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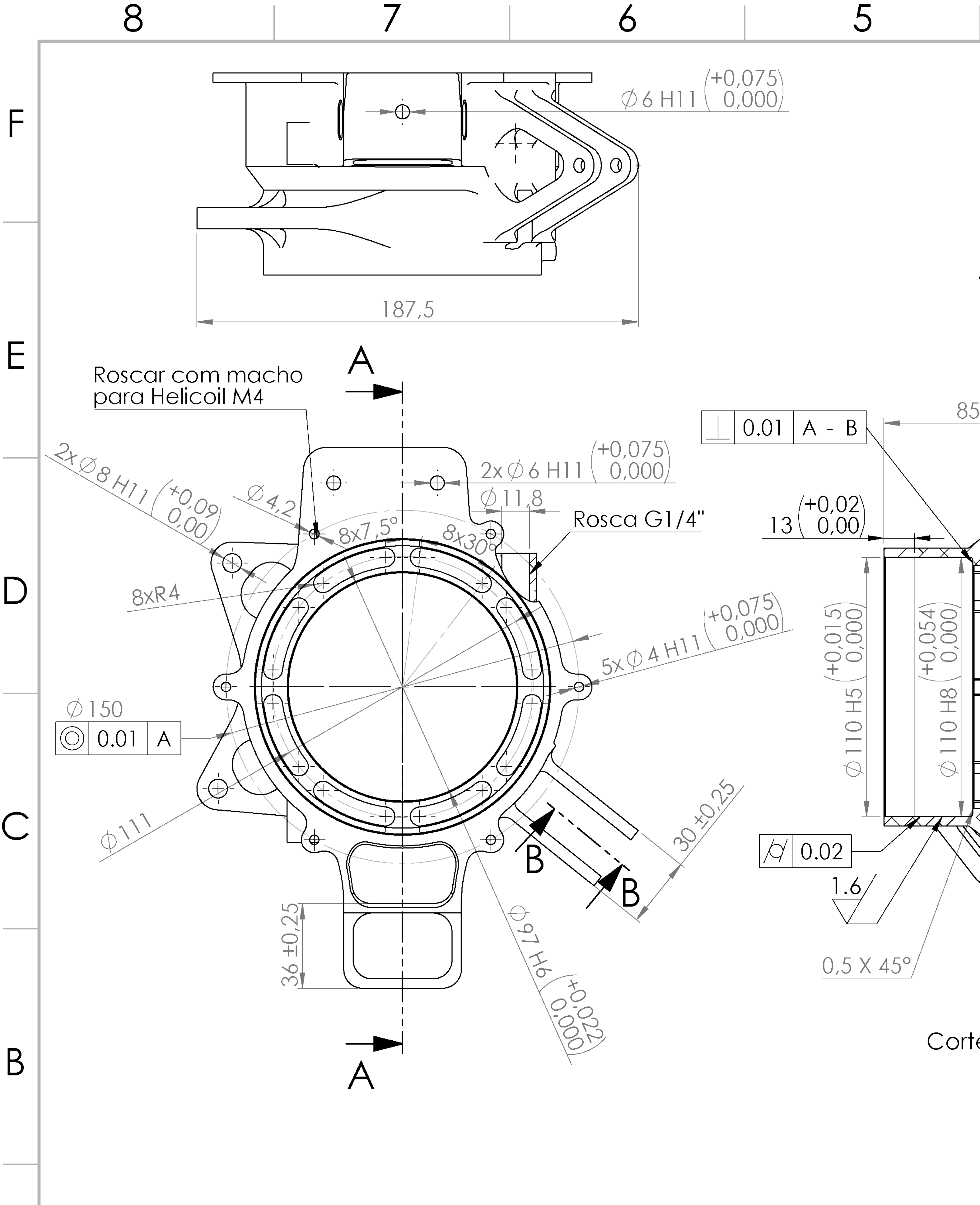
THE DESIGN MAGAZINE

JANEIRO 2023



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devendo ser feito uma simétrica para o lado direito,
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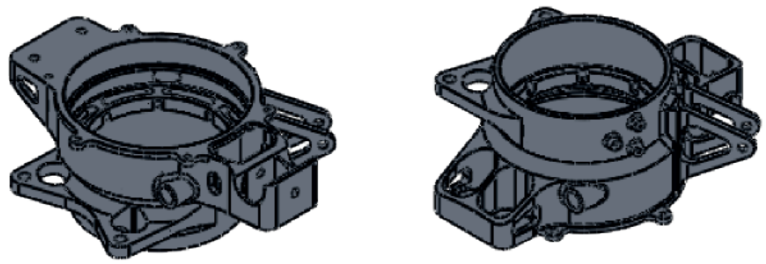

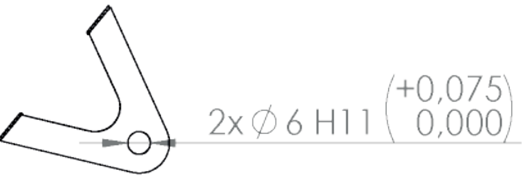

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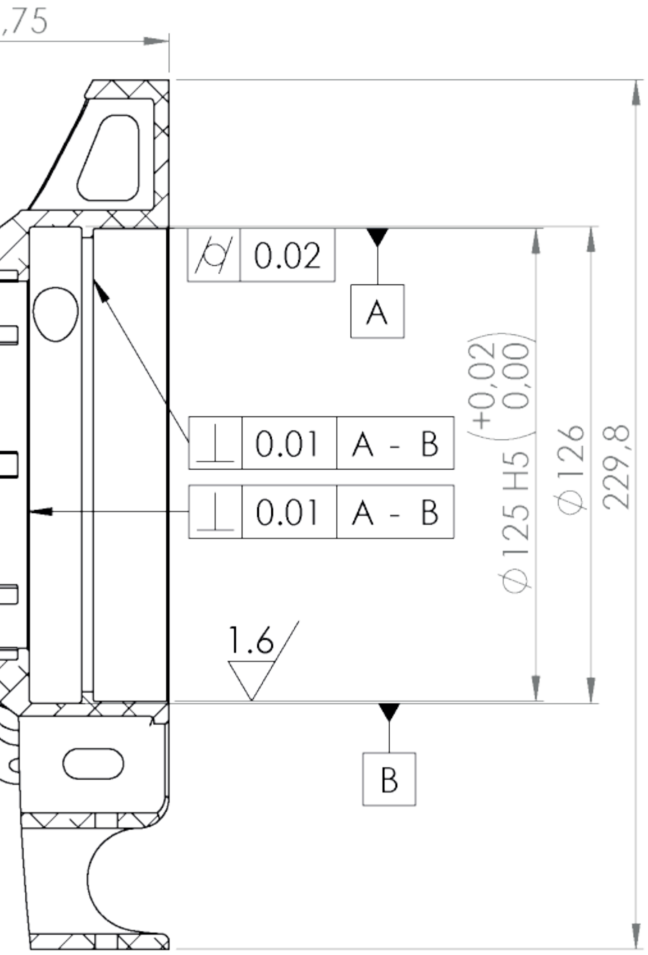

