
DESIGNING THE STRUCTURAL SUPPORT FOR A FRONT AUTOMOTIVE WING FOR A NEW RACE SERIES

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Introduction

This report sets out to aid the development of a new front wing design for a race car in a new race series. The report will use the principles and methodologies of slope and deflections of beams theory to calculate the outside diameter of the front wings structural tubing so that the deflection rate does not exceed that set out by the race regulations.

Research is also included into existing automotive front wing designs, how they have developed and how they may develop in the future. Alongside this is research into manufacturing processes and materials that are currently or have been used in automotive front wings.

The report also include suggests how to evaluate a prototype model, gather useful data from the testing and then interpret the data to make improvements or amendments to the designs or calculations.

1a. Wing Support Structure Calculations

In this section calculations will be made to assume the correct size support tube within a racing cars front wing.

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

$$Y_{MAX} = -0.01m$$

$$W = 5.57KN$$

$$L = 1m$$

$$E = 210GPa$$

Figure 1- Maximum beam deflection equation and values.

The above equation determines the maximum deflection of a cantilever beam with a uniformly distributed load (U.D.L) applied (Nicholas Swanson, 2022). Maximum permissible deflection (Y_{MAX}) and the modulus of elasticity for steel (E) have been provided. The load (W) and wing length have been determined through research.

Second Moment of Area (I)

$$1) I = \frac{-WL^4}{8EY_{MAX}}$$

$$2) I = \frac{-5.57 \times 10^3 L^4}{8EY_{MAX}}$$

$$3) I = \frac{-(5.57 \times 10^3) \times (1)^4}{8 \times (210 \times 10^9) \times (-0.01)}$$

$$4) I = 3.315 \times 10^{-7} m^4$$

Figure 2- Second moment of area calculations.

Rearranging the formula to make the second moment of area (I) the subject and substituting in the values in SI form a value can be obtained. With this value for I the outer diameter of the tube could be calculated using the formula below (Engineering Toolbox, 2019), however both inner and outer diameters are unknown. To find the outer diameter of the trial-and-error calculations using the below equation had to be conducted until a matching or slightly larger value was found.

$$\text{Second Moment of Area of a Tube} = I = \frac{\pi(d_o - d_i)}{64}$$

D_o = Outer Diameter
 D_i = Inner Diameter

Figure 3- The second moment of area for a tube.

D(mm)	D(m)	d(m)2	I
76	0.076	0.072	3.1849E-07
77	0.077	0.073	3.3158E-07
78	0.078	0.074	3.4501E-07
79	0.079	0.075	3.5880E-07

Figure 4- Trial-and-error table used to determine the steel tubes diameter.

Figure 4 shows that with an outer diameter of 0.077m and an inner diameter of 0.073m the second moment of area slightly exceeds what has been calculated. Therefore, the recommendation would be to use a steel support tube with an outer diameter of 77mm or greater. The smallest possible,

regularly available size is 80mm mild steel tube, this is the best compromise between weight, strength, and cost. (Compbrake Motorsport, 2022)

1b. Calculations Assumptions and Limitations

To calculate the diameter of the steel support tube for the automotive wing assumptions, and researched values had to be determined. This causes limitations on the calculations and their effectiveness.

Wing length and load were both unknown. The figures used are based on 2021 formula 1 car regulations, stating front wings must be no wider than two metres (FIA, 2020). Rijeka (2020) claims formula 1 cars of that age can produce up to five G's of downforce, twenty-five percent from the front wing. Rimmer (2022) states the maximum mass of a fully loaded formula 1 car can be up to 908KGs, resulting in 4540KGs of downforce, 1135KG from the front wing. McLaren claim a similar figure of 1000KGs (2021). Each side of the wing produces 567.5KGs, multiplied by the force of gravity (9.8066...) gives 5.57KN of force either side of the wing.

Assumption two is that the force on the wing is a U.D.L, whereas the different shapes and profiles along its length along with end plates produce varying loads across the wing's length. Calculating this would be too complicated requiring computer simulated models or prototype testing. The forces are also assumed to be acting only in the Z axis (down) where drag will be forcing the wing backwards so the force on the support will be a sum of different forces acting in different directions, again this would be too complicated to calculate without simulation. This means the calculations made are limited with the forces used and placement of the forces.

Another assumption is that the fixing of the wing is perfectly rigid holding the wing solid in all six degrees of freedom. The calculation made is for a cantilever beam assuming one end to be fixed. The body of the car reality will flex as the wing is loaded, distributing the load into the body of the car, effectively creating a larger beam.

