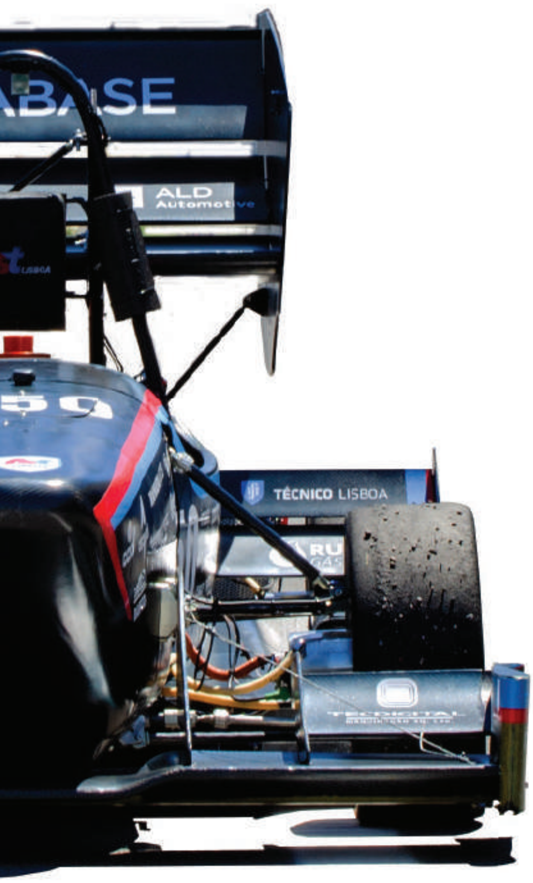
THE MANUFACTURING MAGAZINE

AUGUST, 2021



fst LISBOA
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FST Lisboa

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Figure 1: FST 10s testing day at Estoril Circuit.

