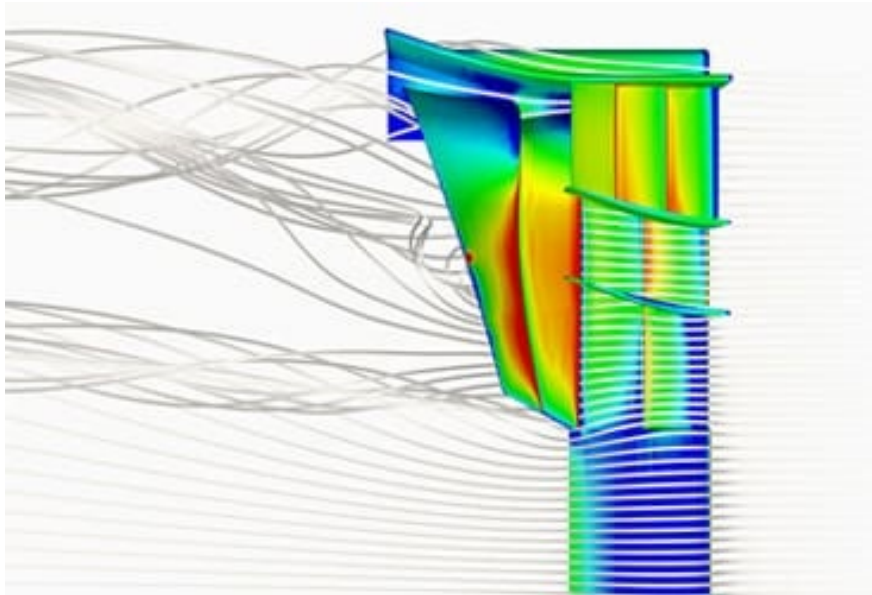




(SIMSCALE, 2016)

DESIGNING THE STRUCTURAL SUPPORT FOR A FRONT AUTOMOTIVE WING FOR A NEW RACE SERIES

AMCA5010

Name: Ryan Harris
Student Number: 2115244
Lecturer: Kelvin Lake
Date of Submission: 29/07/2022

Executive Summary

The following report documents the calculations undertaken in determining a minimum outside diameter for a structural support of a race cars front wing. Also detailed within, is the research of historical front wings and their technological evolution. Carbon fibre is now one of the most important materials used in Formula one along with many other motorsports such as Indy car, rallying and NASCAR to name a few.

The report also looks at the manufacturing processes involved in making the front wing, along with the journey from initial idea to CAD (computer aided design) drafted to CFD (Computational Fluid Dynamics) & FEA (Finite Element Analysis) to prototype and final manufacture.

Heavy investments are made within the motorsport world to make a car as aerodynamic as possible; teams go to great lengths to try to have a competitive edge. Williams racing in 2011 stated that the front wing design may improve lap times by 1 to 2% which is approximately tenths of seconds, but that can often be the difference between winning and losing.

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Introduction

Race cars are subject to extreme forces throughout races, Aerodynamic study has helped race teams understand the importance of the race cars design and manufacture. Specific methods such as computational fluid dynamics, finite element analysis and the use of wind tunnels has helped engineers' perfect material choice and overall car design to better distribute forces and maximise performance.

A key component of a race car in terms of aerodynamics is the race cars front wing. The front wing is often subject to 5 times the weight of the car in force, therefore there is high importance on the material choice. The front wing is also the first part of the car to encounter the air, better distribution of this air can be the deciding factor in winning and losing.

The front wing creates downforce which helps the car to stick to the ground, increasing speeds at which the car can corner. Since the wings introduction to Formula One by Lotus, the front wing has evolved at a rapid pace thanks to not only technological advancements but also the research of material science and material discovery. Carbon fibre now plays a critical role in most aspects of race cars. Carbon fibre has an incredible strength to weight ratio compared to formally used materials such as aluminium and steel.

