
STRESS ANALYSIS AND DYNAMICS

A report explaining the calculations and design of a high-performance automotive car wing.



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Module - ACMA5010

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Introduction

Formula 1 racing has evolved massively over the past 70 years, mainly due to the acceleration of engineering practices over this period. New technologies have been incorporated within the cars helping them improve not only track times but also the safety of the drivers. As Kim (2017) suggest that both technology and Formula One go hand in hand due to the vast millions spent on Formula 1. The top speeds during the start of Formula One's 1950 era was around 180 miles per hour comparing to today's speed which are north of 220 mile per hour (Stuart, 2020). Safety has also made huge strides over the years, at the start of Formula One cork helmets had been made mandatory, but previously to that racer's competitors had the freedom to where what they required which involved cotton overalls, sometimes being short sleeved. This is the total opposite of the 2022 era where competitors must wear full face carbon fibre helmets and must incorporate hand /neck supports devices. During 2019 season drivers' gloves had fitted biometric technology which could feedback real time details including the drivers blood oxygen levels and pulse (Walker, 2018).

One of the vital components of the race car that has evolved over these years is the front wing. This is evidently because the front wing is the first part of the race car in which comes in contact first with the oncoming airflow as the car goes around the circuit (Autosport, 2020) .

This report will include a design of a structural support of a high-performance car wing for a new car series. The structural section will be constructed from a steel tubing with Youngs modulus of 210 Gpa, and with a given circular cross section of 2mm gauge. The wing of the vehicle can be assumed to be holding the wing in all 6 degrees of freedom. The regulations of the race state that the end of the wing deflection will be fixed and the deflection at the end of the wing must be limited to 10mm.

The report will also cover the history and evolution of Formula One cars from the 1950s to present, exploring the changes that have predominately occurred due to the invested of millions within the sport. The front car wing becoming a key part of the evolution of the Formula One car.

Design and Calculations.

When carrying out the wing designs there are certain aspects that need to be considered before carrying out calculations. As Anderson (2022) highlights that the overall aerodynamic load would be around 1820kg, which is distributed 40% on the front and 60% on the rear. This gives a value of 740kg total weight distributed on the front wing, 370kg if the weight was split between the two sides of the front wing. According to Holm, (2023) Formula One cars are 2 metres wide which will be taken into consideration as the steel tubing needed will need to be half of this at 1 metre.

As previously given the wing is required to be stiff with a y_{max} or maximum deflection of 10mm. and assuming the load across the wing is uniformly distributed. The following calculations will be required in order to work out the steel beam needed, to do this the second moment of area needed to be determined. The equation will need re arranging in order to find I .

Given,

Y max	10mm
Weight	370kg
Length	1m
E (youngs modulus)	210GPa
I (second moment of inertia)	?

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

$$10 = \frac{-370 \times 1^4}{8 \times 210 \times I}$$

I will now need to be found as shown below.

$$I = \frac{W \times L^4}{y_{max} \times 8 \times E}$$

$$I = \frac{370 \times 1^4}{0.01m \times 8 \times 21,000,000,000}$$

$$I = 2.20E-08m^4$$

Now that I has been calculated, a table is able to be constructed using Microsoft Excel. The table can be used as an experimental approach to try different sequences to find the diameters that were applied to conduct these equations. The Microsoft excel table give opportunities to try measurements for multiple diameters both internally and externally. It is to be observed that the measurement between internal and external diameters is 4mm. Using the table, a 33mm diameter pipe would be used to continue with the study. The table is shown as figure 1, with the highlighted row being selected to carry out the further equations required.

To find I within the Microsoft table the following formula was inserted $I = \frac{-WL^4}{8EI}$ and i has been calculated by using the formula $i = \frac{m(D^4-d^4)}{64}$. By using the following table the above calculations were proven.