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ELECTRIC

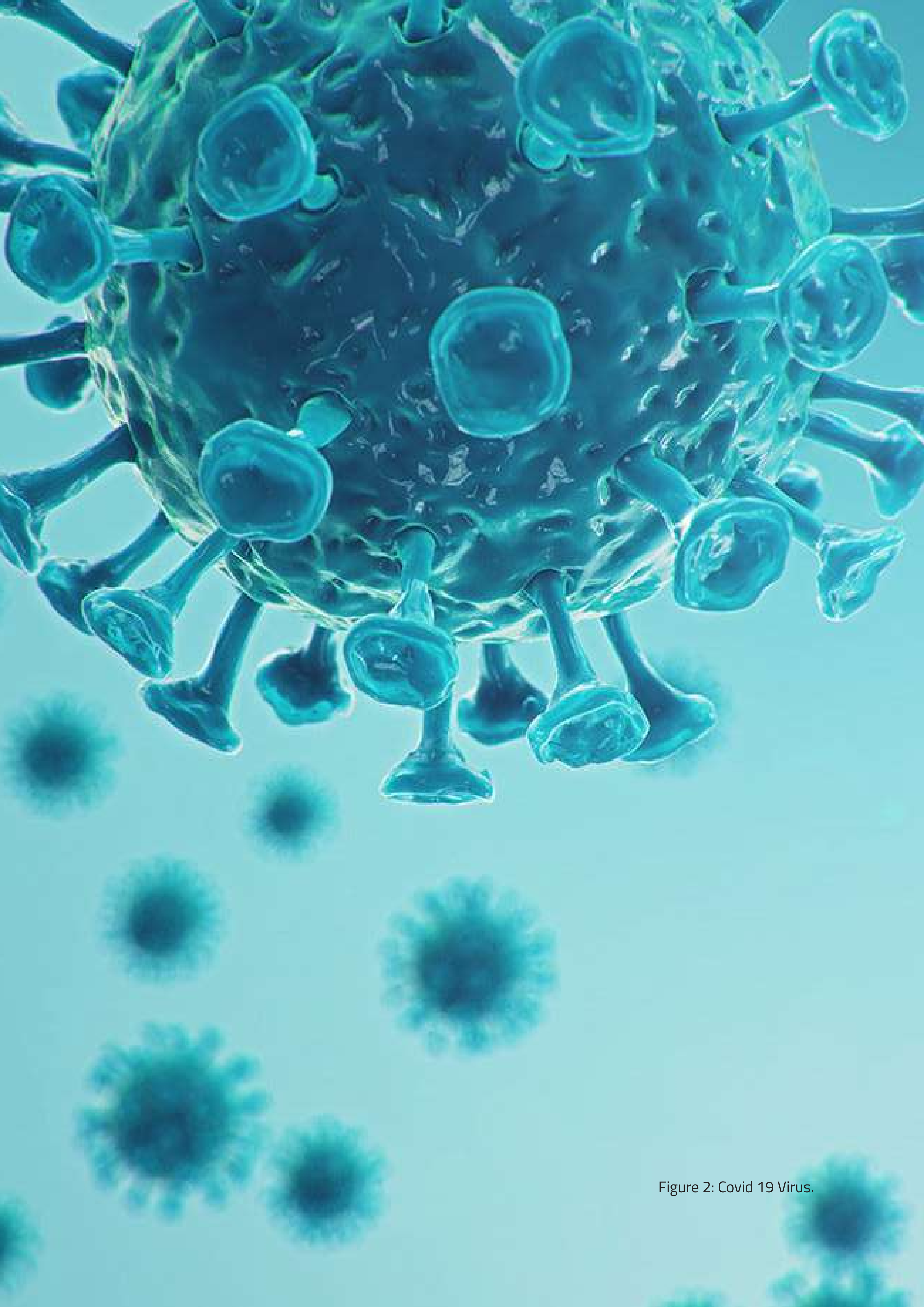


Figure 2: Covid 19 Virus.

Lockdown Manufacture

Project Management

Throwback to the 18th of March of 2020, Portugal had just declared a State of Emergency in all of its territory, immediately on that day Instituto Superior Técnico announced, via email, that all activities on its campuses were suspended, throwing all the general planning of the team into chaos.

By this date the manufacturing season of the FST10e and FST10d was in its initial phase, the team had machined its first in-house parts, and the monocoque moulds were being repaired. Most of the components were still at the sponsors and as a result, the first reaction of the management team was to contact all of its partners to understand the damage that the lockdown would inflict on the team, furthermore all of the mailing addresses were changed to the member's private residences to allow the arrival and quality check of the parts and components that could arrive during the undetermined lockdown period.

After all, the team passed 82 days in lockdown, during this period some of the departments were able to develop their work with minimal damage since they could test their work in test benches, namely the autonomous system department, the electronics department, the software department and the vehicle dynamic department, the latter focusing on developing new tools for future prototypes. However, some had to freeze their development during this period and their focus changed to document the car itself allowing the next team to finish its assembly.

Figure 3: Lockdown online meetings.

When the Instituto Superior Técnico reopened its campuses heavy restrictions were imposed on its operation, not only by the University but also by the team, the working hours were restricted between the 08:00 AM and the 20:00 PM, the limit of team members at one place was 2, and the team was divided into teams of 3 people, with focus on maintaining redundancy between the departments, allowing the team to continue its operations even if an outbreak was detected. In addition to these restrictions, several displaced members of the team returned home, meaning that for most of the manufacturing season the team was understaffed.

This meant that new solutions had to be produced to allow the management of the car to be performed online when presential meetings with the different departments were impossible.

For this many tools were developed, the macro organization tools like the WBS_ Analysis, Assembly Tracking and FST Company Tracking, which were responsible for breaking down the systems of the car allowing the management team to have a clear vision of which steps would be unblocked by the arrival of new parts from the different stakeholders and by the work performed at the workshop and the communication tools.

These communication tools were responsible to create a clear and objective line of communication that allowed the management team to pass important information about the tasks to be performed in regards to the sponsors management and the tasks to be performed at the workshop, these tools were the Covil Weekly Planning and the Sponsors Management Tool.

