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# STRESS ANALYSIS & DYNAMICS – FRONT WINGS

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UNIVERSITY OF WALES TRINITY SAINT DAVID

## Executive Summary

This is a report that looks at the different types of front wings within racing over the last 70 years. Within this report it will detail the material and manufacturing process of racing cars and rigorous testing they are involved in to make sure they are the best on the track.

In May 1950 the world watched the first F1 race which saw very small cars with large engines which was just the starting point of which is the most lucrative sport in modern history. Over the next 70 years there would be massive technology advances that made the cars faster and faster which demanded more care to be taken in the outer body of the car. More understanding was developed into aerodynamics and what effect the cars handling and performance. It wasn't till 1967 F1 saw its first front wing that proved effective in providing airflow and downforce. The front wings predominant use is to provide the front wheels with downforce to gain traction. Due to F1 cars being so light, downforce is vital to keep the cars grounded and to be able to handle correctly. Over the next 55 years there have been many alterations of the front wing. Some proving effective and some proving dangerous. Thankfully due to modern science and engineering the dangerous renditions of the front wings are a thing of the past due to technological advances within testing and knowledge. Engineers can now use computer simulations such as FEA (finite element analysis) and stress calculations to find flaws in designs and amend them before physical testing. Physical testing has still a major effect with the design process such as the use of wind tunnels, but the vast majority defects would be caught before anything was fabricated.

Materials within the F1 cars have also changed dramatically for the same reasons. F1 cars in 1950 were made from a mix of steel and aluminium which made them heavy and slow. In 1980 advances in material sciences saw the first parts being fabricated from carbon fibre. This paved the road in which we see 85% of cars being fabricated from carbon fibre today. Carbon fibre is a much lighter and its strength to weight ratio is much stronger than steel and other metals used. Therefore, a monocoque chassis was adopted so a far stronger outer shell could be fabricated out of a mould.

The report conducted calculations into a basic race car using hollow section tube as structure for the front wing. After calculations included in the report and research it was concluded that 21mm diameter 2mm wall tube was the correct tube to provide the front wing with the correct strength required.

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## Introduction

Since 1968 when front wings first were implemented into racing many adaptations and different ideas have been tested and used. In modern applications the front wing is designed to shape the airflow which will be meeting the car. The front wing primary purpose is to provide downforce for the front end of the car to minimise the risk of the car flipping up and to provide traction to the front wheels. Every year new developments enable race car teams to shape the air that will be causing drag which will in turn create a much more efficient car. Within modern times a F1 car can generate a total of 1700kg of downforce which equates to 2.8 times the mass of the car on low-speed tracks such as Monaco. The front wing generates 650kg on a higher speed track, this is the reason why the front wing is one of the most important components on a F1 car. This amount of downforce is a result of over 60 years of research and trial and error, to create the most efficient outer shell for the car.

## History

On the 13<sup>th</sup> of May 1950 the first ever F1 race was held at Silverstone racetrack in England. At this time aerodynamics were not thought about to extent they are in present day and were not an option until the late 1960's. These cars in 1950 were very simple and often in a tubular shape with a large engine compared to the weight of the car. This can be seen in figure 1. These cars were all front wheel drive. This resulted in the cars being very unstable and difficult to drive.



Figure 1 F1 First race

After seventeen years, the first use of the front wing is seen on the Lotus 49B which was unprecedented at the time. This was the start of every team becoming aware of the positive impact of a front wing when racing. The car can be seen in figure 2, the car featured a simplistic design which had one wing on either side of the front nose of the car. This was designed to manipulate the air stream by using low pressure at high speed and high pressure at low speed. As can be seen in figure 3. When there is a pressure difference that acts on the wing it creates a pulling force acting in the same direction of the low-pressure zone. This creates lift for a wing. It took a man called Jim Hall to have an idea to turn the wing upside down to generate negative lift or commonly known as downforce.



Figure 2 Lotus 49B

Oggioni (2019) explains within an article that the angle of the wing designed has a massive effect on how efficient the wing is. Front wings that were developed initially were in a fixed position and could not be adjusted. Back in the late 1960s they did not have the equipment to test the effectiveness of the aerodynamic profile.

