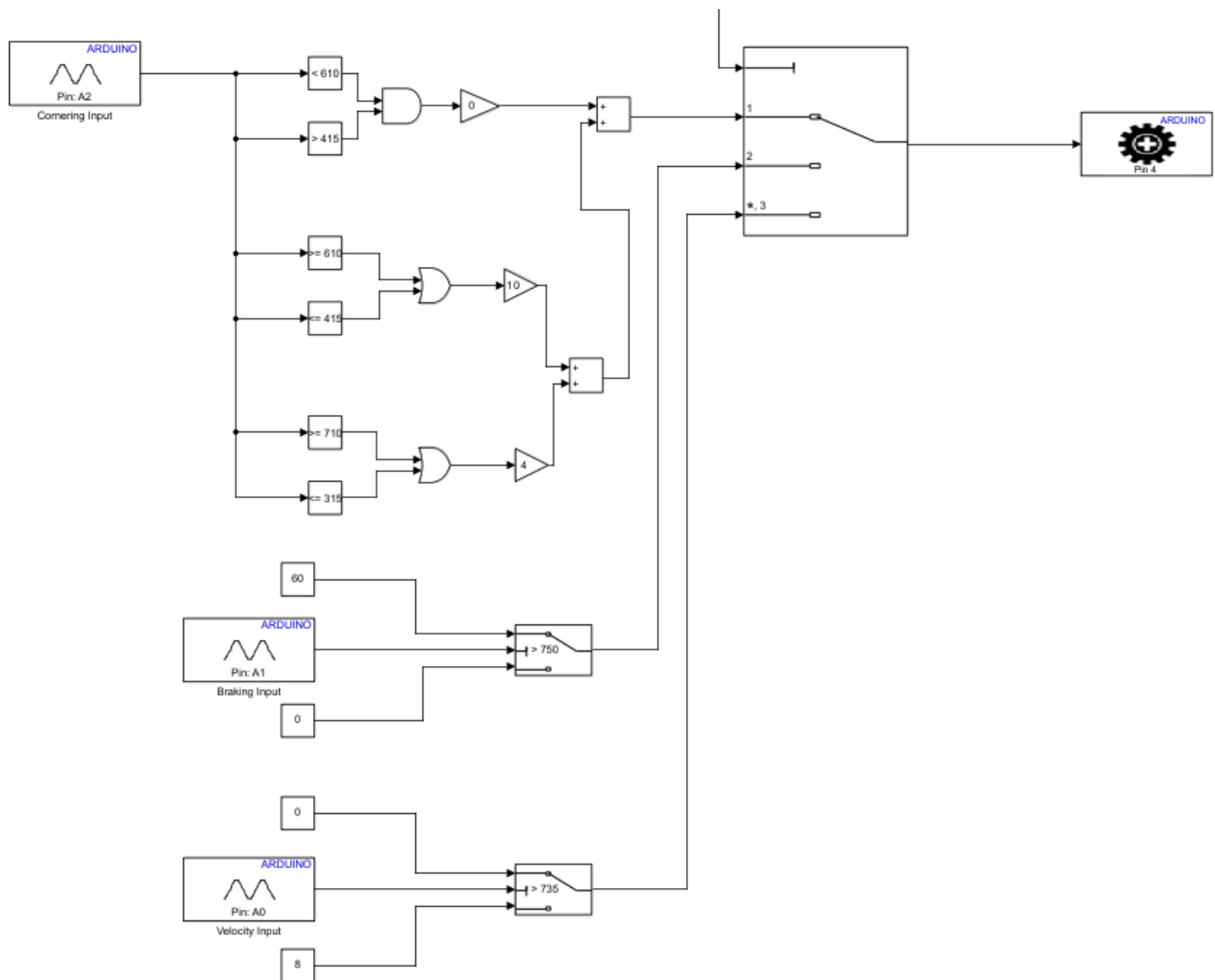
Above is an updated version of my Simulink code. I had to adjust the constants on the switch blocks for braking as on the earlier code I had 60 set to constant input and 0 set to the new angle which is the wrong way round. I also had to completely re-write my code for cornering. This is because the cornering data is positive and negative, for left and right turns, so the data has been offset so that 0 cornering is at around 500 bits on the 0-1023 range. Therefore, I need cornering to give 0 input between 400 and 600, not 0 and 200 like the previous code would have done. The code above uses and/or blocks and compare to constants to achieve that.

Nathan on aerodynamics was also able to give me figures for standard wing angle. 8 degrees is the most effective angle for all round so that was changed, same goes for cornering where it now can go to the angles 10 and 14 degrees depending on how sharp the corner is. As a result, the 5 angles our wing in the prototype will be able to achieve are 0, 8, 10, 14 and 60 degrees.

The sample time of the Arduino inputs have been set to 0.001. Sample time specifies how often the block measures voltage of the analog pin in seconds. Therefore, the code reads the voltage inputs 1000 times in 1 second, giving smooth data reading.

4.6.2.6 Simulink code: 3 inputs final variation (AW)

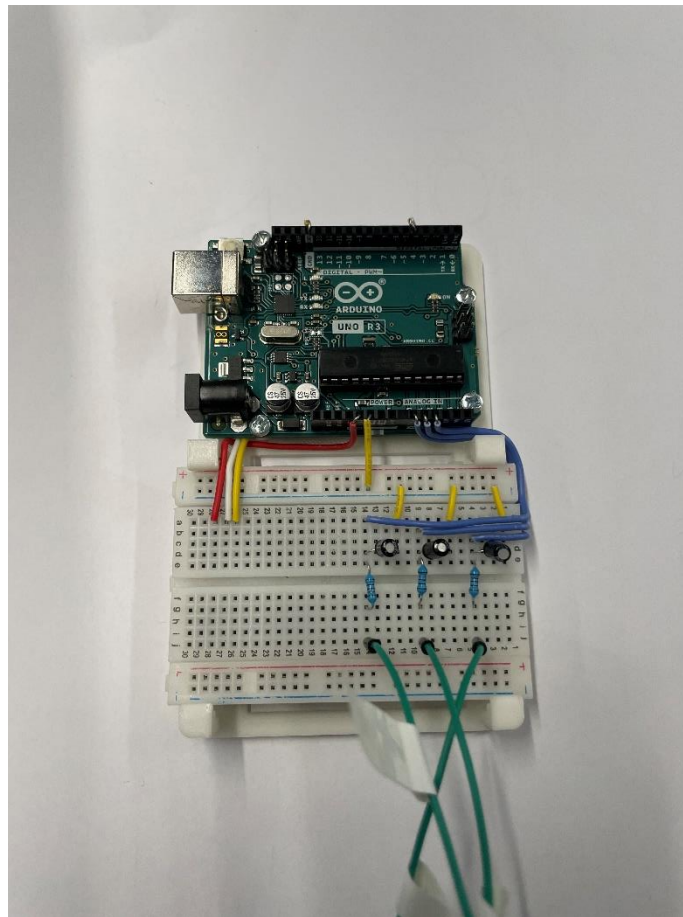




Above is my final version of the Simulink code. In my previous code if cornering and velocity thresholds were both met, it would just add the two angles together. So instead of giving 8 or 10 degrees it would give 18 degrees. To rectify this, I gave priorities to the inputs, making lateral the most important and velocity the least. Then with the use of a multiport switch block, and/or not gates I set up a new section of code that only allows lateral angles when the threshold is met, then braking if braking and velocity are met, which should be impossible anyway as the car is only ever doing one or the other. Then finally velocity, which is the standard angle so if the other two are not met this is angle the wing should be at.

4.6.3 Mechatronics

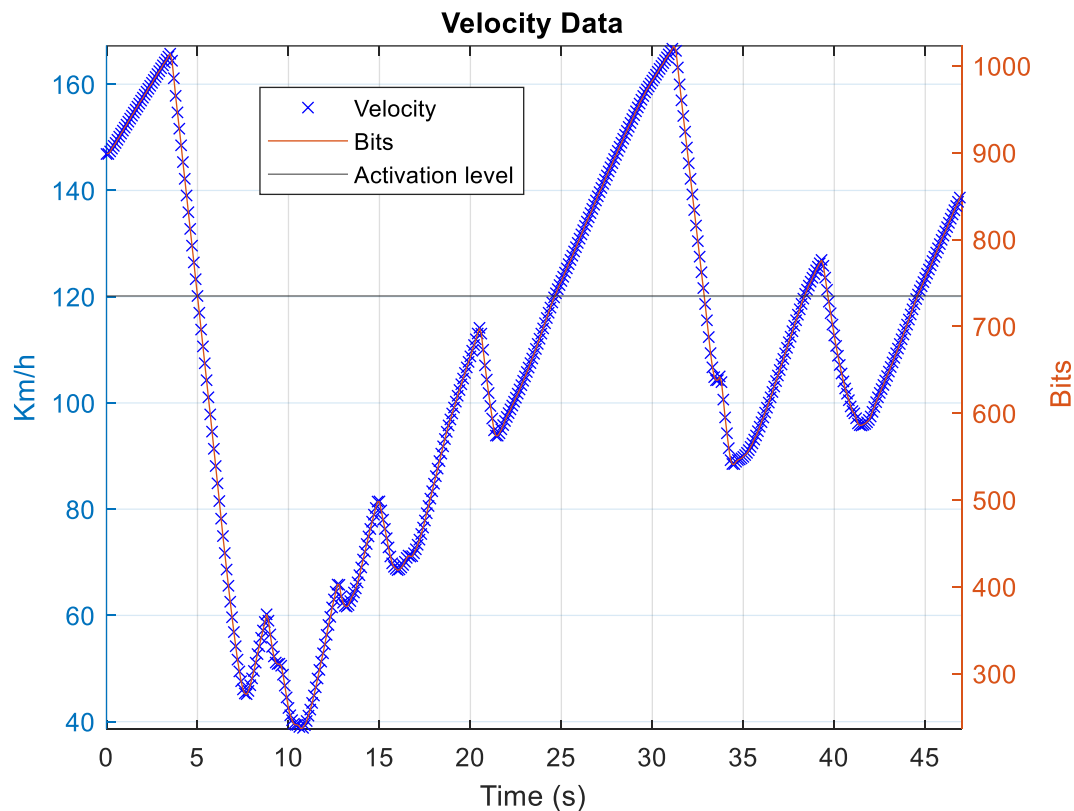
The reason the thresholds are being done in the range of 0 to 1023 bits is because the analogue to digital converter (Arduino) is a ten-bit device. 10 bits can store 1024 (2^{10}) different values, counting 0 as a value give the range 0-1023. When connected to 5V, 0 represents 0V and 1023 represents 5V. However, analog writes work slightly differently. It does not produce a variable voltage on the output. Instead, it uses pulse width modulation (PWM). This involves sending lots of 5V pulses on the output in quick succession (Stack Exchange, 2014). Working on 8-bit number instead of 10, that is 256 (2^8) different values or 0-255. So, to control a motor with a pot connected to the analogue input, we must convert 0-255 coming from PWM to 0-1023 for the Arduino. This can be done by simply multiplying the data by 4 (Arduino, 2018).



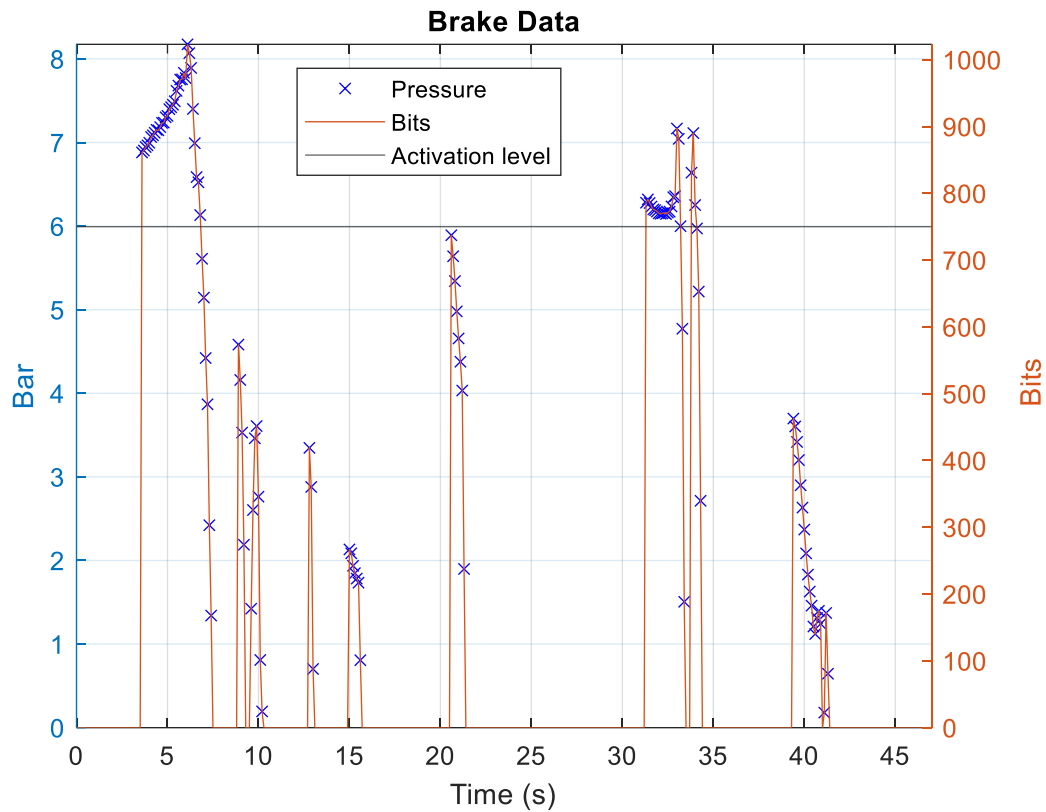
Above is an image of the final mechatronics set up, made up of an Arduino and a bread board attached to a 3D printed support. The three green cables are the inputs for velocity, braking and lateral, which pass through the 10k resistor and capacitor to convert the data in a usable variable voltage. The red, white and yellow cables are to connect the motor, with red for the 5V, yellow for the ground and white for the pin input.

4.6.4 Finding the thresholds (AW)

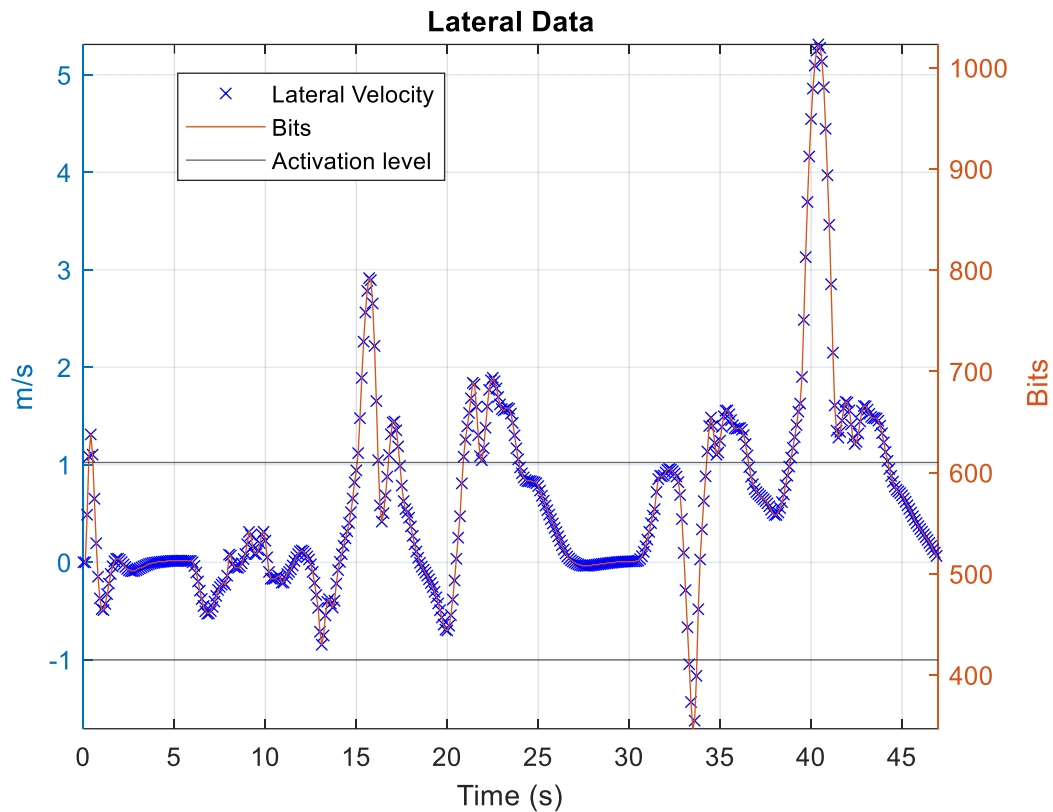
To find out where to set the thresholds of what points the wing changes angles according to the inputs I had to work alongside both the simulation and aero team. Through simulation software they were able to give me the most beneficial/efficient points in speed, cornering and braking where the wing should move to a certain angle, and what angle that should be.