An alternative method of calculating the deflection and stress applied to the wing would be the use of finite element analysis. This breaks the wing into multiple sections and the stresses in each section can be calculated combined back together, not only providing a result for the whole wing but also demonstrating how the stress can vary across the wing. With the use of FEA computer simulations, the accuracy and understanding of the stresses in the system can be increased (Fish & Belytschko, 2007).

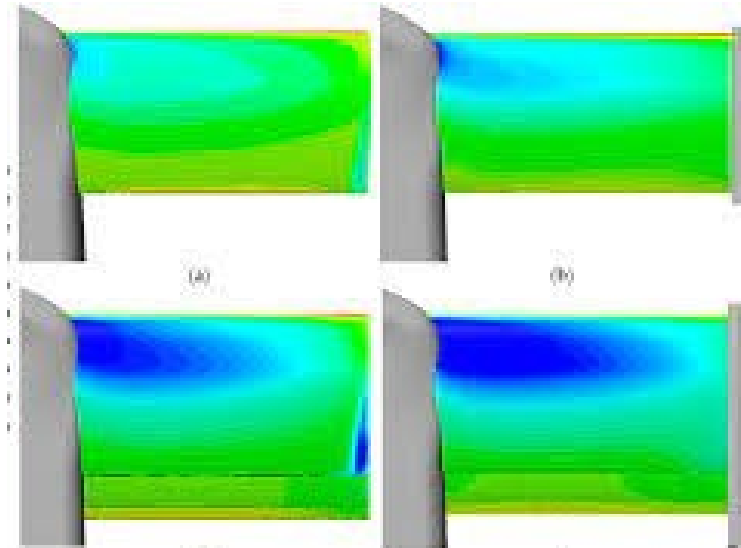


Figure 5- Computational FEA of a front wing. (Castro & Rana, 2020)

2. Type of Automotive Front Wings, Their History and Their Future

Automotive wings have been produced for many different race cars and series since the start of race car aerodynamic development in the late 60s (Minocha, 2018). Front wings serve many purposes on cars, they produce downforce by redirecting airflow over or under the wing creating high and low-pressure zones. Front wings also direct air around the car, reducing drag and channelling it where needed such as to the engine, brake cooling ducts, rear wings or body features that produce downforce (Castro & Rana, 2020).

Aerodynamic front wings were first used on Lotus' 1968 formula 1 car, the Lotus 49. Figure 6 shows the simple designs of early front wings to be solid, singular items, fixed to the cars body.



Figure 6- Lotus 49- (Anderson, 2020)

Design evolution saw front wings become longer narrower and moved further forwards on the car. During the seventies and eighties front wing designs primarily on formula one cars had incorporated the use of endplates on wings. The plates on the end of the wings function to direct air around the front wheels reducing air turbulence and drag (Groote, 2007). Development of new, stronger, and lighter materials such as carbon fibre composites, along with their manufacturing processes from the eighties onwards allowed wings in formula 1, other race series and road cars could become much more complex due to the increase in material stiffness, weight, and strength.



Figure 7- 1990's F1 front wing- (Motor Sport Magazine, 2021)

Figure 7 shows the development in front wing mounting, with stronger and stiffer materials wings could be mounted out in front of the car, providing a larger surface area to control more air. Figure 7 shows front wings having more than one plane, by having different surface shapes and angles, air flow can be carefully controlled around the rest of the car allowing downforce and drag to be controlled more precisely.

More recently front wing designs have exploited 'aero elasticity' where downforce causes it to flex and change shape or position. At speed front wings are pushed closer to the ground, increasing downforce produced from ground effect as the closer the wing is to the ground the lower the pressure will be under the wing and floor of the car (Scarbs F1, 2010). Many race series and governing bodies like the FIA now state maximum deflection rates under certain magnitude loads. Front wings on high end road cars are like the Ferrari 458 use this to change the way air flows into cooling ducts at different speeds.



Figure 8- Ferrari 458 front wings- (Super Tweaks, 2021)

The Future of Automotive Front Wings

Automotive front wing evolution is constant with the development of new materials and more accurate computer simulations to predict a wings behaviour at differing air speeds, but also how it can control air flow for the rest of the car.

Front wings of the past have used aero elasticity to alter the shape and positioning of the front wing to reduce drag at high speeds, therefore increasing the cars top speed. Matt Somerfield (2020) talks on how other designs have created the same drag reduction effect by channelling air from the nose

of the car, through the structure of the wing and then releasing the air across the surface of the wing, stalling the downforce, and decreasing drag.

