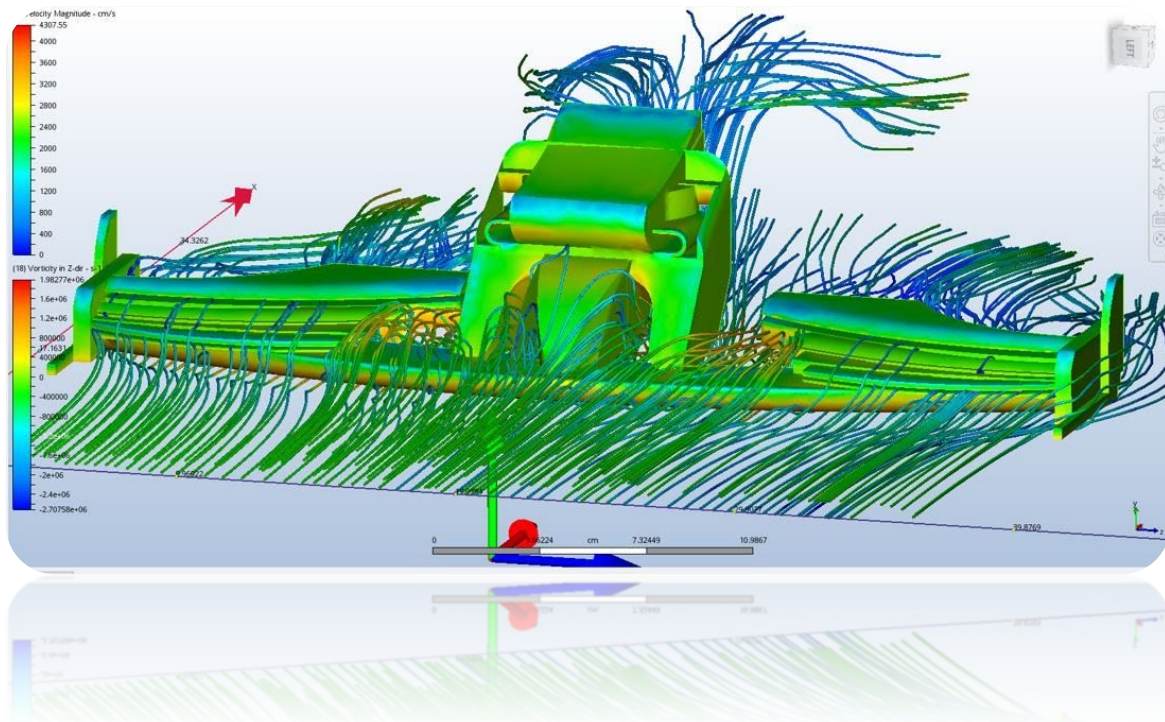


Stress Analysis & Dynamics

ACMA5010

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



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Mechanical and Manufacturing Engineering

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Task 1 Design the structural support for a front wing on a car for a new race series.

Task 1a- Minimum Outside Diameter

Calculate the minimum outside diameter which must be used (all working must be shown), for suitable loading which you must establish.

Values Stated in the question:

$$E = 210\text{Gpa} = 210 \times 10^9 \text{pa}$$

$$\text{Wall thickness: } 2\text{mm} = 0.002\text{m}$$

$$Y_{\text{max}}: 10\text{mm} = 0.01\text{m}$$

Values assumed for question:

$$L: 1.6\text{m} = 0.8\text{m per side}$$

$$W: 5000\text{N}$$

Knowing this information and equation for the maximum deflection:

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

This equation however will need to be rearranged to make I the subject. This can be seen below:

$$I = \frac{-WL^4}{8EY_{\text{max}}}$$

$$I = \frac{5000 \times 0.8^4}{8 \times 210 \times 10^9 \times 0.01}$$

$$I = 1.22 \times 10^{-7}$$

Next calculation is to work what diameter of tube that is needed to achieve the value for the second moment of area. To find the minimum diameter needed for the front wing will take a lot of trial and error so to speed up the process I will be using Excel using the equation below and the values given to me in the question along with my own assumptions.

The value I'm looking for is $I=1.22 \times 10^{-7}$ so will increase the diameter of the tube by 1mm until I reach the value for I again using the equation below.

