Formula one Front Wing Optimization and Configuration
Modelling the Bending and Lift of a F1 Front Wing

Amirah Abdul-Rahman, Fatemah Al-Failkawi, Fatemah Hasan, Fatima Abdullah, Jenan Bin-Ali, and Walid Smew

Industrial Engineering Department
American University of the Middle East (AUM)
Eqaila, Kuwait
Walid.Smew@aum.edu.kw

Abstract

Formula One, F1, is considered as the most technologically advanced and complicated category of racing. The field of F1 is ever growing with challenges due to drivers wanting faster lap times and engineers optimizing their design to fit the season's regulations. The main two forces are the downforce and the drag force. Downforce provides the car with grip and steady handling while the drag force reduces the speed of the car. In the recent seasons, F1 teams have been devoting their attention to optimizing the front wing that generates about 35% alone of the overall downforce generated by the other car. F1 regulations are constantly changing which calls for the need to optimize under their standards. In this paper, a F1 car front wing have been designed and the two forces have been optimized. The downforce exerts abundant amounts of loading on the front wing which causes it to bend. The bending of the wing can permanently deform it. The bending behavior can be examined through the mathematical modelling formulation of a second order differential equation that describes the elastic deformation through mechanical concepts. The overall performance of the car can be enhancing through the optimization of the bending. The optimal wing was configured through finding the optimal Angle of Attack (AoA) and lift to drag coefficient that suits the standard of some selected F1 Racing Tracks. Finally, a prototype of the designed F1 car front wing was built.

Keywords

Design Front Wing Bending, Down-Force, Drag-Force, Mathematical Modelling, Optimization, Configuration.

1. Introduction

F1 cars are at the highest tier of innovation and modern-day engineering designs. In order to excel at the race, the driver needs to be equipped with the design that provides him with the edge over the competition. Annually, the FIA forces the teams to design and optimize under new regulations. The topic of this year was the constant challenge to reduce lap times. In order to acquire the optimal car handling at higher speeds, the focus was on optimizing the front wing that creates about 35 percent of the total downforce on the car (TotalSim, 2016). While the downforce is a downward force exerted on the wing responsible for handling and steadying the car, the drag force is opposite to the direction of the moving car which reduces the speed with causing some turbulence. The optimization of the wing ought to increase the downforce and diminish the drag force. The front wing is the initial component of the car that makes contact with the air, thus it must aerodynamically utilize the air into enhancing the car's performance. The front wing has several components which are: the endplates, upper flaps, adjustable wings, nose cone, nose cone, and main-plate. The nose cone is the longest part of the front wing components that sticks out before the rest. This feature allows it to exclusively make the first actually contact with the coming air. The function of it is to navigate and guide the air below the car. The front wing is similar to a plane's, yet placed upside down. The lift force that is

© IEOM Society International

responsible of pushing the airplane upwards with an upward direction is the same negative lift force which is also called a downforce that instead forces the car to stay grounded with a downward direction due to how that wing is placed. The airflow that was forced to head downward by the nose cone will head over to the main plane. The main plane will split this flow into two, one going over it and one going under it. The air over the plate will inflict a downward pressure on the plate. As this flow continuous, the shape of the wing will resist this airflow causing it to be denser and correspondingly heavier. The air will be slower and more condense at the resistance causing the molecules to be closer to one another which causes more pressure on the main-plate. The force resulting from this will have a downwards direction. As for the air beneath the wing, it will move a lot faster due to the shape of the wing. The pressure will be lower due to the high speed and density of the molecules. The force will be in an upwards direction. The resulting force between the two pressures will ultimately be downwards due to the airflow and pressure at the top being a lot greater. As for the air that flows on the sides of the car, the endplates will direct them around the tires since otherwise the contact between the approaching airflow and tires will cause turbulence. The tires are engineered to be aerodynamic therefore they will not benefit from the airflow. Upper flaps also share the function of redirecting the air over the tires upwards to decrease instabilities. As for the adjustable wings, they can be adjusted in order to have different angles. The higher the angle the more pressure and downforce will be on the main-plane and vice versa.

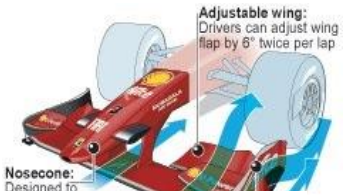

Figure 1: F1 Car's Front Wing

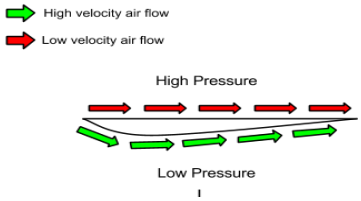

Figure 2: Downforce Location

1.1 Problem Statement

The manipulation of influential existing variables acts as a function that will allow the study of the bending's behavior under different circumstances. A solution and proper parameter values must be found in order to optimize the bending. The function would aid greatly due to the changing regulations and demanding nature of F1 racing

1.2 Objective

1. Optimize the bending of the front wing
2. Find the corresponding angle of attack and lift to drag ratios
3. Provide wing configurations for several tracks
4. Build a SolidWorks model

1.3 Weather conditions

Weather conditions (e.g., density, pressure, and temperature) effects on the performance of the F1 car. Temperature and density are inversely proportional. The lower the temperature is the more density the air is going to have. Cold air is much heavier than hot air due to its molecules being closer to each other. The higher the temperature, the light the air will be and the less density the air is going to have. As for the relationship between density and pressure, the relationship is directly proportional .As previously discussed; the density on top of the main-plane was more which exerted a higher pressure than the one beneath the main-plane. The inversely proportional relationship will cause a higher pressure when the temperature is low. Therefore at different weather conditions the adjustable wings should be set at angles that either reduce or increase the downforce on the wing with respect to the weather.