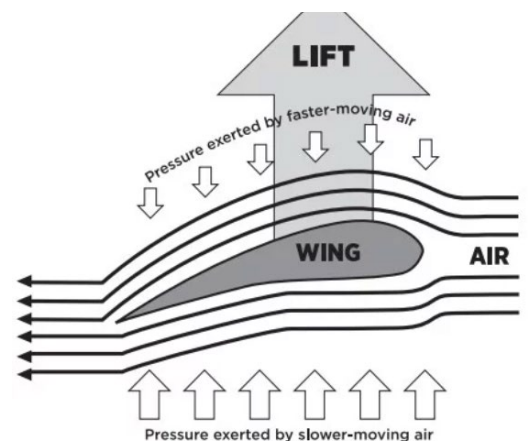


Figure 3 Air Flow Diagram

Mortel (2003) writes in a report on how the Lotus 49B was littered with problems due to the lack of adjustability which led to the wings breaking off on some occasions. This resulted in a large crash in the Spanish grand prix for Lotus. This caused F1 to rethink the design.



Figure 4 McLaren M23-5

In the figure above the McLaren M23-5 can be seen, this was the first car that featured end plates on the front wing. The front wing was implemented to redirect the airflow around the front tires to reduce drag generated. The car still had its problems with a vast amount of understeer due to the fixed position of the wing. The teams were also changing other elements on the car such as the back wing. These changes went on without success for the duration the seventies with the height and width of the wings being changed using trial and error. No major changes were seen till 1980s where a discovery concerning a second element flap being added could give the cars an edge. An element is the number of wings on the front wing. This can be seen in the figure below. This car was a later version of the car in figure 4. In 1984 the introduction of the second element

gave the driver and the engineers the freedom to adjust the element to change the load applied on the front wing. The benefits for this change were seen by the other

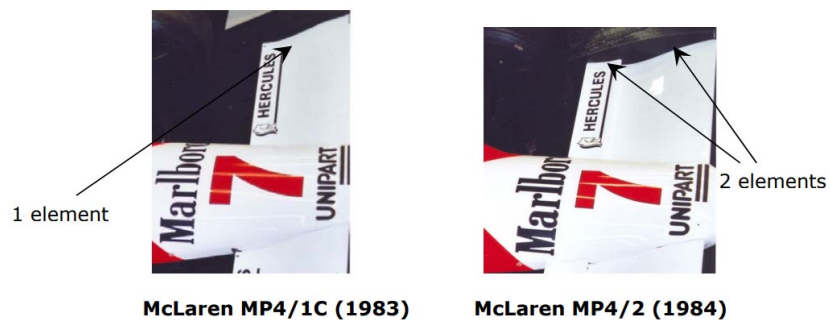


Figure 5 McLaren MP4/1C/2 Front Wing

F1 teams where they chose to adapt their race cars in the same way. The second element could be adapted depending on what course. As stated previously the different racetracks are all different, some demand straight line speed, some demand maneuverability. By having adjustability, it gave the race team the opportunity to have the best setup for downforce in each race. Fagnan (2018) shows details of Ferrari's adoption of the second element within their front wing. Ferrari trialed a much larger front wing to generate far more downforce. The cord length of the wing was made to be half of the span to the location of the nose.

This meant that Ferrari could set their second element angle much higher than their competitors. By doing this it allowed the front wing to channel far more airflow into the engine cooling vents which meant the engine would run far cooler than in previous years.

By the end of the 1980s it was released that teams such as Tyrrell and Benetton would be raising the nose their cars so a full wing from each end could be achieved. This was to avoid any wing body interference and allowed the team to have a much larger surface area to carry the load of the incoming air flow. Mortel (2003) details that after this change that proved to be not as effective as mounting the front wings on either side of the front nose, wing tips were added by McLaren to reduce drag around the wheels as these are the most important part of the car. If the wheels of an F1 car experience drag or any other external forces, it can affect the handling of the car and responsiveness. By doing this it meant that the wing tips would sit in very close proximity to the front wheels to achieve less drag. Doing this it led to a large crash involving Roland Ratzenberger and Ayrton Senna which resulted in the death of the two drivers.

After these fatal crashes F1 association (FIA) implemented regulations to limit ground height of the chassis parts. The regulation ground height differed between the center of the car and the side which allowed engineers to redesign the front wing in order achieve the same outcome.



