fst LISBOA

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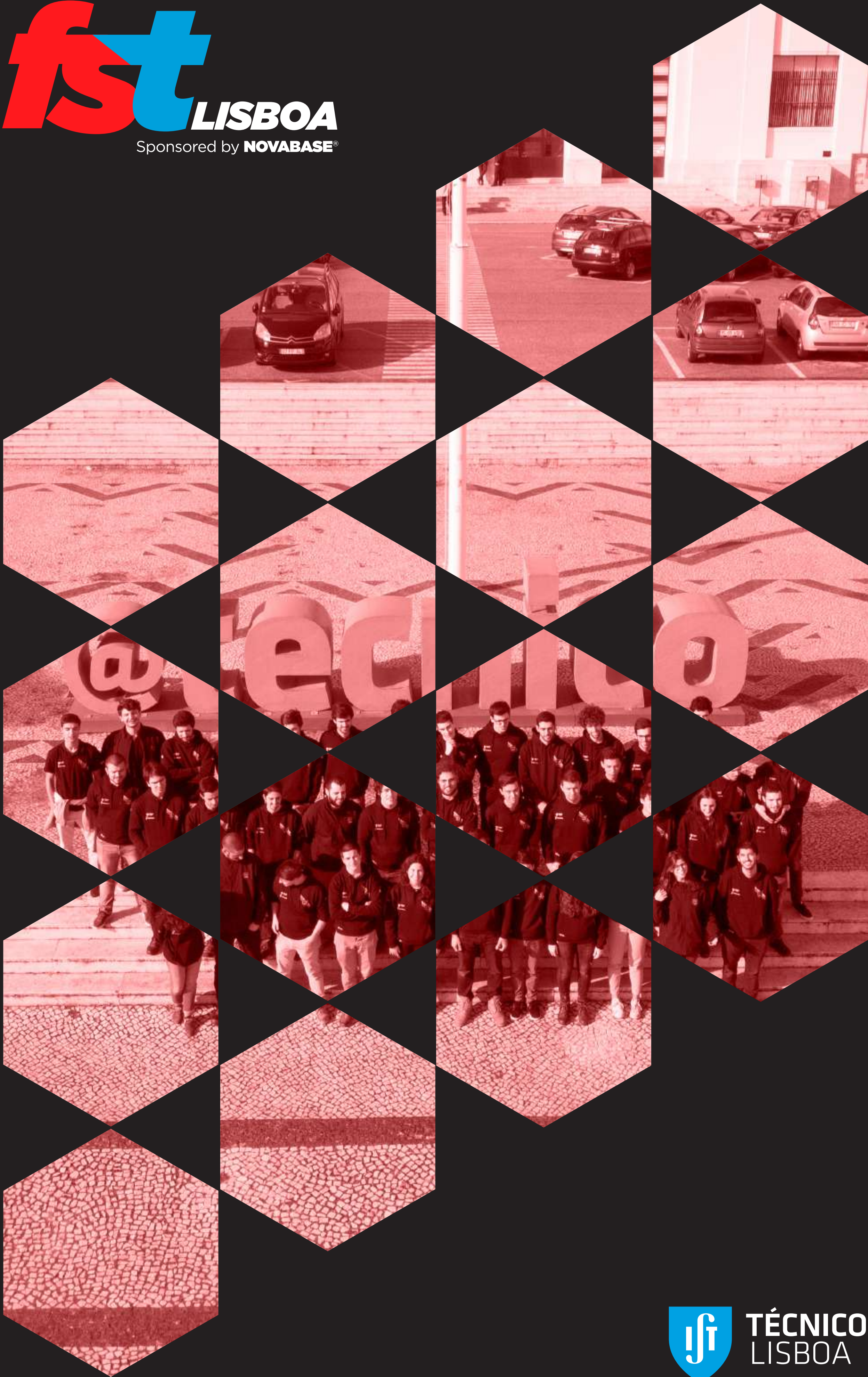

TÉCNICO LISBOA

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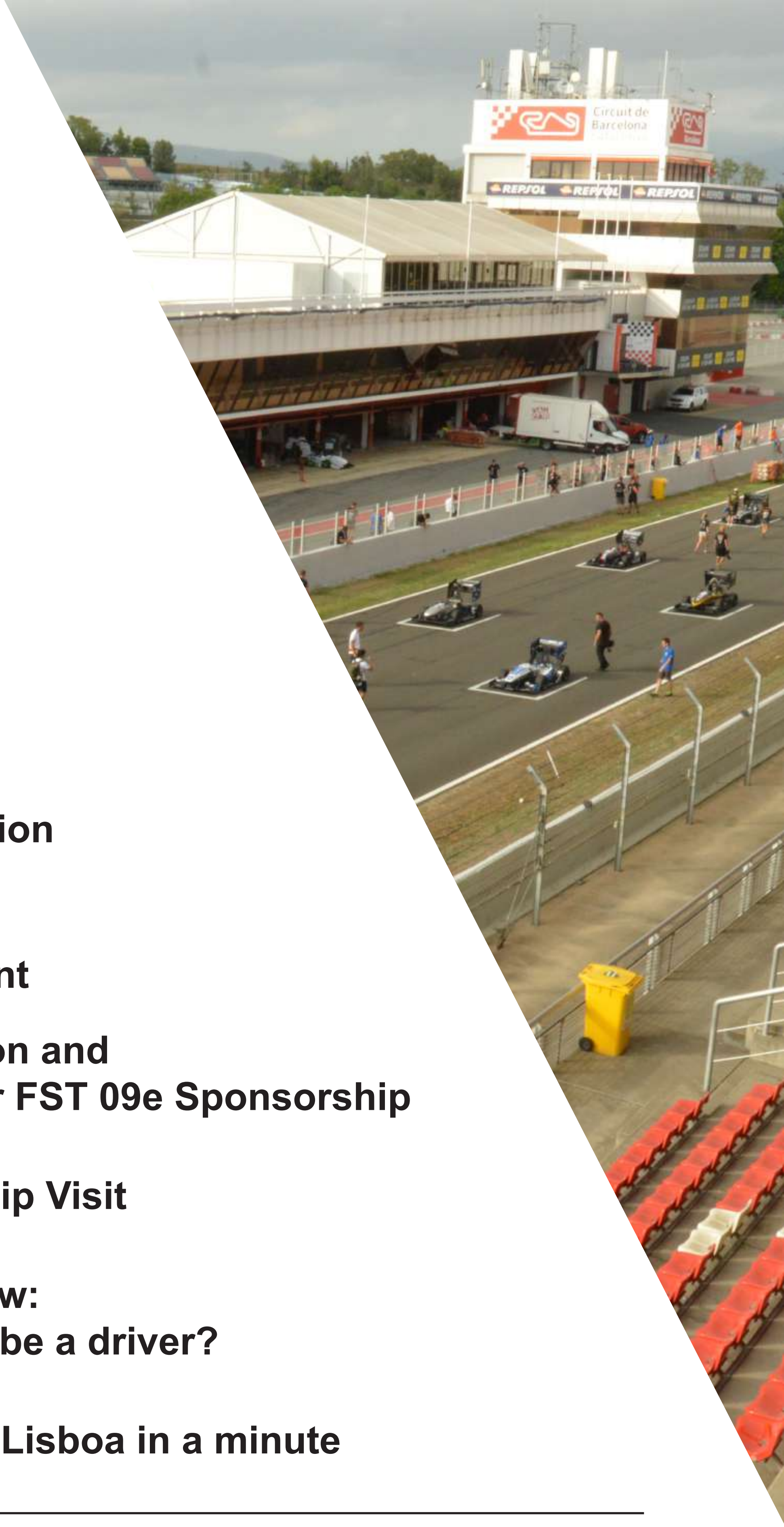

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New Headquarters

In the beginning of 2018, the team was given the choice of moving to a new place of work. Until then the team worked in separate spaces, having at its disposal one room in Pavilhão de Mecânica II and two rooms in Pavilhão de Eletricidade in Instituto Superior Técnico.
Therefore, the project's new "home" is now on the -1 floor of Pavilhão de Mecânica III. Moving to a more spacious workplace allowed the team to work together in just one place which improved all the interactions and facilitated the communication between team members. This improvement was crucial in the design phase since the team's work became much more efficient. In addition to having a workshop, the new space, nicknamed by the team "Covil" (lair), has a meeting room, a room for storage and it also has a room to operate with high voltage where all the work with the battery, inverters and electric motors is done in a safer and controlled environment. The laboratory is also equipped with its own elevator which has access to the outside of the building and can carry the car in and out of the workshop, improving logistics in testing days or when there is an event with the car.

"This improvement was crucial in the design phase since the team's work became much more efficient."

While the team was in the moving process, the FST 08e was being constructed and after that the competition season came, therefore, the process was only finished in 2019. With the support of the companies that sponsor the team was possible to equip the workspace with all the tools and infrastructure needed to fulfill the potential of the new space. Most of the work is now done faster which pushes the team to have better organization and higher standards in order to reach the final goal of improving the quality of the cars built.
This moving opportunity was also a part of the Mechanical Department's (DEM) reorganizing of Student Groups' workspaces, in order to bring them closer together. Now, most of the Student Groups have their workplace in the same Pavilion, which means they can develop their projects side by side.

Text: Henrique Karas

Preparing the new "home" of FST Lisboa.

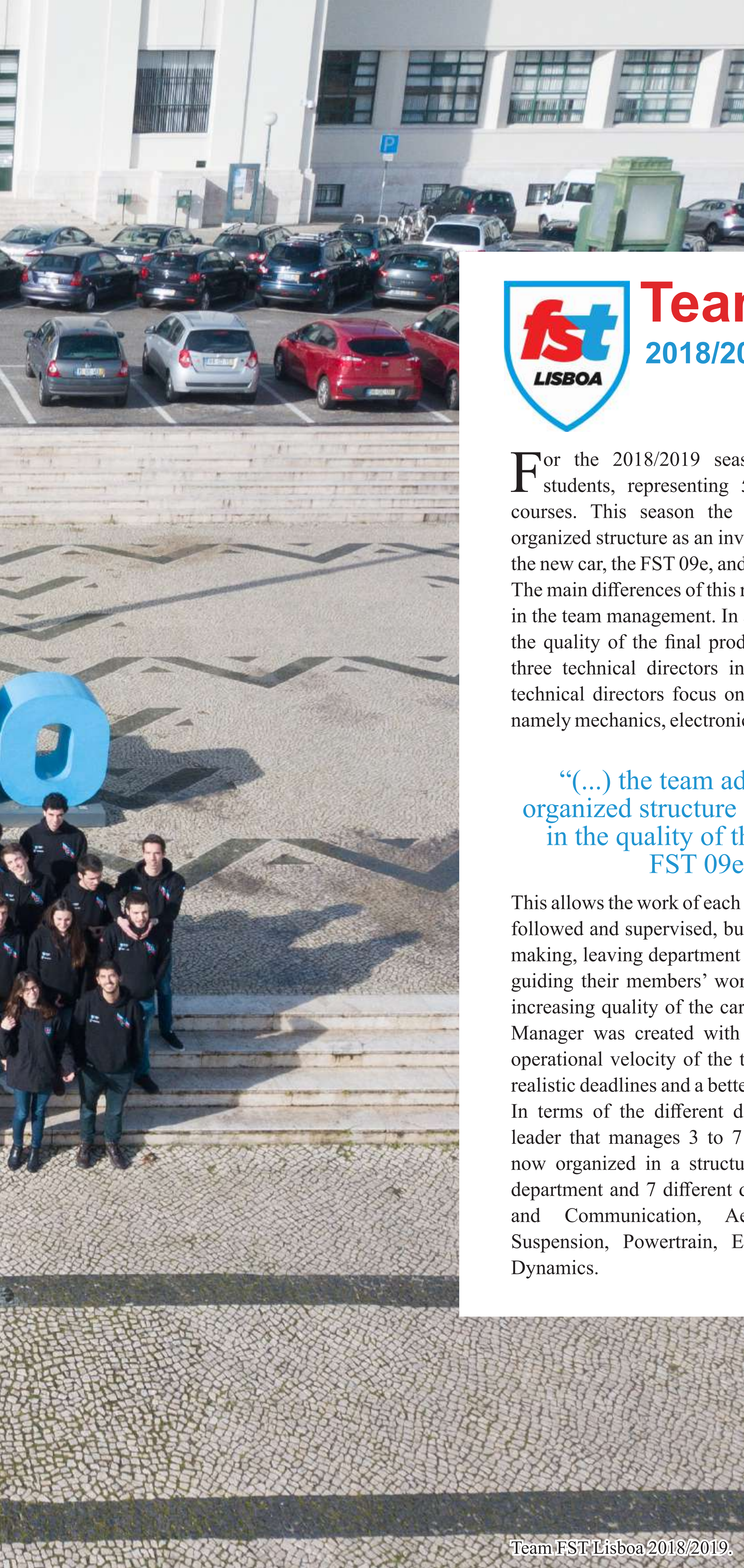
Workspace and workshop.