2 Literature Review

Muzzupappa and Pagnotta (2002), used one of the two currently available methodologies of optimizing a F1 wing in order to approach their optimization problem. The purpose of their optimization was to effectively improve the design of a F1 rear front wing by using a genetic algorithm. The methodology consisted of formulating a genetic algorithm using high processing software called Mathematica with a code developed especially for genetic algorithms called NASTRAN in order to achieve the optimality between reducing the weight of the wing and the stiffness that results in the minimum bend. The case study's objective is to reduce the weight of the wing

© IEOM Society International

maintaining the highest stiffness possible under different ply orientations. Muzzupappa and Pagnotta (2002) state that, the genetic algorithm is set to find the wing with the minimum laminate stacking sequence under different ply orientations. The materials in the study are composite materials that have a laminate stacking sequence "A laminate is a material that is composed of a number of layers laminae bonded together "(Nettles,1994).As for the ply orientation they are how layers stack at angles in other words how the layer stack on top of each other. The lower part of the rear wing is the part of the F1 car that gets subjected to the most loading. The lower rear wing is not only subjected to the air flow pressure which is the downforce, but also the loads resulting from the upper wings. The upper wings are also subjected to certain loads which all adds up to the one acting on the lower rear wing. The combination of these two loads acting on it makes it the part undergoing the heaviest loads compared to all the other wings. The bending should not affect the performance of the car neither should it cause the permanent deformation of the wing, therefore the stiffness optimization was applied. The genetic algorithm will make the optimal combination of reduced weight and stronger stiffness without the stacking sequence failing under loads. The case study as well addresses the ply orientation of the wing and includes it in the genetic algorithm. The desired result is to have a stronger, yet lighter wing. The genetic algorithm possesses a probabilistic optimization technique of combining a range of parameters in order to generate the optimal solution. It is based on evolution in nature and natural random selection which is how the algorithm works.

This case study achieved a weight reduction of about 2% of the weight of the wing. If the wing sacrificed some stiffness the algorithm would reduce the weight by 8%.The optimal ply angles where the weight reduction demonstrated significant results were at angle of thirty and ninety degrees. The case study succeeded in performing an optimization on the bending of the front wing. The results stated that, the genetic algorithm was successful, yet the computational time was very long and insufficient.

Another methodology in studying and optimizing the bending of the F1 front wing is using Computational Fluid Another work by SAAD, M. (2010) was performed to study F1 car aerodynamics front wing using computational fluid dynamics (CFD). Due to its ability, CFD was use to test the formulated wing with various simulations without having to construct a prototype of the wing. The main objective of this case study was to increase the downforce and reduce the drag force effecting the overall performance and speed of the car. It also aims to use CFD and SolidWorks in order to test the usability of the wing without the cost of manufacturing a prototype. The case study finds the lift and drag coefficient of the SolidWorks model based on a NACA 23012 airfoil design and under the 2010 regulations of FIA. The study emphasizes on the importance of the front wing being the first component to be in contact with the airflow. CFD can be used as a computational tool for formulating a model in contact with fluids and airflows. It possesses very powerful computational power in order to represent mathematical systems. The case study used partial differential equations due to its relativity to fluid flows in order to represent the model which is the front wing. The equation studies the bending of the wing with consideration of the fluid's velocity and density. This optimization system consists of the velocity and density as inputs and the downforce as an output of this objective function. Then the CFD analyzes the downforce generated and applies it to the wing in order to report the bending behavior. The case study used a model from another research in order to optimize their bending. After finding the optimum downforce with bending behaviors suited for the regulations of 2010.The case study finds the corresponding lift and drag ratios for the formulated wing. Through the use of CFD the user is able to generate forces in corresponding directions of downforce and drag in order to compute the ratio. CFD uses the lift and drag coefficient equations in order to find them for the system. The case study used the partial differential equation to increase the downforce then apply it on the NACA 23012 design. After the analysis of the bending and lift to drag ratio, alterations to the airfoil were made and retested. The study was finally able to increase the downforce and reduce the drag force by different design alternations in SolidWorks on the endplates. Moreover it was able to reduce the cost of the iterative modification process with simulating the model through CFD.

A third case study was performed using the CFD on the front wing of a F1 car. This case study aimed to study design changes in order to increase the downforce (Patil, Kshirsagar & Parge, 2014). The methodology of the study also was on altering the design of the front wing to reduce the downforce. The case study states that, the front wing is not just important because of its initial contact with airflow, but also it is responsible for redirecting the airflow over the whole car and into the brakes and engine. The airflow at the brakes can improve the steering and handling and the airflow into the engine can prevent the engine from overheating. The regulations of FIA are changing every year which calls for the effective and quick reliable design response in order to meet these regulations. The program uses the partial differential equations in order to represent the aerodynamic principles effecting the bending and behavior of the wing. The case study investigates all the components of the front wing and their interaction with the downforce and airflow. While examining the bending, the case study observed that changes in the height of the main plate have an effect on the downforce. The lower the main plate and the closer it is to the ground, generated more downforce. The study could not however lower the wing due to the regulations of FIA, yet they suggested the

© IEOM Society International

flexibility of the wing to be increase. After they studied the lift and drag coefficients, they reported that two wings can generate less than half the downforce being generated by one wing. The results found that the construction of a simulated model allowed the manipulation of different design aspects. The changes and modifications allowed the study to discover many design implementations and its effect of the downforce affecting the front wing. The conclusion suggested that the vertical endplates' height and area should be increase to reduce the drag and raise the lift to drag ratio.