*Figure 6 Front Wing Design After Regulation Change*

After this event the F1 teams came up with a solution to the problem presented by the FIA. The solution was to design a front wing that had a dip in the middle, thus having the same effect on air flow into the engine but still being far off the ground around the front wheels which was the issue. This can be seen in the figure above. It can be seen this front wing still featured the two element that proved effective in the previous years

Within the 21<sup>st</sup> century there has been vast technological advances when it comes to aerodynamics. With the modern equipment available it is much easier to understand what is needed to direct the airflow to specific places within the car or to the outside of the car. It can be seen in figure 7 that within the 21<sup>st</sup> century front wings become far more intricate to accommodate changes in regulations and changes in advancements. Warrier (2021) explains the need for more than two elements within the front wing assembly. It can be seen in figure 7 that by 2019 there are four wing elements situated on the front wing. Warrier



*Figure 7 Front Wing History*

(2021) shows that the small sections of carbon fibre lead to far more downforce compared to previous years. The drawback to this design is the high angle of attack which generates a larger drag penalty. This is counteracted by the middle of the front wing being blank and having clear flow into the middle of the car. Due to regulations in 2009 the FIA mandated that the central of the wing 250mm either side should be clear to promote overtaking within the sport. Suddenly engineers in F1 had far less surface area to play with to generate the same downforce. Therefore after 2009 a far steeper angle is seen on the front wings to achieve this downforce.

## Materials used

Over the years F1 teams have been using a vast number of materials within their cars and their panels to achieve the most effective car. F1 cars are designed by engineers for two purposes, one, to be fast on the track and two, being able to withstand high impact moments such as a large crash. When F1 initially started in the 1950s the cars were developed as metallic structures predominantly made from aluminium. Since then, scientists have been developing and testing the most effective materials to suit F1. Castro and Rana (2020) states that F1 teams must invest a large amount of money and resources to develop the correct materials and technologies with the sufficient mechanical properties. They state that during the 1950s the car was built up of an assembly of steel and aluminium, this was depending on if the team was developing the car for strength or lightness. After the 1980s the vast amount of aerodynamic panels such as the front wing were made from carbon fibre which in turn meant that there was no need for any internal structure.

## Manufacturing process

The manufacture process of a F1 car is the most streamlined manufacture process within the engineering sector. Larger teams such as Mercedes and Aston Martin will develop and fabricate all their parts from raw materials. These designs start with a CAD model and FEA software development, solid epoxy patterns are then developed using five axis milling cutters which read data directly from the CAD file. Fisimplified (2012) states that epoxy is used to make sure that moulds are being developed to the correct curing temperatures and that thermal expansion is minimised.

Female moulds are developed with an airlocked room to limit the amount of contamination during the moulding process. The chassis are made from layered carbon fibre cloth. The correct layering of the cloth is crucial to gain the correct mechanical properties. The orientation of the cloth depends on the location within the chassis. To limit mistakes, designers develop manuals containing visual instructions to be followed for each ply. The assembly is then contained and placed in an autoclave for the assembly to cure and the composite to set. The monocoque chassis is then sent for any final machining and trimming to produce any further detail. The parts are then sent to inspection which would include testing and assembling any further assemblies that will need to be fixed to the chassis.

## Calculations

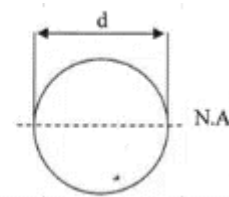
The following calculations will be detailing the deflection of a race car's front wing when being exposed to a certain force. 2022 has had F1 teams redesigning their front wing quite drastically due to regulation changes by the FIA. These regulation changes dictate that all F1 cars' front wings should be 1000mm to the centre line of the car. The reason for the change is to limit the amount of interference from a leading car's turbulence. Anderson (2022) writes that these are not the only changes that have been implemented into F1. Elements that are included within the front wing assembly have also been limited to four, and all need to be mounted directly onto the nose to maintain the car's structural integrity. For this reason and for these calculations, it is assumed that the front wing in question would adhere to the same rules of being 1000mm to the centre line of the car. We can also assume that the front nose is 100mm wide, which dictates that the front wings on either side of the nose are 950mm wide.

Ioannis (2017) Details FIA regulations that dictate front wings should be able to withstand a 1000N point load, acting vertically onto the front wing and should not be able to deflect more than 10mm. This translates to 101kg of force, this is the load that the calculations will derive from due to that this is standard practice for F1 engineering teams.

The outcome required by these calculations is to achieve a front wing that cannot deflect any more than ten millimetres in the vertical plane. The structure of the front wing in question is made up from a hollow steel bar that has an elastic modulus of 210 gigapascals. The forces and the width have also been assumed as dictated above. The following calculations will allow the race car team to select the correct thickness of hollow section round bar that will not defection more than 10 millimetres when in use. The calculations are carried out assuming that the outer layer of the wing provides no structure to the assembly. To find the solution two formulas will be used to find the force exerted on the front wing, and the defection of a specific thickness of round hollow section bar. These formulars can be seen below.

