

Stress Analysis and

Designing the structural support for a front automotive wing for a new race series.



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Stress Analysis and Dynamics

Front wing

To begin calculating the minimum outside diameter which must be used for the structural support firstly a reasonable length of the front wing would need to be determined and secondly a suitable load value for the front wing to bear. After looking and comparing the front wing in the task to a formula 1 front wing using the dimensions and load value on a front wing like this did not seem appropriate due to the front wing on a formula one car comprising of multiple elements attached to the nose with gaps in between for airflow.



This picture is taken from the formula one website and shows the fia mock car for the 2022 races and shows the makeup of the front wing.

For this task a formula 3 cars front wing will be used to estimate the length and load, This estimation was found in the formula 3 technical regulations where the length of the wing is specified at 675mm as all cars need to be functionally the same and the estimated load of 490N this comes from the 50kg point load that is applied at various points of the wing by the fia to ensure compliance with their own maximum deflection. (FIA, 2022)

Using the equation to determine the second moment of area of an annulus $I = \pi/4(R_1^4 - R_2^4)$ and the formula for the maximum deflection for a cantilever beam with a universally distributed load $Y_{max} = -wL^4/8EI$, knowing that $w=490N$, $Y_{max}=0.01m$, $E=210 \times 10^9 pa$, $L=0.675m$ and that R_1 is 2mm bigger than R_2 because the gauge of the steel tube a system of trial and error can be used to determine different values for the second moment of area from a trial radius and plugging that into the formula for maximum deflection (Y_{max}) until a sufficiently close value is found.

40mm diameter	$I=4.322 \times 10^{-8}$	1.4mm deflection
20mm diameter	$I=4.64 \times 10^{-9}$	13.01mm deflection
24mm diameter	$I=8.43 \times 10^{-9}$	7.2mm deflection
22mm diameter	$I=6.35 \times 10^{-9}$	9.5mm deflection

Through this trial and error process it was determined that a diameter of 22mm will be acceptable as the diameter of the tube, Although diameters of higher than 22mm will still give a maximum deflection of less than 10mm to comply with the requirements there's no need to increase the size of the diameter more than necessary to meet the minimum requirement as this would add unnecessary weight to the car.

Assumptions

There are numerous assumptions that have been made to make this calculation in this way which include, the front wing being fixed in six degrees of freedom this is a necessary and reasonable

assumption for the sake of calculations but it is not entirely accurate, there will be some compliance at the connection point of the front wing to the nose as no structure is infinitely rigid, that the front wing is non-structural and that only the inner tube is to be taken into consideration for the calculations, The young's modulus of steel given in the brief is 210Gpa there will be some tolerance on this value given impurities in the steel similarly the outside diameter of the tube supporting the wing will have a manufacturing tolerance it will not be the exact size all the way across the tube or be perfectly circular. Other assumptions that have been made in the calculation are that the load on the tube is uniformly distributed, that the bending moment occurs only in the longitudinal plane of the beam where in reality there would be horizontal forces such as air resistance acting on the tube and that the bending moment does not change along the length of the beam where there could be different loads applied across the beam as the car is in motion.

These assumptions do limit the accuracy of the calculations made but they are necessary for basic hand calculations to be made to get a value for the outside diameter of the tube and while this calculation will not be perfectly accurate it will give a good estimation.

Alternative methodologies that could have been used are the method of superposition which simplifies a complex beam structure into a series of simplified beams with only one load then the simplified beams are all added together to give the solution (Gramoll, 2022), conjugate beam method which relies solely on the principles of statics where a conjugate beam is defined as a fictional beam that's length is the same as the actual beam but with its loading equal to the bending moment of the original beam divided by its flexural rigidity (Alderliesten, 2021), and macaulay's method which is to use "macaulay bracket" to integrate loads from the point of their initial activation to the end of the beam (dougaj4, 2011).

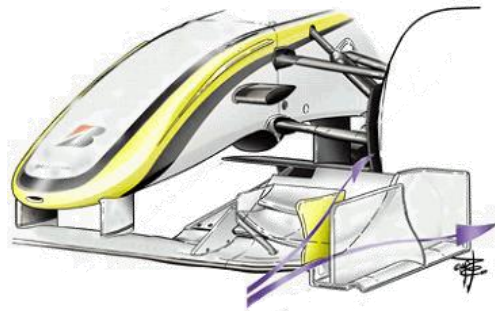
Front wing design

Since the beginning of formula one continuous evolution of the cars has occurred and with that the innovation and improvement of the front wing design. In the beginning formula one cars all had a single element with no end plates and were only a means of producing downforce but since then the front wings have become drastically different and play an important role in directing air flow to the areas needed on the car. The first noticeable change to the front wing occurred when end plates started to be used these end plates direct air flow around the front tyres to minimise the drag that would be produced and directs the airflow to the sidepods and car floor.



Early formula one car with simplistic wing design.