2.1 Summery of the Literature Reviews and Our Work

Muzzupappa and Pangnotta 2002	Saad 2010	Patil,Kshirsagar & Parge 2014	Our project
•Genetic Algorithm	•Partial Differential Equation	•Partial Differential Equation	•2nd Order Differential Equation
•Mathematica	•CFD	•CFD	•Maple
•NASTRAN	•Solid works	•Solid works	•Solid works
•Angle of attack	•Lift and drag coefficients	•Lift and drag coefficients	•Lift and drag coefficients
	•Prototype building	•Prototype building	•Angle of Attack
			•Prototype building

Figure 4: Summery of the Literature Review

3 Methodology

3.1 Optimization and Mathematical Modelling

Most existing systems in reality have interactions with their boundaries and therefore make it far too complicated to study entirely. The mathematical modeling approach focuses on the system's most influential parts then excludes the remainder. The approach studies the most significant variables and manipulates them to examine the changes on the model. A mathematical modeling approach will result in a mathematical formulation of the chosen system. Since the structure of the wing is symmetric only half of the wing will be modeled. The support at the nose cone and the distributed force exerted on the main-plane allow the model to be mathematically represented as a cantilever beam with a uniform exerted loading. The study of mechanical structures provides the bending equation for this type of beam shown in equation (1). It also represents the bending on the different regions of the beam as shown in equation (2).

$$M(x) = EI\frac{d^2v}{dx^2} \quad (1)$$

$$M = -\frac{wx^2}{2} + wLx - \frac{wL^2}{2} \quad (2)$$

The two equations are bending equations that can be equated and combined. The mathematical representation of the whole structure resulted in a 2nd order differential equation as shown in equation 3.The mathematical equation that will be used is equation 3.Table 1 illustrates what each component in the equation represents. The most influential variables that will be studied as decision variables are the material Length L ,and horizontal distance The optimization will allocated the best combination of the decision variables that will result in the minimum and maximum bending while providing the wing's characteristics of what length, which material, and where the force will be on the horizontal distance

$$EI\frac{d^2v}{dx^2} = -\frac{wx^2}{2} + wLx - \frac{wL^2}{2} \quad (3)$$

© IEOM Society International

Symbol	Name	Description
W	Uniform loading/downforce	kN/m
L	Total length	m
E	Young's modulus	GPa
I	Second Moment of inertia	m^4
V	Deflection about the x axis The vertical displacement	m
X	Distance from beam to the support the will be effected by the force	m

Table 1: Variables

3.2 FIA Regulation

The decision variables must be compatible and according to the regulations of the"Federation Internationale de l'Automobile" in short FIA regulations. The federations' goal is to implement different regulations accord multiple automotive categories around the world.F1 stands for the formula being the rules, restrictions, and regulations under which teams must compete and one stand for the highest and most difficult tier of automotive racing. These regulations are enforced mainly to ensure the safety of the drivers and secondly to reduce the costs. The regulations change from year to year which proves why optimization is crucial to the process of coping with changes. In 2017 the regulations that are concerned with the main-plane of the wing are the following:

1. The wing's total length must not exceed 1.8 m.
2. The wing must not bend more than 3 mm while subjected under 0.06 KN/m.

The first condition must apply while choosing the range for the length variable. As for the second regulation it is very crucial to determine whether the wing has passed the test of bending and to validate the optimization model. Although compared to the great force values a 0.06 KN/m is not significant, however it will set a standards for the bending behavior. It is referred to as the new deflection test for the front wing.

3.3 Data Collection

The decision variables of the model must be within a certain valid range in order to effectively be optimized in the model. This process is the data collection in order to define these ranges for the most influential variables which are the modulus of elasticity, length, and horizontal distance.

Decision Variable: Length

The table shown below illustrates that the front wing has been increasing in length over the past years. The data collection starts from the year 2008 due to not being able to find data that is older than that year. As the 2017 FIA regulation stated, the table shows that the maximum length allowed in the current year is 1.8m.The lengths in the tables below are for the total lengths of the front wing, therefore half of these lengths will be taken due to the model considering only half of the wing's structure. The range for the length decision variable was set to be L = [0.7, 0.9] m. The first variable is in accordance with the first FIA regulation discussed which is the length not exceeding 1.8m.

Table 2: Length

II. Year	2008		2009		2016		2017
Front wing length	1400mm		1800mm		1650mm		1800mm

© IEOM Society International

Decision Variable: Modulus of Elasticity

The second variable is E which stands for the modulus of elasticity and also the material. The material plays a major part in the bending behavior of the wing. Each material has a certain modulus of elasticity which is a mechanical property expressing its behavior under tensile or compressive forced exerted. The modulus of elasticity is related to the deformation of the material and its ability to return to its original form after being subjected to compressive or tensile forces. The modulus of elasticity is a benchmark for the material's ability to endure loads without its permanent deformation. Loads within its modulus will cause it to return to its original shape, however loads exceeding its modulus will cause it to permanently deform which in turn cause the wing to break or fracture. In order to comply with the material regulations of FIA, the top five materials chosen for F1 wings were selected in order to set the range of the following variable. The modulus was set to be E = [112.4,270] Gpa according to the table below. Also as a further investigation, the material's prices were found and listed in order to achieve the aim of FIA which is to reduce the manufacturing costs while maintaining safety. The prices will allow optimizing the cheapest will they could pass the F1 deflection test.

Material	E
Carbon Fiber	150 GPa
Zylon	270 GPa
Aramids	112.4 GPa
Dyneema	121 GPa
Spectra	132 GPa

Table 3: Modulus of Elasticity

Table 4: Cost of the Material

Material	Price (per 50 square meters)
Carbon Fiber	7.5-11.8
Zylon	200-400
Aramids	5-9
Dyneema	18$
Spectra	178$

Decision Variable: Horizontal Distance

Lastly, the horizontal distance determines the point exactly from the support where the bending occurs on the wing's structure. As of the previous study of the boundary conditions knowledge of where the bending would be at its minimum should be close to the support where the horizontal distance would be zero. The bending point in the model should be restricted within a range that would force it to effect the most on a distance closer to the support so it can result in a minimal bend. The range was selected to be X= [0, 00003] m with the maximum horizontal distance less than the vertical allowed distance of the deflection test which is 3 mm.

