

STRESS ANALYSIS & DYNAMICS

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Mechanical and Manufacturing
Engineering

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Task 1

- a) Calculate the minimum outside diameter which must be used (all working must be shown), for suitable loading which you must establish.

In order to solve this Task, I will be using the **Slope and Deflections of Beams** Theory.

It is stated the deflection must not exceed 10mm in order to conform to race regulations. The structural section is to be made from Steel ($E = 210GP$) and is to be manufactured from tubing with a circular cross section with a gauge of 2mm. It is stated the wing is held in all 6 degrees of freedom by the nose of the car which indicates the nose is structurally fixed in position. In order to carry out calculations we must first identify what will be assumed.

We will assume the structure is a Cantilever Beam with a uniformly distributed (UD) load in order to do simple calculations. We can therefore use the following equation (Formula Provided and taught by Kelvin Lake through lessons and examples):

$$y_{MAX} = \frac{-WL^4}{8EI}$$

Understanding the Formula:

- y_{MAX} – Maximum Deflection in the Y axis (m)
- W – Weight (N/m)
- L – Length (In m)
- E – Young's Modulus (Pa)
- I – Moment of Inertia

To give a deeper understanding, research has been carried out on a racing series. For my example I have chosen F1. The racecar I have chosen as my model is a **1990's Ferrari 641**.



I have chosen this model based on the wing similarities portrayed on **Figure 1** of the assignment.

Max Speed: 193mph / 310kmph

Mass: 503kg

Dimensions (L / W / H): 4,460mm / 2,130mm / 1,000mm

<https://www.wallpaperup.com/uploads/wallpapers/2013/10/05/155976/6615cb09789f6823f334cd58b45d93ba.jpg>

Due to me unfortunately not having a 1990's Ferrari 641 to hand I am unable to identify exact specifications for the car. Therefore, I will use an alternative method and estimate the size of the wing using images of the vehicle. I will set the width of the vehicle as a means of identifying the size of the wing. (The dimensions are estimates and used as a means of guidance to answer the question)

Firstly, I have a front view image of the vehicle:



[Ferrari 641, Goodwood Festival of Speed, 2015 · RaceFans](#)

Secondly, I used a bird's eye view:



[top view of the 641 | Ferrari, Ferrari f1, Formula 1 car \(pinterest.co.uk\)](#)

I have received values of 750mm and 650mm so I will assume that the wing is 700mm in length. We now need to calculate the downforce imposed on the vehicle. As stated by *CFD, F1 aerodynamics, TotalSim* the front wing is capable of imposing a downforce of between 25%-40% of the vehicle's total downforce at maximum speed. I confirmed this statement through the *Technical Formula 1 Dictionary* which also stated a downforce of 25% can be seen on the front wing depending on configuration set up. Therefore, we shall calculate 25% of the total downforce on the car. First, we must identify the gravitational forces applied at top speed. It is stated in the *Technical Formula 1 Dictionary* that the vehicle can experience 5g's at top speed. That's 5x the mass of the vehicle.

Therefore, the Weight at top speed:

$$503 * 5 = 2515kg$$

Therefore, the car feels a force of 2515kg when travelling at top speed. We require the gravitational force of this value. So:

$$2515 * 9.8 = 24,647Nm$$

We require 25% of this value:

$$24,647 * 0.25 = 6,161.75Nm$$

However, due to the design of the wing, this value must be divided into two as there is essentially two front wings attached to the nose piece:

$$\frac{6,161.75}{2} = 3,080.875Nm$$

From our calculations we know the following set of data (Data simplified and converted):

- $y_{MAX} - 0.01m$
- $W - 3,081Nm$
- $L - 0.7m$
- $E - 2.1 \times 10^{11}$
- $I - ?$

Using the data, Slope and Deflection of Beams Theory of a UD Load Cantilever Beam and re-arranging the equation to make I the subject of the Formula:

$$y_{MAX} = \frac{-WL^4}{8EI} \rightarrow 0.01 = \frac{-3081*0.7^4}{8*(2.1*10^{11})*I}$$