Above is a graph showing the simulation data for velocity for a vehicle going around a track. The activation level line shows at what speed we want the wing to go to 0 degrees or 'DRS mode'. As you can see on the right a second y-axis has been added showing bits. The bits range from 0 to 1023, and this represents the speed in a format that the Arduino can read. This graph clearly shows how the activation speed is translated to bits. So, if we want to active DRS at 120kmh, we need to set the threshold on the code to 740 bits.



The graph above shows the simulated track data for braking. On this graph you can see the activation point is higher than the velocity. This is because we only want full drag force when the car is undergoing very heavy braking. The data on the left y-axis represents foot pressure. So, when the driver applies 6 bar of foot pressure or more the wing will go from standard position to 60 degrees. Which is around 750 bits.



The graph above shows the simulated track data for lateral velocity or cornering. As the car experiences lateral velocity in both directions, it is given as both positive and negative. However, as the Arduino can't read negative numbers the bits have been offset so that 0m/s is 520 bits instead of 0 bits. Therefore, 1 m/s is 610 bits and -1m/s is 390 bits. This graph has two activation levels, this shows the area which the lateral data will give 0 input. Once the data goes above or below that section the wing will change angle. This data is from Llandow, which is mostly right turns hence why the data is bias to positive lateral velocity.

4.6.5 If I was to take this further. (AW)

If I had more time and was looking to implement my work to a full-scale model, there would be a few things I would change. To improve the coding, I would implement a PID system. A PID system is useful for a few reasons; they can reduce noise in the system by filtering the derivative. Each of the 3 branches of a PID can be tuned for one input, this makes PID very precise, minimizing error time. They can also handle very complex control tasks effectively; this is important as if we were to further develop the wing to include vertical height as well the coding would become much more complex.

If I was also to include a cascade loop into the PID, it would be easy to locate problems, and you can run two loops at different speeds giving even more fine-tuning possibilities. PID also add acceleration and deceleration to the code, this is important for full scale model as with bigger moving parts if they move too rapidly it is not a smooth motion effecting performance. This is not a concern on the prototype as it's on a much smaller scale and will not be used in real life conditions. Finally, PID will be an improvement as it prevents the wing from overshooting its new position making it more effective (Ni.com, 2024).

If we had developed the wing to be able to move vertically, I would use linear actuators and a slide potentiometer, using the change in resistance to measure exactly how far the wing is moving up or down. For the full-scale wing, instead of using a breadboard, I would use a soldering board. Soldering boards are ideal for permanent/ finalised circuit constructions as they provide more secure and stable connections which in turn improves electrical performance. offering lower resistance, better conductivity, and improved reliability (J.Proctor, 2023).

4.7 Control systems and mechatronics section 2 (SH)

4.7.1 Introduction (SH)

As set out within the project brief, our group has been tasked with designing an 'Active Aero wing' for the Morgan Plus 4. Within this group we have been split into departments with the philosophy that we can bring our own ideas and attitudes to create a wing that would increase the performance of the Morgan. This section details the process of taking the prototype control system and exploring the applicability of adding the control system to the final model.

The initial idea was to move the wing into clean air above the roofline when moving and implement a Variable AoA system allowing the wing to change its angle of attack based on the requirements needed at the time.

4.7.2 Original group work carried out (SH)

The initial group idea was to have the wing move vertically upward into what would be clean air once the vehicle begins gaining momentum, this would circumvent the rules stated that the wing 'must not project higher than the maximum roofline when viewed from a side orientation at static ride height' **Invalid source specified**. Alongside this, a second actuation point will be implemented along the wing mounts to change the AoA (Angle of Attack) of the wing to suit the needs determined from the simulation department.

With the variable height and variable AoA wing, it would allow the Morgan to push the wing into cleaner air with the idea of it being more effective. The chosen AoA for the wings has been decided at 0° for full DRS (Drag Reduction System) 5° for the standard AoA and 60° to stall the wing and incur as much drag as possible. These decisions have been made from the Simulation and Aerodynamic Development departments.

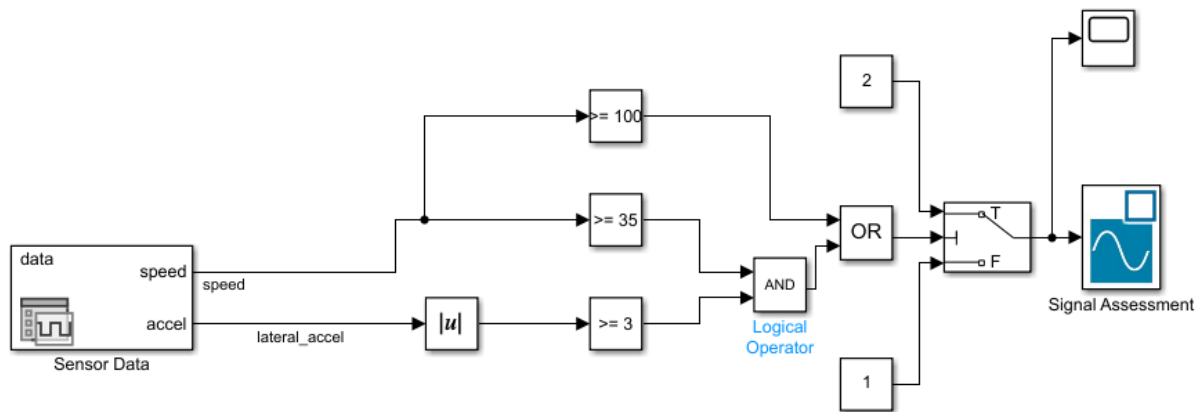
To ensure the usability of the wing, 3 inputs have been used these include Lateral Acceleration, Brake Pressure and Velocity these inputs will allow the wing to be actuated dependent on several cases and maximise its effectiveness around a track compared to the stock Morgan (As seen on VIGrade). To provide the most benefit to the performance, the forces acting on the wing and the speed of actuation for the wing must be correct and effective.

Task	Start Date	Ideal End Date
Gain an understanding of MatLab and Simulink software that can be used to control the electrical and mechatronic system	07/10/2024	04/11/2024
Research into appropriate Mechatronics and confirm the most suitable	14/10/2024	18/11/2024
Produce Initial VIVA presentation section	07/10/2024	06/12/2024
Research Electrical filters to minimise unnecessary noise and irrelevant data	14/10/2024	28/10/2024
Develop initial code to move actuators based off one data input	14/10/2024	04/11/2024
Create initial electrical circuits using the Arduino boards and potentiometers	21/10/2024	11/11/2024
Complete MatLab and Simulink onramp sessions	07/10/2024	21/11/2024
Develop Electrical filters	28/10/2024	11/11/2024
Research PWM at variable voltages and develop an understanding of the associated uses	28/10/2024	04/11/2024
Develop a solid understanding of how an arduino can be controlled by simulink	04/11/2024	25/11/2024
Implement Mechatronics and control systems into the prototype and complete systems integration testing	27/01/2025	24/02/2025

The table above shows the ideal individual tasks set at the start of the group project **Invalid source specified**. As originally made with ideal timings for each task to be completed as progress was made towards the final group project, the specific roles and ideal completion dates have changed and been adapted for the individual strengths of each team member. This table was originally used within a Project Planning report that was written alongside the beginning of this project, this allowed the group to gather a rough estimate of the roles and responsibilities that each member would adhere to.

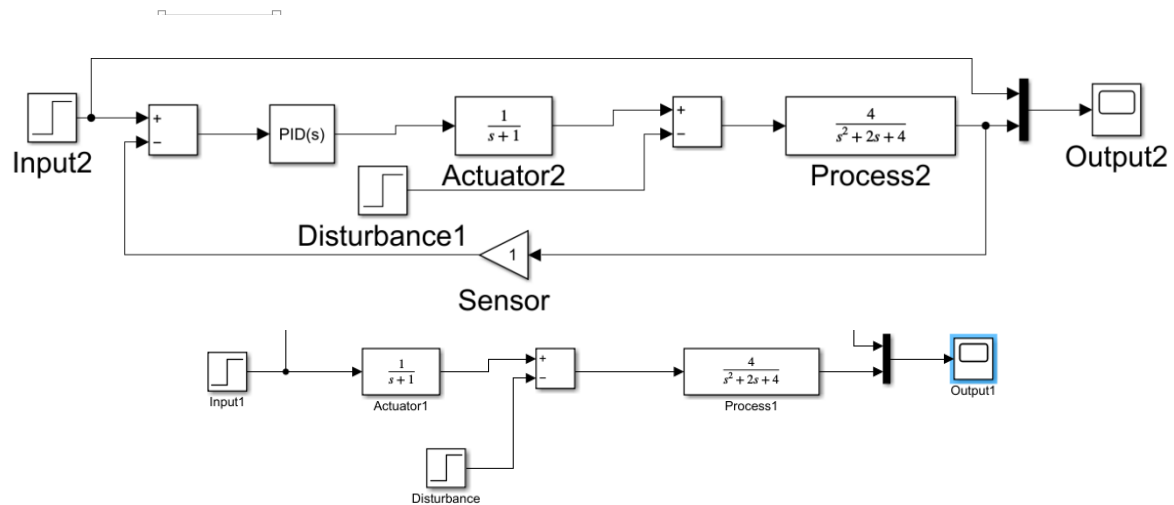
4.7.3 Research Carried Out (SH)

Initial research into control systems and mechatronics included completing the Simulink and Matlab Onramps, these are introductory courses on said programmes. These onramps give a general insight into the different uses of the software.



The figure above shows one of the stages carried out in the Simulink onramp, this shows a basic model of a vehicle deciding its driving style through the use of logical operators, as can be seen, the car can choose a driving style if it is driven past 100 KM/H or if it driven over 35KM/H and has a lateral acceleration value of more than 3M/S^2 . Due to the value of lateral acceleration being positive and negative an absolute value (abs in Matlab and Simulink) is used to show a positive outcome for both directions of acceleration. The Scope block placed on the top right-hand corner is to monitor the signal that has been passed through the model and will give an indication on the PWM signal achieved through the system. The additional constant blocks attached to the switch block represent the two different driving modes that can be activated based on how the car is being driven.

The Figures below show a basic iteration of the closed loops and open loops that had been researched as a preliminary control system.



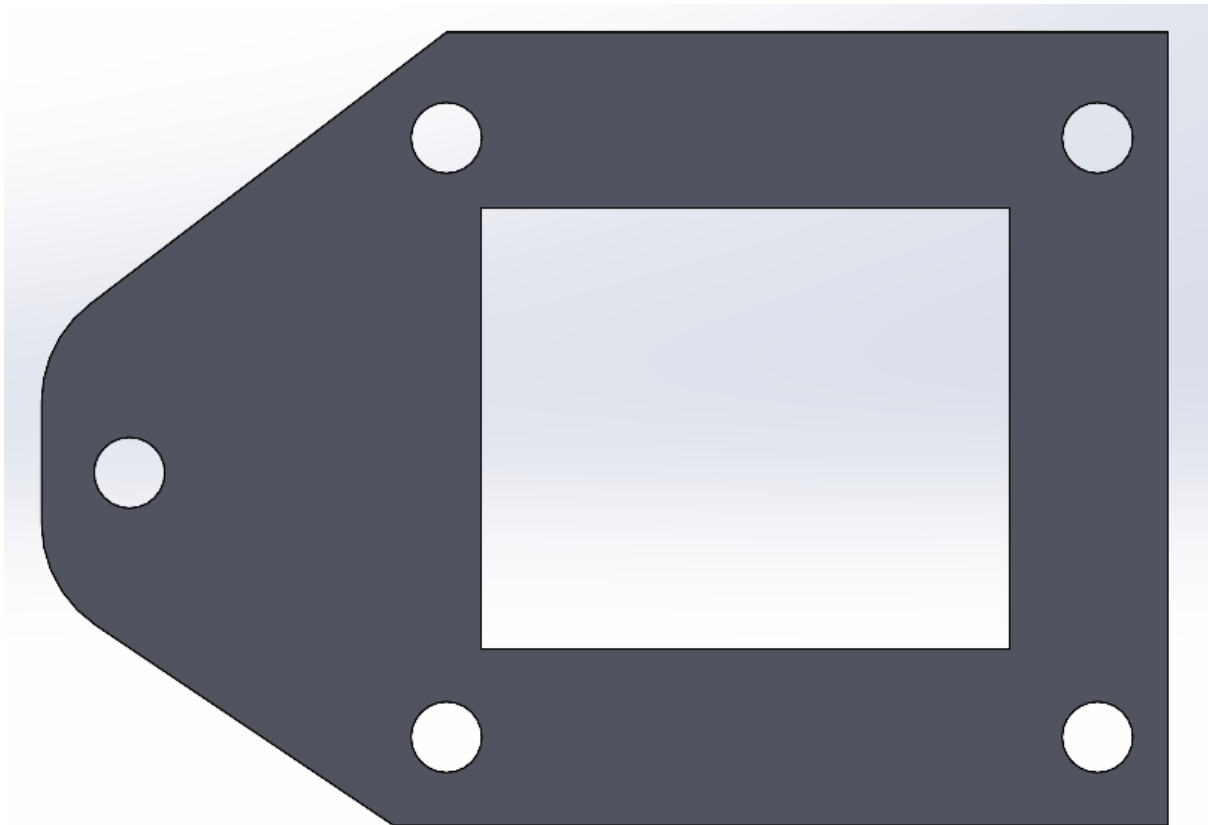
The three figures above show a preliminary control system as stated above the first figure being an open loop system, an ideal control system for a device that does not need any feedback and is essentially an on or off system, the second is the same with the addition of a disturbance this attributed to electrical noise.

The third figure above shows a closed loop system, this system would allow a sensor to give data back through the process and change a specific output, for example a closed loop would monitor the specific inputs applied and would allow the system to adjust the output dynamically. Although these are more complex compared to open loops and will incur electrical noise and time delays due to a sensor having to read the data at the point of data output. Open loops are considered basic systems as they cannot account for changing conditions with the output and cannot change dynamically.

4.7.4 Development Carried Out (SH)

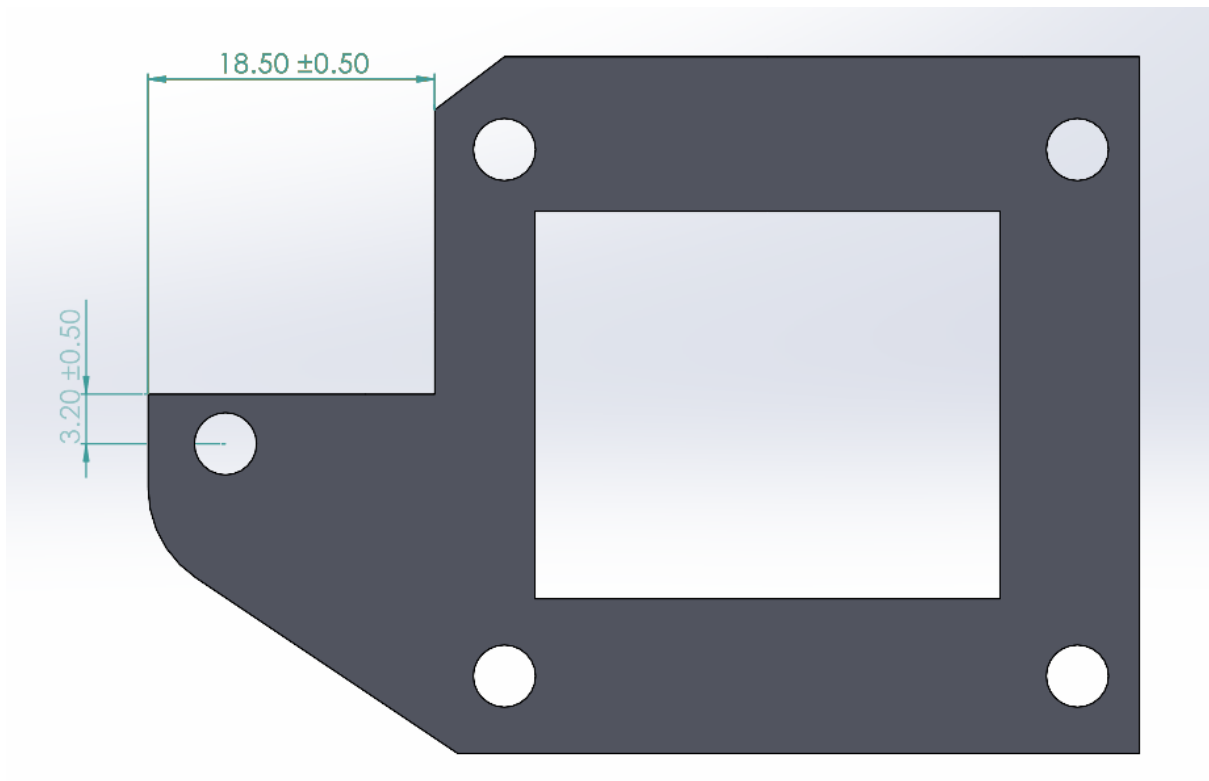
With the ideal design structure designed, it became apparent that the targeted maximum AoA of 60° was unattainable due to the geometry of the designed components. Due to this, adjustments were made to several components on the top end of the wing mounts, this was to accommodate the activation arm and its geometry to attain a maximum AoA of 58°. With the wing able to meet its maximum AoA within the groups chosen tolerances, development work could begin on implementing the correct actuators needed to fit within the structure and provide the correct actuation.