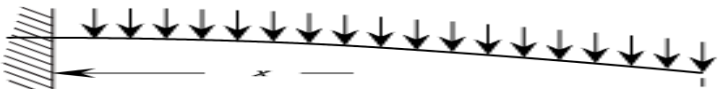

Figure 5: Deflection

© IEOM Society International

CONSTANT INPUTS

The model will be optimized according to three different present variables; however this leaves more components of the equation left to be determined. These remaining components will be known as constant inputs to this optimization model. The constant inputs are the uniform downforce W and the second moment of inertia I.

Constant Input: Downforce

The downforce the model will be subjected to is the same one of the deflection test. The downforce W = 0.06kN/m in order to find the optimal wing to pass the deflection test which in return will validate the model's results.

Constant Input: Second Moment of Inertia

The NACA 23012 airfoil was selected in this study because it is not concerned about the shape of the wing nor the aerodynamics. The airfoil will be used in later discussions as well. In this part the cross section of the beam of this airfoil was used in order for the deflection to be calculated which set a constant input I = 0.0224 $m^{4.}$

After the collection of the data, setting the decision variable ranges, and determine the constant inputs the model is completed and is ready for optimization. The model is summarized as follows for the ease of comprehension.

Table 5: Result

\

Component	Name	Notation	Unit
Decision Variables:			
1	E	Modulus of elasticity	GPa
2	L	Wing length	m
3	x	Distance from wing to support	m
Constant Inputs:			
1	W	Downforce	kN/m
2	I	Second Moment of Inertia	m^4
W = 0.06 kN/m **I=0.0224 m^4**			
Objective Function:			
Min/Max V = $\frac{22.32142857\left(\frac{1}{3}LWx^3-\frac{1}{2}WL^2x^2-\frac{1}{2}Wx^2x^2\right)}{E}$ **m (4)**			
Subject to Constraints:			
1	E	[112.4,270]	GPa
2	L	[0.7,0.9]	m
3	X	[0,0.00003]	m

MAPLE OPTIMIZER

The optimization tool used is Maple which is a powerful mathematical engine that enables the user to find the solution of complicated mathematical formulations within seconds. Maple utilizes the Global Optimization technique with a Differential Evolution as way to optimize differential equations with multiple variables. It is also chosen due to the nonlinearity of the differential equation which is the case for this mathematical model. The optimization method is an iterative process of selection between a wide variety of initial candidate solutions acting under the feasible and constraint range. New combinations of these candidate solutions are then made off of the older ones till the optimal solution is found. The optimization will yield results twice in this case. The first optimization will be done in order to find the optimal wing that passes the deflection test regardless of the cost. The second optimization will be performed by setting the modulus to the cheapest manufacturing

© IEOM Society International

material's modulus in order to find the cheapest possible wing characteristics that can pass the deflection test and correspondingly reduce the cost.

First Optimization: OPTIMAL WING

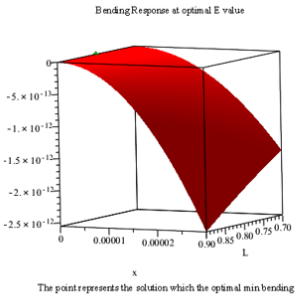

Figure 1: Optimal Result, Min Bending

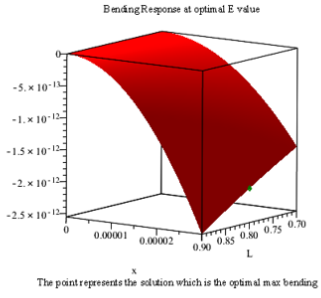

Figure 2: Optimal Result, Max Bending

The above Figures represent all the feasible solution set. Both Figures share the same shape due to it being the same feasible set for this particular wing. The graphs were generated after taking the optimal value E to investigate the interaction effect between the length L and the horizontal distance X in giving the response which is the bending. The X axis side represents the interaction of X with the bending. As X increases the bending increases which applies to the 2nd order differential equation. The further the horizontal distance is from the support the more the bending increases. The side with L represents the relationship and interaction between it and the bending. The smaller the length the smaller the bending would be which also confirms the directly proportional relationship of the L with the bending from the 2nd order differential equation. When the length L and the horizontal distance X interact at an optimal value of E, they produce an interaction surface with the feasible solution set. The solution set represents all the possible bending solutions which then the optimization technique chooses the optimal solution for either the minimization or the maximization and locates it with a green point. The point is the exact location of the solution on the response surface. The graphical representation does not only confirm the validity of the formulation, but also validates the usage and accuracy of the optimization method.

Table 6: Optimal Wing Characteristics

Optimal Wing Characteristics	
Length : 1.6 m	< 1.8 m satisfies FIA regulation
Modulus : 191.2 Gpa	Closest material is Dyneema
Minimum Bend : -3.43.10^-13 m	< 3 mm satisfies FIA regulation
Maximum Bend : -2.01.10^-12 m	< 3 mm satisfies FIA regulation

Second Optimization: CHEAPEST WING

Table 7: Cheapest Wing Characteristics

Cheapest Wing Characteristics	
Length : 1.6 m	< 1.8 m satisfies FIA regulation
Modulus : 112.4 Gpa	Closest material is Aramid
Minimum Bend : -3.81.10^-18 m	< 3 mm satisfies FIA regulation
Maximum Bend : -3.43.10^-12 m	< 3 mm satisfies FIA regulation

WINGS COMPARISION

Table 8: Wing Characteristics Comparison

Wing Characteristics Comparison	
Optimal Wing	**Cheapest Wing**
Length:1.6 m	**Length:**1.6 m
Modulus:191.2 Gpa	**Modulus:**112.4 Gpa
Minimum Bend: -3.43.10^-13 m	**Minimum Bend:** -3.81.10^-18 m
Maximum Bend: -2.01.10^-12 m	**Maximum Bend:** -3.43.10^-12 m

© IEOM Society International

As it can be interpreted from the results both wings possess the same length. The modulus of the optimal wing is stronger than that of the cheapest wing due to its modulus of elasticity. The minimum bend as well for the optimal wing is less than that of the cheapest wing which is also in turn depends on the modulus. The maximum bend for the optimal wing is also less than that of the cheapest wing. These two wings have different bending results and wing characteristics, yet both of these wings succeed to pass the deflection test since both of the bending results are less than that of 3 mms.