Meeting room.

"In addition to having a workshop, the new space (...) has a meeting room, a room for storage (...)"

"(...) it also has a room to operate with high voltage where all the work with the battery, inverters and electric motors is done in a safer and controlled environment. "

Room to operate with high voltage.



Team FST Lisboa 2018/2019.

Team 2018/2019

For the 2018/2019 season, the team has 39 students, representing 5 different engineering courses. This season the team adopted a more organized structure as an investment in the quality of the new car, the FST 09e, and in project management. The main differences of this restructuring are focused in the team management. In an attempt of improving the quality of the final product, the team now has three technical directors instead of just one. The technical directors focus on their respective fields namely mechanics, electronics and vehicle dynamics.

> "(...) the team adopted a more organized structure as an investment in the quality of the new car, the FST 09e (...)"

This allows the work of each area not only to be better followed and supervised, but also speed up decision making, leaving department leaders more focused in guiding their members' work. To keep up with the increasing quality of the car, the position of Project Manager was created with the goal of improving operational velocity of the team guaranteeing more realistic deadlines and a better resource management. In terms of the different departments, each has a leader that manages 3 to 7 members. The team is now organized in a structure with a Management department and 7 different departments: Operations and Communication, Aerodynamics, Chassis, Suspension, Powertrain, Electronics and Vehicle Dynamics.

Text: Henrique Karas

Management

Henrique Karas
Team Leader

António Bento
Project Manager

André Agostinho
Chief Electrical Engineer

Miguel Lino
Chief Mechanical Engineer

Rodrigo Ramos
Chief Dynamics Engineer

Operations and Communications

Henrique Karas
Department Leader

António Bento
Project Manager

Henrique Motta
Sponsors Manager

Alexandra Pereira
Logistics Manager

Mariana Sequeira
Marketing Manager

Mariana Vieira
Marketing and
Internal Affairs

Aerodydamics

Luís Morais
Department Leader

Tomás Fontes
CFD

Miguel Antunes
CFD

Electronics

João Freitas
Department Leader

Filipa Ribeiro
Essential Control

David Ribeiro
Essential Control

Miguel Rodrigues
Essential Control

João Revés
High Voltage Systems

Miguel Lourenço
High Voltage Systems

Diogo Pereira
Telemetry

Teodoro Dias
Driver Interface

Miguel Crespo
Interface

Suspension

Miguel Soares
Department Leader

David Vigarinho
Hub and Upright

Gonçalo Costa
Transmission

João Nunes
Mechanical Project

Luís Figueiredo
Rims and Brakes

Chassis

Pedro Mendonça
Department Leader

Inês Carrondo
Ergonomics

João Rego
Monocoque

Pedro Neves
FEM

Tomás Bastos
Steering

Powertrain

Pedro Santos
Department Leader

Afonso Dias
Cooling and Battery

Alexandre Gouveia
Cooling and CAD

Tiago Santos
Motors and Battery

Vehicle Dynamics

Rodrigo Ramos
Department Leader

Inês Viveiros
Sensors and Control

João Pinho
Control and Vehicle Dynamics

Henrique Furtado
Vehicle Dynamics

Afonso Nogueira
Suspension and Vehicle Dynamics

Stefan Sochirca
Suspension

FST 09e

Electronics

Software
PCBs and harnessing
Interface and telemetry
Programming embedded systems
Safety

Chassis

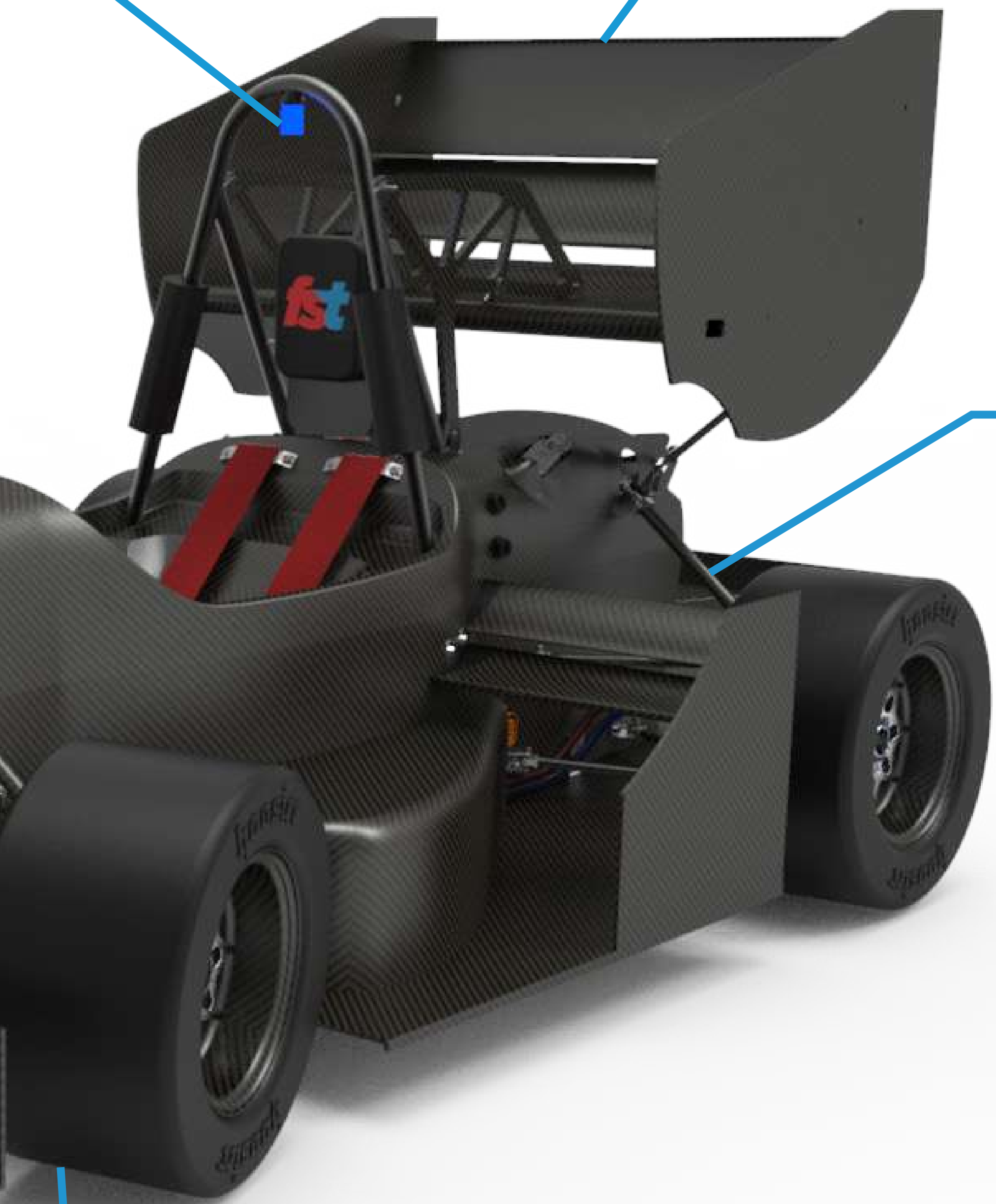
Steering
Ergonomics
Chassis monocoque
Electronic conditioning

Powertrain

Battery
Motors
Cooling
Inverters

Aerodynamics

Aerodynamic structures
CFD



Suspension

Rims
Brakes
Transmission
Cubo e Porta-cubo
Suspension structure

Vehicle Dynamics

Tires
Simulations
Control and sensors
Suspension geometry
Tests and data treatment

Specifications:
Weight: 240 Kg
4 motors (35 kW each)
Maximum Torque: 1340 Nm
Maximum Velocity: 107 km/h
0-100 km/h in 2.3 s
Transmission Ratio: 16:1
Accumulator: 8 kWh, 600 V

Monocoque FST 09e

Monocoque: From Design to Manufacture

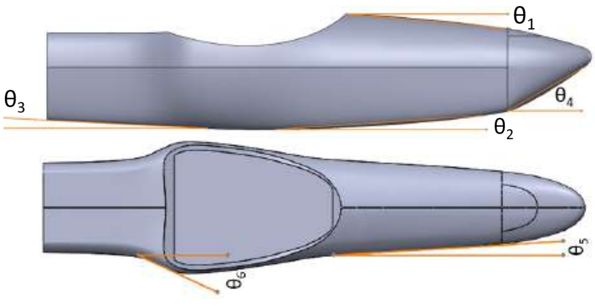
The monocoque is the part that joins all the other systems in the car. The origin of the word is greek "mono" - one; and french "coque" - shell or box. For the first time in the history of the team, the monocoque will be designed and constructed in one year.

Text: Inês Carrondo

First of all, having to make the monocoque in just one year means a significant improvement in the way the team works together since there is more freedom to alter the different systems in the car because there are no constraints from the previous monocoque design. This allows that matters such as ergonomics, powertrain packaging, the placement of the electronics, or the suspension points, to be changed and iterated.

Because of all of this, there is an added difficulty during the design process since there are very few constraints the possibilities are almost endless. Therefore, it is necessary to focus on the issues that are most important and choose which compromises need to be done between the different systems of the car. This year the team outdid itself in this process finishing it in record time.

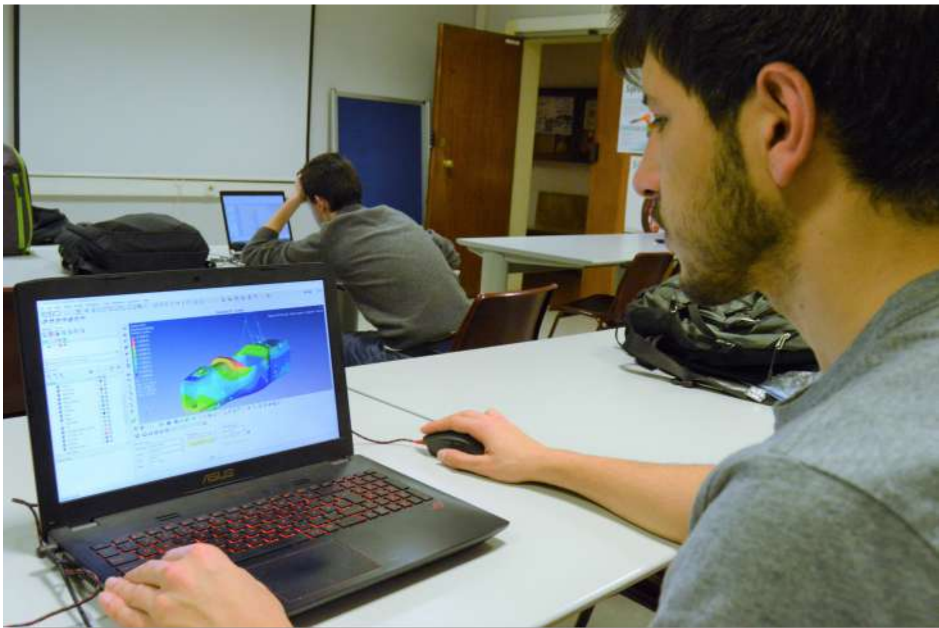
There was also a big input of the Aerodynamics department in the design of the monocoque in order to enhance the quality of the aerodynamics packaging. Several angles were iterated in Computational Fluid Dynamics (CFD) models (Front Top angle (θ_1), Front Bottom angle (θ_2), Rear Bottom angle (θ_3), Nose Inclination angle (θ_4) and Front Side angle (θ_5)) and it was decided that the front shocks will be covered by a lid in order not to disturb the air flow.



Monocoque's angles.

After the monocoque's Computer Aided Design (CAD) is finished the next phase of the design is the structural design. Since the monocoque is constructed with composite materials, an extensive analysis and optimization needs to be done in order to get a structure with the best compromise between mass and stiffness. This whole process also has to take into account the structural equivalencies dictated by the the competition in order to guarantee the driver's safety. When this phase is concluded, the carbon fibre and aluminium honeycomb staks are ready and so it is possible to start the manufacturing phase.
It should be noted that this year the team also had to manufacture the negative carbon fibre moulds using a wet lay-up technique. These negative moulds were done from the positive MDF moulds since the pre-impregnated fibre has to be cured at high temperatures that the MDF would not endure. Although the finite elements' models made by the team are fairly trustworthy, the manufacturing of composite materials is a complex process with significant margin of error. Therefore, the team will have to wait for empirical tests and test runs with the built car to be able to verify that the design was robust and find out improving points to be iterated

"(...) this year the team also had to manufacture the negative carbon fibre moulds using a wet lay-up technique. "


Structural study of the monocoque.


