

Stress Analysis and Dynamics

Designing The Structural Support for a Front Automotive Wing for New Race Series.

Automotive Vehicles Front Wing

The front wing of an automotive racing vehicle is a crucial component to the performance of the car. The aim of the front wing is to direct the air over the top of the body work of the car, the angle of the wings will determine the efficiency of the vehicle's aerodynamicist. The height of the car will be kept low, to keep the cars centre of gravity low and aid the creation of aerodynamic downforce.

(McLaren, 2022) the aerodynamic downforce of a race car plays a crucial role in how the car can take corners, and typically generates 80% of the grip required for the car (Harish, 2022)

The front wings are responsible for approximately one third of the downforce, which can be increased to one tenth if tailing a car in front. Whilst controlling the downforce of the vehicle, the front wing will also control airflow around the vehicle, producing the most efficient aerodynamic force to reduce drag.

The makeup of a front wing composes of, the main flap, main plate, cascade, turning vanes and end plates. The end plates also play a very important part in directing airflow around the tires, due to the tyres shape and size, they are inefficient in aerodynamics, so the end plate will circulate the airflow, around the outside of them to reduce drag.

Typically, the front wing of an automotive race car will be 1.65m with the tip of the nose allowed to have a maximum of 0.185m above the reference place. The wing will weight approximately 10kg if it's made from carbon fibre and will generate up to 100 times its weight in downforce. (McLaren 2022)

Assumptions, Limitations and Methodologies Surrounding the Structural Calculations

Assumptions made in the calculation:

- Assuming the aerodynamic load applied on the wing is uniformly distributed, using and therefore using $y_{\max} = (-wL^4)/8EI$
- Assuming a generated aerodynamic load of 150kg (50% extra than the value given in source).
- Assuming the singular wing length is 0.825m.

Given the support is a tube, not a solid, and the cross-sectional area gauge thickness is 2mm. There will be a 4mm difference in outer diameter to inner diameter of the tube. And thus, the formula of $I = \pi/64 (D^4 - d^4)$ will be used to consider the tube diameter when calculating I.

Principles and methodologies include using the $y_{\max} = (-wL^4)/8EI$ formula to calculate I.

This is formulated from differentiating the moments around xx. Another method that could be applied is known as Macaulay's method, where relationship between bending moment and curvature of the beam is assessed, through the Euler-Bernoulli beam theory.

Limitations of this structural calculation analysis for this project includes having to assume the load is UDL, as opposed to knowing the specific point loads or specific UDL lengths.

The Development of Automotive Front Wings and Expected Continued Development.

The role of a wing on a regular car, will be more focused on directing the air over the car and around the tyres. Typically, regular cars are designed to travel at far lower speeds than racing cars.

Considering the legal speed limit for any UK road is 70mph, and the weight of the car, the vehicle does not produce anywhere near enough lift to take off as racing vehicle does, requiring such a calculated and engineered front wing set.

Whilst modern regular cars are designed to counteract any force acting as drag, they aren't required to be as structurally aerodynamic as race cars.

In the earlier stages of racing wings for race cars looked more like this:



The photo here shows an F1 car from 1950. We can see that the designers of this racing vehicle were in pre-development stages of understanding aerodynamics, whilst they allowed a streamlined design to the body of the vehicle, this would allow directional airflow, but marginal amounts, what was not considered was any components to act in a way which will redirect the air, over or around the tyres, thus creating a large drag in the tyre region.

It wasn't until 1968, when Lotus made the advancement in F1 and racing vehicles, it was during this period that the engine sizes doubles, hitting horsepower of 450. It was this drastic increase in power that had Lotus considering that they needed to adapt their race cars to allow for more grip. Jim Hall, former F1 racer, took the concept of an aeroplane wing and considered how a wing of an aeroplane can be reversed to apply a negative lift affect to race cars. Hill attached a pedal powered wing at the rear of his race car, which would allow it to create downforce on the corners but would allow positive directional air flow on the straights.

Colin Chapman of Lotus recognised this as a steppingstone to his breakthrough engineering ingenuity concept and adapted Graham Hill's 1968 Lotus F1 car to include a similar concept.

Cue the introduction of front wings in the automotive racing industry.



Graham Hill went on to add mini front wings to the front of the race car, directing airflow and creating maximum downforce possible from a new component. Hill went on to win that race in Monaco in 1968 – a historical and revolutionary moment in automotive engineering that would be still used and adapted drastically decades later. Ferrari went on to adapt the concept in the next race, on just one of their two race vehicles, and the one with the wing adaption went on to beat their sister wing-less Ferrari racer by five seconds (Fagnan, 2018).

The development of wings, adding rear wings too became dangerously experimental and applied to the cars without extensive research having been conducted. The next race, in the Netherlands had almost every race car having had a wing variation of some sort. The various wing 'prototypes', if you will, front and rear were applied, each being bigger and yet lighter than the last, making them more daring. This resulted in many near-misses and accidents on the racetrack. Due to the lack of testing equipment and aerodynamic knowledge and application, the wing variations continued to be experimental and were risky, posing threats to the lives of drivers, taking a few too.