Written by Tiago Carvalho
Project Manager

Figure 4: Returning to the workshop.

Figure 5: FST 10e.

Front Wing Manufacturing & Assembly

Aerodynamics

The FST 10e front wing is composed of a large main flap, two smaller ones, two airfoil-shaped endplates, and vertical plates which ensure the correct mounting on the rest of the car. These components are made of carbon fiber, which is highly optimized to achieve the lightest components possible, with some regions reinforced with Kevlar to add impact resistance.

The manufacturing process followed a resin infusion process. Given that a Formula Student car is a unique prototype with each part being manufactured only once, resin infusion is an extremely cost-effective method of manufacturing high quality and high strength carbon fiber parts. This is widely used in the composites industry for achieving a better fiber to resin ratio and reducing the amount of wasted resin.

The moulds used for this purpose were mostly made of MDF (medium-density fiberboard). This type of wood is used in engineering due to its easy machinability, low weight and cost. The downsides of using MDF are related to its high porosity and the fact that it needs surface treatment before being used. Since the surface finish of the main flap was extremely important, we decided to use POM C (Polyoxymethylene) exclusively for this component, as it shows less porosity and does not require an extensive surface treatment prior to its use.

The lamination process had some improvements regarding the techniques used, following the expertise gained in this field. The new methods allowed to reduce air leaks and better distribute the resin along the component. Moreover, the resources and supplies used, such as

Figure 6: FST 10e's front wing.

the new vacuum pump and other consumables, led to a high-quality resin infusion. Apart from this, the support and mid-plates were manufactured using a pre-preg lamination process. Using pre-preg carbon fibre is a great advantage as it generally produces lighter components.

The assembly process was much tougher than the manufacturing one. Assembling all the components involved high precision methods and good planning to ensure that it was all correctly placed and fixed. Given some design changes, particularly the endplates' design which is completely different from the one in the FST 09e prototype, significant changes were introduced in the way this system is assembled.

Each flap, including the main flap and also the endplates, were manufactured in two distinct parts and were glued together using a two-part epoxy structural adhesive. This adhesive has outstanding properties for bonding composite materials with excellent resistance to impact and vibrations being ideal in such applications where toughness and high strength are one of the main requirements.

Figure 7: FST 10e's nose and front wing.

Figure 8: FST 10e at Estoril Circuit.

One of the most complex methods in this process was the assembling of the main flap. Due to its design, this component had to be assembled in just one step. This involved high precision to ensure all the stiffeners inside were aligned, while also guaranteeing a perfect bonding between those parts and between the two parts of the flap itself.

Regarding the most recent shape of the endplates, fitting the main flap and the smaller one proved to be a challenging process. Both solutions were carefully thought and designed to ensure no gaps existed between the components which may have compromised the airflow.

Therefore, the endplate was precisely trimmed to fit the main flap while the smaller flap has an in-house 3D printed solution to perfectly adapt to the endplate shape.

In the end, the front wing system weighs around 6kg, which is not ideal but it is still a remarkable achievement considering the design changes and removal of the middle flaps and introduction of a more complex and robust endplate. Furthermore, it is important to note that the FST 10e front wing has excellent structural rigidity and strength, the result of great design work combined with a skilful manufacturing process. All challenges were overcome with success, and after a noteworthy improvement over last year it is hoped that for the next year the aerodynamic package manufacture can evolve to the next level with the experience and knowledge gained throughout this process.

Written by Gonçalo Biltes
Structural Analyst

Figure 9: Post lamination work on the FST 10e's monocoque.

From Fibre Layers to the Monocoque

Chassis

There are many ways to build a car, but at FST Lisboa we accept nothing less than the fastest car possible! For this reason, we have chosen to build a carbon fibre chassis in a monocoque structure. A monocoque (from the French "single shell") is a structure where the applied forces are supported by the outer walls of the chassis like an eggshell. This load distribution, combined with the use of extremely rigid and lightweight materials such as carbon fibre, creates a chassis that is extremely rigid and yet with less weight than the ones obtained with more traditional methods.

