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

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1. Introduction

The topic of the thesis is the design of a front wing support bracket that meets the specified conditions.

The planning was carried out without the need for completeness, as not all influencing factors were known. However, knowing all the influencing factors would have made the calculations extremely complicated, possibly incalculable.

During the thesis, the required minimum diameter of the support bracket was determined using the slope and deflections of beam theory. Furthermore, the development of Formula 1 front wings, the materials that can be used, and the possible testing methods are discussed.

As well as possible shortcomings and possible improvements.

2. Method

According to Continentalsport (2022) recent Formula 1 car can generate about 750 kg of downforce at 100 mph. The car weighs less than the current downforce, which means it could theoretically drive upside down.

The fastest race time was 372.5 km/h (231.4 mph) at the 2016 Mexican Grand Prix by Valtteri Bottas.

So, if at a speed at 100 mp/h the downforce of the whole car is 750 kg, then at a speed at 231.4 mp/h – because this is the fastest speed ever measured in race – it will be 1735,5 kg.

This can be calculated as follows:

$$\text{total downforce at 231,4 mph} \Rightarrow 2,314 * 750 = 1735,5 \text{ kg}$$

According to Nakawaga and Hojo (2014), the front wing serves to balance the car aerodynamically and accounts for 25% of the total downforce generated.

It follows from the above statement that the downforce of the wing will be 433,875 kg.

This can be calculated as follows:

$$(750 * 2.314) * 0.25 = 433.875 \text{ kg}$$

Converting the result into Newton, the result would be 4256.31 N which is the result of the following calculation:

$$433.875 \text{ kg} * 9.81 = 4256.31 \text{ N}$$

So, if the whole car can generate 750 kg of downforce at 100 mph, then at 231.4 mph the downforce will be 1735.5 kg, which is obtained by multiplying kg by 2.314. Since the front wing accounts for 25% of the total downforce, multiplying 1735.5 kg by 0.25 gives 433.875 kg (4256.31N), which is the downforce of the front wing at 231.4 mph.

To simplify the further calculations 4256 N will be used.

The article written by Anderson (2022) also reveals that the width of the front wing cannot exceed 2000 mm. Taking this fact into account, 2000 mm was established as the basis of the

calculation as the width of the front wing. During the calculations, 1000 mm was used, which is half the width of the entire wing.

As stated in the task, the outer diameter of the tube supporting the front wing must be determined. To determine this, calculations were made based on the theory of slope and deflections of beams.

As the downforce is affected by too many factors, such as air density, speed, the design of the Formula 1 car, the wing design, including the location and weight of the plates, endplate, flap etc, the angle of the wing. The weight distribution of the front wing is not uniform, this is due to the location of the flaps, end plates and the overall design. There is no data on these factors, so it is most suitable if the calculations are performed using a uniformly distributed load. As Abdul-Rahman et al. (2018) did in their study.

The maximum deflection can be determined using the following formula:

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

Y_{max} means the maximum of deflection. In this case it is -10 mm.

W means the load which in this case was determined to be 434 kg according to the previous findings.

L is the length of the front wing 1000 mm.

E is 210 GPa.

Young's modulus is the elasticity factor that measures the stiffness or tensile of the material when a force is applied to the material, so it measures how the material can resist the pressure exerted on it. The higher this number, the better the material can resist the impact on it. (Material Properties, 2022.)

I which is the second moment of area of the tube which needs to be calculated. Second moment of area is a property that shows the shape's resistance to bending and deflection. (Academic dictionaries and Encyclopedias, 2022.)

The following equation was used to calculate the moment of area of the hollow tube.

$$I = \frac{\pi}{64} * (D^4 - d^4)$$

Where **D** means the outer diameter and **d** means the inner diameter of the tube. The inner diameter can be calculated as the following

$$D = D - 2t,$$

where **t** is the wall thickness.

Knowing the already specified wall thickness, which is 2 mm, a table was created to determine the **I** values for tubes with different possible diameters.