Passive drag reduction systems (DRS) like these have been outlawed in most race series due to unpredictable downforce levels and wing 'flutter,' also the use of flexible structures that are weaker and more likely to fail. The future of front wings for race cars and road cars could be to use an active DRS controlled by a computer or the driver. An actuator could be used to move flaps on the wing or the position of the wing, reducing drag at high speeds. This would have the benefits of higher top speeds and an increase in fuel efficiency as aerodynamic drag will be reduced.

Also, with the further development of materials and manufacturing processes to be stronger but still allow flex passive front wings utilising aero elasticity may be more commonplace on race cars as well as on road cars improving efficiency, this is backed up by Richard Hill (2022) who talks about Lotus cars having morphing body panels improving their aerodynamic characteristics.

3. Manufacturing Processes and Materials Used for Automotive Front Wings

Manufacturing process as well as the materials used in the production of automotive front wings vary for multiple reasons. This can be down to cost, style, weight requirement or other property characteristic required.

Simple, early wing designs like that of the Lotus 49 were manufactured from sheet aluminium and tubular steel supports. Later designs began to use composites and manufacturing techniques to create fibre glass wings. Moldless fibre glass involves cutting a polymer foam supporting core to the desired shape of the wing and then placing sheets of fibre glass on top, each sheet is coated with epoxy resin to make it solid and adhere to the foam or other sheets of fibre glass. This technique also allows for metal components like lifting and wing mounting points to be moulded into the structure of the wing as the sheets are layered. Nowadays fibre glass production like this is cheap and easy to do, hence why low budget race teams in formula 1000, formula student as well as car manufacturers like Ariel, Nobel, and Lotus used it as a material on their cars. (Formula 1000 Race Car Front Wing Moldless Fiberglass Foam Construction Fabrication Build, 2016)

During the 1980's materials in motorsport progressed with the introduction of carbon fibre composites by McLaren (Thomas, 2013). Carbon fibre allowed wing designs to evolve, becoming more complex in shape, having multiple surfaces and extra air flow controlling wings and as shown in figure 9. These intricate shapes could only be produced strong enough to withstand the aerodynamic forces thanks to carbon fibre and computer simulation. Its introduction also allowed for strong, stiff, and flexible wings to be produced, by altering the way in which certain areas of the wing have the carbon fibre weave oriented along with its thickness and support structures, the wing could be made to move under certain loads but elastic enough to return to its original shape with a reduced load. This is how the effects of aero elasticity as mentioned in part two are used.



Figure 9- 2018 McLaren front wing- (Karl, 2022)

According to Castro and Rana (2020) modern formula 1 front wing designs are produced using multiple materials, creating a composite 'sandwich' capable of supporting forces of up to 1000N. The top and bottom skins of the wing are made of a carbon fibre and Kevlar reinforced polymer, when aligned correctly the results are light weight and stiff. Sheets of carbon fibre and Kevlar are layered around internal support structures, placed into a vacuum bag or mould where polymer resin is applied to the carbon fibre. Air is then removed from the vacuum bag drawing air pockets in the wing preventing cavities and therefore structural weaknesses. Alternative resins cure using different methods, some are baked in an autoclave or require ultraviolet light to cure. Wing internal structures use polymer foam ribs to reinforce and further stiffen the structure. The spacing of the ribs is calculated to support the high load areas on the leading edge as well as preventing flexural rotation from forces applied to the trailing edge. Design (b) in figure 10 shows holes in the ribs to reduce the weight of the structure. These ribs are constructed of high-density reinforced polymers such as carbon fibre reinforced plastic with a weave pattern that best withstands the predicted forces. Like fibre glass wings, carbon fibre wings can be built to have metals components in them as supports for other winglets or as jacking points (Williams Production of a new front wing, 2011). Different wings sections are fixed to an aluminium machined kick insert. This manufacturing technique is also adopted by race series such as formula 2, 3 and student. However, as budgets decrease in lower race series along with car performance the requirements and ability to calculate, simulate and produce such complex designs is reduced (How to Make Carbon Fibre Foam Sandwich Panels, 2021).

