University of Wales Trinity Saint David

Stress Analysis & Dynamics

Assignment 1

Designing the structural support for a front automotive wing for a new race series

---

Author: *Supervisor:*

Morgan Wheeler

20th September 2022

Contents

1. Introduction: 3
2. Task 1a - Calculation: 4
3. Task 1b – Assumptions & Alternative Methodologies: 8
4. Task 2 – Types of Front Wings & Development: 9
5. Task 3 – Manufacturing Processes: 11
6. Task 4 – Testing & Interpreting Results: 12
7. Conclusion: 13
8. Bibliography 14

1. Introduction:

Front wings in motor racing are a very important feature of the car; they help to direct the airflow over the rest of the vehicle and help to produce downforce, which in turn improves the handling and stability of the vehicle at faster speeds. Front wings used to be made from a steel spar tube covered by an aluminium aero foil, today they are mainly produced from carbon fiber which makes it easier for teams to make their vehicles lighter but improve the strength of their components. This report will cover the manufacturing processes between old and modern front wings, how they are tested and some of the materials which are involved in producing them.

2. Task 1a - Calculation:

The values which were used were W = 5883.5N, L = 1m, E = 210Gpa.

By knowing all of this information, the equation $ymax = \frac{-WL^4}{8EI}$ can be modified to find the moment of inertia. The equation was modified to $I = \frac{-WL^4}{ymax\ x\ 8\ x\ E}$ which calculated to be 3.50E-07.

An excel sheet could then be used to find the minimum diameter of pipe which coresponded to the I value, The I value for each diameter was caluculater by the formula $\left(\frac{3.14}{64}\right) \times (D^4 - d^4)$. The excel sheet was very useful as it allowed quick calculations by being able to drag the formula down the excel sheets for different diameters. This method was much more efficient than using trial and error by using different values within the formula.

Once the numbers were substituted into the formula, it could be determined that the minimum outer diameter for the wing would be 79mm, meaning the internal diameter would be 75mm. This can be supported by the calculations below.

ymax = 0.01m

W = 5,883.5N

L = 1m

E = 210 Gpa

ymax = $\frac{-WL^4}{8EI}$

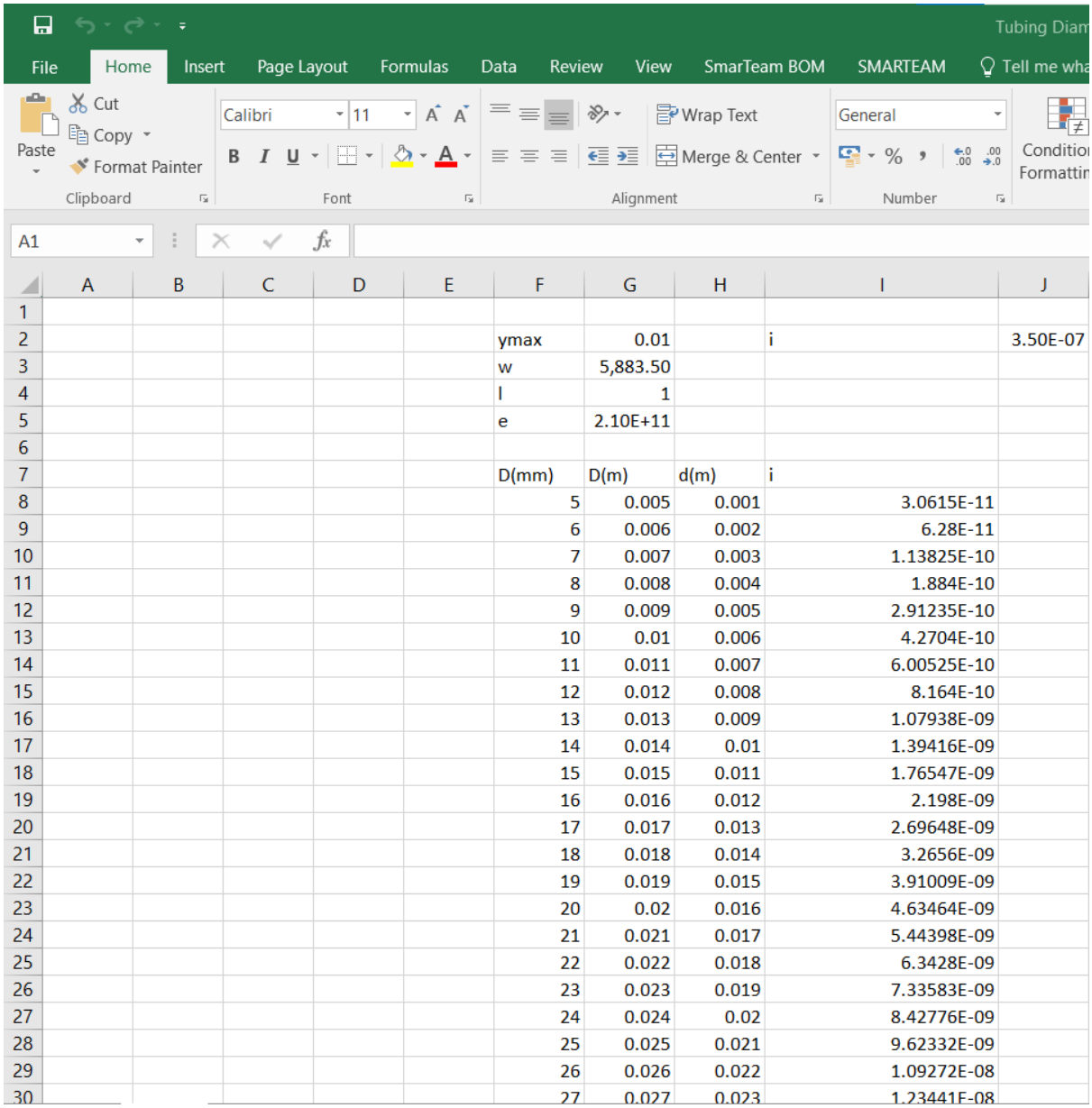
I = $\frac{-WL^4}{ymax\ 8\ E}$ = $\frac{5883.5\ x\ 1^4}{0.01\ \ x\ 8\ x\ 210\ x\ 10^9}$ = $3.50x10^{-7}m^4$

