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BACHELOR'S DEGREE IN ENGINEERING FOR INDUSTRIAL TECHNOLOGY (GITI)

END-OF-DEGREE PROJECT

WILLIAMS FW-31 FRONT WING DESIGN AND UPGRADE

Author: Ignacio Hernández Apolinario Fernández de Sousa

Director: David Wolenski

Madrid

May 2020

I declare, under my responsibility, that the project report presented with the title

WILLIAMS FW-31 FRONT WING DESIGN AND UPGRADE

submitted to ICAI School of Engineering of Comillas Pontifical University

in the academic year 2019/20 is my authorship, original and unpublished,

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Fdo.: Ignacio Hernández Apolinario Fdez. de Sousa Date: 05/10/2020

I authorize the submission of this project.

THE PROJECT DIRECTOR

Fdo.: David Wolenski Date: 05/10/2020

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DISEÑO Y MEJORA DEL ALERÓN DELANTERO DEL WILLIAMS FW-31

Autor: Hernández Apolinario Fernández de Sousa, Ignacio.
Director: Wolenski, David.
Entidad Colaboradora: Colorado School of Mines

RESUMEN DEL PROYECTO

En este proyecto, el alerón delantero del coche de Fórmula 1 Williams FW-31 se ha diseñado y simulado con el fin de hallar sus respectivos coeficientes de arrastre y sustentación. Más tarde, se introdujeron algunas mejoras tratando de disminuir estos coeficientes, para aumentar el rendimiento del coche. Por último, se realizó un estudio sobre el proceso de fabricación y los posibles materiales que se pudiesen emplear para disminuir el peso, manteniendo la fuerza necesaria.

Palabras clave: Formula 1, Aerodinámica, Materiales, Fabricación

Introducción

Este Proyecto tiene como objetivo responder a la pronunciada evolución en el rendimiento que los monoplazas han tenido en la Fórmula 1 durante la última década, principalmente debido a la aerodinámica. El cambio más notable en la aerodinámica se produjo desde 2017, cuando entró en vigor una nueva regulación. En esta nueva regulación, a los equipos de Fórmula 1 se les permitió desarrollar aún más su paquete aerodinámico.

Por lo tanto, la idea de este Proyecto es comparar el rendimiento del alerón delantero del Williams FW-31 con la versión mejorada del mismo, añadiendo nuevas mejoras aerodinámicas permitidas en el actual reglamento. Para ello, los diseños serán simulados para comparar sus coeficientes de sustentación y de arrastre, y se analizarán los resultados. Una vez comprobado que el rendimiento aumentará con el nuevo diseño, será el momento para elegir el mejor proceso y material de fabricación, a fin de reducir el coste.

Definición del proyecto

Este Proyecto tomará como referencia un alerón delantero Williams FW-31 ya diseñado, que se modelará en el software SolidWorks. Además, todas las partes agregadas al primer diseño también se introducirán con SolidWorks. Una vez que se diseñe el alerón delantero, se simulará a través de Ansys. La selección de material se estudiará a través del software CES EduPack.

Los objetivos del Proyecto son los siguientes:

- Realizar simulaciones para entender como funciona la aerodinámica del alerón.
- Ir realizando pequeños cambios al modelo para encontrar una mejora en su rendimiento.
- Estudiar las diferentes formas de fabricación que se pueden aplicar al modelo.

- Estudiar las distintas opciones de materiales que se pueden emplear en el modelo, tratando de reducir peso y mantener la fuerza necesaria.

Descripción del modelo y las herramientas empleadas

En primer lugar, el diseño del alerón delantero Williams FW-31 se propuso en SolidWorks, siguiendo los pasos de una réplica del mismo alerón delantero. Una vez diseñado, la pieza tenía que ser preparada para introducirla en Ansys, eliminando todos los espacios internos que tenía. Esto se debe a que estas superficies interiores podrían ralentizar el proceso de mallado, ya que el programa de simulación tendría que cubrir mucha más superficie de la necesaria.

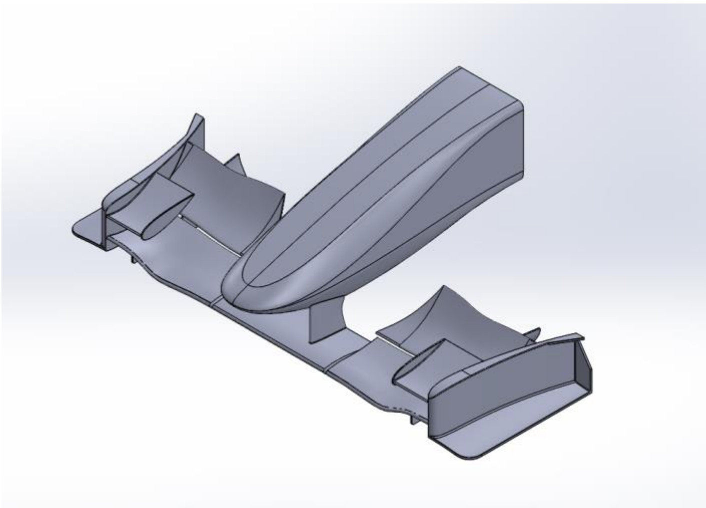

Figura 1 – Williams FW-31 diseñado en SolidWorks

El siguiente paso consiste en simular el alerón del FW-31 usando el software de Ansys. Se introducirá en una región suficientemente grande que hará de túnel de viento. Esta simulación servirá para comprender como circula el aire por la pieza.

En consecuencia, las fuerzas sustentación y de arrastre también se obtuvieron a partir de Ansys. Para comparar el rendimiento de los diseños, se utilizarán los coeficientes de sustentación y arrastre. Para calcular estos dos coeficientes, será importante usar las siguientes ecuaciones:

$$C_z = \frac{F_z}{q.A_{ref}}$$

$$C_y = \frac{-F_y}{q.A_{ref}}$$

donde q será la parte cinética en la ecuación de Bernoulli:

$$q = \frac{1}{2}\rho V^2$$

donde ρ es la densidad del aire y V es la velocidad.

Aref will be the reference area, that equals to the projected area on the air direction.

Una vez obtenidos todos estos coeficientes, el siguiente paso consiste en estudiar cómo se fabrican estas piezas hoy en día en la competición de Fórmula 1. Además, los posibles materiales se analizarán a través de CES EduPack, siguiendo algunos parámetros que nos ayudarán a mejorar nuestro resultado final.

Resultados

El primer punto a determinar fueron las líneas de aire que atravesaron el alerón delantero. Esto ayudará a comprender cómo se podrían agregar futuras mejoras para aumentar o reducir la carga aerodinámica y los coeficientes de resistencia dependiendo de las condiciones de la pista.

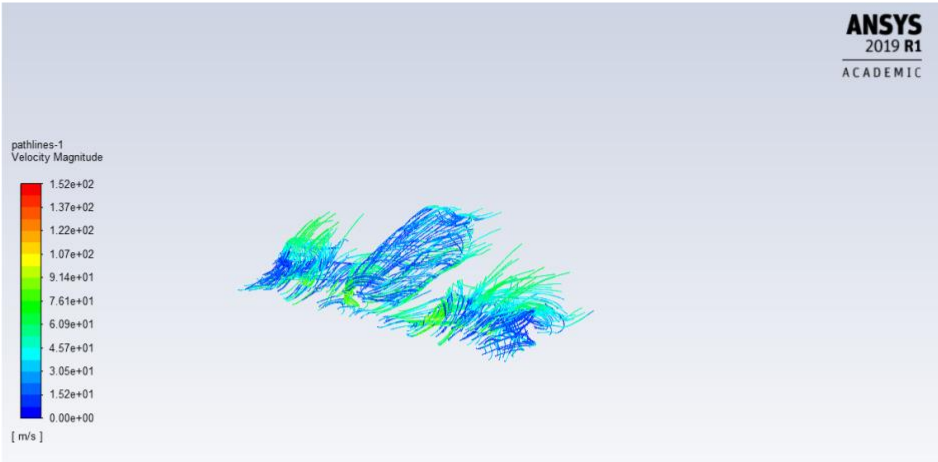

Figura 2 – Líneas de aire a través del alerón delantero del Williams FW-31

Una vez analizado cómo interactúa el ala con el flujo de aire, el siguiente paso sería obtener los resultados numéricos para la carga aerodinámica y los coeficientes de resistencia. Por lo tanto, las fuerzas se obtuvieron analizando el ala en Ansys. Para comparar los diseños en las mismas condiciones, estableceremos la velocidad como 60 m/s, que es la velocidad promedio de una Fórmula 1 teniendo en cuenta rectas y curvas.

Los diseños se simularán a la mitad, partiendo el diseño por su plano de simetría. Esto facilitará los cálculos, pudiendo llegar a resultados más precisos. Cabe destacar que las fuerzas obtenidas serán la mitad de las esperadas.

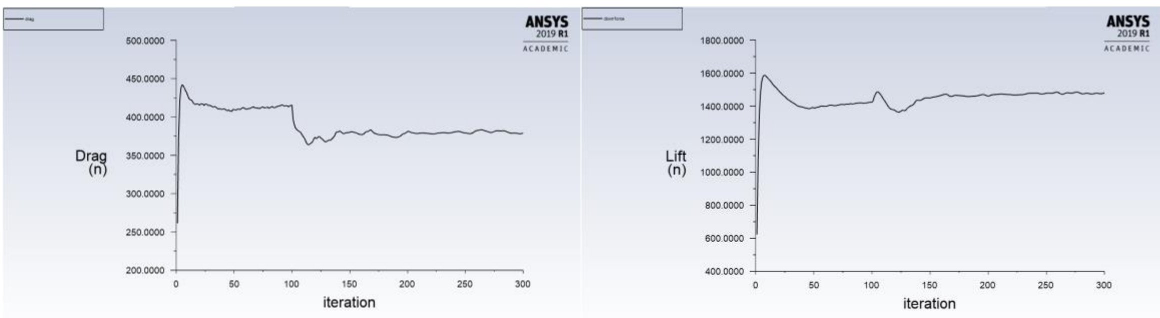

Figura 3 – Fuerzas de arrastre y sustentación del Williams FW-31

Estas dos fuerzas se compararán con los nuevos diseños del alerón. Las mejoras del alerón se centrarán en las zonas menos trabajadas, como es el *endplate* (placas laterales en los extremos del alerón). Con estos nuevos diseños se tratará de disminuir el coeficiente de arrastre y aumentar el coeficiente de sustentación. Los nuevos diseños se denotarán como FW-31.1, siendo este ultimo número el que denotará el número de la mejora introducida.

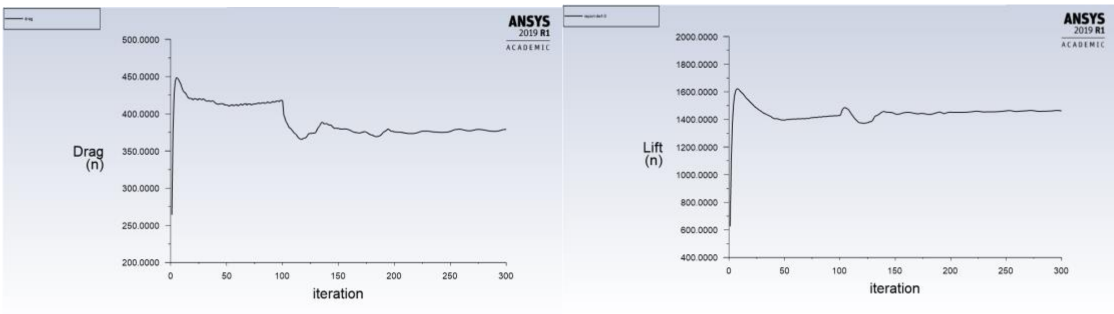

Figura 4 – Fuerzas de arrastre y sustentación del Williams FW-31.1

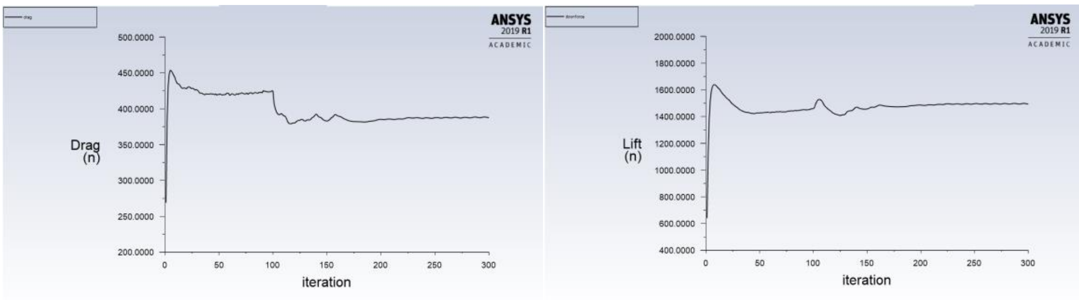

Figura 5 – Fuerzas de arrastre y sustentación del Williams FW-31.2

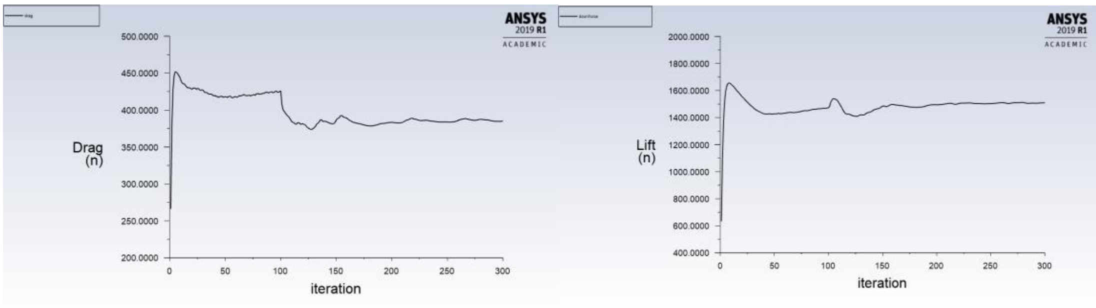

Figura 6 – Fuerzas de arrastre y sustentación del Williams FW-31.3

Una vez obtenidas ambas fuerzas para cada diseño, el siguiente paso será obtener sus coeficientes. Se espera que el nuevo diseño aumente su carga aerodinámica gracias a los nuevos spoilers, pero el área proyectada en esa dirección aumentará, lo que podría hacer que el coeficiente de arrastre aumente. La siguiente tabla muestra la comparación entre los diferentes diseños propuestos.

	FW-31	FW-31.1	FW-31.2	FW-31.3
Drag (N)	757.93	757.84	774.98	770.35
Downforce (N)	2960.54	2922.97	2986.29	3019.26
Cd	0.8901	0.8890	0.9091	0.9033
F1 points	***89.01***	***88.90***	***90.91***	***90.33***
Cl	3.4767	3.4290	3.5031	3.5402
F1 points	***347.67***	***342.90***	***350.31***	***354.02***

Estos resultados muestran cómo cada diseño afectará de un modo diferente al rendimiento. Considerando el diseño final como el FW-31.3, se puede observar que la carga aerodinámica y el arrastre aumentarán. Comparando los valores finales en la terminología de la Formula 1, donde aumentar 10 puntos de carga aerodinámica significaría que el monoplaza iría 0.3 segundos más rápido por vuelta, sería justo decir que siguiendo esta regla, el rendimiento del automóvil mejoraría cerca de 0.2 segundos por vuelta. También habría que tener en cuenta que el arrastre aumentará un poco, lo que se traduce en pérdida de velocidad en las rectas.

