

DESIGNING THE STRUCTURAL SUPPORT FOR A FRONT AUTOMOTIVE WING

Stress Analysis and Dynamics (ACMA5010)

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Table of Contents

Question 1.....	2
a).....	2
b)	4
Question 2.....	5
Question 3.....	7
Question 4.....	9
Bibliography.....	10

Question 1

a)

Using the methodology of 'Slopes and Deflections of Beams' the minimum outside diameter for suitable loading can be established for an automotive front wing. One of the assumptions that has been made is that the load of the front wing is uniformly distributed (UDL). The reason for making this assumption is that the steel rod used in the front wing could be considered to operate in a similar fashion to a Cantilever Beam. As this is the case, then the equations for a Cantilever Beam with a UDL can be applied to this scenario. Below is the equation for that can be used to work out maximum deflection:

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

It is stated in the race regulations that the deflection at the end of the front wing must be limited to 10mm. Based on research from other race series we can also presume that the force applied to the front wing would be in the range of 1000N. The length of the front wing is also not specified therefore it has been assumed that the total length of the front wing is 2000mm, meaning that the length either side of the centreline of the vehicle is 1000mm. The end of the wing is to be manufactured from steel which gives 'E' a value of 210GPa. These values are summarised below:

$$\begin{aligned}y_{max} &= 0.01 \\ W &= 1000 \\ L &= 1\end{aligned}$$

The formula can then be transposed to work out the value of 'I'. This can be found below:

$$\begin{aligned}I &= \frac{1000 \times 1 \times 10^4}{0.01 \times 8 \times 210 \times 10^9} \\ I &= 5.952mm^4\end{aligned}$$

Now that the value of 'I', which is the second moment of area, has been determined the following equation can be transposed to figure out the minimum outside diameter of the front wing:

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

The above equation was put into Excel so that the values for the outside and inside diameter could be changed with ease. This is shown on the following page.

	A	B	C	D	E	F	G	H	I	J
1	Minimum Outside Diameter					ymax	0.01		I	5.9524E-08
2						W	1000			
3	D (mm)	D (m)	d (m)	I		L	1			
4	5	0.005	0.001	3.0615E-11		E	2E+11			
5	6	0.006	0.002	6.28E-11						
6	7	0.007	0.003	1.1383E-10						
7	8	0.008	0.004	1.884E-10						
8	9	0.009	0.005	2.9124E-10						
9	10	0.01	0.006	4.2704E-10						
10	11	0.011	0.007	6.0053E-10						
11	12	0.012	0.008	8.164E-10						
12	13	0.013	0.009	1.0794E-09						
13	14	0.014	0.01	1.3942E-09						
14	15	0.015	0.011	1.7655E-09						
15	16	0.016	0.012	2.198E-09						
16	17	0.017	0.013	2.6965E-09						
17	18	0.018	0.014	3.2656E-09						
18	19	0.019	0.015	3.9101E-09						
19	20	0.02	0.016	4.6346E-09						
20	21	0.021	0.017	5.444E-09						
21	22	0.022	0.018	6.3428E-09						
22	23	0.023	0.019	7.3358E-09						
23	24	0.024	0.02	8.4278E-09						
24	25	0.025	0.021	9.6233E-09						
25	26	0.026	0.022	1.0927E-08						
26	27	0.027	0.023	1.2344E-08						
27	28	0.028	0.024	1.3879E-08						
28	29	0.029	0.025	1.5536E-08						
29	30	0.03	0.026	1.732E-08						
30	31	0.031	0.027	1.9236E-08						
31	32	0.032	0.028	2.1289E-08						
32	33	0.033	0.029	2.3483E-08						
33	34	0.034	0.03	2.5823E-08						
34	35	0.035	0.031	2.8314E-08						
35	36	0.036	0.032	3.096E-08						
36	37	0.037	0.033	3.3767E-08						
37	38	0.038	0.034	3.6738E-08						
38	39	0.039	0.035	3.9879E-08						
39	40	0.04	0.036	4.3194E-08						
40	41	0.041	0.037	4.6688E-08						
41	42	0.042	0.038	5.0366E-08						
42	43	0.043	0.039	5.4232E-08						
43	44	0.044	0.04	5.8291E-08						
44	45	0.045	0.041	6.2548E-08						
45	46	0.046	0.042	6.7008E-08						
46	47	0.047	0.043	7.1674E-08						
47	48	0.048	0.044	7.653E-08						
48	49	0.049	0.045	8.1649E-08						
49	50	0.05	0.046	8.6965E-08						