Monocoque design

Steering wheel's CAD (front part).

Steering wheel's CAD (rear part).

Ergonomic Perspective in the Steering Wheel Design

The steering wheel is an extremely important part when it comes to the driver-car interaction. It is through this part that the driver gives most of the inputs to the car. This year, the team tried to give more importance to the ergonomics of the steering wheel and reduce its weight. To this end, a jig was constructed to allow the driver to test different distances between both handles in order to reduce the possible fatigue of the driver's arms. After the optimum distance was defined, a mouldable material (clay) was placed in the handles so that the driver could hold them in a comfortable and natural way, creating a mould of his hands in the steering wheel. With the support of Lisbon's Biomechanics Laboratory the mapping by 3D scan of the mould was possible, achieving a map of millions of surfaces and the CAD was drawn using these surfaces. It was also decided, with the driver's input, the best layout for the buttons since they need to be easily pushed but not so easily that the driver accidentally pushes one of them.
Another important aspect of designing the steering wheel is that the electronics in its interior have to be accessible. The electronics change quite a lot during test runs, therefore, it's important to spend as little time as possible opening and closing the steering wheel. For this reason, a lid system was created. The steering wheel will be carbon fibre laminated in order to guarantee its reliability and stiffness.

Text: Inês Carrondo

Scan to the steering wheel's handles.

3D printing of the steering wheel's handles.

TECDIGITAL
MAQUINAÇÃO 3D, Lda.

Tecdigital Maquinações 3D has supported FST Lisboa for three years with the manufacturing of moulds in MDF for the construction of the team's cars. The participation of the company in the project has proven to be increasingly important for the team with the evolution of the prototypes, that year after year have more innovative designs and, consequently, require more complex moulds.
It is important for Tecdigital Maquinações 3D to be involved in innovative student projects, that encourage students to develop their own projects and gain experience. This allows to form qualified engineers and at the same time the development of national technologies. The company is proud to be a part this process and is committed to give its contribution. This long lasting relationship provides good moments, especially during the manufacturing period, where there is exchange of experiences between team and company members which, hopefully, will continue to happen for many years.

FST 08e rear.

Suspension Design

The suspension dictates how the wheels are connected to the chassis of the car. This connection not only affects their relative motion, it also controls the forces transmitted between the two.

Text: Afonso Nogueira

Unlike road cars, where the primary purpose of the suspension is improving ride comfort and safety, the main goals of the suspension in a Formula Student car are the following:

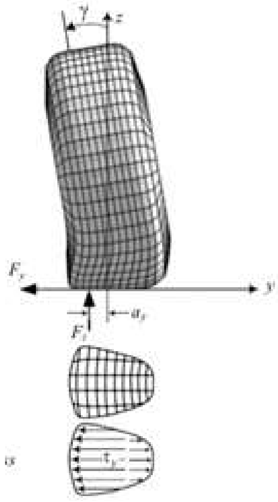
- Optimize the grip of the tyres for better acceleration and cornering performance;
- Improving the vehicle response on corner entry and exit;
- Increase the aerodynamic potential of the car for more downforce on corners and less drag on straights.

The typical Formula Student track is a very technical circuit with short straights and tight corners. As such, the primary focus of our suspension design is improving the mechanical grip of the tires while ensuring a fast response in corners.

To do this, the suspension must be designed with two main goals in mind:

- **Tyre position relative to the road**

The inclination of each tyre – camber- will heavily impact the amount of mechanical grip that the same tyre is able to produce. The ideal camber will vary with the vertical and lateral loads and as the car rolls in corners this angle will also change. This means that the suspension geometry needs to position the tyre on the road with the camber that maximizes grip throughout all of the car's movements.

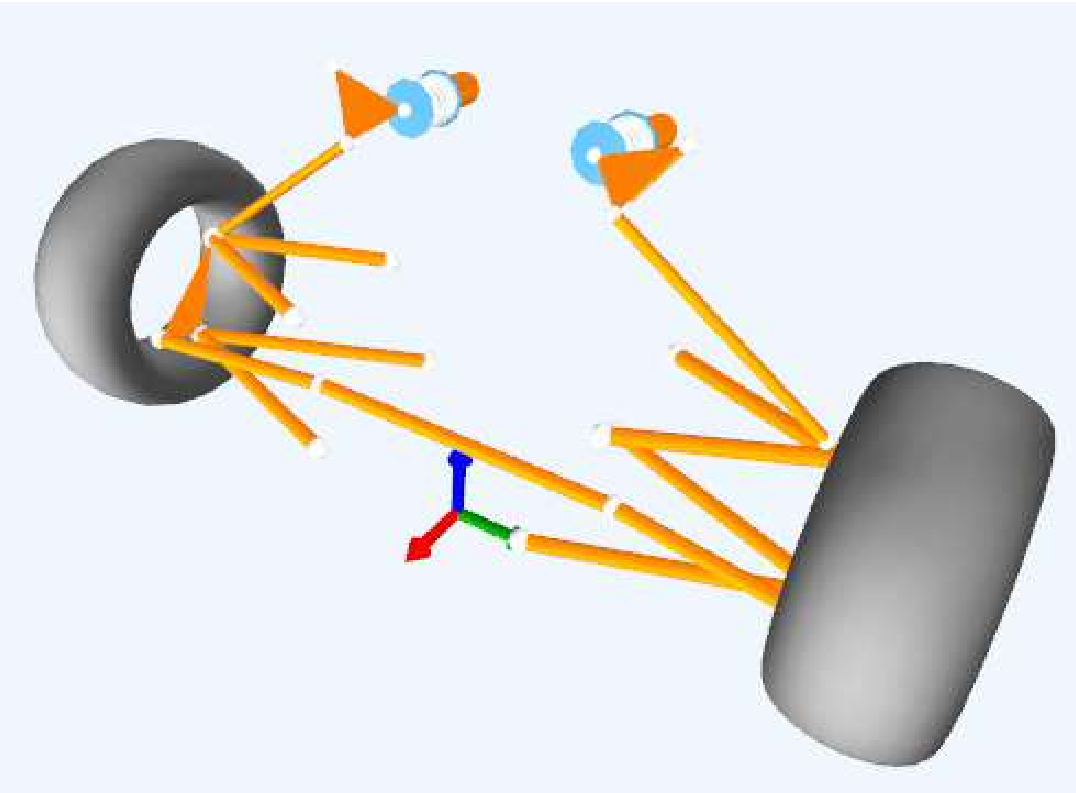


Cambered tire

- **Suspension stiffness**

The suspension needs to be soft enough to smooth out the contact patch loads – improving grip – but stiff enough to have a responsive car that reacts fast to the driver's inputs. Furthermore, the suspension stiffness also dictates the amount of roll and pitch movement of the car. With a stiffer suspension, the car will move less and the aerodynamic package can be closer to the ground, which makes it more efficient and effective.

The tyres are the only direct connection between the car and the road and without a good suspension design the car won't be able to transmit its power to the asphalt.



Computational design of the suspension geometry.

Topological Optimization

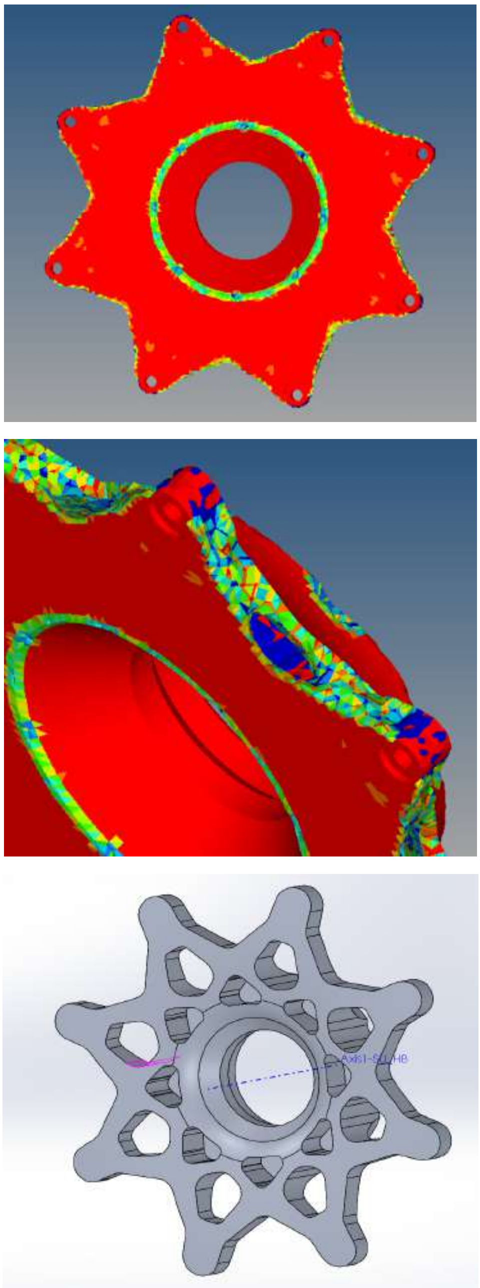
The first step to follow when designing a part/system is defining the requirements and operating features. After this, the modeling of the part in a CAD software follows. After the first, and very simple, topology is developed, an iterative process begins between structural analysis of finite elements (in a commercial software) and modeling of the part. In these analyses, we apply forces and constraints which are representative of the prototype's lifetime to the topology created previously, hence we are able to find out to what extent it complies with the requirements. Essentially, we analyse the tensions and deformations that occur in the part. If it meets the requirements, with a given margin, then we alter its topology by mostly removing material in non critical sections. This way, we are able to reduce the total weight of the prototype and improve its performance.

Having the goal of saving time in the design of some parts, we use the mathematical method of topological optimization (in the same commercial software where we perform the analyses). We start by defining a design box that delimits the maximum dimensions of the part. Then, forces and constraints are applied, just like a simple analysis.

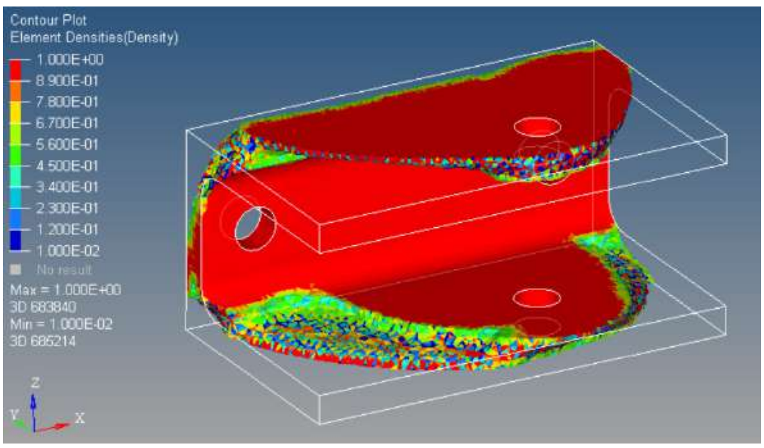
When we start an optimization, the algorithm will start to reduce the density of the material in the non critical sections if the chosen goal is to reduce mass. Normally, the final result merges to a truss structure and/or very organic and nature-like shapes. Thus, we are able to understand, in an initial phase, which sections of the material we can remove and rapidly get to a final solution.

This year, in the Suspension department, we performed a few topological optimizations to the suspension supports, the upright and the center of the rim. In the Chassis department an accelerator pedal prototype to be 3D printed was developed with the same method.

Text: Miguel Soares



Topological optimization of the wheel center.



Topological optimization of the suspension support.

Final result of the topological optimization.

FST 08e in the Bahco stand in the Mecânica 2018 exposition.

