



Designing the structural support for a front automotive wing.

16/07/2022

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Table of Contents

Table of contents	1
Introduction.....	2
Slope and beam theory.....	3
History and development of automotive front wings.....	4
Manufacturing, materials and process'	5
Prototype testing and Experiments.....	6
Conclusion.....	7
Bibliography.....	8

Introduction

Automotive racing has been present since the invention of the automobile, in the early days of the vehicle, companies took part in durability tours to prove the reliability and endurance of vehicles to consumers. These events were the foundations of what would evolve to become automobile competitive racing (James J. Flink, 1970)

Today, Automotive racing has branched into many categories, vehicles equipped with set ups that are adapted to the driving challenges the vehicle will meet. proving themselves, manufactures attend competitions set in environments ranging from ice, desert, mud and the most popular, tarmac. Auto races have a primary factor in common, which is, a vehicle shall cover a piece of road in the shortest time possible. To achieve success in competition, the driver of a vehicle will aim to accelerate the vehicle to the fastest speed possible whilst braking the car as late as possible over the minimum possible distance and ensuing the exit of a corner with maximum velocity (Derek seaward, 2014)

A proposition to design the structural support on the front wing of a new race series has arisen. The front wing of a race car functions as part of an aerodynamic package, to include Rear wing, Diffuser, the underbody and barge board. In this report the minimum outside diameter for the support will be decided. Various assumptions were made to fulfill the lack of data on the factors influencing the wing. "Slope and bend theory" is used to evaluate and analyze the required minimum diameter for the structural support tube. Different variations of automotive front wings are explored with a focus on a wing's interactions and relationships with airflow, past and future designs are discussed alongside their advantages and shortfalls for their era. In addition, manufacturing processes and materials are investigated to understand the need for such advanced technologies. Finally, suggestions of experimental testing will be delivered alongside an interpretation of the results.

Slope and Beam theory

- a) The proposed structural support of an automotive front wing must be able to withstand the maximum required downforce that wing evenly exerts as part of the aerodynamic package, with a maximum deflection of 10mm. In racing, a team's downforce is a variable that is finely adjusted depending on the competition environment and track.

To be able to make a sensible calculation of the supports capabilities we must make various assumptions regarding the wing, we will assume the wing will be subject to a uniformly distributed load of 800N. we will also assume limited dimensions of the wing to be 800mm from fixed point to end of wing.

Calculations

Known factors

- Elastic modulus of the support tube = 210 GPa
- Gauge (wall thickness) = 2mm
- Maximum allowable deflection = 10mm
- 6 degrees of freedom
- Aerodynamic profile is non structural
- Density of air at sea level = $\rho = 1.22\text{kg/m}^3$

Assumptions

- Top speed of vehicle = $v^2 = 200\text{mph}$ or 89.4 m/s
- Weight of wing at rest = 5kg
- Front wingspan including nose = 2m
- Nose of car = 0.2m
- Chord = 0.2m
- Individual left side wing = 0.8m
- Area of wing = $S = 0.2 \times 0.8 = 0.16\text{m}^2$
- Angle of attack (AoA) = 10°
- Lift coefficient = 1
- The car is at sea level @ 15 degrees & 14.7psi

The last assumption we must make is downforce, we will calculate this using the factors we have.