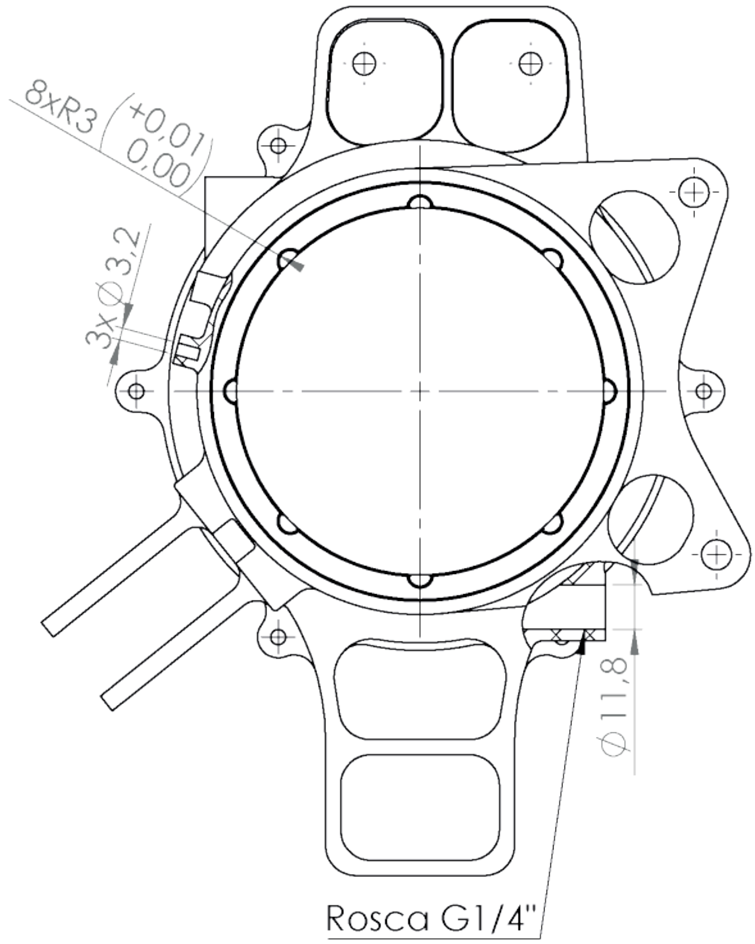

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	NOME	ASSINATURA	DATA
DESENHO	João Fernandes	João Fernandes	13/11/2022
REVISÃO	Diana Sanchez	Diana Sanchez	13/11/2022
APROVAÇÃO	XXX	XXX	XXX

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Folha: A3	Designação: SU_DT_UP_01_F

Nota:	Material: Al 7075-T6 (SN)	Massa: 799 g	Nome: Front Left Upright

Rugosidade geral: 3.2	Tolerância geral: ISO 2768-mK	Escala: **1:2**	Quantidade: 1

A

THE DESIGN MAGAZINE

Design Magazine
FST Lisboa

January, 2023
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EDITORIAL

Após vários momentos adversos resultantes da situação pandémica que vivemos nos passados anos, a FST Lisboa está agora determinada a projetar um novo protótipo, definindo novos objetivos.

A Magazine de Design vem assim introduzir aspetos técnicos considerados durante a fase de design do FST11, que irá competir no Verão de 2022, nas mais variadas competições de Formula Student, ao lado das melhores Universidades do Mundo. São quatro os eventos que vão traçar a fase de competições, sendo uma delas a maior competição de engenharia do mundo - Formula Student Germany, na qual marcamos presença nos últimos três anos consecutivos.

Esta Magazine destina-se a todos os interessados pelo mundo do automobilismo e engenharia, visto que abordam vertentes técnica dos vários departamentos que constituem a equipa.

O FST11 irá competir tanto em provas dinâmicas para veículos elétricos como para veículos autónomos, significando que este será o primeiro protótipo da equipa desenhado de raiz para ter capacidades autónomas. É de notar que a constante evolução das competições resulta em regulamentos cada vez mais restritos e complexos, derivando em consideráveis remodelações no nosso protótipo face aos carros anteriores.

Assim sendo, deixamos então à sua disposição uma grande variedade de artigos associados ao Design do FST 11, escritos por alguns dos membros da FST Lisboa que partilham uma paixão comum - o entusiasmo e curiosidade por todos os traços que

BY MARGARIDA CARDOSO

CONTENT


accenture
MAINTENANCE
& ENGINEERING
ETECH
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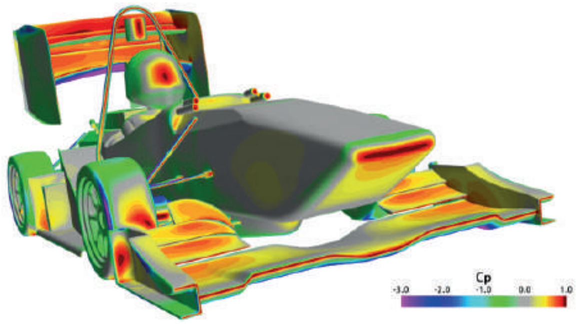
AERODYNAMICS

The design of the aerodynamic package of the FST12 was oriented towards 3 main known areas where performance could be extracted. The flow around the car was studied using Computational Fluid Dynamics (CFD), a well known friend of the Aerodynamics Department! Several improvements on the domain discretization were made in order to adapt the mesh to the current car and new vortical structures that are formed with the new components introduced.

CFD – FRONT WING

The Front Wing was designed to extract the maximum performance possible from its main element. The number of flaps was reduced from 10 to 6, introducing the curved tip flaps that bring great performance in all aerodynamic components of the car. Moreover, the endplate features a bigger canard that generates a powerful vortex that controls the front tyre wake and generates more front end downforce.

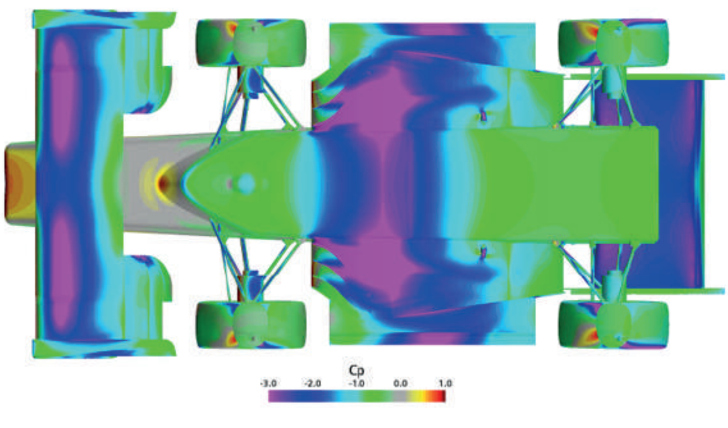
Figure 1 - C_p on the FST12 - perspective view.



CFD – SIDE WING

This year, the department has decided to move away from side elements, introducing a vertical flat plate in front of the rear tyre which will house the radiator and fan for motors' cooling. The team continues to use its custom made profile of the Side Wing and its angle of attack was increased to generate more downforce. The Side Wing ground strakes are redesigned to be better aligned with the flow, generating more downforce on a crucial and sensitive spot of the aerodynamic package. The footplate features a vortex generator that seals the underside of the car.

Figure 2 - C_p on the FST12 - bottom view.



CFD – REAR WING

Designing an aerodynamic package using CFD without validating the mathematical models used is exciting, colorful and very dangerous. In order to quantify the errors associated with the approximations made on the models, several techniques will be used when the car hits the track for testing. The three main interest variables that will be evaluated are the (negative) lift coefficient, the drag coefficient and the aerobalance. The coast down procedure will evaluate the drag coefficient, while the downforce coefficient and aerobalance will be estimated using potentiometers on the suspension. Additionally, flow-vis and wool tufts will help visualizing boundary layer transition and flow separation.

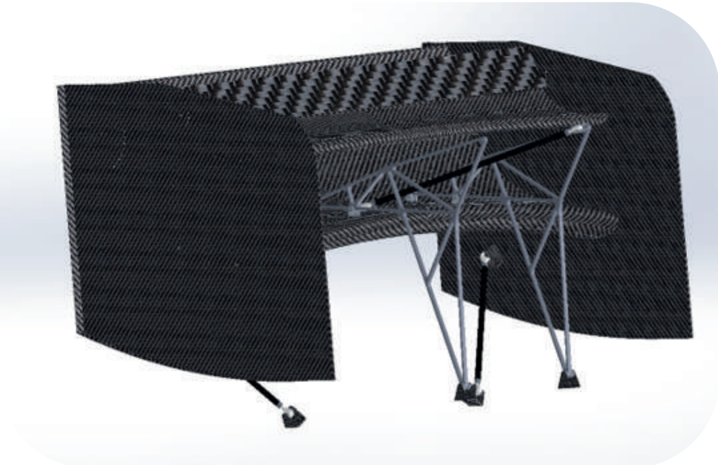


Figure 3 - FST12's Rear Wing.