The design process of the FST 10e's monocoque has been considerably improved, even though we used the same mould as the previous prototype. Previously, the stacking of the fibre layers was mostly defined from composite optimisation performed in finite element analysis software.

This year, we first performed a series of iterations of several layer sequences for the different parts of the chassis primary structure, where we analysed the stiffness of each one individually using a software tool. This also allowed us to account for a number of basic factors of the classical laminate theory that are not always taken into account in computational results. Finally, these predefined stackings were incorporated into the optimisation software, creating an optimal sequence of layers to build the monocoque.

This new methodology made it possible to considerably reduce the mass of the chassis while maintaining its rigidity.

Figure 10: Honeycomb Placing.

Another important factor that contributed to this positive outcome was the acquisition by the team of a prepreg fibre with better mechanical properties than the one used in previous years. This way, there was a reduction of the weight of fibre needed to reach the required structural rigidity, as well as a better sequence of fibre arrangement, doubly allowing the reduction of the fibre weight used.

In the manufacturing process, the team benefited from the facilities of lamination of a prepreg fibre, where the material is already impregnated with resin, becoming only necessary to cut and to overlap the several layers without the concern of applying resin between each layer in the correct proportion. This speeded up the process and saved precious time throughout the whole procedure, which as we all know well, represents extra testing and preparation time leading to better results in competitions.

Written by João Oliveira
Ergonomics Responsible

Figure 11: Copper mesh placement.

Figure 12: FST 10e's monocoque at it's manufacturing early stages.

Figure 13: Monocoque sanding.

Figure 14: Lamination preparation.

Figure 15: Edaetech building.

The Sponsor Check Edaetech

ABOUT US

Founded in 2002, EDAETECH is an engineering and technology company for the Automotive, Aeronautic and Metalomechanic Industries. EDAETECH provides engineering services in the creation of products, and in the development of new solutions and manufacturing processes, seeking to be at the knowledge forefront.

The core business focuses on the development and manufacture of prototypes, production of small series of metal components, with special emphasis on the Automotive Industry.

With qualified collaborators EDAETECH combines its know-how with advanced technology to achieve its main goal, which is to foster strong customer orientation, in order to be recognized as a partner of good quality products and services, adopting a transparent relationship with our customers, ensuring excellent support to encourage dialogue, in order to meet their needs and expectations.

INNOVATION IS OUR PASSION

EDAETECH is committed to pursuing value creation opportunities in the development phase of projects, fostering a strong Research & Development (R&D) culture, namely, for the analysis and implementation of better processes and technological solutions.

Since its foundation, EDAETECH has invested in a planned and systematic research, as well as in the formation of a world-class R&D team.

Throughout the 15 years of R&D, important results have been achieved for the affirmation of this department, from which we highlight the 3 and 5 axis laser cutting equipment with incorporation of high power fibre optic generators.

More recently, the investment in internal training through Industrial Research has been reinforced with the development of equipment for the additive manufacturing of metals. This technology allows the company to provide its customers with optimised solutions and to complement the supply of subtractive technologies with innovative prototyping concepts, such as additive manufacturing. The developed equipment has a printing area of Ø 120 x 90 mm and with a laser source of 400 W allows the printing of several types of metals such as carbon steel, stainless steel, aluminium, titanium, among others.

Figure 16: 3D printed turbine.

Figure 17: 3D printed turbine.

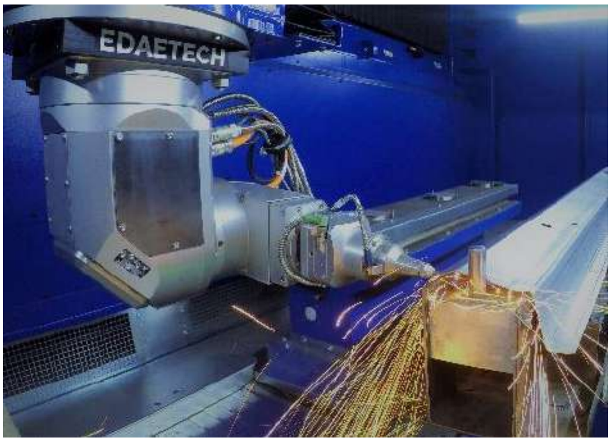


Figure 18: 3D printed turbine.