La fibra de carbono es el material más usado dentro de la Formula 1. Gracias a su relación entre densidad y fuerza, hace de este material el idóneo paran la Competición. De todas formas, se ha tratado de buscar materiales con similares caracteríaticas, con el resultado de distintas fibras de carbono y alguna fibra de vidrio.

Conclusión

Sería justo concluir que este diseño mejorado del alerón delantero Williams FW-31 hará una mejora teórica en la pista. Entendiendo que en la competencia de Fórmula 1 las diferencias entre equipos se miden en décimas, se puede concluir que esta mejora definitivamente haría que el equipo se acercara más a sus rivales.

Sin embargo, también es importante tener en cuenta que este diseño sería útil para pistas de con mayor carga aerodinámica, como sería el caso de Montecarlo (GP de Mónaco), ya que no importaría sacrificar cierta velocidad punta. Para otras pistas podría ser interesante disminuir la resistencia del aire, por lo que la fuerza de arrastre disminuiría, siendo más rápido en las rectas.

La fabricación de fibra de carbono busca continuamente nuevos avances y mejoras en las propiedades. Estas mejoras se deben en gran medida a los avances logrados en la química, que continúan mejorando la fuerza y otros parámetros de rendimiento, al tiempo que reducen el peso. Los avances en química no solo se limitan a la construcción de fibra de carbono, sino que también se aplican a la química de aglutinante, como los epoxis y otros materiales a base de resina para mantener juntas las capas de fibra. Estos avances en química también impulsan nuevos métodos de producción, con el fin de obtener vehículos de carrera más fuertes y rápidos, que también son más livianos y más resistentes a los choques.

WILLIAMS FW-31 FRONT WING DESIGN AND UPGRADE

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Director: Wolenski, David.
Collaborating Entity: Colorado School of Mines

ABSTRACT

In this project, the Williams FW-31 Formula 1 car front wing was simulated in order to find its drag and downforce coefficients. Then, some upgrades were introduced to increase the downforce coefficient and reduce the drag coefficient. Finally, a study of the manufacturing process and possible materials to reduce weight and cost while maintaining strength was carried out.

Keywords: Formula 1, Aerodynamics, Manufacturing, Analysis, Materials

Introduction

This project aims to respond to the pronounced evolution in performance that cars have had in Formula 1 during the last decade, mainly due to aerodynamics. The most noticeable change in aerodynamics occurred since 2017, where a new regulation came into force. In this new regulation, Formula 1 teams were allowed to make a further development to their aerodynamic package.

Therefore, the idea of this project is to compare the performance between the front wing of the Williams FW-31 F1 car, with the upgraded version of it, adding some technology from the actual Formula 1 competition. To do this, both designs will be simulated in order to compare their downforce and drag coefficients, and analyze the results. Once checked that the performance will increase with the new design, it will be the stage to choose the best manufacturing process and material, in order to reduce costs.

Project definition

Consequently, this project will take as a reference an already designed Williams FW-31 front wing, which will be designed into SolidWorks software. In addition, all the parts added to the first design will be also introduced with SolidWorks. Once the front wing is designed, it will be simulated through Ansys. The material selection will be studied through CES EduPack software.

The objectives of this project will be the following:

- Conduct simulations to understand how spoiler aerodynamics work.
- Make small modifications to the spoiler to be able to make corrections to its performance.
- Study different manufacturing processes that can be used to make the spoiler.
- Study all the different materials for the different applications they may have in the design, and try to reduce weight and cost by maintaining strength.

Model and tools description

First of all, the design of the Williams FW-31 front wing was proposed in SolidWorks, following the steps of a replica of the same front wing. Once it was done, it had to be prepared to introduce the part into Ansys, by reducing all the wholes it had. This was because this interior surfaces could slow down the meshing process, as the simulation program would have to cover a lot more surface than needed.

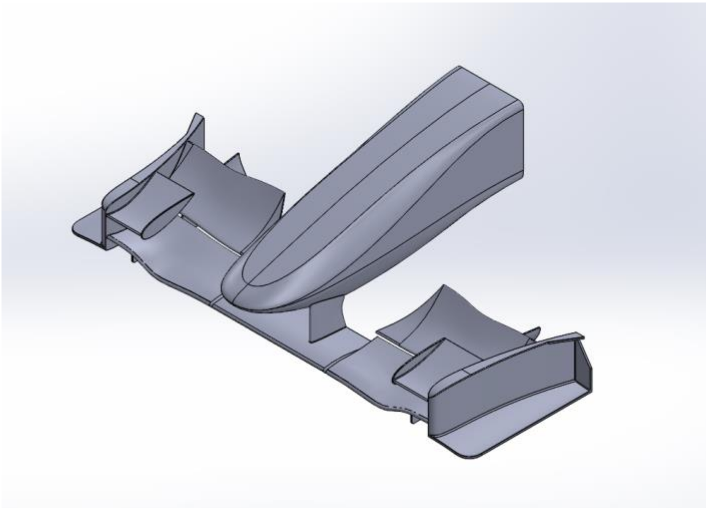

Figure 1 – Williams FW-31 designed in SolidWorks

The next step is to simulate the FW-31 front wing in Ansys simulating software. The part will be analyzed in Ansys by defining a large enough region. Simulating the part will be useful to understand how the airflow will go through the spoiler and where it should go.

Consequently, the downforce and drag forces were also obtained from Ansys. This forces would be useful in order to calculate the drag and downforce coefficients. To calculate these two coefficients, it will be important to use the following equations:

$$C_z = \frac{F_z}{q.A_{ref}}$$

$$C_y = \frac{-F_y}{q.A_{ref}}$$

where q will be the kinetic part in Bernoulli's equation:

$$q = \frac{1}{2}\rho V^2$$

where ρ is the density of the air and V is the velocity.

Aref will be the reference area, that equals to the projected area on the air direction.

Once obtained all these coefficients, the next stage consisted on studying how these parts are manufactured nowadays in Formula 1 competition. Furthermore, possible materials will be analyzed through CES EduPack, following some parameters that will help us improve our final result.

Results

The first point to be determined were the air path lines that went through the front wing. These will help understand how future improvements could be added in order to increase or reduce downforce and drag coefficients depending on the race track conditions.

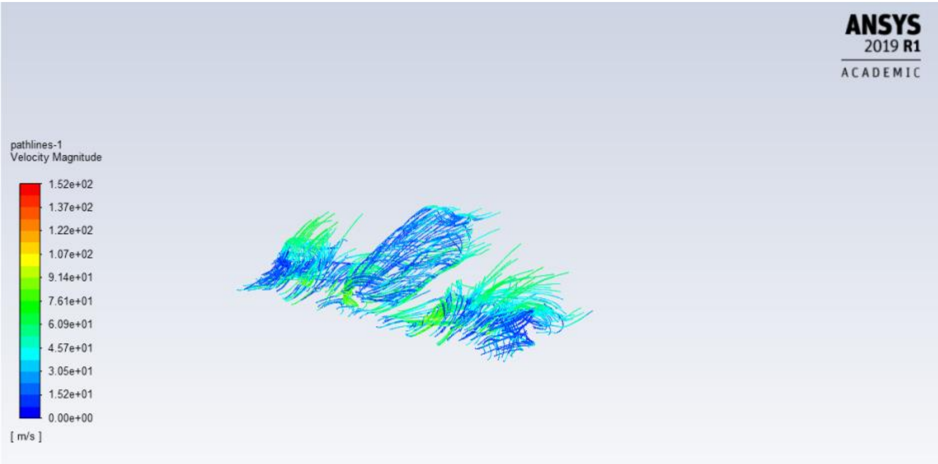

Figure 2 – Williams FW-31 air path lines through the front wing

Once analyzed how the wing interacts with the airflow, the next step would be to obtain the numerical results for downforce and drag coefficients. Therefore, the forces were obtained by analyzing the wing in Ansys. In order to compare both designs in the same conditions, we will stablish the speed as 60 m/s, which is the average speed of a Formula 1 taking into account straights and turns.

Designs will be simulated in half, splitting the design by its plane of symmetry. This will facilitate the calculations and may lead to more accurate results. It should be noted that the forces obtained will be half of those expected.

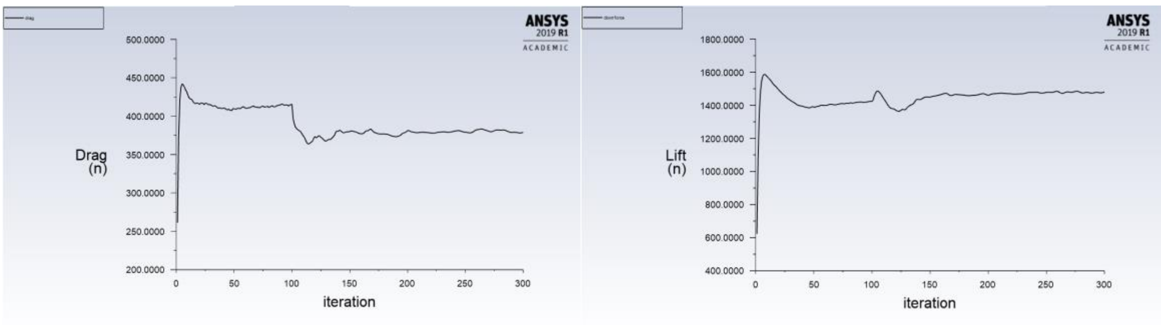

Figure 3 – Williams FW-31 drag and lift forces

These two forces are compared to the new spoiler designs. Spoiler improvements focus on less-worked areas, such as the endplates. These new designs will try to decrease the drag coefficient and increase the lift coefficient. The new designs will be denoted as FW-31.1, the latter number denoting the number of the improvement introduced.

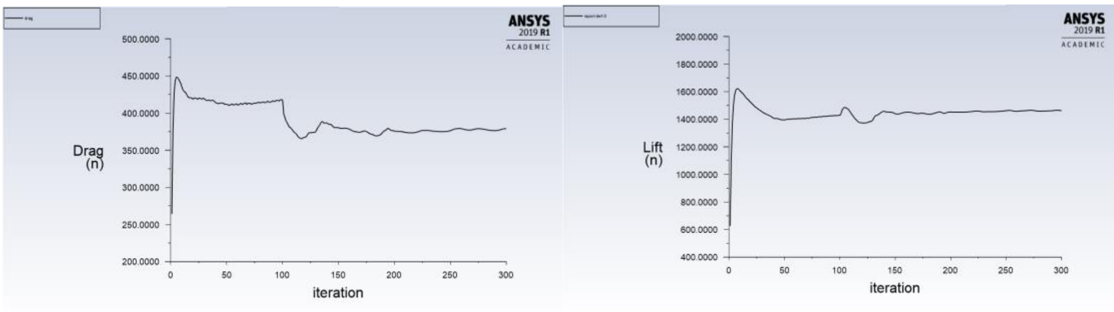

Figure 4 – Williams FW-31.1 drag and lift forces

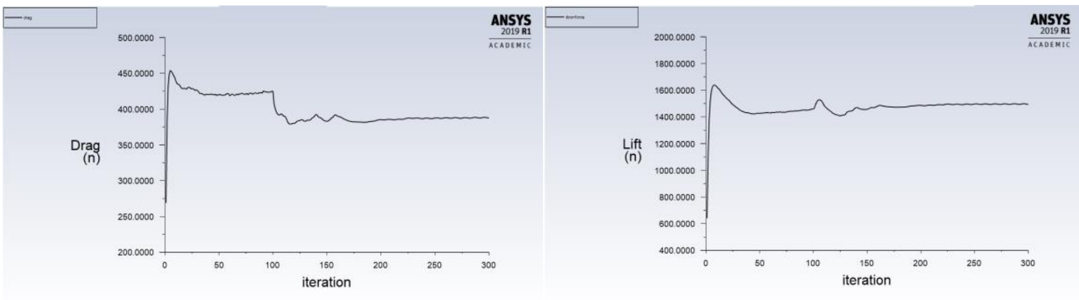

Figure 5 – Williams FW-31.2 drag and lift forces

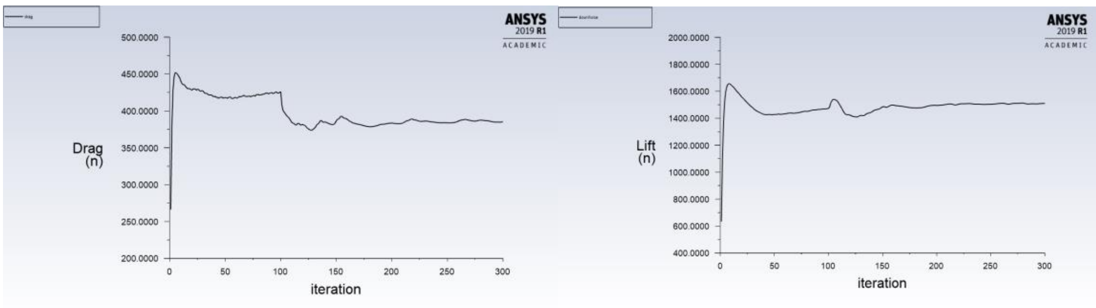

Figure 6 – Williams FW-31.3 drag and lift forces

Once both forces are obtained for each design, the next step will be to obtain their coefficients. The new design is expected to increase its downforce thanks to new spoilers, but the projected area in that direction will increase, which could cause the drag coefficient to increase. The following table shows the comparison between the different designs proposed.

	FW-31	FW-31.1	FW-31.2	FW-31.3
Drag (N)	757.93	757.84	774.98	770.35
Downforce (N)	2960.54	2922.97	2986.29	3019.26
Cd	0.8901	0.8890	0.9091	0.9033
F1 points	***89.01***	***88.90***	***90.91***	***90.33***
Cl	3.4767	3.4290	3.5031	3.5402
F1 points	***347.67***	***342.90***	***350.31***	***354.02***

These results show how each design will affect performance differently. Considering the final design as the FW-31.3, it can be seen that the downforce and drag will increase. Comparing the final values in Formula 1 terminology, where increasing 10 downforce points would mean the car would go 0.3 seconds faster per lap, it would be fair to say that by following this rule, the car's performance would improve by about 0.2 seconds per lap. . It should also be taken into account that the drag will increase a little, which results in loss of speed on the straights.

Carbon fiber is the most widely used material in Formula 1. Thanks to its relationship between density and strength, it makes this material the ideal one for the Competition. However, an attempt has been made to find materials with similar characteristics, with the result of different carbon fibers and some fiberglass.

Conclusions

It would be fair to conclude that this upgraded design of the Williams FW-31 front wing, will make a theoretical improvement on the track. Understanding that in the Formula 1 competition differences between teams are measured in tenths, we could tell that this improvement would definitely make the team come closer to its rivals.

However, it is also important to keep in mind that this design would be useful for tracks with higher downforce, such as the case of Monte Carlo (Monaco GP), since it would not matter to sacrifice a certain top speed. For other tracks it might be interesting to decrease the air resistance, so the drag force would decrease, being faster on the straights.

Carbon fiber manufacturing continually seeks out new advancements and improvements in properties. These improvements are largely thanks to breakthroughs made in chemistry, which continue to improve strength and other performance parameters, while reducing weight. The advancements in chemistry are not just limited to carbon fiber construction, but also apply to binder chemistry, such as epoxies and other resin-based materials to hold the fiber layups together. These advancements in chemistry drive new production methods too, and together the end result is stronger, faster race vehicles that are also lighter and more crash resistant.