The front wing has become one of the most important parts of a Formula One car, with teams heavily investing in both the development and manufacture of the component each season. The front wing has changed dramatically each decade since the late 60s, but it's importance in the sport means that it will remain for years to come.

TASK 1

Research & Calculations

The present Formula One car is lighter, safer, and faster than it has ever been due to material science advancements (Thomas, 2013). Being able to calculate required material mass and size is another factor that influences a race cars performance. The following task calculates the minimum outside diameter of a front wings' steel structural support using well researched figures.

For this task it was important to utilize slope and deflection of beam theory. First, determining the type of loading on the cars' front wing. The front wing is made up of modifiable components which in turn provide different levels of down force (Patil, 2014). These varying levels of down force led the author to determine the type of loading across the wing as non-uniform or varying. Therefore, the following equation applies:

$$\gamma MAX = \frac{-23WL^4}{120EI}$$

Figure 1 - Formula for Non-Uniform Varying Load

The other factors that required research were values for the front wings' length and average force. According to research carried out by Smith (2020), during the 2020 Formula One Grand Prix in Spa de-Francorchamps, The Ferrari front wing experienced 861.9 N of downforce at 210 mph. The SF1000 being the seventh car built by Ferrari during the hybrid era had a width of 1600mm (Technical, 2020).

Table 1 - Figures Used for Calculation from research

Item	Figure	Unit
Y MAX	0.01	M
W	861.9	N
L	0.8	M
E	210	GPa

Formula re-arranged to make the second moment of area the subject:

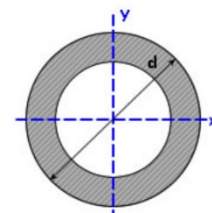
$$I = \frac{-23WL^4}{\gamma MAX \times 120E}$$

Figure 2 - Re-Arranged Formula

With reference to Appendix 1, the front wing experienced a second moment of area of $3.22214 \times 10^4 \text{ CM}^4$ with the researched and given values from the task. Now that the value for second moment of area was established, the next step was to determine the minimum outside diameter of steel tube that could withstand forces calculated. Moment of inertia for a hollow cylinder is calculated with the following equation (AmesWeb, 2022):

$$I_{xx} = \frac{\pi(DO^4 - DI^4)}{64}$$

Figure 3 - Second Moment of Area of a Hollow Tube



Having completed the initial phase of calculation, the author utilized the second moment of area for a cylinder equation to figure out the minimum diameter required for the steel section. Trial and error was used to establish which diameters the second moment of area was equal to or slightly greater than $3.22214 \times 10^4 \text{ CM}^4$. The table of results are illustrated in Appendix 2 with a handwritten example show in Appendix 3.

Results from the calculations and trial and error are illustrated below:

Results	
Bar Gauge	2mm
Outside Diameter	37mm
Inside Diameter	33mm

Figure 4 - Results

From the calculations, the minimum outside diameter of the steel section would need to be at least 37mm to satisfy a second moment of area equal to $3.22214 \times 10^4 \text{ CM}^4$. After completing calculations, it was important to research some costings on specific sections, average cost was approximately £50 per meter. However, testing would need to be completed to understand what grade of steel would be acceptable for the application.

Assumptions & Limitations

An assumption made by the author was that the front wings loading was exactly 861.9N when travelling at 210MPH, when realistically the front wing would experience several loading forces across the entire length of the wing, moreover, the wing would experience different forces at every area of the racetrack whether that is on a straight or cornering.

CFD is a computational method to understand the aerodynamics of a part, helping the design team shape parts of the vehicles for the best aerodynamic results. According to Formula one dictionary (2022), CFD offers limitless options during the calculation process when developing aerodynamics.

However, using Slope and Deflection of beam theory yielded reasonable results for the task. Having had the money, training, and time to fully calculate the steel tube required for the race car, the author would have employed the use of computational methods in solidifying the final decision.