Roland Ratzenberger. A 33 year old, who died in the 1994 San Marino Grand Prix qualifier due to front wing failure on the Simtek S941 (Walther, 2014). A kerb strike meant two of the four bolts had worked loose, detaching it from the nose of the vehicle, running off the track and into a concrete wall at high speed. This was the biggest accident caused from a front wing, almost 30 years after they were added as a critical component. History almost repeat itself in the 2013 Malaysian Grand Prix when Fernando Alonso, after making contact with another vehicle, the front wing of his car detached, causing the wing to fail, resulting in Fernando skidding into the safety gravel trap.

The Formula Racing League have since brought in regulations and legislations design teams must follow in regard to their designs and restrictions to their product in order for them to compete. The legislations are there for the driver's safety. Components designed must be compliant with minimum and maximum lengths, weights, fixing points.

Great advancements have been achieved in the years since the original concept, technologies including wind tunnels allowing extensive testing and research to be conducted in the industry, with design teams considering how different angles of the wing can direct the airflow down to the floor, allowing higher speed to be achieved.

Similarly to race cars, regular road cars have started to adapt their front wings to be achieving positive aerodynamic applications. Whilst the cars don't need the downforce produced by a formula race car, the manufacturers will benefit from being able to promote a car as more fuel efficient, due to its streamline and aerodynamic body work. Typically, the design of road cars bodywork has been leaning more towards curved fronts.

Take for example, comparing the Tesla Model 3, to a Jeep Wrangler, the two cars couldn't be further apart in aesthetics or body shape, but the facts lay in the results, the co-efficient drag to be specific. The Tesla model 3, holds a low figure of 0.21 Cd, (Lambert, 2016) which could possibly go on to be the most aerodynamic mass-produced car ever.



The Tesla model 3's body work is all about all the curves in all the right places, from the curved wings wrapping around the tyre, to the prominent nose directing the air flow around and under the car. These hugely impactful design components allow the car to be as aerodynamic as it is, making it one of the greatest of its type and time.

On the other hand, we can examine a Jeep Wrangler, nothing quite says outdoors like a Jeep Wrangler.

The purpose of a Jeep Wrangler is not to be aerodynamic, but more of a sports utility vehicle, nonetheless, to examine the aerodynamic profile and co-efficient drag is insightful. The Jeep Wrangler comes in at 0.454 Cd. (Car Sales, 2017). So, whilst the Jeep may be great for the outdoors, it's just not a racing car. The tank like front shows very limited curvature, with barely any components directing air around or under smoothly. This is one of the reasons the Jeep Wrangler isn't the greatest on fuel, but you don't choose a Jeep Wrangler for its fuel efficiency or aerodynamic profile. You might choose to opt for the Tesla model 3 for those reasons, however.



Manufacturing Processes and Materials

Typically, a metal tube would be produced via extrusion, where the product is extruded (mechanically or pneumatically pushed) through a die and will produce a hollow tube like, seamless

structure. Whilst this is cheap to produce – providing the die is a simple design -, can be produced in either hot or cold temperatures, and tends to have a favourable elongated grain structure in the product, the limitation lies with the minimum wall thickness of steel, being no smaller than 3mm (Engineering Product Design, 2022). This is 1mm larger than the allowed in the specification. Ways to overcome this issue can be to change the material, Aluminium having a minimum wall thickness of 1mm, meaning the specification is achievable. Calculations would be done in order to verify that the aluminium is good enough to support the wing with the downforce produced and exerted on the support.

Alternative methods of manufacture can ensure the specified steel material selection can be used, like instead of having a plain cylindrical tube, it could have a different profile, with fins internally to allow a smaller diameter used, but the fins allowing extra support - similar to how a honeycomb structure acts.

Alternatives manufacturing methods can also include carbon fibre manufactured tubes, produced by split moulds. Again, calculations will need to verify if the strength to load ratio is sufficient for the Carbon Fibre tube to act as a structural support in this instance.

Mild steel would not be the best choice of material if the desired steel is the required choice, it's got high impact strength and high tensile strength, but an alloy would need to be produced with it, to reverse/counteract the magnetic properties. The temperature versatility means the produce can be effectively used in cold manufacturing processes and the high temperature allows applications in a variety of places.

Alternatively, a material choice of carbon fibre can be used, if the process of the split mould for carbon fibre as above, is used. The highly desirable material within the automotive vehicle racing industry achieves properties very similar to those of steel but at the fraction of the weight. The properties of high rigidity, high strength and low weight are what make it highly desirable. What makes it comparable to steel is the rigidity levels, similar but almost five times lighter. More often than not, carbon will be applied in various types, typically tubing but also in a honeycomb formation, to allow for greater strength properties.

A similar concept can be adapted for the design and production of the structural support in the design brief given.

Testing, Prototypes and Limitations Surrounding Product Testing

For the production of a prototype, which is unachievable to be produced at this given time, firstly, I'd produce a 3d Model on a software that can analyse the stress analysis after applying a similar force on the model. This will rule out any errors in my calculations, highlighting easily any defects or miscalculations, possibly resulting in recalculating, redesigning and producing a new prototype if the diameter of the 3D analysis isn't sufficient.

Another method of testing that can be applied before a prototype is a simple force applied practical test. This would ensure that practically the product is sufficient, under all variables, heat, wet, weather factors. Once this has all been done, a prototype can then be produced, allowing real situation, practical air tunnel air testing to be done.

The tests would compare similarly to the results achieved in the mathematic calculation produced to determine the minimum diameter of the tube support given the given value of E.

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