Index

Figures Index

Tables Index

Chapter 1. INTRODUCTION

1.1 PROJECT MOTIVATION

This project arises from the idea of understanding more thoroughly the huge evolution that Formula 1 competition experienced during the last decade. One of the main reasons for this improvement is thanks to the evolution of aerodynamic elements and designs that have been introduced in the new standards.

This project tries to respond to this pronounced improvement by comparing a 2009 Formula One car and introducing some aerodynamical improvements to verify that the performance of the car will actually be superior. The project will be focused just on the front wing of a Formula 1 car.

1.2 HISTORY ABOUT AERODYNAMICS IN FORMULA ONE

This historic competition is running since 1950 uninterruptedly until nowadays, making it the most supported sport in the motor world so far. This 70 year journey has made Formula One cars experience huge modifications through years. This part summarizes the most important changes in the history of Formula One.

Back in 1950, when F1 World Championship was officially created, simplicity and purity were the main characteristics of single-seaters. The front layout of the engine and the rear driving position, completed the hallmarks of those pioneering machines. 1950 was dominated by the Alfa Romeo 158.

It was not until the 1960s when the front of the single-seaters became more streamlined and less bulky than in the previous decade. The aerodynamic appendages used as an element to improve the performance of the racing cars had just been born. It was all because of Colin Chapman's wonderful mind. [1]

Figure 1 – Lotus F1 car designed by Colin Chapman in the 1960s

This generated a huge reaction in other teams, kicking off a crazy race for spoilers and aerodynamics. This produced another great leap in the evolution of F1 cars. In this stage, double spoilers were introducing, giving monstrous results.

Figure 2 – March Formula 1 car of 1971

McLaren entered the 1980s ready to win the F1 World Championship. In 1981, McLaren created the carbon fiber monocoque chassis, which would become a model to be imitated by all adversaries. This supposed one of the biggest fundamental contributions to the evolution of Formula 1 cars. [2]

Figure 3 – McLaren introduced carbon fiber monocoque in 1981

In 2009, a new regulation came into effect, where a much more minimalist aspect could be appreciated. This project will analyze the Williams FW-31 front wing and compare it to the actual designs, characterized by more complex designs. The following figure shows a good comparison on how aerodynamics evolved on this last decade, evolving into wider cars.

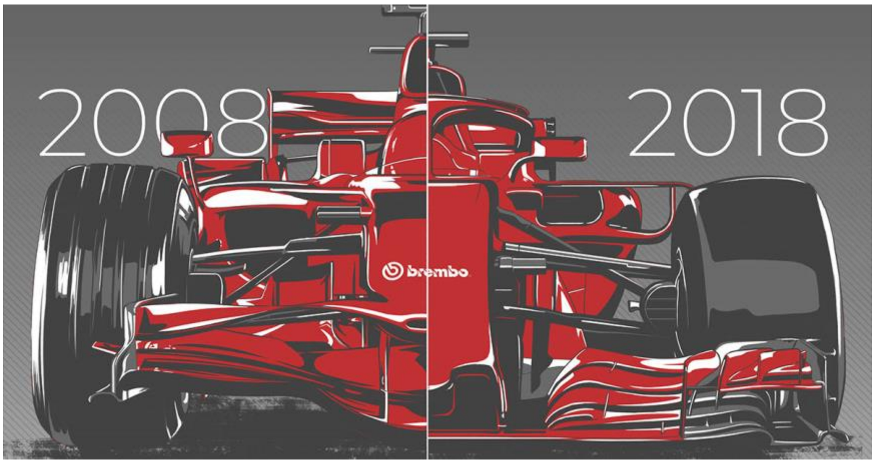

Figure 4 – Comparison of F1 aerodynamics in the last decade

During this last decade, Formula One cars evolved into more complex shapes, having as a result the fastest cars in the Formula One history.

1.3 AERODYNAMICS IN FORMULA ONE

Aerodynamics in Formula One represent a large part of the total performance of the car. The teams spend much of their time understanding the aerodynamics of the car, since it is estimated that it comprises a 20% of the total budget. That is why a modern Formula One car can take corners much faster than normal, commercial cars, which would not be possible without downforce.

To achieve good results, there must be a huge process of meticulous precision work by using computations and experiments in wind tunnels to accurately tailor the wings and the wing deflectors to the last millimeter. Actual Formula 1 car designs are aimed at increasing the downforce and reducing the drag. This also permits shorter braking distances and higher corner speeding. Downforce generates 80% of the grip required for the car. This makes the car withstand forces up to 4G without sliding off the track primarily due to the aerodynamic designs allowing high speed corners. [3]

Figure 5 – 2021 Formula 1 prototype tested in Sauber F1 Team wind tunnel

Apart from wind tunnels, Formula One teams use other methods of research. Computers are used to mathematically simulate the flow of air through the cars to model the vehicle behavior on the track. Computational Fluid Dynamics, or CFD, is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows.

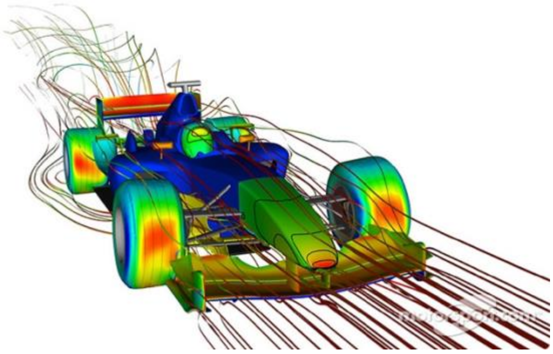

Figure 6 – CFD programs used to simulate aerodynamics in F1 cars

However, it is important to understand that downforce is not the only factor to be optimized, as there is no particular design that works for all circuits. This means that depending on the type of circuit, the car will need to be configured according to the requisites of each track.

1.3.1 DOWNFORCE

The front wing of a Formula One car is designed in a shape opposite to an airfoil to prevent it for taking off. The front wing is suspended from the nose and runs along the entire length of the Formula One car. It also accounts for a quarter of the total downforce generated by the car, so every improvement on this part will be significant for the resulting performance of the car.

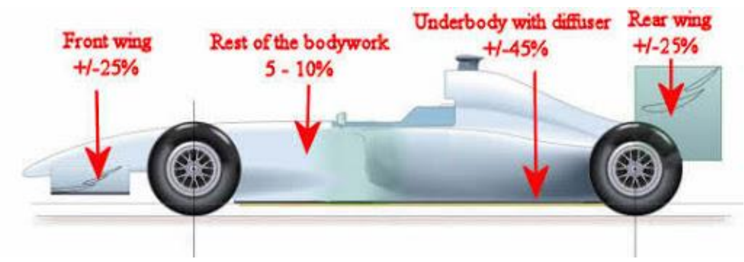

Figure 7 – Downforce distribution through a Formula 1 car

Downforce, as it name suggests, is the force that occurs in the negative vertical direction. Otherwise, if this force happened to be positive, that force would be called lift, as it would make an object go up, as occurs with airplanes. For the lift, the force is generated when air come in contact with the spoiler, generating high pressure in the lower side of the wing (or what is also called camber) and reducing this pressure on the upper camber. This would make the body to go up, as there would be a big pressure pointing up, while in the upper part would not be a big resistance.

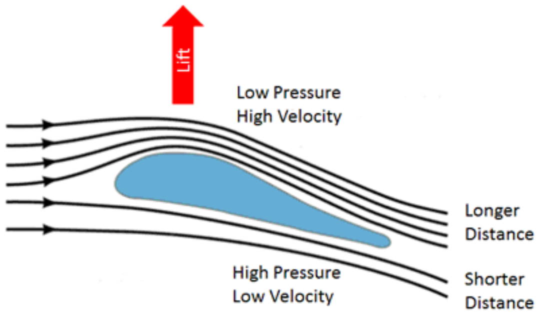

Figure 8 – Aerodynamic lift example

Therefore, as mentioned before, a Formula One car needs to increase its downforce in order to go faster. This force will be generated in the opposite way in which lift worked. The air will come through what is called the leading edge and will be directed to the trailing edge, where the airflow would end its journey. The higher pressure would happen to be on the upper camber of the spoiler, while the low pressure would be in on the lower part of the spoiler. This pressure difference will generate a force in the negative vertical direction which will help the car go faster. [4]

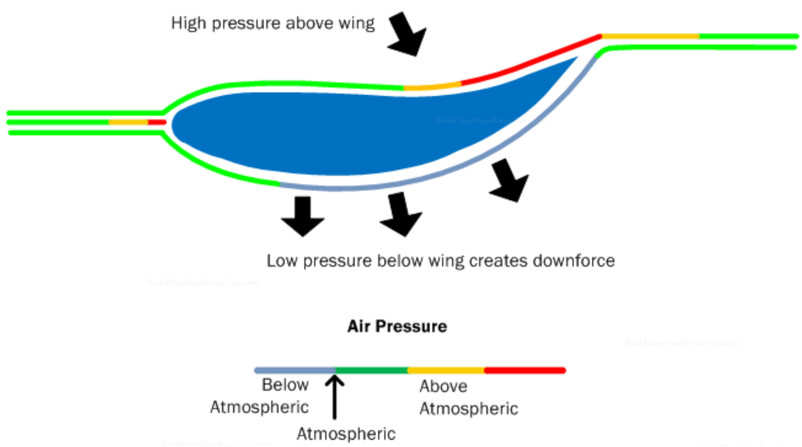

Figure 9 – Wings generate downforce by pressure difference between the upper and lower camber

1.3.2 DRAG

Another important part of the aerodynamics in a Formula One car is the drag force. This force is generated by the resistance experienced as a solid object that goes against the air. By reducing the drag, the car will go faster on straights.

Figure 10 – Representation of drag force

One form of drag occurs when air particles pass over a surface and the closer particles of the airflow adhere to this surface. This resistance will decrease if the attack angle of the spoiler is small. Contrary, the higher the attack angle is, the higher the drag will result. [5]

1.3.3 DOWNFORCE AND DRAG COEFFICIENTS

These coefficients represent the changes in lift and drag as the angle of attack changes. Initially, both downforce and drag coefficients will increase as the angle of attack increases up to a certain point, where they would begin to drop drastically. Furthermore, if any spoiler is modified or added, these coefficients will also measure if the performance increases.

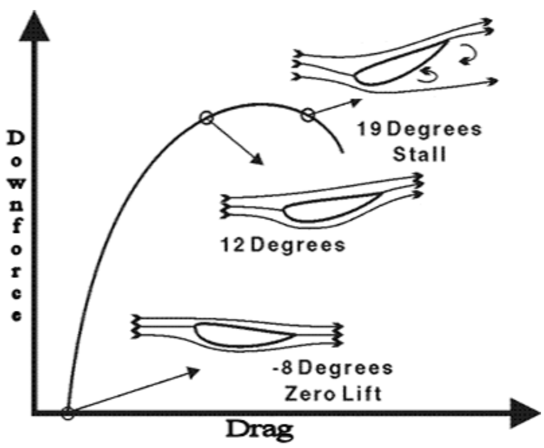

Figure 11 – Relation between downforce and drag depending on the angle of attack

As an spoiler cuts through the relative wing, an aerodynamic force is produced. This force can be separated into two components, lift and drag. The angle of attack is the angle between the chord line and the relative wind.

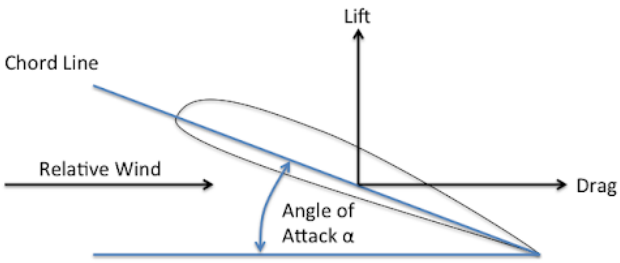

Figure 12 – Angle of attack produced by an airfoil

The drag coefficient expresses the ratio of the drag force to the force produced by the dynamic pressure times the projected area in *z* direction. Consequently, the downforce or lift coefficient, expresses the ratio of the lift force (negative in a F1 car) to the force produced by the dynamic pressure time the projected area in *y* direction. [6]

E.1 $$C_z = \frac{F_z}{q.A_{ref}}$$

E.2 $$C_y = \frac{-F_y}{q.A_{ref}}$$

where q will be the kinetic part in Bernoulli's equation:

E.3 $$q = \frac{1}{2}\rho V^2$$

where ρ is the density of the air and V is the velocity.

Aref will be the reference area, that equals to the projected area depending on the direction.

Some typical values these coefficients would be around 4,4 to 4,8 for downforce, and around 0,9 to 1,1 for the drag. These numbers into Formula One terminology would have to be multiplied by a hundred, resulting in 440 to 480 points of downforce and 90 to 100 points of drag.

To measure how a car of these characteristics can improve its performance, adding 10 points of downforce can improve up to 0,3 seconds per lap. In the same way, reducing drag coefficient in 5 points, can make the car increase 10 kph in top speed. [7]

Chapter 2. TECHNOLOGIES OVERVIEW

This section includes some of the software used through the different parts of the project. These programs respond to the different necessities that the project required. Therefore, the two principle requirements are designing the front wing for later simulation.

2.1 SOLIDWORKS

SolidWorks is a solid modeling computer-aided design (CAD), which will result to be the most useful software to design a 3D part. Therefore, the Williams FW-31 front wing will be designed with this software.

Figure 13 – Williams FW-31 front wing designed in Solid Works

When the front wing is designed, the next step will be to simulate it through Ansys to find the lift and drag coefficients. Once obtained the numerical solutions, the next step is to add the new parts on the endplates to improve the car performance. In order to find improvements, every part will be added one by one, being tested every time and compared with the original part.

2.2 ANSYS

Ansys is a software package that lets you model digitally model real world phenomena. It uses computer-based numerical techniques to solve physic problems. The range of problems that Ansys can solve is immense, and could be anything from fluid flow, heat transfer, stress analysis and more. This project is simulated through the fluid flow option with Fluent, which will allow us to apply fluids equations in our front wing, obtaining a wide range of values that would be very useful for the project analysis.

Furthermore, with this software package that contains fluid flow with Fluent, will let us study the how the air goes through the car. This will be crucial to understand what improvements can be added so the spoiler evacuates the air in the best possible way.

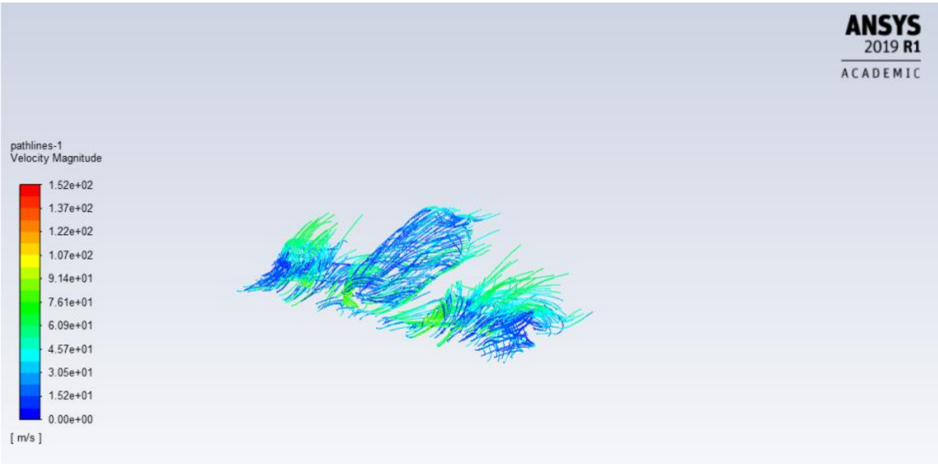

Figure 14 – Air path lines through the Williams FW-31 front wing in Ansys

The development of the wind tunnel technology in the Formula 1 Competition seems insignificance alongside the rapid growth of Computational Fluid Dynamics (CFD). With a wind tunnel, experiments are made by blowing wind over a real object in a controlled environment and measuring the aerodynamic forces that arise. In CFD, the same experiment may be conducted in the form of a computer simulation.

