

MECHANICAL & MANUFACTURING ENGINEERING

STRESS ANALYSIS AND DYNAMICS – ACMA5010

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



Figure 1 - (Miller, 2021)

MANMEET SINGH – 2114501

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Structural Support System for a Front Wing on a Car

Slope and Deflections of Beams' Theory

In this activity, the essence was to apply the slope and deflection theory to design structural support for the front wing. The first step was to select the best method for performing the calculations.

The variable provided led to a determination of the best method for calculations. Based on the information given, the deflection is 10 mm, whereas the EI is 210 GPa or $2.1 \times 10^{11} \text{ N/m}^2$. The requirement was to determine the minimum outside diameter and maximum loading. However, the length of the bar and the slope were not provided

For calculating the minimum diameter required for the support of a front wing on a car, the equation for cantilever with uniformly distributed load can be used. The equation is shown below.

$$\gamma_{\max} = \frac{-wL^4}{8EI}$$

The w value known as the force exerted on the wing can be calculated using the equation below, in this equation the force exerted (w) is indicated as downforce.

Downforce is calculated using the equation below (geumotorsports, 2016):

$$D = \frac{1}{2}WHFpv^2$$

Downforce equation		
Symbol	Designation	Description
D	?	Downforce
W	0.9m	Wingspan, according to (Rana & Castro, 2020) 900mm is the maximum length allowed by the 2022 FIA formula one regulations.
H	0.02m	Thickness of section, (geumotorsports, 2016) indicates the value to be 0.02m, this is defined by the shape of the wing
F	1.6	Lift coefficient, this is a given value by (geumotorsports, 2016), this is calculated by many factors such as angle of attack of the wing as well as area of the wing and air density.
p	1.225 kg/m ³	Air density, with change in atmospheric pressure, temperature and humidity the air density can vary but according to International Standard Atmosphere values at sea level at 15° C it is 1.225 kg/m ³ (V, 2021)
v	110.38 m/s	Velocity, the fastest ever speed recorded on a formula 1 car is 397.36km/h (Duxbury & Holding, 2022), which can then be converted into m/s by using the formula $1\text{km/h} \cdot \frac{1000\text{m}}{3600\text{s}}$ (Cuemath, 2022). Therefore $V = 397.36 \cdot \frac{1000}{3600} = 110.377778\text{m/s}$

∴

$$D = \frac{1}{2} \cdot 0.9 \cdot 0.02 \cdot 1.6 \cdot 1.225 \cdot 110.38^2 = 214.92\text{kg}$$

$$1\text{kg} = 9.81\text{N} \quad \therefore 214.92 \cdot 9.81 = 2108.37\text{N}$$

Updated cantilever equation using known values:

$$0.01 = \frac{-2108.37 \cdot 0.9^4}{8 \cdot 210 \times 10^9 \cdot I}$$

To calculate I:

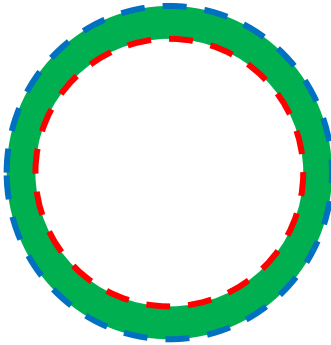
$$I = \frac{-w \cdot L^4}{\gamma_{\max} \cdot 8 \cdot E}$$

Using known values:

$$I = \frac{-2108.37 \cdot 0.9^4}{0.01 \cdot 8 \cdot 210 \times 10^9}$$

$$I = 8.233937839 \times 10^{-8}$$

Calculating minimum tube diameter was done by using Microsoft Excel and implementing a trial-and-error technique to find the optimal dimension for the tube. The formulas used are shown below:



Formula for calculating the value for the outside diameter

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

Formula for calculating the value for the inside diameter

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

Simplified version:

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

$\therefore$

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

The table below shows the calculations achieved from the Excel file.