i = $\left(\frac{3.14}{64}\right)\ x\ (D^4 -\ d^4)$

i = $\left(\frac{3.14}{64}\right)\ x\ (0.02^4 -\ 0.016^4) = 4.634\ x\ 10^{-9}$

To ensure that the calculation was correct, an external diameter of 0.02m and an internal diameter of 0.016m was used to put into the formula for i. This gave the answer of 4.634 x 10^{-9}. An excel sheet was then created to be able to quickly identify the diameter which would be needed as the formula could be copied for all diameters easier on the excel sheet.

To identify the formula was correct with the hand written calculations, i for the 0.02m diameter had to be the 4.634 x 10^{-9} which it was. This gave confidence that the formula could be copied and pasted for other diameters. This saved a lot of time doing calculations as there would have been a lot of trial and error involved to find the diameter which corresponded to 3.50 x 10^{-7}.

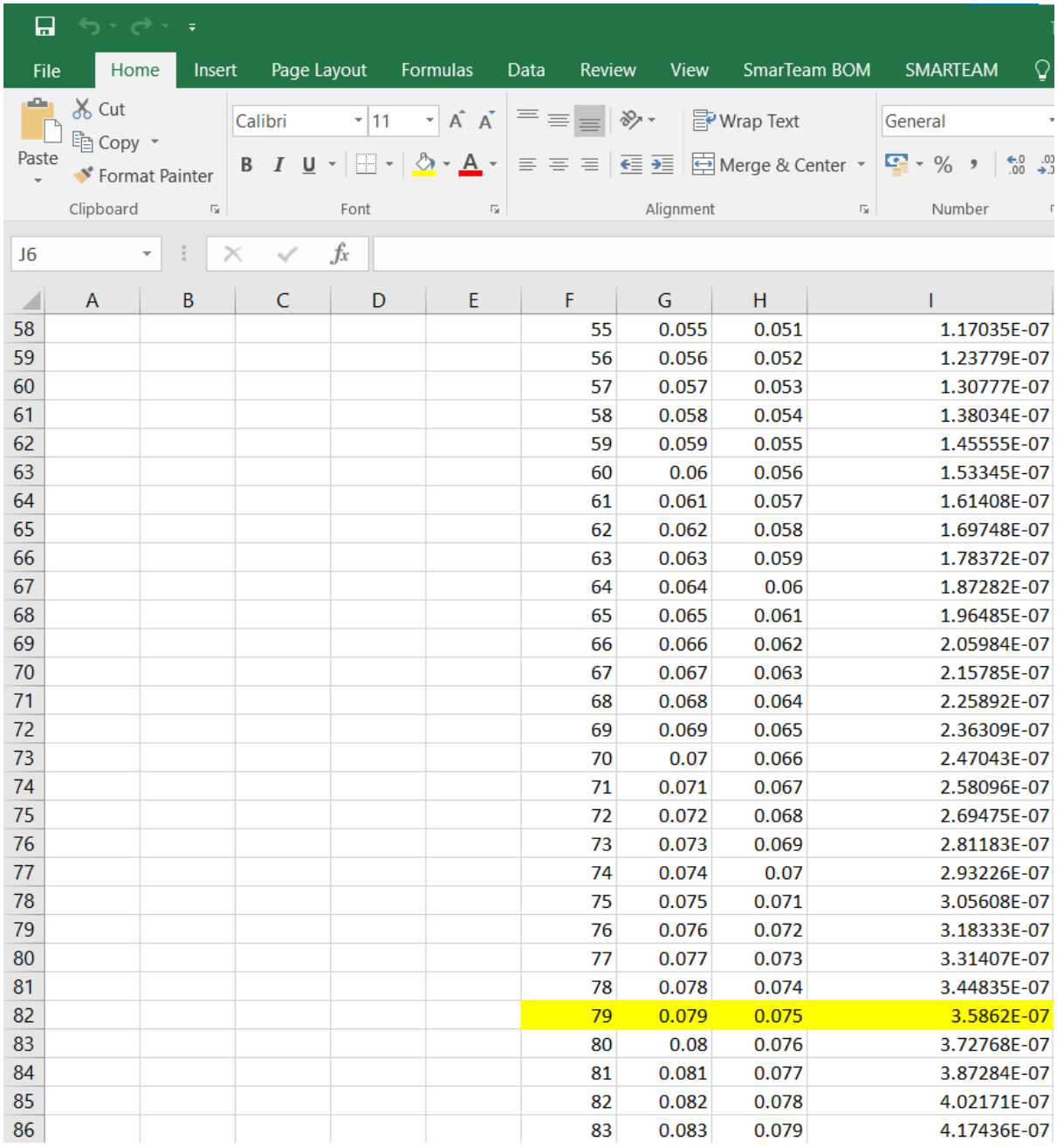


	A	B	C	D	E	F	G	H	I	J
1										
2						ymax	0.01		i	3.50E-07
3						w	5,883.50			
4						l	1			
5						e	2.10E+11			
6										
7						D(mm)	D(m)	d(m)	i	
8						5	0.005	0.001	3.0615E-11	
9						6	0.006	0.002	6.28E-11	
10						7	0.007	0.003	1.13825E-10	
11						8	0.008	0.004	1.884E-10	
12						9	0.009	0.005	2.91235E-10	
13						10	0.01	0.006	4.2704E-10	
14						11	0.011	0.007	6.00525E-10	
15						12	0.012	0.008	8.164E-10	
16						13	0.013	0.009	1.07938E-09	
17						14	0.014	0.01	1.39416E-09	
18						15	0.015	0.011	1.76547E-09	
19						16	0.016	0.012	2.198E-09	
20						17	0.017	0.013	2.69648E-09	
21						18	0.018	0.014	3.2656E-09	
22						19	0.019	0.015	3.91009E-09	
23						20	0.02	0.016	4.63464E-09	
24						21	0.021	0.017	5.44398E-09	
25						22	0.022	0.018	6.3428E-09	
26						23	0.023	0.019	7.33583E-09	
27						24	0.024	0.02	8.42776E-09	
28						25	0.025	0.021	9.62332E-09	
29						26	0.026	0.022	1.09272E-08	
30						27	0.027	0.023	1.23441E-08	