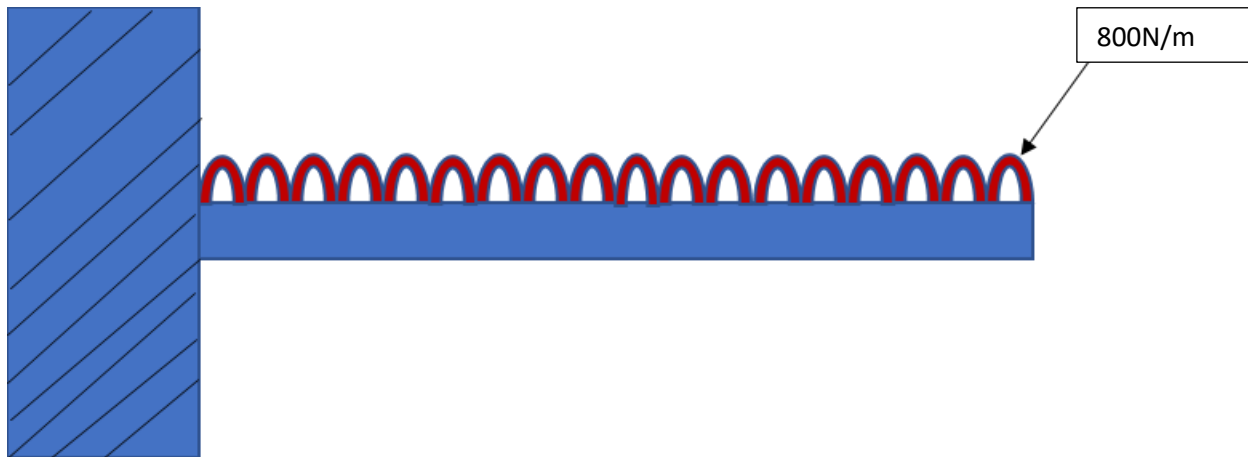
Downforce or lift = $L = 799.77\text{ N}$

If the formula for lift is:

$$\frac{1}{2} \times \rho \times v^2 \times S \times C$$

Then

$$\frac{1}{2} \times 1.25 \times 89.43^2 \times 0.16 \times 1 = 799.77\text{ N} \text{ or rounded to } 800\text{N of downforce is produced}$$



EI = Flexural stiffness =

Second Moment of Area is defined as the capacity of a cross-section to resist bending.

Area moment of inertia for a solid round bar

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

$$I = \frac{\pi \times 10^4}{64} = 490.87$$

Area moment of inertia for a hollow tube

$$I = \frac{\pi 10^4}{64} - \frac{\pi 8^4}{64} = 289.81 \text{ m}^4$$

$$\gamma_{max} = \frac{-wl^3}{3EI} = \frac{-300 \times 0.8^3}{8 \times 60 \times}$$

History and development of Front wings

Early in the development of automotive vehicles and as vehicles became faster, engineers recognised by understanding this invisible force of air, vehicles would be able to breach the limiting factor and set the fastest land speed records. Streamlining was the term remarked for the refinement of the body of a vehicle, Sir George Cayley was touted as the father of aeronautics, he was the first to propose a fixed winged aircraft with a separate propulsion system John D. Anderson, Jr, (1997). Sir George Cayley recommended that 'a very oblong spheroid but varied according to what may be found the true solid of least resistance' Gibbs-Smith, C. H. (1962). This 'Oblong spheroid shape' would become an inspiration for future vehicle designs with curved profiles. Cayley was a pioneer in the development of aircraft, he paved the way for research and the understanding into aerodynamics 'In 1804 he used, for the first time in history, the whirling arm in the service of aeronautics, to test an aerofoil at varying angles of incidence' Gibbs-Smith, C. H. (1962). The whirling arm would prove to have huge drawbacks as the air around center would rotate with the arm, causing an unreliable testing environment. Nonetheless these tests were accurate, and Cayley was able to derive the first modern configuration of an aero plane in history Gibbs-Smith, C. H. (1962).

Sir George Cayley, the father of aeronautics. Part 1

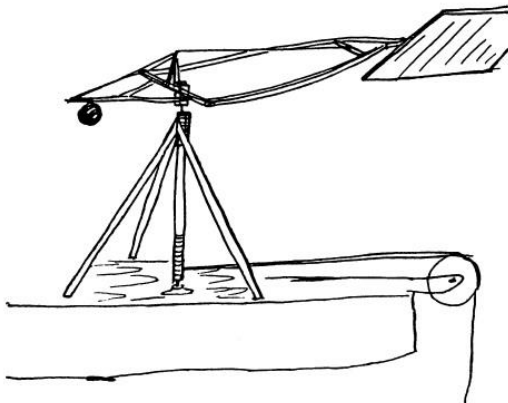


Figure 3. Cayley: whirling arm, 1804.