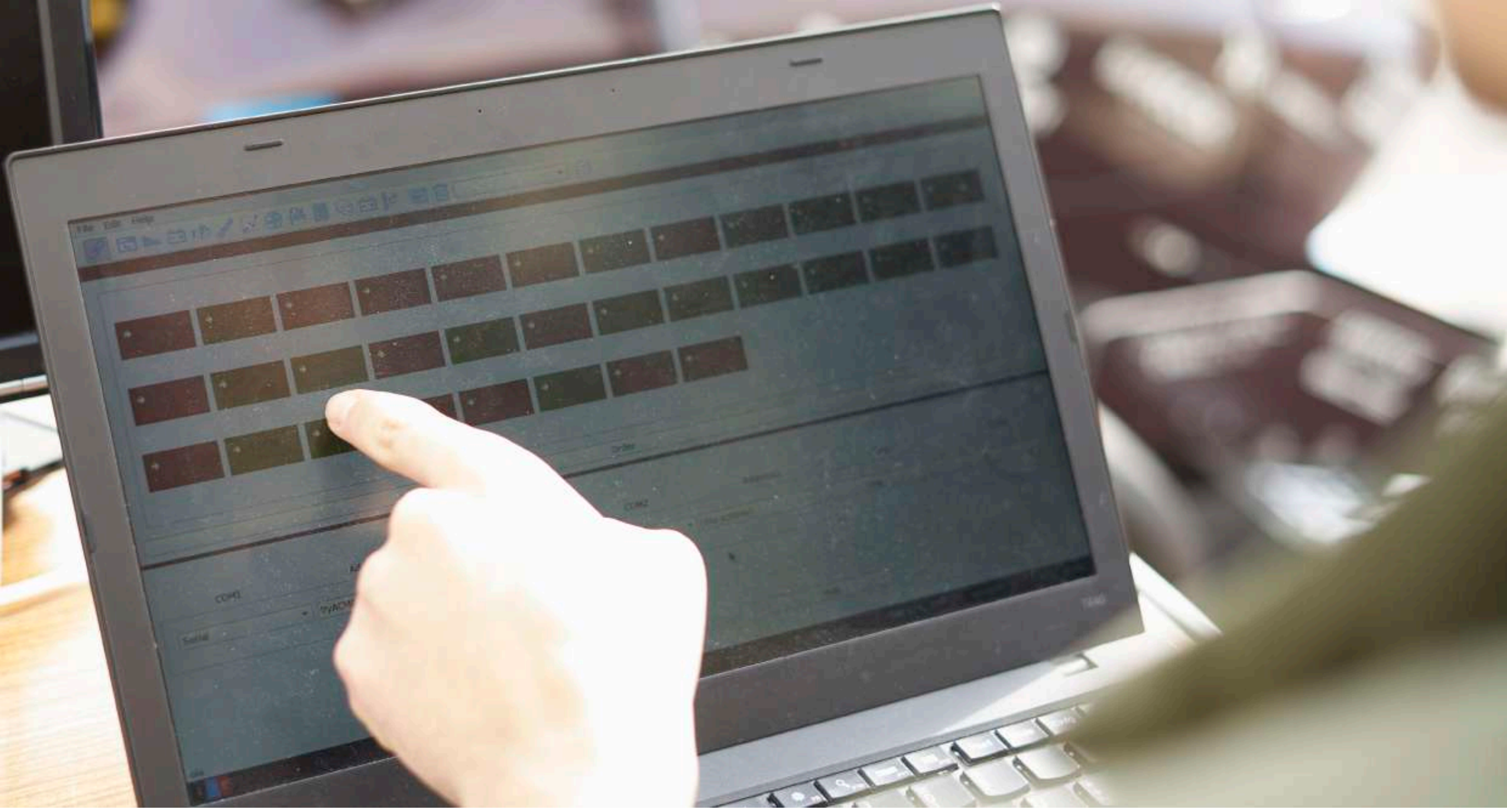
BAHCO

Bahco, a swedish company of the SNA Group, has sponsored the team since 2018. With the recent change in facilities, a renewal and uniformization of tools was one of the objectives set and was made possible thanks to this support. The team's workshop is equipped by one of the leaders in the market of tools, with its distinctive quality and ergonomics.

RAMADA AÇOS
SPECIAL STEEL SOLUTIONS

Ramada Aços has been in the market of global steel solutions for 80 years so far, starting out as a pioneer and today being a leader. More recently Ramada has been sponsoring the team with all the needed steel for the car's development, used mostly in brake discs and suspension. Although steel is being less used in the cars, its specificity and technical requirements are increasing. The team can count on the special steel solutions provided by Ramada Aços, essential for the development of crucial car subsystems.

Visit to Ramada Aços.



FST CAN Interface.

FST CAN Interface

The FST CAN Interface is a software fully developed by members of the FST Lisboa Formula Student Team, written in C++ using Qt libraries. The main goal of the interface is to allow its user to monitor, interpret and manipulate any CAN data that is being sent out by the vehicle at any given time. As any user interface should, we strive to make this program as user-friendly as possible, so that any team member that needs to retrieve information from our car can have a clean, functional and appealing platform from which to do so.

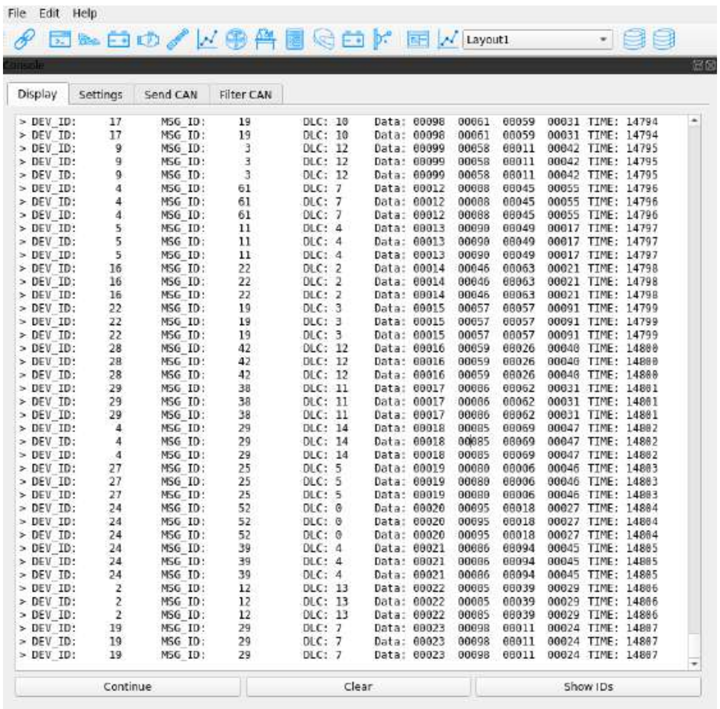
Text: Miguel Crespo

The FST CAN Interface has a multitude of features, which allow us to fully visualize the state of the electronic system of the car:

Console

The interface packs a console-style widget where all the messages that are being sent are listed. All the parameters a CAN message has are shown in the widget: Device ID, Message ID, DLC and its data. To the more experienced user, this is a great way of visualizing which messages are being sent by PCBs in the car, which in turn helps debug any errors that might be occurring with them.

“(...) we can visualize all the parameters a CAN message has (...)”



Console in the FST CAN Interface.

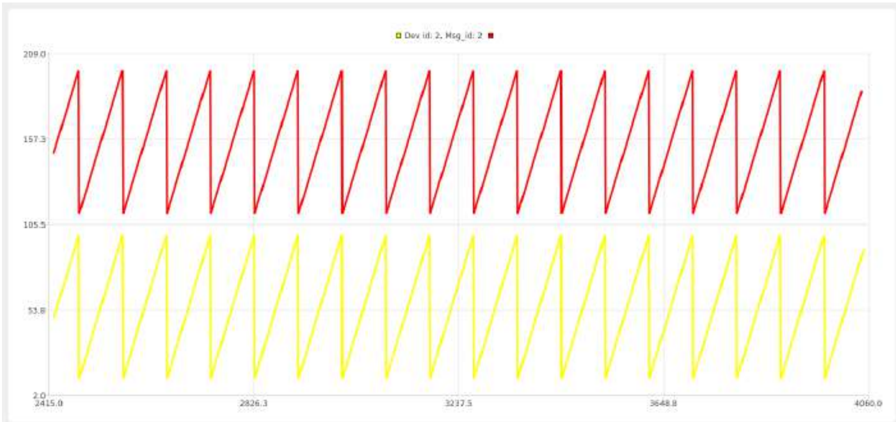
Monitoring in the FST CAN Interface.

Monitoring

The interface has a wide range of widgets that allow us to monitor the state of all the electronic systems of the car. As we can see in this image, we are able of monitoring several parameters of the batteries, such as minimum and maximum values of temperatures and even the values of every single stack on the battery. This allows our team members to easily check the condition of the most important part of the car's powertrain.

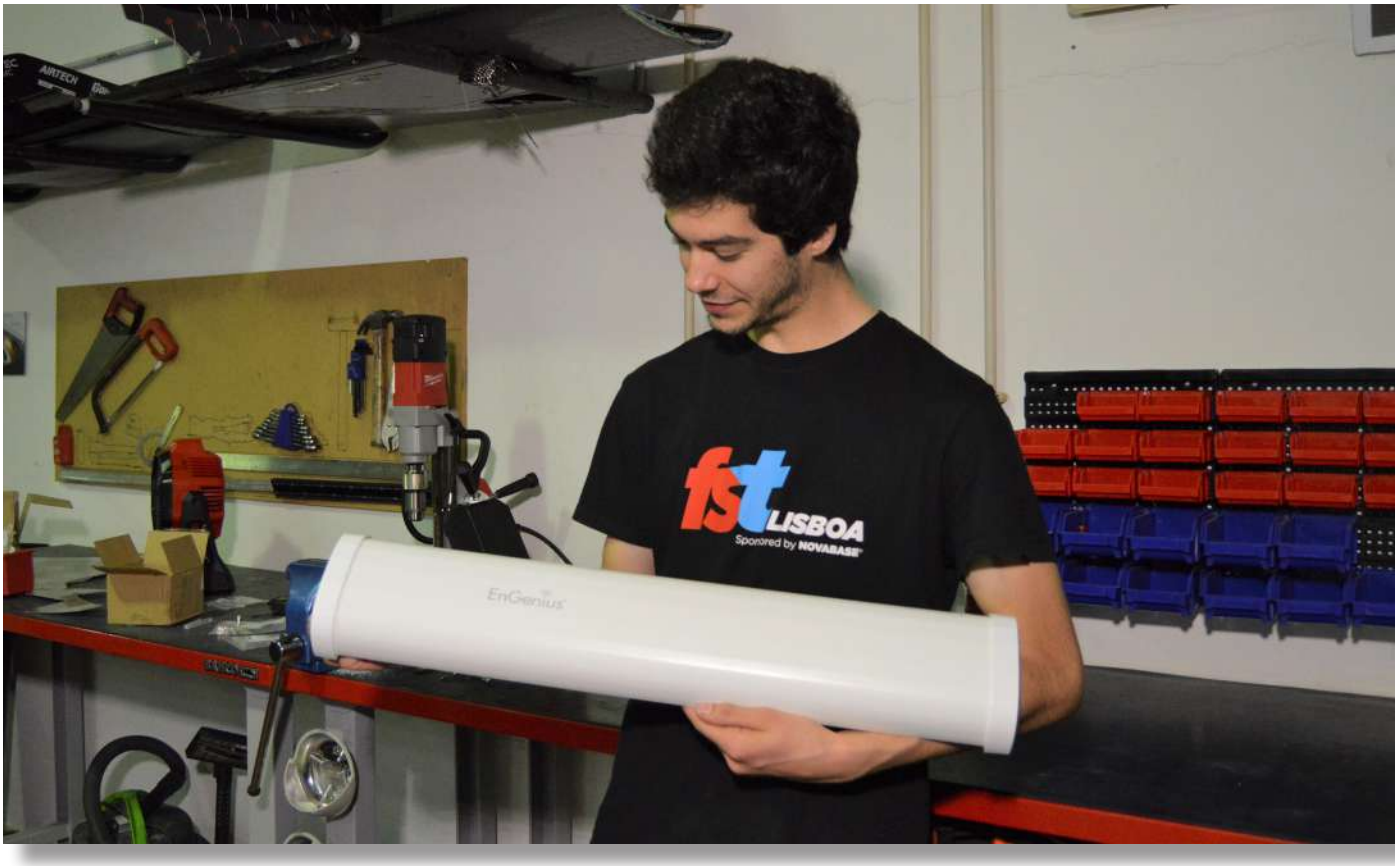
Plots

A more visually appealing feature is our plotting tool. Any CAN message received by the interface can have its contents plotted using this tool. You only need to choose a handful of parameters that define a CAN message and its data is automatically plotted on your screen. All of the mathematical operations can be stacked on top of each other, meaning that this tool offers an unlimited range of options for data manipulation.



Plot in the FST CAN Interface.

FST 08e testing.



Diogo Pereira with the Engenius Networks antenna.

How CAN we communicate with a car?

Around motorsport there is a lot of diversity, different regulations, objectives, budgets, but there is one common ideal: to maximize the car's potential. In Formula Student, the car must be extensively tested and all the data from these tests must be correctly managed to be used. Thus, data management is very important.

Text: Diogo Pereira

Firstly, how can one maximize test time?

In the past we communicated with our car through serial port (USB) meaning that every single time we needed to know or do something in our car we needed to stop and connect our computer to the car which made the team lose test time. Therefore, the team needed a way to communicate with the car wirelessly, but how? It is not an easy choice with the array of wireless technologies available.

How to communicate via wireless?