TASK 2

Historical Development of the Front Wing

The front wing was first introduced in Formula 1 by Lotus at Monaco Grand Prix in 1968 as shown in figure 5 (Oggioni, 2019). Since then, it has undergone multiple evolutions due to not only technological advancements but smart material availability.



Figure 5 - Lotus Front Wing Introduction 1968

Front wings have changed dramatically from their first introduction by Lotus. The Formula One front wing was influenced by an American car designer Jim Hall, the principle was taken from a lift-generating aircraft and inverted to push the car into the ground at high speed (Kew, 2022). Down force is created by having a pressure difference act on the wing, where both low pressure-high speed area and high-pressure low speed area is created. When there is a negative angle of attack shown in figure 6, downforce is created (Oggioni, 2019).

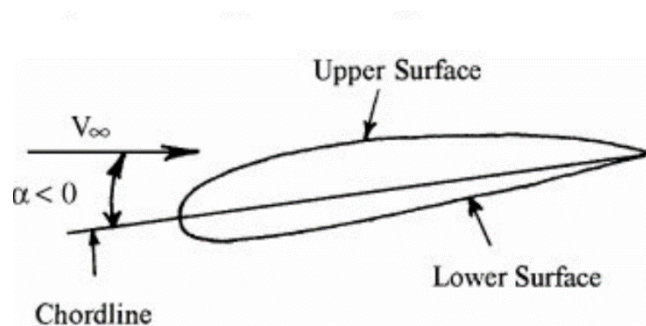


Figure 6 - Negative Angle of Attack

In 1978 there was another evolution in the front wing design that led to ground effects, this was designed by Chapman again on the Lotus in particular the Lotus 79 which led Andretti to a world title, Colin Chapman placed inverted wings inside the side pods. This Exploited Bernoulli's principle to create mass areas of low pressure sticking the car to the ground to allow for higher speeds at corners (Kew, 2022).

The 1985 TG185 Toleman had a much longer front wingspan which meant that the team understood the importance of aerodynamics. Having the wingspan across the width of the car meant the team had more control over the cars air distribution. This front wing also featured gurney flaps, first introduced in racing in 1971 by Dan Gurney, increasing traction for better car handling (Wilbur, 2020). The gurney flap is a small lip placed on the trailing edge of the wing which sharpens the exit angle of the air further creating downforce (McLaren, 2022).

With the 2012 Sauber the size of the front wing majorly increased, teams understood the importance of the front wing. In addition, lots of winglets and air flow adjustment were added. Though the front wing is much larger, the progression in both material science and computational power led to the use of materials such as carbon fibre, making the front wing super light. End plates helped to control turbulent air flow over the tyres, where a vortex is created between the front nose and inner area of the wheel known as the Y250 Vortex (Giuliana, 2020).

The new 2022 FIA technical rules have banished the Y250 vortex which has been utilized on most modern front wings. As can be seen in figure 7, the distance between the nose and wing end has been dramatically decreased allowing for cleaner racing by minimising the amount of 'dirty air' created by heavily modified front wings (Hughes, 2022).



Figure 7 - 2021 vs 2022 Front Wing

Types of Automotive Front Wings

Racing plays a major role in all automotive industries; this is an area that automakers can advertise the racing wins and sponsorship deals as a fuel to increase production sales. There are many types of automotive racing these include, Formula One (as mentioned), Formula E, Indy car and NASCAR just to name a few. These different types of motorsports have an impressive range in the way that they function and look. Figure 7 compares Formula One, Indy car and NASCAR. It is clear to see the differences (Perez, 2019).



Figure 8 - Comparing Different Autosport Cars

The Indy Car's front wing is far more simplistic with only three elements making up the wing, where as the Formula One car prior to the 2022 FIA (Federation Internationale de l'automobile) rule changes featured a five-element wing. The main reasoning behind this is often the difference in both budget and manufacture. In Indy Car, all body work is the same and often bought from the same manufacturer (Kim, 2014). The Formula One front wing is built different by each team and free development means they often vary massively. In IndyCar there are varying types of racing, from road courses to high-speed oval circuits. Aerodynamic kits change for superspeedways with aerofoils replacing multi element front wings in a bid to minimise the drag and increase pace (Car Throttle, 2022).