The theory of lift

The aerodynamic wing was first developed within the aviation industry, on race cars the wing is inverted to create downforce Seward (2014). The most basic sense of a wing is a flat sheet of rigid material, as the air flows over the sheet, air is diverted like a rudder on a boat thus the momentum of the air is deflecting.

Momentum = mass x velocity

Front wings manipulate airflow to create downforce, airflow can be categorised into two types, laminar and turbulent flow. Turbulent flow can be chaotic and is caused by the transition of kinetic energy into heat thus wings have increased performance inside laminar flows. Front wings have played a vital role in the aero package of an automobile, fundamentally front wings are modified aerofoils. single element Aerofoils function by creating a vacuum on the bottom surface and a positive pressure above, this creates a resultant downforce, this is due to Bernoulli's principle. A single element wing can be positioned into an angle of 12 degrees this is when it will reach peak downforce, after this angle flow

becomes turbulent and separated thus reducing efficiency. To counter this issue engineers added an extra flap, these are known as multiple element wings, as airflow flows through the gap between the flap it reenergises the air, allowing an increased angle of attack of 20 degrees thus deflecting the momentum of air further increasing downforce.

To be able to effectively enhance aerodynamic systems in the future, it is important to understand the Modes of testing that allow the desired criteria of the vehicle or part. When manufactures have developed automobiles, the wind tunnel has been a crucial tool in testing and understanding the relationship solid bodies have with the air mixture. wind tunnels can have variable parameters to suit the application, maximum achievable speed, turbulence, and uniformity of flow can be adjusted to simulate on track dynamics Hernández, M. A. G. et al., (2013). Using the data obtained from a wind tunnel, a front wing can be carefully studied resulting in an enhanced product. Angle of attack can be utilised to create desired amount of downforce, unfortunately this can increase the drag coefficient and reduce the overall speed of the vehicle on straight parts of the track. Adjustable wing angle have been developed so a mechanic can change the angle of attack during a pitstop.

Manufacturing, materials, and processes

Historic Chassis'

Space frame tubes have long been a popular chassis style due to the availability and ease of fabrication. These tubes can be formed in a circular or squared profile, each provide their own benefits and disadvantages. Currently, Steel has long been the most popular material for competition cars such as rallying and cross country. In many races it is mandatory to fit a steel roll cage due to its high durability during impacts. Aluminium alloy can be used as a space frame due to its lightweight properties but suffers with reduced elastic modulus over steel. In a recent article researchers stated that "AISI 4130 tubes can be easily replaced with Carbon-Reinforced Epoxy based Polymeric Composite Tubes" They conclude that using these advanced composites can reduce chassis weight by up to 78% Sinha, Kumar (2019). This study is a good example of the influence that motorsport innovations have when crossing over into the domestic market.

Influence of carbon fibre

The use of carbon fibre has revolutionised the racing world, more than 80% of formula 1 cars are made of carbon/epoxy composite. A carbon fibre monocoque was first used on the McLaren MP4 which enjoyed many successful seasons using the design. Carbon composites allow the designer to create parts with a higher value of stiffness thus improving handling around corners and helping to deal with understeer. Recently, racing teams are experimenting with individual components such as push rods and gearbox casings, as a result these components are not only under high stress and strain scenarios but also chemical and temperature attack.