3.4 Wing Configuration

The F1 world is known for its competitive nature, so F1 designers and engineers are on a constant move to find and discover the fastest F1 car. The engineers' first trial began in trying to power up the car's horse power but after trials and error they found that they could enhance a car's performance by enhancing the applied Aerodynamic forces which are the downforce and the drag force, and enhancing the Aerodynamic coefficients which are the lift and drag coefficients. To configure the needed aerodynamic setup designers must first study the race track in terms of length and types of corners. It was found that the car's front wing is considered as a significant component that fits the aerodynamics requests that will attain the forces and coefficients. The front wing is the first part to have contact with the aerodynamic airflow when the airflow pressure hits it, the front wing's performance will then affect the rest of F1 car body once the airflow flows over the car. So as a result, the faster the airflow was the greater was the exerted downforce on the wing.

The coefficient of lift and drag are critical elements for generating the downforce but to recognize them the Angle of Attack (AOA) must be obtained. The angle of attack is the angle between the wing's chord line and the direction of the airflow based on different speeds. The adjustable wing, which is one of the components of the front wing is the part that depends on the angle of attack. Also, the amount of lift and drag is directly proportional to angle of attack. As for the relationship between the front wing's length and the AOA it is the opposite, the longer the wing was the less AOA.

In this study, the approach studies and examines the needed wing (front wing) configurations to relate it with the resulted length that was obtained through Maple Optimizer. As mentioned previously, the longer the wing the more force (downforce) it generates and the less AOA it needs, and the Angle of Attack can be investigated through the lift and drag coefficients or to be more specific it has a direct relationship with the lift and drag ratio. So based on what was discover through the mathematical modeling, the study's approach was to find the values of coefficient of lift based on the following equation:

$$AOA = CL/\pi * AR \quad (4)$$

This equation is known as the Angle of attack equation, Where:

AOA= Angle of attack, unit of degree
CL= coefficient of lift
AR= Aspect ratio,

The needed calculations were obtained through the AOA formula. These calculations were needed to set possible ranges to calculate the Lift and Drag (L/D) ratio and compare them with each track's needed downforce, AOA values, L/D ratio and to confirm it with the examined wing length that was obtained though the mathematical modeling, which was 1.6 meters.

So, first the values of the coefficient of Drag (Cd) were to be set at certain values. According to (Formula1-dictionary.net, 2017), it was found that the Drag coefficient ranges between 0.85 to 1. Then there were the values of AOA, although these values could be calculated using the AOA formula but the problem was that these values could not be validated due to secrecy of the databases, so a possible way was instead of calculating the values of AOA, the needed angles were to be found and examined as a fixed values based on this study's chosen wing length which was 1.6 meters, the downforce and car speed depending on the chosen tracks and circuits. So, each angle represents its track or circuit based on its needed car speed and downforce and try to fit it with the required front wing length. The investigation lead to the following angles 2°, 6°, 4°, 14° and 24°, theses angles were found to be the most suitable ones, and to obtain the right values the angles were converted from Degree into RAD (radian). The coefficient of lift values (CL) were calculated by the AOA formula as in equation (4) with an Aspect Ratio of 6 and angles of 2°, 6°,4°,14° and 24°, as shown in Figure(8).

© IEOM Society International

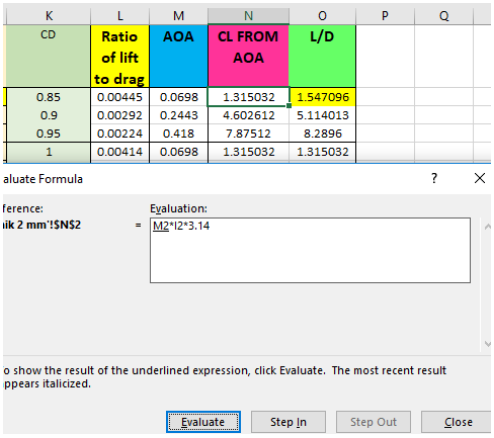

Figure 8: New CL values

Finally the values of L/D ratio were calculated using Excel as shown in Figure (9), but most importantly was the validation of these obtained values. So according to (team, 2017), which is the real-life database, a comparison for the L/D ratio values was accomplished successfully.

