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1.0 - Introduction

Front wings are one of the most important components on a F1 car and depending on design depends on how the car performs. With a major rise in technology along with a significant increase in money and availability has allowed for complex designs to be made and used on cars. Throughout the report below, the importance of front wings is looked at along with the history of them and how they have changed throughout the years. As well as this a look at testing and results allows for a greater understanding for how the front wings are designed to meet specifications and reach its optimum level.

2.0 - Slope and Deflection of Beams

An important part of stress analysis and design is to understand how much a material or component is going to move under a load or stress. Front wings are a vital aspect for the F1 car and produce around 25% of the total downforce according to Howson (2021), therefore a calculation needs to be done to understand how much the front wing is going to deflect.

Looking at the data, it is known that the front wing will be a cantilever with the wing coming off the tubular section, it is also known the structure is made from steel and has a Young's Modulus of 210 GPa. Part of the FIA regulations are the front wing cannot deform or slope more than 3mm otherwise it cannot be considered fixed, states Sommerfield (2015). The first assumption to be made is that the front wing is a cantilever beam with a uniformly distributed load, this can be assumed due to the downforce pressure being fully distributed along all the surface. Assuming this allows an equation to be used to calculate the maximum

deflection. EJ Hearn suggests that from the assumption the formula $y_{max} = \frac{-WL^4}{8EI}$ where W is Load, L is Length, E is Young's Modulus and I is Moment of Inertia, from this formula only E is known as 210GPa. Anderson (2011) states that during the 2011 season F1 front wings were around 1 metre long and underwent loads of around 3000 Newtons each. From research what W and L is only I is left, rearranging the equation to $I = \frac{-WL^4}{y_{max} \times 8 \times E}$ makes I the subject and allows for the formula to be completed.

$$L = 1\text{m} \quad y_{max} = 10\text{mm} = 0.01\text{m} \quad E = 210\text{GPa} = 2.10 \times 10^{11} \quad W = 3000\text{Nm}$$

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

$$I = \frac{-WL^4}{y_{max} \times 8 \times E} \quad I = \frac{3000 \times 1^4}{0.01 \times 8 \times 2.10 \times 10^{11}}$$

$$I = 1.79 \times 10^{-7} \text{ m}^4 \quad \text{Moment of inertia cannot be greater than this.}$$

From this we can use the formula for moment of inertia of a cylindrical tube to help find the minimal diameter. According to Dr Lemonis (2020) the formula is $I = \frac{\pi}{64} (D^4 - d^4)$, where D is the outside diameter and d is the inside diameter.

Calculating I from our slope deflection equation means it is known that the moment of inertia that is calculated using the area cannot be greater than the value. Using the formula shown above and knowing the cross-sectional area has a 2mm gauge so a 4mm difference in diameter allows a calculation to be made for the minimum outside diameter. A spreadsheet was done to help with the calculations and to find the minimum diameter, this can be seen in figure 1 below.

whereas really, manufacturing tolerances are vitally important and not being within tolerance or setting the wrong tolerances could seriously hinder the cars performance.

3.0 - Designs and History of Front Wings

Ever since the introduction of front wings in 1968, their importance has rapidly increased and is now a vital aspect for aerodynamics and downforce for car. Continuous innovation has led to the evolution of front wings, by carrying out thorough research for aerodynamic performance and impact of front wings has allowed for formula 1 cars to perform and drive at optimum levels.

Front wings have become so important on formula 1 cars due to the downforce it provides the car along with the air flow it creates for the rest of the vehicle. By including and having a front wing on the car it allows for air to hit the front of the car and depending on the shape and design of the wing, to follow its curvature. Due to the speed in which the car drives at when the air hits the wing it forces it to go over the car body and therefore act as downforce on the vehicle, this is a critical part of formula 1 as it allows the car to stick to the track and therefore corner better. Nichols (2021) suggests that front wings are vital to the performance of the car due to the way it directs air to other areas of the vehicle, and having slight damage to the wing can cause major performance issues.

Front wings started as just small curved sheets of metal which were used as winglets at the front of the car. This was the first sort of design for a front wing on formula 1 cars and started to allow the car to turn corners at higher speeds. However, there is an issue with the design, due to the angle of attack of the front wing even though it increases downforce, due to the flow of air separating an area of low velocity is developed which leads to an increase in drag, this is dealt with by the rear wing however. Front wings have developed over the years due to research finding the amount of downforce produced is dependent on the front ground clearance of the wing according to Myling (2017). So, from this research front wings have become lower to the ground on the car along with additional elements being added to help aid the air into different areas for the car.