You probably have already heard about Wi-Fi, it's in our routers, TVs, speakers, cellphones, cars, watches, computers, light bulbs, AC units, pretty much everywhere. This widespread use gives Wi-Fi loads of advantages when comparing to other technologies.
Hardware is cheap because it is available both for professionals and consumers and is well documented because everyone uses it. Software is hardware independent; this means that the code we write can be used in any Wi-Fi hardware. Wi-Fi has a very good bandwith and has a long communication range (more that 1km) with the proper hardware.
Concerning the code, our interface app (app that displays car data and allows for some control) uses C++ with Qt libraries which is cross platform, meaning that we have one flavor of code and several environments to run it (we deploy this code already for Windows, macOS, Linux and Linux Arm). Taking this into account, if we already have cross platform code to manage our car's communications, why write more code to do the same thing? We didn't, we combined the interface's code that handles communication in a C++/Qt library and made it independent to be used in the interface and the telemetry. Now, if we fix or change something in the telemetry's code, we change it automatically in the interface and vice versa.

How can we use this system in the car?

We can't just put a personal computer inside the car, it consumes a lot of energy, it's heavy and expensive, if only there was a board that runs Linux, while remaining cheap, light and operating under low power. There is! It's very popular, requires 2A at 5V, runs Linux, has Wi-Fi and the most expensive version costs around 30€, it's called Raspberry Pi (RPi). The RPi is the perfect choice for the first version of this telemetry. It has several interfaces, one of them is SPI but our car communicates with CAN, so we have a shield that combines our 2 CAN buses to SPI and this only requires socketCAN drivers to enable communication and since it runs Linux, we can compile the code in the RPi itself, we can also replace it with other board, even with a different processor architecture and the code will run!

What about outside the car?

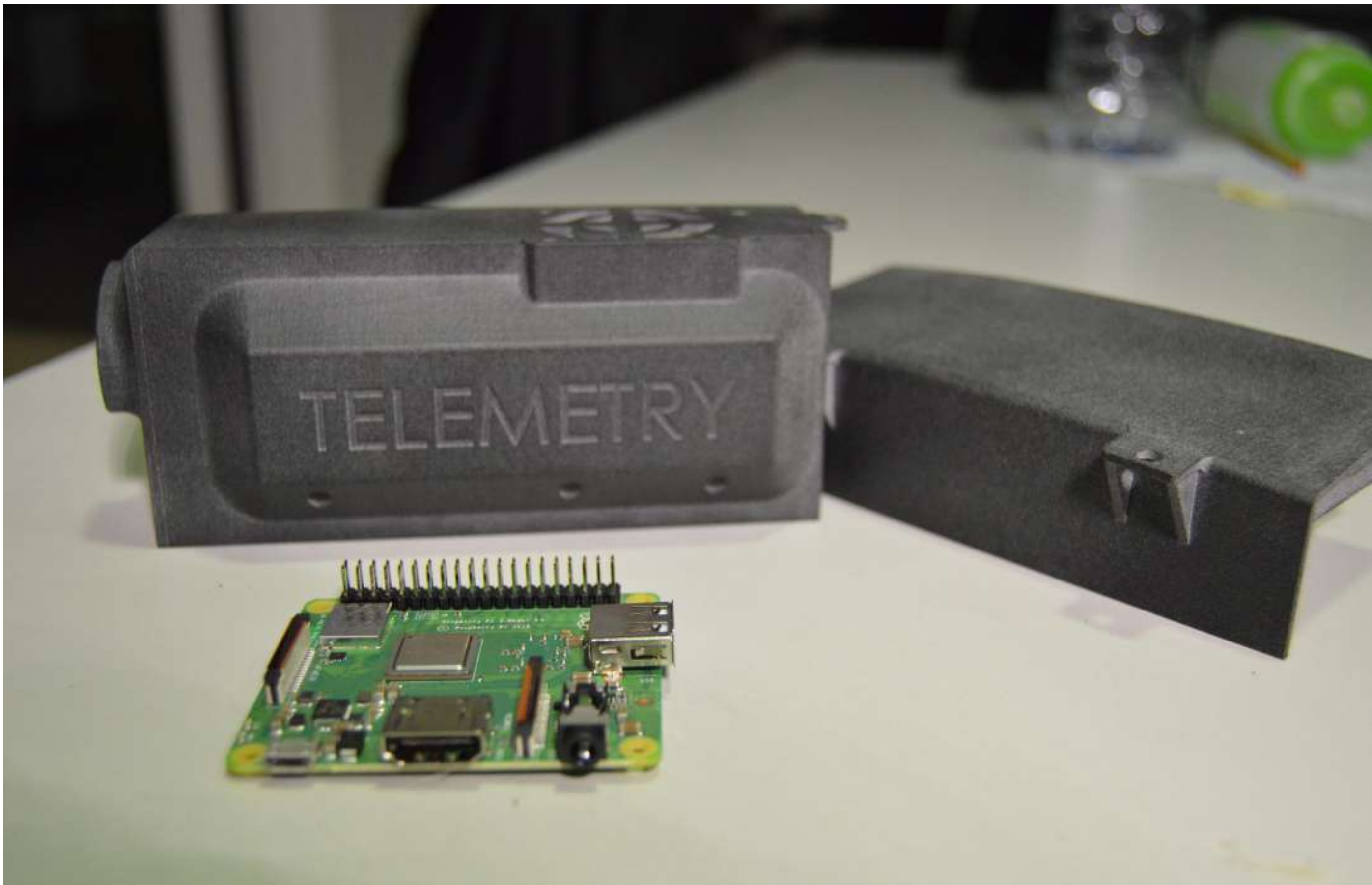
Well, to enable long range communication for us that means around 1 Km maximum, we have a 5GHz 23dBm access point paired with a 5GHz 19dBi 120º antenna. This hardware comes from Engenius Network.

How does this communication method work?

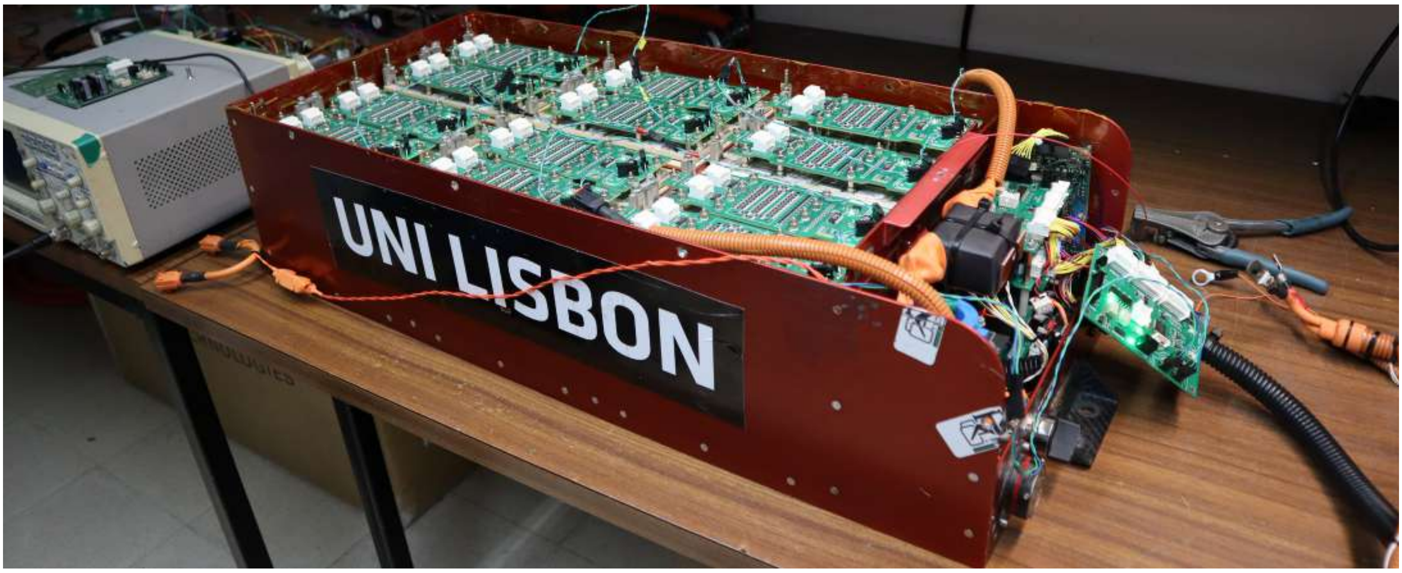
Our library can communicate with serial port as before, it can open a file with logged messages, it can log messages, communicate through UDP or TCP, generate custom messages and also communicate directly with CAN. Thus, our RPi receives messages from the car and relays them to our desired transmission method, UDP or TCP for wireless transmission. In our end, our computers receive messages through UDP or TCP with the same code that's running in the car. For sending messages back to the car the method is the same, any communication method is bidirectional.

How future-proof is this system?

Turns out it is quite future-proof: on the hardware side our devices are not going to change dramatically anytime soon, our code will run in new hardware for years. On the software side, Qt isn't going away and even if its development stops there are multiple things we can do like video/audio transmission for example. Also, since we are running linux we can use apps built by others to do things we need but lack the time to code it.



Raspberry Pi and its box to insert it in the car.

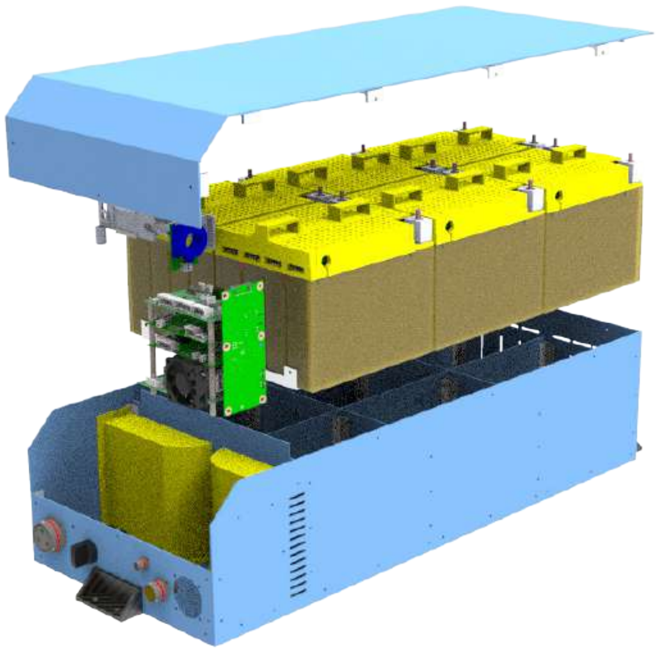


FST 08e accumulator.

Accumulator's Cell Testing

The battery of a Formula Student electric car is made of multiple lithium cells. The layout of the cells is done in 144 pairs in series made of two cells connected in parallel making up a battery of 600 V, with a storage of 8 kWh. The battery weighs 60 Kg which means that it is one of the heaviest components of the car. The low charge capacity of the cells is one of the main constraints in designing regenerative braking. To answer the team's request, it was decided as an investment for the future a lighter battery with a higher charging capacity would be made. To do this, it is necessary to chose new cells.

> "To answer the team's request, it was decided as an investment for the future to make a lighter battery with a higher charging capacity "



Exploded view of the FST 09e accumulator.

Before purchasing samples, the specifications for the new battery were analysed and quantified in order to minimize the expensive trial and error process. A necessary energy value was obtained, which is equivalent to 85% of the current value, and it is expected that there is a reduction of weight by the same percentage. Since the values given by manufacturers are not always appropriate for the running conditions of a Formula Student car, it is necessary to test the main parameters such as capacity, charging and discharging currents and internal resistance.

To conduct the tests to the candidate cells, we contacted a Student Group formed by Master and PhD students of Instituto Superior Técnico called NanoSat that has the goal of sending a satellite into space. Since the satellite is not easily accessible, it is necessary to properly test the satellite's cells before they are assembled. Thus, we will use the equipment made available by NanoSat, located at Taguspark, to be able to conduct the tests to our cells. The tests consist of charging and discharging the cell to different charges with the aim of characterizing the cell. Tests at different temperatures may be done with the help of a heating dome in order to find the optimum temperature point that confers the highest battery efficiency. After the tests to the cells, it will be possible to characterize them and choose which one gives us the ideal battery.

Text: João Revés

"TE Évora has supported Formula Student for 5 years and is seen by the company as one of the most interesting projects concerning university partnerships. These types of projects help students join an organizational reality where commitments are assumed for a greater objective and this helps reducing the initial impact in the transition from academic life to the professional one. At the same time it involves dealing with different fields of expertise and therefore is a learning experience in project management, communication skills and influence, which during the academic course are seldom possible. We noted a great value added to students that have been through experiences such as Formula Student and the proof is that we have many students whose integration in the company is easy and acknowledged. In most cases they are fit into departments that they have been previously in contact with during the project and this networking turns out to be very helpful in the welcoming and integration process. Without a doubt it has been a very enriching experience, and it is with aspiring interest that we see former students to continue their journey inside TE."