2.3 CES EDUPACK

The last software package that will be used in this project is the Cambridge Engineering Selector (CES), a PC toolkit used for the evaluation of information for engineering design. It can be used to search for materials that fulfill our design or application requirements.

This software will be used in this project to choose a material from this database that will be used to design the final design of the front wing. To achieve that, some requirements such as reducing weight and cost will be set, by maintaining the strength restrictions. The software will produce a range of materials to choose, which will help to reduce the huge amount of materials available.

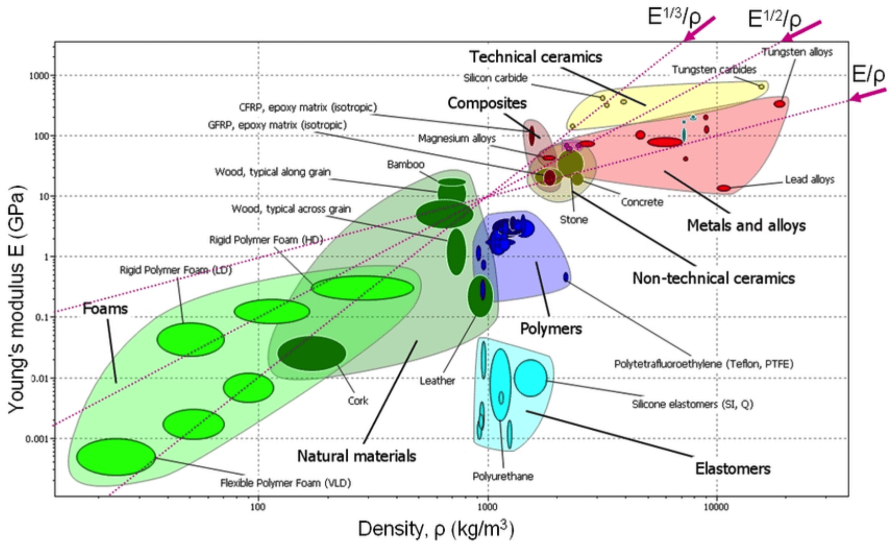

Figure 15 – All materials families possible in CES EduPack software

Chapter 3. CURRENT STATE OF THE QUESTION

This chapter will review the progress there is respect how aerodynamics have improved the Formula One competition during the last decade. It has to be noted that this project is a comparison of current Formula 1 cars with those of ten years ago. Thanks to this, the increase in performance is already known.

Based on the real results, the project aims to answer how a 2009 Formula One car would improve its performance by adding the new regulation in aerodynamics to these cars.

Chapter 4. PROJECT DEFINITION

4.1 JUSTIFICATION

That the Formula One competition cars have evolved their performance it is a well-known fact. The new regulations set in 2017 pretended, taking the Barcelona circuit as a reference, that cars were five seconds faster than in 2015. Some of the pillars of this challenge were based in making wider tires, more efficient spoilers, larger cars and an oversized diffuser.

The first great step in the regulation came in 2009 with the first significant evolution in this century. The next table shows the evolution in performance of a Formula 1 car in the last decade.

TEMPORADA	PILOTO	EQUIPO	TIEMPO
2009	Jenson Button	BrawnGP-Mercedes	1:26.202
2010	Sebastian Vettel	Red Bull-Renault	1:23.919
2011	Sebastian Vettel	Red Bull-Renault	1:23.529
2012	Lewis Hamilton	McLaren-Mercedes	1:24.922
2013	Sebastian Vettel	Red Bull-Renault	1:27.407
2014	Lewis Hamilton	Mercedes	1:30.775**
2015	Lewis Hamilton	Mercedes	1:26.327
2016	Lewis Hamilton	Mercedes	1:23.837
2017	Lewis Hamilton	Mercedes	1:22.188

Table 1 - Comparison of lap times in the Circuit of Barcelona in the last 10 years

This project tries to respond to the question raised about whether the 2009 Formula One cars could be able to compete with actual cars by adding some modifications. Analyzing the results of this project not only could confirm that aerodynamics are important when we talk about improving performance, but also the huge debate of which engine would be faster, the V10 engines or the hybrid V6 engine era stablished since 2014.

4.2 OBJECTIVES

In order to make this project possible, there will be a series of objectives to follow. Achieving these objectives will ensure the reliability of the project.

- Conduct simulations to understand how spoiler aerodynamics work.
- Make small modifications to the spoiler to be able to make corrections to its performance.
- Study different manufacturing processes that can be used to make the spoiler.
- Study all the different materials for the different applications they may have in the design, and try to reduce weight and cost by maintaining strength.

4.3 METHODOLOGY

The methodology that this project will follow is based on the trial and error method. This means that every new part added to the already existing Williams FW-31 front wing will be tested and named as FW-31.1. This las number will vary depending on what design we are referring to, being 1 the first proposed design to modify the already existing FW-31 front wing.

For every new design, the downforce and drag coefficients will be calculated and compared with each other. Following this logic, it would be possible to analyze where modifications should be done and what will be more efficient configuration in order to improve performance.

It is also important to take into consideration that the modifications to the front wing depend on the type of circuit for which is intended. This means that for small aerodynamical load circuits, such as Monza, high speed on the straights will be the objective, whereas for higher aerodynamical load circuits, as it could be Monaco, the objective would be to find a faster car in turns.

To be able to fulfil these objectives, it will be important to cover the different stages that the project demand to obtain good results. Therefore, the following planned schedule will help to organize the different tasks that have to be done during the beginning of the year. Some of these tasks include the design of the front wing in SolidWorks, obtain basic notions on how to work with Ansys Fluent in order to simulate the parts, and study the actual manufacturing processes and materials that fit best to the front wing.

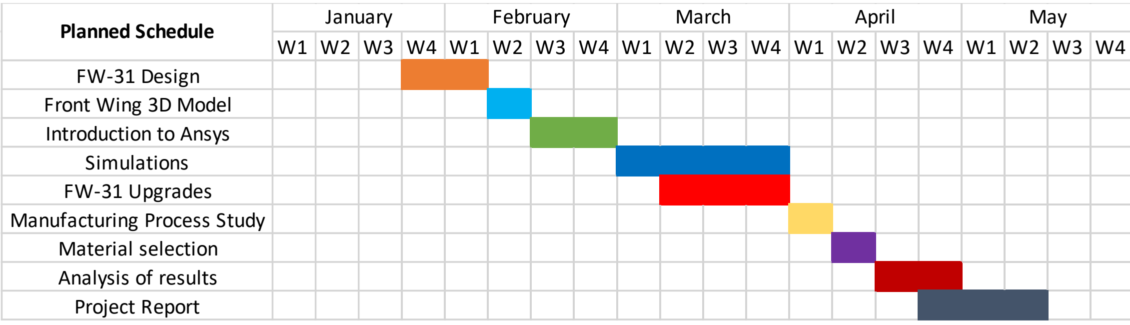

Table 2 - Gantt chart designed to face the project

4.4 ECONOMIC ESTIMATION

An important part of the project idea is based on cost reduction. Formula One is a very expensive sport, and will differentiate those with astronomical budgets with others with more humble budgets. Therefore, this project will not try to reinvent how car parts are built to reduce millions of dollars, but to establish some techniques that can make reduce money by implementing more economical manufacturing processes and adding less expensive materials that will help reduce a significant amount of money.

Chapter 5. DEVELOPED MODEL

This section shows the process followed in order to achieve a valid result, that allows the comparison between the Williams FW-31 front wing design and the upgraded front wing. Therefore, this chapter will follow an organized structure by showing what has been done in each part, and a general part where the simulation in Ansys will be explained.

5.1 SYSTEM ANALYSIS

The first step of the project will consist in designing the Williams FW-31 front wing in SolidWorks software. This design is based on an already designed part, which means that it will be used as our starting point. [8]

When the front wing is designed and ready to be simulated, the next step will be to simulate the part in Ansys. Drag and downforce coefficients will be calculated, as there are going to be the principal tool to compare performance between front wings. Therefore, if downforce coefficient increases, the resulting car will be faster on turns, and if the drag decreases, the car would be faster o straights.

The final part will consist on analyzing the already existing manufacturing processes and how the new additions should be included on the production. Besides, some materials that fulfill strength restrictions will be proposed in order to find if there are other materials lighter and cheaper than carbon fiber.

5.2 DESIGN

As mentioned before, the starting point of the project is based on an already designed Williams FW-31 front wing. It has been all designed from scratch in SolidWorks and will be the base to develop future modifications.

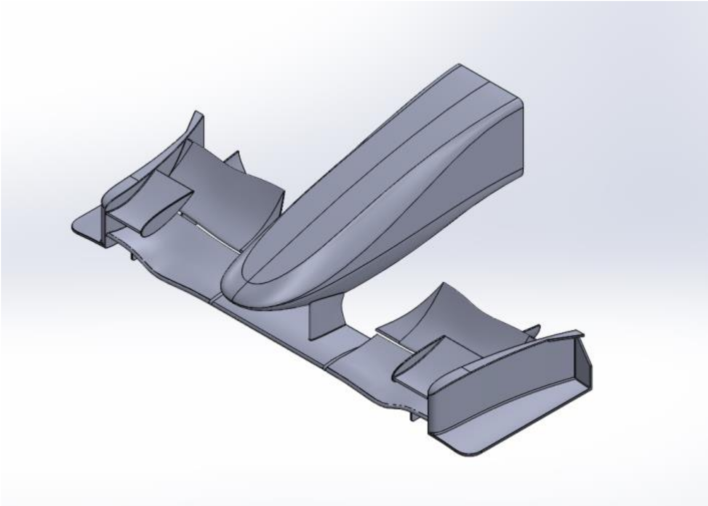

Figure 16 – Williams FW-31 designed in SolidWorks

The modifications were chosen to be made on the endplates of the front wing, as it one of the parts that suffered more modifications during the years. Besides, this design offers more space on the endplates, which will be very useful to introduce additional spoilers. Every new modification on the original wing will be noted as Williams FW-31.1, the latter number denoting the number of the improvement introduced.

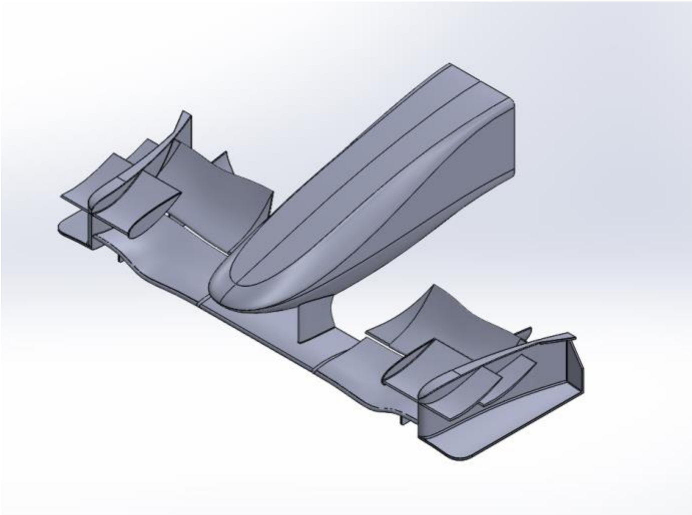

Figure 17 – Williams FW-31.1 designed in SolidWorks

The second modification is based on the actual designs in Formula 1, where spoilers form a cascade. These cascade wings are considered to increase the car performance on the corners. [10]

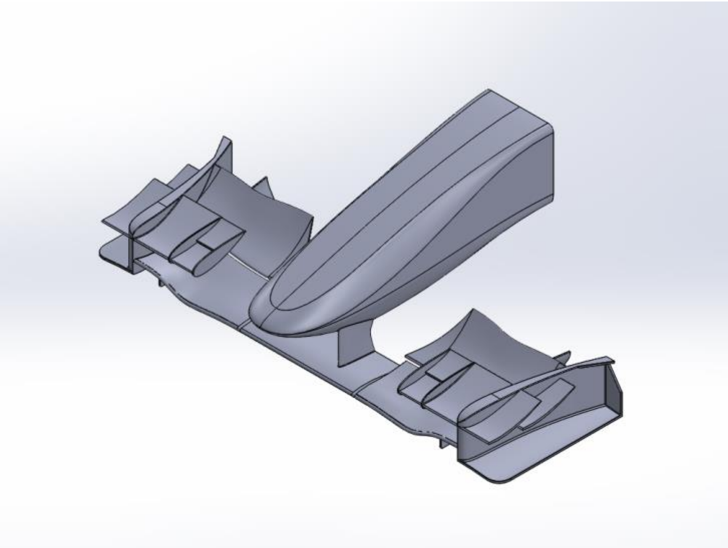

Figure 18 - Williams FW-31.2 designed in SolidWorks

The last design will tend to reduce the drag while increasing downforce. Even though it is a small wing with not a big angle of attack, it is supposed to improve the car performance.

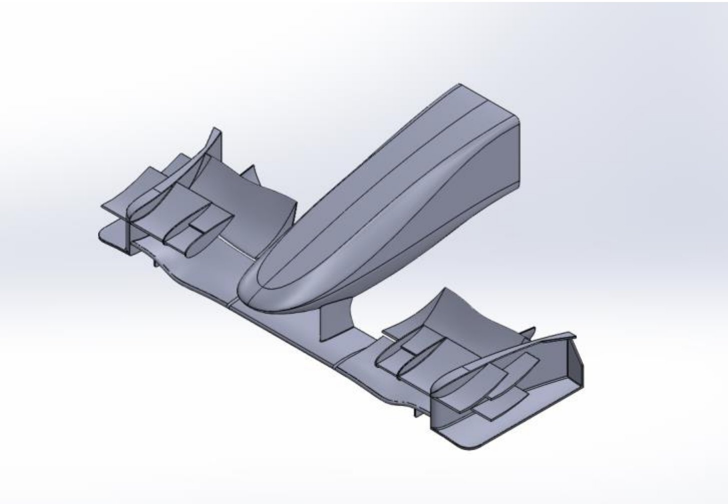

Figure 19 - Williams FW-31.3 designed in SolidWorks

5.3 ANSYS CONFIGURATION

To carry out all the simulations needed in order to make this project possible, there has to be some configurations stablished so there are no errors that stop the progress. Therefore, in this section, all the configurations used when simulating the designs, will be displayed in order.

The first step, once working with Ansys software, will be to select the Fluid Flow (Fluent) option. This tool will allow to study the external flows of any system that want to be simulated.