VALIDATION

Designing an aerodynamic package using CFD without validating the mathematical models used is exciting, colorful and very dangerous. In order to quantify the errors associated with the approximations made on the models, several techniques will be used when the car hits the track for testing. The three main interest variables that will be evaluated are the (negative) lift coefficient, the drag coefficient and the aerobalance. The coast down procedure will evaluate the drag coefficient, while the downforce coefficient and aerobalance will be estimated using potentiometers on the suspension. Additionally, flow-vis and wool tufts will help visualizing boundary layer transition and flow separation.

Figure 4 - C_p on the FST12 - bottom view.

STRUCTURAL ANALYSIS

The Front Wing structural design was made with innovation in mind. The FST12 will have supports, both for the flaps and main wing, whose concept has not been seen before on the team. Not only this, it will also avoid issues this system had last year (high lateral displacement during high speed turns, mainly during Skidpad and the Front Wing initially not passing regulations due to high displacement).

There was a need to reduce the lateral displacement, solved by reducing the size of the supports in order to lower the moment created at the attachment points (in this case, brackets). To enforce this idea, the supports are directly in front of the AIP, attaching to this part through the use of brackets. The brackets attach to the AIP through the already existent M8 bolts that belong to the IA assembly. This means that the brackets are well fixed and do not need to be removed. Furthermore, to ensure adjustable height is still available, they have several holes at different heights to choose from.

The supports are truss-like and made of AL-7075 aluminum and are positioned closer to the center which causes the moment to become higher. This means that the main wing will reach a higher displacement with the same load as applied before. This combined with the fact that last year´s Front Wing did not pass the displacement regulations, meant that the rest of the assembly had to be reinforced and a higher safety factor needed to be used.

To reduce bending, the once single spar sustaining the main wing turned into 3 aluminum spars. The number of aluminum ribs was reduced by almost half due to them being rather redundant and 4 foam ribs were added to prevent high torsion values, but also keep a light assembly.

The flaps attachment to the main wing was also changed. For the past few years, the team has made midplates made of foam and a composite of carbon fiber and resin, but now that concept has been changed to aluminum supports that attach to ribs inside each flap. This fixes the hindrances that involved not only manufacturing a midplate and its assembly but also the constant use of inserts. Not only that, supports also show better results aerodynamically than midplates do.

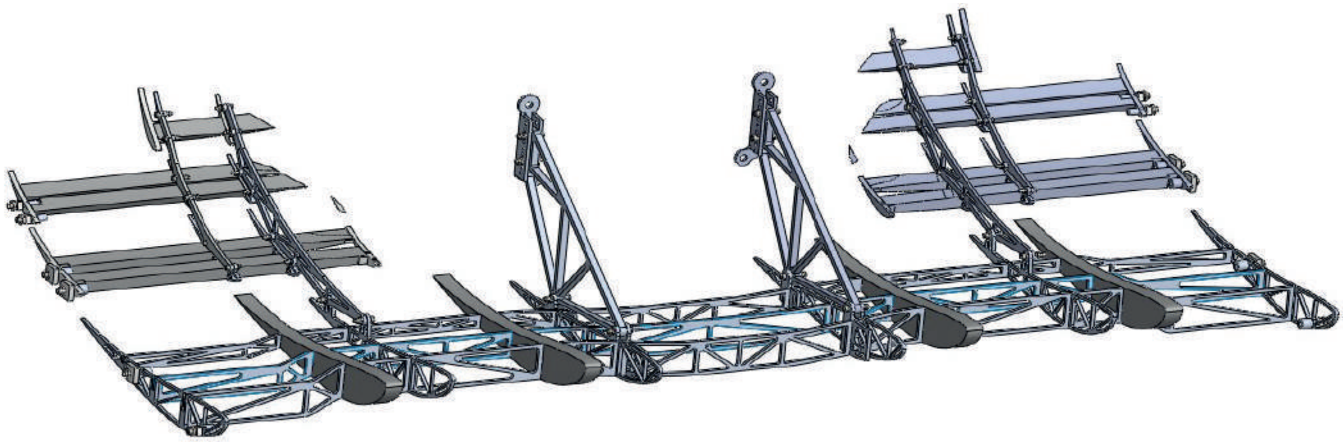
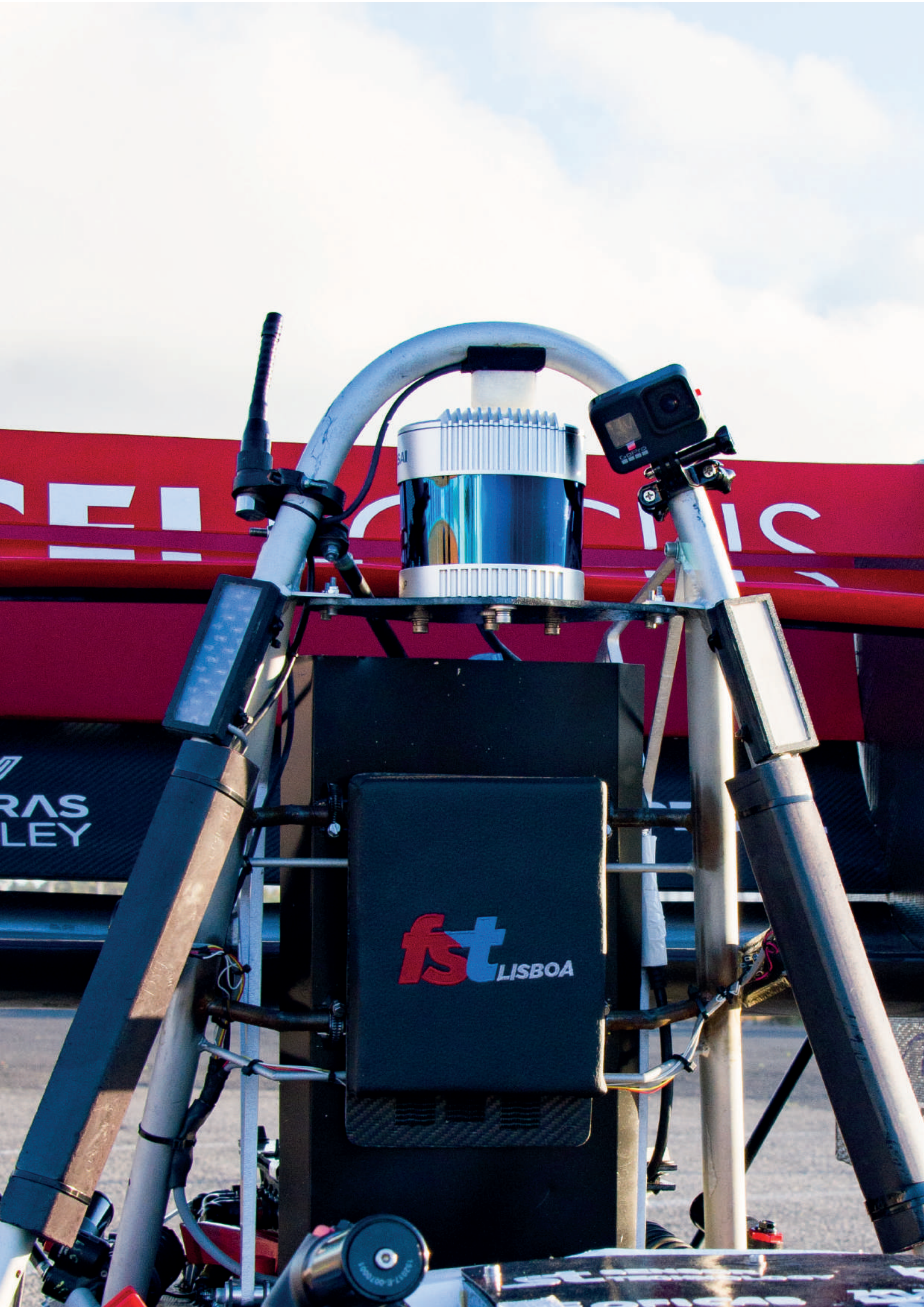


Figure 5 - Structural components of the Front Wing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AUTONOMOUS SYSTEMS

If it is already extremely hard for a human to extract the maximum performance out of a racing car, it is no easy task for a computer as well. The software needs to detect the vehicle limits, make decisions real-time, and actuate on the car accordingly. Hence, for the FST12 the AS department decided that one of its main goals was the implementation of the state-of-the-art control technique, Model Predictive Control (MPC).