Re-arranging the formula:

$$I = -\frac{WL^4}{8Ey_{MAX}} \rightarrow I = -\frac{3081*0.7^4}{8*(2.1*10^{11})*0.01} \rightarrow I = 4.4032625 * 10^{-8}$$

Converting for Excel:

$$I = 4.40326E - 08$$

Now that we have the I value, we can use it to calculate the Second Moment of Area for a circle. However, we are dealing with a tube so we must use the Principle of Superposition. Therefore:

$$I = \frac{\pi d^4}{64} \quad \text{and so} \quad I = \frac{\pi D^4}{64}$$

Thus making:

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

We will use our data in Excel to confirm it is correct using the UD Cantilever Beam Equation:

Ymax	0.01			I	4.40326E-08
W	3081				
L	0.7				
E	2.1E+11				

The values are the same for I therefore we can use it to find the most suitable Steel Pipe size.

Using the Second Moment of Area and Principle of Superposition:

D (mm)	D (m)	d (m)
5	0.005	0.001

We know there is a 2mm gauge material, therefore there is 4mm worth of material across the pipe. Which can be seen from the conversion into meters there is a 4mm difference.

We use the equation at the top of the page:

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

D (mm)	D (m)	d (m)	I
5	0.005	0.001	3.0615E-11

As the size pipe D (mm) has increased, a figure closer to our I value has been obtained and we can see our Ideal Size which you would not find on the market and is precision made. To the nearest mm which is more manufacturable to a company and then we have real world availability of 42mm pipe which is easily available to buy.

Ideal Size (High Budget)	40.025	0.04025	0.03625	4.40331E-08
Nearest mm Size (Medium Budget)	41	0.041	0.037	4.66879E-08
Real World Availability (Low Budget)	42	0.042	0.038	5.03656E-08

Therefore, the minimum outside diameter which must be used is 40.025mm. However, the realistic choice is 42mm pipe as it is more readily available to the market. **The answer is 42.** Reference: Douglas Adams' Hitchhikers Guide to the Galaxy.

Task 1

- b) Discuss any assumptions that you have made, the limitations of your calculations and how these may be overcome. Discuss alternative principles and methodologies that could have been used.

The wing length will have an effect on the results, a longer dimension would lead the pipe diameter to change. The larger the wing, the greater the pipe diameter required. The smaller the wing the smaller the pipe diameter is required. Due to there being no exact specifications online it is not exact to the model I have selected and has margin for error. This assumption can be overcome precisely by having the specifications of the vehicle.

The aerodynamic load on the wing is based on a Cantilever Beam which is correct to the assumption made on the design of there being two front wings attached to the nose piece. However, the load would not be uniformly distributed in a real-life scenario. The wing is used to create downforce as well as deflect air into directions which enhance the airflow of the vehicle. The end plates of a front wing which are often in line with the wheels will deflect the air flow to go above the tires to reduce the drag. Additionally, the wing may want to create vortexes in the air to help the flow as it moves towards the rear of the vehicle. This isn't specific to the model I have chosen, however F1 cars are built to have as minimum drag as possible in order to increase speed. We have made the assumptions that the moment of inertia is 10mm as it is the maximum allowed and we have used that in our results however I would assume 10mm of deflection is in perfect conditions. A windy day could potentially cause this value to exceed should the variables align. A UD Cantilever Beam has been used for easy calculations due to the limits of the data available. Testing or CFD would be carried out to actually work this out. This is more computational, and a greater number of numeric calculations required.

The downforce on the wing is 25%. While sources indicate this is correct, it is not exact. Downforce on the front wing ranges between 20% and 45% and over the decades may be even more so. This is due to the nature of the design and changing this value will change the weight experienced on the vehicle travelling at top speed. For example, if we take 40% as our range. The force acting on our wing is now 15% more than our calculations. The downforce on each area of a racing car will be specific to the car's needs. What you wouldn't want is the downforce on the front to be too low and suddenly the vehicle starts wanting to fly. This is why on a vehicle such as an airplane the shape and design are built upside down to create lift as opposed to downforce.