Figure I - Diameter Excel Sheet

F	G	H	I	J
ymax	0.01		i	=(G3*G4^4)/(G2*8*G5)
w	5883.5			
l	1			
e	210000000000			
D(mm)	D(m)	d(m)	i	
5	0.005	0.001	=(3.14/64)*(G8^4-H8^4)	
6	0.006	0.002	=(3.14/64)*(G9^4-H9^4)	
7	0.007	0.003	=(3.14/64)*(G10^4-H10^4)	
8	0.008	0.004	=(3.14/64)*(G11^4-H11^4)	
9	0.009	0.005	=(3.14/64)*(G12^4-H12^4)	
10	0.01	0.006	=(3.14/64)*(G13^4-H13^4)	
11	0.011	0.007	=(3.14/64)*(G14^4-H14^4)	
12	0.012	0.008	=(3.14/64)*(G15^4-H15^4)	
13	0.013	0.009	=(3.14/64)*(G16^4-H16^4)	
14	0.014	0.01	=(3.14/64)*(G17^4-H17^4)	
15	0.015	0.011	=(3.14/64)*(G18^4-H18^4)	
16	0.016	0.012	=(3.14/64)*(G19^4-H19^4)	
17	0.017	0.013	=(3.14/64)*(G20^4-H20^4)	
18	0.018	0.014	=(3.14/64)*(G21^4-H21^4)	
19	0.019	0.015	=(3.14/64)*(G22^4-H22^4)	
20	0.02	0.016	=(3.14/64)*(G23^4-H23^4)	
21	0.021	0.017	=(3.14/64)*(G24^4-H24^4)	
22	0.022	0.018	=(3.14/64)*(G25^4-H25^4)	
23	0.023	0.019	=(3.14/64)*(G26^4-H26^4)	
24	0.024	0.02	=(3.14/64)*(G27^4-H27^4)	
25	0.025	0.021	=(3.14/64)*(G28^4-H28^4)	
26	0.026	0.022	=(3.14/64)*(G29^4-H29^4)	
27	0.027	0.023	=(3.14/64)*(G30^4-H30^4)	

Figure II - Formulas Implemented in Excel Sheet



	A	B	C	D	E	F	G	H	I
58						55	0.055	0.051	1.17035E-07
59						56	0.056	0.052	1.23779E-07
60						57	0.057	0.053	1.30777E-07
61						58	0.058	0.054	1.38034E-07
62						59	0.059	0.055	1.45555E-07
63						60	0.06	0.056	1.53345E-07
64						61	0.061	0.057	1.61408E-07
65						62	0.062	0.058	1.69748E-07
66						63	0.063	0.059	1.78372E-07
67						64	0.064	0.06	1.87282E-07
68						65	0.065	0.061	1.96485E-07
69						66	0.066	0.062	2.05984E-07
70						67	0.067	0.063	2.15785E-07
71						68	0.068	0.064	2.25892E-07
72						69	0.069	0.065	2.36309E-07
73						70	0.07	0.066	2.47043E-07
74						71	0.071	0.067	2.58096E-07
75						72	0.072	0.068	2.69475E-07
76						73	0.073	0.069	2.81183E-07
77						74	0.074	0.07	2.93226E-07
78						75	0.075	0.071	3.05608E-07
79						76	0.076	0.072	3.18333E-07
80						77	0.077	0.073	3.31407E-07
81						78	0.078	0.074	3.44835E-07
82						79	0.079	0.075	3.5862E-07
83						80	0.08	0.076	3.72768E-07
84						81	0.081	0.077	3.87284E-07
85						82	0.082	0.078	4.02171E-07
86						83	0.083	0.079	4.17436E-07

Figure III - Required Diameter Excel Sheet

When the formula was copied for all of the diameters, a value just bigger than 3.50×10^{-7} corresponded to an outer diameter of 0.079m. The required diameter is between 0.078 and 0.079 meters. This is quite a large diameter for a front wing which also indicates the material strength difference between a metallic tube and carbon fibre.

3. Task 1b – Assumptions & Alternative Methodologies:

Some assumptions were made so that a calculation could be used to calculate the minimum diameter of tubing that could be used for the front wing. These assumptions were supported by online research of some forces, dimensions of an F1 car front wing. It was understood from this research that an F1 car front wing from the centre of the nose to one end is one meter (Anderson, 2022). McLaren Racing (2022) describes how the weight of the front wing only weighs roughly ten kilograms however, it can withstand downforce up to one-hundred times the weight of the wing (1,000Kg). From this information, it can be said that a wing can experience up to 11767 Newtons of fore across the wing. This value was then halved as only one half of the wing is being considered in this instance, so the load used was 5883.5N.

Some limitations of the calculations was that some of the values were assumptions, meaning that there is no set value to say if it is correct or incorrect. The answer could completely depend on where the research / information was taken from. The value was also dependant on the type of motorsport that as being researched as Formula 1 cars have much more downforce compared to Formula 2 or Formula 3 cars.