Figure 1 - Minimum Outside Diameter Calculations

It can be determined from Figure 1 that minimum outside diameter of the front wing is 45mm. Even though the value of I is greater than the calculated second moment of area if the outside diameter were to be 44mm then it would not be sufficient. Ideally the second moment of area would be closer to the calculated value of $5.952mm^4$. The difference in second moment of area is $0.302mm^4$.

b)

To determine the outer diameter for suitable loading there were a few assumptions that were made. One of these assumptions being that the load applied to the front wing of the vehicle would be uniform. Reflecting upon this it is likely that the load applied to the front wing would not in fact be uniform. This is due to modern day front wings having multiple features such as endplates and flaps which can have a varying load at any given time. To calculate the minimum outside diameter of the front wing more accurately the varying load should have been taken into consideration.

Another assumption that was made was maximum load that the front wing would need to sustain. This was taken from the 2022 Formula 1 Technical Regulations. According to section 3.15.3 of the technical regulations "the flexibility of the Front Wing Bodywork will be tested by applying a load of [0, 0, -1000] N at points [Xf, Y, Z]" (FIA, 2021). Based on this information it was interpreted that the maximum load that would be applied to the front wing during scrutineering would be 1000N therefore, this load was used within the calculations above.

The length of the front wing was also an assumption that was made in the above calculations. After researching the length of front wings across multiple race series a length of 1m was selected. The reason for this being that for the 2022 Formula 1 Regulations the front wing "runs to the full width of the car – 1000mm each side of the centreline" (Anderson, 2022). Since the full length of the front wing is 2m the length of the front wing either side of the centreline of the vehicle would be 1m.

Based on the above assumptions there are many limitations to the suitable loading calculations. To overcome these issues alternative methods of calculation could have been taken into consideration which would address the fact that the load on the front wing would not have been uniform. The load applied to the front wing will change depending on the direction the vehicle is travelling. For example, the load would be different on a straight section of track compared to a corner.

To establish a more accurate value an alternative methodology such as CFD (Computational Fluid Dynamics) could have been instead. CFD is used to simulate varying aerodynamic conditions that the vehicle may experience in Formula 1 and other racing categories. CFD allows engineers to virtually calculate the aerodynamic performance of parts that are being designed for a vehicle before they are manufactured giving them a better insight to how the part will perform. It is important to remember that the results provided by CFD may not always be 100% accurate.

Another alternative methodology also used within Formula 1 is a Wind Tunnel. Like CFD a Wind Tunnel is used to determine the aerodynamic performance of parts however, this is done practically rather than virtually through CFD. Solid parts will be prototyped and tested in the Wind Tunnel so that the aerodynamic performance can be analysed. If the part performs as expected, then it can be put into production.

Question 2

There are multiple types of automotive front wings used throughout different race series. Depending on the race series the type of front wing can vary due to factors such as financial resources and personnel. Some of the race series where the cars have front wings include Formula 1, Formula 2, and IndyCar. There are similarities between the front wings used across both Formula 1 and IndyCar. One of these similarities being that both front wings are slightly raised to allow for the clean flow of air underneath the car which helps to reduce drag. The modern-day Formula 1 car has four front wing elements and a straight end plate to feed air around the front wheels. This is shown in Figure 2.

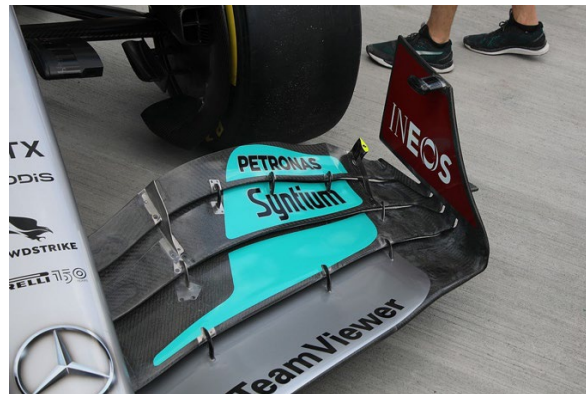


Figure 2 - 2022 Formula 1 Front Wing

The front wing in Formula 1 has developed drastically through the years. One of the main visible differences is that the front wing now sits much lower to the ground. The reason for this being that “the closer to the ground the smaller the cross section under the wing will be and remembering that in steady state condition the mass flow rate is constant” (Oggioni, 2019). This principle combined with the intricate floor design increases downforce which is especially important in vehicles that utilise ground effect.