D (mm)	D (m)	d (m)	I (m4)
5	0.005	0.001	3.0615E-11
6	0.006	0.002	6.28E-11
7	0.007	0.003	1.13825E-10
8	0.008	0.004	1.884E-10
9	0.009	0.005	2.91235E-10
10	0.01	0.006	4.2704E-10
50	0.05	0.046	8.69654E-08
51	0.051	0.047	9.25083E-08
52	0.052	0.048	9.8282E-08
53	0.053	0.049	1.04291E-07
54	0.054	0.05	1.10541E-07
55	0.055	0.051	1.17035E-07
56	0.056	0.052	1.23779E-07
57	0.057	0.053	1.30777E-07
58	0.058	0.054	1.38034E-07
59	0.059	0.055	1.45555E-07
60	0.06	0.056	1.53345E-07
61	0.061	0.057	1.61408E-07
62	0.062	0.058	1.69748E-07
63	0.063	0.059	1.78372E-07
64	0.064	0.06	1.87282E-07
65	0.065	0.061	1.96485E-07
66	0.066	0.062	2.05984E-07
67	0.067	0.063	2.15785E-07
68	0.068	0.064	2.25892E-07
69	0.069	0.065	2.36309E-07
70	0.07	0.066	2.47043E-07

Table 1 - Required tube diameter

Since all factors other than I are known, this value can be calculated by rearranging the equation.

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

$$Y_{max}8EI = -WL^4$$

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

So, the I value can be calculated from that equation. Which will be the following:

$$I = \frac{-4256 * 0.9^4}{-0.01 * 8 * 210 * 10^9}$$

$$I = 1.6621 * 10^{-7} m^4$$

Knowing this value, the required tube diameter can be selected from the table. The required outer diameter will be 61 mm as it can be seen from Table 1.

3. Result

As mentioned above, the calculations were performed using the slope and deflections of beams theory, assuming a uniformly distributed load.

The reason for this is that not all influencing data was available, and in the case of uneven loading, it would have been difficult to determine the distribution of the weight.

As can be seen from the calculations, the required diameter must be 61 mm, since the 62 mm diameter pipe would be too stiff, the 60 mm diameter would have more than 10 mm of deflection.

I value is known at it was calculated above. To calculate the actual y the following equation is used:

$$y = \frac{-WL^4}{8EI}$$
$$y = \frac{-4256 * 0.9^4}{8 * 210 * 10^9 * 1.6621 * 10^{-7}}$$
$$y = -0.0100001203m$$

The value obtained in this way corresponds to the value specified in the description, so the deflection cannot be more than 10 mm.

4. Importance and history of front wing

Front wings are extremely important in car racing.

As it can be read on the Trinity Formula page, the front wing is what the incoming air hits first. The front wing essentially acts like an airplane wing that is upside down with some extra flaps. However, due to the front wings close proximity to the ground, the front wing has a ground effect element which causes the air under the wing to move faster than it would normally. This produces a much lower pressure region underneath the wing which leads to more downforce.

(Formula Trinity 2021)

The importance of the front wing lies in where it directs the incoming air. The main function of the front wing is to create downforce.

During driving, the front wing shapes this air so that it creates a high pressure zone on top of the wing and a low pressure zone below the wing.

The force resulting from the difference in air pressure, which presses the wing down.

These forces and the forces resulting from friction make up the downforce of the wings.

The front wing is able to direct the wind to parts of the car such as the wheels, thereby providing better grip, which is essential when it comes to racing cars. In addition to being able to provide better grip to the wheels, it is able to reduce the drag on the rest of the car.

It is very important to maintain the right balance with the design of the front wing, so it is important not to have too much downforce, as this can negatively affect the performance of the car.

As Harish writes, the front wing essentially consists of a main plate to which flaps and end plates are attached. The purpose of the flaps and the end plates is to allow the air to pass under and over the front wing.

The aerodynamics of the racing car can be improved by properly adjusting the end plates, they have 5-10 times more influence than the other parts, so it can be said that this is the most important part of the front wing.

As Castro and Rana write the aerodynamics of cars have played a major role in racing since the 1950s.

However, the focus was not on that, but on reducing drag.

Wings first appeared in Formula 1 in 1968 on the Lotus 49 racing car. All this is attributed to Colin Chapman.

The purpose of the wings was to hold the car closer to the ground, thereby providing better traction, which plays a key role during acceleration, braking and manoeuvres. Also, the lower the air resistance, the higher the speed that can be achieved.

In terms of aerodynamics, the front and rear wings and the spoiler are the most important, and all three must be designed in harmony with each other, they cannot be modelled separately from each other.

During the design of the front wing of Formula 1, it is essential to strive to reduce the weight of the wing. At the same time, it must also comply with Formula 1 regulations, such as stiffness, which significantly degrades the aerodynamic performance of the front wing and therefore the car.