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

$i = \frac{\pi}{64} x (D^4 - d^4)$		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	1.1383E-10
y _{max}	0.01m	8	0.008	0.004	1.884E-10
W	5000N	9	0.009	0.005	2.9124E-10
L	0.8m	10	0.01	0.006	4.2704E-10
E	2.10E+11	11	0.011	0.007	6.0053E-10
i	1.22E-07	12	0.012	0.008	8.164E-10
		13	0.013	0.009	1.0794E-09
		14	0.014	0.01	1.3942E-09
		15	0.015	0.011	1.7655E-09
		16	0.016	0.012	2.198E-09
		17	0.017	0.013	2.6965E-09
		18	0.018	0.014	3.2656E-09
		19	0.019	0.015	3.9101E-09
		20	0.02	0.016	4.6346E-09
		21	0.021	0.017	5.444E-09
		22	0.022	0.018	6.3428E-09
		23	0.023	0.019	7.3358E-09
		24	0.024	0.02	8.4278E-09
		25	0.025	0.021	9.6233E-09
		26	0.026	0.022	1.0927E-08
		27	0.027	0.023	1.2344E-08

40	0.04	0.036	4.3194E-08
41	0.041	0.037	4.6688E-08
42	0.042	0.038	5.0366E-08
43	0.043	0.039	5.4232E-08
44	0.044	0.04	5.8291E-08
45	0.045	0.041	6.2548E-08
46	0.046	0.042	6.7008E-08
47	0.047	0.043	7.1674E-08
48	0.048	0.044	7.6553E-08
49	0.049	0.045	8.1649E-08
50	0.05	0.046	8.6965E-08
51	0.051	0.047	9.2508E-08
52	0.052	0.048	9.8282E-08
53	0.053	0.049	1.0429E-07
54	0.054	0.05	1.1054E-07
55	0.055	0.051	1.1703E-07
56	0.056	0.052	1.2378E-07
57	0.057	0.053	1.3078E-07
58	0.058	0.054	1.3803E-07
59	0.059	0.055	1.4556E-07
60	0.06	0.056	1.5335E-07
61	0.061	0.057	1.6141E-07
62	0.062	0.058	1.6975E-07
63	0.063	0.059	1.7837E-07
64	0.064	0.06	1.8728E-07

Copying the formula eventually landed me on the value 1.23×10^{-7} resulting in a value of 56mm diameter for the tube. The actual minimum diameter needed will be between 55 and 56mm as the I value is slightly greater than 1.22×10^{-7} . The diameter of 56 is more than suitable and could realistically be used for this application but really highlights the strength of carbon fibre being able to withstand a force far greater than 5000N and still only flex by 0.01m.

Task 1b- Assumptions

Discuss any assumptions that you have made, the limitations of your calculations and how these may be overcome. Discuss alternative principles and methodologies that could have been used.

In order to calculate the minimum outside diameter for the steel tubing inside the front wing, I had to make a few assumptions as not all the information was available to me to use. Firstly, the length of the wing was not stated in the question, so the values used were found online and interpreted from there. It stated that the current F1 front wing has a span of 1.65m so this was halved as I only needed to work out one side of the wing due to how it will be fixed to the nose of the car as a cantilever beam effectively. And for simplification I used the value of 0.8 instead of 0.825m.

Secondly the amount of force that acts upon the wing was also not included in the question, therefore more research was necessary to carry out the calculus. The data I had available online stated that the current F1 wing weighs 10kg and can withstand 100x times its own weight (McLaren Racing 2022) which results in a force of 9800N. This value was halved due to the older design shown during the question and simplicity of its aerofoil. Likewise for this value I used 5000 instead of 4900 to simplify the figures involved with the equation. As this force is a UDL this means the force of 5000N was distributed across both sides of the wing hence why I did not half it like the length.

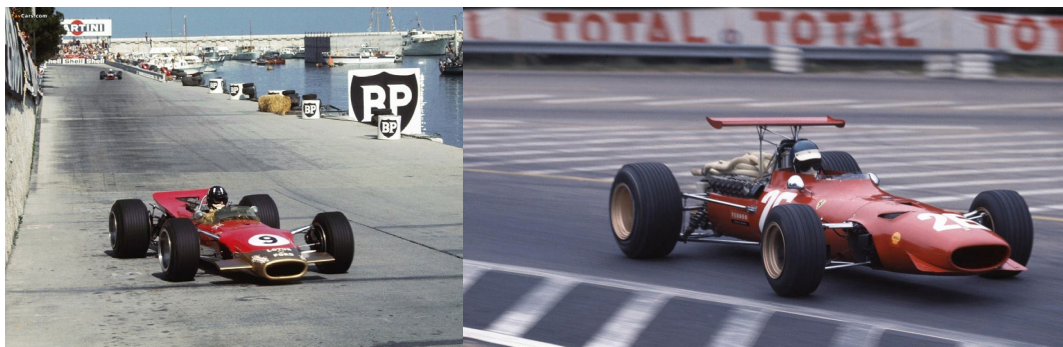
Lastly the force of 5000N will vary depending on conditions such as speed of the car, weather and environment and the state of motion of the car for example going in a straight line or flat out through a corner. These factors have the potential to increase and/or decrease the force implied onto the wing and therefore steel tubes. In addition, the final value achieved was based heavily from assumptions derived from researching figures online. It is impossible to say whether the minimum diameter for the tubing is actually 55-56mm for this reason, it will be wise to choose a slightly larger diameter to have a reduce the likelihood of a structural failure with the tubing.