Future Development of The Front Wing

The future race car will be heavily influenced by new technology, material, and fuel type. As more advanced materials are added to the sport such as shape memory materials that can change shape when influenced by stimuli (Iberdrola, 2022). The front wing would possibly be able to change shape dependent on environment and speed etc. McLaren recently released a possible prototype car for the year 2050 that features some of the points discussed. The MCLExtreme, as described by (NES Fircroft, 2019) will feature active aerodynamics-technology that will enable cars to change shape maximising velocity etc.

TASK 3

Aerodynamics play a critical role in present race cars. The front and rear wing of a Formula One car help to perfect downforce that is significant in helping race teams' corner faster during races. The front and rear wing are susceptible to extreme conditions which means the design and material choice for the wings are crucial. Materials are often chosen with key properties in mind. Lightness, strength, and durability are often the key factors, however consideration to performance is often related to the materials reliability (Motorsport, 2007).

The technology surrounding material science has advanced at a rapid pace throughout the years of Formula 1. There were very minimal rules in the way of what materials could be used. This rapid progress has meant that FIA has had to set rules to restrict the use of materials. In section 15.3 of the 2022 FIA technical regulations there is a section that lists "Permitted Materials" (FIA, 2022) this ensures that all teams have a fair playing field when it comes to the material choices utilized.

Sheet Aluminium was used on the majority of the F1 cars up until the 80s. Both body panels and wings were primarily crafted from sheet aluminium which has impressive strength to weight ratio. Aluminium was also super lightweight compared to steel sections. Aluminium was also easy to form into the concave shapes required for the front wing.

In 1981 McLaren introduced a carbon fibre monocoque on its MP4/1 race car (3MB Co, 2015), this revolutionized the manufacture of Formula one car parts. Carbon fibre is ultra-lightweight, but still holds a super impressive strength to weight ratio and is said to have 2-5 times more rigidity compared to aluminium and steel (DexCraft, 2015). This change to carbon fibre in race cars allowed the teams to strip the weight of the car but still hold the same safety factors, as a result, cars performances rocketed. The front wing of an F1 car needs to flex under forces that it encounters, contributing to roughly 25-40% of the downforce created (TotalSim, 2016). The aerodynamic downforce can be equal to 5 times the weight of the car, meaning that not only is the front wing responsible for the aerodynamic distribution, but it must be able to withstand these forces.

Carbon Fiber Reinforced Plastic commonly known as Carbon Fiber is a material composed of carbon atoms that are formed into a long chain. In F1, teams use what is known as a pre-impregnated epoxy resin and aluminium honeycomb layer which is sandwiched between layers of carbon fiber (Vilva, 2019). The front wing starts off as a model that has been tested using CFD, Prototypes are then manufactured shown in Figure 10 (Holmes, 2017) and simulated in a wind tunnel before the aerodynamics team confirm the readiness of the design. Sheet carbon fibre is lasercut to the shapes required before fitment to a premade mould. These carbon fibre pieces are then thermally treated and cured in an oven (TheF1Spy, 2011). This curing process can change the properties of CFRP.



Figure 9 - Laser cutting sheet CFRP

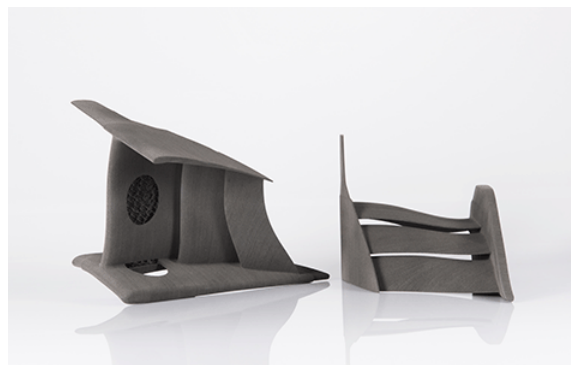


Figure 10 - William's 3D Printed Prototype of Front Wing Parts

TASK 4

There has been a huge increase in computer power in recent years. Many motorsports have used this to an advantage. In F1, CFD and FEA (Finite Element Analysis) has been utilized to model and test types of parts. The front wing has been a specific beneficiary of this technological advancement. Flow can be calculated and improved using this specific method. Aerodynamic understanding has improved rapidly due to such advancements.