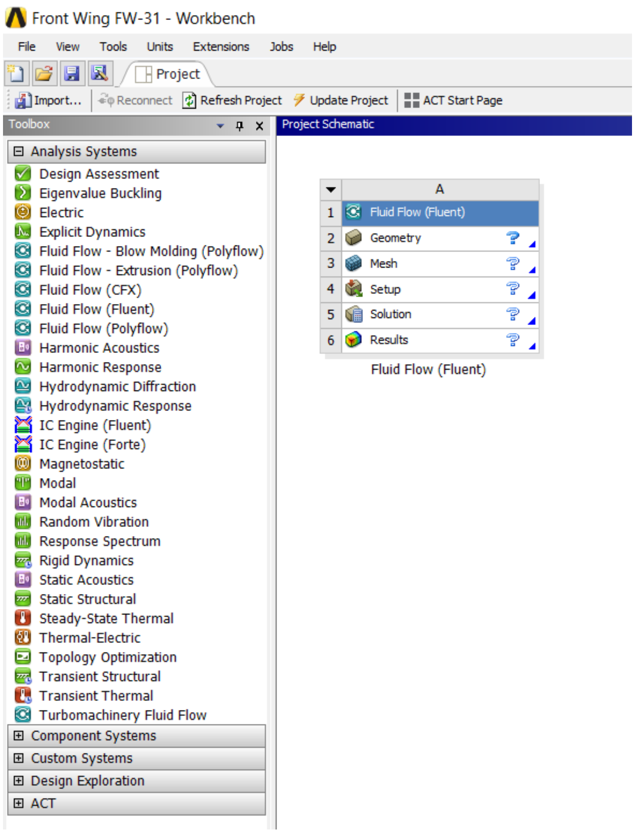

Figure 20 – Fluid Flow (Fluent) analysis in Ansys

Once selected how the part will be simulated, the succeeding steps will be to follow every requirement. In the geometry section the selected design has to be imported in a .IGS file. Then, the Design Modeler option will be selected to design an enclosure region where the part will be simulated. It is important to leave the required space following the rule shown in *Figure 19*, but with the exception of leaving only 30 cm with the floor, as the car will be almost touching it. To create this space, the tool *enclosure* will be used, selecting the plane of symmetry to only simulate half of the design. This will make the design easier to simulate with a higher precision.

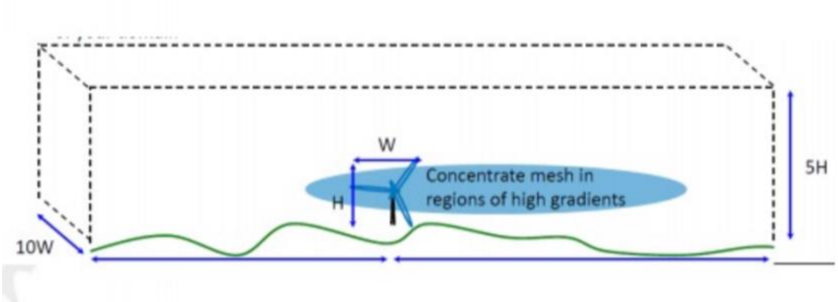

Figure 21 – Criteria followed to create the enclosure of the front wing

Once this region is created, the next step is to create a Boolean, subtracting the wing from the enclosure, which will create the space of air needed to simulate the design. To prepare a better mesh, it is important to add an sketch around the wing to extrude it later and create a more precise mesh around the design.

To achieve good results, it is of huge importance to generate a correct mesh. The requisites to do this are trying not to be really precise when choosing the element size of the mesh, as it can be really heavy for most computers to simulate, and also checking that the element size is small enough so every important part of the design can be simulated correctly. To summarize, there must be an equilibrium between precision and reliability of the simulation.

All designs were simulated in the same conditions and with the same mesh parameters. Some of this parameters included using the option of *CutCell* to assembly the meshing, including a face sizing to the front wing to reduce the element size down to 5 mm, and introducing a body of influence, already introduced around the wing, to reduce the elements size down to 25 mm. The mesh will have a maximum element size of 600 mm. All these parameters were the equilibrium point to make this mesh possible.

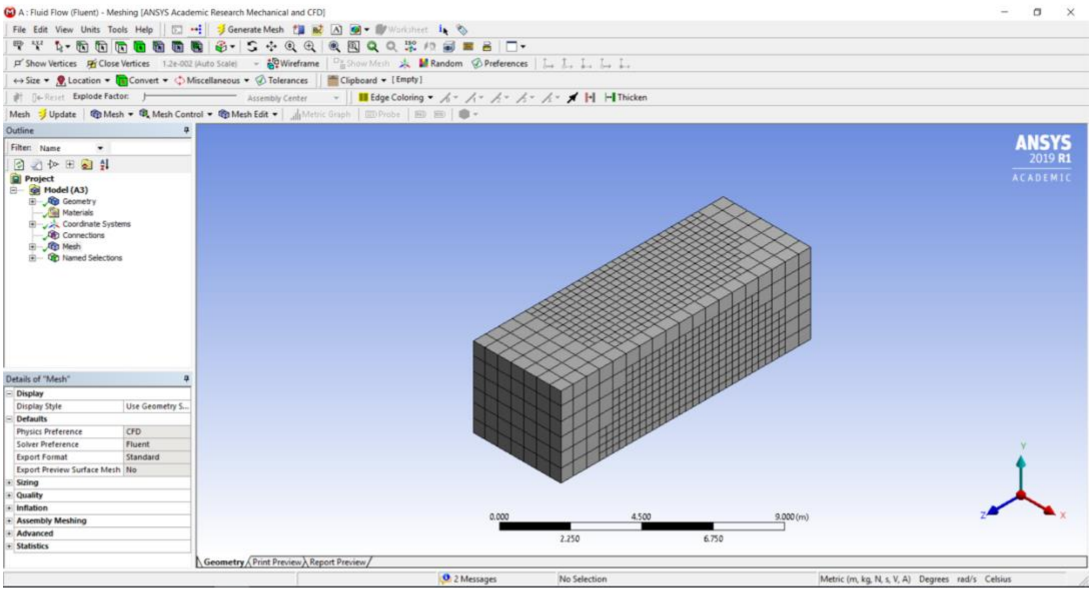

Figure 22 – Front wing meshed in Ansys software

Once the front wing has been meshed, it is time to move into the Setup section, where all the boundary conditions required and all the results needed will take place. In order to get a smooth solutions, the configuration used in *Figure 21* will be used.

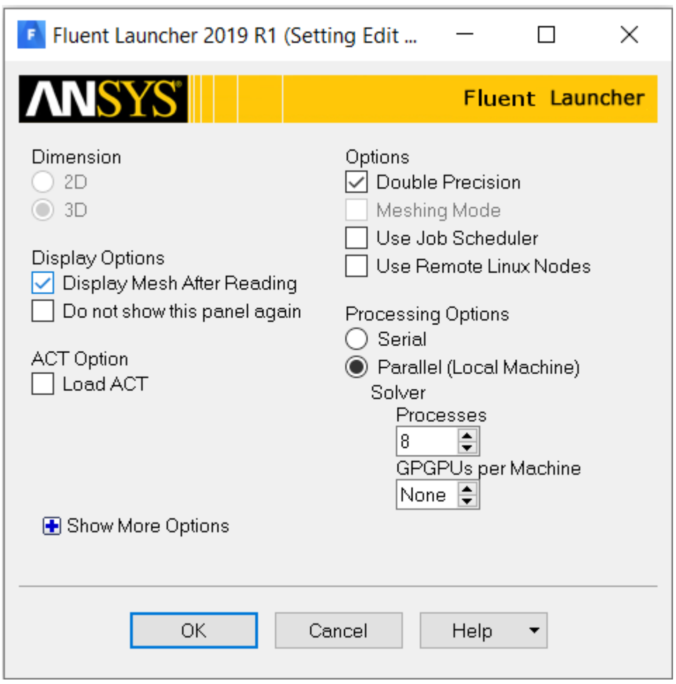

Figure 23 – Fluent Launcher configuration used in this Project

Moving on to the setup options, the first step will be to select the configuration of our model. In this case, our model will be a *k-epsilon*, as it is shown in the next figure.

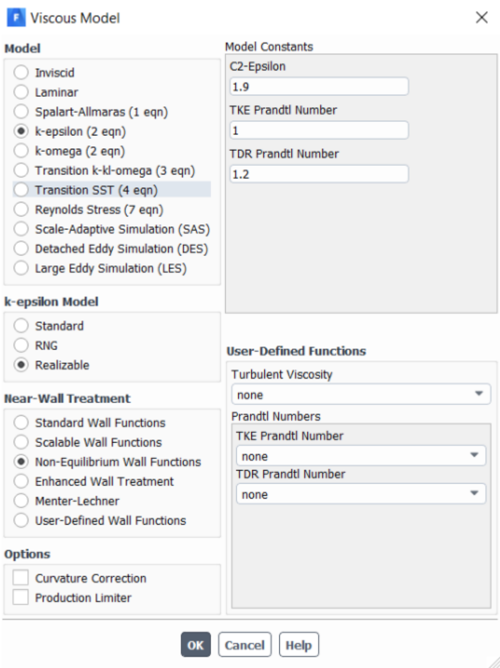

Figure 24 – Viscous model k-epsilon realizable with non-equilibrium wall functions

The inlet velocity set to simulate the wing will be of 60 m/s, which responds to an average speed of a Formula One car taking into account both straight and turn speeds.

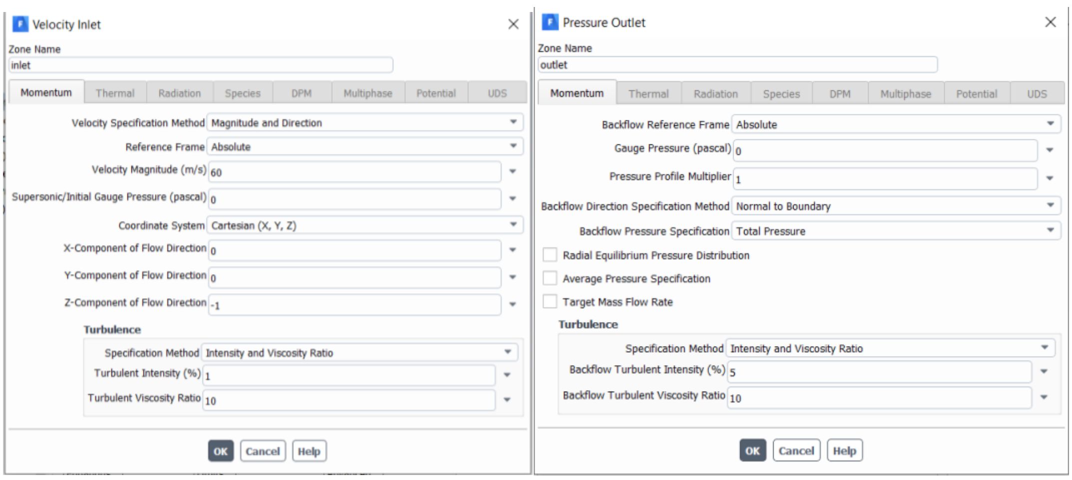

Figure 25 – Velocity inlet and pressure outlet boundary conditions

The only and most important part to change for the reference values will be the projected area in the wind direction. Thanks to this value, downforce and drag coefficients will be plot and calculated without any error.

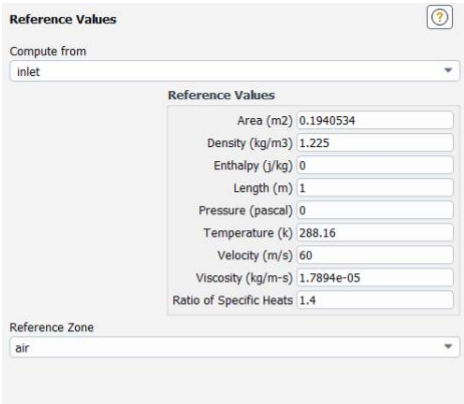

Figure 26 – Reference values

Now, the most important part of the setup relies on the method used to simulate the design. Therefore, there will be one first simulation of 100 iterations, which will be less precise. Consequently, the second part of the simulation will consist on 200 iterations of second order, giving a more precise solution.

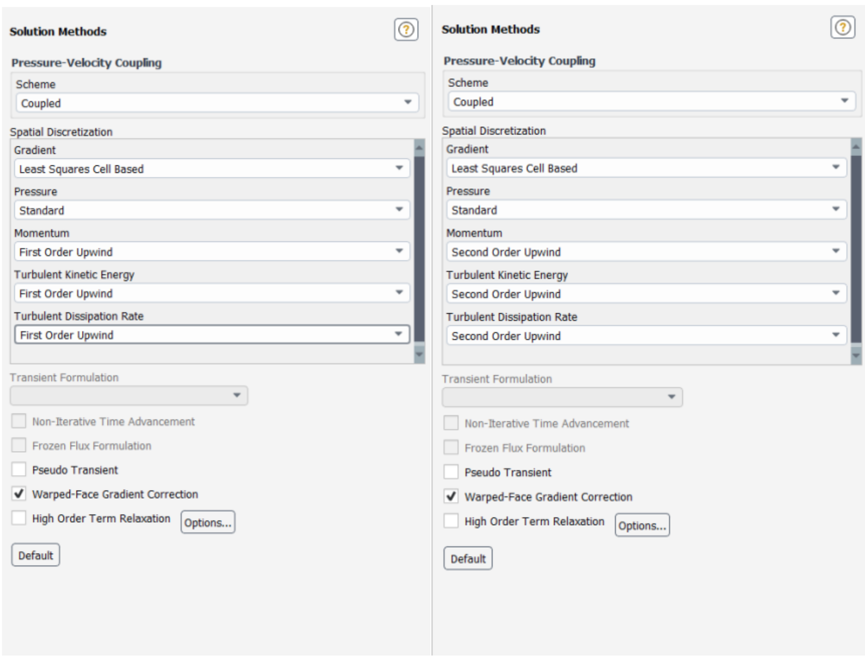

Figure 27 – First and second order solution methods

The last part to take into account will be the solution controls, where the turbulent viscosity will change depending on the precision of the simulation. Therefore, for a first contact, the value for the turbulent viscosity will be of 0.8, while for the second part of the iteration, the value will be of 0.95.

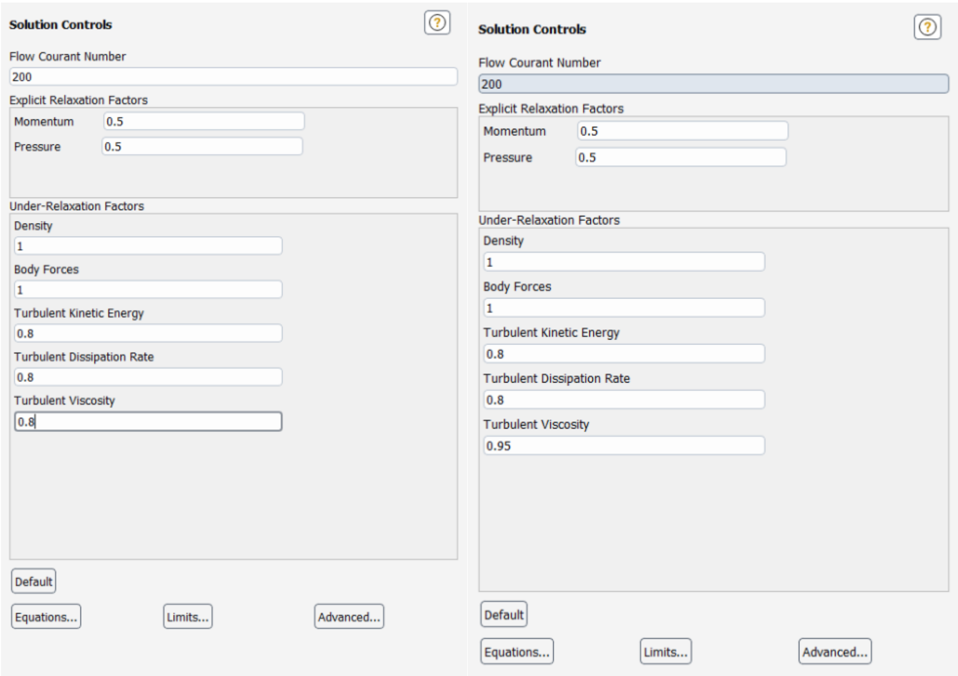

Figure 28 – First and second order solution controls

To simulate this project and to run the calculations needed, the project has to be initialized, choosing the Hybrid Initialization to do so. It will also be important to check the mesh quality, checking that the volume values are all positive.

Chapter 6. ANALYSIS OF RESULTS

Once all values are simulated and calculated, it is the time to analyze how much this modifications affected the final performance of the car.

6.1 AERODYNAMIC RESULTS

This section will be divided into three different parts. The first part consists on some basic simulations on the first designs, which will allow to calculate the drag and downforce coefficients using the Bernoulli equations. The second part will cover all the results obtained for each design with a higher precision than the first simulations. To end up with, future work to ensure more reliable results will be specified.

6.1.1 INDICATIVE CALCULATIONS

In this section, certain preliminary calculations will be made with a low quality mesh to get a basic idea of what values to expect. Thanks to this lower precision mesh, all simulations will require a smaller amount of time. Therefore, this calculations will serve as a guide and not as a final result.

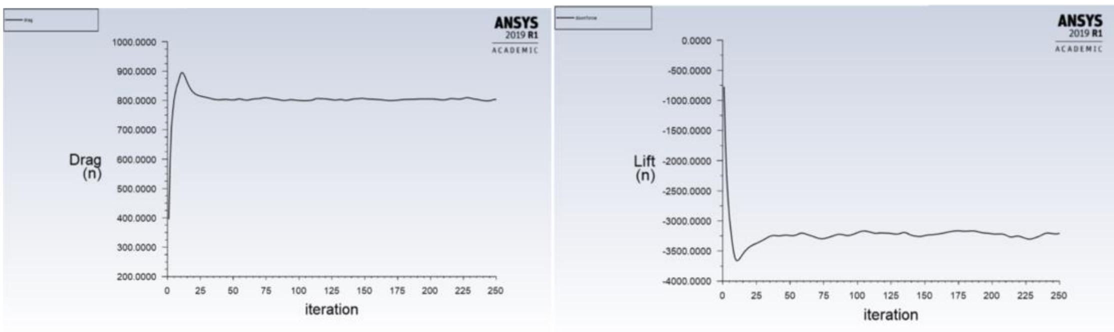

Figure 29 – Drag and Lift plots of the Williams FW-31

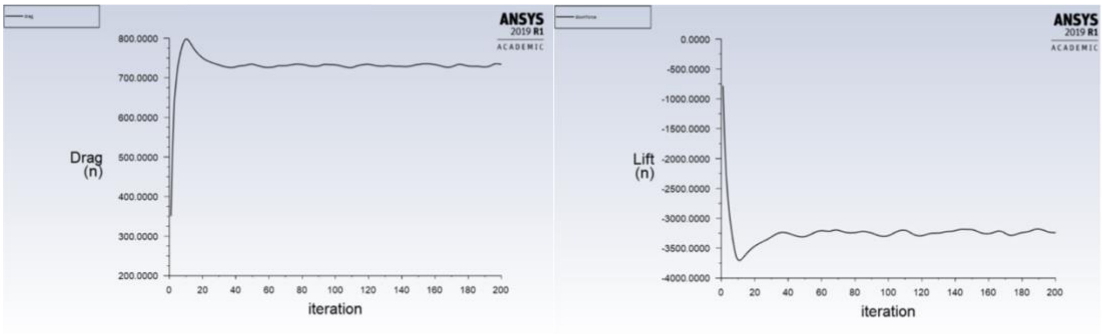

Figure 30 – Drag and Lift plots of the Williams FW-31

These results do not show a significant change on the downforce curve, but there is a significant change on the drag representation, which drops some newtons compared to the first design. In order to get a better idea of these change in performance, the exact numerical results will be displayed.

Forces - Direction Vector (0 1 0)

	Forces (n)		
Zone	Pressure	Viscous	Total
wing	-3207.4207	1.4419901	-3205.9787
Net	-3207.4207	1.4419901	-3205.9787

Figure 31 – Downforce in newtons for the Williams FW-31

Forces - Direction Vector (0 0 -1)

	Forces (n)		
Zone	Pressure	Viscous	Total
wing	768.35852	34.353416	802.71194
Net	768.35852	34.353416	802.71194

Figure 32 – Drag force in newtons for the Williams FW-31

Forces - Direction Vector (0 1 0)

	Forces (n)		
Zone	Pressure	Viscous	Total
wing	-3241.3181	1.8692758	-3239.4488
Net	-3241.3181	1.8692758	-3239.4488

Figure 33 – Downforce in newtons for the Williams FW-31.1

```
Forces - Direction Vector (0 0 -1)
                          Forces (n)
Zone                      Pressure        Viscous         Total
wing                      698.54791       35.619766       734.16768
------------------------- --------------- --------------- ---------------
Net                       698.54791       35.619766       734.16768
```

Figure 34 – Drag force in newtons for the Williams FW-31

These results show favorable values for the downforce, as it increases over 30 N, and the drag decreases up to 70 N. The new projected area of the upgraded front wing will increase due to the new surfaces included. This factor can also make the coefficients to decrease. Therefore, obtaining all the projected areas needed, *Table 2* can be done to calculate the coefficients by using the following equations:

E.1 $$C_z = \frac{F_z}{q.A_{ref}}$$

E.2 $$C_y = \frac{-F_y}{q.A_{ref}}$$

E.3 $$q = \frac{1}{2}\rho V^2$$

	Williams FW-31		**Williams FW-31.1**	
	Drag	***Lift***	***Drag***	***Lift***
Forces (N)	802.71	-3205.98	734.17	-3239.45
Area (m2)	0.5109	0.5109	0.5109	0.5109
Coefficients	0.7125	2.8459	0.6517	2.8758
F1 points	***71.25***	***284.59***	***65.17***	***287.58***

Table 3 – Downforce and Drag coefficients comparison

It is visible that the general performance of the car is expected to increase, as the downforce coefficient will increase, while the drag coefficient decreases. This means that the final car design should be faster on both straights and turns.

6.1.2 PROJECT RESULTS

This section includes the final results obtained for each design of the front wing. All results will be analyzed by comparing them to the original design, taking into account both drag and downforce coefficients. Designs will be simulated maintaining an equilibrium between precision and reliability of the simulation, as if the mesh is too precise, it will be impossible to simulate with only one computer.

In each design, the residuals plot will be shown. Those plots show if the calculation follows a correct pattern. In this case, the continuity line will be a little bumpy, as the mesh is not as precise as it should be. However, that is the best result possible taking into account it has been done with only one computer.

6.1.2.1 FRONT WING FW-31

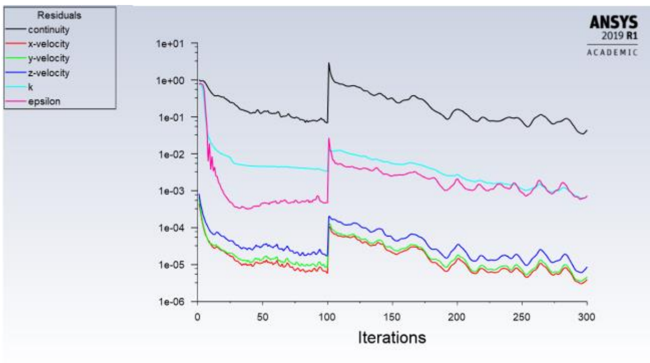

Figure 35 – Residuals of the Williams FW-31

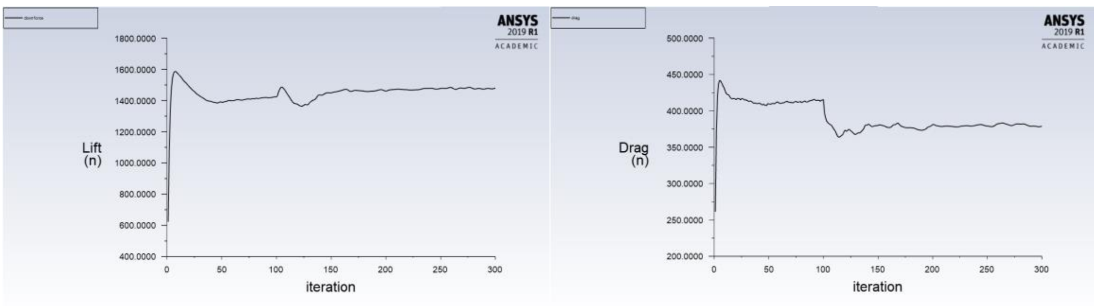

Figure 36 – Drag and Lift forces plots of the Williams FW-31

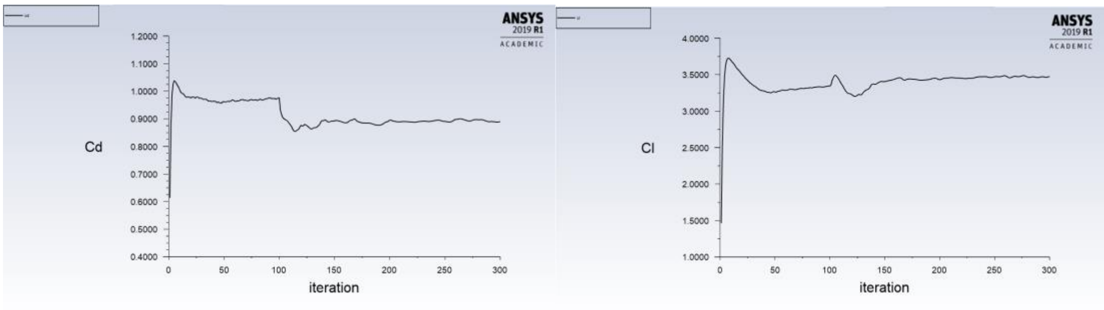

Figure 37 – Drag and Lift coefficients plots of the Williams FW-31

```
Forces - Direction Vector (0 0 -1)
                          Forces (n)                                     Coefficients
Zone                      Pressure        Viscous         Total           Pressure        Viscous         Total
wing                      364.89986       14.067211       378.96707       0.85704877      0.033039986     0.89008876
------------------------- --------------- --------------- --------------- --------------- --------------- ---------------
Net                       364.89986       14.067211       378.96707       0.85704877      0.033039986     0.89008876
```

Figure 38 – Drag force and coefficient of the Williams FW-31

```
Forces - Direction Vector (0 -1 0)
                          Forces (n)                                     Coefficients
Zone                      Pressure        Viscous         Total           Pressure        Viscous         Total
wing                      1480.3001       -0.029999551    1480.2701       3.4768152       -7.0460643e-05  3.4767447
------------------------- --------------- --------------- --------------- --------------- --------------- ---------------
Net                       1480.3001       -0.029999551    1480.2701       3.4768152       -7.0460643e-05  3.4767447
```

Figure 39 – Lift force and coefficient of the Williams FW-31

6.1.2.2 FRONT WING FW-31.1

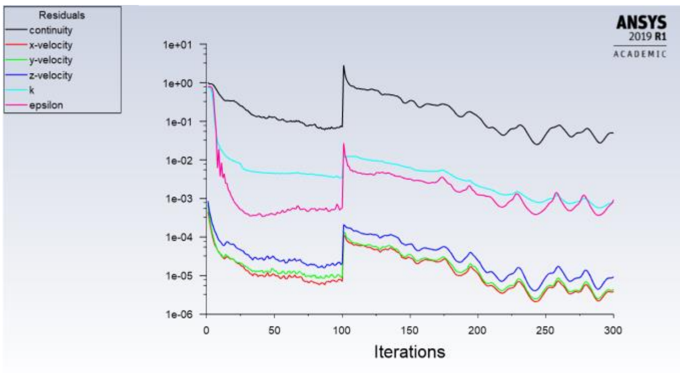

Figure 40 - Residuals of the Williams FW-31.1

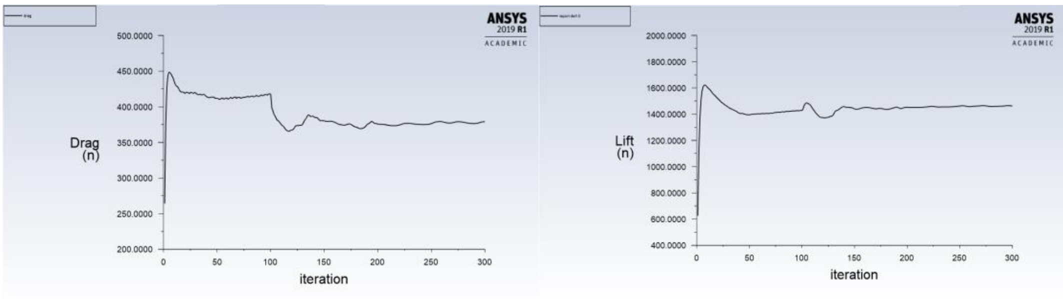

Figure 41 - Drag and Lift forces plots of the Williams FW-31.1

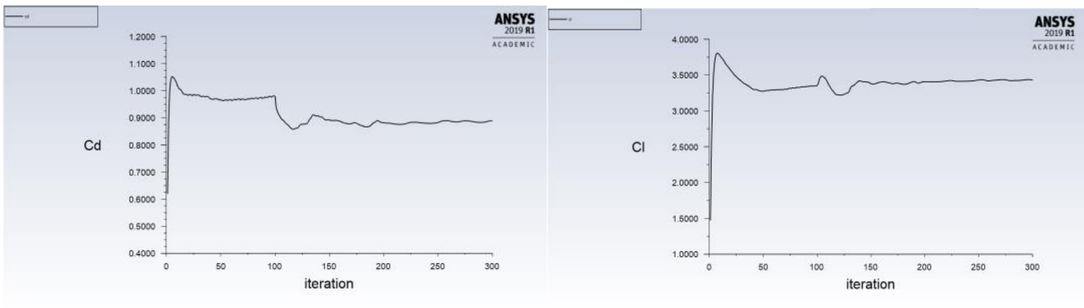

Figure 42 - Drag and Lift coefficients plots of the Williams FW-31.1

Forces - Direction Vector (0 0 -1)

Zone	Forces (n) Pressure	Viscous	Total	Coefficients Pressure	Viscous	Total
wing	364.47406	14.445092	378.91915	0.8551399	0.033891504	0.88903141
Net	364.47406	14.445092	378.91915	0.8551399	0.033891504	0.88903141

Figure 43 - Drag force and coefficient of the Williams FW-31.1

Forces - Direction Vector (0 -1 0)

Zone	Forces (n) Pressure	Viscous	Total	Coefficients Pressure	Viscous	Total
wing	1461.618	-0.13097798	1461.487	3.4292917	-0.00030730444	3.4289844
Net	1461.618	-0.13097798	1461.487	3.4292917	-0.00030730444	3.4289844