The adjustments made to the designed structure will be shown below.

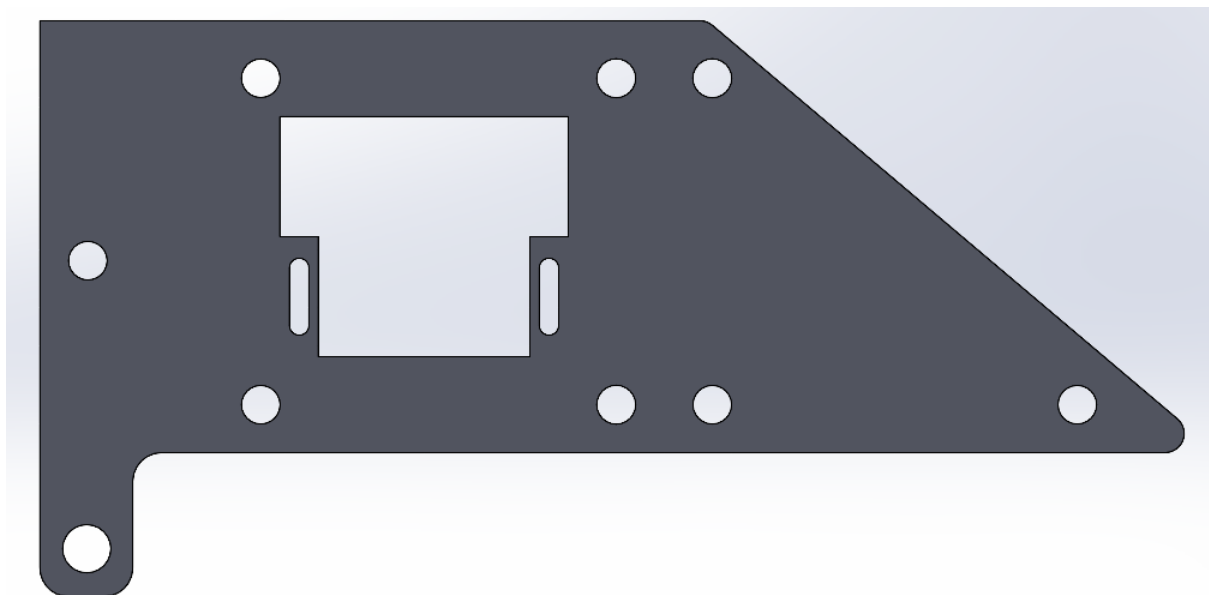


The Figure above shows the original design for the Upper Strengthening mount, due to the geometry needed to raise the wing up to 58° a small portion of the top angled surface needed to be cut away to allow the activation arm to be moved further in order to maximise the AoA available to the wing.

The figure below shows the final adjustments made to the strengthening mount, the cut out used here was decided to be a simple solution to avoid unnecessary complexity. With the cut out being 18.5 mm into the original design, the activation arm is allowed to travel closer to the point of contact and therefore allow more degrees of freedom for the wing to achieve it's 58° desired max AoA.

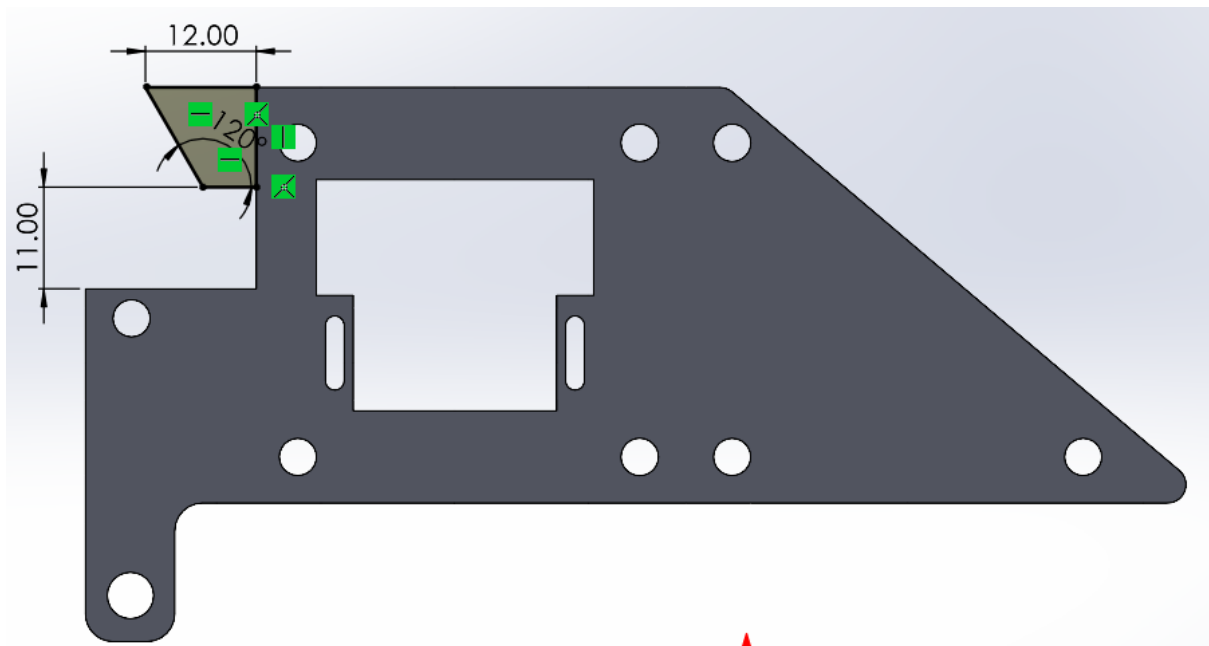


The figure above shows the original implementation of the Centre rear piece for the mount structure, on the top left-hand side of the piece it is cornered off where the activation arm would normally intersect this piece the same applies with the support pieces in the figures shown above. To circumvent the issue of the activation arm contacting the Centre Rear piece, a cut out was made



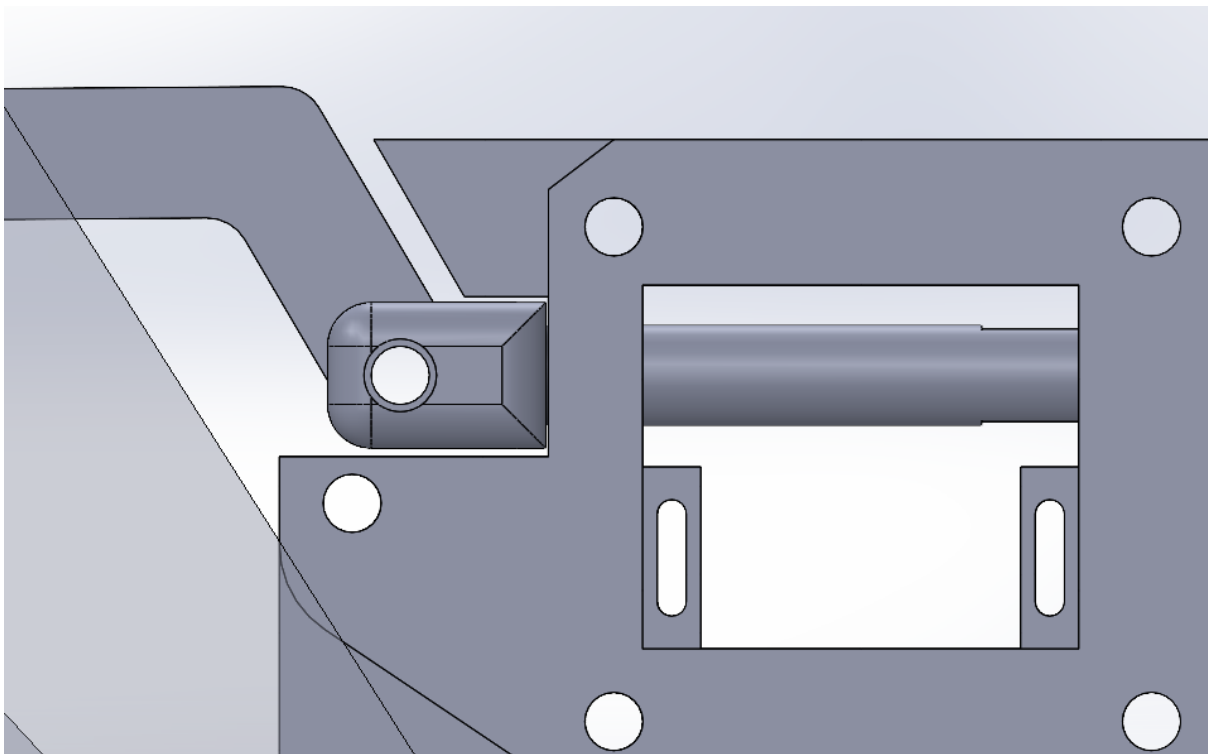
to allow the arm to have the correct freedom needed to allow the AoA to be pushed to a maximum of 58°

As shown in the figure below, a cut out has been made to allow the activation arm to be placed



accordingly.

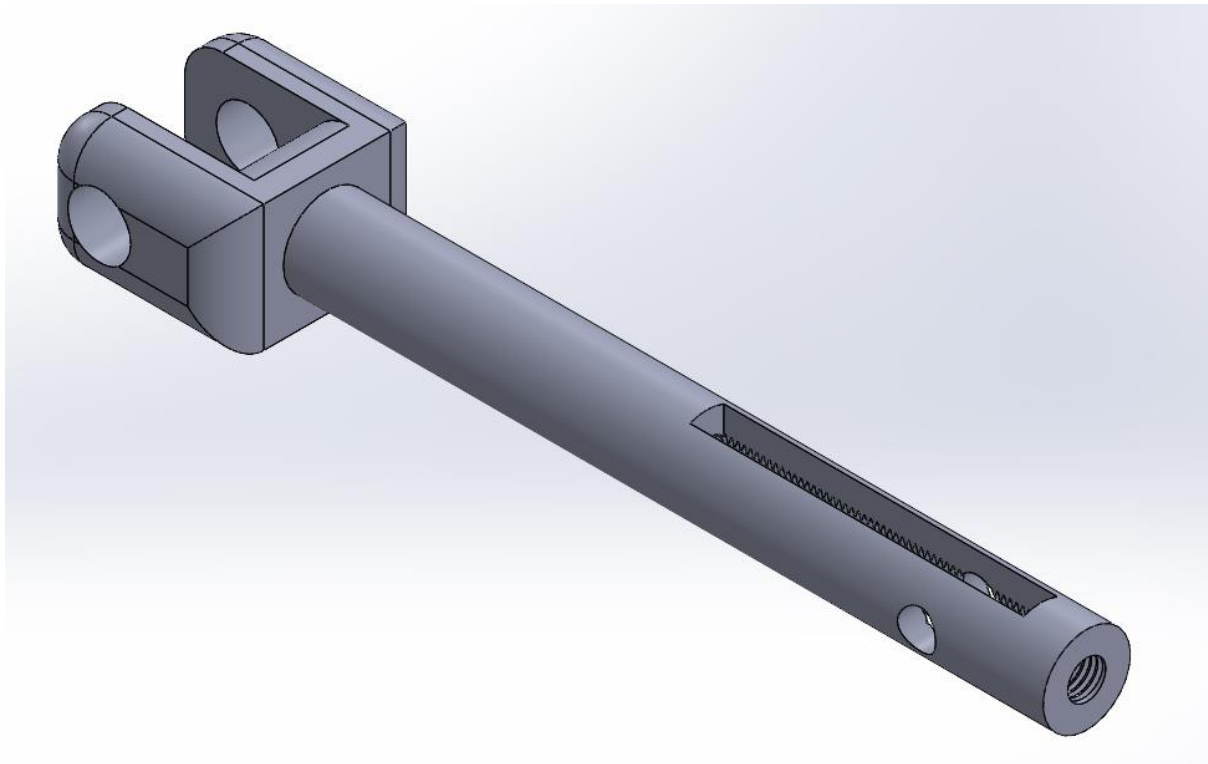
From the figure above, it is shown that the cut out placed on the piece leaves a Trapezoidal shape, this shape is to allow the connecting arm and the activation arm to move freely into the centre rear piece without leaving a large gap on the dorsal viewpoint, this can clearly be seen in the figure



below.

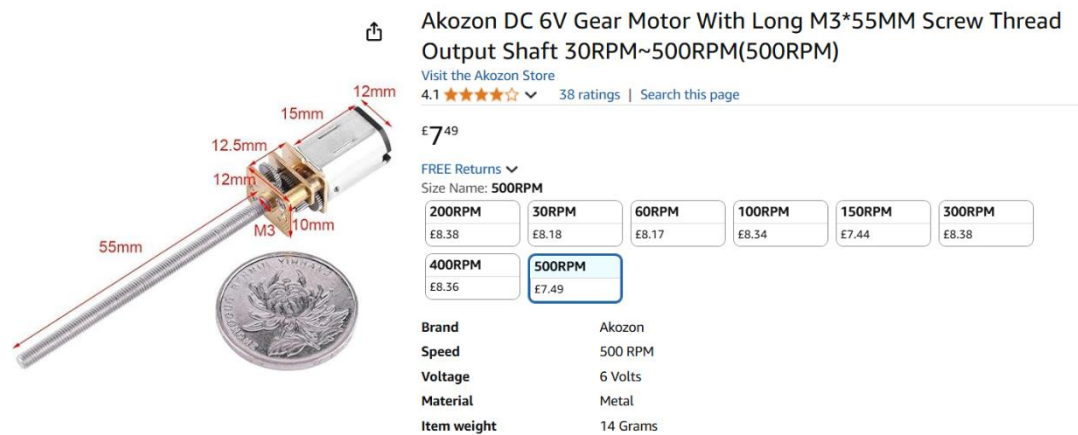
The figure above shows a completed assembly of the wing, mounts and the main structure, alongside all the alterations that have been made to allow the wing to meet a higher AoA. As it is shown, the trapezoidal shape that was added to the Centre Rear piece allows the activation arm to move to its upright position without intersecting the main piece while also minimising unnecessary gaps in the top structure

With these Changes made to the design, it allows the wing to have the complete travel freedom decided by the relevant departments.



The figure above shows the activation rod that has been adjusted to house an M3x0.5 threaded hole; this thread has been implemented into this piece as it allows the linear actuator to be threaded into it. When the actuator begins to move it will thread in or out of the rod depending on the needs for the wing at the time.

To complement this piece, the figure below shows the linear actuator that has been chosen for this application, with a 55mm long M3x0.5 threaded output shaft, this will fit perfectly and allow the

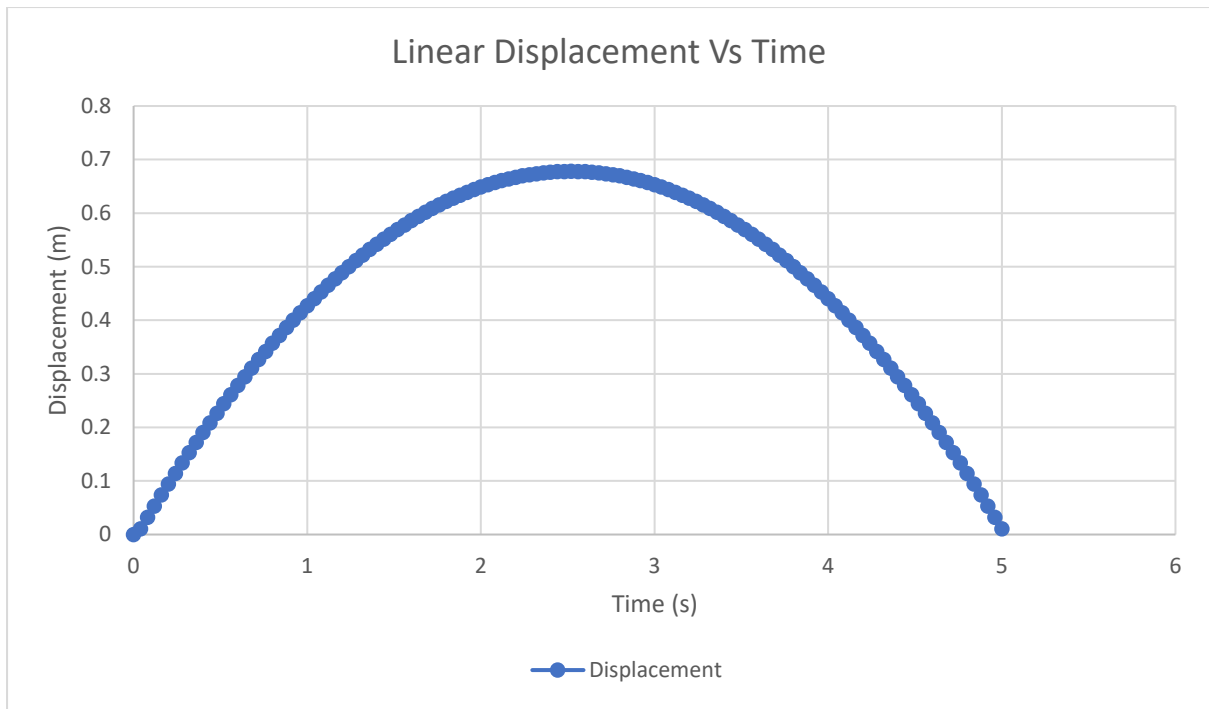


activation rod to be actuated as discussed in this report. **Invalid source specified.**