There are two front wings attached to the nose piece. Based on the images provided an assumption has been made that there are two front wings attached to the nose piece and therefore the downforce equally distributed between them. This caused my calculations to be adjusted to accommodate for this. The % of downforce calculated for a single front wing is 12.5% of the total downforce experienced by the vehicle travelling at top speed.

Alternate forms of calculations that could have been carried out include computer simulations, analytical methods, numerical methodologies. Slope and Deflection of Beam Theory has been considered a reasonable approach for the assignment.

Task 2

- ❖ Discuss different types of automotive front wings, how they have developed historically and how you think they may develop in the future.

In order to understand how automotive front wings have developed over the years. It is important that we focus on F1 as an example. F1 cars originally did not have an aerodynamic front wing, the cars weight most likely would have been reason for it staying on the ground. The first front wing in F1 appeared in 1968 where Jim Hall understood an inverted plane wing would have the opposite effect of lift. It is hard to describe how they have changed through history so instead a picture will demonstrate it:



https://media-exp1.licdn.com/dms/image/C5612AQGhY1kO0QCM2w/article-inline_image-shrink_1000_1488/0/1551460579818?e=1669248000&v=beta&t=ei7a5lClpXheHet6KKYORHtU30f1XjtgrET17kFcvE

From the image above you can see how over a period of 40 years the front wing has drastically changed. But let's discuss what those changes actually are! There are two main characteristics which we need to look at in order to define their differences. That being Increased wing flaps and also a reduction of the wings height from the ground. The height of the wing can be linked with some simple fluid dynamics. Bernoulli's Principle states an increase in the speed of a fluid occurs simultaneously with a decrease in static pressure or a decrease in the fluid's potential energy. The smaller the gap between the floor and the wing and understanding that in a steady state condition the mass flow rate will be constant, a reduction in area will be balanced by an increase in the fluid's speed. This is responsible for the increased pressure difference acting on the wing.

In order for F1 cars to increase the aerofoil camber they require a multitude of wings attached to the front wing. This is done without experiencing any flow detachment. The area between each individual wing allows high energy airflow to interact with the lower wing surface. This in effect strengthens the boundary layer and delays the flow separation. These smaller wings are placed close together and overlap to create upwash which prevents detachment. This happens due to there being a peak minimum pressure on the top flap very close to the trailing end of the lower wing. So as time has progressed and the technology of wind tunnels has progressed the front wing has evolved to make F1 cars even more aerodynamic but with more control of the flow and

direction in which suits the vehicles performance. Additionally they will have been restricted by FIA compliance. As we progress in the world, petrol and diesel is being left behind. The world must adapt and Electric vehicles are coming into the world. I believe going forward there will be drastic changes as the weight of the vehicle changes and a change in aerodynamic flow is required. Battery power has immense torque and I would guess front wings will remove the number of flaps and eventually have a front wing which attaches from the nose and goes over the tyres to re-attach to the central body of the vehicle essentially creating one large front wing. A design that will feature as minimum wind resistance as possible.

Task 3

- ❖ Discuss the manufacturing processes and materials used in the development of automotive wings and relate this to task 2.

The automotive front wing has had a number of changes throughout the years, materials included. We know all F1 cars today are mostly made from Carbon Fiber, chassis included. The first use of Carbon Fiber in F1 was in 1975 by Hill and Brabham, therefore we shall look at the materials used before then.

Many of the vehicles would have been made from aluminium, front wing included. Molded sheet aluminium would have been used prior to the introduction to carbon fiber. Sheet aluminium comes in all sizes and the material would have been cut for the desired shape. This cut of sheet metal would then be molded into the desired form of the car. Aluminium is a strong and lightweight material compared to steel. This is due to its low density. Back then however you would see a large quantity of bolts and rivets holding the pieces together which again adds to the overall weight of the vehicle. Aluminium wings would have lasted into the late 1970's where carbon fiber eventually phased them out of existence.