40 years ago, the front wings on Formula 1 cars were considerably raised compared to front wings nowadays. An example of this can be found in Figure 3. They were also considerably narrower than they are for the current regulation set. Modern day front wings also have a greater number of flap features which improve aerodynamic performance of the car. Race categories with a lower budget to Formula 1, such as Formula 3, will have less complex front wings which will be more alike to front wings seen in Formula 1 in the past. There are however some common features between the front wings. For example, front wing endplates are still used within current front wing designs.



Figure 3 - 1980s Formula 1 Front Wing

Historically the development of the front wing has increased the complexity of the design and the materials used to manufacture the front wing have changed. In the past the front wing would have been manufactured from a material such as fibre glass which would be light but not very strong. The impact resistance of this material would be low meaning that the driver would be more at risk to injury or worse. In this type of front wing the structural support would more than likely be some sort of metal. Due to current regulations constructors now must manufacture the front wing to withstand certain levels of impact. This means that materials such as carbon fibre are due to the strength and weight properties.

Future development of automotive front wings will be designed with the aim of creating better racing. The 2022 Formula 1 technical regulations were “designed to improve the spectacle and allow for more wheel-to-wheel battles by reducing the amount of dirty air produced” (Smith, 2022). Due to the above the 2022 Formula 1 front wing has been designed so that cars can follow the car in front without being disadvantaged by aerodynamic interference from the car in front. The issue of ‘Dirty Air’ has been prominent in previous regulation sets but has been significantly improved with the introduction of the 2022 regulations.

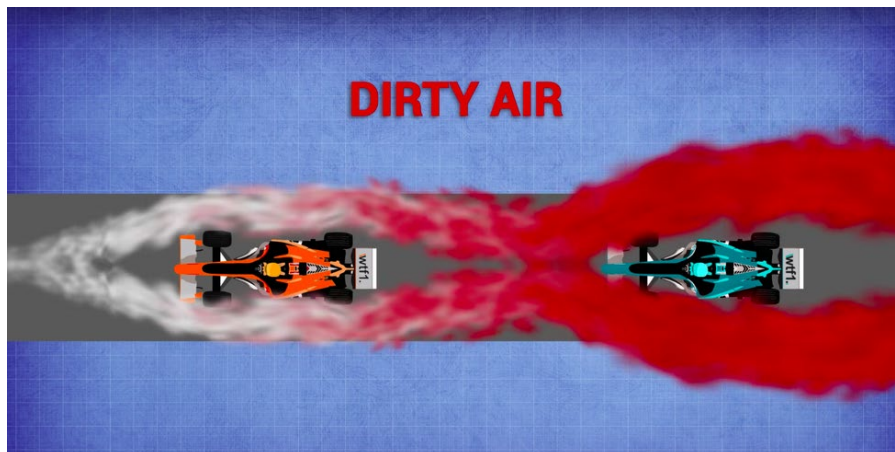


Figure 4 - Dirty Air Diagram

Another factor that may affect the development of the front wing in the future is the ‘Cost Cap’ that has been introduced in Formula 1. This has meant that constructors have been limited to the amount that they can spend throughout the season with the aim of creating closer racing between teams who have a large budget and teams who have a lower budget. The ‘Cost Cap’ means that teams have limited development compared to the development allowance in the past which will ultimately affect the development of the front wing. It also means that they may choose to design the front wing differently to reduce costs. Whether this be reducing the complexity or manufacturing from a lower cost material, the front wing development change due to the ‘Cost Cap’.

Question 3

The modern-day manufacturing process of the front wing is extremely complex because of the materials being used within the process. As discussed in the previous section the evolution of the front wing has increased the complexity resulting in more advanced manufacturing processes being required. Previously the manufacturing of the front wing would have consisted of CNC machining of the supports and features along with a moulding process for any of the fibreglass parts. An example of this process can be seen in Figure 5.