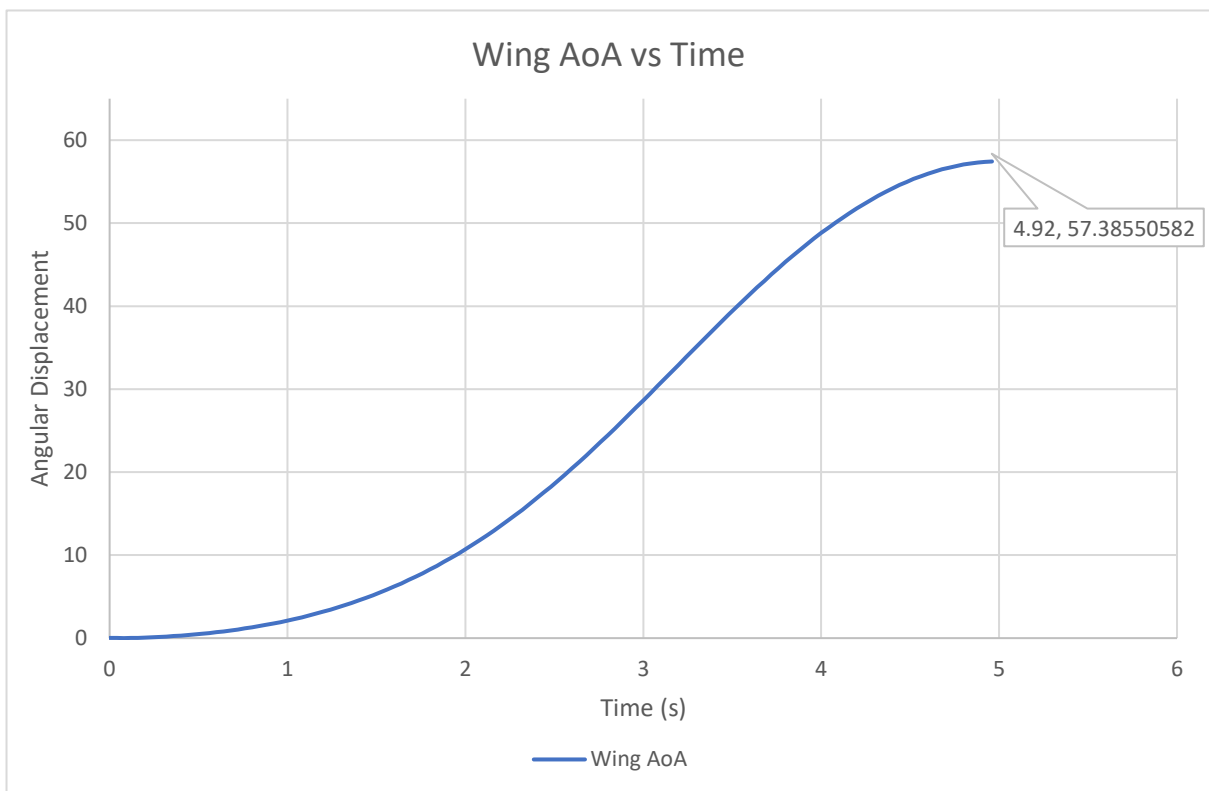
The chosen speed for this actuator has been chosen to be a maximum of 500rpm, this will allow the prototype wing to have the speed and correct movement ratio needed to change the AoA of the wing dynamically.

4.7.5 Motion Study Results (SH)

In order to calculate the Wing AoA vs the linear displacement of the activation arm, a motion study was conducted in SolidWorks, once the motion study was completed, the data gathered could then be imported as a CSV file into excel to begin an analysis of the data to find out the travel of the activation arm compared to the change in AoA. In order to visualise this correlation, the data gathered from linear displacement vs time and AoA vs time were both exported from the motion study in Excel. The figure below visualises the Linear displacement of the activation rod vs Time through the motion study.



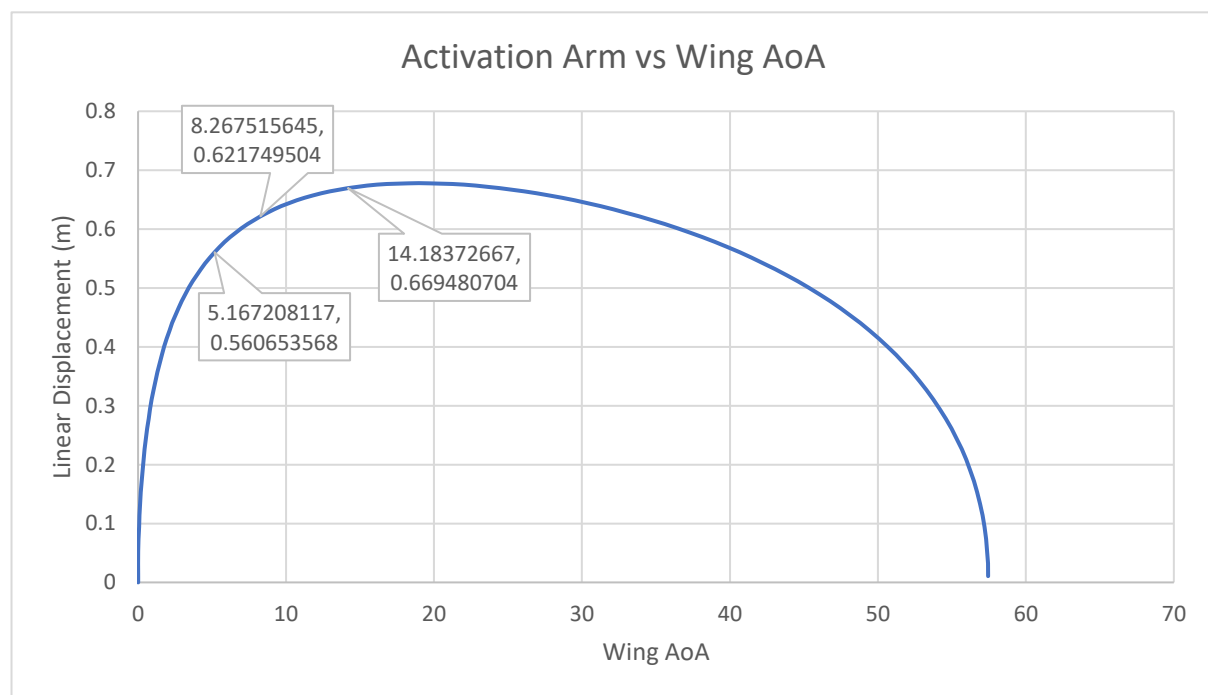
It can be seen in the figure above, the displacement per second changes over time, this can be attributed due to the geometry of the rocker arm that connects the activation rod to the wing itself.



The Figure below shows the change in AoA compared to time within the motion study, due to the rocker arm ratio, the rate of change of the wing is not linear and varies over time.

The Figure above shows the rate of change over the time used in the motion study; it has been noted with the maximum AoA the wing can achieve as determined by the geometry of the moving components.

The Figure Below shows the calculated Rate of change in the linear displacement compared to the rate of change in the wing's AoA. This graph has been noted with the ideal AoA decided by the simulation and Aerodynamics departments compared to the linear travel experience by the



activation arm

The Figure above shows the calculated Rate of change in the linear displacement compared to the rate of change in the wing's AoA. This graph has been noted with the ideal AoA decided by the simulation and Aerodynamics departments compared to the linear travel experienced by the activation rod. As the individual data points correlates the displacement of the wing vs the displacement of the activation rod per time step. On the figure above, there is a point marked at 14°, this has been noted as it is the point where the wing stops producing lift. This is important as it allows the group to know where the wing will stall and stop producing lift this allows the control systems department to understand where the final points the wing will produce lift.

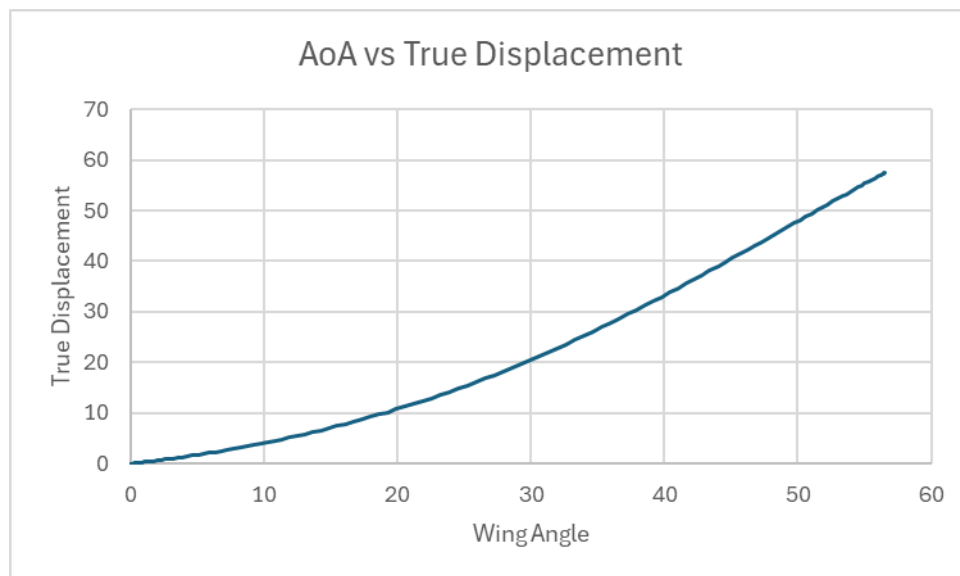
4.7.6 Analysis (SH)

As decided by the simulation and aerodynamic departments, a wing angle of 58° is within an acceptable tolerance and falls under the maximum 60° as set out in the assignment brief. A base AoA of 0° for full DRS has been applied and will be the wings resting state. As can be seen in the figure above, the distance needed to move the activation rod for 5° of AoA is 0.56mm from the last data point. As the rate of change ratio between the angular displacement and the linear

Linear Displacement		Angular Displacement	
Time (sec)	Displacement	Time (sec)	Displacement
0	0	0	0.012338813
0.04	0.010790144	0.04	0.009123726
0.08	0.032139008	0.08	0.000467102
0.12	0.053140736	0.12	0.016372943
0.16	0.073795328	0.16	0.038559809
0.2	0.094102784	0.2	0.067019074
0.24	0.114063104	0.24	0.101766173
0.28	0.133676288	0.28	0.142839362
0.32	0.152942336	0.32	0.190298542
0.36	0.171861248	0.36	0.244224144
0.4	0.190433024	0.4	0.304716062
0.44	0.208657664	0.44	0.371892632
0.48	0.226535168	0.48	0.445889658
0.52	0.244065536	0.52	0.526859477
0.56	0.261248768	0.56	0.614970057
0.6	0.278084864	0.6	0.710404131
0.64	0.294573824	0.64	0.813358352
0.68	0.310715648	0.68	0.924042481
0.72	0.326510336	0.72	1.042678589
0.76	0.341957888	0.76	1.169500276
0.8	0.357058304	0.8	1.30475191
0.84	0.371811584	0.84	1.448687864
0.88	0.386217728	0.88	1.601571772
0.92	0.400276736	0.92	1.763675773
0.96	0.413988608	0.96	1.935279766
1	0.427353344	1	2.116670648
1.04	0.440370944	1.04	2.308141549
1.08	0.453041408	1.08	2.509991049
1.12	0.465364736	1.12	2.722522379
1.16	0.477340928	1.16	2.946042596
1.2	0.488969984	1.2	3.180861734
1.24	0.500251904	1.24	3.427291921
1.28	0.511186688	1.28	3.685646465
1.32	0.521774336	1.32	3.95623889
1.36	0.532014848	1.36	4.239381942
1.4	0.541908224	1.4	4.53538653
1.44	0.551454464	1.44	4.844560629
1.48	0.560653568	1.48	5.167208117

displacement of the two pieces changes over time, the data point needed needs to be in addition to the total movement before, this can be seen in the table below.

The figure above is a portion of the data carried over from the motion study carried out, as mentioned above, the displacement values calculated is per time stamp; to calculate the total displacement up to that point, all former values must be used in addition.



The figure above shows a visual representation of the correlation between the distance the activation rod travels compared to the change in wing angle experience due to the rocker arm ratio experience by the activation arm, this causes this graph to have a curved pattern. As discussed above, the change in wing angle per mm of rod travel changes due to the specific geometry used in the design.

4.8 Design process of the wing mounts (AC)

When designing the wing mounts it is important to consider that they must be capable of withstanding the aerodynamics loads and forces of the wing while incorporating the control systems and impacting the efficiency of the wing as little as possible. (William F Millikiten & Douglas L. Milliken, 1994)

4.8.1 First design iterations (AC)

The design team initially explored 3 main mounting configurations that would be considered legal within the regulations.

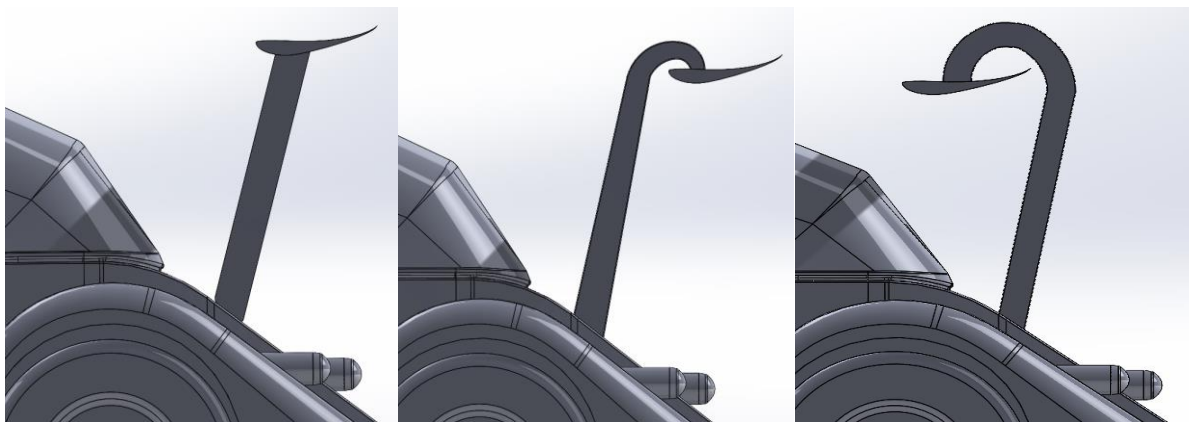


Figure 40 – Initial mount considerations. Underside, swan neck and reverse swan neck.

These designs included an underside mounting position, a swan neck design, and reverse swan neck design. These iterations allowed us to evaluate the pros and cons of each approach in terms of structural integrity, aerodynamic performance, and freedom of movement.

Key Design Considerations:

- **Simplistic Design:** The first iteration was focused on a straightforward structural approach, ensuring robustness and simplicity in the mounting system. This design, however, had reduced aerodynamic performance due to the mounts interrupting airflow.
- **Improved Aero Efficiency:** By incorporating the swan neck design, we were able to improve the airflow underside of the wing, which led to better aerodynamic performance. This approach also provided more freedom of movement, allowing the wing to adjust its position more effectively. However, it would increase the complexity of the activation system, which then requires more sophisticated control mechanisms.
- **Uninterrupted Airflow:** The final design iteration prioritised the need for uninterrupted airflow to the wing. The mounts were redesigned to be more aerodynamically efficient,

while still maintaining structural integrity. One of the challenges was balancing the clearance in the airbrake position, where the mounts needed to be low-profile yet still durable enough to support the wing during various conditions.

(Joseph Katz, 1995)

The work content during this phase included extensive research, and design iterations to find the most optimal solution. Once a decision was made on the mount configuration, we proceeded with the development, testing, and build stages, in collaboration with the structural team, to ensure that the wing mounts were capable of withstanding aerodynamic and structural constraints

4.8.2 Actuation design integrates into the mounts (AC)

The design of the actuation mechanism plays a crucial role in ensuring that the wing operates as intended. The challenge was to integrate the linear actuator system into the wing mounts without compromising the mount's structural integrity or the wing's aerodynamic efficiency. The actuator needed to be compact yet powerful enough to perform precise vertical and tilt adjustments based on dynamic forces.