Other principles or methodologies that could have been used to determine the minimum diameter of tube is Finite Element Analysis (FEA). This computational analysis software will be able to indicate if the component / system will work how it is supposed to, how it will wear under certain conditions or if it will fail during operation. This is a good way to show the behaviour difference between a diameter tube which is not strong enough to withstand the forces and a diameter tube that can cope with the forces. FEA is also a good tool to use as it is allows any material type to be applied, along with all of the material characteristics so it is easy to simulate different materials in the same environment to compare the performances of the materials against each other. To achieve this, a representative shape / model is needed so that it can be produced into a mesh which will allow

4. Task 2 – Types of Front Wings & Development:

Many racing cars including F1 cars started to introduce front wings onto their cars from around 1968. Front wings are structures that are attached to the front of racing cars as it is the helps to streamline the air around the rest of the car, they are also able to help produce downforce which works in the same way an aircraft produces lift via its wings. Howson (2021) states that if an F1 car did not produce any downforce then the car would be prone to coming off the floor as they travel at such fast speeds. Downforce on a racing car improves the vertical grip between the tyres and the track, which is important when travelling at over 180mph. By looking at F1 cars, it is obvious to see how the front wing has developed and become a lot more complex by using materials that are more advanced and more complex designs.

Front wings have various different sections that make up the overall structure of the wing. These are the endplates, main plate and flaps. The endplates are used to condition and smooth airflow which will be directing airflow over the wheels. They are located on the outsides of the wing. The main plate is the first flap on the wing; this is a fixed part of the wing and is where the adjustable flaps are then fitted. The flaps are adjustable plates so that the amount of downforce can be adjusted easily during setup or even in the pit stop during a race.

Below are some images to demonstrate how the front wing has changed since 1968.

Figure IV - 1968 (Mortel 2003)

Figure V - 2000 (Briet 2016)

Figure VI - 2022 (Anderson 2022)

The structure of the front wing is designed so that there is low-pressure air flowing beneath the wing and high-pressure air flowing over the wing. This high-pressure 'pushes' the car downwards towards the track creating downforce.

Front wings should be designed in such a way that they are able to be flexible while travelling at high speeds and still generate smooth airflow over the structure. In sports such as F1, the flexing of the front wing should have tolerances so that it stays within the rules and regulations of the sport. Front wings are now made out of carbon fibre so that they can withstand the large loads that they undergo. It also means that they can become very expensive to replace if they are damaged. The average cost of an F1 front wing is approximately £150,000, which are also made in-house, at most teams. Carbon fibre is a good material to use, SMI Composites (2021), who explains that it is a poor conductor of heat, support this and that airflow can become very hot if following another race car, so the wing must not be affected by the hot air flowing over it.

Front wings could evolve in the future when more advanced materials become available. The design of the front wing will also depend on the type of race car which it's fitted too. The wings on Indy500 cars are completely different to F1 cars due to the different tracks they are used on and the amount of downforce that is required for either car.

Teams have historically had to test their cars on a track and witness the impacts effectiveness via the driver. Today, teams have prototypes which are approximately 60% of

the full-size. This allows teams to do some testing on the car which can be put in wind tunnels, Non-Destructive Testing (NDT) and development testing.

5. Task 3 – Manufacturing Processes:

When front wings were first introduced into F1, they were manufactured from metallic materials that went through various processes to produce. The old wings used to retain their strength by the tubes attached to the front nose, they would then have an aerodynamic shaped foil around the tubing to produce downforce. These wings were much easier to produce by using easier processes and machinery compered to today's front wings. Today they are manufactured of the most advanced / expensive materials which consist of carbon fibre, Kevlar and lots of other sophisticated fibres. To produce modern front wings, the bodywork / wing shape must be designed using CAD software so that a mould can then be created to lay the carbon fibre matting over. motorsport.com (2022) describes how the carbon fibre is designed into certain patterns as the properties of carbon fibre can change depending upon their pattern. The carbon fibre layup is then placed onto the mould by hand, this is assisted by lasers so that certain plies of carbon fibre can be placed in the higher stress areas of the wing. Once the carbon has been placed into a mould, it is placed in an autoclave which will cure the carbon fibre under controlled pressures and temperatures. The front wing could be in an autoclave for around two to eight hours depending on the size of the part. In turn, this will make the carbon fibre five times stronger than steel, twice as stiff but also a lot lighter than steel too.