Figure 5 - Fibreglass Moulding

The current manufacturing of the front wing involves process such as laminating due to the use of carbon fibre in many parts. These parts are often then bonded together to form the front wing assembly. These types of parts are manufactured by the composites department within a race team. The front wing manufacturing process requires high precision making it quite a costly process. To manufacture carbon fibre parts, the “carbon is laid up in the mould it is put into a vacuum bag, placed into an autoclave (a large oven)” (Motorsport.com, 2022). The carbon is then “put under pressure. It is then cured at a controlled temperature and pressure for hours” (Motorsport.com, 2022). Figure 6 below shows an example of a carbon fibre mould.



Figure 6 - Carbon Fibre Mould

Before parts begin the manufacturing process, they go through various simulations that allow engineers to analyse the performance. After this stage the part will then be prototyped so that it can be tested in the wind tunnel. It is likely that the prototype will be a scaled down version of the actual part. Once the aerodynamic performance of the part has been analysed in the wind tunnel the part will then go on to be manufactured fully. Throughout the manufacturing process analysis of the part is conducted to check dimensions and tolerancing. Once the manufacturing of the part has been completed it will

then be the subject of various forms of testing including NDT (Non-Destructive Testing). If the part, then passes the vigorous testing to ensure it complies with regulations it can be signed off and fitted to the car. Many of the parts manufactured for the front wing will have specialist test rigs that have specifically been designed for testing that part. This is to ensure it complies with regulations. The results from the testing process will be stored so that if the part were to fail in the future, they could be referred back to so that the root cause of the failure can be investigated.

Even though many of the parts of the front wing are manufactured from composites, there are still a few that will be manufactured using more traditional methods such as CNC machining. This type of manufacturing process is typically used for the parts of the front wing that are made from metals. Like the manufacturing process of the composites, after the part has been manufactured it will undergo various types of analysis and testing for it to be signed off and fitted to the car.

Question 4

Before producing the prototype part to verify the front wing loading calculations I would propose conducting CFD simulations to verify the aerodynamic performance of the part. If the results of the simulations reflect the results from the calculations, then the part can progress through to the prototyping stage. There are multiple manufacturing techniques that could be used to manufacture the prototype part, one of these being 3D printing. Some of the advantages of 3D printing include the capability of rapid prototyping, cost effective manufacturing and minimal waste material. An example of the 3D printing process can be seen in Figure 7.

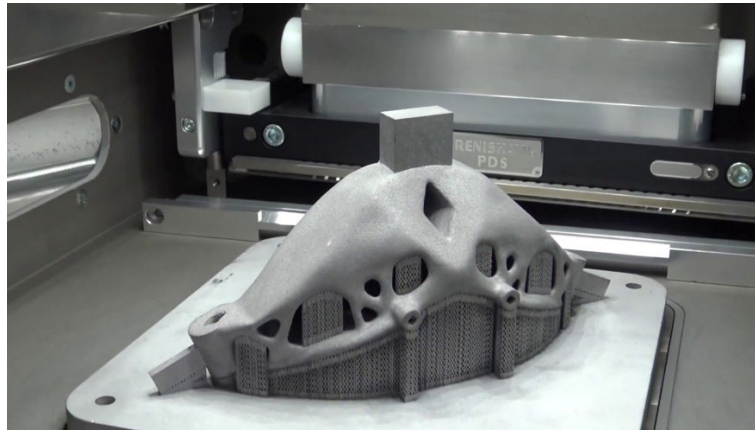


Figure 7 - 3D Printing Example

The prototype part that is manufactured does not need to be a full-scale model of the final part. Once the prototype part has been produced through the chosen manufacturing technique it needs to be practically tested. For a front wing this would include some sort of aerodynamic testing therefore, the parts aerodynamic performance would be tested in the wind tunnel. If the parts performance in the wind tunnel under load reflects the calculation results, then it can move on to the next stage of the testing process. This would include NDT to ensure it complies with the race regulations.

Once the testing on the part has been completed and the results have been obtained, they would need to be analysed in depth to decide of whether the part will move onto the manufacturing stage. The experimental results obtained from the testing are arguably more accurate than the calculations as they have been gathered from real world testing rather than theory-based calculations. Ideally the experimental results that have been gathered will identically reflect the calculations performed at the beginning.

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