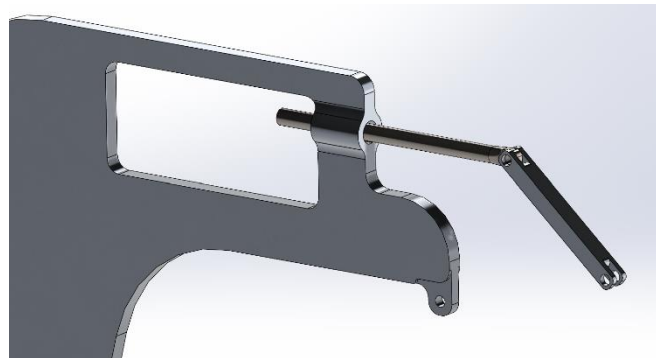


Figure 41 - The linear actuator design and mounting space

The actuation system was divided into two distinct subsystems to handle these movements effectively:

- **Vertical Adjustments:** A dedicated linear actuator extends and retracts the wing mounts vertically. This allows the wing to move into clean air when needed to optimise downforce or retract behind the vehicle to reduce drag. The ability to raise the wing mounts ensures that the wing profile can be positioned in undisturbed airflow, improving aerodynamic performance during high-speed conditions.

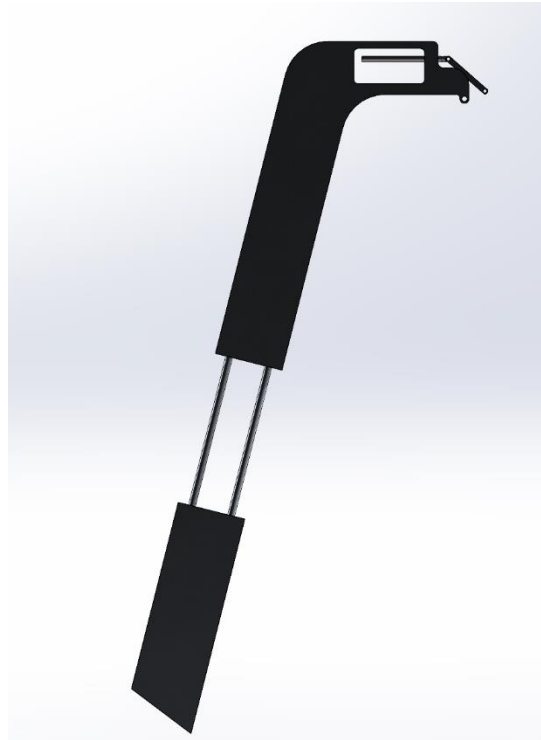


Figure 42 - Vertical adjustment design for the wing mounts

- **AoA adjustment:** Separate from the vertical adjustment system, the linkages are responsible for tilting the wing along its length. This allows the wing's angle of attack to be adjusted dynamically, optimising its performance at different speeds by controlling the amount of downforce generated.



Figure 43 - Angle of Attack change

4.8.3 Further work and optimization (AC)

The current design iteration is focused on maximising both aerodynamic efficiency and structural integrity. Additional FEA simulations will also be carried out to fine-tune the materials and geometry for optimal performance.

Additionally, the ongoing use of Design of Experiments (DOE) principles will help further refine the design parameters by identifying the most significant factors that affect the system's performance. By conducting well-structured testing, we can optimise the actuator settings, material choices, and structural configurations, ensuring the wing system achieves maximum efficiency while maintaining the necessary strength and durability. Along with looking into producing an aerodynamic shrouding for the mounts to further improve the design.

4.9 Materials and mounting (MS)

4.9.1 Introduction (MS)

Our roles and responsibilities in the structural and materials department section of the project were to identify and evaluate the most suitable materials and structural solutions for our active rear wing assembly for a Morgan Plus Four. As part of the structural and materials department, my primary responsibility was to research and select materials that offer the best balance between strength, weight, cost, and manufacturability. The rear wing plays a crucial role in generating downforce and improving aerodynamic performance; therefore, its material composition and mounting system must be carefully designed to withstand high loads while maintaining structural integrity.

The project involved a comprehensive material selection process, comparing options such as carbon fibre, aluminium, and flax fibre composites. I assessed each material based on its mechanical properties, cost implications, and feasibility for use in both the wing profile and mounting system. Additionally, alternative solutions such as foam core inserts (Rohacell) were explored to optimize weight and material efficiency.

Beyond material selection, the design of the wing mounting system was a critical aspect of the project. Various configurations were examined, including the use of carbon fibre and aluminium tubing to house linear actuators for an adjustable wing setup. The final design integrates a robust framework that allows for both structural stability and potential active aerodynamics.

To validate these design choices, Finite Element Analysis (FEA) simulations were conducted but other members of the structural department, to assess material performance under real-world loading conditions. The findings from these simulations guided the final material and design selection, ensuring that the rear wing assembly meets the necessary strength and durability requirements.

This report will outline the research, analysis, and engineering considerations that informed the final material and structural decisions for the rear wing assembly. It provides an evaluation of different material options, their mechanical properties, and their application in both the wing profile and mounting system. Through collaboration with the aerodynamics team specifically, along with the whole team in general, this project has contributed to the development of an efficient and high-performance rear wing solution.

4.9.2 Methodology, Challenges and Solutions (MS)

To achieve our objectives, we adopted a structured approach involving research, design, and implementation. The research phase involved gathering relevant data from reputable sources, in my case this was material research. Followed by the design phase, where concepts were refined through group discussions and iterative prototyping, The final stage involved executing the design and testing for functionality and efficiency, such as the FEA processes for chosen materials on our wing assembly.

At the initial stage, our group established clear objectives and divided responsibilities among members to maximize efficiency. We used project management tools such as Gantt charts and weekly progress meetings to ensure timely completion of tasks.

Challenges and Solutions

During the course of the project, several challenges arose, including:

- **Time Constraints:** Managing individual schedules alongside group deadlines required careful coordination. We mitigated this by implementing and setting intermediary deadlines.
- **Technical Difficulties:** Some aspects of the project demanded expertise beyond our initial knowledge. To address this, we conducted additional research and sought guidance from academic advisors.
- **Communication Barriers:** Differences in availability and working styles occasionally led to miscommunication. This was resolved by scheduling regular check-ins and ensuring all discussions were documented.

4.9.3 Initial Materials Research (MS)

My initial role for the structural team was to research and identify appropriate materials that can be used for the various aspects of the wing development. Starting off with the wing profile, I researched into the costing and strength characteristics of both carbon fibre and aluminium, this was due to these 2 materials being the most relevant and likely to be used in practice. Both materials retain a decent enough strength properties, however, carbon fibre gets ahead due to its increased strength factors and superb lightweight aspect making a suitable choice for final design and production. Although with this comes the increased cost of carbon fibre material in general, below I have listed and explained the research into these 2 materials, comparing their strengths and pricing. Further to these 2 main material options, I have investigated a more sustainable material option in the form of 'Flax Fibre'

composites. The information below gives and more detailed idea of what Flax fibre is, however in brief it is a more sustainable option than carbon fibre due to its manufacturing using plant-based fibres, although it has a lower strength rating than carbon fibre and in fact often heavier. These are 2 factors we don't want when identifying a strong material for our active rear wing.

Further to identifying the overall material of the wing profile, I have identified a foam material specifically called Rohacel foam. This foam can be used to pack the middle of the wing profile whilst externally wrapping it in our chosen material of either carbon fibre or aluminium sheeting. This can help with cost due to not having to make a solid wing profile out of carbon fibre for example. Research has also shown that this foam insert idea has been used in various Formula 1 team wings such as Williams F1 team.

(See image below)



4.9.3.1 Material Research for wing profile (MS)

Carbon Fibre Sheeting:

- Research has shown that the Average costing a carbon fibre sheeting is £12 for a 0.25m x 0.32mm sheet. (**Easy Composites** (n.d.-a) - High Strength Carbon Fibre Sheet)
- High-quality carbon fibre filaments can have tensile strengths ranging from 3,500 MPa to over 7,000 MPa. (**Rinasclta Bike** (n.d.) - Carbon Fiber Materials)

Aluminium Sheeting

- Average costing for a 2m x 1m x 0.0012m thick - aluminium sheet is £52.72. (**Aluminium Warehouse** (n.d.-a) - 2000mm x 1000mm x 1.2mm Aluminium Sheet)
- The tensile strength of pure aluminium is at around 90 MPa. (**Aalco Metals Ltd** (n.d.)

Flax fibre composite

- Flax fibre is a natural, plant-based material derived from the flax plant, known for being lightweight, strong, and biodegradable. It's often used in eco-friendly composites for applications like automotive parts and textiles.
- While strong, flax is not as stiff or strong as carbon fibre, and it has more flexibility. It's often used in applications where moderate strength is sufficient and sustainability is a priority.
- Lighter than many natural fibres, but generally heavier than carbon fibre due to the lower density of the material.
- Less expensive than carbon fibre, making it a more cost-effective alternative for certain applications, especially where high strength is not the primary requirement.

Foam Wing Inserts:

- Most high-end performance wings contain foam inserts (Rohacel foam) for which they wrap the chosen material around, for example carbon fibre.
- This is due to a foam's lightweight properties, and although not very strong, when wrapped in material such as carbon fibre the overall package would be adequate in the end.
- Pricing is around £37 for a 625x625mm, 5mm thick sheet. (**Easy Composites** (n.d.-b) - Rohacell 31 IG-F PMI Foam)

4.9.3.2 *Material Research/design inspiration for wing Mounts (MS)*

Following on from my research into the material for the wing profile itself, I then went on to identify suitable materials and designs for the wing mounting/fixtures. I initially identified these carbon fibre or aluminium tubes that can be seen below. The idea of these was that we could place our linear actuators, that will allow the wing to actively move up and down, inside these tubes providing increased strength and protection for the mounts.

Alternatively, if we decided to go down the route of not actively raising/lowering the wing height, we would be able to use the carbon fibre or aluminium sheeting identified above in a solid form to create the wing mounts.

Our final prototype design encompasses a framework like upright design for the wing, which will require the use of more solid materials and sheeting etc rather than the tubing.

However, we have allowed space internal of the upright design with hole cut outs for these tubes etc containing linear actuators in, so we have the option to implement them if we wanted to continue down the route of raising/lowering the wing in any final design choices.

- The pricing of these carbon fibre tubes is around £61 per metre of tube for a 50mm OD tubes (47mm ID). (See Figure to right) (**Easy Composites** (n.d.-c) - 50mm - 47mm Woven Finish Carbon Fibre Tube)



50mm (47mm) Woven Finish Roll Wrapped Carbon Fibre Tube

CFT-WF-50-47-1 | 5 stars | No reviews

High strength roll wrapped carbon fibre tube with a glossy, woven carbon fibre finish making them a great choice for a huge range of both structural and cosmetic applications including drones, UAVs, camera rigs, automation, tripods, lightweight structures and much more.

This tube has an outside diameter (OD) of 50mm and an inside diameter (ID) of 47mm, resulting in a 1.5mm wall thickness and is manufactured using alternating layers of high strength unidirectional carbon fibre running length-ways down the tube for stiffness and at 90° around the tube to provide hoop strength and resistance to crush, burst and torsional loads. Externally the tube is finished with a smooth, UV stable clear coat showing off the classic appearance of its 2x2 twill woven carbon fibre outer layer.

Available in 1m and 2m lengths.

PRODUCT VERSIONS

LENGTH

☒ 1000mm (1m) ☐ 2000mm (2m)

AVAILABILITY:
MORE THAN 20 AVAILABLE
for immediate shipping

PRICE **£61.20** ex.VAT
(£61.20 /M)

TRADE DISCOUNTS

0-4	5-19	20+

PRODUCT VIDEOS (2)



- Alternatively, we could get these tubes in aluminium at around £50 per metre of 50mm tube. (See Figure to right) (**Aluminium Warehouse** (n.d.-b) - 2-in-x-3-8-in- Aluminium Round Tube)



50.8mm x 9.5mm (2" x 3/8") Aluminium Round Tube

☐ ☐ ☐ ☐

Length: 1000 mm

☒ 1000 mm ☐ 2000 mm ☐ 3000 mm ☐ 4000 mm ☐ 5000 mm

Price: £50.40 Inc. Vat
£42.00 Exc. Vat

Weight: 3.35kg

4.9.4 Material Research and Properties for FEA simulations (MS)

4.9.4.1 Aluminium types (MS)

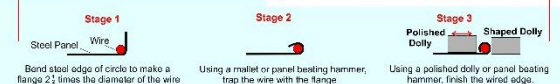
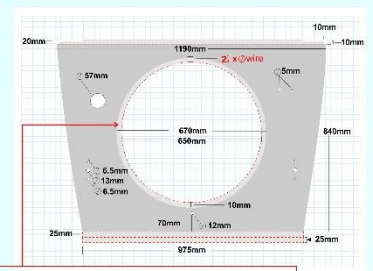
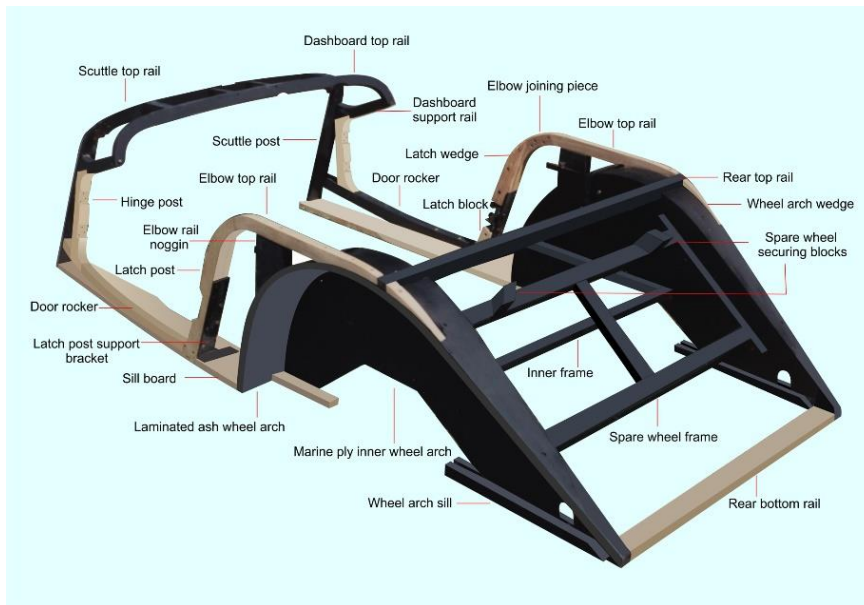
<u>Aluminium types</u>	
1060 Alloy vs 6061 T6 Alloy	The hardness of 1060 is moderate, which can adapt to common processing conditions, such as bending, while the hardness of 6061 is better, which is widely used in places with high hardness requirements. The common aluminium plate thickness of 6061 alloy is 6-100 mm. At the same time, 6061 aluminium plates can be heat treated. 6061-T6 aluminium sheet is such a temper, which is suitable for Mold and machinery manufacturing industries. 6061 aluminium is a medium to high strength, heat-treatable alloy with good corrosion resistance and weldability. It's often used in structural applications. Pricing: £99 for a 4ft x 2ft 0.025" thick sheet.

6082 T6 Alloy	• The aluminium 6082 alloy is mainly known for offering increased resistance when compared to the 5xxx series alloys. This is the strongest alloy in the 6xxx series, and it is often called structural aluminium alloy since it is very popular for structural components. • The main reason for this alloy to be so strong while having very high corrosion resistance is that it contains a large amount of manganese which controls the grain structure, thus making it more stable. • Perhaps the only negative characteristic of the aluminium 6082 alloy is that thin walls are difficult to machine as well as complex shapes are difficult to achieve via extrusion. Also, while it accepts welds, it is important to consider that the welded zone will lose strength. • These characteristics, as well as its light weight and excellent mechanical properties, contributed to the use of 6082-T6 alloy in automobile, aviation, and high-speed rail applications. Perfect for the application type we are looking for. Pricing: Average £206 per square meter of 6mm thick sheet.
7075 Alloy	• A strong, heat-treated alloy that's comparable to many steels. • Used in safety-critical components like bicycle parts and rock-climbing equipment. • Has a good strength-to-weight ratio. • Not recommended for applications that require corrosion resistance. Pricing: Average £20 per square meter of 10mm thick sheet.

4.9.4.2 Other material options (MS)

<u>Other material options</u>	
<u>Carbon fibre composite materials</u>	
High Elastic Modulus Type (HM)	The high elastic modulus type, or HM, has a tensile elastic modulus ranging from 350 to 600 GPa. And its tensile strength is at least 2,500 MPa. It is commonly utilized in aerospace, automotive, and advanced sporting goods. High elastic modulus carbon fibre enables the creation of lightweight components without compromising strength.
PAN-based Carbon Fiber	PAN-based carbon fibre is created by PAN (Polyacrylonitrile) precursor carbonization. This carbon fibre has high tensile strength and elastic modulus. It is widely used for structural material composites in aerospace, industrial fields, and sports / recreational products. Pricing: £234 per square meter of 2mm thick sheet.
<u>Titanium alloy – Grade 5</u>	Mechanical Properties Tensile Strength, Ultimate: 1170 Mpa Tensile Strength, Yield: 1100 Mpa Elongation at Break: 10% Modulus of Elasticity: 114 Gpa Pricing: around £540 per 500mm x 500mm x 6mm thick sheet
<u>Flax Fibre</u>	Flax is a natural fibre that comes from the stem of the flax or linseed plant, which is grown and harvested specifically for its fibre. Flax fabric, commonly known as linen, has been produced for thousands of years and is in fact the oldest known textile. What makes this fibre viable as a reinforcement material for us in composites is its long, continuous, cellulose fibres which – for a natural fibre - have excellent tensile strength and stiffness.