In the 1980s MPC had its first appearance in industrial processes such as oil refineries or chemical plants. It produced outstanding results for these types of applications since it would come up with an optimal solution for the designated problem. The drawbacks at the time (but still now but less noticeable) resided in its computational demand and guaranteeing the system's stability. Hence, it was only used in specific industries that had slow processes. Over the years, the computational resources evolved managing to reduce MPC's computation time from minutes/seconds to the hundredth of a second.

MPC has a very intuitive formulation behind it. The idea is to predict the future in order to act in the present accordingly. Similar to how a chess player would try to predict their opponent's next moves. Or a Formula 1 driver trying to predict the best opportunity window to overtake its opponent. Hence, MPC produces a control input that takes into account not only the present but also the future, and possibly the past. The control input is also chosen based on a cost function that it tries to minimize (example, taking the least time possible), therefore its solution is said optimal in the sense that it is the best solution for the given problem. Furthermore, in order to predict the future, MPC needs an accurate model of the car so it "knows" what is the vehicle's behavior when a control input is given, effectively predicting the future. Lastly, one of the biggest advantages is the capability of dealing with constraints (for example, in the driving scenario, demand that the car can never leave its lane). Specifically, the current MPC design has two main goals: minimizing the distance to the reference path while maximizing the velocity at which this path is followed.

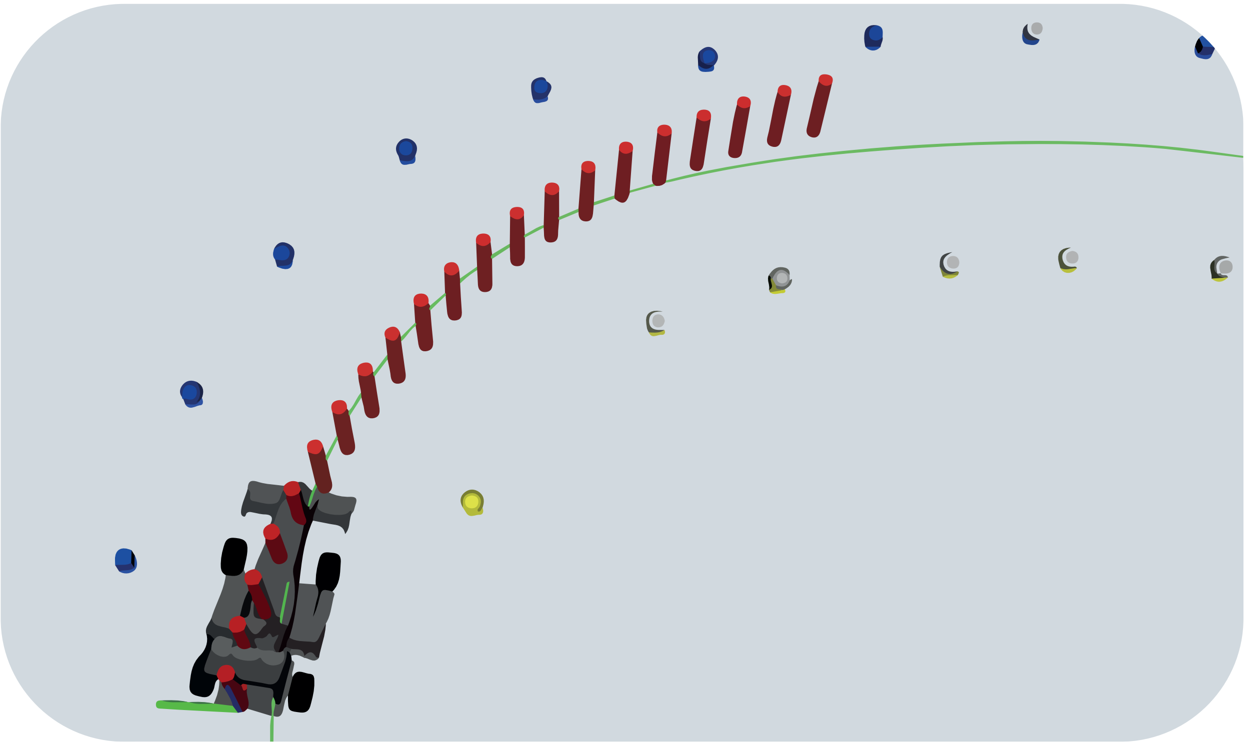


Figure 6 - MPC Simulation in ROS. The red cylinders represent the predicted trajectory of the car and their height the predicted velocity. In this case, the controller is looking one second into the future.

The physical model that MPC uses to predict the future is based on the bicycle model. The parameters it relies on are the validated car parameters obtained by the vehicle dynamics department. A full car model is not supported since such complex model would make the real time computations infeasible.

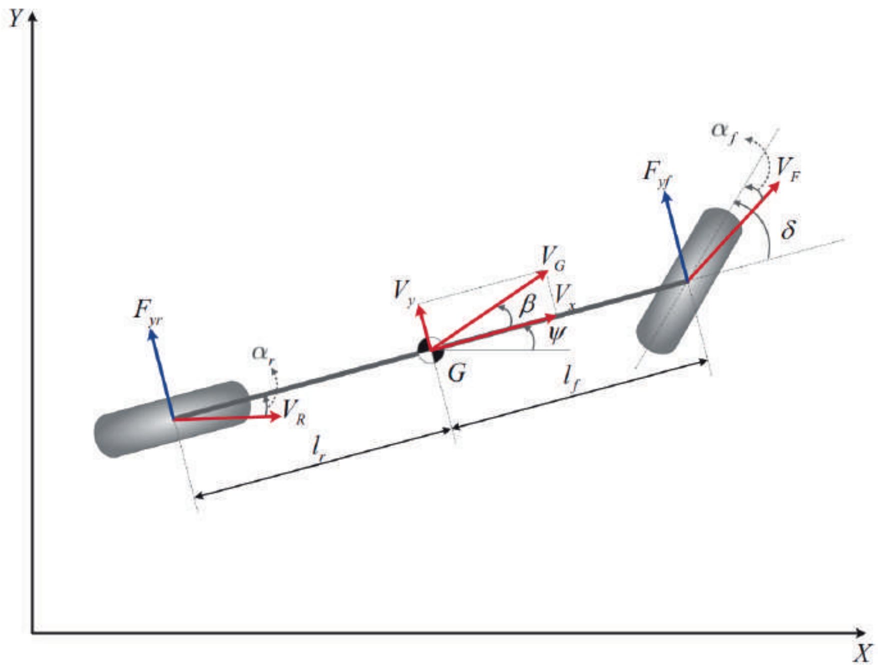


Figure 7 - Bicycle Model used inside the MPC.

MPC's performance is very much dependent on the quality of this model. Therefore, in order to better approximate the car's behavior while still keeping the complexity low, a neural network is introduced. This neural network learns the disparity from the predictions of the MPC to what actually happened, mitigating possible model mismatches and therefore, better predicting the future. This means that every time the vehicle is racing, it is learning with it, so he can apply that knowledge to the remaining laps. This new technique is called Learning-MPC (LMPC).

LMPC is a promising control approach for the Formula Student since it takes into account the behavior of the race car it is controlling while learning with it, effectively reaching the handling limits of the car, something that the last team's controller was agnostic to. Therefore, by incorporating such a technique in the FST12 it can be be expected that all dynamic events will suffer from a significant boost in performance, especially where cornering is a big part of the track.

Overall, while the use of an MPC in a Formula Student autonomous car can provide many benefits, the implementation of the technology is not without its challenges. Developing and validating a complex model, handling the computational requirements, and dealing with the uncertainty of the environment are among the main challenges that must be overcome in order to implement an MPC successfully in an autonomous car such as FST12.


CENFIM

CHASSIS

EBS: FEET FOR WHAT?