When Carbon Fiber was introduced into Formula 1 it changed racing forever. For the front wing and the rest of the vehicle it would have meant a reduction in weight. From 1979 to 1989 as shown in Task 2 you can see the front wing is not decreasing in size. As a matter of fact, it is increasing as time progresses but also becoming more intricate with its design. As time progresses in F1 the cars are progressively reducing in weight. A reduction in weight means they will have a greater amount of lift when travelling. In order to prevent this from happening the front wing design has changed to accommodate for a greater downforce while also allowing wind to be deflected and moved for increased aerodynamic flow. Carbon Fiber is a very unique material, it's first stages of production it is like a mesh cloth. Capable of being molded and moved freely. A five-axis milling machine would cut desired shapes out of solid epoxy. The milling machines would have received the dimensions through CAD drawings to specify exactly the shape they wish to be molded. Layers upon layers of carbon fiber mesh are added on to suit the mold and glue to stick it all together, it is then classified as a composite material. The material is clamped and mounted, heated and it is a very labor-intensive process to make small components. This is all carried out in a clean room environment and thus the greatest of care taken for such a delicate process. Carbon Fiber is a high tensile material with low density. The material has a high modulus making it stronger than Steel. It is also highly resistant to heat once cured making it the perfect material for F1 Racing and is used for the majority of F1 Parts.

Task 4

- ❖ In order to verify your calculations, it is proposed that a prototype is to be produced and tested. Explain how you think this should be done and how you would interpret the experimental results.

Design

Firstly, a specification must be made to ensure whatever is being created is to conform with what its going to be used in. For this instance, the FIA for Formula One. The front wing account for between 25%-40% of the total downforce so depending on the rest of the vehicle this will need to be considered for the design. A hand drawing with dimensions would be made initially as concepts and ideas. These ideas are then converted into 3D CAD models where adjustments can be made with ease. Within the CAD software is the ability to test different scenarios and forces on the design. In this instance a Simulation of what you expect to happen. If it is attached to the nose and you have specified, the material is 6mm thick then you may want to see the total deflection if you may need to increase the thickness of the materials in certain areas as a form of reinforcement. The design can have a Von-Mises Stress applied onto the wing to understand the maximum load the wing can take. The Simulation of airflow at a certain speed can be measured to see how the air may affect the rest of the vehicle. The front wing is crucial as it affects the airflow to the rest of the car and vortex currents may be needed to help the airflow to the car to reduce drag as much as possible. Any design changes will generally be made here as complex simulations can be made to define specific parameters. This will enable you to view what we expect to see in different scenarios. Due to how advanced F1 teams have become, they could integrate this design onto their cockpit simulation to test the performance as a real-world simulation. Essentially, we are doing a Computational Fluid Dynamic (CFD) simulation in order to determine what we will expect from the performance of the fully built wing. CFD simulations are used as a supplement to the experimental and analytical methods used to analyze the design. The experimental results stage is where any and all modifications to the design should be done based on the needs of the vehicle. If more downforce is required, then potentially changing the angle of the wing or adding more smaller wings to attain the results specified.

Prototype Creation

To ensure the wing is suitable, a five-axis milling machine is to be used to cut and contour the shape of the wing's component pieces. Due to the complexity of carbon fiber some planning is required as the carbon fiber will require molding and shaping bit by bit to create the shape desired for each component and the joining of the components. Once the components are cured and joined together you will have a full wing assembly exactly as drawn on the CAD design.

Advanced Testing

To ensure the front wing is free from any potential defects it will be tested in a wind tunnel to better understand the aerodynamic flow around the wing. This can replicate different conditions with wind affecting different sides of the wing. Potentially further testing within the simulation such as rain might be used to further understand how weather conditions can affect the performance of the wing. When in the wind tunnel you can simulate speeds at which the flow of air will be affecting the vehicle and a measurement of the downforce created by the wing can be taken. From our previous simulations we would expect results that correlate with the CAD simulations.

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