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

$$I = \frac{\pi d^4}{64}$$



The first formula is to find the force exerted onto the front wing and the second is to find the defection of the hollow round bar. The formula detailed in the previous page is for a solid round bar so in order the achieve the defection for a hollow bar the outer diameter and inside diameter will be subtracted to find the defection.

The first formula has been transposed to find the value in question (I)

$$\frac{WL^4}{Y_{\max} 8E}$$

W = Load L = Length Y<sub>max</sub> = Maximum defection E = Elasticity modulus

$$\frac{(100 \times 0.950^4)}{(0.01 \times 8 \times 210 \times 10^{11})} = 4.85\text{E-}09$$

Using this calculation, it has been found that the defection for this front wing is **4.85E-09**.

The calculation that will be used to find the defection of the hollow steel bar is as follows:

$$\frac{\pi}{64} \times (D^4 - d^4) \quad D = \text{Outside Diameter} \quad d = \text{Inside Diameter}$$

$$\frac{\pi}{64} \times (0.005^4 - 0.001^4) = 3.06\text{E-}11$$

By achieving the I value of the steel bar, a simple spreadsheet can be created to find the align the two defection values. This can be seen below.

|       | ymax  | 0.01     |          | I | 4.85E-09 |
|-------|-------|----------|----------|---|----------|
|       | W     | 100      |          |   |          |
|       | L     | 0.95     |          |   |          |
|       | E     | 2.10E+11 |          |   |          |
|       |       |          |          |   |          |
| D(mm) | D(m)  | d(m)     | i        |   |          |
| 5     | 0.005 | 0.001    | 3.06E-11 |   |          |
| 6     | 0.006 | 0.002    | 6.28E-11 |   |          |
| 7     | 0.007 | 0.003    | 1.14E-10 |   |          |
| 8     | 0.008 | 0.004    | 1.88E-10 |   |          |
| 9     | 0.009 | 0.005    | 2.91E-10 |   |          |
| 10    | 0.01  | 0.006    | 4.27E-10 |   |          |
| 11    | 0.011 | 0.007    | 6.01E-10 |   |          |
| 12    | 0.012 | 0.008    | 8.16E-10 |   |          |
| 13    | 0.013 | 0.009    | 1.08E-09 |   |          |
| 14    | 0.014 | 0.01     | 1.39E-09 |   |          |
| 15    | 0.015 | 0.011    | 1.77E-09 |   |          |
| 16    | 0.016 | 0.012    | 2.2E-09  |   |          |
| 17    | 0.017 | 0.013    | 2.7E-09  |   |          |
| 18    | 0.018 | 0.014    | 3.27E-09 |   |          |
| 19    | 0.019 | 0.015    | 3.91E-09 |   |          |
| 20    | 0.02  | 0.016    | 4.63E-09 |   |          |
| 21    | 0.021 | 0.017    | 5.44E-09 |   |          |
| 22    | 0.022 | 0.018    | 6.34E-09 |   |          |
| 23    | 0.023 | 0.019    | 7.34E-09 |   |          |
| 24    | 0.024 | 0.02     | 8.43E-09 |   |          |
| 25    | 0.025 | 0.021    | 9.62E-09 |   |          |

By looking at the spreadsheet on the above the formula has been inserted into the I section cells. By projecting the spreadsheet, the different defection for the different diameter bar can be easily seen. The ideal bar diameter has been highlighted in yellow, which is a twenty-one-millimetre bar with a

two-millimetre wall thickness. This is found by comparing the deflection value from the first formula calculated. There are many other unique forces that would affect a race cars front wing when on a track that have not been factored for within these calculations. By carrying out the calculations on the previous page it only rules that the front wing would be structurally sound but other forces will have an impact on the design of a front wing.

## Aerodynamic Tests

Manual calculations can offer a team the sound knowledge that the assembly will be structurally sound but there are other factors that race teams need to consider before the car is ready for the track. With the correct facilities F1 teams can completely replicate real world scenarios without even taking the car onto a track. There are many ways of replicating reactions of the front wing assembly using methods such as computer simulations. This is known as CFD, this simulator can estimate turbulent behaviour accurately. Ajay (2016) writes a report detailing the features CFD (computational fluid dynamics) can offer to F1 teams. He writes that CFD simulations offer a great method to fine tune the initial design before experimentation can take place. CFD offers a cost-effective way for F1 teams to locate areas that are not optimal before any experimentation can take place which would be attached to associated costs. Using figure, you can see that the software can accurately map out high friction areas within the design which will create the most about of turbulence. In history before this software the only way of knowing this was by making a replica of the design and finding the drawbacks physically.