The image shows the development and change with front wings. As you can see the modern wings are a lot more complex with more time and money being spent researching and designing them.



Figure 2 – History of Front Wings. Oggioni (2019)

As the front wing produces around 25-30% of the total car downforce it needs to be optimised. New modern front wings have a lot more elements compared to the basic 1968

front wing. The modern designs include a variety of flaps and plates which allows for channels to be created to allow for flow to be diverted to targeted areas. Harris (2017) states that the new front wings allow for the air to stay attached to the car after the front wing, by doing this it reduces drag and increases downforce. By including slotted gaps high energy airflow is allowed to interact with lower wing surface, this creates a higher coefficient unless the wing becomes in contact with something blocking air flow.

An advancement in materials has meant that front wings can move away from basic curved metal sheets and more towards composites such as carbon fibre. Elson (2021) states that around 80% of the car is now manufactured with carbon fibre due to the fact its twice as strong as various metals but also up to five times lighter. He also goes on to mention that modern front wings can cost up to £100,000 due to design and material.

4.0 - Manufacturing Process & Material for Front Wings

Further development can be found in materials being used for front wings, along with wings becoming more complex and efficient, modern materials such as Carbon Fibre have replaced the old curved sheets of metal. Carbon Fibre is much stronger than the old sheet steel used on previous wings, but more importantly it is a lot lighter which allows the car to drive faster due to it carrying less weight. Replacing sheet metal with Carbon Fibre has allowed for more complex designs to be created to benefit the car, the cost of carbon fibre is extremely high, however due to the huge budgets in research and design in F1 this is not a problem.

The manufacturing process has changed over the years too due to the change in materials and the advancement in technology. Previous front wings were simple curved sheets of metal which would have been hand crafted or machined, this then would have been tested on track circuits with feedback and results being taken from lap times and car performance analysis. The modern process is much more thorough, with the design and development being done using CAD models, carrying out these designs for mechanical, electrical, and aerodynamic components allows for them to be designed and tested before they get manufactured. The introduction of tools such as simulation and scanning means materials and components can be evaluated for bonding, condition, firmness and many more. Mitchell (2021) suggests that by using tools such as CAD, designs can be made and simulations such as displacement and stress can be completed on the component in order to understand its performance under load.

Once an appropriate design has been made and simulation has been carried out on the component it can then be manufactured and put through further testing. As stated above Carbon Fibre is the prominent material used, creating a pattern with epoxy using a milling machine begins the life of the material, these patterns are then used for moulds to make the final part according to Motorsport (2022). Composite manufacturing areas are kept under tight control within factories, with air pressure, humidity, and temperature all being strictly reviewed, this because of the issues and problems which can occur if impurities get into the component.

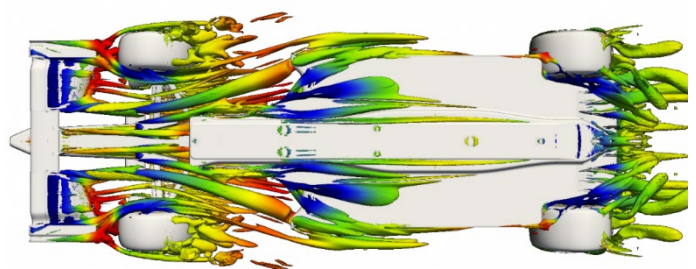
The Carbon Fibre composites are then cut out and moulded into different shapes according to the design of the front wing. Within the moulds the material is vacuumed, placed in an oven, and put under pressure. This allows for the resin to melt between the carbon strands and set making a solid part. The number of treatments and process the part has affects how it reacts and performs on the car.