CFD is a highly predictive software that is combined with powerful graphics allowing aerodynamic engineers the ability of visualising parts in multi-dimensional scenarios. This also allows engineers to change the shape of the front wing without having to fully prototype and test it (Peritus, 2019). The only negative with CFD is the expense of equipment required to successfully run the software. CFD certainly would be a technique utilized by the author in the verification of testing results.

FEA is another computer aided design technique. FEA uses a system of points identified as nodes which combine to make a mesh around the components. The mesh is programmed or defined by the designer as a specific material with structural properties. This information is used by the software to imitate how the material would react under certain loading conditions (Technical IF1 Dictionary, 2020). This again is an ideal method for verifying the results from calculations.

The wind tunnel is a tool often used in aerodynamics to study the way in which air flows over specific components (Race to A cure, 2021). This is utilized by engineers to imitate exact conditions the component may encounter. This analysis is also a form of non-destructive testing helping to make much needed improvements to maximise performance. This could also be utilized as a tool in the analysis to understand what areas of the front wing would encounter the most downforce, helping to mimic the exact conditions when testing the steel sections.

A test rig could also be developed to hang specific weights off a range of steel sections with the amount of flex measured as an output. The test rig could also be used to bring the steel bar to failure to understand exactly how far the front wing and in particular the structural support could be pushed until it failed. This testing could also be performed in a cyclic manner, further understanding the fatigue ranges of the steel to further justify the calculations before making a final decision on the material to use.

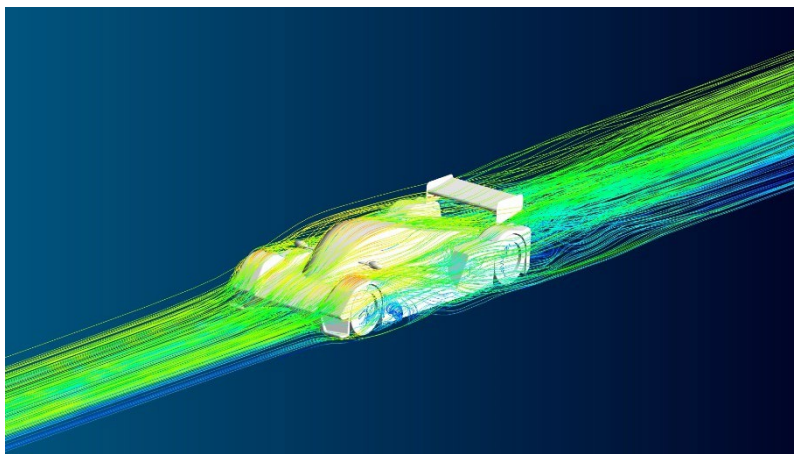


Figure 11 - CFD completed on F1 car (FetchCFD, 2019)

Conclusion

To conclude, the importance of the front wing has remained throughout this report. Once the front wing was introduced to motorsport, cars performances tremendously improved. The ability to distribute air remains one of the most important factors in winning and losing. It is crucial that calculations are precise and justified when selecting an acceptable material, this plays a factor in both driver safety and car performance.

The driver is another important factor of the car. However, the best race car is often the one that has the best design and performance specification. The front wing plays such an important role in the cars handling and abilities to take corners at maximum speed. The engineers are able to take live data from the car and adjust the aerodynamics to suit which again shows the advancements within the sport.