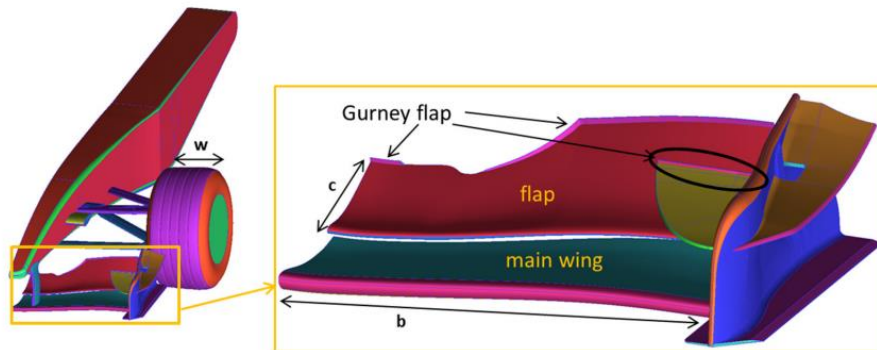
From the 1960s, the front wings of Formula 1 have continuously developed and changed.

The front wing of the Lotus 49 was a completely simple wing consisting of only one element with vertical plates at the end.



Picture 1 - Lotus 49 (Fagnan, 2018)

In the 1970s, the so-called Gurney wing appeared, the main characteristic of which is the elliptical shape.



Picture 2 - Front wing with Gurney flap (Basso,Cravero,Marsano 2021)

Multi-element front wings were implemented in 1984 by McLaren, however, three-element front wings were not created until 2004.

After the tragedies in Imola in 1994, the FIA introduced a number of changes, including to the front wing, such as increasing its height.

In 2001, the FIA changed the regulations regarding the distance between the front wing and the road, increasing it even further. Due to this, the teams had to start designing front wings with a positive dihedral angle.

In 2010, the so-called CFD, i.e. computational fluid dynamics, was introduced, which facilitated the development of the front wings. Due to the tightening of the rules, this plays an extremely important role in the further development of racing cars.

5. Materials used for Formula 1 cars

As can be read in the Flow Racers article, 60-80% of Formula 1 racing cars are made of carbon fibre. It is the most suitable material as it is resistant to heat, light, extremely strong and durable.

In the event of a collision, it can absorb an extraordinary amount of kinetic energy.

In fact, with the exception of the engine and transmission, almost everything on the Formula 1 racing car is made of carbon fibre.

Another material used in production is titanium, so for example the protective plate found under the car is also made of it. The engine is made of aluminium, but Kevlar is also used in certain parts of the car.

The front wings are made of carbon fibre and in certain parts of Kevlar.

Carbon fibre is definitely the best material to choose because of its properties. However, it is expensive due to its complicated production process, which of course depends on the purpose for which the material will be used.

In 2020-2021, the production costs continued to increase due to the growing demand and the difficult supply to satisfy it. At the same time, the manufacturing companies further increased the costs by using specific techniques.

In the case of Formula 1 race cars, in addition to pre-ignitions, the testing of the individual produced pieces is of course also costly.

The most suitable material for the production of the front wing support would be aluminium, as it is light, durable, not difficult to produce and shape, and cost-effective.

6. Testing results

Wind tunnels were initially used in aircraft production, but they have been present in the development and testing of F1 cars for half a century.

As Wang et al. (2018) write in their dissertation, wind tunnels and simulation with CFD software are most typically used to determine the aerodynamic characteristics of Formula 1 cars.

As you it can be read in the article on Auto123, the point of the wind tunnel is to study the movement of the wind as it passes by the body. A closed, tube-like system, in the middle of which the object to be tested is fixed, and then the air is moved towards the outlet with the help of a high-performance fan. There are 2 types of wind tunnel.

One is the so-called open wind tunnel, one end of which is open, the air travels in a straight direction through the entrance towards the body.

The other is the closed system wind tunnel, in which case the air coming out at the outlet is led back to the ventilators with the help of blades, so the same air is used.

When testing Formula 1 cars, the use of open-circuit wind tunnels is used because they generate a more even wind flow than the other type.

During the test, the car to be tested is fixed on a rolling road, which simulates the racetrack. The goal is for the rolling road to move at the same speed as the car would travel on the track.

The car is attached to a vertical bar, which can be used to adjust the car's distance from the ground, it can simulate braking and cornering, the most important thing is that they generate the same effects as what happens to the car in a race, so that the most accurate values can be calculated.