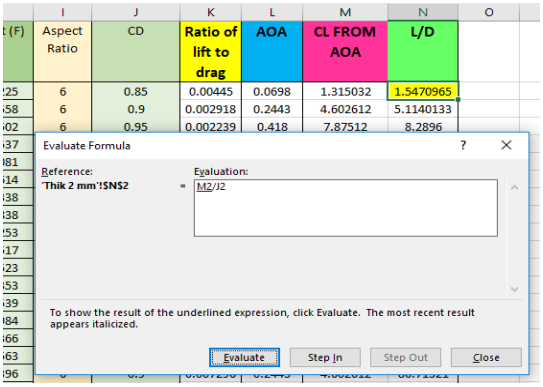

Figure 9: L/D ratio values

Downforce in Newton kN/m	Downforce (D) Kgf	Wingspan (W)	Thiknes s (H)	Air Density (P)	Velocity (V) m/s	Coefficient (F)	Aspect Ratio	AOA	CD	Ratio of lift to drag	AOA	CL FROM AOA	L/D
2	203.943	1.6	0.12	1.225	67.056	0.003782225	6	0.007227182	0.85	0.00445	0.0698	1.315032	1.547096
2	203.943	1.6	0.12	1.225	80.467	0.002626558	6	0.005018901	0.9	0.00292	0.2443	4.602612	5.114013
2	203.943	1.6	0.12	1.225	89.408	0.002127502	6	0.00406529	0.95	0.00224	0.418	7.87512	8.2896
2.19	224	1.6	0.12	1.225	67.056	0.004141537	6	0.007913764	1	0.00414	0.0698	1.315032	1.315032
2.19	224	1.6	0.12	1.225	80.467	0.002876081	6	0.005495697	0.9	0.0032	0.2443	4.602612	5.114013
2.19	224	1.6	0.12	1.225	89.408	0.002329614	6	0.004451492	1	0.00233	0.418	7.87512	7.87512
3	305.914	1.6	0.12	1.225	67.056	0.005673338	6	0.010840773	0.85	0.00667	0.0698	1.315032	1.547096
3	305.914	1.6	0.12	1.225	80.467	0.003939838	6	0.007528352	0.9	0.00438	0.2443	4.602612	5.114013
3	305.914	1.6	0.12	1.225	89.408	0.003191253	6	0.006097935	1	0.00319	0.418	7.87512	7.87512
3.88	396	1.6	0.12	1.225	67.056	0.007337517	6	0.014020733	0.85	0.00863	0.0698	1.315032	1.547096
3.88	396	1.6	0.12	1.225	80.467	0.005095523	6	0.009736669	0.9	0.00566	0.2443	4.602612	5.114013
3.88	396	1.6	0.12	1.225	89.408	0.004127353	6	0.007886662	1	0.00413	0.418	7.87512	7.87512
3.99	407.886	1.6	0.12	1.225	67.056	0.007545539	6	0.014418228	0.85	0.00888	0.0698	1.315032	1.547096
3.99	407.886	1.6	0.12	1.225	80.467	0.005239984	6	0.010012708	0.9	0.00582	0.2443	4.602612	5.114013
3.99	407.886	1.6	0.12	1.225	89.408	0.004244366	6	0.008110253	1	0.00424	0.418	7.87512	7.87512
5	509.858	1.6	0.12	1.225	67.056	0.009455563	6	0.018067955	0.85	0.01112	0.0698	1.315032	1.547096
5	509.858	1.6	0.12	1.225	80.467	0.006566396	6	0.012547253	0.9	0.0073	0.2443	4.602612	5.114013
5	509.858	1.6	0.12	1.225	89.408	0.005318754	6	0.010163225	1	0.00532	0.418	7.87512	7.87512
5.44	555	1.6	0.12	1.225	67.056	0.010287653	6	0.019657935	0.85	0.0121	0.0698	1.315032	1.547096
5.44	555	1.6	0.12	1.225	80.467	0.007144239	6	0.013651412	0.9	0.00794	0.2443	4.602612	5.114013
5.44	555	1.6	0.12	1.225	89.408	0.005786805	6	0.011057588	1	0.00579	0.418	7.87512	7.87512
8.88	906	1.6	0.12	1.225	67.056	0.01679308	6	0.032088688	0.85	0.01976	0.0698	1.315032	1.547096
8.88	906	1.6	0.12	1.225	80.467	0.011661919	6	0.022283922	0.9	0.01296	0.2443	4.602612	5.114013
8.88	906	1.6	0.12	1.225	89.408	0.009446108	6	0.018049887	1	0.00945	0.418	7.87512	7.87512

Figure 10: New calculations using excel evaluator (AOA and L/D values)

© IEOM Society International

Table 9: New calculations using excel evaluator (AOA and L/D values)

AOA=2 CL= 0.56	
CD	**L/D Result**
0.85	0.658
0.9	0.622
0.95	0.589
1	0.56
AOA=4 CL= 1.315	
CD	**L/D Result**
0.85	1.547
0.9	**1.4611**
0.95	**1.38**
1	**1.31**
AOA=6 CL= 1.972	
CD	**L/D Result**
0.85	**2.32**
0.9	**2.191**
0.95	**2.07**
1	**1.972**
AOA=14 CL= 4.602	
CD	**L/D Result**
0.85	**5.414**
0.9	**5.11**
0.95	**4.84**
1	**4.60**
AOA=24 CL= 7.875	
CD	**L/D Result**
0.85	**9.26**
0.9	**8.75**
0.95	**8.2**
1	**7.87**

Table (9), shows that each Angle of Attack (AOA) has its own value of the lift coefficient (CL), which basically this value was calculated through the AOA equation. So to reach the needed L/D values, each of the CL values were divided by each of the following CD values (0.85, 0.9,0.95,1) to calculate the L/D ratio. The importance of the lift and drag ratio lists as follows, basically it shows a critical significance for the F1 teams, where the L/D ratio enables designers to search for the right components that will be incorporated in the car to run efficiently per track. Having different L/D values will be associated to faster lap times depending on the track, so the L/d ratio is critical for circuit efficiency and it is not just about minimizing the drag while maximizing the lift. Also it shows the needed downforce that should be generated for each track. The F1 tracks, most of the corners of each circuit are between low to medium speed and high speed are the most difficult ones (team, 2017).