The future of racing is fast approaching and having researched the topic, smart materials are set to play a vital role in further evolving the front wing. Heavy investment is made by each Formula One team every season in developing and prototyping the best components for the car. CFD and FEA play vital roles in simulating the racing environment to improve the overall design of the front wing. Without this front wing design would not have evolved as quickly as it has.

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Appendices

Appendix 1 – Handwritten calculations for second moment of area

Ryan Morris.

Calculations 1a:

From Research, W and L to be taken as 861.9 N and 0.8 m . The loading across the frame using has been determined as non-uniform or varying.
 $\therefore y_{\text{max}} = \frac{-23WL^4}{120EI}$

Where: $L = 0.8 \text{ m}$ $W = 861.9 \text{ N}$ $y_{\text{max}} = 0.01 \text{ m}$
 $E = 210 \text{ GPa}$.

Re-arrange formula, making I the subject

$$I = \frac{-23WL^4}{y_{\text{max}} \times 120E}$$

$$\therefore I = \frac{23 \times 861.9 \times 0.08^4}{0.01 \times 120 \times 210 \times 10^9}$$

$$I = 3.22214 \times 10^{-8} \text{ cm}^4 \text{ (S.D.P)}$$

Trial and error using Excel will be used to determine minimum OD Required using the following formula:

$$I_x = \frac{\pi (d_o^4 - d_i^4)}{64}$$

- Second moment of area for a hollow cylinder.

Appendix 2 – Computational Results from Trial and Error For Minimum Outside Diameter

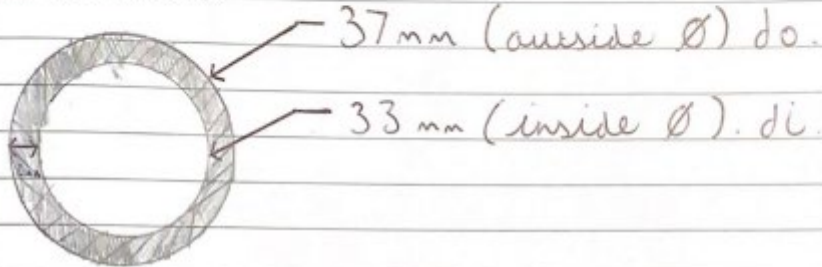
Do(M)	Di(M)	I (CM ⁴)
0.01	0.006	4.2704E-10
0.011	0.007	6.00525E-10
0.012	0.008	8.164E-10
0.013	0.009	1.07938E-09
0.014	0.01	1.39416E-09
0.015	0.011	1.76547E-09
0.016	0.012	2.198E-09
0.017	0.013	2.69648E-09
0.018	0.014	3.2656E-09
0.019	0.015	3.91009E-09
0.02	0.016	4.63464E-09
0.021	0.017	5.44398E-09
0.022	0.018	6.3428E-09
0.023	0.019	7.33583E-09
0.024	0.02	8.42776E-09
0.025	0.021	9.62332E-09
0.026	0.022	1.09272E-08
0.027	0.023	1.23441E-08
0.028	0.024	1.38788E-08
0.029	0.025	1.55359E-08
0.03	0.026	1.73202E-08
0.031	0.027	1.92364E-08
0.032	0.028	2.12892E-08
0.033	0.029	2.34833E-08
0.034	0.03	2.58234E-08
0.035	0.031	2.83142E-08
0.036	0.032	3.09604E-08
0.037	0.033	3.37668E-08

Appendix 3 – Hand Calculations for Second Moment Of Area Using Trial And Error

Ryan Morris

Calculations 1a)

Calculating second moment of area of a steel tube with the following dimensions:



Second moment of area for a hollow cylinder:

$$I_{xx} = \frac{\pi (d_o^4 - d_i^4)}{64}$$

$$I_{xx} = \frac{\pi (0.037^4 - 0.033^4)}{64}$$

$$I_{xx} = 3.37839 \times 10^{-8} \text{ m}^4 \text{ (S.D.P.)}$$