To manufacture hollow push rods components, prepreg plies of carbon fibre are inserted into a two-part cavity Mould then a hollow silicone mandrel is expanded pushing the fibre into place after this, the assembly is placed into an autoclave to cure. In automobile racing epoxy composites can increase weight saving by 50% whilst still retaining the mechanical properties of previously used alloys, although it is important to note that in an article, researchers found that in the event of an impact and when under compressive stress, carbon fibre will exhibit buckle failure and thus not absorb the energy required to

protect the occupants Gilchrist, M. D., & Curley, L. (1999). The suggestion of this study contrasts the research of Sinha, Kumar (2019) as the author recommends that the steel chassis of vehicles be replaced with carbon fibre.

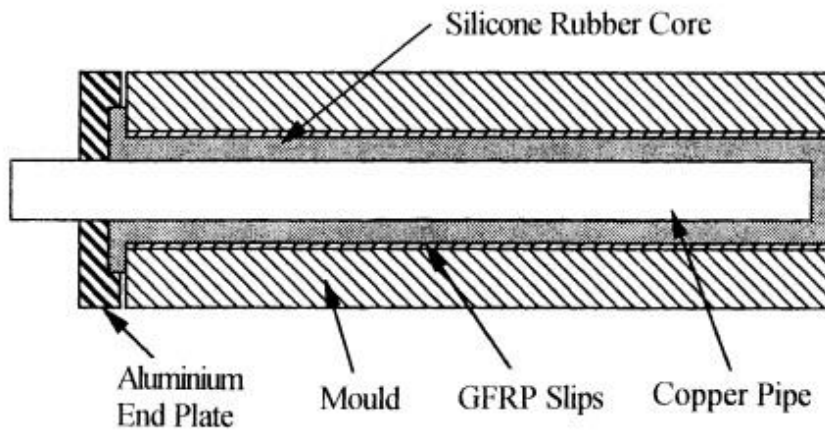


Fig. 2 Arrangement of the mould assembly for manufacturing the hollow silicone mandrel.

Figure 2 source: Gilchrist, M. D., & Curley, L. (1999)

Carbon fibre reinforcement via fused deposition modeling

Manufacturing has been a bottleneck for the uptake of composite materials according to the Imperial college London (2022). Competitive automotive racing has long been known for its advanced Manufacturing techniques. For a race team to constantly evolve designs, it is crucial that parts are created quickly with fast lead times. Davies, & Clarke, A. (2013). Motor sport teams require low volume production, this means they will not benefit from the mass scale of production akin to road cars. A future solution to this problem, could be Fused deposition modelling, this type of additive manufacturing binds a filament of carbon fibre alongside a filament of polymer commonly ABS, this allows the designer to create the complex geometries that by traditional Manufacturing techniques were rendered impossible. Alongside this benefit, designs can quickly be transferred from a 3D modelling file into a functional part within hours. In a study on oil sump optimization in competition vehicles, it was found that using an additive manufacturing technique minimised sloshing effect of the sump thus improving engine lubrication. This technique allowed a weight reduction of 22% over its aluminium counterpart whilst allowing complex shapes to be formed to improve oil lubrication. Cazón, Prada, García, Larraona, Ausejo (2015)

Prototype testing

To begin with the development of a prototype front wing support, using the data of dimensions derived from the slope and beam theory calculations, a 3D model can be constructed in a relevant modelling program such as solid works. With a 3D model available the support can now be tested virtually through

various programs of Computational fluid dynamics; this will allow the engineer to analyse and test the support to identify weak areas throughout the structure. Nowadays, it is common to see design engineers bypass the physical prototype stage altogether. For competition racing the introduction of CFD techniques, associated with available computational resources increase, has significantly contributed to the development of ever-increasing aerodynamic performance for the entire vehicle, CFD is the comparison between computational and experimental results, although it can have its limitations Lai, Liu (2020). Regarding testing turbulence inside CFD programs results are taken as estimates as “its mathematical intractability does not yield exact mathematical solutions” Wyngaard (2010).