Task 2- Front Wing Designs

Discuss different types of automotive front wings, how they have developed historically and how you think they may develop in the future.

History

Front wings have been involved with automotive design since the late sixties and remain a significant area of design and innovation to this day. Front wings can be seen across multiple racing divisions/ disciplines such as Indy Car, Formula 1, F2 & F3. They first appeared on a car in Formula 1 during the 1968 season during that years Monaco Grand Prix, this street track benefits a car with good handling and grip for all the tight low to mid speed corners. Knowing this the team boss of Lotus took an aerofoil concept used to generate lift for planes and turn it upside down, affectively creating a force that pushes the car into the ground and thus giving the car more grip for the corners. As a result, the car won after qualifying on pole by 0.6 seconds ahead of the next fastest car. (F1 History 2014)



Development

After wings were introduced by Lotus in 1968; all other teams started to develop their own designs after seeing the potential benefits gained in cornering speeds and grip. Innovations and improvements over Colin Chapman's design came soon after with Ferrari the next race after Monaco using a rear wing on one of its cars during the 14km Belgium Grand Prix at Spa. Unlike Lotus' design using sheet steel, Ferrari designer Mauro Forghieri used an inverted wing supported just behind the driver and used endplates on either side of the wing. This had the bonus of preventing the air flow to spill off the side and maximising the performance of the aerofoil. The Ferrari driver Chris Amon captured pole position with a time of 3.28.6 while Jacky Ickx in the wingless Ferrari could do no better than a time of 3.34.3, which was five seconds slower. (Rene Fagnan 2018)

With every passing year, front wing design became a crucial technical aspect of the car with innovations and often experimental designs over the next 4 decades bringing success or often missed expectations. Noteworthy examples being the 1970 Lotus 72, this car's front wing was one large assembly as the radiators had been moved to the flanks improving its performance and distributing the car's weight reducing under-steer.



Present Wing Design

Of recent time over the past ten years the F1 cars have only used two types of front wing design, a high nose and low nose design. A higher nose allowed for more airflow to be directed underneath the car, benefitting the under-body aerodynamics yielding greater improvements for the amount of down force produced. The F1 governing body 'FIA' stepped in to affectively ban high nose from wings over safety for the 2014 season, meaning every team had to design a low nose wing. These haven't evolved much in terms of design/ innovations since their initial conception, only minor changes to dimensions and a reduction to their complexity to satisfy new regulations.



Future

Future front wing designs I believe to become less complex and important as automotive company's and motorsport teams will develop more into the under-body aerodynamics. This has a number of benefits highlighted in F1 as this year's regulations focus on reducing in turbulent air flow by reducing the complexity and overall down force produced by the front wing. The cars under-body now generates the majority of the needed for the cars to perform which produces very little turbulent air so I can see in the years to come that this affect will be exaggerated and less emphasis on the front wing will be priorities. This goes for all open wheel race cars such as F1 and Indycar.



Task 3- Manufacturing process of Automotive Wings

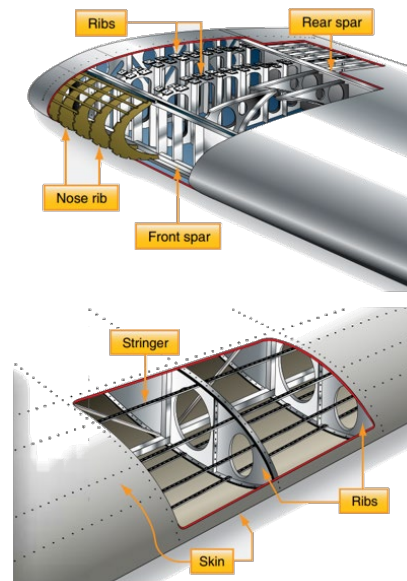
Discuss the manufacturing processes and materials used in the development of automotive wings and relate this to task 2.

Early Wing Manufacturing

1968-1980

When Front wings were first introduced, they were manufactured the same as an aerofoil for a wing of a plane. This construction was made from spars to run through the length of the wing then ribs would give the surface its form and shape. These components would be made from either a lightweight steel or aluminium as the wings were by today's standard very small. This helped to reduce the weight over the front wheels and to retain rigidity in order to prevent the wings from bending during high speeds. A skin would be riveted by hand to the ribs that would make up the surface of the aerofoil that would generate low air pressure on the underside surface and thus push the car into ground.