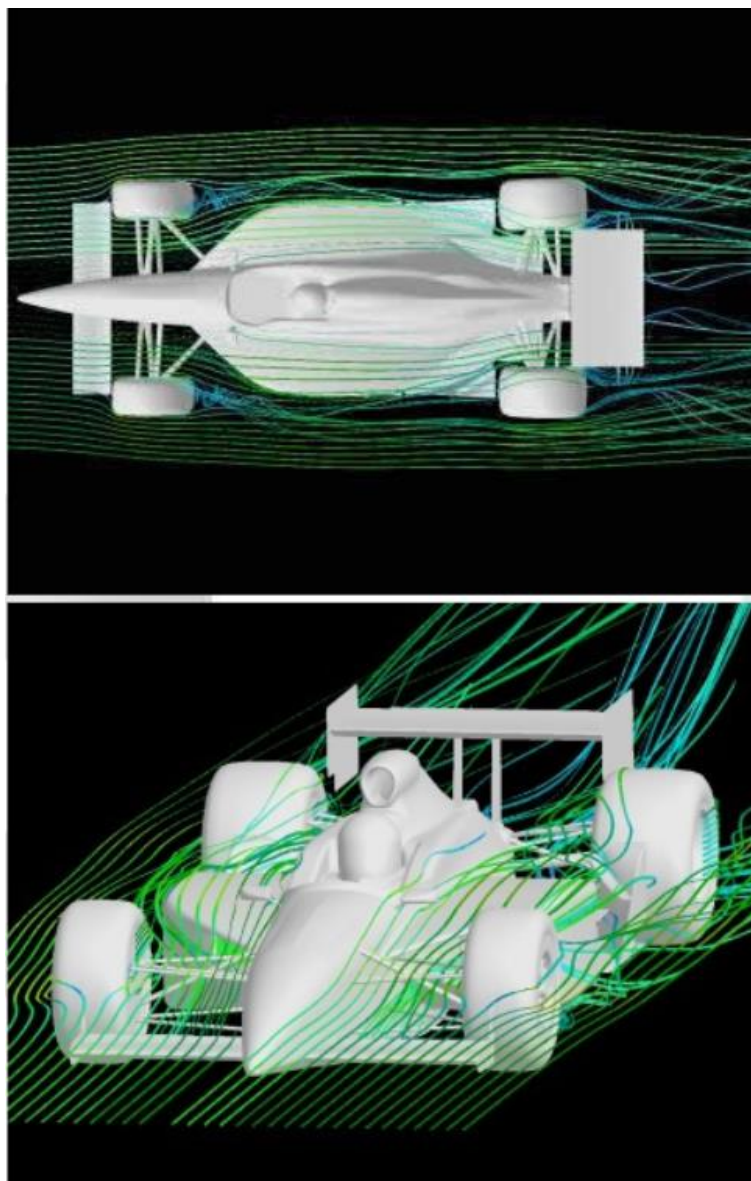
Cords and cables are usually connected to the car, so the forces are acting on the car and the direction of the wind flow can be observed.

According to Jiyuan Tu, Guan Heng Yeoh, Chaoqun Liu CFD is now more and more common in modern engineering, but in the early days it was only used in the fields of aviation and

astronautics. CFD is based on fluid mechanics and heat transfer, the use of this application helps to reduce costs and improve performance.

Computational fluid dynamics is a combination of mathematics, fluid dynamics and computer science. The boundaries must be defined before the process

During CFD, the properties and behaviour of the fluid during movement are studied, as well as how it affects processes such as heat transfer or chemical reactions. The characteristics of the liquid flow can be determined using mathematical equations. These complex equations are then converted into computer programs and thus become solvable.



Picture 3 CFD (Formula1 dictionary, 2022)

7. Conclusion

As previously stated, the car's aerodynamics and aerodynamic factors play an essential role in its performance. These factors can be improved by changing individual elements on the car or by better design. The role of the front wings is the most important, as they account for 25% of the total downforce of the car, so the use of the right wings is essential.

Throughout history, different wing designs have appeared, of course all of them had to meet FIA regulations. Not only the designs, but also the raw materials have developed, however, up to 80% of Formula 1 cars are made of carbon fibre, due to its corresponding material properties.

In the report, the diameter required for the design defined in the task was determined, calculated with a uniformly distributed load. However, this report also has shortcomings, such as, for example, the calculations were performed without the need for completeness, thanks to certain missing data, and the lack of testing of the obtained results.

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