Experiments

Physical prototype testing is regarded as the most dependable form of engineering experiment, it can be required when an organisation does not possess the computational skills and resources or when the physics of a scenario is too complex or not fully understood. Physical modes of testing can be of considerable time with high development costs, ultimately leading to a slowed production.

To begin the experiments of a structural front wing support, firstly an engineering team shall commence various testing methods of the mechanical properties such as understanding the tensile strength of the material often to failure of test piece. Compiled with this, shear stresses can be documented through a direct shear test. If advanced testing is required fatigue testing can be carried out by repeated cyclic loading, this will investigate the stress and strain lifespan before fractures appears promoting failure. Using the data from these experiments, adjustments to the design can be changes, optimising the component to increase performance in these various tests.

For aerodynamic testing to enhance drag reduction and lift force, wind tunnels can be utilised to highlight hotspots of air resistance and to provide an insight to flow separation areas. To begin testing of an aerofoil within a wind tunnel, it is important to understand the relationship of scaling laws such as Reynold's number, wind speed and dimensional scale. By understanding these parameters, scale model tests can be performed to produce very accurate real-world scenarios Mollinger and Nieuwstadt (1996). Before the aerofoil is placed inside the tunnel it must be fitted with wind sensing technology, it is common to use hot wire style sensors which create precise data to be recorded by heating a wire and allowing it to be cooled by the flow of air, this data can then be formulated inside a computer to show problematic areas Merrison, J., (2011).

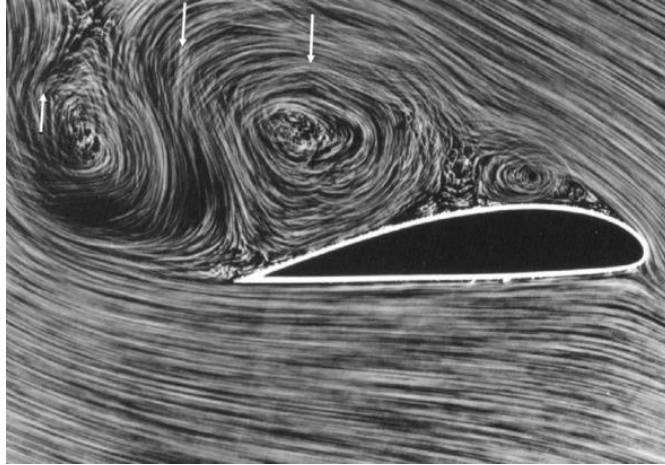


Figure 3: Flow separation caused by an airfoil in a wind tunnel.

www.researchgate.net/figure/Flow-separation-caused-by-an-airfoil-in-a-wind-tunnel-The-tendency-to-develop-flow_fig3_330624606 (9 Sep 2022)

Conclusion

The requirement for a structural support of a competition racing front wing had arisen. For the front wing to successfully deliver the desired amount of downforce, the support must be able withstand the exerted forces. The design criteria contained many unknowns, with very few certain factors. Due to this, many assumptions were made such as maximum velocity of the vehicle and the environment the vehicle will compete in. Using the lift equation, calculations were made to determine the force in newtons that the aerofoil will produce at a set speed. After this, the area moment of inertia of the tube was found and it was able to be determined that the minimum tube diameter that will not deflect to 10mm max.

The history and development of automotive front wings has been explored, where the theory of lift in aerofoils was first studied by Sir George Cayley also known as the father of aerodynamics. The most popular explanation behind the phenomena of lift has been described by Bernoulli's equation although it has also been accepted that it does not fully explain the complete reasons behind lift. In the 1900s wind tunnels have crucially contributed to the understanding of aeronautics whereas more recently Computational techniques such as CFD have furthered the development of wings in all areas of industry.

The influence that carbon fibre has had on the automotive industry has been examined along with the manufacturing techniques involved in creating parts for racing cars. To finalise the report, a prototype experiment is to be suggested where the mechanical properties will be tested, and the best shape of design will be structured using appropriate simulation package.

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