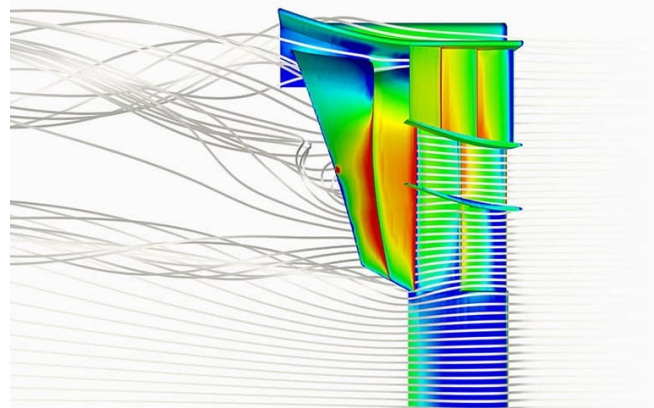


Figure 8 CFD Simulation

## Stress testing

By gathering data such as calculations, models, and simulations the team can then use a method such as finite element analysis (FEA). FEA is used to develop an overview of physical behaviours of mechanical structures or a system so it can be analysed. Bi (2018) states that FEA can be used to view truss structure, plane stress, plane strain, modal analysis, and fatigue analysis. As can be seen in the figure on the right, the weak points on the design can be clearly identified by the respective colours.

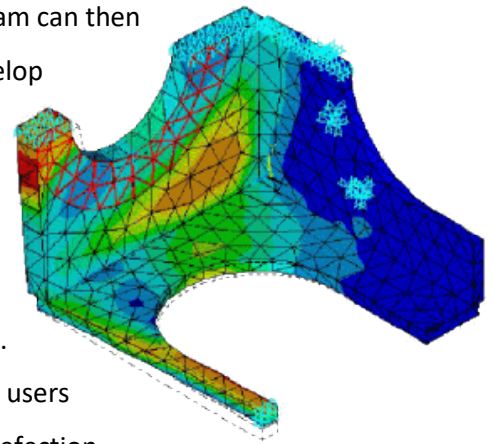


Figure 9 FEA analysis

The respective colours can be set to different values depending on the users needs. The most common use for stress analysis would be gauge the deflection in the part. The force that is encountering the part can be dictated by the user, the user can use the mesh view of the part to find the high stressed areas and find the value of deflection at that specific point. By gaining the information from the FEA the teams can then alter the design and fabricate the part to be physically tested.

## Physical testing

Physical testing is the last testing that will take place before the season starts. This is when all development using the methods above have been carried out and engineers are confident within their design. Often teams would make a replica of the cars aerodynamic components and test them within a wind tunnel to show that they are not making any unwanted vortexes. F1 teams are limited to the time spent inside wind tunnels to a total of 62 hours. The cars in the past would be hand made from predominantly wood and some aluminium components. Vyssion (2018) writes in a report in recent times F1 teams have adopted 3D printing to manufacture their replica of the model. This adoption of 3D printing comes hand in hand with FEA, this due to that engineers can directly export the model developed through FEA to the 3D printing. This makes sure that the design teams design is 100% replicated and limits fabrication error. Don (2014) explains that wind tunnels floor has sensitive scales that will accurately measure the horizontal drag and vertical lift forces. He also explains that apparatus within the tunnel will also measure air temperatures around the car to maintain an accurate result. With

in F1 as opposed to have a static car within the wind tunnel they use a rolling road assembly on the floor of the tunnel. By doing this the tunnel can accurately replicate real world speed differences between the vehicle and the road. Aero rakes are used when testing on track to measure flow being produced from various elements. These rakes are used to measure the flow after the aerodynamic

panelling which can then be used to paint a picture for engineers to what is creating vortexes and to improve airflow.

## Future of F1 Front wings

We have seen massive changes in F1 in 2022 which brought regulations into place that would stop aerodynamic panels such as the front wing from generating “dirty air”. This is when the car in front would disturb the normal air and cause the car behind to not be as efficient as the car in front. This was due to the large number of elements within the front with which was disturbing the airflow. In 2022 regulation have been brought in to limit the number of elements to three again to give cars a better chance of overtaking when within DRS range. The aero packages have been dedicated to teams to direct airflow vertically to make sure the trailing car is not affected as much. The future of F1 is completely in the FIA’s hands. In my opinion I think that the FIA will want to dial back the complexity of the F1 car to make a more interesting sport. I feel by doing this it will bring new life to the sport which has been dominated by the teams that had the most money to throw at research into new ways to make their car more efficient and even the playing field.

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