D (mm)	D (m)	d (m) ²	I
49	0.049	0.045	8.169E-08
49.01	0.04901	0.04501	8.17421E-08
49.02	0.04902	0.04502	8.17943E-08
49.03	0.04903	0.04503	8.18464E-08
49.04	0.04904	0.04504	8.18985E-08
49.05	0.04905	0.04505	8.19507E-08
49.06	0.04906	0.04506	8.20029E-08
49.07	0.04907	0.04507	8.20551E-08
49.08	0.04908	0.04508	8.21074E-08
49.09	0.04909	0.04509	8.21597E-08
49.1	0.0491	0.0451	8.2212E-08
49.11	0.04911	0.04511	8.22643E-08
49.12	0.04912	0.04512	8.23166E-08
49.13	0.04913	0.04513	8.2369E-08
49.14	0.04914	0.04514	8.24213E-08
49.15	0.04915	0.04515	8.24737E-08
49.16	0.04916	0.04516	8.25262E-08
49.17	0.04917	0.04517	8.25786E-08
49.18	0.04918	0.04518	8.26311E-08
49.19	0.04919	0.04519	8.26836E-08
49.2	0.0492	0.0452	8.27361E-08

D (mm)	D (m)	d (m) ²	I
49	0.049	0.045	8.169E-08
50	0.05	0.046	8.70096E-08

As it can be seen from the table above the minimum diameter required is 49.13mm but as a safety factor and easy of availability this size can be rounded up to 50mm. So, to proof check the excel figures these numbers can now be inputted in the formula shown before.

$$I = \frac{\pi}{64}(0.050^4 - 0.046^4)$$

$$I = 8.700955013 \times 10^{-8}$$

Now these figures can be inserted into the original equation of cantilever with uniformly distributed load.

$$\gamma_{\max} = \frac{-2108.37 \cdot 0.9^4}{8 \cdot 210 \times 10^9 \cdot 8.700955013 \times 10^{-8}}$$

$$\gamma_{\max} = 9.46325757 \times 10^{-3}m$$

$$\gamma_{\max} = 9.46325757 \text{ mm}$$

As seen above the highlighted number in green is the maximum deflection of the wing under the given circumstances. This number gives the deflection of the wing of +0.5mm tolerance. This means that if a 50mm diameter tube is used the race car will be well within the allowed requirement.

Several assumptions related to the deflection and slope theory were made when calculating the deflection, slope, and bending moment. The first assumption was that the wing support structure has rigid joints, hence the angles of each joint do not change even after loading the momentum. The second assumption was that the axial and shear stresses lead to negligible distortion. The third assumption was an equal distribution of the load. Hence, the point of bending moment, or where the load is exerted is at the centre of the support structure (the beam).

The moment-area method has two limitations. First, the method does not apply to determining deflection and slope at multiple sections of the beam. Instead, the technique is relevant where the bending momentum occurs at only one point, mostly at the beam's centre. Second, the method assumes that the cantilever beam does not break, hence not interfering with slope continuity. These assumptions make it difficult to predict the strength of the materials used in developing the aerodynamic profile for a car wing, which must withstand a high load, pressure, or downward force.

Alternative methods could be used to calculate the slope, deflection, bending momentum, and diameter. The double integration method would have been effective in determining the deflection and slope (y and x coordinates) of the elastic curve. However, the

deflection was already provided leading to the selection of a direct method. Another technique is the modified deflection-slope equation. The method considers situations where there is no specific amount of a load or bending moment defined, or the application point (Hussain, 2022).

Different Types of Automotive Wings

Different types of wings play a critical role in the aerodynamics of automobiles. According to (Szudarek & Piechna, 2021), most race cars have front wings. The wings (Szudarek & Piechna, 2021), explored are grouped as the clean wing and the Gurney flap wing. Both wings influence the car's aerodynamics. However, (Szudarek & Piechna, 2021) observed that the Gurney flap wing generates less body drag compared to the cars without the wing. In their study, Yoanita et al. (2021) note that the gurney flap increases the airflow characteristics, leading to a higher velocity and downforce. The Gurney flap wing has been used in the rear wing of the Formula Mazda.

Flexi wings are the second and resulted from a high innovation seeking to enhance the aerodynamics of the racing cars (Mishra et al., n.d). The flex wings focus on the concept of flexibility whereby aeroelasticity is applied to prevent shear deformation. The deflection in the flex wings extends up to 21 mm. The presence of fibre plies influences the wing's deflection. Modification of the wings allows bend-twist coupling whereby a decrease in the angle of attack lowers the drag. The flex wings are further categorized based on their arrangement. The first type is the flexible flaps, which occur when the rear wing has two parts – an upper part placed on the axis and a fixed lower part (Mishra et al. n.d). The pivoted upper flap can move depending on the car's speed.