When comparing historical wings compared to modern wings, it demonstrates the advancements made in materials and different processes. Producing carbon fibre is still a complex process due to the advanced machinery which is involved in producing it. The shape of front wings has also become a lot more complex and streamline. In earlier front wings there would be ribs and other metallic structure supports as shown in the image below, which would also give the wing its strength.

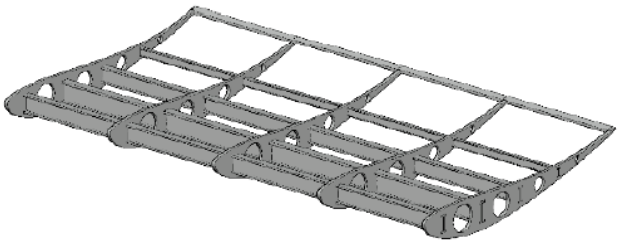


Figure VII - Rib Design (Castro 2020)

Due to the thin flaps, it is no longer possible to be able to create ribs and spars to go inside of the hollow front wing it is now just a hollow carbon fibre structure or sometimes the endplates can be filled with an expanding foam inside of the carbon fibre to save weight compared to a metallic internal structure.

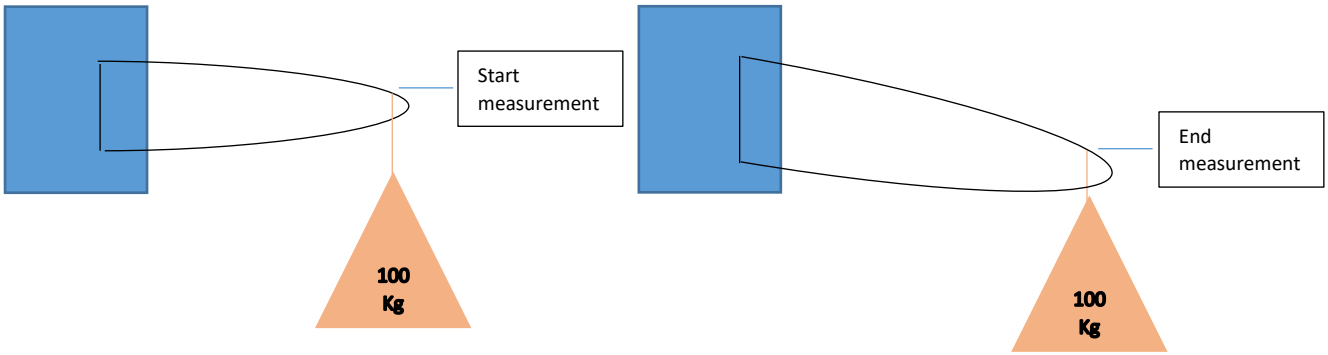
Front wings have also been able to advance very rapidly due to the enhancement of Computational Fluid Dynamics (CFD) software and testing. Formula1-dictionary.net, (2022) describes how CFD software now allows accurate aerodynamic simulations for front wings to be designed more effectively. It also helps to speed up the design process as simulations can be easily performed, in different environments and also very early on in the design process. This will help to iron out any problems early on.

6. Task 4 – Testing & Interpreting Results:

To test the results from Task 1a, some practical tests can be carried out to see the effects of different diameter tubing, to see how much it will affect the deflection of the front wing. Various tests could be carried out due to race cars being subjected to various forces in different situations e.g. a car can be tested in a wind tunnel, with static loads applied to various parts of the front wing and checking the deflection measurement.

The first tests which would be considered would be computer simulations, this would be a great way to determine how the front wing with various different diameters of tubing experience the various loads acting up on it without using physical components. Simulations are an advantage as it reduces cost of producing numerous prototypes to test the different diameters of tubing.

A static test that would then be carried out would be applying a load of approximately 100kg on the end of the wing. Piola (2017) desmonstrates how the 100kg force on the wing should not provide anymore than 10mm of deflection to the wing. This test could be carried out by creating a point load on the wing by either using ballasts or pneumatic / hydraulic rams to apply the force on the wing. The deflection could then be measured by the initial measurement minus the final measurement. This is how much the wing is bending in the downwards position.