TE Connectivity

João Nunes welding a PCB.

How to control FST 09e?

The aim of the Control subdepartment is to maximize the car's performance through the electronic implementation of algorithms that react in accordance to the behaviour of the car when it is on the track. This way, it is possible to divide the design in two parts: **sensors** and **controllers**.

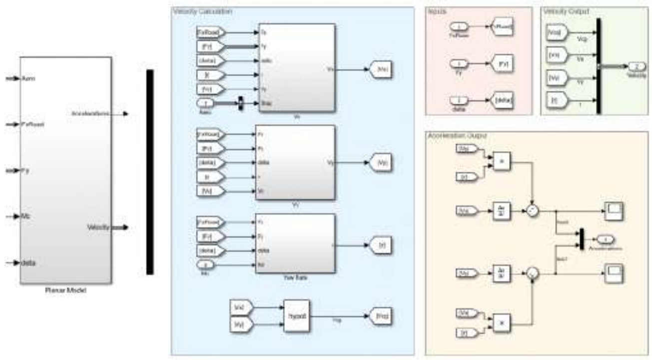
Authors: Inês Viveiros & João Pinho

The sensor design begins with the selection of sensors that allow a complete characterization of not only the prototype and its movement but also the interaction between the driver and the car. Thus, the FST09 will have linear and rotary potentiometers,a GPS, an AHRS (gyroscope, accelerometer and magnetometer) and strain gauges, among others.
From there on, the Control subdepartment creates software (in C language with the aid of MatLab Simulink) that processes and combines the data obtained by the sensors, with the objective of knowing and estimating several parameters of the car, at a given instant. To do this, several digital filters are used, by combining equations that describe the kinematic and dynamics of the prototype. The FST 09e stands out by using a Kalman filter whose purpose is to estimate the linear velocity, reducing significantly the measurement error when compared to the FST 08e. It is important to note the use of an algorithm that estimates the vertical force in the wheels that adapts itself to the different suspension tuning references in the FST 09e. In addition, this year a way of calculating the time of each segment and lap in the track using the GPS was introduced.
Likewise, the controllers' design begins by choosing the types of controllers to be designed. This year the team opted for an improvement in the previous control algorithms: lateral control based on the variation of the yaw angle

> "(...) this year was introduced a way of calculating the time of each segment and lap in the track using the GPS."

FST 08e.

(Yaw Moment Controller) and longitudinal control based on the maximum possible traction of the tires (Launch Control). Consequently, it is necessary to establish a traction limiter, that follows the wheel's force, and also a torque limiter, that this year has a strong reliability aim. This limiter represents a great improvement in this year's controllers, since their characteristics change according to the car's critical conditions, such as battery voltage, motor and inverters temperatures, among others, which conferred it the name of Endurance Finisher.



Subsystems' model.

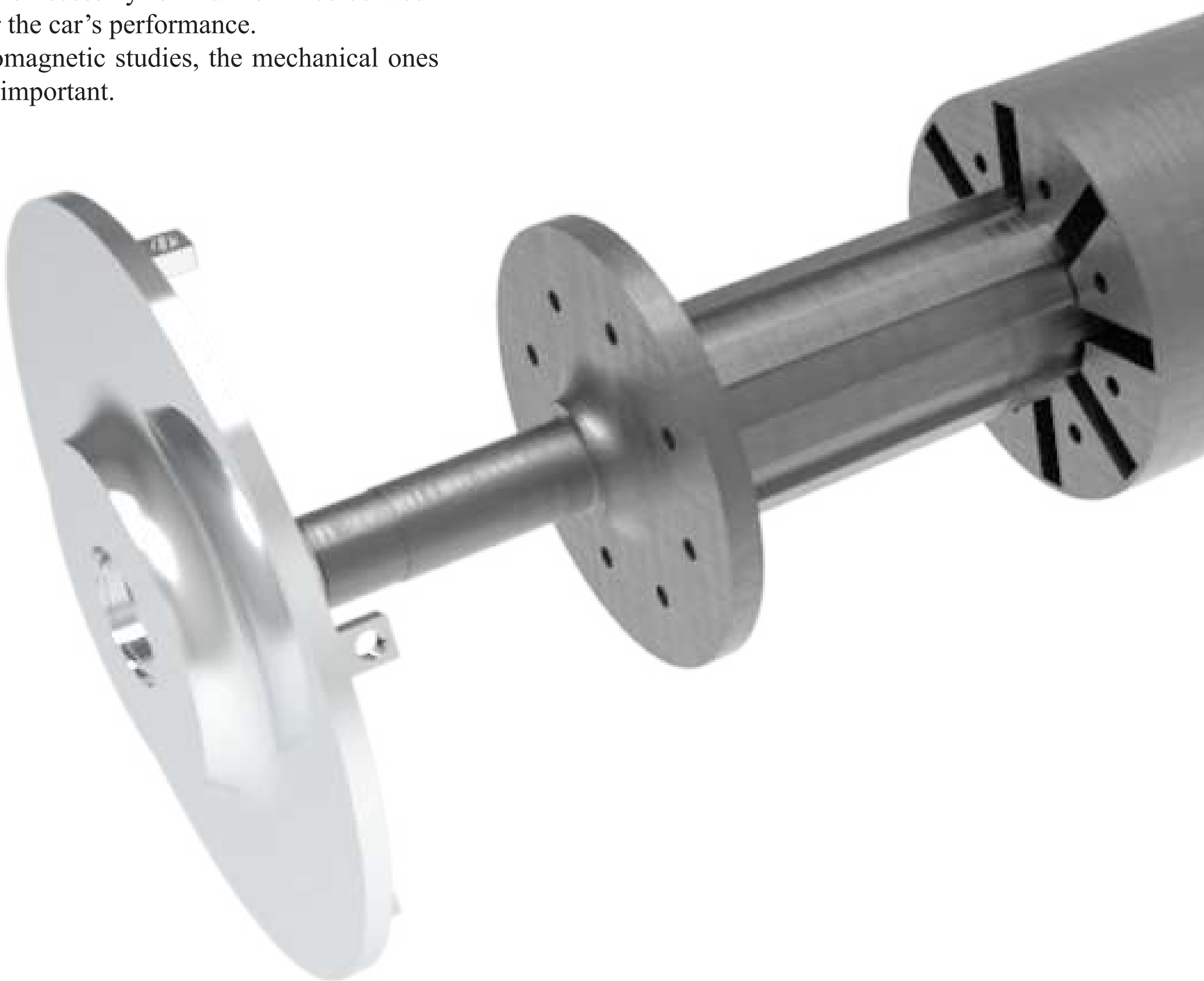
"This year, in order to have a more reliable and robust software, an algorithm for verification and validation of the activity of the different car modules (...)"

This year, in order to have a more reliable and robust software, an algorithm for verification and validation of the activity of the different car modules was implemented, allowing that, in case some of these modules fail, the car continues to run normally. Furthermore, this year the team is beginning the project for a regenerative braking system, even though it is on a basic level. The testing and development of the controllers is done in MatLab Simulink and their implementation is done in C language in ARM processors.

To sum all this up, the Control subdepartment is working towards improving the existing algorithms, with special attention to reliability and at the same time maximizing the prototype capacities, with the aim of obtaining the best track performance.

New Motor Generation

One of the team’s goals is to build its own electric motors. Thus, the Powertrain department has been developing the team’s third electric motor generation. the MJF, that is closer and closer of fulfilling the requirements needed for it to be used in the car. Among the requirements is the amount of torque that the motor can produce and its efficiency, which together make the car have a strong acceleration while spending the minimum battery energy possible. Thus, the Powertrain department develops different studies. Among these are the electromagnetic studies. In order to produce a maximum torque, the geometry of the stator and rotor has to be adapted, having the previous prototypes as a starting point, changes are made to maximize the power density in the motor. At this point it is important to remember that many of the alterations that maximize torque minimize speed of the motor, therefore it is necessary to find a balance between what is the best for the car’s performance.
Besides the electromagnetic studies, the mechanical ones are also extremely important.



MJF’s exploded view.

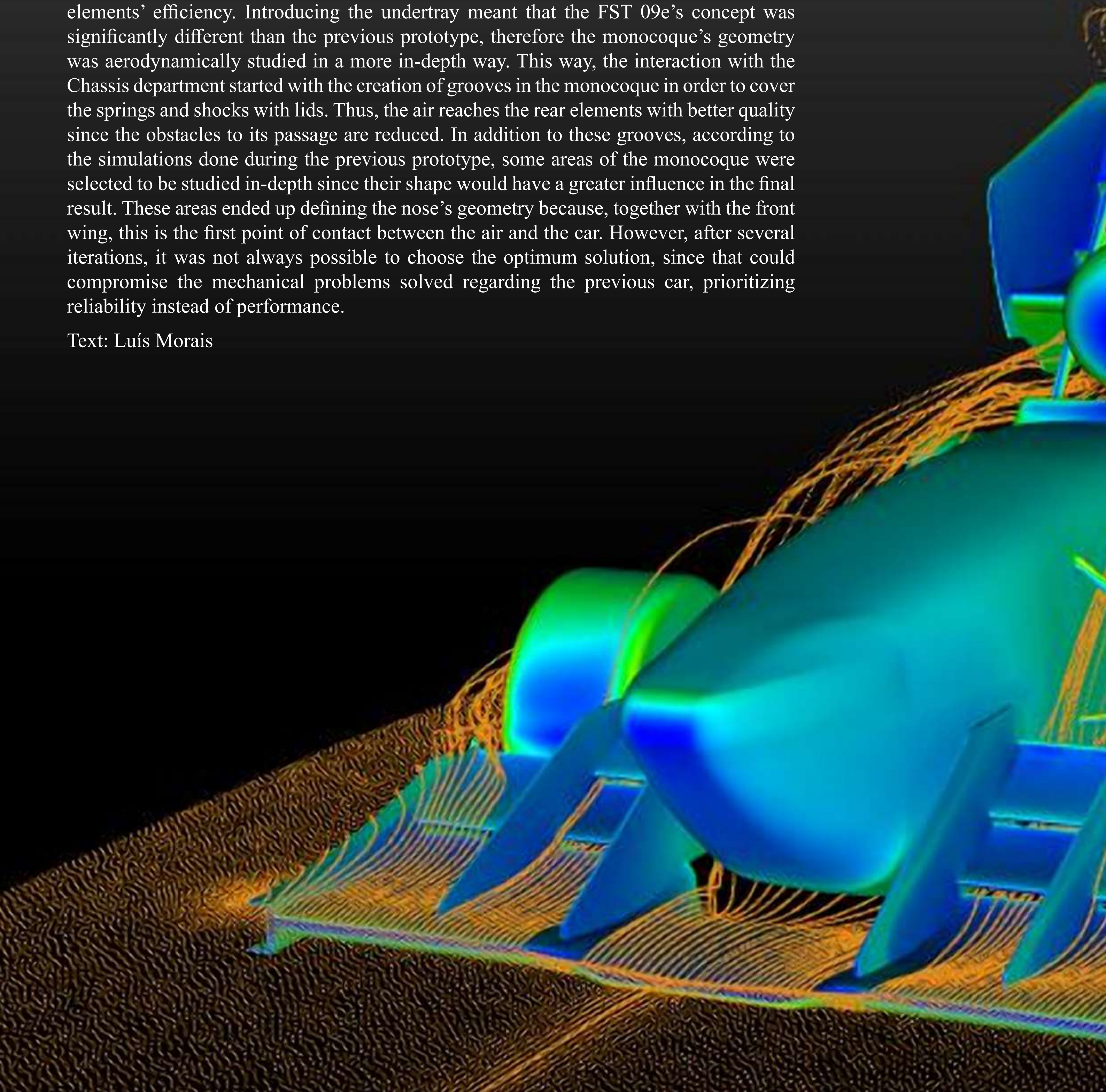
With an elevated torque to be transmitted through the motor's shaft, it is necessary to guarantee that the shaft is resistant enough to support the mechanical efforts. For this, the finite elements method is once again used and maximum load studies are done as well as fatigue studies. Finally, the thermal studies are conducted. It is important to remember that the motor will be heated due to the dissipation of energy, as in any other system. Thus, a prediction of the dissipated power is done in each functioning regime, and, using CFD studies, a motor housing where the water will go through is designed. These motor housings has the aim to absorb the motor's dissipated energy guaranteeing that it does not reach a critical temperature in the coils as well as in the magnets. Finally, for the motor to be used in the car, it has to be very reliable. This way, it is necessary to use simple geometries, which means easy to build and to study, which are the best manufacturing and assembling