THE CORE BUSINESS SHEET PROTOTYPES

With over 18 years of experience in aluminium plastic forming, high and ultra-high yield strength alloy steels, deep drawing steel and stainless steel, EDAETECH is a reference supplier in the national and international sheet prototyping market. The mastery of programming and the high precision machining, combined with the technology of 3 and 5 axis machines (multitasking), allows the production of machined parts in a short period of time. This way, even with

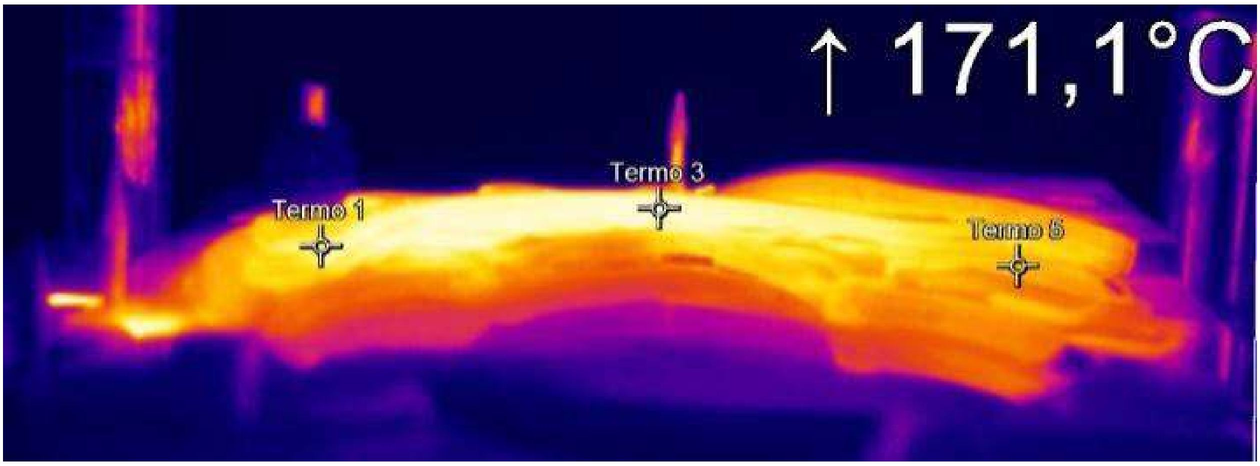


Figure 19: Termographic Camera.

complex geometries and demanding tolerances, from light alloy metals to stainless steels, pre-treated steels, hardened steels and superalloys (HRSA), there is a total guarantee of precision and repeatability.

It has high Know-How in stamping and deep drawing in various types of materials, and with the help of joining technologies, from Laser Welding, MIG/MAG Welding, Conventional Welding, Resistance Welding, Clinching and Inserting can supply assemblies of high complexity and technical accuracy.

NEW CHALLENGES IN THE AUTOMOTIVE FIELD - HOT FORMING

At the end of last year, with the mission of meeting the customers needs, Edaetech invested in a new technology - Hot Forming. The steel sheet components produced by Hot Forming / "PHS" (Press Hardened Steels) combine in a single process the advantage of resistant Moments of Inertia, achieved by geometric transformation of the sheet, with the advantage of changing the properties of the material (by tempering the steel).

Faced with the complexity resulting from the combination of technologies, Edaetech has been trained in several aspects to be able to optimise, monitor, trace and control the components produced. This training ranges from the engineering phase, which uses simulation software to perform virtual tests to the entire process by temperature measuring with thermocouples & thermographic camera, measuring and tracing cycle times (piece by piece), final dimensional control and material properties.