Track	Country	Type	Front wing Downforce KN/m	L/D ranges	AOA	Calculated L/D
Fuji	Japan	Race circuit	1	1,3,7,8,15	2°	0.658
					4°	1.31
					24°	7.87 , 8.2
Monza	Italy	Race circuit	1	3,9,10,11	24°	8.75, 9.26
Monaco	Monaco	Street Long	2	9,13/14	24°	8.75, 9.26
Silverstone	Silverstone	Street short	3	1,5,9,10,11,14,15	2°	0.658
					4°	1.31
					14°	5.11
					24°	7.87, 8.2
Sebring	USA	Road circuit	5	2,3,4,5,17,18	6°	1.97, 2.07
					14°	4.6, 5.1
Yas Marina	UAE	Road circuit	5	5,6,12	14°	5.11

Table 10: track & circuit configuration

© IEOM Society International

The previous Tables (9) and (10) summarized, configured and confirmed that the calculated Lift and Drag (L/D) ratio ranges that were examined for F1 track and circuit (L/D). Proving that the approach of finding a suitable front wing configuration was successfully attempted. In Table (10), each of the known F1 tracks and circuits were specified by their type of track or race, the needed downforce for each track, official L/D ranges and finally a comparison between this study's examined Angle of Attack and its calculated L/D ratio by applying the AOA equation. So, the goal was to provide a suitable front wing configuration to compete in tracks that is why the values of Angle of Attack and the values of lift and drag ratio were significantly needed to be found for the wing based on the wing's length.
In general, the previous configuration approach was examined because F1 databases are considered as confidential and top- most privacy, because every configuration is a team's secret. So a direct comparison of the Angle of attack (AOA) values with real configurations of other F1 teams could not be made. So the approach investigated the Lift to drag ratio and obtained their values as a way to configure and provide a suitable front wing for each race track.

4 Conclusion

The bending of the front wing is a trending topic in the last two years of F1 designs. The front wing is mainly responsible for generating a great portion of the downforce acting on the wing. The wing's bending must be optimized in order to withstand such downforce loadings otherwise it will permanently deform, fracture, and evidently cost the driver his life. The teams are always striving for optimal performance annually which regards the performance of the front wing. The front wing controls the steadiness, handling, and steering in order to reduce lap times and provide the driver with precision in control. In order to find the optimum bending for a F1 front wing, a new approach was developed using 2nd order differential equation with several variables. The approach differs from what has been done previously in this field in methodology and computational tools. It is also highly replica table with almost no costs in time nor capitals. It was established so it can be optimized according to the changing regulation and constraints of FIA.The optimization is capable of generating wings under different constraints and a different choice of variables. It can be used for multiple purposes under studying the bending such as finding the optimal wing, optimizing for a certain downforce, optimizing for several airfoils, optimizing for the cheapest wing, and optimizing a certain modulus of elasticity. The conducted study used the developed optimization in order to find the optimal wing and the cheapest wing that can pass the deflection test which validated the mathematical model. Every track in F1 demands different wing configurations. After that, the wing configurations were found in relatively to the corresponding wing in order to set the wing for different tracks.

5 Future Works

A 3D prototype of the wing was made in SolidWorks in order to test the design that have been developed. The design would be placed under analytical tests of Computational Fluid Dynamics in order to determine modifications or beneficial alterations. The wings must in their final process undergo either testing or simulations which CFD is recommended for strongly.

Acknowledgements

We would like to thank Dr. Joao Fialho for his contribution and help in mathematical modeling and Dr. Suat Kasap for all the feedbacks and assistance to facilitate producing this work and participating in IEOM (2018).

Biography

Walid Smew is an Assistant Professor in Industrial Engineering at the American University of the Middle East (AUM), Kuwait. He earned B.S. and Masters in Industrial and Systems Engineering from Benghazi University, Libya and Ph.D. in Supply Chain Management (SCM) from the School of Mechanical and Manufacturing Engineering in Dublin City University (DCU), Ireland. Dr. Smew has published journal and conference papers and supervised many graduation projects. He has an excellent experience, both theoretically and practically in Machining and Metal Forming operations and the application of Lean Six Sigma for reducing variations and problem solving through the application of different statistical techniques to identify root causes and find appropriate optimized solutions. He provided technical guidance to assembly processes using Work Measurement techniques to identify opportunities to improve production performance in terms of time and cost. He has done consulting in the area SCM and Simulation Modeling along with Dr. John Geraghty from DCU; they developed a comprehensive production and distribution simulation model for Ireland's future oil supply on behalf of Byrne Ó Cléirigh for engineering and management consultancy. Dr. Smew research interest include Lean Six Sigma, SCM,

© IEOM Society International

Manufacturing, Simulation and Optimization. Dr. Smew is a Chartered Engineer and member of Libyan Engineers Association, he is also a certified Lean Six Sigma Greenbelt and Product and Process Validation engineer in Ireland.

References

A breakdown of the materials used in Formula One cars. (2017, January 16). Retrieved April 30, 2017, from http://www.textiletechnologies.co.uk/blog/a-breakdown-of-the-materials-used-in-formula-one-cars/

Applied Math Example 2nd Order Initial Value Differential Equation F1 Front Wing Bending. (2017). Kinvert.com. Retrieved 28 April 2017, from http://www.kinvert.com/content/applied-math-example-2nd-order-initial-value- differential-equation-f1-front-wing-bending

Aerodynamics of F1. (2017). Formula1-dictionary.net. Retrieved 6 November 2017, from http://www.formula1-dictionary.net/aerodynamics_of_f1.html

Beam Formulas with Shear and Moment Diagrams. (2007). 1st ed. [ebook] Washington: American Forest & Paper Association. Available at: http://www.awc.org/pdf/codes-standards/publications/design-aids/AWC-DA6 BeamFormulas-0710.pdf [Accessed 18 Feb. 2017].

