

Stress Analysis and Dynamics

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

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Introduction

The purpose of the report is to identify and evaluate the design and manufacture of a structural support for a front wing on a race car series, also the evaluation of production and manufacturing processes to deliver it successfully and on time within budget. Firstly, calculating the diameter of a steel tube to support the wing, researching previous and future examples of front wings and how these have evolved. Followed by providing manufacturing techniques used to develop the wing and concluding with prototypes and testing.

1 Calculations.

For the calculations the maximum length and width of a f1 race car was researched and it stated 2m wide, the most practicable length selected then for the max width of wing would be 950mm. There is no set regulation that restricts the overall length of an F1 car, but its width must not exceed 2000mm. [How big is a Formula 1 car? Mercedes' F1 car examined \(motorsport.com\)](#) The current race car for 2022 is 2 meters wide, other teams have slightly smaller dimensions so therefore it was assumed the average. The race car design used for the purpose of the exercise will be 1900mm wide hence a max width of a front wing at 950mm. The wing in this report is slightly smaller than the maximum allowance of 2 meters, totalling 950mm to allow for fixings and end finish.

To allow the workings out a method and principle on slope and deflection of beams can be used.

The figures used for the calculation and workings are as follows, The W value used some assumptions on the length and loads / forces on the wing. Working attached below. The I value also needs to be calculated first to allow use of the below calculation assuming the load on the wing is uniformly distributed.

$$Y_{\max} = \frac{-WL^4}{8EI} \quad \text{Calculation used}$$

$$Y_{\max} = 10\text{mm}$$

$$W = 192.718 \text{ N/m}^2 \text{ working for the maxim load shown below figure 3}$$

$$L = 950 \text{ mm (half the overall width of the race car)}$$

$$E = 210 \text{ GPa}$$

$$I = \text{UNKNOWN? working shown below figure 1}$$

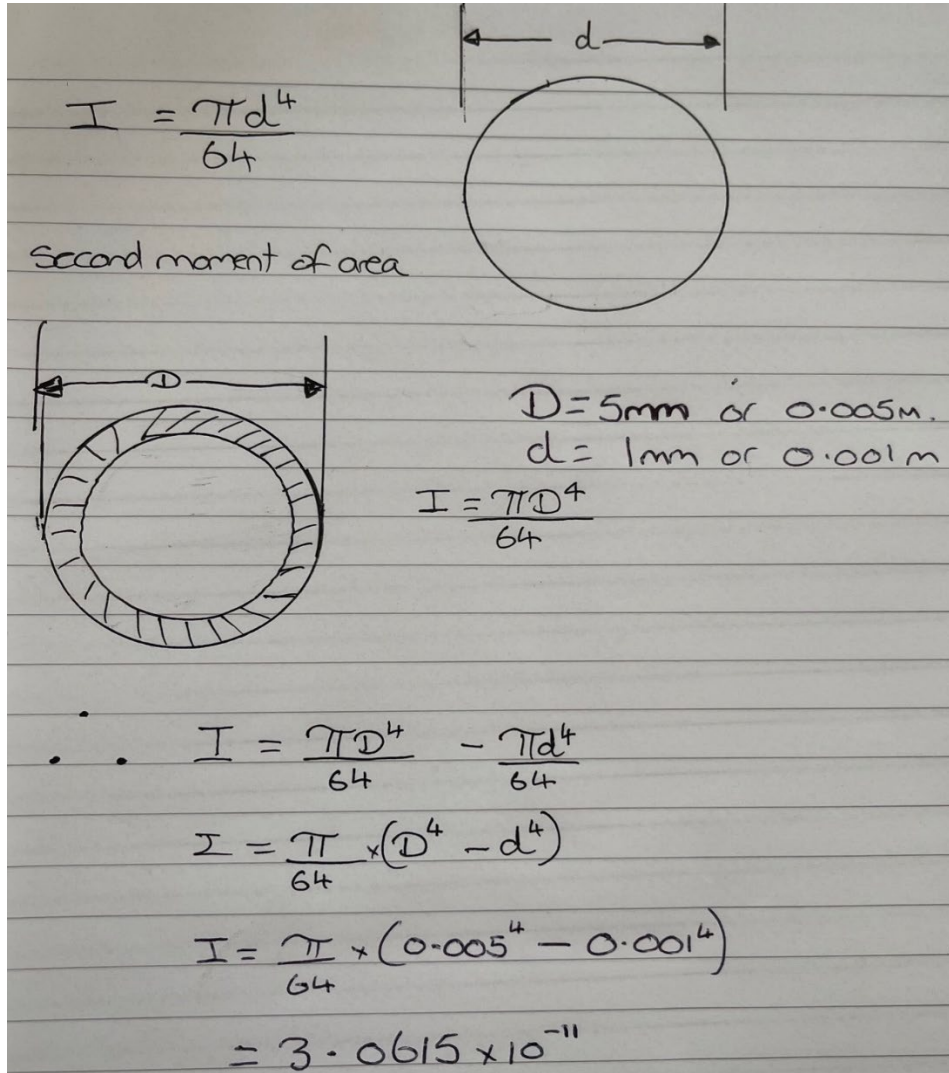
Working out for I show below and on attached hand workings, using the second moment of area of a circle, then subtracting the second moment of area of the circle inside using the set cross section given in the question brief of 2mm gauge

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

64 64
Transposed below to work out.