The history of front wings dates back to 1960s. In 1968, Colin Chapman of Lotus fitted small wings on his Lotus 49 during the Monaco Grand Prix (Castro and Rana, 2020). He placed the small wings at the front of his car and a curved metal sheet at the rear to have a balance. This front wing was rectangular with flap vertical endplates. Then in 1970s, the simple wing had its main components introduced. There are the flaps and top-view elliptical shape. McLaren then introduced multiple components of the front wing in 1984 (Castro and

Rana, 2020). In 2004, the front wing was designed into a three-element wing. Then in 2005, the slats were introduced to the front wing, particularly on the Ferrari F2005. The FIA banned further innovations on the front wings since 2010. However, introduction of computational fluid dynamics (CFD) has enabled development of multi-element front wings with a high performance (Castro and Rana, 2020). The design of future wings is based on the 2022 FIA Formula One regulations. The wing will have high efficiency airfoils designed based on the attack angle, wing area and the overlap/gap elements. Modification of the top view will ensure it is proportional to the downforce (Castro and Rana, 2020). Then, the end plates are designed at a 90° circular path. The spars, ribs and skin will be designed to make them resistant to deformation.

Manufacturing Process and Materials used to Develop Automotive Wings

The manufacture of automotive wings involves different materials. One of the common materials is steel. According to Zin and Rahman (2022), part of Formula 1 car front wing has steel as part of the supportive structure. The strength of steel is the main factor leading to its high preference for making structural supports for the front wings.

Another material is rattan fibre. Purina Irawan and Sukania (2020) state that composite technology has led to the identification of the Rattan fibre as a suitable material for manufacturing car spoilers or rear wings. The areas with a high abundance of forests that provide rattan fibre are Malaysia, Vietnam, Asia, and some African countries. Rattan fibre has unique properties such as high strength of polymer matrix and availability, which makes it applicable to the automotive industry. In their research, Purna Irawan and Sukania (2020) found that rattan fibre had a maximum tensile, flexural, comprehensive, and impact strength of 27, 46, 44, and 29 MPa respectively.

The third material is ABS plastic mixed with granular fillers. This mixing stiffens the ABS material. The Selection of ABS among different car manufacturers results from its properties such as high resistance to abrasion and strain, great dimensional stability, and good impact resistance.

The last material is carbon fibre. Due to its high prices, carbon fibre is not widely utilized in automotive design. Carbon has different properties such as resistance to corrosion, chemical stability, and stiffer (2.5 times higher) than aluminium. Carbon fibre has other properties including a high tensile strength.

Manufacturing front and rear car wings is a process involving multiple steps. Purna Irawan and Sukania (2020) provide a detailed description of the process used in car

manufacturing, especially where the ratan fibre material is involved. The first step is the preparation of the material for making the wings. Depending on the nature of the material, this step focuses on ensuring the final product matches the dynamics of the car. For instance, preparing the rattan fibre requires considering the direction of degree, in which to bind the fibre and resin material, ensuring that it is not too tight or loose. The subsequent step is testing the strength of the material (Purna Irawan and Sukania, 2020). The main strength tests include flexural, mechanical, and comprehensive. Other tests involve analysing the morphological characteristics of the material.

When designing the front wing, it is important to consider all our baseline configurations. This approach differs significantly from the methods used to design conventional wings described in previously. This analysis helps to establish the influence of endplates and flaps on the wings' structural and aerodynamic performance. The configurations should extrude spanwise up to 900 mm, the length recommended for racing cars such as the 2022 FIA Formula. The design depends on the wing components. Spars are the first component designed when making the wings. The spars form the longitudinal beams of the wings and they help to prevent vertical deformation. They also absorb different loads, especially those coming from the skin. Each wing has five spars and measures 10mm in width according to the airflow geometry. The second component is the ribs, which form the wing's transversal element. The ribs have an airfoil shape, which supports the wing's stiffness. They protect the wing from the normal compression stress. The last component to design is the skin, which forms the wings' external. The skin has high exposure to flexion loads, which also depends on the number of wings' spars and ribs (Castro and Rana, 2020). The skin must express a high corrosion resistance.

The material that has become commonly used in designing the front wing is carbon fibre. The low weight and strength of carbon fibre makes it suitable for making the front wing. Carbon fibre manufacturing is a technical process. The first step is spinning whereby the polyacrylonitrile (PAN) material is mixed with other ingredients and spun into fibres. The materials are then washed and stretched. The second step is stabilizing using a chemical. The third process is carbonizing, whereby the stabilized fibres are heated at high temperatures to form carbon crystals tightly bonded. The surface is then treated at the fourth step to improve the bonding properties. The fifth step is sizing, whereby the fibres are wound onto bobbin and twisted into different yarn sizes. The last step entails binding the fibres with plastic polymer at a high-pressure heat and pressure to form composite. The carbon fibre composite is then used to make the front wing. As noted in task 2, the future front wings will be designed according to the FIA 2022 regulations. Using the carbon fibre composite to design the wings, instead of steel, will make it easy to adhere to the FIA regulations.

Prototype Testing

Prototype testing is an important process that verifies if the established design or manufactured product will work as expected. In designing a car wing, prototype testing ensures that the wing can withstand the pressure or downward force and stabilize the car when moving at a higher speed. Based on the calculation above, prototype testing should show that deflection, slope, bending momentum and minimum outside diameter meet the front wing specifications as per the FIA 2022 regulations.

The type of prototype applicable to testing the F1 car front wing is the digital prototype. The digital or 3D prototype is a simulation that demonstrates a product, making it possible to test the assumptions. Thus, testing the front wing requires design its 3D model, then using a computer program to analyse all the components. Computer programs such as CAD will be used to test different loads, deflection and slopes using the same length of steel according to the calculations obtained in Task 1. With the same prototype, the impact of different materials such a carbon fibre composite on the wing's ability to create a strong downward force will be compared.

The key elements considered in the calculations were the deflection, slope, and modulus elasticity of steel. The first aim of the testing should be to ensure an accurate answer is determined. For instance, designing the wing or the aerodynamic support system requires the establishment of the correct slope angle and the length of deflection. These two factors show the maximum force or load the steel can withstand.

Thus, when explaining the results, I will relate the deflection, slope, and bending momentum to the diameter or the radius of curvature. The key determining factor is the load and elasticity of the material. For instance, a higher load and low elasticity will lead to a low deflection and slope. On the contrary, a high load and greater elasticity will result in a higher

deflection and slope. A high deflection and slope are likely to cause deformation of the beam, or wing support system in the case of automotive. Based on the results, I will explain the strength of the material based on the level of deflection and slope resulting from the load exerted evenly. The load will be exposed to downward force at different levels of acceleration. When testing the wing, the intention will be to establish the intensity of pressure at which the wing support system breaks.

References

- Cuemath, 2022. *Cuemath*. [Online]
Available at: <https://www.cuemath.com/measurement/km-h-to-m-s/>
[Accessed 19 08 2022].
- Duxbury, A. & Holding, J., 2022. *Autosport*. [Online]
Available at: <https://www.autosport.com/f1/news/how-fast-is-an-f1-car-top-speeds-of-f1-indycar-motogp-and-more-4980734/4980734/#:~:text=Top%20speed%3A%20300km%2Fh%20%2F%20186mph%20approx.>
[Accessed 17 08 2022].
- geumotorsports, 2016. *GEU Motorsports*. [Online]
Available at: <https://geumotorsports.wordpress.com/2016/09/12/the-wings/>
[Accessed 19 8 2020].
- Goulamhoussen, D., 2021. Materials for morphing application. *Improvements of the aerodynamics*.
- Hussain, M. A., 2022. New Modification for slope-deflection equation in structural analysis. *International Journal of Engineering and Technical Research*, 3(7), pp. 387-390.
- Irawan, P., Sukania, A. & I.W., 2020. International Journal of Mechanical Engineering & Technology (IJMET). *Manufacturing Process Of Car Spoiler Product Using Continuous Rattan Fiber Composite Material*, 11(1), pp. 9-15.
- Miller, C., 2021. *Car and Driver*. [Online]
Available at: <https://www.caranddriver.com/news/a37038474/2022-f1-car-revealed/>
[Accessed 2022 09 2022].
- Mishra, S., Singh, S., Sharma, S. & Bhardwaj, M., 2022. International Journal of Mechanical Engineering. *Flexi wings: An innovative approach for the future of material science with an aerodynamic influence in motorsport engineering*, 7(5).
- Rana , Z. A. & Castro, X., 2020. Aerodynamic and Structural Design of a 2022 Formula One Wing Assembly. *Fluids*, p. 3.
- Szudarek, M. & Piechna, J., 2021. *Energies*. *CFD Analysis of the Influence of the Front Wing Setup on a Time Attack Sports Car's Aerodynamics.*, 14(23), p. 7907.
- V, W., 2021. *Mac Instruments*. [Online]
Available at: <https://macinstruments.com/blog/what-is-the-density-of-air-at-stp/>
[Accessed 22 08 2022].
- Yoanita, Y., Pinindriya, S., Kumolosari, E. & Didik, R., 2021. Journal of Physics: Conference Series. *The influence of gurney flap on the stability of formula car rear wing with simulation*, 1823(1), p. 012064.
- Zin, M.Z.M. & Rahman, 2022. Simulation, the addect of spoiler on aerodynamic for sedan car. *Journal of Automotive Powertrain and transportation Technology*, 2(1), pp. 1-8.