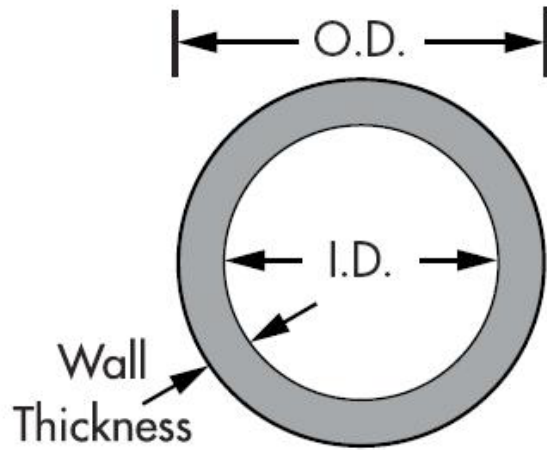
D(mm)	D(m)	d(m)	i
5	0.005	0.001	3.0615E-11
6	0.006	0.002	6.28E-11
7	0.007	0.003	1.13825E-10
8	0.008	0.004	1.884E-10
9	0.009	0.005	2.91235E-10
10	0.01	0.006	4.2704E-10
11	0.011	0.007	6.00525E-10
12	0.012	0.008	8.164E-10
13	0.013	0.009	1.07938E-09
14	0.014	0.01	1.39416E-09
15	0.015	0.011	1.76547E-09
16	0.016	0.012	2.198E-09
17	0.017	0.013	2.69648E-09
18	0.018	0.014	3.2656E-09
19	0.019	0.015	3.91009E-09
20	0.02	0.016	4.63464E-09
21	0.021	0.017	5.44398E-09
22	0.022	0.018	6.3428E-09
23	0.023	0.019	7.33583E-09
24	0.024	0.02	8.42776E-09
25	0.025	0.021	9.62332E-09
26	0.026	0.022	1.09272E-08
27	0.027	0.023	1.23441E-08
28	0.028	0.024	1.38788E-08
29	0.029	0.025	1.55359E-08
30	0.03	0.026	1.73202E-08
31	0.031	0.027	1.92364E-08
32	0.032	0.028	2.12892E-08
33	0.033	0.029	2.34833E-08
34	0.034	0.03	2.58234E-08
35	0.035	0.031	2.83142E-08
36	0.036	0.032	3.09604E-08
37	0.037	0.033	3.37668E-08
38	0.038	0.034	3.6738E-08
39	0.039	0.035	3.98788E-08
40	0.04	0.036	4.31938E-08

Y max	10mm
Weight	370kg
Length	1m
E (youngs modulus)	210GPa
I (second moment of inertia)	2.20E-08m ⁴

i	2.20E-08
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Figure 1 - Elliot Jenkins excel table

The highlighted row will be used as reference in the below calculations. Firstly, the area thickness must be calculated between the larger and smaller diameter of the tube.



$$\text{External Diameter} - I = \frac{\pi D^4}{64}$$

$$\text{Internal Diameter} - I = \frac{\pi D^4}{64}$$

Figure 2- chassis shop(2023)

Thickness between external and inside diameters shown below.

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

This can also be written as .

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

This will now provide us with the second moment of area of a tube.

Internal Diameter

$$I = \frac{\pi \times 0.029}{64} = 1.42$$

Outside Diameter

$$I = \frac{\pi \times 0.033}{64} = 1.62$$

Thickness between internal and outside diameter:

$$I = \frac{\pi}{64} (1.62^4 - 1.42^4)$$

$$I = 0.1555$$

By calculating this figure we are now able to use the original formula shown below:

$$y_{max} = \frac{-W \times L^4}{-8EI}$$

$$10mm = \frac{-370 \times 1^4}{-8 \times 210 \times 0.1555}$$

Final Answer = 1.4163mm

With the final answer being 1.4163mm it shows us that the car under a load of 370kg can perform under the 10mm acceptable bend movement.

Analysis

As previously mentioned by using the Microsoft excel table figure 1, using a 33mm beam would be preferred, whereas if a 32mm or 31mm were to be used the numbers lower slightly. By being able to use an excel table it helps a trial-and-error process become far easier when comparing sizes, using Microsoft excel can help users analyse the data rather than waste valuable time (Salmons, 2021).

There were little assumptions made due to the lacking access to data and figures, one assumption however was that the load of downforce on the front wing was disrupted uniformly across it. Nonetheless due to factors such as the weather, particularly the wind, will have an effect on the wing which will result in the load not being uniformly disrupted across it. (AMG Petronas F1 2022).

As the regulations and rules change yearly with formula 1 car specifications, it was decided that 2019 specifications would be used, with the maximum span overall of the front wing being 2 meter, thus making one wing of the car 1 meter as shown ion figure 3 below. With this data we were able to carry out our calculations on the downforce acting on the wing itself (Giuliana, 2020).