Figure 44 – Lift force and coefficient of the Williams FW-31

6.1.2.3 FRONT WING FW-31.2

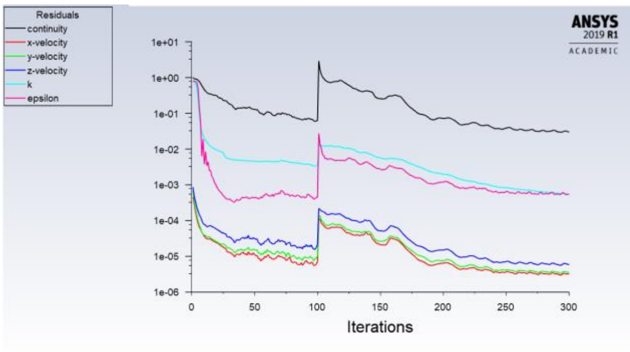

Figure 45 - Residuals of the Williams FW-31.2

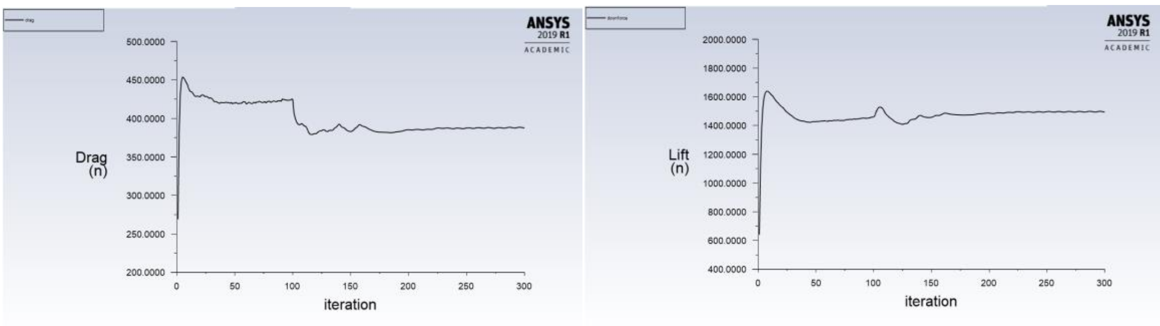

Figure 46 - Drag and Lift forces plots of the Williams FW-31.2

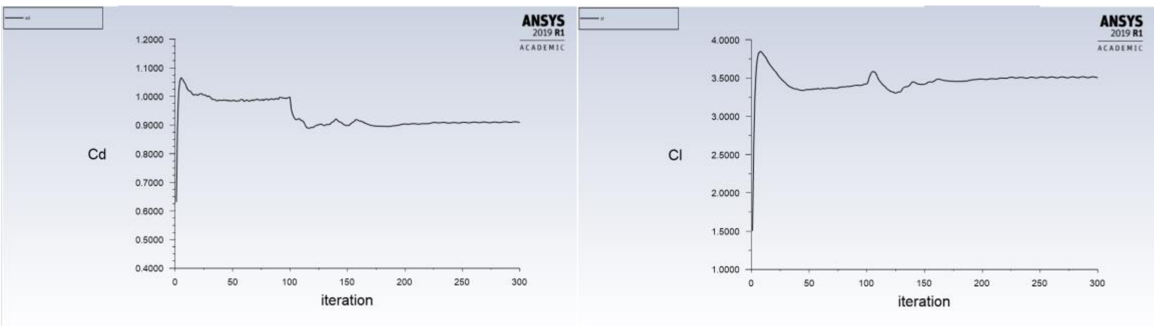

Figure 47 - Drag and Lift coefficients plots of the Williams FW-31.2

```
Forces - Direction Vector (0 0 -1)
                          Forces (n)                                     Coefficients
Zone                      Pressure        Viscous         Total          Pressure        Viscous         Total
wing                      372.71801       14.771328       387.48933      0.87443915      0.034655227     0.90909438
------------------------- --------------- --------------- -------------- --------------- --------------- ---------------
Net                       372.71801       14.771328       387.48933      0.87443915      0.034655227     0.90909438
```

Figure 48 - Drag force and coefficient of the Williams FW-31.2

Forces - Direction Vector (0 -1 0)

Zone	Forces (n) Pressure	Viscous	Total	Coefficients Pressure	Viscous	Total
wing	1493.3469	-0.20446649	1493.1425	3.503563	-0.00047970182	3.5030833
Net	1493.3469	-0.20446649	1493.1425	3.503563	-0.00047970182	3.5030833

Figure 49 - Lift force and coefficient of the Williams FW-3.2

6.1.2.4 FRONT WING FW-31.3

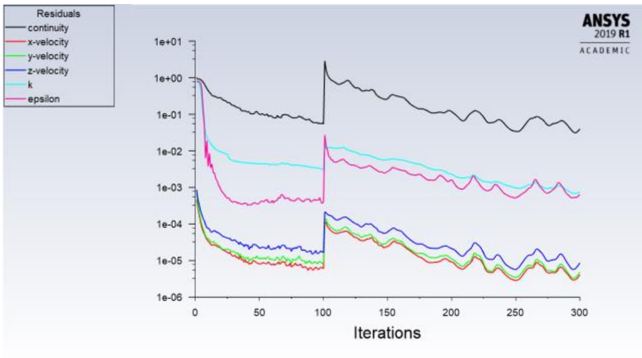

Figure 50 - Residuals of the Williams FW-31.3

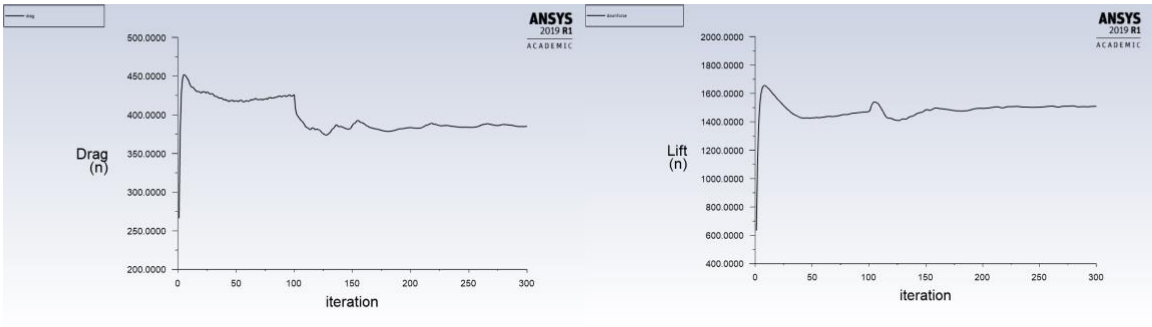

Figure 51 - Drag and Lift forces plots of the Williams FW-31.3

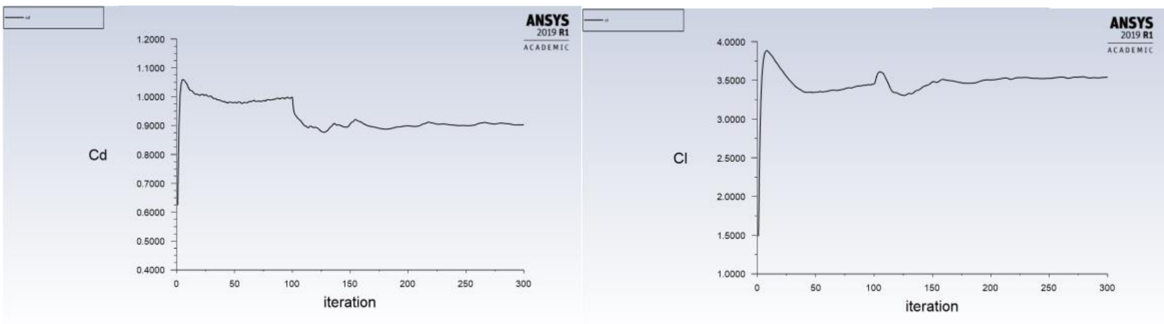

Figure 52 - Drag and Lift coefficients plots of the Williams FW-31.3

```
Forces - Direction Vector (0 0 -1)
                         Forces (n)                                 Coefficients
Zone                     Pressure       Viscous        Total          Pressure       Viscous        Total
wing                     370.13034      15.042352      385.17269      0.86799322     0.035275842    0.90326906
------------------------ -------------- -------------- -------------- -------------- -------------- --------------
Net                      370.13034      15.042352      385.17269      0.86799322     0.035275842    0.90326906
```

Figure 53 - Lift force and coefficient of the Williams FW-3.3

```
Forces - Direction Vector (0 -1 0)
                          Forces (n)                                       Coefficients
Zone                      Pressure        Viscous         Total            Pressure        Viscous          Total
wing                      1509.8567       -0.2277933      1509.6289        3.5407672       -0.00053419841   3.540233
------------------------- --------------- --------------- ---------------- --------------- ---------------- ---------------
Net                       1509.8567       -0.2277933      1509.6289        3.5407672       -0.00053419841   3.540233
```

Figure 54 - Lift force and coefficient of the Williams FW-3.3

6.1.2.5 RESULTS

Once all downforce and drag results have been calculated, they will be set on a table in order to compare them with the rest of the designs. All forces obtained have to be multiplied by 2 because all designs were simulated in half, divided by their symmetry plane. Coefficients will stay the same.

	FW-31	FW-31.1	FW-31.2	FW-31.3
Drag (N)	757.93	757.84	774.98	770.35
Cd	0.8901	0.8890	0.9091	0.9033
F1 Points	***89.01***	***88.90***	***90.91***	***90.33***

Table 4 – Drag forces and coefficients in F1 terminology for the different front wing designs

Analyzing the drag results, there is not a big difference between all designs, although is true that the only design where the performance may improve is the FW-31.1. However, considering the FW-31.3 as the final result, it would be fair to say that the performance will suffer a decrease. Comparing the final results in Formula 1 Points, the difference between the original and the final design would be of 1.32. Taking into account that 5 F1 Points of drag reduction equals to 10 kph increase in top speed, this new design would make the car around 2.5 kph slower on straights.

Even though the forces in newtons do not differ much between each other, the projected area will vary depending on the design. This means that the smaller the projected area, the bigger the coefficient will be. Therefore, every spoiler added to the design will increase the projected area, but on the contrary, the force will increase. That means that there is a necessity of finding an equilibrium between adding more spoilers or designing a simpler wing.

	FW-31	FW-31.1	FW-31.2	FW-31.3
Downforce (N)	2960.54	2922.97	2986.29	3019.26
Cl	3.4767	3.4290	3.5031	3.5402
F1 Points	***347.67***	***342.90***	***350.31***	***354.02***

Table 5 – Downforce and lift coefficients in F1 terminology for the different front wing designs

Following the same procedure, comparing the downforce results, the difference between each design are more visible than for the drag. In this case, the FW-31.1 will be the only design that will not increase the performance of the car on turns. Looking at the final design result, there is clearly an improvement, as in F1 Points there is an increase of 6.35. Considering that adding 10 F1 Points of downforce would mean winning about 0.3 seconds per lap, the overall car performance would be almost of 0.2 seconds per lap.

Although this improvements seems as a very small difference, the truth is that in the Formula One Competition, every change makes a difference. Distances between cars are so small, that this upgrade could totally make a car win some places on the grid.

Furthermore, it is important to understand that the overall performance of this car is supposed to be faster on turns and slower on straights. This means that this setup would be interesting to apply on those circuits with higher aerodynamic load. Some examples would be the GP of Monaco or the GP of Singapore, where all improvement relies on going faster on turns.

6.1.3 FUTURE CALCULATIONS

All simulations were calculated from a remote controlled computer, with an Ansys license for students. There was no restriction in the software, but the only problem was that simulations could not be as precise as this kind of designs require. Therefore, in order to make this simulations more precise, the idea would be to use a cluster of computers, forming a more powerful computer that will allow to simulate these complex designs. To do so, calculations with higher number of iterations could be done, and the mesh quality could be refined.

6.2 MANUFACTURING PROCESS AND MATERIALS SELECTION

Once all results are analyzed, it is time to explain how these additions to the front wing will be manufactured. Nowadays, Formula One teams use carbon fiber structures, in which a pre-impregnated epoxy resin and an aluminum honeycomb layer are sandwiched between two layers of carbon fiber. The idea of this project is to keep manufacturing essential parts as how is actually done in Formula 1 cars.

6.2.1 CARBON FIBER MANUFACTURING PROCESS

The raw material used to make carbon fiber is called the precursor. Carbon fibers, or also called graphite fibers, are 90% made from polyacrylonitrile. The remaining 10% are made from rayon or petroleum pitch. All these materials are organic polymers, characterized by long strings of molecules bond together by carbon atoms. Depending on the application, the compositions will vary, and is usually considered a trade secret. [11]

Some of the advantages of graphite composites are high specific stiffness (stiffness divided by density), high specific strength (strength divided by density) and extremely low coefficient of thermal expansion (CTE). That is why Formula 1 cars use this material, as it has a big relations between strength and density, making extraordinary strong and light materials. Furthermore, thanks to its low CTE, in case of accident and fire exposure, the safety of the driver will increase. [12]

Before the fibers are carbonized, they need to be chemically altered to convert their linear atomic bonding to a more thermally stable ladder bonding. This is accomplished by heating the fibers in air to about 200-300° C for 30-120 minutes. This causes the fibers to pick up oxygen molecules from the air and rearrange their atomic bonding pattern. The stabilizing chemical reactions are complex and involve several steps, some of which occur simultaneously. They also generate their own heat, which must be controlled to avoid overheating the fibers.

Once the fibers are stabilized, the precursor is drawn into fibers and kept under tension while it is heated under high temperature (> 1000 ºC) without allowing it to come in contact with oxygen, so it cannot burn. These high temperatures causes the atoms in the fiber to vibrate violently until most of the non-carbon atoms are expelled. This process is called carbonization.

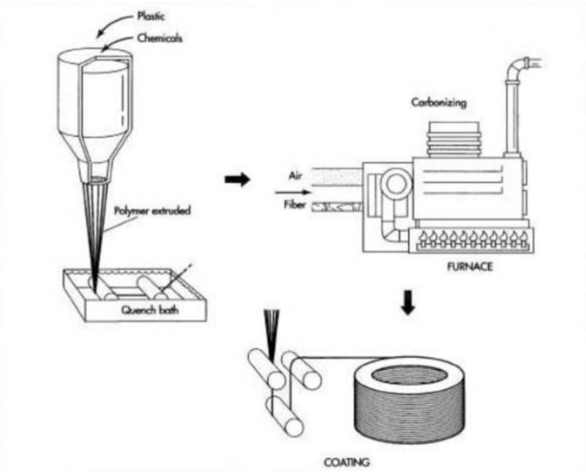

Figure 55 – Graphite fibers through carbonization process

After carbonizing, the fibers surface does not bond correctly with the epoxies. To give the fibers better bonding properties, their surface is slightly oxidized. This is because the addition of oxygen atoms to the surface provides better chemical bonding properties and also etches and roughens the surface for better mechanical bonding properties. Oxidation can be achieved by immersing the fibers in various gases such as air, carbon dioxide, or ozone. It can also be immersed in various liquids such as sodium hypochlorite or nitric acid.