4.9.5 Wing Mounting Solutions (MS)



These images above will help us to develop and decide on the correct and appropriate place to attach and mount our final wing assembly to the morgan plus four.

The top beam bar that can be seen on the real image above as well as the chassis Skelton image is likely an ideal spot to have our main mounting points. This is placed behind the spare wheel assembly which we can remove to gain access to this area. Similar to the Morgans in the Uni, we can get a circle sheet to cover the hole where the spare wheel would sit, and then create cut outs to access this framework upon the wing mounts to go through.

I have also gathered measurement values for these components to help with constructing and designing the wing mounting points for the morgan, and what distance apart they should be spaced etc.

4.9.6 Conclusion (MS)

Overall, I believe my section of the project ended up going well in the end. There were a few mishaps at the start with deciding/knowing exactly what each member of the structural team should focus on, but this was eventually decided on quick enough. The final jobs were done by specific timeline dates such as interim viva, final viva and report etc which ultimately is the main thing that the jobs got done.

The structural and materials research conducted for this project has successfully identified optimal material choices and design solutions for the rear wing assembly. Through detailed analysis of carbon fibre, aluminium, and flax fibre composites, we have determined that carbon fibre offers the best balance between strength, weight, and performance, despite its higher cost. Additionally, the use of Rohacell foam as an internal core material has been explored to enhance structural integrity while minimizing weight.

For the wing mounting solution, both carbon fibre and aluminium tubes were considered, with an emphasis on structural stability and adaptability for an active wing system. The final prototype design incorporates a robust framework that accommodates potential actuation mechanisms, ensuring flexibility in future design iterations.

Finite Element Analysis (FEA) simulations have further validated the suitability of the selected materials by assessing their mechanical properties under real-world aerodynamic and load conditions. The results confirm that the chosen materials and design strategies effectively balance performance, durability, and cost-efficiency.

Overall, I the project has achieved its objective of identifying and justifying the best material and structural choices for the rear wing assembly. The collaborative efforts between the structural and aerodynamics teams have ensured a well-integrated approach, aligning with the project's performance goals and manufacturing feasibility. Future work could involve further optimization through physical testing and refinement of the mounting system to enhance aerodynamic efficiency an

4.10 Structure and FEA (CJ)

4.10.1 Introduction to Structural Role (CJ)

This section outlines how the structural design team played a crucial role in our group project's finite element analysis (FEA), centring on developing and validating an active rear wing system for the Morgan Plus 4. While the project involved various disciplines like aerodynamics, mechatronics, control systems, and simulations, the focus of this section is specific to the structural design and mechanical assessment of the wing and its supporting elements.

Our FEA analysis mainly aimed to assess and verify how the wing structure would behave under different loading conditions based on realistic aerodynamic forces. CFD simulations from Aerodynamics defined performance limits under challenging driving conditions.

4.10.2 Purpose of FEA simulations (CJ)

The need to conduct FEA in this project stems from the dynamic and load-sensitive nature of the active rear wing system. Unlike fixed aerodynamic surfaces, the wing is designed to move within a 60-degree range of motion, maintain an FOS of 1.25 and a weight limit of 60kg, as mentioned in the project overview (UWTSD, 2024). This movement subjects the structure to variable forces dependent on speed, wing angle, and actuation. These fluctuations impact the load path through the wing, uprights, and mounting interfaces.

Without simulation, components risk being under-designed (and prone to failure) or over-designed, adding unnecessary weight and cost.

Wing mounts form a vital structural link; failure here could affect aerodynamics, actuator precision, or chassis integrity. Therefore, it was essential to assess all parts for their strength, stiffness, and deformation under real-world forces.

4.10.3 Application of FEA to the Project (CJ)

FEA was conducted using SolidWorks Simulation. However, ANSYS was utilised during the earlier stages of the project to learn the simulation process. This is evident in the initial FEA simulations performed on a basic rear wing, as seen below. SolidWorks was chosen for its CAD compatibility and built-in analysis tools. Models were created for the swan neck uprights, actuator mounts, and the complete wing assembly. Models were tested under aerodynamic load cases.



Figure 44 - Initial FEA Simulations Images on ANSYS

The CFD analysis conducted by the Aerodynamics team yielded force distributions across the rear axle of the Morgan Plus 4 at different wing heights (Aerodynamics Group, 2025). These values were directly applied to the wing model within the simulation environment. This ensured structural loads reflected aerodynamic behaviour during high-speed cornering, braking, and straight-line acceleration scenarios.

The image below demonstrates that fixture conditions were applied at specific attachment points to create realistic constraints, which included the base mount. Contact definitions were incorporated to accurately model the mechanical behaviour of interfaces, such as fastener holes, bearing seats, and mating surfaces.

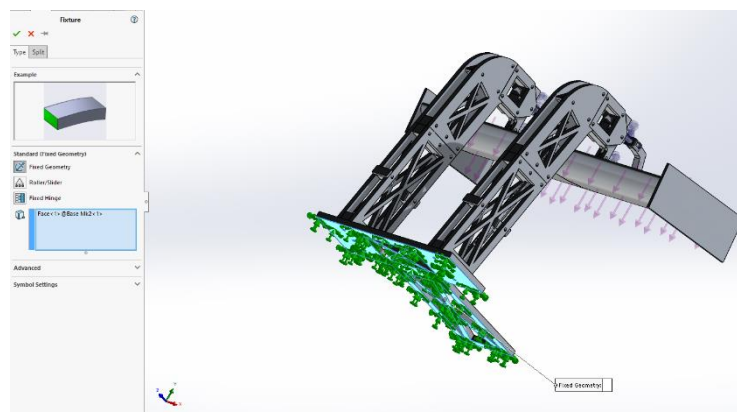


Figure 45 - Fixed Geometry in FEA Simulation

The assemblies were meshed using curvature-based meshing, seen in the image below, with mesh controls applied in high-stress areas, such as sharp corners, flanges, and transitions between composite and metallic components.

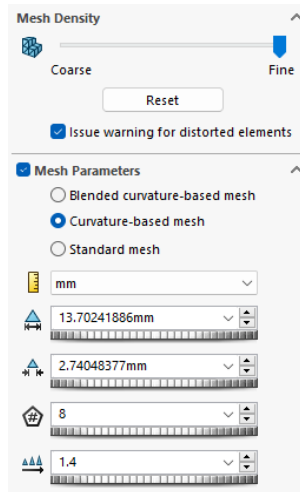


Figure 47 - Meshing Parameters

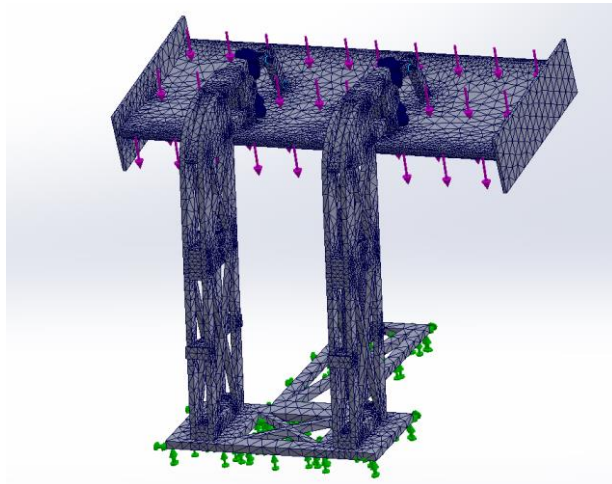


Figure 46 - Curvature-Based Mesh Applied to Assembly

4.10.4 Static and Transient Load Analysis (CJ)

Static load analyses were performed to simulate the rear wing's performance under sustained aerodynamic pressure. Simulations using 1060 aluminium assessed peak downforce response, including stress and displacement, as seen below. Additionally, the analysis identified weak points in the initial mounting designs, prompting several iterations to eliminate stress concentrations and improve load distribution.

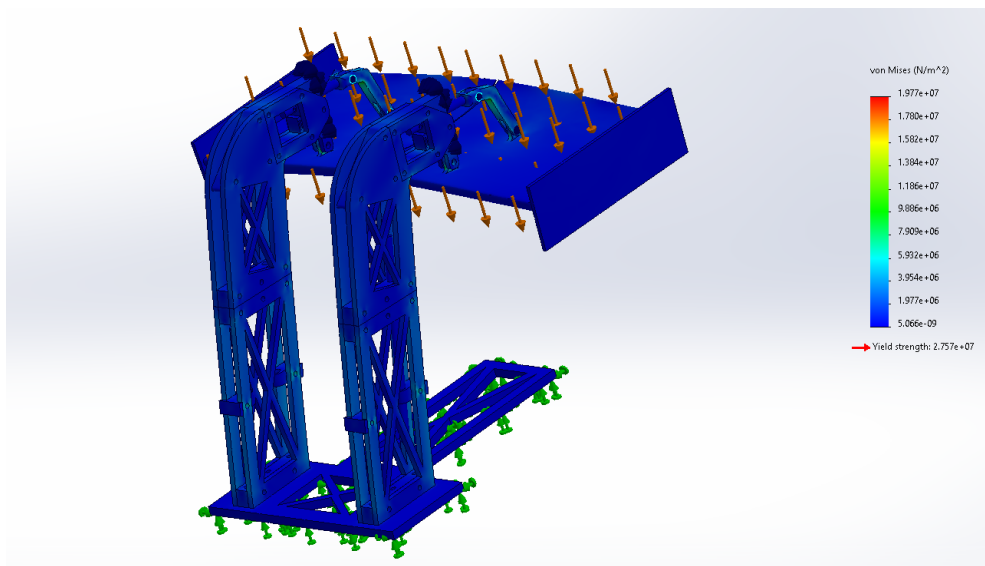


Figure 48 - Stress Plot 1060 Aluminium at 165N of Downforce

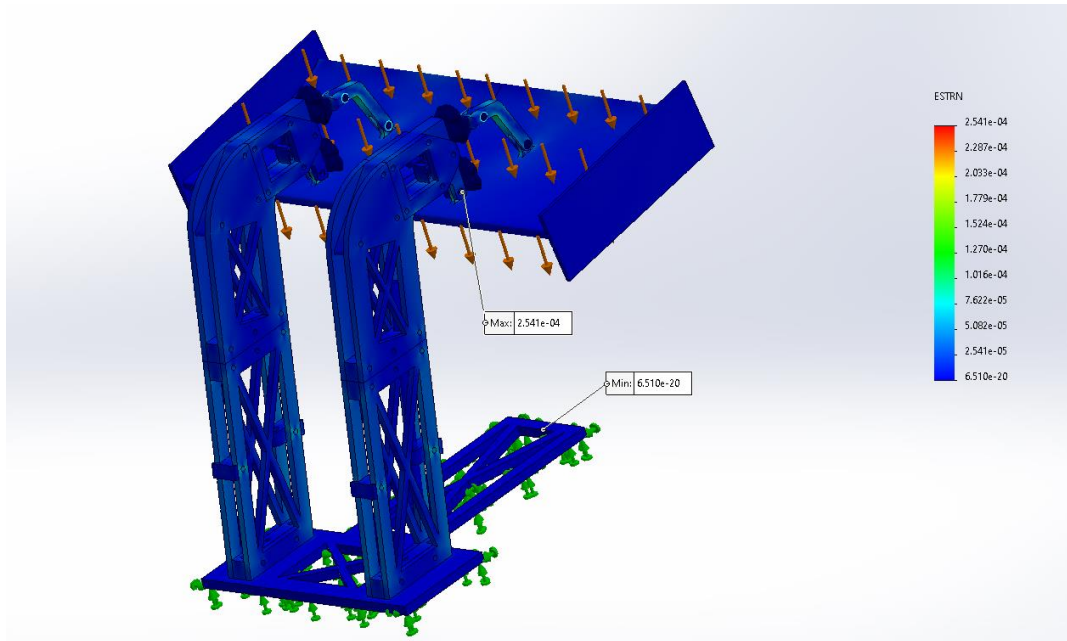


Figure 49 - Strain Plot 1060 Aluminium at 165N of Downforce

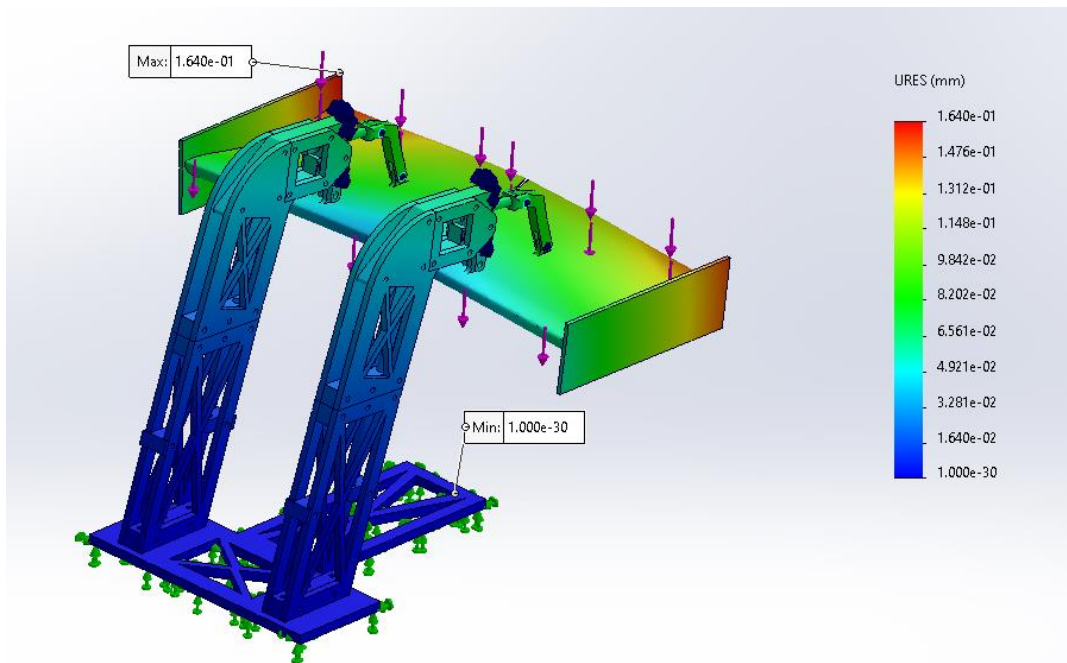


Figure 50 - Displacement Plot 1060 Aluminium at 165N of Downforce

Transient load simulations were conducted to estimate the wing's response to changing loads over time, particularly during braking, cornering, or rapid actuator movement. Although SolidWorks does not offer a complete dynamic response analysis, the simulations presented below were performed in a time-stepped format, where forces were applied incrementally to mimic time-varying loads.

These simulations were crucial for assessing fatigue risk, actuator-bracket interactions, and cumulative stress in components under repeated actuation. The dynamic loading highlighted specific vulnerabilities around bolt holes and unsupported overhangs, as seen below.

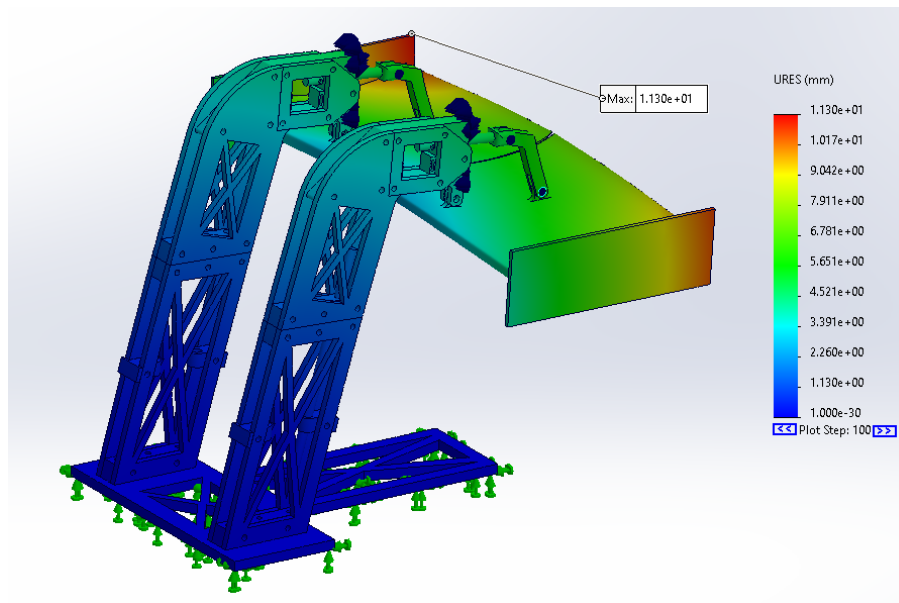


Figure 51 - Transient Load Displacement Plot 6082 T6 Aluminium

4.10.5 Material Comparison Study (CJ)

One of the primary objectives of our structural analysis was to conduct a comprehensive study of several candidate materials, all tested under the same loading conditions. This analysis was informed by material research conducted by the team (Structural Group, 2025), which examined various alloys and composites in terms of their mechanical properties, manufacturability, and cost.