For the autonomous capability of the next prototype of FST Lisboa, there is a need to immobilize the vehicle without manual intervention. Thus, both by regulation and for safety reasons, there must be an ASB (Autonomous Braking System). Within this system, there are two components: one electrical and one mechanical. The Chassis department develops the EBS (Emergency Braking System), which consists of the mechanical integration of the system.

This year, the team will be designing the third iteration of the EBS, with a completely new concept for the conversion from pneumatic to hydraulic pressure. Unlike the previous versions of the system, this year goal's won't be optimization, but trustful.

The working principle of the new concept consists of a direct conversion of pressure between two different fluids. In simple terms, the new EBS works just like those giant jumping pillows that we see in water parks, in which three people jump at a low velocity, and the person already in the pillow is thrown away with a greater velocity.

Thus, our system consists of a pneumatic chamber (in this case, a pre-made piston) with superior dimensions in comparison to the hydraulic chamber, a pressure of 8 bar, and another chamber with 80 bar. To ensure this operation, it consists of three subsystems: Pneumatic System, Mechanical System, and Hydraulic System.

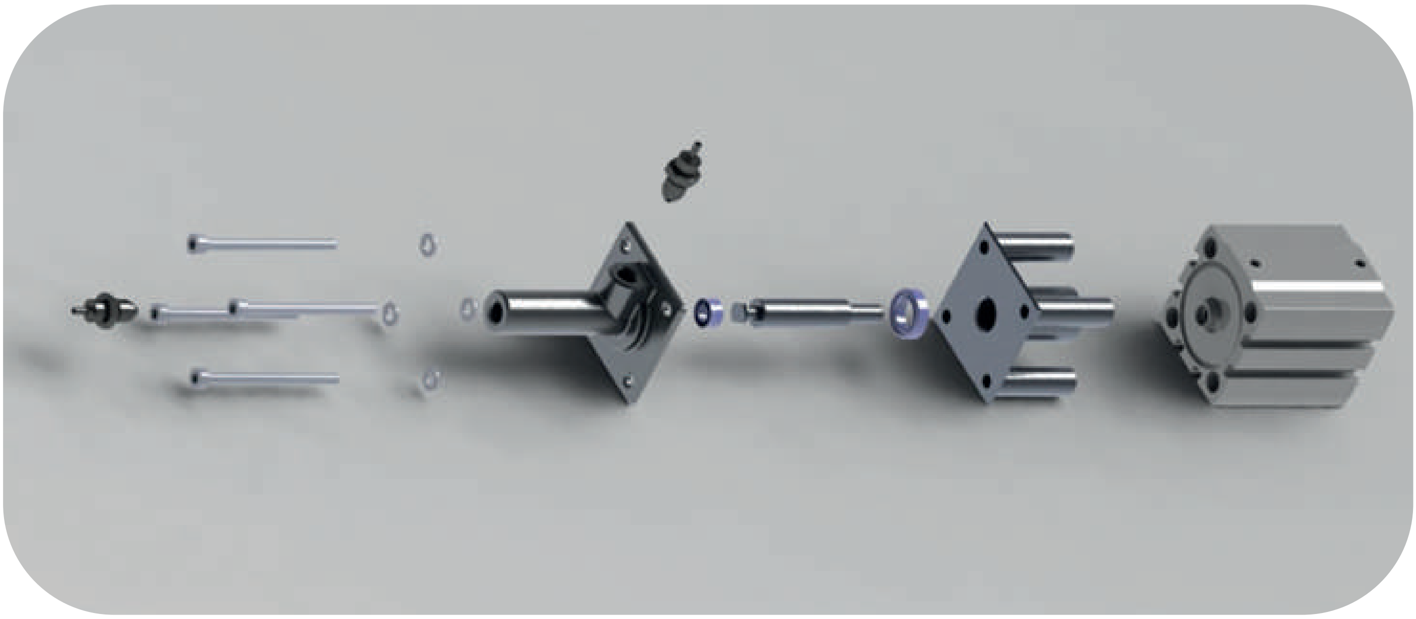


Figure 8 - EBS exploded view.

PNEUMATIC SYSTEM

To create the necessary pressure in the brake line, compressed air is used by advancing the piston of the pneumatic cylinder. To ensure air supply to the cylinder, an entire pneumatic line has been designed, consisting of a set of electric and manual valves. The electric valves (solenoids) allow the system to operate when the Shutdown Circuit is opened, which is remotely activated by human action or automatically in case of an emergency. The manual's valves allow the system to be actuated by hand.

MECHANICAL SYSTEM

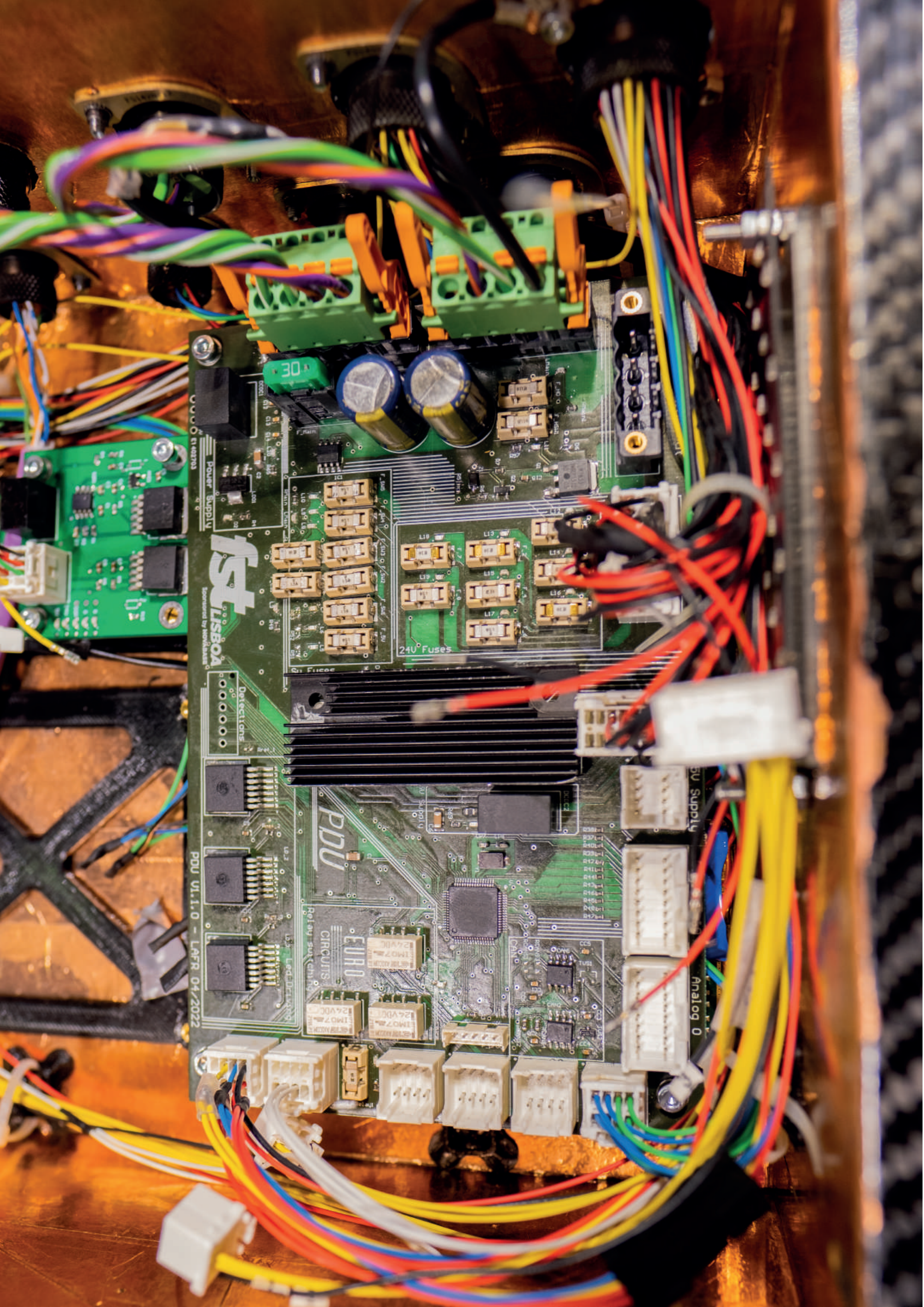
The peculiarity of the current implementation is the existence of two separate lines of action. This leads to the existence of two sets of levers that create pressure on the two hydraulic lines (front and rear), this being through the advance of the hydraulic cylinder piston caused by pneumatic actuation. This mechanical integration consists of the levers and an optimized structure to attach and hold all components to place.