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

64



Handwritten calculations and diagrams for the second moment of area of a thick-walled tube.

Diagram 1: A circle with diameter d . The formula $I = \frac{\pi d^4}{64}$ is written next to it. Below the diagram, the text "Second moment of area" is written.

Diagram 2: A thick-walled tube with outer diameter D and inner diameter d . The formula $I = \frac{\pi D^4}{64}$ is written next to it.

Calculations:

$$D = 5\text{mm or } 0.005\text{m}$$

$$d = 1\text{mm or } 0.001\text{m}$$

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

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

$$I = \frac{\pi}{64} (0.005^4 - 0.001^4)$$

$$= 3.0615 \times 10^{-11}$$

Working out for I Figure 1

Trial and error can then be used to allow a correct worked example (attached below) once this was proved to work, an excel spreadsheet was used to run the correct working equation and all available diameters checked until the correct thickness tube was found. The thickness required from my working and assumptions show that the required thickness tube needed would be 25mm to allow for the required deflection of 10mm. (highlighted on the excel sheet attached below) this value of 25mm tube is above the maximum required from the calculation as the tube with a diameter of 24mm is not within the set limitations.

$y_{Max} = \frac{-WL^4}{8EI}$				MM				I =	9.34E-09		
		Ymax		0.01							
		w (n/mm^2)		192.718							
		I (M)		0.95						I = $\frac{\pi d^4}{64}$	
		E (Gpa)		2.10E+11						64	
		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						
		31	0.031	0.027	1.92364E-08						
		32	0.032	0.028	2.12892E-08						
		33	0.033	0.029	2.34833E-08						
		34	0.034	0.03	2.58234E-08						

1B Assumptions made during calculations

For the purpose of the calculations above the following assumptions and limitations to calculations were made.

The connection to the race car doesn't have a strong resistance to rotating torque however the overall strength of the wing and steel tube used in the application with the maximum force and speed calculation will be applicable for the structural section

The I value was worked out by hand using the second moment of area calculations, this could have slight discrepancies from the workings out as two separate circles were used at a set diameter wall gauge thickness given at 2mm.

The wind load acting on the wing when travelling at different speeds to a maximum of 230mph depending on if the wing had been damaged or misaligned due to an impact or hit the curb on a racetrack.

The use of computer simulation would give the results of the thickness required but is expensive software to use.

Testing on several different thickness of steel supports to obtain the correct size for the allocated tolerance. This could also be affected dependant on the grade of steel used or the process to manufacture.

Assuming that the aerodynamic load on the wing is uniformly distributed, and also that the wing is a cantilever beam and used the formula to work this out from the slope and deflection of beams principle from the Cantilever Beam with uniformly distributed load equation, this is identified as the most reasonable approach. This is not the most accurate way of working out though due to the nature of different aerodynamic forces acting on the wing while driving at speed.

$$Y_{\max} = \frac{-WL^4}{8EI} \quad \text{Calculation used}$$

2 Research on relevant areas.

When we experience change or new projects, we move from what we had known and done, through a period of transition, below are examples of how the front wing was introduced and how its evolved to today's races in Formula1. The first wings appeared on F1 race cars in 1968 but had long been positioned on other type of motor vehicle race cars prior to this. The solution came from Texas where Jim Hall, a former Grand Prix driver, cleverly understood that if a normal wing could make an airplane fly, an inverted wing should create a similar force, but in the other direction. The negative lift should be capable to increase tire grip. Hall engineered and created

the legendary Chaparral 2F in the mid-60s, a sport car fitted with a huge wing at the back, mounted on the wheel hubs and not on the bodywork. The wing is also moveable, a bit like the DRS [Drag Reduction System] on today's F1 cars.