The materials assessed included:

- **Aluminium Alloys:** 1060, 6061-T6, 6082-T6, and 7075-T6
- **Carbon Fibre Composites:** High Modulus (HM) and PAN-based
- **Titanium Alloy:** Grade 5 (Ti-6Al-4V)
- **Polymers:** PLA and PETG (for prototyping only)

Each material was tested on the entire assembly; key outputs included stress, strain, displacement, and FOS.

As shown below, High Modulus Carbon Fibre offered the best stiffness and lowest deflection, making it ideal for the wing. At the same time, PAN-based carbon fibre followed closely with a strong performance-to-cost ratio. However, both materials posed challenges in manufacturing complexity and required careful verification of the FOS because their yield points are less defined in composite materials (Keane, 2018).

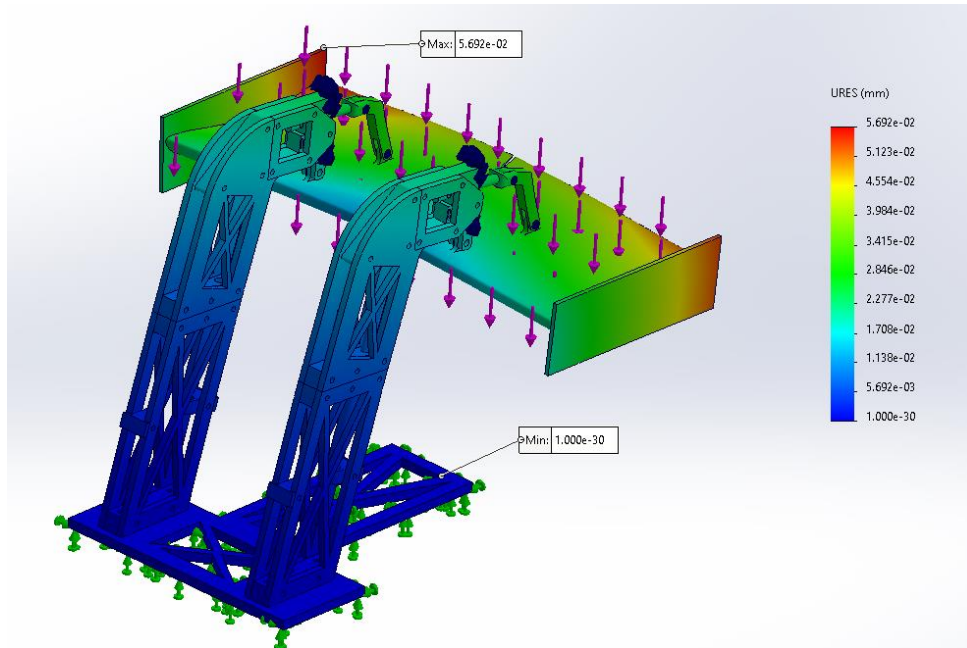


Figure 52 - Displacement Plot PAN-based Carbon Fibre at 165N of Downforce

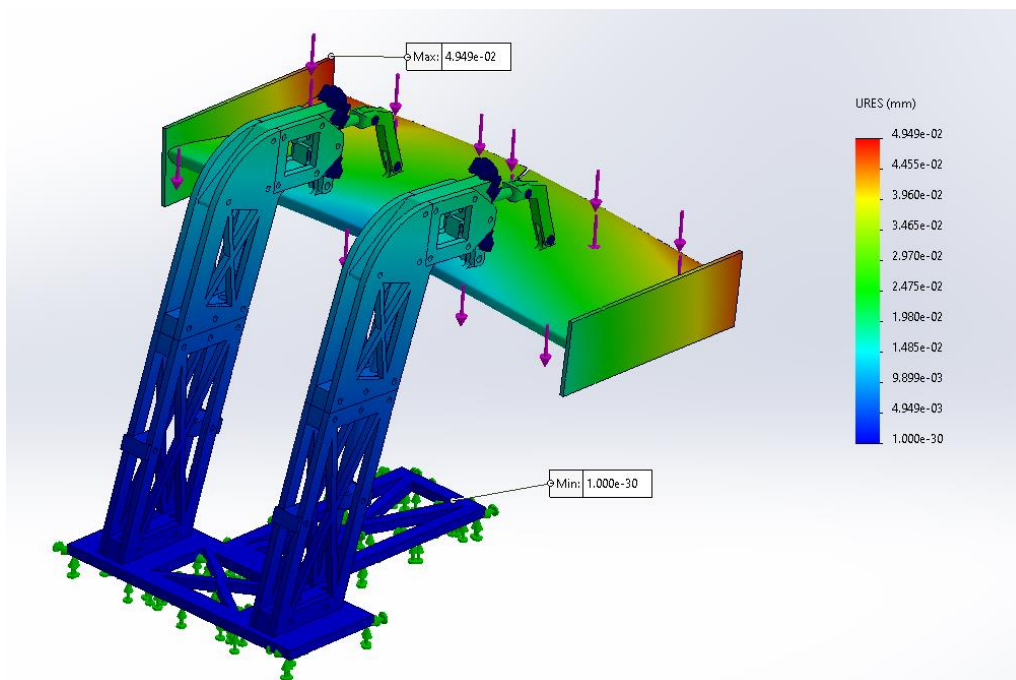


Figure 53 - Displacement Plot Carbon Fibre High Elastic Modulus at 165N of Downforce

Among the metallic options, 7075-T6 aluminium (see below) played a significant role in the material selection process, demonstrating one of the best structural performances. It consistently maintained an FOS above 1.5 with minimal deflection. Its high strength-to-weight ratio (OnlineMetals.com,

2025) and relatively affordable cost made it one of the preferred choices for mounting and supporting elements from an FEA perspective.

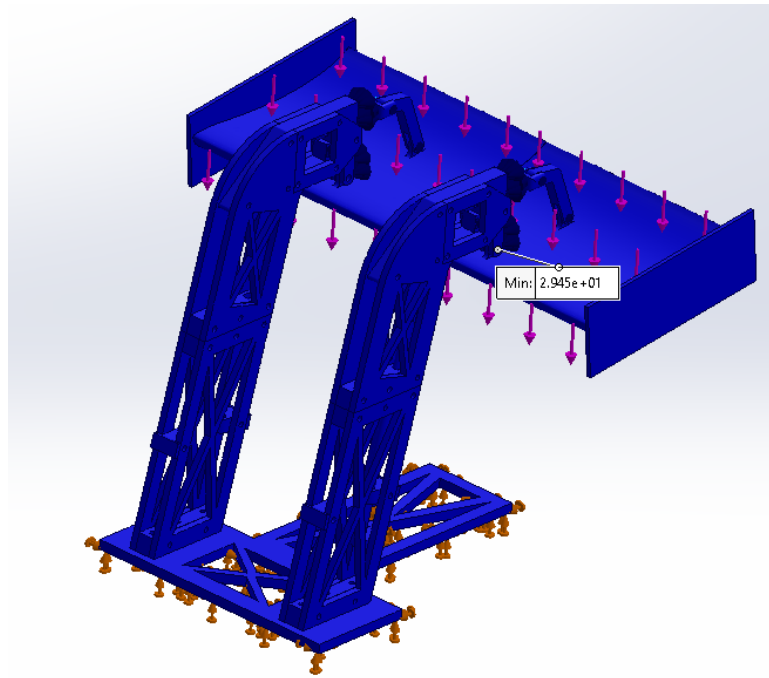


Figure 54 - Minimum Factor of Safety 7075 T6 Aluminium

While 6082-T6 and 6061-T6 were acceptable alternatives (OnlineMetals.com, 2025), they exhibited more significant deformation and slightly lower FOS values under the same loading conditions. On the other hand, aluminium 1060, although inexpensive and easy to work with, showed poor structural behaviour, with lower values than that of the different materials.

Titanium Grade 5 showed excellent performance, exhibiting high strength and minimal deformation. However, its high density and cost (OnlineMetals.com, 2025b) were considered. Its properties, nevertheless, validated simulation accuracy, serving as a benchmark for metallic performance.

PLA and PETG were initially included in the simulation group not as structural options but to assess their appropriateness for prototyping. However, meaningful FEA results could not be achieved. The simulation for PLA did not converge during the meshing and solving phases, likely due to instability caused by significant deformation under load. The PETG simulation generated data, but the validity of the input properties was questioned because of insufficient reliable mechanical data for use in simulations (Hsueh et al., 2021). Consequently, no conclusive values for stress, strain, or FOS were reported for either material. These difficulties illustrate a limitation in simulating non-engineering polymers and suggest that future efforts might benefit from conducting material testing to obtain accurate physical properties or from utilising validated third-party material libraries designed for

additive manufacturing materials. Despite the issues encountered during simulation, the endeavour reaffirmed their intended use as low-risk options for prototyping, suitable solely for visual presentations and fitment evaluations but not for applications that require load-bearing capabilities. The comparative material study informed final design decisions by enhancing the team's understanding of material behaviour under load, especially in complex assemblies. It highlighted the need to balance theoretical performance with practical considerations. For example, carbon fibre showed excellent stiffness, but its anisotropic behaviour complicated stress predictions. Observing the failure of PLA and PETG under load also revealed the limitations of rapid prototyping materials. The FEA-driven evaluation helped select materials based on datasheets and performance suited for specific applications.

4.10.6 Factor of Safety Variation and Structural Integrity Assessment (CJ)

A significant outcome of the material comparison was the FOS variation among different materials, which directly influenced their suitability for the final assembly. High-performance materials, such as High Modulus Carbon Fibre and Titanium Grade 5, achieved FOS values well above the 1.25 threshold (UWTSD, 2024), indicating substantial margins against failure under aerodynamic loading. This highlights the critical role of FEA in identifying structurally viable materials that affect the entire project. An inadequate FOS could result in structural failure and compromise aerodynamic and control system performance, potentially undermining the whole active wing concept.

To maintain the FOS, any materials or geometries that failed to meet the 1.25 FOS were subjected to a review process. Components that did not satisfy the criteria were either refined through design modifications or, if they remained inadequately robust after iterations, were outright rejected. This meticulous approach ensured the integrity and safety of the final structure, ultimately contributing to the project's overall success and reliability.

Using carbon fibre composites posed a unique challenge because traditional definitions of yield and failure do not apply neatly to anisotropic materials (Korenczuk et al., 2017). We utilised conservative estimates for yield stresses and adapted models to focus on maximum principal stresses and strains. This approach enabled the simulations to more accurately reflect the risk of failure, particularly in areas around bolt holes and curved edges. Below is the data on the FOS for both carbon-based materials.

4.10.7 Collected FEA Data Table (CJ)

Material	Max Displacement(mm)	Max Stress	Max Strain	Min FOS	Yield Strength
1060 Aluminium	1.640x10 ⁻¹	1.977x10 ⁺⁷	2.541x10 ⁻⁴	1.7	2.757x10 ⁺⁷
6061 T6 Aluminium	1.647x10 ⁻¹	2.135x10 ⁺⁷	2.744x10 ⁻⁴	1.6	2.75x10 ⁺⁸
6082 T6 Aluminium	5.682	2.135x10 ⁺⁷	9.465x10 ⁻³	1.6	2.8x10 ⁺⁸
7075 T6 Aluminium	1.585x10 ⁻¹	2.135x10 ⁺⁷	2.640x10 ⁻⁴	2.9	5x10 ⁺⁸
Carbon Fibre High Elastic Modulus	4.949x10 ⁻²	2.1x10 ⁺⁷	7.931x10 ⁻⁵	3	5x10 ⁺⁹
Pan-based Carbon Fibre	5.692x10 ⁻²	2.1x10 ⁺⁷	9.121x10 ⁻⁵	2	3.5x10 ⁺⁹
Titanium Grade 5	1.1x10 ⁻¹	2.115x10 ⁺⁷	1.776x10 ⁻⁴	5	8.8x10 ⁺⁸
PLA	N/A	N/A	N/A	N/A	N/A
PETG	N/A	N/A	N/A	N/A	N/A

4.10.8 FEA of Possible Mounting Solutions (CJ)

Alongside the primary structural evaluation of the wing assembly, a simplified, unscaled representation of the Morgan Plus 4's rear tyre frame was created and analysed to investigate its potential as a mounting option for the active wing system. Although based on rough geometry (Morgan Rebuild, 2025), the model was adequate for simulating typical loading conditions and evaluating overall structural behaviour (Morgan Motors, 2025).

The objective was to determine if the current frame or a reinforced version could serve as a mounting point for the wing's support uprights. A distributed load of 165 N, which symbolises aerodynamic forces acting on the wing, was applied to the top surface of the frame, with boundary conditions simulating its attachment to the chassis and suspension.

The findings indicated minimal displacement, with the maximum deflection being only 0.101 mm, primarily occurring around unsupported mid-span components (see below). This implies the structure is stiff under moderate loads and may be suitable for further development as a mounting interface. The simulation was based on 6082-T6 aluminium, a standard structural alloy used in automotive contexts. While the analysis did not account for full-scale dimensions or detailed stress analysis, it showcased the benefits of early digital prototyping in evaluating integration approaches before physical fabrication.

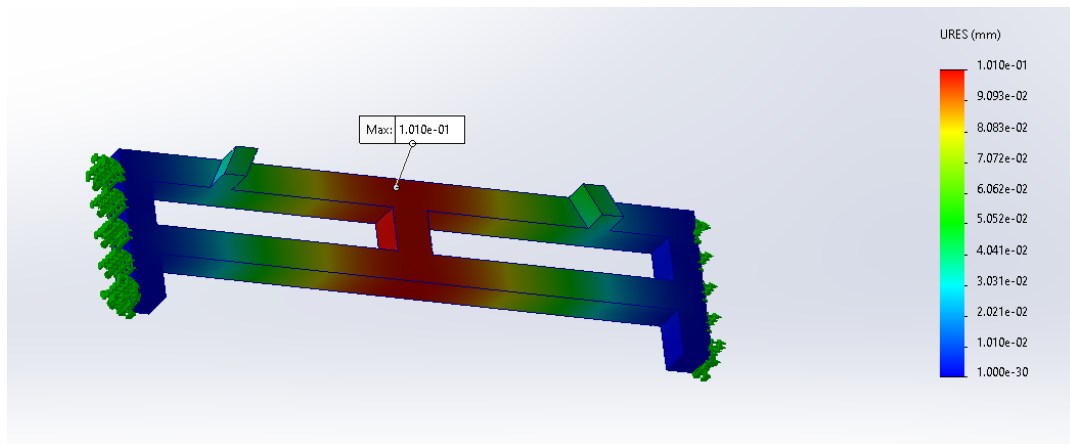


Figure 55 - Displacement of Spare Tyre Frame 6082 T6 Aluminium

4.10.9 FEA Team Integration and Collaboration (CJ)

The effectiveness of the structural FEA efforts relied significantly on strong cooperation with other teams. The Aerodynamics group was crucial by providing verified CFD results (Aerodynamics Group , 2025), which determined the strength of forces and their distribution and change with wing angle. This information was vital for establishing realistic load scenarios, especially for modelling the wing's response under maximum downforce conditions.

The Mechatronics team played an essential role in advising on the placement of actuators. This input was incorporated into the structural models with specific constraints and load applications at the actuator mounting locations. In certain instances, the deflections anticipated by the FEA prompted discussions about the limits of actuator travel and the tolerances for positional feedback.

Collaboration across teams was crucial for the success of the FEA work, but integration within the structural team itself was equally important. The material comparison studies conducted through simulation relied on earlier collaborative research undertaken by team members (Structural Group , 2025). This research, documented in the team's shared material review, provided essential data on mechanical properties, cost considerations, and manufacturing feasibility for various candidate materials. These findings guided the selection of materials for simulation, allowing the FEA process to concentrate on the most viable options in terms of both performance and practicality.

4.10.10 Challenges and Resolutions (CJ)

One of the most time-consuming aspects of FEA involved meshing the intricate geometries of the wing assembly. Small fillets, bolt holes, and transitions created regions prone to poor mesh quality. Local mesh controls and adaptive meshing techniques were employed to tackle these issues.

Transient simulations posed additional difficulties. The requirement to simulate moving or time-varying loads with the constraints of available software meant we had to rely on approximations. Rather than executing comprehensive motion simulations, we employed load steps to represent the significant actuation and aerodynamic load phases. Although this method might not have provided the high level of detail found in a full dynamic simulation, it acted as a practical and reasonably accurate compromise.

4.10.11 Summary of Findings (CJ)

Each wing system component was assessed and optimised through a structured FEA approach to meet aerodynamic, mechanical, and regulatory requirements. Using high-strength materials, including 7075-T6 aluminium and high-modulus carbon fibre, combined with collaborative design refinements, ensured the structure remained lightweight and durable. This project showcased the effectiveness of simulation-driven design in delivering efficient and integrated engineering solutions.

4.10.12 Conclusion of Structural Contribution (CJ)

The FEA conducted in this project served as the basis for validating and refining the design of the active rear wing system. By integrating high-fidelity simulations with collaborative design efforts, the team successfully developed a solution that is mechanically sound, lightweight, and compliant with regulations.