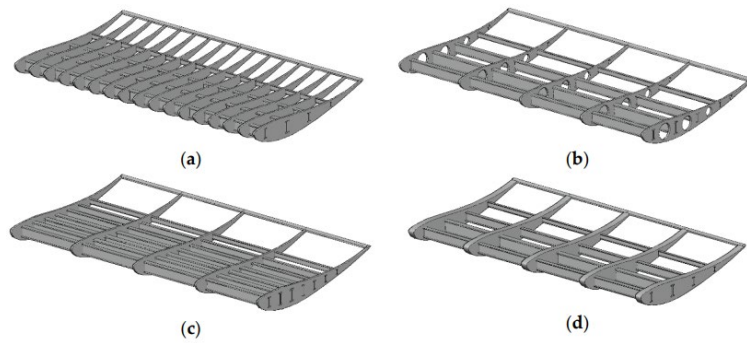


Figure 10- 2022 Formula 1 wing structure designs- (Castro & Rana, 2020)

4. Calculations Verification by Prototype Testing.

To verify the results of the calculation made for the race car front wing in part 1 it is proposed to conduct some form of prototype testing. To evaluate if the support structure is strong enough to only deflect 10mm under the proposed load of 5.57kN. The prototype would only require the steel tube support over 1 metre long, this would be fixed as firmly as possible to a solid body where 1 metre of the steel tube diameter and gauge matching that of the one calculated in part 1 is protruding.

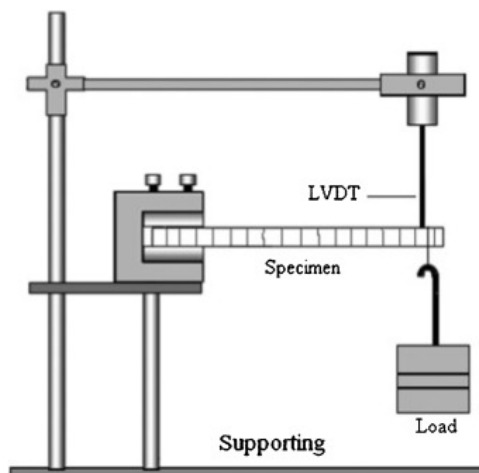


Figure 11- Cantilever beam testing - (Segovia, 2013)

Figure 11 shows a basic set up, however the load would be uniformly distributed across the length of the test specimen or similarly pushed down using hydraulic cylinders. With a loaded steel tube, the deflection can be measured at the unsupported end in comparison to its unloaded state.

The deflection data will then need to be interpreted to see if the deflection amount compares to the calculation. If deflection is greater, the outer diameter of the steel tube needs to increase, if it is less than 10mm the size of the steel tube outer diameter should be reduced to save weight and lower the profile of the wing.

A more accurate and definitive test would be to create 1:1 scale version of the wing and subject it to wind tunnel testing at expected wind speeds. Again, the steel support tube would need to be fixed solid and be the diameter calculated in part 1. This test would show the wings true deflection as the load placed on it may not be the same as assumed, it is likely that the load would not be uniformly distributed as well as there being loads in other vectors due to drag that may add alter the results.

The results from this setting could then be treated in the same manner as cantilever beam testing. An issue with this method is that it is expensive build the wing and rebuild it as well as to use a wind tunnel. To reduce the cost the prototype could be a scaled down (Everything You Need to Know About Wind Tunnels | F1 Explained, 2021)

Conclusion

In conclusion the structural of a car's front wing in a new race series when constructed using 2mm gauge steel tube requires an outer diameter greater than 77mm to keep wing deflection under load within 10mm. This was calculated using slope and deflection of beams theory assuming a uniformly distributed load acting on a cantilever beam. Other methodologies such as finite element analysis and computational fluid dynamics have also been discussed in the report, explaining their potential to improve accuracy and map out stress, calculating for wing designs and cutting costs with regards to prototype testing.

Designs, construction methods and materials used through out history on road and race cars have changed to allow automotive front wing to become lighter, stiffer, flexible if needed as well as much more intricate to achieve better results. This is thanks to materials such as reinforced polymers replacing metals and computer analysis techniques helping design engineers balance design requirements with less expensive prototype models.

Bibliography

Anderson, B., 2020. *Formula 1: Autosport Plus*. [Online]

Available at: [https://cdn-](https://cdn-1.motorsport.com/static/img/amp/5100000/5110000/5113000/5113800/5113882/s6_1000854/1000854.jpg)

[1.motorsport.com/static/img/amp/5100000/5110000/5113000/5113800/5113882/s6_1000854/1000854.jpg](https://cdn-1.motorsport.com/static/img/amp/5100000/5110000/5113000/5113800/5113882/s6_1000854/1000854.jpg)

[Accessed 16 07 2022].

Castro, X. & Rana, Z. A., 2020. Aerodynamic and Structural Design of a 2022 Formula. 09 12, pp. 1-2.