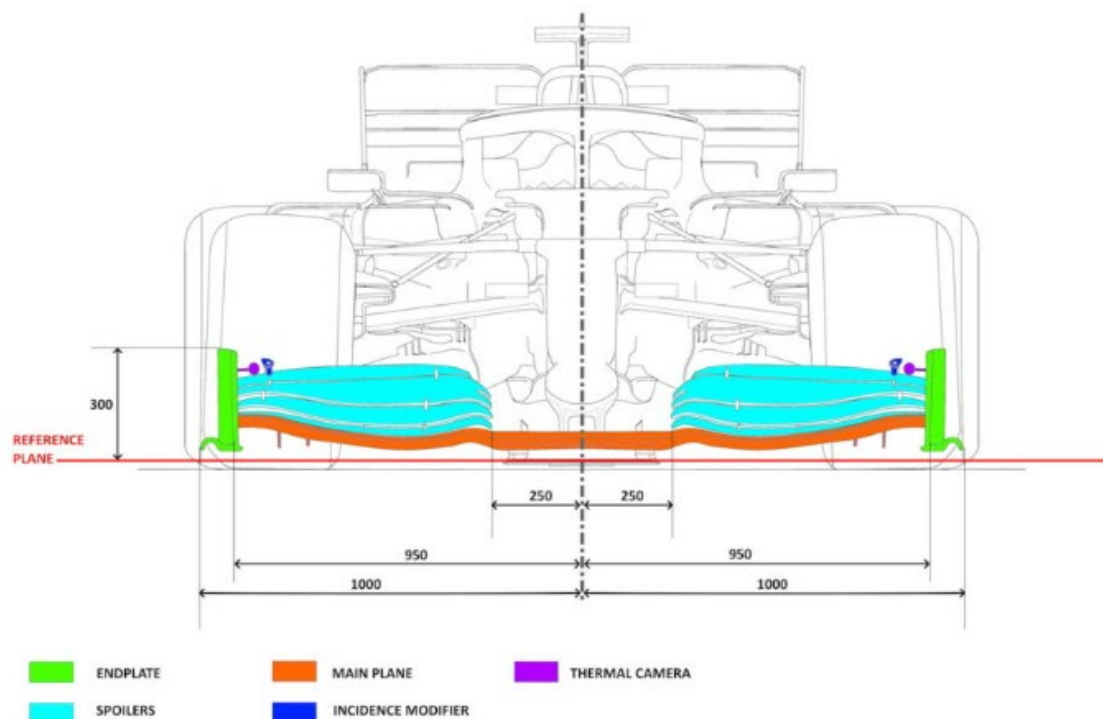


Figure 3 - (Giuliana, 2020)

Evolution of automotive front wings

The evolution of high performing automotive racing started in 1950s when the first Formula One season took place. Since then, the world of high performing car racing has changed incredibly (Harris, 2016). With the increase in followers, and the influx of money being spent within the sport, formula one teams are forever modifying the cars for performance and safety aspects. Automotive designs have changed greatly with a main focus on the aerodynamics, with “ the front wing not only being one of the most visible aerodynamic components, but also the most significant” (Anderson, 2022).

The first sighting of a front wing on a formula one car was during 1968 at Monaco Grand Prix, Colin Chapman from Lotus decided to fit small winglets on the front of Graham Hill's Lotus car as shown below.



Figure 4 Fagnan 2018

Hill achieved first position at the Monaco races, two races later at the circuit Zandvoort, every car was fitted with some type of wing varying in shapes (Fagnan, 2018). Colin Chapman trialled this idea by researching other types of wings from another racing car sport, when the driver of the car pushed a pedal, the angle of the wing flattened, reducing the drag on the straights. This is very similar to the DRS (Drag Reduction System) used on today's Formula One cars (Fagnan, 2018).

When looking at the 2019 Formula One cars there is a noticeable difference with the front wings. The cars all have a prominent drop where they are closer to the track, and also are wider almost covering the tyres as shown in figure 5.. This is to best direct the airflow around the tyres in the most efficient way possible, which is imperative for aero efficiency and will help to produce downforce from the wing itself (Hughes,2020).



Figure 5 Hughes 2019

During the 2019 season it was evident that each racing team's car had a different shaped wing, this was to have an advantage during different parts of the race. The front wing has two main sections which are the endplates and the cascades, both sections are altered by teams to try and optimise the aerodynamics. These are used to manipulate airflow as previously mentioned around the tyres, where the endplates are used to avoid uncontrolled vortices due to the high-pressure air going over the wing and low pressure air to the edges of the wing to reduce drag (Ayushman, 2020). By modifying the end plates would help increase or decrease the air vortex between the wheels, getting the modifications wrong could predominantly direct the airflow at the tyres which could be costly (partridge, 2022). Additionally, by teams maximising the outwash effect not only can they make their car more aerodynamic but create more turbulence for the trailing car behind, shown in figure 6.