In addition to confirming the design, the FEA process enhanced geometry, clarified interface definitions, and fostered a team-wide comprehension of structural limitations. It had a direct impact on actuator positioning, aerodynamic adjustments, and decisions related to prototyping.

Consequently, this contribution illustrates how design grounded in simulation can support safety, innovation, and integration in an engineering project.

Should this project move forward, further refinement of the FEA process would involve investigating more advanced simulation techniques, such as composite layup modelling for carbon fibre components. This would allow for a more accurate directional stiffness and failure criteria representation. Moreover, employing ANSYS Mechanical for comprehensive dynamic simulations could significantly enhance the accuracy of transient analyses, particularly during actuator operation and high-speed manoeuvres. Lastly, conducting physical tests on prototype components would validate the simulation results, bridging the gap between theoretical modelling and real-world performance. This step would further bolster confidence in design decisions for future developments.

5 Group Conclusion (AC)

The development of the fully active rear wing system for the Morgan Plus Four successfully explored the balance between aerodynamic performance, regulatory constraints, and mechanical feasibility. By analysing all the simulation data to optimise the wing's effectiveness and integrating a mechatronics-driven actuation system, the design provides active aerodynamic control while maintaining structural integrity. The project showcased a structured approach, from initial concept selection to detailed design and analysis, ensuring a functional and regulation-compliant solution. Further refinement through additional simulation and physical testing would enhance the system's real-world performance, reinforcing the value of active aerodynamics in performance vehicle applications.

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7 Appendix

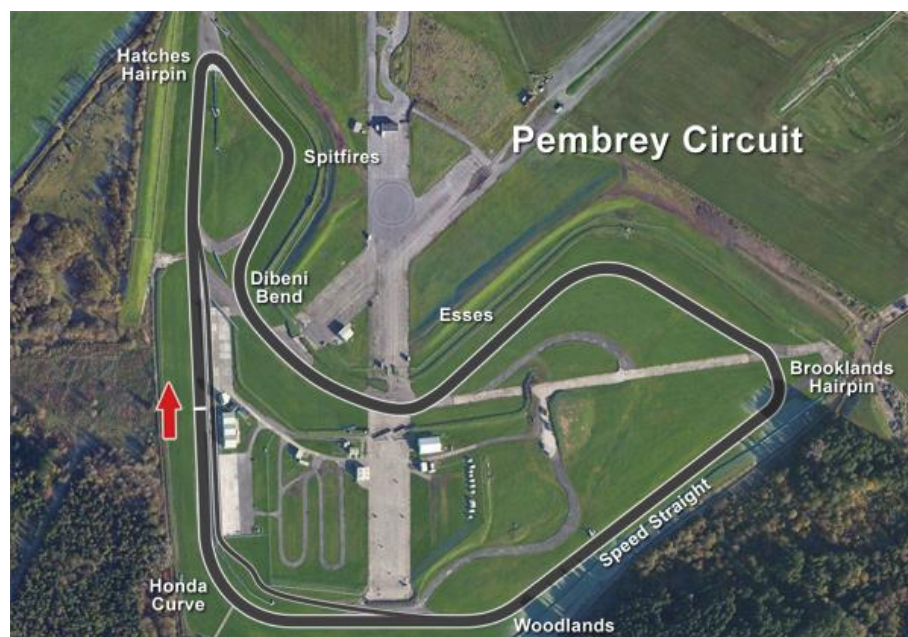
7.1 Simulation (DB)

Appendix A – Llandow Track Map



(My Racing Career, 2015)

Appendix B – Pembrey Track Map



(Debnar, F. 2015)

7.2 Mechatronics and control systems (SH)

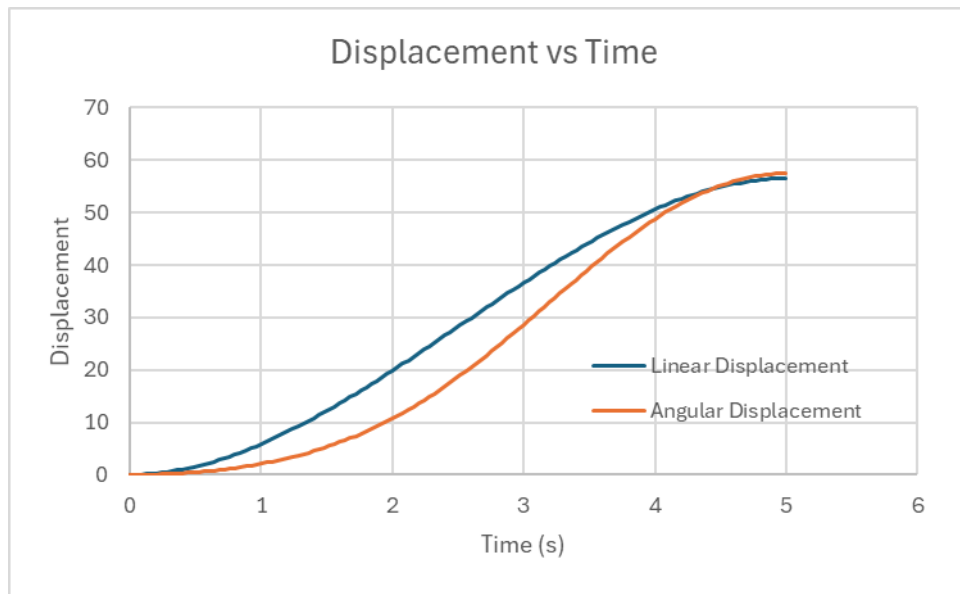


Figure above shows both Linear and Angular displacement vs time as calculated from the motion study data.

Linear Displacement		Angular Displacement	
Time (sec)	Displacement	Time (sec)	Displacement
0	0	0	0.012338813
0.04	0.010790144	0.04	0.009123726
0.08	0.032139008	0.08	0.000467102
0.12	0.053140736	0.12	0.016372943
0.16	0.073795328	0.16	0.038559809
0.2	0.094102784	0.2	0.067019074
0.24	0.114063104	0.24	0.101766173
0.28	0.133676288	0.28	0.142839362
0.32	0.152942336	0.32	0.190298542
0.36	0.171861248	0.36	0.244224144
0.4	0.190433024	0.4	0.304716062
0.44	0.208657664	0.44	0.371892632
0.48	0.226535168	0.48	0.445889658
0.52	0.244065536	0.52	0.526859477
0.56	0.261248768	0.56	0.614970057
0.6	0.278084864	0.6	0.710404131
0.64	0.294573824	0.64	0.813358352
0.68	0.310715648	0.68	0.924042481
0.72	0.326510336	0.72	1.042678589
0.76	0.341957888	0.76	1.169500276
0.8	0.357058304	0.8	1.30475191

0.84	0.371811584	0.84	1.448687864
0.88	0.386217728	0.88	1.601571772
0.92	0.400276736	0.92	1.763675773
0.96	0.413988608	0.96	1.935279766
1	0.427353344	1	2.116670648
1.04	0.440370944	1.04	2.308141549
1.08	0.453041408	1.08	2.509991049
1.12	0.465364736	1.12	2.722522379
1.16	0.477340928	1.16	2.946042596
1.2	0.488969984	1.2	3.180861734
1.24	0.500251904	1.24	3.427291921
1.28	0.511186688	1.28	3.685646465
1.32	0.521774336	1.32	3.95623889
1.36	0.532014848	1.36	4.239381942
1.4	0.541908224	1.4	4.53538653
1.44	0.551454464	1.44	4.844560629
1.48	0.560653568	1.48	5.167208117
1.52	0.569505536	1.52	5.503627553
1.56	0.578010368	1.56	5.854110896
1.6	0.586168064	1.6	6.218942151
1.64	0.593978624	1.64	6.59839595
1.68	0.601442048	1.68	6.992736062
1.72	0.608558336	1.72	7.402213828
1.76	0.615327488	1.76	7.827066521
1.8	0.621749504	1.8	8.267515645
1.84	0.627824384	1.84	8.723765146
1.88	0.633552128	1.88	9.195999569
1.92	0.638932736	1.92	9.684382143
1.96	0.643966208	1.96	10.18905281
2	0.648652544	2	10.71012619
2.04	0.652991744	2.04	11.24768953
2.08	0.656983808	2.08	11.80180061
2.12	0.660628736	2.12	12.37248556
2.16	0.663926528	2.16	12.95973683
2.2	0.666877184	2.2	13.56351099
2.24	0.669480704	2.24	14.18372667
2.28	0.671737088	2.28	14.82026251
2.32	0.673646336	2.32	15.47295523
2.36	0.675208448	2.36	16.14159771
2.4	0.676423424	2.4	16.82593726
2.44	0.677291264	2.44	17.52567404
2.48	0.677811968	2.48	18.24045959
2.52	0.677985536	2.52	18.96989569
2.56	0.677811968	2.56	19.71353334
2.6	0.677291264	2.6	20.47087207

2.64	0.676423424	2.64	21.24135952
2.68	0.675208448	2.68	22.02439139
2.72	0.673646336	2.72	22.81931167
2.76	0.671737088	2.76	23.62541326
2.8	0.669480704	2.8	24.44193902
2.84	0.666877184	2.84	25.26808316
2.88	0.663926528	2.88	26.10299305
2.92	0.660628736	2.92	26.94577146
2.96	0.656983808	2.96	27.79547914
3	0.652991744	3	28.65113787
3.04	0.648652544	3.04	29.51173379
3.08	0.643966208	3.08	30.37622113
3.12	0.638932736	3.12	31.24352621
3.16	0.633552128	3.16	32.11255174
3.2	0.627824384	3.2	32.98218126
3.24	0.621749504	3.24	33.85128385
3.28	0.615327488	3.28	34.71871884
3.32	0.608558336	3.32	35.58334067
3.36	0.601442048	3.36	36.44400365
3.4	0.593978624	3.4	37.29956669
3.44	0.586168064	3.44	38.14889788
3.48	0.578010368	3.48	38.9908789
3.52	0.569505536	3.52	39.82440912
3.56	0.560653568	3.56	40.6484095
3.6	0.551454464	3.6	41.46182603
3.64	0.541908224	3.64	42.2636329
3.68	0.532014848	3.68	43.05283519
3.72	0.521774336	3.72	43.82847118
3.76	0.511186688	3.76	44.58961418
3.8	0.500251904	3.8	45.3353739
3.84	0.488969984	3.84	46.06489749
3.88	0.477340928	3.88	46.77736996
3.92	0.465364736	3.92	47.47201433
3.96	0.453041408	3.96	48.14809134
4	0.440370944	4	48.80489873
4.04	0.427353344	4.04	49.44177023
4.08	0.413988608	4.08	50.05807427
4.12	0.400276736	4.12	50.6532123
4.16	0.386217728	4.16	51.22661698
4.2	0.371811584	4.2	51.77775011
4.24	0.357058304	4.24	52.30610036
4.28	0.341957888	4.28	52.81118091
4.32	0.326510336	4.32	53.29252695
4.36	0.310715648	4.36	53.7496931
4.4	0.294573824	4.4	54.18225079

4.44	0.278084864	4.44	54.58978559
4.48	0.261248768	4.48	54.97189456
4.52	0.244065536	4.52	55.32818356
4.56	0.226535168	4.56	55.65826469
4.6	0.208657664	4.6	55.96175364
4.64	0.190433024	4.64	56.23826723
4.68	0.171861248	4.68	56.48742092
4.72	0.152942336	4.72	56.70882647
4.76	0.133676288	4.76	56.90208965
4.8	0.114063104	4.8	57.06680807
4.84	0.094102784	4.84	57.2025691
4.88	0.073795328	4.88	57.30894795
4.92	0.053140736	4.92	57.38550582
4.96	0.032139008	4.96	57.43178826
5	0.010790144	5	57.44732359

Table above shows the complete data set taken from the SolidWorks motion study.

7.3 Extra Aerodynamics Images (OW)

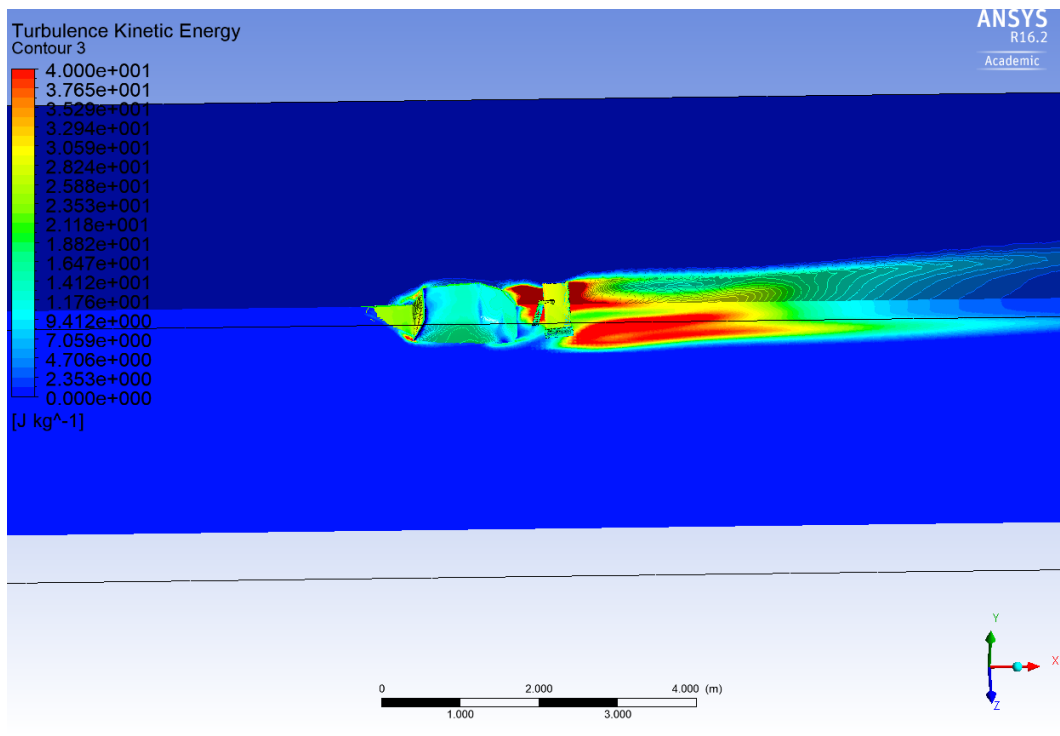


Figure 56-KE Turbulence CFD results at peak flow on wing 1100mm @ 5 Deg

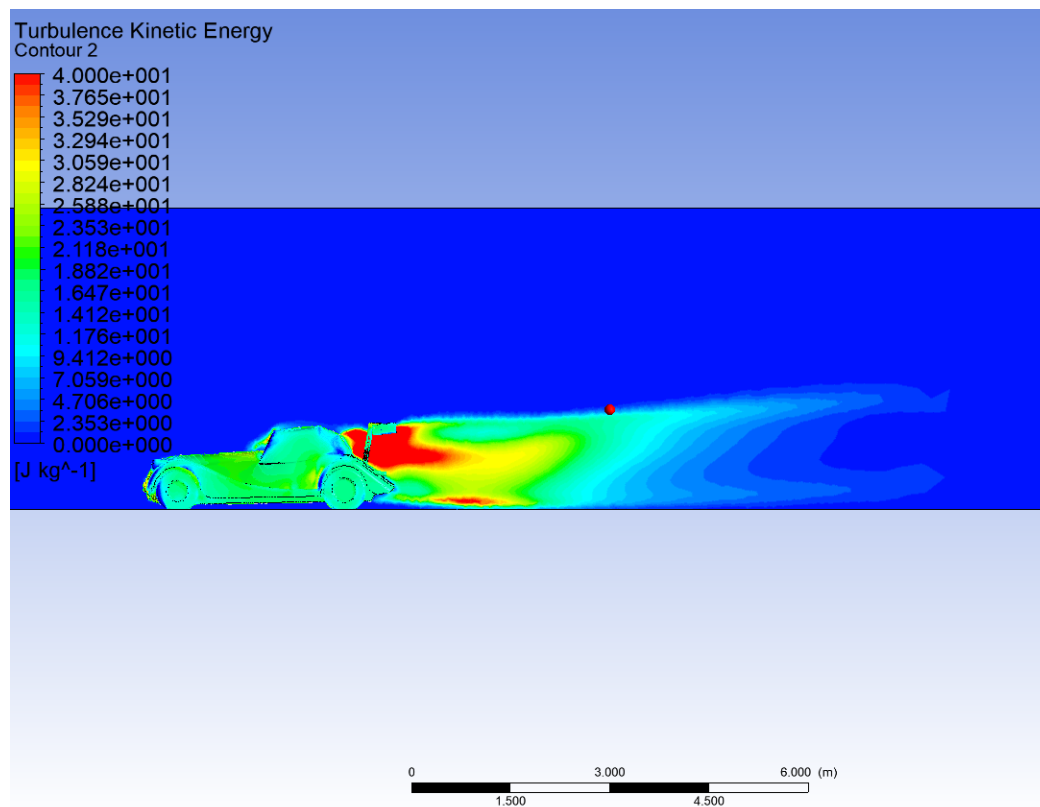


Figure 57-sym plane of KE Turbulence on 1100mm @5 Deg