This process was improved to reduce the weight of the construction while increasing the size and performance of the wing throughout the 1970's. Advancements were made to the construction and the manufacture of the wings with additions such as adjustability for example. This was designed to allow the teams to set up how much down force the driver wanted on any track. This design was manufactured using the same techniques for the ribs and skin to make up the wing, then used a steel tube that would allow the wing to be rotated on a mounting attached to the nose of the car and secured in place using fasteners. This is still a design feature today and you can often see a team making minor adjustments mid race.



1980-Present

During the 1981 season McLaren's designer John Barnard introduced a new material to F1 called carbon fibre with the McLaren MP4/1. This very lightweight material was initially doubted by other teams over its strength but was proved during a crash the same season. What was also proved was the material was very light and very rigid, improving the car and wings performance immensely and still used to this day. The manufacturing process of these carbon fibre wings haven't changed, although the designs are now created using CAD software and simulated rather than using clay models and multiple prototypes to test their design. The carbon fibre itself is made up of layers of woven mesh which is moulded into shape and through a combination of controlled pressures and heat treatment of up 1800 degree Celsius to cure, results in an ultrahigh young's modulus (stiffness) for the fibres. A major advantage of using this high strength and light weight material is that it could be manipulated to reduce or increase the stiffness by weaving a different pattern into the design of the component. By designing a suitable front wing pattern would allow the wing to distort during

high speed, this would reduce the angle of attack of the aerofoil affectively reducing the amount of down force produced and therefore drag, allowing the car to gain a higher top speed. Red Bull Racing F1 team used this to their advantage in 2011 and 2021 seasons both of which they won the world championship, quite possibly due to how they were able to manufacture their wing using carbon fibre.

Task 4- Interpreting Results

In order to verify your calculations, it is proposed that a prototype is to be produced and tested. Explain how you think this should be done and how you would interpret the experimental results

To back up the calculations in task 1 there are a few practical tests that can be carried out in order to see if the wing exceeds more than 10mm of deflection. These will be important as they should reflect what will happen in reality when the front wing is subjected to forces with air passing over the aerofoil. As the calculus was based largely from assumptions various diameters should be tested to obtain a good strength to weight ratio.

CAD Simulations

Firstly, use CAD software to simulate the forces acting upon the front wing. This will be a great tool to use for a number of reasons including that the tests can be carried out before any physical model is made negating the time and cost of producing multiple models and prototypes. Different sizes and materials can easily and quickly be substituted and re-tested, also different loads and forces can be subjected to the design and the amount of deflection can be measured. Finally, the force that will be implied on the wing in the simulation will be a UDL (universally distributed load) which will be accurate to the real world conditions the wing will face, all of which making it very clear on how to design the wing to be legal for the race series.

Wind Tunnel

Secondly, use a wind tunnel to generate the forces on the wing by passing air over the aerofoil. This method of testing does require a physical model however is regarded as the most accurate to real world conditions for a test as the air passing over the wing will be the same as the car driving out on track. Although it wouldn't be 100% accurate as the wind tunnel is a controlled environment and doesn't account for all conditions/factors such as cross winds or the car hitting bumps in the road or going round corners. In the wind tunnel the wing would be fixed in a position to reflect the cantilever beam and the air would be accelerated over the aerofoil surface producing the down force. This would cause the wing to deflect downwards which will be measured and recorded. The force produced will also be a UDL again proving the accuracy of the test also a smoke stream can be used to test the performance of the wing in terms of down force and drag.

Static Weights

Finally, to use weights of varying loads to be placed or hung from the outer edge of the wing when fixed as a cantilever beam. This will cause the wing to deflect downwards of which can be measured for varying loads and should not exceed the limit of 10mm. This test uses single point loads so it will not be a true reflection of the real-world effect but is cheap and easy to perform therefore can be valuable test in order to gain a good base line for the strength of the tube inside the wing.

References

McLaren Racing 2022 Front wing Data <https://www.mclaren.com/racing/f1-playbook/front-wing/>

Task 1a & 1b

https://uowtsd.sharepoint.com/:v/t/PTStressAnalysisDynamics2223_GRP/EYFNIBlo0vJEiE7AZT_K2YIBvm6l_RTDyrb51JSY6CsRrQ

F1 History (2014) 0.6 seconds ahead of the next fastest car. [#F1 History: Aerodynamics in Formula One - Part I | thejudge13thejudge13](#)

Rene Fagnan (2018) Captured pole position with a time of 3.28.6 while Jacky Ickx in the wingless Ferrari could do no better than a time of 3.34.3, which was five seconds slower [The first appearance of wings on Formula 1 cars \(motorsport.com\)](#)

Task 3 (1980-present) <https://www.youtube.com/watch?v=0VclWzIhtFg>