After the part has been moulded it is put through inspection and various testing such as CMMs to check accuracy and dimensions. If the component passes the inspections and testing it can then be fitted to the assembly, testing such as wind tunnels can then be conducted to understand the amount of downforce and drag which the front wing is generating. Crash testing must also be passed before signing the component off, it is important to understand that FIA (Federation International Automotive) sets several standard and legislations which the car must adhere too, this may impact the design and structure of the front wing. It is important to remember that however much testing you do, it is not until the car can compete in a race or qualifying that a true indication of the performance of the front wing can be seen. This is like how the manufacturing process and testing was conducted when front wings were first introduced, however as explained above modern processes are much more thorough and precise. Obviously this costs a lot more than previous front wings due to the material, the amount of staff and technicians in place to perfect and design these processes and parts are another reason why the cost is so high, however, the actual process is more cost-effective than older times due to the rise in technology allowing for simulation and testing to be carried out before manufacturing takes place.

5.0 - Prototyping and Testing

In order to verify and test the calculations and results gathered from Task 1a, some testing and simulation can be carried out to see what effects different diameters have on the performance and deflection of the front wing. With cars going through different conditions and going under different loads it's important to see how they perform under various scenarios. This can be done by testing the front wing in wind tunnels under different speeds, by applying static loads to different areas of the wing, this is done by placing the wing so it acts as a cantilever beam, applying continuous weights to the end of the front wing causes the beam to deflect, this can then be measured by distance moved. Doing this it will give an understanding of how the wing differs with deflection and slope.

The first testing to be carried out is simulation testing, this allows for designs to be made and tested on software which helps reduce spending costs due to the prototype not being physically produced. Using software, the front wing can be designed and modified to meet FIA regulations and maximise performance for the car, loading can then be applied to the wing to help identify areas of highest stress and strain, but also the amount of displacement and



deflection under different loads. TotalSim (2016) shows below in the image how simulation can be used to visualise how the front wing direct the flow of air to different areas of the car.

The use of simulation allows F1 teams and engineers to understand how the front wing is going to perform and react to loads and conditions before physically producing the prototype and testing it with static loads and in wind tunnels.

Figure 3 - Simulation Testing. Mitchell (2021)

Static testing could then be carried out on the front wing; this involves placing a load on the end of the wing and measuring how much the wing deflects. Anderson (2015) claims that during the 2015 season, teams had to apply a 60N load to the end of the wing and make sure the deflection is not greater than 3mm. From task 1a however the maximum deflection is 10mm, this allows for weight to be applied to the end of the wing until the deflection exceeds the 10mm allowance. It is important to consider material and different materials have different tensile strengths, therefore some materials may have less deflection when applying higher loads.

One of the most important tests carried out on formula 1 front wings is the wind tunnel test. Wind tunnels are a great way to test a prototype in a real-life scenario and to help collect data for how the front wing performs with wind acting as an additional down force. The test will also help understand how the front wing distributes air flow and downforce throughout the car, it would be one of the final tests carried out to see whether the designs have helped the car achieve its optimum performance. Anderson (2020) states that during a typical wind tunnel test a series of parameters are set to simulate a car going through a corner sequence and a straight. From this, data will be collected which includes downforce, thrust, and drag. Adjusting the temperature and humidity can allow for comparisons to be made to how it effects the wing differently. The results from the tests can then be interpreted and changes or improvements can be made. For example, it might be found that at high speeds so high winds the front wing displaces too much and therefore airflow is not being directed to the correct place, therefore the pipe diameter may need to be greater or a change in design or material would need to be considered. It is critical that a good correlation is found between wind tunnel data and track data, this helps confirm that the testing is suitable and gives off reliable data.

An example of the testing can be seen below:

Load (N)	Displacement (mm)
1000	0.6
2000	1.1
3000	1.7
4000	2.1
5000	2.4

6000	2.6
7000	3.0

6.0 – Conclusion

In conclusion from the report, front wings are a critical component in order to allow a F1 car to reach its optimum performance and achieve the top speed, best handling, and best braking. The front wing is the pinnacle of the car and the first component used to help airflow reach different components of the car. Using the correct material and thoroughly testing the front wing using different techniques such as simulation, wind tunnel, static loading is critical for designing and manufacturing the best performing component. It is vital that these tests provide accurate results in order to meet strict regulations.

The history of front wings is also incredibly important to understand and visually seeing the difference in complexity and performance, and within regulations these front wings will continue to change in order to improve the performance of the car. The report also shows a basic calculation to find the Moment of Inertia of a given front wing along with some assumptions being made. This is an example of how a calculation can be made to find the slope and deflection of a beam.

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