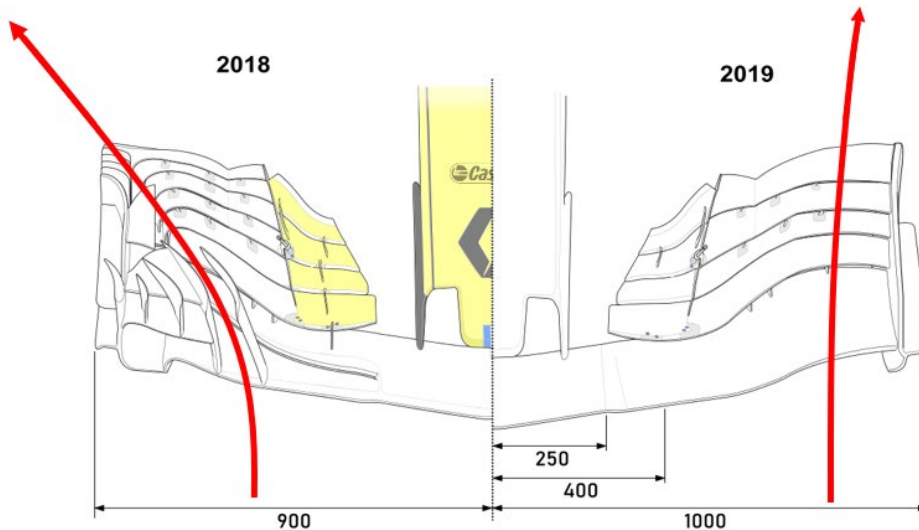
[<https://us.motorsport.com/f1/news/1968-first-wings-f1>]

Early designs linked wings directly to the suspension, but several accidents led to rules stating that wings must be fixed rigidly to the chassis. No movement is allowed. The cars' aerodynamics is designed to provide maximum downforce with a minimum of drag. The front wings on the car can produce 25-40% of the cars downforce.

Looking at Formula 1 wing evolution over the years, two main characteristics can be spotted: reduction of ride height and increase in number of wing flaps. In order to understand the ground effect a brief recall of fluid dynamics is needed: the Bernoulli principle states that "an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy" and can be expressed with the formula: $\frac{v^2}{2} + g \cdot z + \frac{p}{\rho} = \text{constant}$. This is only true for isentropic and incompressible flows and operating at low Mach

www.pulse/aerodynamics-formula-one-front-wing

Since the regulations change in 2009, teams are continuously evolving front wings in order to achieve the maximum possible outwash, even if this means reducing aerodynamic efficiency of the individual body. The consequence of this attitude is a bigger wake that heavily affects the aerodynamics of a following vehicle, decreasing the air flow rate. While everybody knows that in straight line this has a positive effect reducing drag force, not everyone is aware about the serious drawback of lift reduction that obviously affect cornering.



The 2019 Regulations limited the number of flaps to five (main plate included) and banned every kind of turning devices in order to decrease the wake width of formula cars and promote overtake opportunities even when riding through corners. The aim of this changes is to bring back the original goal of front wings that is downforce generation rather than flow deviation as seen in latest years, leaving the outwash philosophy and re-joining the upwash.

3 Manufacturing Processes.

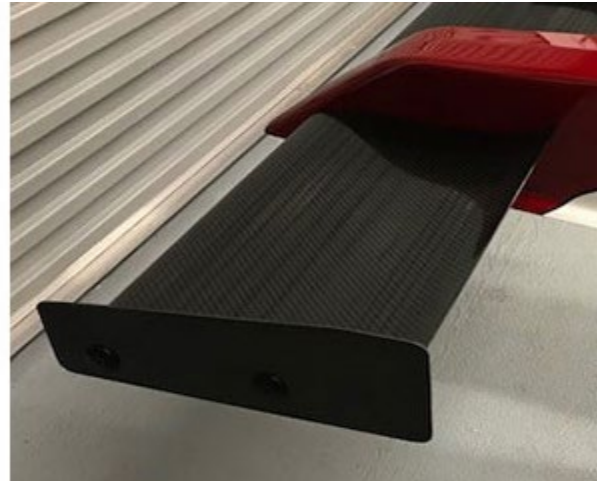
Each front wing is made of a mainplane running almost the whole width of the car suspended from the nose. Onto this are fitted two aerofoil flaps, one on each side, which form the adjustable parts of the wing. These flaps are usually made of one piece of carbon fibre. A variety of materials could be used to manufacture the wing, from a lightweight alloy to carbon fibre, the main constraint on the design would be to have the wing formed as aerodynamically as possible and as light as possible, hence the need for a carbon fibre wing. McLaren f1 race team front wing is currently made from carbon fibre it weighs around 10kg but can generate 100 times its own weight in downforce. [<https://www.mclaren.com/racing/f1>]

The front wing is designed to increase downforce so that it acts like a weight pushing the car closer to the ground, without adding weight (that would cause major disadvantages on acceleration, braking and cornering).

Aluminium could be considered for the wing material selection as it offers some serious benefits for race cars, in the form of a vastly reduced weight compared to other metals. It can be used to fabricate almost any part for a race car using aluminium.

The material selected is carbon fibre due to its material properties a mold is created via 3d printing and machining. The next step is the formation of the composite laminate After the first two layers of carbon fibre applied to the mold, a vacuum process is applied to it. The mold is inserted into a vacuum bag, and it is vacuumed at 0.8 bar.