Borole, S., Bhasale, O., Patil, S., Khot, A. and Navadagi, V. (2016). Analysis of Aerodynamic Characteristics In Front Wing of F1 Car Using CFD. 2nd ed. [ebook] Department of Mechanical Engineering, pp.1-9. Available at:http://ijsart.com/Content/PDFDocuments/IJSARTV2I63452.pdf [Accessed 18 Feb. 2017].

Downforce. (2017). Formula1-dictionary.net. Retrieved 8 May 2017, fromhttp://www.formula1-dictionary.net/downforce.html

Federation Internationale de l'Automobile. (2017). Federation Internationale de l'Automobile.

Retrieved 7 May 2017, from http://www.fia.com/regulation/category/110

Front Wing of F1 Car: How to Optimize its Design?. (2017). SimScale. Retrieved 18 February 2017, from https://www.simscale.com/blog/2016/10/front-wing-f1-car-optimize/

Front Wing of F1 Car: How to Optimize its Design with CAE. (2017, April 20). Retrieved April 28, 2017, fromhttps://www.simscale.com/blog/2016/10/front-wing-f1-car-optimize/

Grayling, M. (2014). Modelling with Differential Equations: nrich.maths.org.Nrich.maths.org. Retrieved 15 March 2017, from http://nrich.maths.org/11052

Kieffer, w., Moujaes, s., &Armbya, N. (2006). CFD study of section characteristics of Formula Mazda race car wings. Sciencedirect.com. Retrieved 7 April 2017, from http://www.sciencedirect.com/science/article/pii/S0895717705004590

Lawson, D., & Marion, G. (2008). An Introduction to Mathematical Modelling (1sted.pp.1-26).Scotland.Retrieved from https://people.maths.bris.ac.uk/~madjl/course_text.pdf

Modulus of Elasticity or Young's Modulus - and Tensile Modulus for common Materials. (2017). Engineeringtoolbox.com. Retrieved 28 April 2017, from http://www.engineeringtoolbox.com/young-modulus-d_417.html

Mulsanne's Corner Race Car Aerodynamics Database: 2007-2008 Panoz DP01 Champ Car. (2017). Mulsannescorner.com. Retrieved 28 April 2017, from http://www.mulsannescorner.com/aerodatabasepanozdp01.html

Muzzupappa, M. and Pagnotta, L. (2002). Optimum Design Of A Formula One Rear Wing Using A Genetic Algorithm. 1st Ed. Dubrovink: International Design Conference, pp.1-4.

Noble, J. (2003). Formula One for dummies (1st ed.). New York: Wiley.

Optimization Model Basics - Optimization - Mathematics Library User's Guide - Documentation - Math, Statistics and Matrix Libraries for .NET in C#, VB and F#. (2017). Extremeoptimization.com. Retrieved 28 April 2017, from http://www.extremeoptimization.com/Documentation/Mathematics/Optimizatio_n/Optimization-Model-Basics.aspx

© IEOM Society International

Reddy, J., & Gupta, M. (2006). FINDING THE OPTIMUM ANGLE OF ATTACK FOR THE FRONT WING OF AN F1 CAR USING CFD. Citeseerx.ist.psu.edu.

Saad, m. (2010). Study of f1 car aerodynamics front wing using computational. 1st ed.[ebook] pahang: universiti malaysia, pp.1-5. Available at: http://umpir.ump.edu.my/1705/1/Mohd_Syazrul_Shafiq_Saad_(_CD_5074_) pdf [Accessed 13 Mar. 2017].

Savage, G. (2008, July). Composite materials technology in formula 1 motor racing.Retrieved from http://www.formula1dictionary.net/Big/Composite%20Materials%20Technology%20in%20Formula%201%20Motor%20Racing.pdf

Seljak, G. (2008). Race Car Aerodynamics. 1st ed. [ebook] Available at: http://www f1.ijs.si/~rudi/sola/RaceCarAerodynamics.pdf [Accessed 18 Feb. 2017].

Sochi Autodrom information · F1 Fanatic. (2017). F1 Fanatic. Retrieved 28 April 2017, from http://www.f1fanatic.co.uk/f1-information/going-to-a-race/sochi- autodrom-circuit-information/

SAAD, M. (2010). STUDY OF F1 CAR AERODYNAMICS FRONT WING USING COMPUTATIONAL FLUID DYNAMICS (CFD). Faculty Of Mechanical Engineering UNIVERSITI MALAYSIA PAHANG, page : 1-9. Retrievedfrom http://umpir.ump.edu.my/1705/1/Mohd_Syazrul_Shafiq_Saad_%28_CD_5074_%29.pdf

THE FIA. (2017). Federation Internationale de l'Automobile. Retrieved 7 May 2017, from http://www.fia.com/fia

Thomas, G. (2014, June 25). Materials Used In Formula One (F1) Cars. Retrieved April 28, 2017, from http://www.azom.com/article.aspx?ArticleID=8194

Total Sim.(2016). Secrects of formuals one Retrieved from https://www.totalsimulation.co.uk/secrets-formula-1-part-3-role-front-wing/

Top 15 Disasterous Formula One Car Crashes. (2017). TheSportster. Retrieved 7 May 2017, from

http://www.thesportster.com/racing/top-15-disasterous-formula-one-car-crashes/team, T. (2017). L/D ratio for race cars - F1technical.net. F1technical.net. Retrieved 6 November 2017, from http://www.f1technical.net/forum/viewtopic.php?t=18486

Wing Design Parameters. (2017). [online] Adg.stanford.edu. Available at: http://adg.stanford.edu/aa241/wingdesign/wingparams.html [Accessed 18 Feb. 2017].

What is this guy doing to the front wing during a pit stop? • r/formula1. (2017). reddit. Retrieved 6 November 2017, from https://www.reddit.com/r/formula1/comments/1ar46d/what_is_this_guy_doing_to_the_front_wing_during_a/

© IEOM Society International