Compbrake Motorsport, 2022. *Ebay*. [Online]

Available at: <https://www.ebay.co.uk/itm/281856173027>

[Accessed 19 08 2022].

Engineering Toolbox, 2019. *Engineering Toolbox*. [Online]

Available at: https://www.engineeringtoolbox.com/area-moment-inertia-d_1328.html

[Accessed 12 07 2022].

Everything You Need to Know About Wind Tunnels | F1 Explained. 2021. [Film] UK: Mercedes AMG Petronas.

FIA, 2020. *FIA:2021 formula 1 technical regulations*. [Online]

Available at: https://www.fia.com/sites/default/files/2021_formula_1_technical_regulations_-_iss_7_-_2020-12-16.pdf

[Accessed 09 07 2022].

Fish, J. & Belytschko, T., 2007. *A First Course in Finite Elements by Jacob Fish and Ted Belytschko*. s.l.:Wiley.

Formula 1000 Race Car Front Wing Moldless Fiberglass Foam Construction Fabrication Build. 2016.

[Film] s.l.: Ludemann Engineering.

Groote, S. D., 2007. *Technology: F1 Technical*. [Online]
Available at: <https://www.f1technical.net/development/20509/bmw-develop-front-wing-endplates>
[Accessed 16 07 2022].

Hill, R., 2022. *Lotus Cars: Blog*. [Online]
Available at: <https://media.lotuscars.com/en/blog/%E2%80%98morphing%E2%80%99-body-panels-and-the-future-of-aerodynamics,-by-richard-hill.html>
[Accessed 16 07 2022].

How to Make Carbon Fibre Foam Sandwich Panels. 2021. [Film] Finland: Formula Student Oulu.

Karl, 2022. *Reddit*. [Online]
Available at:
<https://preview.redd.it/jjtsw6y2o9i81.jpg?width=640&crop=smart&auto=webp&s=6f8c1b4883b5dd0b33e7c1dfcd8e46ebb111a5da>
[Accessed 17 07 2022].

McLaren F1, 2021. *McLaren:F1 Racing*. [Online]
Available at: <https://www.mclaren.com/racing/f1-playbook/front-wing/>
[Accessed 18 07 2022].

Minocha, A., 2018. *Car Throttle*. [Online]
Available at: <https://www.carthrottle.com/post/3l5vbg2/>
[Accessed 09 07 2022].

Motor Sport Magazine, 2021. *Motor Sport Magazine*. [Online]
Available at: <https://cdn.motorsportmagazine.com/wp-content/uploads/2021/05/14124033/93benettonmsc.jpg>
[Accessed 16 07 2022].

Nicholas Swanson, .: K. A., 2022. *Omni Calculator*. [Online]
Available at: <https://www.omnicalculator.com/construction/beam-deflection#:~:text=To%20calculate%20the%20maximum%20deflection,about%20by%20each%20load%20configuration.>
[Accessed 19 08 2022].

Rijeka, 2020. *Formula 1 dictionary*. [Online]
Available at: <https://www.formula1-dictionary.net/downforce.html>
[Accessed 09 07 2022].

Rimmer, L., 2022. *Auto sport: F1 news*. [Online]
Available at: <https://www.autosport.com/f1/news/how-much-does-an-f1-car-weigh/10246442/>
[Accessed 09 07 2022].

Scarbs F1, 2010. *Scarbs F1*. [Online]
Available at: <https://scarbsf1.wordpress.com/2010/07/30/aero-elasticity-%E2%80%93-red-bulls-front-wing/>
[Accessed 16 07 2022].

Segovia, F., 2013. *Science Direct*. [Online]
Available at: <https://www.sciencedirect.com/science/article/pii/S2238785419319714#bib0270>
[Accessed 17 07 2022].

Somerfield, M., 2020. *Autosport: Formula 1*. [Online]
Available at: <https://www.autosport.com/f1/news/banned-the-mercedes-f1-teams-double-drs-device-4982943/4982943/>
[Accessed 17 07 2022].

Super Tweaks, 2021. *Super Tweaks*. [Online]
Available at: <https://www.supertweaks.com/ferrari/ferrari-carbon-fibre/ferrari-458-carbon-fibre/ferrari-458-italia-spider-capristo-carbon-fibre-front-wings>
[Accessed 16 07 2022].

Thomas, G., 2013. *AZO Materials*. [Online]
Available at: <https://www.azom.com/article.aspx?ArticleID=8194>
[Accessed 16 07 2022].

Williams Production of a new front wing. 2011. [Film] UK: BBC.