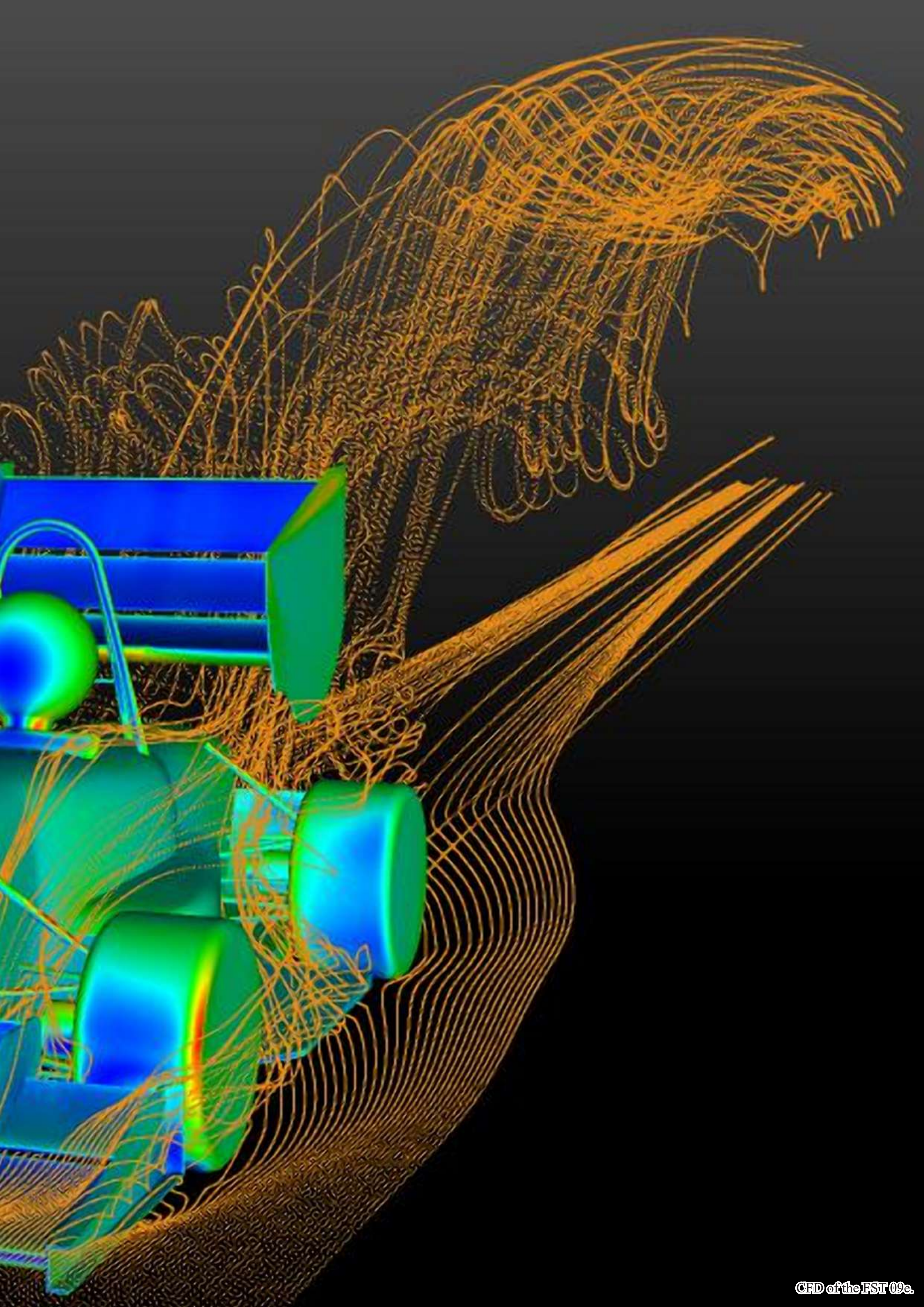
Text: Pedro Santos

Aerodynamic Design

The aerodynamic package for the FST 09e stands out for its adjustability and its stability as a whole. Together with the Vehicle Dynamics department, a value for the Aero Balance was reached, which is the percentage of aerodynamic load applied to each of the car's axles. Since this result was very different from the previous prototype a change of concept regarding the lateral elements of the aerodynamic package was needed, introducing an undertray. To make this change it was necessary to keep almost all front and rear wing unchanged, which allowed the remanufacturing of moulds and accelarate this process. This element, which is divided into two side channels in order to minimize its weight and ends in a diffuser, improves its proximity to the ground to create a suction area (low pressure) under the car, responsible for downforce. Comparing the lateral wings used in the FST 08e, the undertray has the advantage of creating a greater amount of downforce near the rear axle of the car, improving stability at higher speeds. Some of the details introduced in this element aim to improve the diffuser's efficiency, like small footplates placed in its exit to minimize the impact of the tire wake, that is, turbulent air that reduce elements' efficiency. Introducing the undertray meant that the FST 09e's concept was significantly different than the previous prototype, therefore the monocoque's geometry was aerodynamically studied in a more in-depth way. This way, the interaction with the Chassis department started with the creation of grooves in the monocoque in order to cover the springs and shocks with lids. Thus, the air reaches the rear elements with better quality since the obstacles to its passage are reduced. In addition to these grooves, according to the simulations done during the previous prototype, some areas of the monocoque were selected to be studied in-depth since their shape would have a greater influence in the final result. These areas ended up defining the nose's geometry because, together with the front wing, this is the first point of contact between the air and the car. However, after several iterations, it was not always possible to choose the optimum solution, since that could compromise the mechanical problems solved regarding the previous car, prioritizing reliability instead of performance.

Text: Luís Morais





CFD of the FST 09e.

FST 08e.

Aerodynamic Validation

During the FST 09e design phase it was possible to combine the CFD simulations to the tests done with the FST 08e. The simulations allow for a prediction of the air's behaviour around the surface of a structure, but since it is based on models, which are not always representative of the reality and have associated errors, they present some limitations. For this reason, the validation on track is very important, especially when it is done during the design phase because it reveals these inconsistencies.

This way, the elements that would remain unchanged in the new prototype were tested: the front and rear wing and also the side ducts, in order to better understand the air's behaviour in this area. Through these tests, areas where the boundary layer is separated - where air does not flow around the surface and has an unpredictable behaviour - were found. To achieve these results the Aerodynamic department used techniques of flow visualization suggested by professor Luís Eça, namely the placement of small threads of wool in the different geometry areas, subsequent video recording of the car's movement during test runs, and also the application of flow vis, a liquid with a specific viscosity that marks the air's trajectory along the surface but its recipe is still being improved.

After some test days, it was possible to conclude that the air shows a similar behaviour to the one in the simulations of the rear wing, whereas it was slightly different in one of the front wing's elements, which made this result very important for the development of the new prototype, especially in the implementation of position adjusting systems of certain elements. There was also flow separation in the rear wing during curves which shows the necessity of investing some time in curve simulations to then compare them to the recorded images.

Text: Luís Morais

Detail of the smal threads of wool in the rear wing.

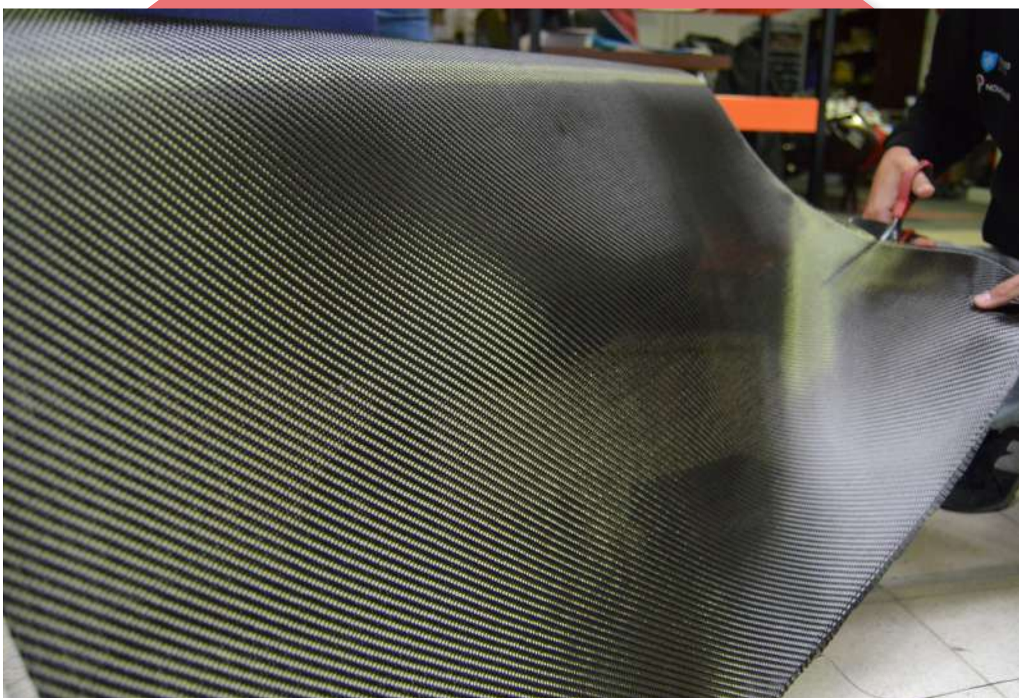
Team members with Milwaukee tools.

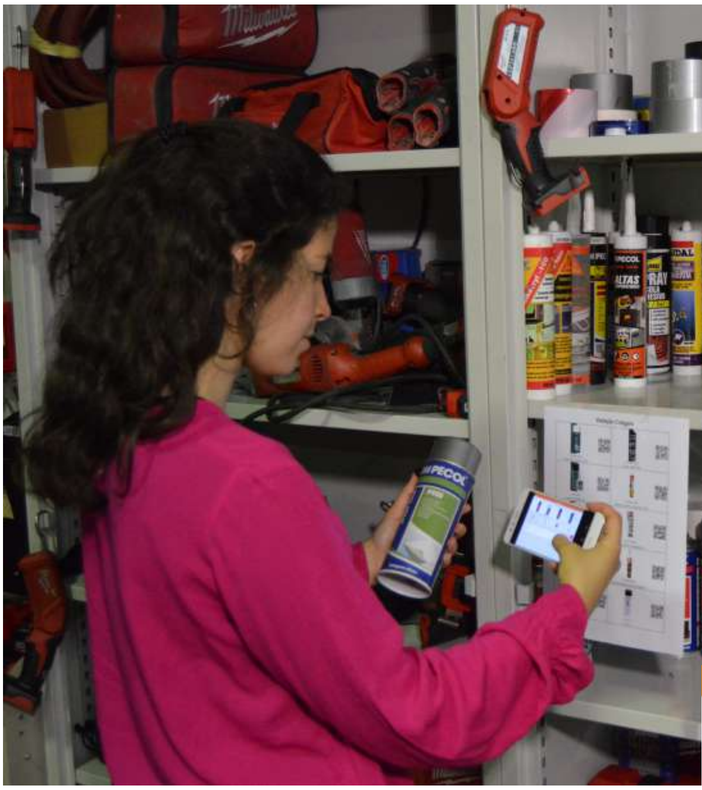
Power tools market leader, Milwaukee has been with the team for five years now. The brand's high duration batteries allow for all tools to be easily transported to competitions, as well as lightning solutions so the team can work at any time. The team can also work in several different locations thanks to the packout organizer, assuring equipment and consumables are where the tools are too.

REBELCO

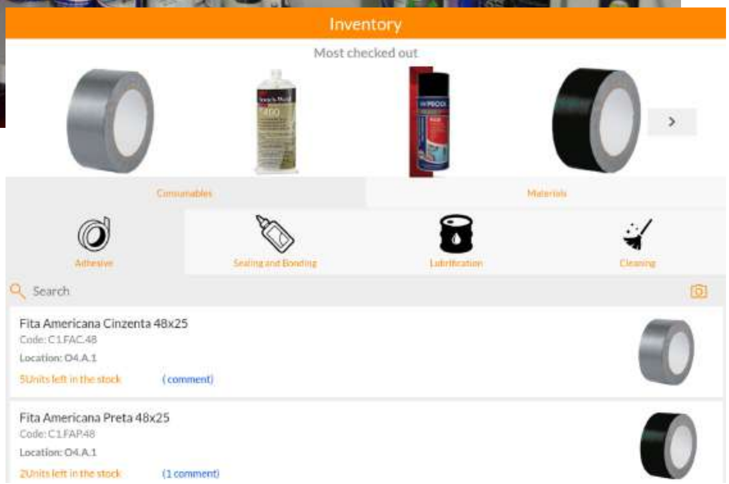
CIT composite materials italy

The FST 09e has been through changes in the chassis and therefore needed new moulds. Since the monocoque will have to be cured at high temperature, the negative moulds are made in carbon fibre. This year, Composite Material Italy (CIT), in partnership with its local distributor Rebelco, provided all the material needed for the moulds' manufacturing. CIT is one of largest composite manufacturers in the world, while Rebelco is the exclusive distributor of several companies for similar works in Portugal.