HYDRAULIC SYSTEM

The pressure exerted on the hydraulic line through the mechanical system is then transmitted to the brake line. It should be noted that the hydraulic line that drives the brakes is common to the Pedal Box, that is, for there to be permutation enters the different performances of the line are used two logical valves (type OR).

All these systems mentioned above were designed with delineated objectives, with the principles being the reduction of volume and weight referring to the previous year (30\% lighter and 80\% less bulky), an innovative integration in the car, and reliability above all.

To achieve the best possible design some software´s have been used: Matlab, to achieve the best dimensions for the system given a specific algorithm; HyperMesh for finite element analysis to study whether mechanical implementation had a scalable behavior and within safety limits, and subsequent optimization of structures; and finally, FluidSIM to draw the pneumatic lines and confirm their proper functioning.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EURO CIRCUITS

ELETRONICS AND SOFTWARE

Control is a vital aspect of a Formula Student race car, as it can give a competitive edge over other vehicles. In our car, control systems is divided into two main areas: Estimation and Control. These two areas work together in a pipeline, where the first stage is to analyze various parameters of the car, such as wheel speed, motor torque, and steering angle, to determine the current state of the car in terms of speed, trajectory, and handling. The second stage is to use this information to calculate the best way to distribute power to the wheels, in order to maximize performance and ensure safety.

One of the challenges we faced last year was the use of closed-source hardware and software in our control algorithms. This meant that we had limited access to the source code, documentation, and support, and we had to rely on proprietary libraries, interfaces, and protocols. To address this issue, we considered several solutions: running the code on a commercial microcontroller, such as a Zybo; running the code on a low-cost single-board computer, such as a Raspberry Pi or a Jetson Nano; or running the code on a high-performance single-board computer, such as a Nvidia Drive or a Xavier. After careful analysis of the pros and cons of each option, we decided to use a Raspberry Pi for its simplicity, performance, and cost-effectiveness, you can see an example of this board in figure 9. This decision was based on several factors, including ease of implementation, hardware support, software compatibility, scalability, and portability.

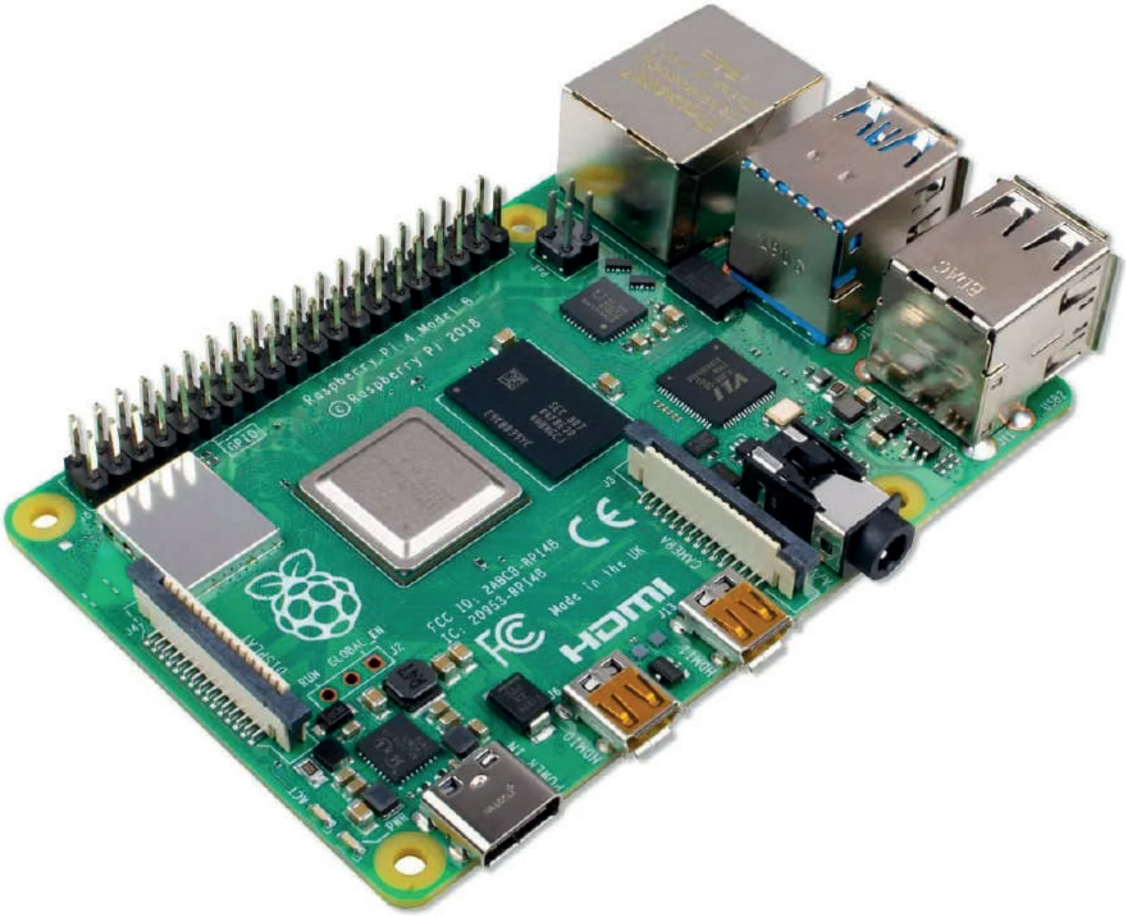

Figure 9 - RaspberryPi board.

In terms of software, we utilized Matlab for our algorithms. Matlab is a powerful and versatile tool that allows us to design, simulate, and test our control algorithms in a simulated environment, without the need for a physical car. To run the code on the Raspberry Pi, we used the code generation feature of Simulink, which allows for the conversion of a Simulink file into code that can be compiled for specific hardware. This feature also allows for customizations such as optimization, code generation report, and faster compilation. This allowed us to run our Matlab code easily and efficiently on the Raspberry Pi, and also gave us the flexibility to optimize the code for our specific needs.

For communication between the Estimation and Control areas, we used the open-source framework ROS (Robot Operating System). ROS is a robust and widely used framework that provides a standard set of tools and libraries for creating, managing, and exchanging data between different nodes in a distributed system. This allowed us to easily publish and subscribe to data, making it simple to share information between the different parts of our control system, such as sensors, actuators, and algorithms. This made it easy to implement and also allowed for easy communication between the different nodes of our control system.

The following scheme, as seen in figure 10, is the current state of our pipeline. Of course, the processing modules involve a lot more than just a simple box, but for reader simplicity, we decided to show them in this way.

The CANsniffer is a special module that reads from two different CAN bus lines, and separates the information into different topics for the rest of the system to use. It also inputs information into the CAN bus lines for the actuators to receive and use. This module plays an important role in the communication between the different parts of the control system and enables the sharing of information in real-time.