Another test to carry out would be wind tunnel test where a car model with a front wing is attached. Airflow can then be blown over the aerofoil with a light mist, so it is easily visible to detect how the airflow is behaving over the front wing to the rest of the car. This test will allow a uniformly distributed load (UDL) to flow over the wing, which will allow the front wing to experience a force across the whole wing, which is evenly distributed. From this test, it will indicate how much airflow goes over the wing so the downforce can then be calculated. This will give accurate figures which can then be used within the formula so the discrepancies between researched values and physical testing values can be seen. Pitot tube racks are used during pre-season testing so teams can find out how the aerodynamics are behaving. These can provide lots of relevant data so teams can determine how to improve the setup of the vehicle.

Figure VIII - Pitot Tube Rack

Figure IX - Wind Tunnel Testing

7. Conclusion:

In conclusion, this report has discussed the importance of front wings on racing cars which is a very aerodynamically key area, which should provide the rest of the car with the least undisturbed airflow as possible. It is easy to determine that the materials involved have made producing the front wings has become a lot more complex however, the strength and lightweight materials are definitely an advantageous upgrade. To withstand the forces racing cars see these days, the metallic tubes would have to be increased dramatically compared to when they were first used.

The introduction of CFD is very useful within the design phase, as models and prototypes do not have to be created until a full analysis on the assembly has been completed first, which saves a lot of money and use of expensive materials. FEA is also a software which will help in the testing phase as this can be done once the design phase is completed without having to produce a single part for testing as it is all computer simulated.

To conclude a front wing prototype, it should go through various tests tor flexibility, deflection, strength and aerodynamics. It would be important to gather the information to ensure that it is suitable to go on a racing car and to enhance the performance of it as well.

8. Bibliography

Anderson, G. (2022) Retrieved from HOW F1 FRONT WINGS ARE CHANGING FOR 2022: https://the-race.com/formula-1/gary-anderson-how-f1-front-wings-are-changing-for-2022/

Anderson, G. (2022) *HOW F1 FRONT WINGS ARE CHANGING FOR 2022*. Retrieved from the-race.com: https://the-race.com/formula-1/gary-anderson-how-f1-front-wings-are-changing-for-2022/#:~:text=The%20front%20wing%20must%20sit,down%20from%20five%20last%20year.

Briet, T. (2016) Retrieved from CREATE DOWNFORCE AND REDUCE THE DRAG: FRONT WING AND BARGE BOARDS: https://www.linkedin.com/pulse/create-downforce-reduce-drag-front-wing-barge-boards-timoteo-briet

Castro, X. (2020) Aerodynamic and Structural Design of a 2022 Formula.

Chachra, T. (2021) *What are those nets installed behind F1 cars during testing?* Retrieved from https://thesportsrush.com/f1-news-aero-rakes-f1-what-are-those-nets-installed-behind-f1-cars-during-testing/

Formula1-dictionary.net. (2022) *Computational Fluid Dynamics*. Retrieved from https://www.formula1-dictionary.net/cfd.html#:~:text=CFD%20and%20FEA%20are%20used,maximum%20of%20100%20million%20cells.

Howson, G. (2021) *How Do Formula 1 Cars Generate Downforce?* Retrieved from F1chronicle: https://f1chronicle.com/how-do-formula-1-cars-generate-downforce-f1-tech/

McLaren Racing. (2022) *F1 Playbook*. Retrieved from https://www.mclaren.com/racing/f1-playbook/front-wing/

Mortel, F. (2003) *The Front wing*. Retrieved from https://f1-forecast.com/pdf/F1-Files/CRANFIELD%20TEAM%20F1%20-%20THE%20FRONT%20WING.pdf

motorsport.com. (2022) *Insider's guide: How is an F1 car made?* Retrieved from https://www.motorsport.com/f1/news/how-is-an-f1-car-made/7626323/

Piola, G. (2017) *Front wing deflection tests*. Retrieved from Motorsport.com: https://www.motorsport.com/f1/video/giorgio-piola-front-wing-deflection-tests-82966/24721/

SMI Composites. (2021) *Why Carbon Fiber Car Parts Are the #1 Choice In Auto Racing*. Retrieved from https://smicomposites.com/why-carbon-fiber-car-parts-are-the-1-choice-in-auto-racing/#:~:text=Carbon%20fiber%20has%20the%20highest,car%20experiences%20during%20a%20race.