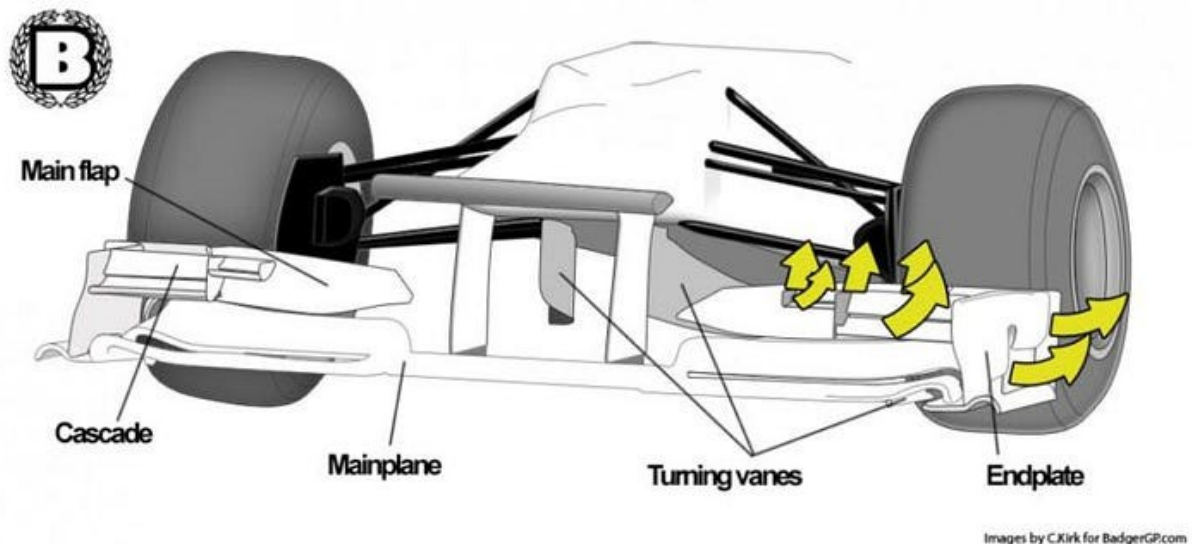


Figure 6 End Plate design. - (Chris kirk, 2017)

One of the main roles of the front wing is to create downforce. In the aircraft industry aircrafts would use their wings to create an uplift to take off, this is obtained by a speed increase which causes air to pass over the wings. This would create an area of low pressure above the wing and an area of slower moving high pressure air beneath the wing. This difference in pressure produces the upwards force of lift. This is what permits the plane to fly. The front wing in Formula One has the reverse effect on the car, as the wing is inverted thus creating a section of lower pressure beneath the wing, with the pressure imbalance producing downforce. Downforce is essential in Formula One as it promotes the grip to increase cornering speeds and reduce tyre wear even with increasing drag.

Manufacturing and materials used within wing designs.

Within Formula One there are constant research into ways in which teams can improve their cars designs, to help enable teams to gain advantage and faster track times. One aspect of research is on the material that the car is constructed of. Different materials are tried and tested in computer simulations where they are trialled under different forces and conditions.

One of the main material used within the Formula One car is carbon fibre. Carbon fibre is used throughout the Formula One by between 60%-80%, this is mainly due to the increased strength and durability of the material (Racers, 2022). Carbon fibres are able to endure high temperatures that F1 cars can achieve, with it being five times lighter than steel its perfect for racing cars. Furthermore, with these qualities of being durable and light it meets the requirements to help achieve the lowest speeds with the highest safety achievable. Carbon fibre is layered around 5 times within a mould in order to create the shape of a front wing, it is then exposed to various temperatures and pressure cycles in order to create the desired affect. It's during this treatment any resin that have been inserted into the carbon fibre flows into the surrounding fibres, which is what cures the carbon fibre (groote, 2022).

Another material to be considered is Kevlar, which is similar to carbon fibre. Kevlar is both strong and lightweight which makes it attractive to Formula One designers. Due to Kevlar being extremely firm it adds protection to both drivers and body work when the automobiles are racing at high speeds. Kevlar is five times stronger than steel, and the main reason why it is used in such area such as the fuel tank to stop it from exploding if there were a collision. Kevlar has been used as the final layer of a carbon fibre front wing, this is to help protect the car in an event of a crash and to stop the carbon fibres from breaking into small pieces (Groote, 2022).

Conclusion

This the calculations given within this report a 33mm steel tube would be required for a front wing of a race car. It would need to be this diameter in order for the front wing to hold a uniformly distributed load of 370kg with a 10mm maximum deflection .

As previously mentioned this was calculated assuming the load was distributed uniformly but as research has shown under race conditions and weather the load would more then like not be even. For more accurate results tests could be undertaken within a wind tunnel, or on race tracks, within Formula 1 lowest ranked teams have the most time to use on the wind tunnel comparing with the race winner who has least time available on the wind tunnel.

Calculations in the report were made using a steel structure with a Youngs Modulus of 210 GPa, with the technology in todays age the material that would be used is carbon fibre due to its light weight property and its toughness with a Youngs Modulus of 230GPa. If there was not a cost issue when manufacturing the front wing carbon fibre would be the preferred material.

Technology within the racing industry will continue to improve due to the popularity and large sums of money spent on the sport, but will always be governed by regulations in order to keep the sport fair and drives safe.

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