In 2009 the fia changed the technical directive on front wings and required them to be close to the width of the car, this created the problem of turbulent air being created by the front wheels and increasing the drag of the car reducing its aerodynamic efficiency, because of this the teams adjusted their endplates to create an outwash effect directing the air flow around the wheels and adding multiple elements to the end plates to create different effects that influence the performance of the car. (f1dictionary, 2022)



This is the brown BGP001 racer for the 2009 series.

Apart from end plates there are two main things that have changed with the front wing over the years these two main changes are moving from a single element wing to multi element wings with an increased number of wing flaps and reduction of the ride height. As the front wing is an incredibly important factor in creating downforce for the car estimated to be around 30% of the total downforce produced, researchers and teams found that multi element wings the slotted gaps in the wing between the flaps allows high energy airflow to interact with the lower wing surface which delays flow separation. (Kachare, 2017) (Oggioni, 2019)

The second thing that is consistent in the changes to the f1 front wing is that they get closer to the ground, this is due to the fact that the closer to the ground that the team can get the front wing of the car the more downforce the front wing can produce. This increase in downforce is due to the airflow is squeezed through a much smaller area, this restriction on the flow results in much higher flow speeds which in turn produces more suction for the front wing creating more downforce. (warrier, 2021)

With the two main characteristics that change on the front wing over time in mind, it is clear that the designs will continue to push this trend to its limit edging the wing ever closer to the ground while still allowing for the car to race on the track and there will be as many wing flaps as the fia will allow.

Manufacturing processes and materials

In the early days of formula one racing the bodywork of cars was made up of aluminium with tubular steel frames supporting its structure this type of construction was normal until monocoque constructions started in the 1960s, a monocoque shell uses the external structure to support the load which is a fabricated external frame into a single unit this allowed for a stiffer car and a lower frontal area. In the 1980s carbon fibre made its debut for mclaren as a material that would be used in motorsports, this material replaced the aluminium that was previously being used on the vehicles as it is lighter and stronger, currently including the monocoque between 60-70% of a formula one car is made up of carbon fibre. (M.Rosario, 2022) (autosport, 2020)

Along with material changes the manufacturing methods have severely changed when producing these cars for example the chassis is designed and developed using CAD software and FEA software that when motorsports started, they would not have had access to, The machines being 5 axis cnc milling machines that cut epoxy patterns this epoxy is used to ensure that moulds minimize their thermal expansion, then female moulds are made from these epoxy patterns out of carbon fibre and are subject to rigorous inspection at every stage to make sure they are compliant with tolerance. Other parts on the formula one cars have begun being produced through 3d printing, the layup of the carbon fibre matting is done by hand but with the help of a computer guided laser placement system more layers are used on areas that will receive more stress and this nature of layering the body allows the team to use less layers in certain areas so that they can flex more on the track but still pass a load test for deflection by the fia. (motorsport, 2022) (f1simplified, 2012)

Its clear that with the evolution of manufacturing technologies and innovations in material science that the formula one cars have adopted these new technologies to produce ever faster, safer and lighter cars, there would be no way for the teams to produce the cars of today with the manufacturing techniques of the past and the cars would look drastically different if not for innovations in materials such as carbon fibre which has allowed for the intricate wing designs seen on the modern race cars with the ability to flex under certain load conditions.

Prototype testing

There are three main ways that are used to test race series concepts which are computational fluid dynamics or CFD, track testing and wind tunnel testing these three forms of testing are considered the “holy trinity” of motor racing testing. CFD allows for aerodynamicists to simulate the airflow around various geometries over a wide range of operating conditions, A cad model is created and used in the CFD software to simulate the airflow and turbulent vortices that come off the geometries and how they affect the downstream components. Importantly for the testing of the front wing CFD will show the different surface pressure across front wing from air flow as it is simulated in various conditions. (Sullivan, 2021)

The second method of testing the front wing would be wind tunnel testing, this testing is done to back up any simulations that have previously been done and to analyse the effectiveness of different concepts. During this stage of testing sensors would be attached to the front wing to check for compliance to the 10mm deflection as the prototype is on the rolling road of the wind tunnel and its simulated at 180kmph, the high levels of accuracy of the wind tunnel will give a very good idea of how the front wing will deflect and act on the car whilst on track but it cannot predict with perfect accuracy due to limitations on the rolling road stiffness, with the rolling road being more flexible than the track surface, this limitation in modelling was one of the factors leading to the purposing of the 2022 f1 car seen at the beginning of the season. (media, 2021) (hughes, 2022)

Track testing would be the final verification of the calculations made at the beginning of development with the front wing on the car and sensors attached to measure the deflection it would give the opportunity to see how closely the cfd and wind tunnel testing have modelled how the front wing will behave and deflect on track as the car is driving around the circuit (wodehouse, 2022). If during track testing it was found that the front wing was deflecting more than what was allowed under the regulations, then the diameter of the inner tube structure would need to be increased but if the front wing was deflecting less than anticipated there could be opportunity to reduce the diameter of the tube structure as a weight reduction measure and re do the test if budget was of no concern.

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