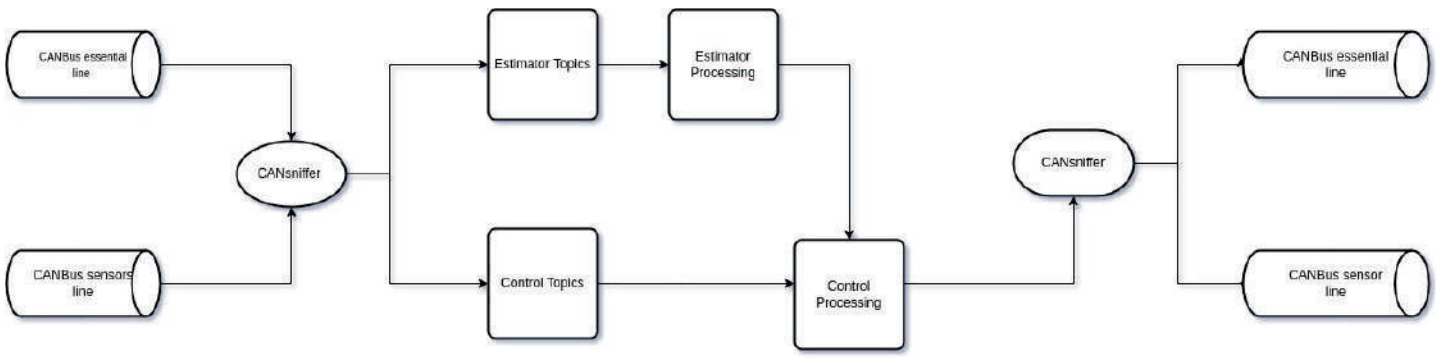

Figure 10 - Control pipeline architecture.

Another important aspect of our control system is the ability to adjust and improve it over time. By using open-source solutions and customizing our code, we are able to optimize our control system and have more control over its development. This allows us to adapt to changing conditions such as track and competition, and make adjustments as necessary to improve performance. We also have the ability to update our control system in real-time, based on the data that we collect during the race, which allows us to make adjustments on the fly and fine-tune our car performance.

In conclusion open-source solutions and customizing our code, we are able to optimize our control system and have more control over its development, allowing us to improve our car performance over time and be more competitive in the race. Our control system is also designed to be flexible and adaptable, which allows us to make adjustments and improvements as needed to stay ahead of the competition. With the use of open-source solutions, we have the ability to continuously update and improve our control system, giving us a competitive edge in the Formula Student race.


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POWERTRAIN


Simoldes
STANDOX
Tintas Robbialac

SUSPENSION

For obvious reasons, mostly safety-related, the braking system is one of the most crucial systems in the car. The main focus of the brake system is to be functional, but as with everything in Formula Student we aim to produce efficient and lightweight components and the brake system is no exception.

The Chassis department is in charge of nearly the entire system, particularly with regard to the driver interface (the brake pedal, for example). The brake disc is controlled by the Suspension department, given that it is situated on the wheel hub. Both departments work together to design our prototype braking system.
A brake disc slows the car down, or keeps it still, by the friction generated by the contact with pads pressing against it. This procedure slows the rotation of the hub which is connected to the wheel. Motion energy is transformed into heat that needs to be dissipated, meaning that the brake disc goes through rapid heat cycles that depend not only on the dynamic event the car performs but also atmospheric and track conditions.

The material is the first consideration to be made while designing this particular component. Our sponsors play a significant role in material supply and technical advice. Ramada Aços provides the team with the raw material to be machined to the final brake disc geometry. The very well detailed datasheets provided by the company allows us to design the brake disc with greater assurance that our component meets the expected requirements.

Before choosing one material over another, mechanical and thermal properties are compared to target values and functional requirements of our car. With a selection of potential materials, a second design phase begins, a back-and-forth process between CAD design and finite element analysis. The process culminates on the final brake disk geometry as well as the choice of material.

An important study is carried out, a thermal analysis, in order to verify that the assumed maximum operating temperature of 400ºC does not lead to failure of the component at study. The target value was determined by analytical calculations regarding heat transfer methods and also by analyzing data from our previous prototypes during competitions and through our testing season.

The calculations begin with the vehicle's speed during a dynamic event and end with the determination of the temperature difference on the brake disc. Our process takes into account aerodynamic braking, the kinetic energy of the vehicle, the frictional heat flux put on the brake disc, and related convection phenomena. An important factor that can be added into the analysis is braking regeneration as it is usually used in the car.

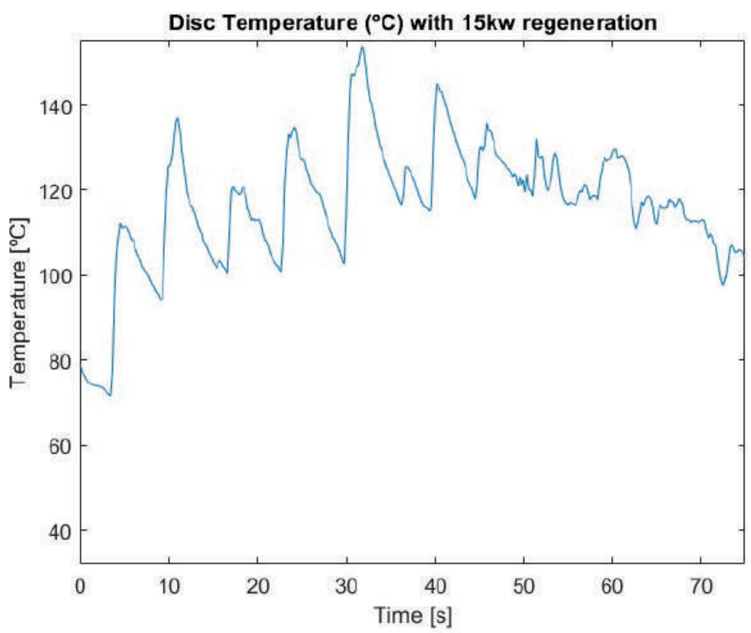

Figure 14 - Brake Disc temperature variation with 15 kW regeneration - graphic obtained from the theoretical analysis.

A very important step was taken this year towards validation of our analytical calculations, the integration for Hot Wheels on our car. Hot Wheels are a board developed by our Electronics and Software department that houses temperature sensors that record the live temperature of our drivetrain and brake discs.

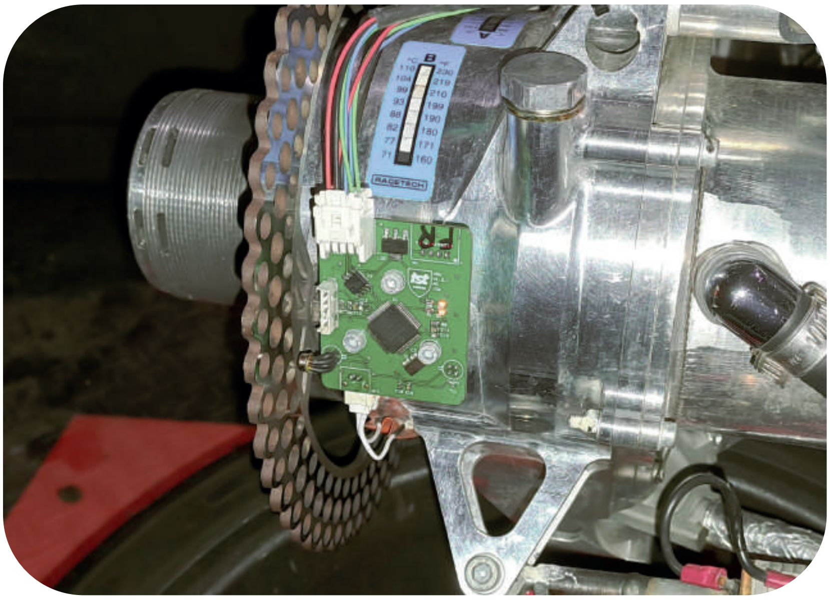

Figure 15 - Hot Wheels device implemented in the FST12.

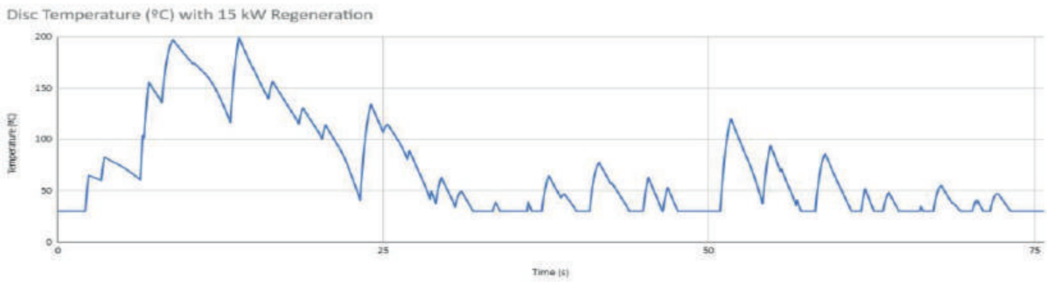

Figure 16 - Brake Disc temperature variation with 15 kW regeneration - graphic obtained from the Hot Wheels.