After the vacuuming the other layers are applied. The two molds are closed on the separation planes and a 40 mm additional material is left on the entire length of the mold. The purpose of this material is to connect the two laminated components formed into the mold. After closing the molds, the added material is overlapped, and a new vacuum process started. after polymerization the composite laminate is removed from the mold. Through a machining process the excess material from the separation area is adjusted. The obtained prototype is tested and measured to determine any forming dimensional errors that could appear during the manufacturing process.



Carbon fibre front wing examples picture 2

A cheaper at home alternative solution to the manufacturing process involves a series of pre-cut ribs tack welded together onto a frame to form the shape of the wing. This skeleton can then be filled with a polymer such as foam and machined to create a solid structure, this then when cleaned up and polished will create the desired streamlined effect.



The wing can then be given it ridged form and strength by covering in fibre glass and edged with carbon fibre for further support and stability.



4 Prototype and Testing.

In order to prove the calculation, a prototype can be produced and tested, this can be achieved by manufacturing a one off to test at home. This prototype can then be tested several ways as highlighted below, not all are practicable to use.

A wind tunnel test could be considered, this is where a full-size part or scaled model part can be tested this, this method is widely used in Formula1 and motorsport today. Wind tunnel testing is the traditional method for developing racing car aerodynamics. There are two distinct variants of wind tunnel testing: full scale testing with actual racing cars and reduced scale testing with purpose-built models.[[Wind Tunnel Testing - Aero Performance Engineering Limited \(aero-performance-engineering.co.uk\)](http://www.aero-performance-engineering.co.uk)] This wind tunnel method has many disadvantages for testing the prototype manufactured due to the cost implication around £12,000 per day for sole use of this technique, the time would be better spent on a racetrack actual testing in real life for a fraction of the price.

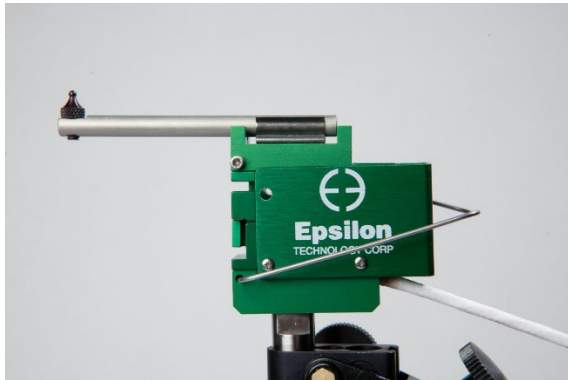
Race track/ road testing is another testing option, a GoPro camera would need to be mounted to a fixed part on the chassis recording the front wing in real time while traveling at speed and cornering on track, a fixed point will then be used to record and measure the deflection in the front wing, this can be measured also using a LVDT- An LVDT (linear variable differential transformer= is an electromechanical sensor used to convert mechanical motion or vibrations, specifically rectilinear motion, into a variable electrical current, voltage or electric signals, and the reverse. The LVDT construction is a hollow metallic cylinder in which a shaft of smaller diameter moves freely back and forth along the cylinder's long axis. The shaft, or pushrod, ends in a magnetically conductive core which must be within the cylinder, or coil assembly, when the device is operating. In common practice, the pushrod is physically attached to the moveable object whose position is to be determined (the measurand), while the coil assembly is attached to a fixed reference point. Movement of the measurand moves the core within the coil assembly; this motion is measured electrically.[[What is a LVDT? | linear variable differential transformer \(omega.co.uk\)](http://www.omega.co.uk)]

The use of CAD model that has been used to study the Ferrari F2004 front wing is an option but again required software and can be less costly to implement, the

drawback with this method will require a skilled programmer and use of the software needs to be known in depth taking time into effect to learn.

The method recommended to test at home on budget constraints would be the fixed bench bolted testing method. This method would be best practice for time and budget constraints. The method is to look at the resistance to bending for each of our tube profiles. The fixed end of the structural section will be bolted or pinned to enable it to be 'fixed' at one end horizontally, a series of weights will be positioned along set measurements from the fixed point and the deflection in the tube measured using a deflection gauge, The deflection is measured with a single arm with an attached spherical contact tip, similar to those on a dial indicator. The full bridge strain gaged construction provides an electrical output compatible with any electronics designed for a strain gaged transducer.

The magnetic base furnished with the gage can be mounted to the desired reference surface, whether flat or round. The tip can then be positioned to measure the deformation encountered during the test. This is a common process used in larger scale engineering tests



Deflection Gauge as discussed above

[<https://www.epsilontech.com/products/deflectometer-model-3540/>]

Bibliography

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[Wind Load vs. Wind Speed \(engineeringtoolbox.com\)](#)

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