After the surface treatment, the fibers are coated to protect them from damage during winding or weaving. This process is called sizing. Coating materials are chosen to be compatible with the adhesive used to form composite materials. Typical coating materials include epoxy, polyester, nylon, urethane, and others.

Figure 56 – Carbon fiber sheet after surface treatment

6.2.2 MANUFACTURING CARBON FIBER PLATES

The first stage on the manufacturing of a Formula 1 car consists on building a solid pattern in order to produce the molds required to produce the different parts of the car. Once the molds are ready, the carbon fiber layers pre-impregnated in an epoxy resin will be mounted over the molds, and depending on the part, they can have up to a hundred layers.

As these molds are open, a vacuum bag molding will improve the mechanical properties of the part. By reducing the pressure inside the vacuum bag, the external atmospheric pressure will make force on the bag. The pressure on the laminate removes entrapped air, excess resin, and compacts the laminate, resulting in a higher percentage of fiber reinforcement. [13]

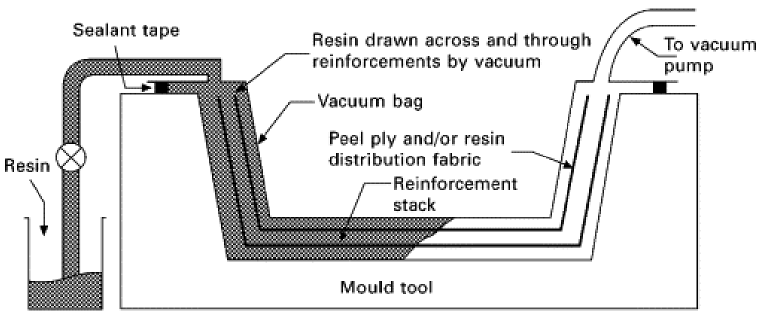

Figure 57 – Vacuum bag molding process

When all the layers are set up, the next stage of the process is to cure the carbon fiber in the autoclave. Therefore, the material will be exposed to temperatures around 90 to 100 ºC and a pressure of 7 atmospheres. Each part may spend anything from 2 to 8 hours in the autoclave. All this process will make the layers to squeeze them together. [8]

Figure 58 – Autoclave used in F1 competition to manufacture carbon fiber parts

Carbon fiber manufacturing continually seeks out new advancements and improvements in properties. These improvements are largely thanks to breakthroughs made in chemistry, which continue to improve strength and other performance parameters, while reducing weight. The advancements in chemistry are not just limited to carbon fiber construction, but also apply to binder chemistry, such as epoxies and other resin-based materials to hold the fiber layups together. These advancements in chemistry drive new production methods too, and together the end result is stronger, faster race vehicles that are also lighter and more crash resistant.

The idea of the project is to manufacture the new proposed parts independently from the rest of the front wing so that they can be incorporated depending on the Grand Prix configuration needed.

Figure 59 – Final result of a carbon fiber front wing in Formula 1

Carbon fiber is the most widely used material in Formula 1. However, due to its high resistance and lightweight, it makes it very expensive, with a manufacturing process that takes from two to three days. Therefore, these prerequisites will be computed into CES EduPack, which will give a range of possible materials that could substitute carbon fiber.

6.2.3 MATERIAL SELECTION

As carbon fiber is the main material used in the Formula 1 Competition, this project aims to consider other material options that would fit these demanding conditions. Therefore, a study will be carried out considering some of the most important properties that carbon fiber meet in order to be the most used material in the competition.

Physical properties	Mínimo	Máximo	
Density		1800	kg/m^3
Mechanical properties	**Mínimo**	**Máximo**	
Young's modulus			GPa
Specific stiffness	12		MN.m/kg
Yield strength (elastic limit)			MPa
Tensile strength	100		MPa
Specific strength	65		kN.m/kg
Elongation		5	% strain

Figure 60 – Physical and mechanical conditions to find other options

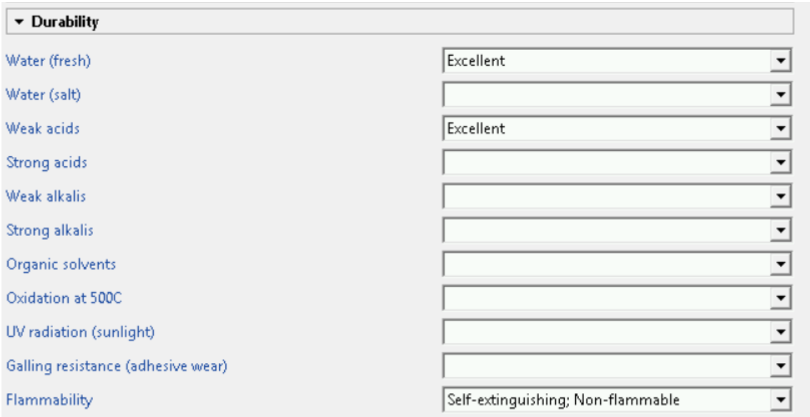

Figure 61 – Some other important characteristics that the material must meet

All these conditions will limit the result of a total of 23 materials. In order to find what options would fit best, they will be plotted according to the tensile strength and comparing it to the material density. Furthermore, a second comparison will be plotted between the tensile strength and the price.

Figure 62 - Materials that meet the proposed conditions

The first thing to note is that all the materials obtained are both glass and carbon fibers. What differentiates these materials is the percentage of fiber used in each of them, which will result in changes in density and strength. This means that finding different materials that would meet all Formula 1 demands is a very difficult task. However, as there are many carbon fiber options, it is of great importance to find the most efficient material.

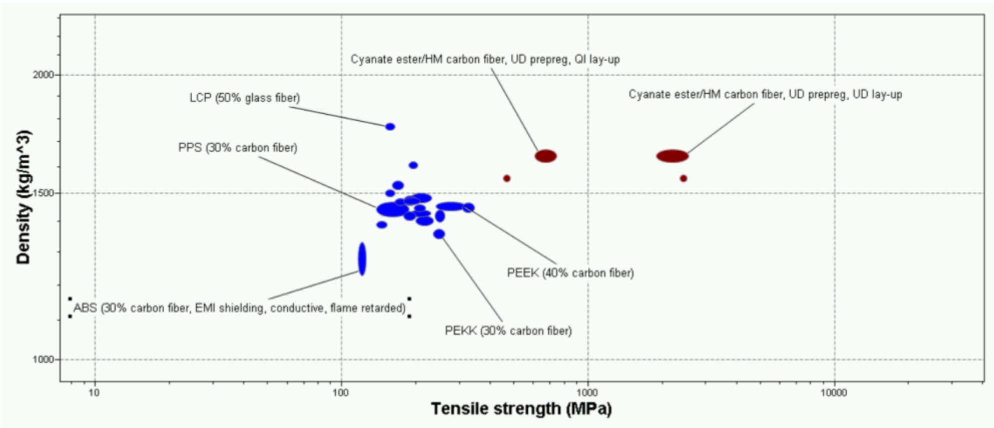

Figure 63 – Tensile strength compared with the materials density

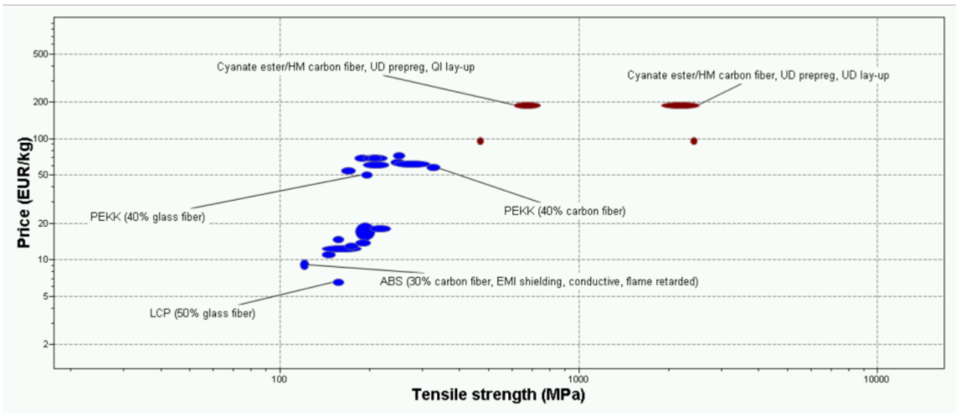

Figure 64 – Tensile strength compared with the materials price per kilogram

Looking at both graphs, all materials seem very close in terms of performance, as they all meet with the strength conditions required in a Formula 1 car. However, as Formula 1 Teams will seek for the lighter materials to get faster cars, this composites cluster clearly show what Formula 1 Teams should aim for. Making small changes to the carbon fiber percentage, the material will experience variations either in strength and density.

Chapter 7. CONCLUSIONS AND FUTURE PROJECTS

This project set out to answer the initial question whether it would be possible to improve the performance of a 2009 Formula One car, the Williams FW-31, by adding certain modifications from the new regulations. These modifications were firstly introduced in the front wing and simulated. To measure the improvement, downforce and drag coefficients were calculated and compared with the original design.

Once proving that the modifications improved the car performance, it is time to answer to the project purpose, compare these cars with Formula One cars nowadays. It would be fair to say that with little that the front wing changed, the lap time would be significantly reduced. Therefore, considering that the front wing consists on a 25% of the total downforce of the car, it seems to be possible that the performance of those old cars could reach nowadays lap times.

However, more research should be done in order to find more convincing results. New modifications should be proposed by analyzing them little by little, and every time progress is made, compare it to the most recent successful part. This methodology should make this project achieve its purpose.

Given that during the project certain limitations have been found, they are still some sections where more work could be done to reach a more complete result. On the one hand, with the help of a set of computers, the simulations could be made more precise, leading to more concrete results. On the other hand, new designs should be proposed, thinking of designs for circuits with other characteristics. In addition, simulations can be made in different parts of the circuit, differentiating between straights and turns of different types.

Furthermore, more research should be done in order to understand what materials could be proposed in order to satisfy the restrictions of reducing cost and weight by maintaining the strength. Carbon fiber manufacturing continually seeks out new advancements and improvements in properties. Therefore, Formula 1 Teams should invest time studying new materials that may form lighter carbon fiber parts.

Today, Formula 1 cars are benefiting from advances in technology in all areas covered by the Competition. Despite the fact that these single-seaters are the fastest cars in motorsport history, cars form previous times have nothing to envy. The racing conditions have changed in many ways that it would be very difficult to compare the real performance of Formula 1 cars from different years.

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APPENDIX I

SUSTAINABLE DEVELOPMENT GOALS

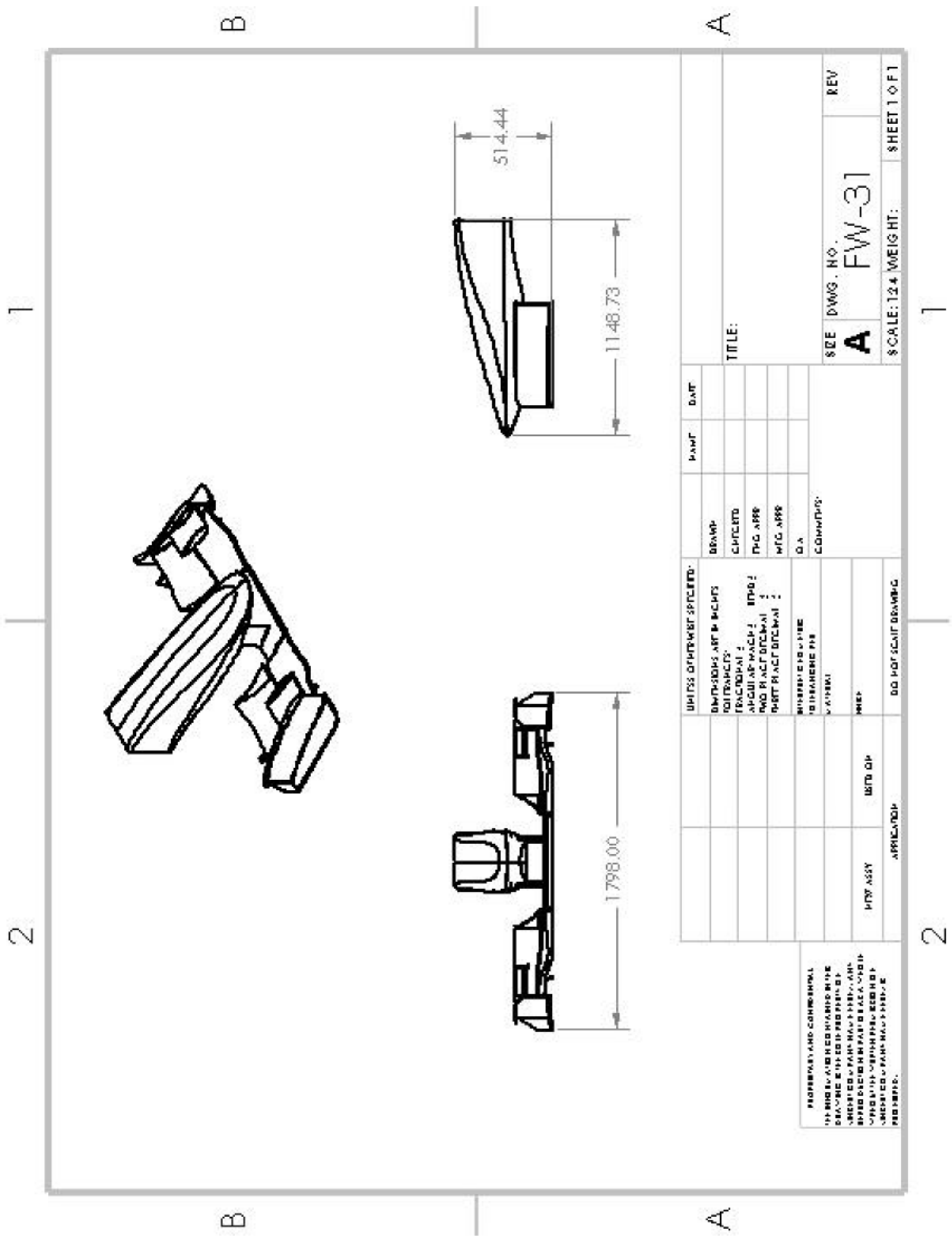
Formula 1 cars are mostly made of carbon fiber. This material is widely used I various industries, especially in aeronautics, since it is resistant like steel and light as wood. However, these types of synthetic fiber are very difficult to break, making recycling and reuse extremely difficult.

Therefore, as this material constitutes a large part of this competition, there is clearly a Sustainable Development Goal (SDG), developed by the United Nations, that can be identified as primary in this project. The SDG number 12 tries to ensure sustainable consumption and production patterns. Consequently, the target of this project will have as a goal that by 2030, there will be a substantially reduce waste generation through prevention, reduction, recycling and reuse.

Furthermore, all the manufacturing processes involved in the design of these parts, have a significant impact on the environment. For that reason, in the biosphere dimension, Formula 1 competition should strive to ensure SDG number 13, which focus on taking urgent action to combat climate change and its impacts. As a secondary role, the goal should be to improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

Regarding to the society dimension, historically Formula 1 is characterized for facing problems of transparency inside the competition, since some of the teams have been favored during the years. Therefore, one last SDG identified would be number 16, which will try to promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels. The goal of the project will focus on developing effective, accountable and transparent institutions at all levels.

APPENDIX II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1148.73
1798.00
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A
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FW-31
REV
SCALE: 1:24
WEIGHT:
SHEET 1 OF 1