The temperature progression in time for autocross and endurance events of our analytical approach was validated successfully and proves adequate for the preliminary design phase. However with the newest edition of the How Wheels, the team can move on to more challenging and complete thermal analysis and keep improving the design and performance of the brake discs.


AMG
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Formula Student
O.Z RACING
MAGNESIUM

VEHICLE DYNAMICS

The process of designing a Formula Student car is something extremely complex and very hard to get right. It involves a long list of decisions and choices which are intrinsically connected and mutually dependent in what is already a complicated and non-linear process. During this process, many of the decisions made are done so merely on a theoretical basis, without any practical validation.

This is even more critical when designing a car from scratch without any guiding baseline. As such, the fact that we are able to develop new prototypes within a few years time span can be of great help in the design of each car. That is where data analysis comes into play.

For our new prototype, the FST12, we have used a data driven approach. Data driven means that progress in activity is compelled by data, rather than intuition or personal experience. This analysis serves merely as a complement to intuition and personal experience, it doesn't replace them. The value is not in the data itself but rather in the conclusions that can be drawn from it.

SENSORS

In order to visualize and process data, we need some way to acquire it. For that reason, we have multiple sensors in our car with various functions and purposes. Data acquisition is used to monitor and understand better the systems we are working with. By processing signals into something readable and from which we can conclude something about. We can see if everything is working as expected or not. This enables us to study and comprehend our cars better, as well as verifying and validating if what we designed is actually what we see in reality. The necessity and usefulness of validation/ verification is undeniable, as we can always learn from mistakes and take them into account for future designs.

Figures 17 and 18 represent some of the sensors the team uses to collect data.

Figure 17 - AHRS (Attitude and heading reference system) - Xsens MTi 670.

Figure 18 - MLP-7 Linear Potentiometer.

DATA

There are multiple ways in which data can be useful to us. Here we will talk about some of them and how we use them in order to help them in our day to day work as well as in the design of our cars. This comprehends, for example, the data driven performance and data driven design aspects we will be targeting here.

In a data driven performance approach we try to use and process the data in many different ways and forms depending on our objective and what we are trying to see. For that, we generally use different types of graphs/ charts, from run/ lap time charts, to tables and trends, to track maps and histograms.

If we analyse and look at the ones depicted below, we can respectively see:
- A lap time evolution graph for different control modes where we can evaluate and infer about the controllers reliability, consistency and effectiveness
- A chart with three signal at the same time and where we can establish performance metrics
- A track map obtained through GPS data where the variation of velocity is portrayed

These graphs have different usages and serve different purposes. Some can be used to determine where the driver can improve and change his driving style in order to achieve lower lap times. For example, we can look at the driver's consistency and aggressiveness by verifying how early he breaks in cornering or how constant the steering signal is.

Whereas others can be used to conclude about what our testing approach should be and where we should spend most of our testing time. This can be done, for instance, by looking at how laptime is evolving when we spend time adapting controller's gains, training drivers or changing the car's setup and concluding which one is the most significant. Finally, we can just look at the data, study and comprehend how the car is performing and try to correct or improve it with setup and tuning changes.

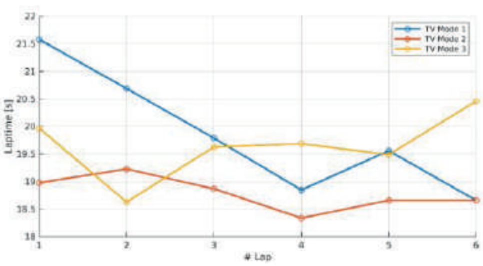


Figure 19 - Testing Different controllers and evaluating lap time.

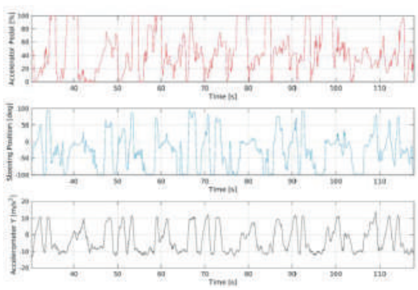


Figure 20 - Driver Inputs.

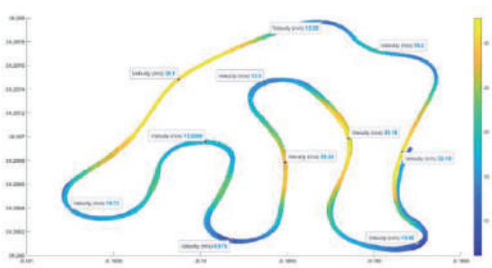


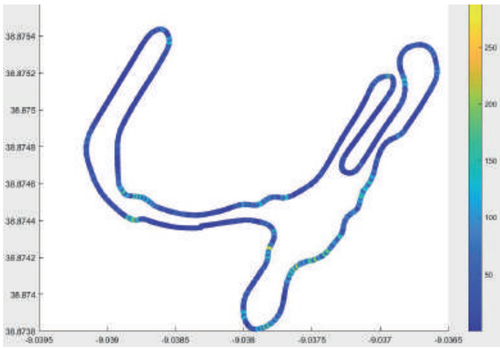
Figure 21 - Speed over track

FSTANALYSE

In order to better visualize and process data the team has created a tool called FSTAnalyze. Using GPS data we can define a star/finish line and section all the data from the run into laps. With this it becomes possible to easily graph the data from our over 1000 sensors in relation to distance/time for a desired lap.

With this the KPIs potential can be unlocked. KPI stands for Key Performance Indicators and they are very usefull because it allow us to objectively quantify the performance of each driver.

For example, in the graph below it is possible to see how smooth a driver was during a lap. The program will give us a number which we can then compare to other laps/drivers and see how smooth/agressive/consistent they were on different laps and compare them to one another.



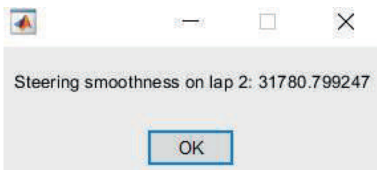


Figure 22 - Steering smoothness

It is possible to evaluate a number of parameters such as the accelerator pedal input where we can see where the driver is pressing the pedal and how much he is pressing it. We can compare different laps to see where the driver gained or lost time

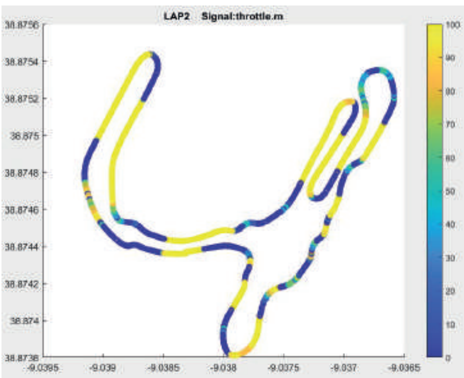


Figure 23 - Throttle Input - Lap 1

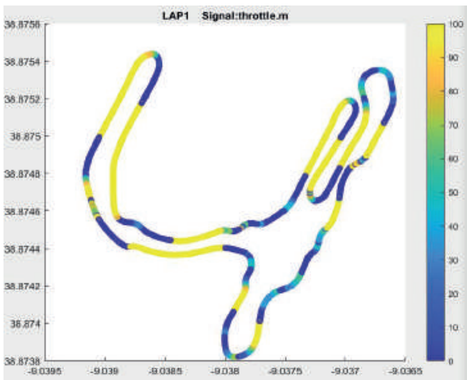


Figure 24 - Throttle Input - Lap 2

FSTAnalyze is used on post test analysis and on driver briefings where the drivers discuss possible time losses/gains on a multitude of parameters and are able to find out what they are doing wrong/right and on which area they should focus so that on the next time the team tests they know exactly where to bring their attention to in order to maximize performance.