Carbon fibre.



Alexandra Pereira testing the app in the team's workshop.



App's screenshot.

App: Stock Management

In FST Lisboa "factory", the management of stock becomes essential for the production of a formula car. Similarly to what happens in the industry, the management of resources allows the anticipation of the team's needs, which ensures a more efficient work to achieve the goal of making a car in one year. Plus, it could have a significant impact on finances by reducing the expenditures, since it gives the team more time for problem solving.

"(...) have a significant impact on finances by reducing the expenditures, since it gives the team more time for problem solving."

Therefore, a mobile application with QR Code reading was developed in PowerApps, a Microsoft platform, to manage the stock of the team.

By using the App, the user can update the quantity of the products, get information about the products' application, reserve items or even give feedback about the products' use. Every time the quantity of a product reaches the minimum defined, the responsible for the App receives an email alert.

At the moment, the project has been implemented to be integrated with the manufacturing phase of the FST 09e.

Coding of lubricating oils in FST Lisboa's workshop.

Text: Alexandra Pereira

Team members with Mark Preston.

Communication and Image Plan for FST 09e

One of the greatest team challenges for the year of the FST09e was defining specific goals that addressed increasing its visibility, not only inside the university, but also in reaching other external entities. To do so, different strategies and approaches were considered to reach such acknowledgment and different ways to be able to measure its impact were debated.

Text: Mariana Sequeira

Given the stability in terms of knowledge and technical support the team already has in place, fruit of the partnerships with numerous companies, the need arose to invest in creating a self-evident identity, with a clear image recognizable by teachers, students, companies, and other entities. This identity is intrinsically connected to the recognition that such people have of the project and the team, having a fundamental part to play in answering who are we?; what do we do?, how do we do it?, and why do we do it?.

Consequently, by word of mouth, more and more curious people appear at the team's shop. Examples of it were the visits the team received during Técnico Career Weeks. During these weeks, different events are organized by students and for students, which include talks and other activities where companies of different branches of engineering give their testimony. During some of these activities, the team welcomed in its shop engineers from Tesla Motors, Alfa Romeo Sauber F1 Team and even Red Bull Advanced Technologies. Apart from this, the will to actively participate in events organized by Instituto Superior Técnico related to electrical mobility was achieved multiple times, highlighting the future presence in "Academia meets Auto-Industry" that partnering with Mobinov, will mobilize more than 30 speakers. The team's facilities were the chosen place to publicize the event in newspapers and television shows.

When it comes to the recruitment process and the relationship with the university community, one of the goals was to spread the word to Taguspark Campus where, until now, there was no significant connection in comparison to the Alameda Campus. With the team's participation in events at the IST facilities in Oeiras, recruitment advertisement and more detailed description of developing areas, the team increased in about 20% the number of new recruits coming from Taguspark.

To measure their success, the above mentioned goals are seen reflected in establishing new partnerships and strengthening pre-existing ones. The fact that both the team and the companies are in tune will allow to enhance the achieved results in the future, namely during the competition season ahead. Even though some of these goals can only give fruits in the future, the team is focused in developing new strategies to adapt to its needs, and eventually give good feedback and due acknowledgement.

Sponsorship Visit

It has become a tradition in the team. The Operations and Communications department crosses the country to visit some of the sponsoring companies to present the results from the previous year and discuss improvements and design for the next year.

Text: Henrique Motta

In October of 2018 the five department's members visited some companies in the north of the country with great importance for the manufacturing of the FST 09e, in order to improve the car's design process taking into account manufacturing constraints and to clarify technical questions. After some issues with the previous prototype at a structural level, the Operations and Communications department made an effort to bring solutions proposed by the companies to the members responsible for the new design, with the objective to improve the car's parts, thus having a more reliability and avoiding later damages. This trip had two more members than the previous year, and apart from introducing the new ones to the sponsors, the trip was also a way of strengthening the relationships with the companies. An example of this was the visit to the SNA Europe, in Portugal represented by Bahco, where members had an introduction to lean manufacturing principles resulting in a deal to equip the entire workshop with tools, increasing last year's sponsorship. Apart from the recent sponsors, the team also made sure to see some longtime sponsors as Ramada Aços, where the traditional photo in their facilities is taken and where two weeks later the FST 08e was to shoot the "Fast Steel" promotional video. At the end of the journey a positive balance was achieved, bringing home relevant information for all departments, as well as hints and tips from professional engineers for the FST 09e project.

Visit to Ramada Aços.

Visit to Emmad.

"(...) the Operations and Communications department did some effort to bring, to the members responsible for the new design, solutions proposed by the companies with the objective to improve the car's parts (...)"

Bahco's showcase.

Interview: How to be a driver?

Name: Luís Abreu
Position: Chief Engineer (FST 07e)
First year on the team: 2013
Cars driven: FST 05e, FST 06e, FST 07e, FST 08e
Course: Integrated Master in Mechanical Engineering

How were the drivers chosen this year?
Miguel Lino (M.L.) - We started by taking everyone interested in being a driver to a go-kart race. Based on this run, we were able to pre-select the ones that had the best lap times. This way we were able to make up a list of 8 to 9 people, and amongst those we did one more race in order to eliminate more people and begin to understand which ones were better for which type of event. Each one that was chosen will be able to do a number of test runs with the FST 08e to get to know the car and mark new lap times. My idea is to, after they get to know the car, have a day of tests where each driver has a certain number of laps put in, and then decide who will drive the Endurance and Autocross. With the remaining drivers we will spend a day doing Skidpads and register the best times and consistency to choose the remaining types of events suited for each driver.

How do you evaluate the drivers apart from their lap times?
M.L. - We have a Go Pro that is pointed at the steering wheel and that way we can see the driver's movements and we also have sensors in the pedals, but what counts most is the lap time and consistency of the driver and their performance.

Which should be a driver's main qualities?
M.L. - One of the main qualities is consistency. For example, in the Skidpad it is very important not to loose control of the car and to do the best time possible in a consistent way. Another quality is to keep a cool head, if the first run did not go as planned, you have to let it go and focus on the next one, having learned from your mistake. Also a driver cannot be afraid; during each event there is only you, the car and maximum focus. Finally, it is important to be able to learn on the spot. Most of the times we cannot practice the types of circuits that we'll face in the competition, especially the Endurance one, therefore you need to have the ability of improving your lap time after each run.

> "(...) when there is the opportunity of driving something that you helped build is a huge pride."
>
> \- M. L.

Luís Abreu (L.A.) – It all depends on the event, but the most important is consistency and being calm while driving. Out of the event the driver can do almost anything he wants to do but during the event he needs to keep his head cool and to make the right decisions, because the tracks are narrow and it all happens very quickly which makes it very easy to suffer unnecessary penalties that jeopardize the team. In fact, it is important for a driver to be consistent because this way he knows that if anything changes in the car setup, any variation in dynamic behaviour or data is due to said change.

What are the main difficulties that a driver has?
M.L. - A driver must endure the event. Especially during the Endurance it is very important to have physical and psychological strength, since the performance needs to

Miguel Lino and Luís Abreu in FS Spain 2018.

Name: Miguel Lino
Position: Chief Mechanical Engineer (FST 09e)
First year on the team: 2016
Cars driven: FST 08e
Course: Integrated Master in Mechanical Engineering

remain at its maximum during the whole event. Another difficulty is the ability to handle pressure. You can practice a lot with the car but when you are in the middle of the competition the pressure is completely different. You are representing your whole team, you're in front of other teams and you know that if you fail during your turn you can be jeopardizing your whole year's work.
L.A. – One of the great difficulties is to know what to expect from the car. Especially now that the cars are designed and built in just one year, the practicing time with the car is reduced which makes it hard to predict the car's behavior in response to your input and it is necessary to rapidly adapt yourself to the behavior of the car and to the circumstances. Also, having to attend the team briefings at 9am is hard.

What do people not know that a driver has to do?
M.L. – A driver must know how to give feedback about the car. It is impossible for a driver to have a fast car without it being tuned. And to have a tuned car you need to be able to give good feedback on the car's status and what you are feeling at the moment in order for it to be corrected. It is also important to have experience, especially with the car that the driver will drive during the event, hence the importance of having as much time of test runs with the car as possible before the competitions.
L.A. - The driver must know the car's limits. During car testing it is important to take the car to the extreme to know where the car's limit is. During the tests it does not matter if you hit a cone or you end up out of the track, because all that makes you more familiar with the behavior of the car in as many different situations as you can. The most important thing is to take the car to the competitions as well tested as you possibly can.

> "(...) when you finish the event and you feel like you have done what you could and you represented well the team in front of so many people it is very satisfactory."
> - L. A.

Why do you like being a driver?
M.L. - I have been an adrenaline addict since I was a little boy. Driving cars like the one the team build is a very liberating experience, driving the car simply makes me happy. When I go inside the car I can think of nothing and just enjoy the moment. Besides that, when there is the opportunity of driving something that you helped build is a huge pride.
L.A. - In the Formula Student specific case, there are 40 people building a car and the fact that you are the driver is a great responsibility because it is a year's work that you have in your hands. And, everything that has a lot of responsibility, when it is accomplished with the minimum of success is very rewarding, therefore, when you finish the event and you feel like you have done what you could and you represented the team well in front of so many people it is very satisfactory. Besides that, the adrenaline that you feel when you are driving the car is incredible.


FST 01

FST 08e

FST Lisboa in a minute

Formula Student, initially FSAE in the United States of America and FS UK in England, was created as a challenge for young college students, many of which interested in automobile technology with a passion for motorsport. Combining both these characteristics, creating a competition sponsored by an entity of great importance in the world stage - SAE - and with its own rules, fastly gathered hundreds of students around the project and the manufacturing of prototypes with high dynamic performance. Once the ball got rolling, there was no stopping it.

Text: Prof. Luís Sousa

Around the turn of the century, the interest reached Instituto Superior Técnico (IST), through a group of five Mechanical Engineering students who founded Fórum Mecânica and thereafter the Projecto Formula Student Técnico (FST). The beginning of a project like this is always hard. Starting from nothing, convincing many others of the viability of the project, finding the human and financial resources to execute and then to actually deliver! CAD, FEM, CFD, CAM - everything is simple because what is computed with these excellent Engineering tools gets stored in a magnetic or optical unit and rarely leaves the screen of a computer. But, in Formula Student, that isn't the end of it - the parts really get built and are part of an actual competition, in front of a qualified and experienced jury.
It wasn't easy, but in 2004, the FST 01 was born. Simply conceived, so manufacturing was achievable with the teams means, and reliable to try to avoid issues. In 2011, the FST 04e stamps the change to electric vehicles, and in 2013, FST 05e marks the switch to a carbon fibre monocoque chassis together with an aerodynamic package (front and rear wing and a diffuser in some cases). In 2018, with FST 08e, a new car was built in only one year, something unprecedented in FST.
Nowadays, everything is simpler! The team grew, reaching now around 40 members. Given this, the amount of work of each member is "much smaller", needing "only" to devote 8, 9 or 10 hours a day to the project - a "hobby" when you're twenty-something years old. The technical and organizational evolution of the team are far superior today - fruit of the experience and learning by trial and error. On the other hand, responsibility also increases and with it, pressure rises.
Formula Students organizational boards constantly develop the rules, allowing for new concepts, project solutions, materials and manufacturing processes applied to these technology displays, that are the fabric of the competition events. FSG's (Formula Student Germany) example is very expressive, where on the last February 1st, 313 teams participated on the competitions access Quiz, this competition which will take place from 5th to 11th of August, in Hockenheim. 118 teams were accepted (60 in combustion , 40 in electric and 18 in driverless).
The Department of Mechanical Engineer in IST and IST itself cherish this project since the beginning, building the support mechanism to allow the project to blossom. Year after year, a broader range of degrees and departments are brought in because the needs so demand it.
Multidisciplinarity and group work are key concepts on the project, mimicking the industry in this aspect. This group of students have been sought after by the best companies in their recruitments.
In July and August of this year we will do our best with FST09e. Most parts of this vehicle are already ready, other components are coming. Now we only have to assemble, test, and compete. The project is bound to continue and rapidly take the next step, towards Formula Student Driverless.

FST 04e

FST 05e

FST 06e

FST 07e

FST 03

"(...) in Formula Student (...) the parts really get built and are part of an actual competition, in front of a qualified and experienced jury."

FST 02

Get to know more about the team here: