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Design the Structural Support for a
Front Automotive Wing for a New
Race Series

Stress Analysis and Dynamics
ACMA5010

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Summary

The objective of the report was to design a front wing support for a race vehicle. The structure ran from the nose cone of the racecar to the end of the wing and was made from steel tubing with a given cross section and stiffness value. The instructions stated the structure must remain in a fixed state and had given limitations on the extent to which the beam can deflect.

The front wing is an aerodynamic feature added in the motorsport industry to primarily increase the amount of downforce the vehicle has when accelerating and by doing so enabling sufficient traction while racing. It creates downforce by using the pressure from clean air directed at the racecar which then pushes the front end down. End plates then direct the incoming air around the tyres behind them for less turbulence.

The task required was to calculate the slope and deflection of the support using approximated loading and length values from research. Initially the direct integration method was used to calculate maximum deflection. Following this the second moment of area formula was used to find the minimum diameter limit of the support.

Assumptions were identified during the process, namely that the deflection of the mounted surface of the cantilever type support was zero when loaded. Also that the loading was equally distributed across the support, when this would be false with the existence of the end plate attached. The suggested solution would be to calculate both a point and an equally distributed load using Macaulay's method to find a more accurate value of deflection.

Research was undertaken to identify the development stages in the history of motorsport racing and when the implementation of front wing was first introduced. More innovations were introduced and shown to aid the performance of racing vehicles giving advantages to teams competing in competitions. Design engineers such as John Barnard whose creative ideas revolutionized Formula One are discussed and the impact such engineers had for the future.

In addition, the manufacturing processes of the materials used in the front wing support were also explored. With the heavy use of composites being introduced to motorsport to create high stiffness to weight ratios. The most influential composite introduced to the industry in the last few decades was identified as carbon fiber. Research was found to understand how the material was regarded fit for applications due to its properties.

Testing using simulation was also covered in the report as being an effective tool to determine how the applied loading would affect the support and could determine if any changes in properties were required.

Research on how to test the safety and quality of the material was explored using solid works to create a diagram of the beam apparatus. This would help plan a suitable method testing the support.

The analysis of the beam was achieved due to the correct methodology introduced and through sufficient research in reliable resources. The results showed the importance of the design characteristics and how profoundly it impacts on the overall performance and safety for the car and driver.

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Introduction

A structural support frame is an essential part of the front wing design on a racecar being the first point of contact of the clean air. Its purpose involves holding the wings in position whilst being attached underneath the nose cone of the car. The job of the front wing components is to divert the air from the center; it passes over the top of the car tyres and can then go into the side pods to cool the vehicle. The purpose of this is to prevent turbulence and increase the traction without increasing the mass. According to Steward (2017), the front wing is effective in creating aerodynamic downforce in the racecar due to its design that creates higher pressure on the top of the wing and lower pressure at the bottom.

The support structure of the front wing is required to have sufficient strength and rigidity to fulfill its duties when the vehicle is either static or mobile. The design specification for the structure identified that the support was to be created in steel tubing with the Young's modulus of two hundred and ten giga pascals and a cross section of two millimeters. It also specified the tubing was to pass through to the end of the aerodynamic feature which would then involve using nonstructural implementing calculations. As the only attachment for the support structure was to the nose cone of the car, it was suggested that it was a cantilever style load.

The conditions needed were that the load should not cause the support to move over six degrees of freedom of movement or deflect more than ten millimeters in order to abide by the race regulations. The weight was then approximated and calculated using direct integration method. This then gave the minimal dimension for the support to be further developed.

The goal in the report was to determine an understanding of what is required to design a stable and fixed structure to support the front wing of a racecar. To further identify assumptions and the limitation of calculating the data given and estimated independently. Finally to gain knowledge in the automation design, how it has evolved and the way materials have developed the performance.



Figure 1 Steel Pipe Cross Section & Side View Of Aerodynamic Profile

Methodology

In order to calculate the minimum diameter, using the direct integration method, it was necessary to estimate a load and the length of the support. While referring to Randall (2011) who wrote the RB5 Red Bull workshop manual, Formula one association initially set checks for the front wing with a fifty kilogram of weight and allowed ten millimetres of flex. This was used as an estimated load for the theory. Although, if applying the aerodynamic forces Temrtaeyne (2004) suggests that a modern race car can generate up to 560 kilograms of downforce at top speed, therefore the load chosen was of the smaller value with the consideration that there is no aerodynamics in the theory.

The length of the front wing was based on the research of the Ferrari 312T workshop manual by Garton (2016), which indicates the width of the vehicle to be two metres. Considering that the front wingspan of the 312T was shorter, for the purpose of the report, it was estimated that the length of the support was 0.823 metres.

The diagram in Figure 2 displays all the data needed for the method to be calculated using the direct integration method. The cross section of the support is also in Figure 3.

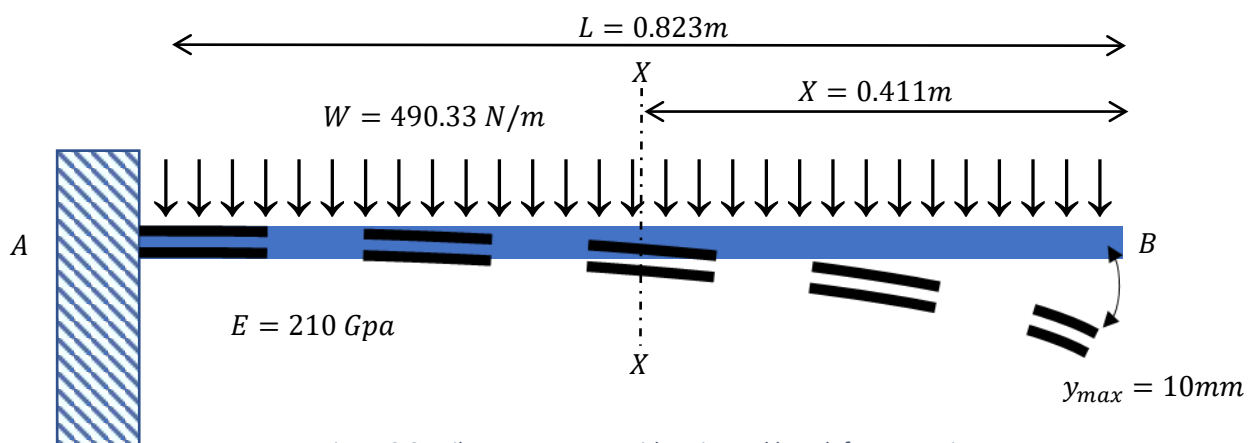


Figure 2 Cantilever Beam Type with estimated length for Front wing

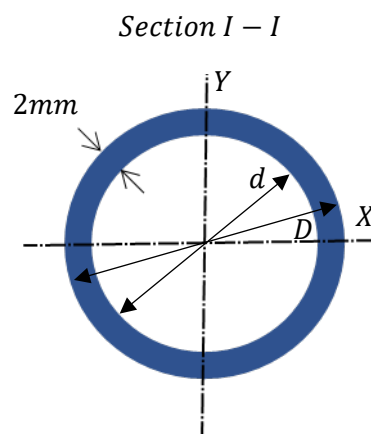


Figure 3 Cross Section of Support

Implementing Methodology

Referring to Hearn (1997) for the following method for calculating slope and deflection of a cantilever beam. The bending moment equation was first introduced, and then integrated once to find the slope with one constant added as shown in Equation 1. It was integrated for the second time to find the deflection with another constant also included, as illustrated in Equation 2. However at the supported side of the cantilever, the deflection was presumed to be zero in the racecar.

The constants of integration are calculated, according the Hearn (1997) with the condition that when x equals the length, deflection and slope equal zero and then substituted to create Equations 3 & 4.

Using the formula for maximum deflection shown in Equation 6, it was then transposed to find the second moment of area. To find the minimum diameter required for the support, Table 1 was calculated using a listed a gradual increase in diameter and its second moment of area value. The closest value to Equation 7 was highlighted as the minimum diameter the support needs to be within the deflection required.

$$M_{xx} = -490.33(0.411x) \frac{0.411x}{2}$$

$$M = \frac{-490.33(0.411x)^2}{2}$$

$$EI \frac{d^2y}{dx^2} = \frac{-490.33(0.411x)^2}{2}$$

$$EI \frac{dy}{dx} = \frac{-490.33(0.411x)^3}{6} + A$$

Equation 1 First Integration for Slope

$$EIy = \frac{-490.33(0.411x)^4}{24} + Ax + B$$

Equation 2 Second integration for Deflection

The constants of intergration using boundary conditions

$$\text{when } x = L \frac{dy}{dx} = 0$$

$$\text{slope } 0 = \frac{-490.33(0.823)^3}{6} + A \text{ \& tranposing gives } A = \frac{490.33(0.823)^3}{6}$$

Equation 3 Finding Constant of integration using Boundary Conditions

$$\text{when } x = L \ y = 0$$

$$\text{deflection } 0 = \frac{-490.33(0.823)^4}{24} + \frac{490.33(0.823)^3(0.823)}{6} + B \text{ tranposing gives}$$

$$B = \frac{-490.33(0.823)^4}{24} - \frac{490.33(0.823)^4}{6}$$

$$B = -\frac{490.33(0.823)^4}{8}$$

Equation 4 Finding Constants of Integration using Boundary Conditions to Find Deflection

Calculating the Maximum Slope and Deflexion

$$\text{slope } \frac{dy}{dx} = \frac{1}{210 \times 10^9 I} \left(\frac{-490.33(0.823)^3}{6} + \frac{490.33(0.823)^3}{6} \right)$$

$$\frac{dy}{dx_{\max}} = \frac{-490.33(0.823)^3}{(6)210 \times 10^9 I}$$

Equation 5 Maximum slope of the Beam

$$\text{deflection} = \frac{1}{210 \times 10^9 I} \left(-\frac{490.33(0.411)^4}{24} + \frac{490.33(0.823)^3 x}{6} - \frac{490.33(0.823)^4}{8} \right)$$

$$\text{when } x = 0$$

$$y_{\max (10\text{mm})} = \frac{-490.33(0.823)^4}{(8)210 \times 10^9 I}$$

Equation 6 Maximum Deflection of the Beam

Finding the Minimum Diameter Using Second Moment of Area

$$\text{Transpose for } I = \frac{-490.33(0.823)^4}{(-0.01)(8)210 \times 10^9} = 1.34 \times 10^{-08} \text{ mm}^4$$

$$1.34 \times 10^{-08} = \frac{\pi D^4}{64} - \frac{\pi d^4}{64}$$

$$1.34 \times 10^{-08} = \frac{\pi d^4}{64} (D^4 - d^4)$$

Equation 7 Second moment of area for a Cylinder

Research Table Using Equation 7

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

Table 1 Second moment of area for a Cylinder Results

Assumptions

It was assumed that the load was uniformly distributed along the shaft; this would be incorrect with the existence of the endplates attached to the sides of the structure. Hence, a close estimation would be that the loading was a combination of uniformly distributed load because of the body of the wing and point loaded due to the endplates. Solution for a more accurate approach of calculation to cover all loading conditions would have been Macaulay's method. In support of Cherchuk (2017) and when this theory is coupled with Bernoulli's theory, it could be used to integrate the equation for the bending moment and express the deflection anywhere along the beam.

The load across may have varied due to the design of the wing, the assumption that that the load was equal across the support would be inaccurate. Referring to Hearn (1997) who indicated that in some cases it is not convenient to use integration with an unequal load over standard procedure. Instead commence with the equation for the loading of X-X on the beam shown in Figure 3. Then integrate to have a total of four constants of integrations to solve with certain conditions.

Another important aspect on the aerodynamic properties of the car whilst mobile is the drag it produces. The calculations were based on a downward action and no consideration was taken into account that the wing would resist forces from the front when accelerating. In order to calculate the aerodynamic loading according to Katz (2005) and obtain an understanding of the velocity and the vehicle geometry he suggests using Daniel Bernoulli's formula, which allows measuring speed at a point of flow by simply measuring the pressure.

Another influence not calculated was the vibration of the vehicle. In accordance to Voltera (1965), the inertia of the beam will cause it to vibrate in that location but assuming the elastic modulus and cross sectional are constant then the vibration equation can be calculated using the following Equation 8,

$$EI \frac{\partial^4 v(x, t)}{\partial x^4}$$

Equation 8 Vibration Equation according to Voltera (1965)

Type of Automotive Front Wings and Their Development Through History

Wing design over previous generations of motorsport has significantly changed to increase their performance and their aerodynamic capabilities. Automotive industry, sport technicality and innovation had expanded to create more effective ways to stay competitive in the sport, which in late 1960s introduced the concept of aerodynamics to the racecar. This was stated by Autosport (2020) and went on to say “the consequences of the car taking part in the Formula One season were devoid of downforce producing wings and bodywork feature”.

The front wings of a race car were first innovated by former grand prix driver Jim Hall - Fanam (2018) who understood the similar force a wing of a airplane produces and invented the concept to work the opposite direction for surface traction on a car.

Colin Chapman introduced the concept into Formula One in 1968 according to Alamy (2014). They were installed into the lotus 49 racecar and were mounted higher than those which modern race cars use today for effective use of clean air.

Other years, wing design continued to upgrade with designers like John Barnard (Greens, 2018). One of the models, which introduced the M23, is shown in Figure 4. The wing design continued to evolve with side plates added to the end of the structure and the positioning being lower down toward the chassis of the car. This design would be similar to the one introduced for the assignment in Figure 1, with what is presumed inserted into the nose cone with one difference being the angle of the M23 being slightly tilted forward.



Figure 4 McLaren M23 Photographed at Goodwood Festival of Speed by Lewis Nekreus

The modern racing cars front wings became much more complex with many added aerodynamic features implemented to the side plates and wings. This was to create a controlled vortex to the front of the car and explored by Peterson (2021). The second biggest difference was the way that the wing is mounted to the nose of the car, attached through separate sections along the side.

In regards to future designs, this could be dependent on any new regulations being instigated. Miller (2021) states that the future of motorsport is electric. If true, this could also impact the design of the cars aerodynamic features including the front wing. This was similarly stated by the Williams formula one driver Alex Albon according to Henderson (2022).

Referring to the designs illustrated in the Formula E manual (Smith 2021) evolution and development of design was seen by noticing the difference in geometry and positioning of the front wings in comparison to most racing organisations who use turbo charged engines. Further potential involvement of these electric racing vehicles meant a low drag design of vehicle according to Smith (2021) and hence the contribution of downforce being minimal due to the shape of the wing design shown in Figure 5. This could effectively mean more acceleration in future, less downforce being produced from the front wing and hence an updated design in support.



Figure 5 Porsche 99X Electric Car at Goodwood Festival Of Speed
Photographed by Lewis Nekrews

Manufacturing Processes & Materials of Sports Front Wings

In relation to what was previously discussed, the materials have changed over generations to create a lighter, stronger and more durable structure in motorsport. One of the most commonly known materials used on a racecar are composites and eighty five percent of the vehicle is created from this, Hatton (2022), which would include the front wing support.

For the report the material specified was steel. With the stiffness grade given, a suitable manufacturing method could be explored. Firstly, the manufacturing process was assumed to be low volume but with high precision. Using the typical properties listed by John (2003) to find a similar steel grade with a familiar stiffness value was considered. Most variants of steel listed had similar stiffness value, however differed in their values of corrosion resistance and yield strength. Comparing properties according to Murray (2007), alloy 738 would be an ideal candidate for the support, having high strength and resistance to natural elements.

Manufacturing steel for the front wing support was a concept that would have been implemented before the introduction of composites, as previously mentioned in design history about the lotus 49b (Oilver, 2003). The front wing was assumed to be made out of steel tubular and the aerodynamic feature aluminum. The manufacturing process of tubed steel could be rolled with the suggest grade of 738 alloy. Advantages to using this material was the presumed low volume required and cost.

It could be argued that steel, being the specified material in the task, was a cause for concern due to the strength to weight ratio properties, as the car may have not attained its maximum performance due to the extra weight. Furthermore, while referring to McBeath (2016) and the specification given, carbon fiber had twice the stiffness of steel despite being a much lighter material. This material is superior in stiffness to weight ratios, which attracts designers to utilize it into their racing car manufacture. As explained by 3mb (2015) who then followed to say that not only it improves the drivers performance but also the safety and comfort.

The manufacturing process of carbon fibers used for most modern race cars such as the Porsche 99x mentioned in Figure 5, was explained by Beazley (2018), the fibers are grouped in a thread form and weaved together in a cloth, this is then coated in resin and cured. He goes on to explain that these clothes are layered together and then treated to create maximum stiffness.

Testing & Development

After examining the results from theory, predictions on design preferences were made according to the task specifications. However, for the design to be implemented further testing procedures would be required. A prototype would be essential when creating new components to test their reliability, durability and safety.

Before physically developing a prototype for testing, simulating the new concept on a three-dimensional modelling package before manufacturing would be justifiable as this would save money and reduce the risk of failure in further testing. Solidworks (2022) could be used to simulate the stresses applied with certain studies like static and fatigue. The simulation the results potentially could show the amount of deformation being applied to the application and could even be compared with the theoretical results. Von Mises could be also identified in simulation where the most affected areas to stress are and then could assist in the further knowing the limitations of the material.

Once the first prototype is manufactured then physical testing could be applied using the data gathered from theory. An apparatus, such as the SM1004 by tequipment (2020), could be a suitable investment to test the beam deflection. This could then be paired with the VDAS acquisition software shown in Figure 6 and so the user would be able to gain an accurate amount of data from the beam deflection. The data could be further analysed, charted and export results into spreadsheet format.

An alternative idea would be instead of purchasing testing equipment for the wing support, the design in Figures 7 and 8 were created from generic engineering equipment. Reasons for this were on the assumption that there may not have been finance for new professional testing equipment and a more practical approach may be chosen.

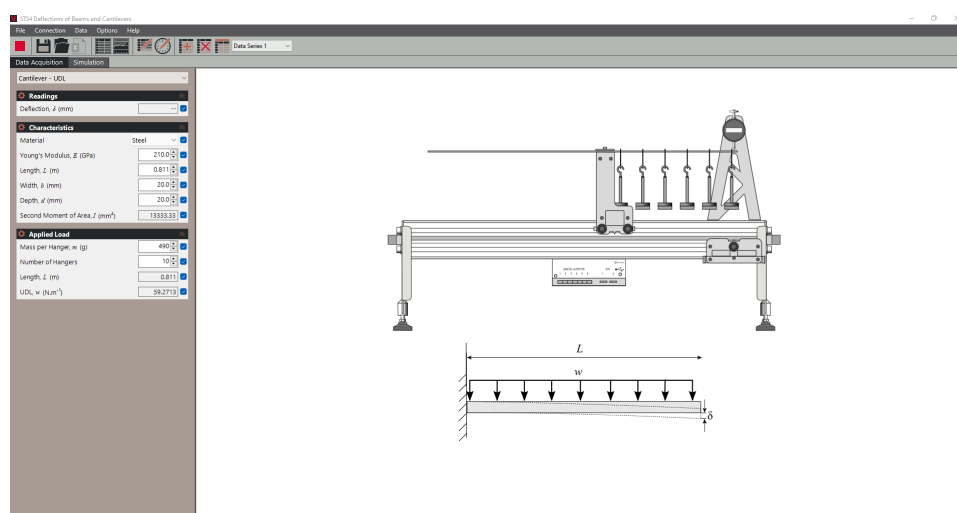


Figure 6 VDAS Software for UDL Cantilever Beam

Diagram of Designed Testing Apparatus

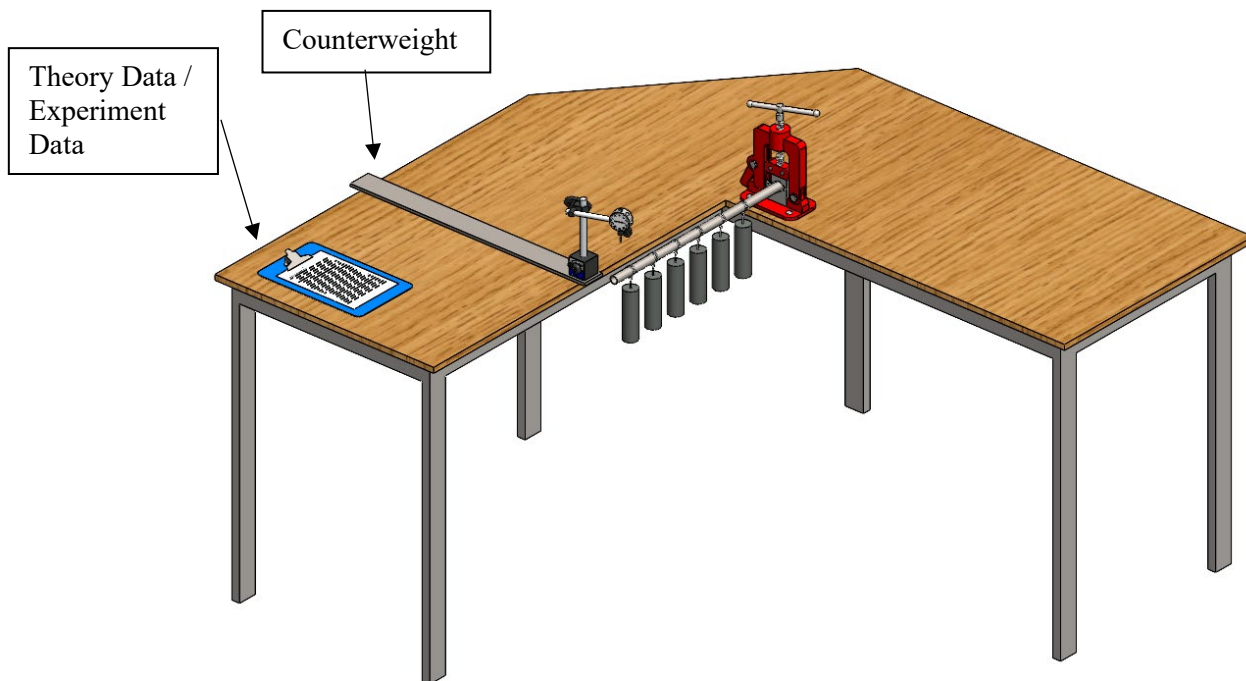


Figure 7 Apparatus Designed on Solidworks (2022)

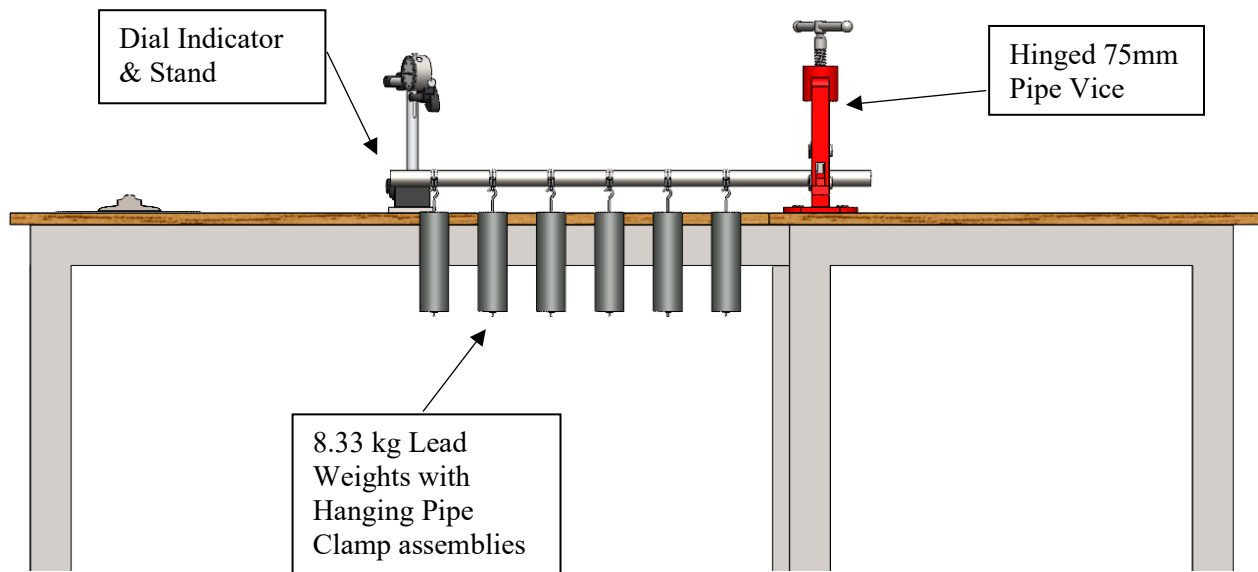


Figure 8 Side view of Deigned Solidworks (2022)

Procedure of Apparatus Testing

Operation Stage	Procedure Description
1	Locate a suitable workbench and attach pipe vice in position
2	Insert steel tubing into vice with diameter specified from theoretical data
3	Set counter weight and dial indicator / stand to touch the steel pipe
4	Attach weights to the steel pipe and release for the pipe to deflect
5	Read depth of the deflection using gauge and record data to compare with theory

Table 2 Procedure of Operation

Conclusion

The task was to design a structural support for a race car suitable for a new race car series. It involved using the information given to calculate the deflection and slope of the support when under loading and to then predict what size diameter can minimally be used for the shaft of a steel pipe. Moreover, assess any assumptions while calculating the support, evaluate limitations, and suggest further alternative methods.

In addition the task involved to further discuss the automotive front wing and its development in motorsport over generations including the manufacturing techniques and materials used in the applications and how they benefits the vehicles performance. These materials are then tested and prototyped in order to gain their full potential with and regard to current regulations.

The significance of the study was to understand what is required when designing a product that deal with forces acting against it and how to increase the chances of success when done effectively. To also gain an understanding of the principles behind the deflection of materials and apply them to the engineering processes.

The method of calculating the slope and deflection proved effective in estimating the necessary data in order to find the minimum outside diameter of the steel pipe. Further recommendations made could be to gain a more accurate estimation on how the wing support would behave when under loading.

For instance there was no data calculated to predict how the support would behave when forces are acting multidirectional. The vehicle will be travelling at high velocity creating forces against in more than one axial making calculating the true loading against the front wing support more complex.

In conclusion it could be argued that creating a physical prototype with the steel material could be potentially beneficial after sufficient theoretical data is established. Additionally, this would be followed by a prototype test by applying loading to study the deflection of the application.

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