The components resulting from this process usually exhibit high performance both in terms of rigidity and resistance, being therefore components of excellence in the application in structural and safety parts in an automobile.

THE RELATIONSHIP WITH IST

EDAETECH has in its DNA the commitment to innovation and seeks to bring, through technologi-

Figure 20: Sponsorship Pieces FST 08e.

cal evolution, more value to its partners. Since its foundation, the company has invested in relationships with Universities and other entities of the Scientific-Technological System in order to complement and disseminate scientific knowledge in strategic areas for the sustainability of the company.

The relationship with IST has resulted in the development, mainly of highly complex machined parts. Edaetech has sponsored the Formula Student team from Instituto Superior Técnico "FST Lisboa" for over 10 years. This partnership started with the project "FST 04e" and has remained solid. The contribution has been vast in finding solutions to challenges. Whether these are in the suspension, transmission, cooling and electric motor systems, or in new R&D opportunities.

It is with pride and a sense of mission that these projects are part of the company's background and surely are an incentive to the development of projects by Portuguese academies and institutes.

Edaetech is a reference in the market where it operates, respects and cooperates with its partners, innovates for passion, with committed teams based on respect and seriousness.

Figure 21: Sponsorship Pieces FST 08e.

Figure 22: Centerlocks, hub and upright - Edaetech.

Figure 23: Edaetech logo placing on the FST 10d.

Figure 24: FST 10s PCBs.

Harnessing & PCB Manufacture

Electronics

HARNESSING MANUFACTURE:

Harnessing is an integral part of the electronics system of our prototypes. The manufacturing of this system started on paper, where each connection, conductors and other components were designed. The cable was then drawn in CAD (Computer Aided Design) to estimate the size of each cable in order to make manufacturing as efficient as possible and to avoid wasting material. It also allowed us to start manufacturing with confidence without the need for a finished chassis. Wooden boards with the technical drawing of the cable on top were used to help assemble the cables. Brackets embedded in the wood helped to maintain the shape of the cables when they were laid out on top of the technical drawings.

At this stage of the manufacturing process, the handles were cut to size, contacts were crimped and final details such as kapton tape, sleeves and boots were applied. In order to avoid mistakes before the cables were finished, a second person carried out a final visual inspection to ensure that the cable

Figure 25: Harnessing manufacture.

Figure 26: Harnessing manufacture.

manufactured was up to the standards practised by the team.

A test bench composed of all the electronic modules existing in the car allowed the testing of each cable before it was integrated in the prototype. In this way, any problems derived from the manufacturing process are identified and corrected in advance.

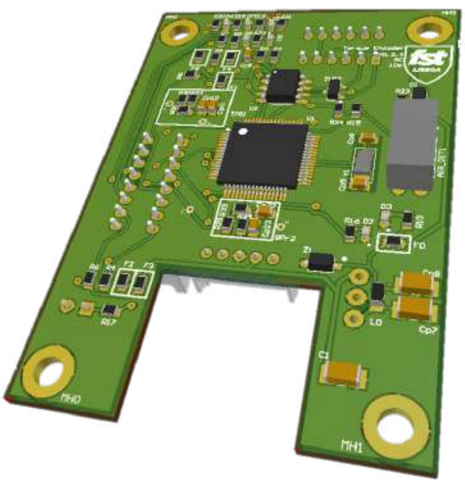


Figure 27: Torque Encoder PCB.

PCB MANUFACTURING:

The team's electronics system has 26 modules developed entirely in house. The team developed its own electronics, which allowed for great flexibility in terms of integration and functionality. However, something that is not guaranteed a priori is reliability. Since one of the most recurrent sources of problems in the car's electronic systems are related to the poor quality or carelessness in the assembly of each module, the manufacturing of the modules is a critical moment and one of the most important in the development of these systems throughout the year. The manufacturing process of each printed circuit board (PCB) started with the order in a specialised manufacturer. Typically this process takes between 1 to 2 weeks and during the year between 100 and 200 units of PCBs were

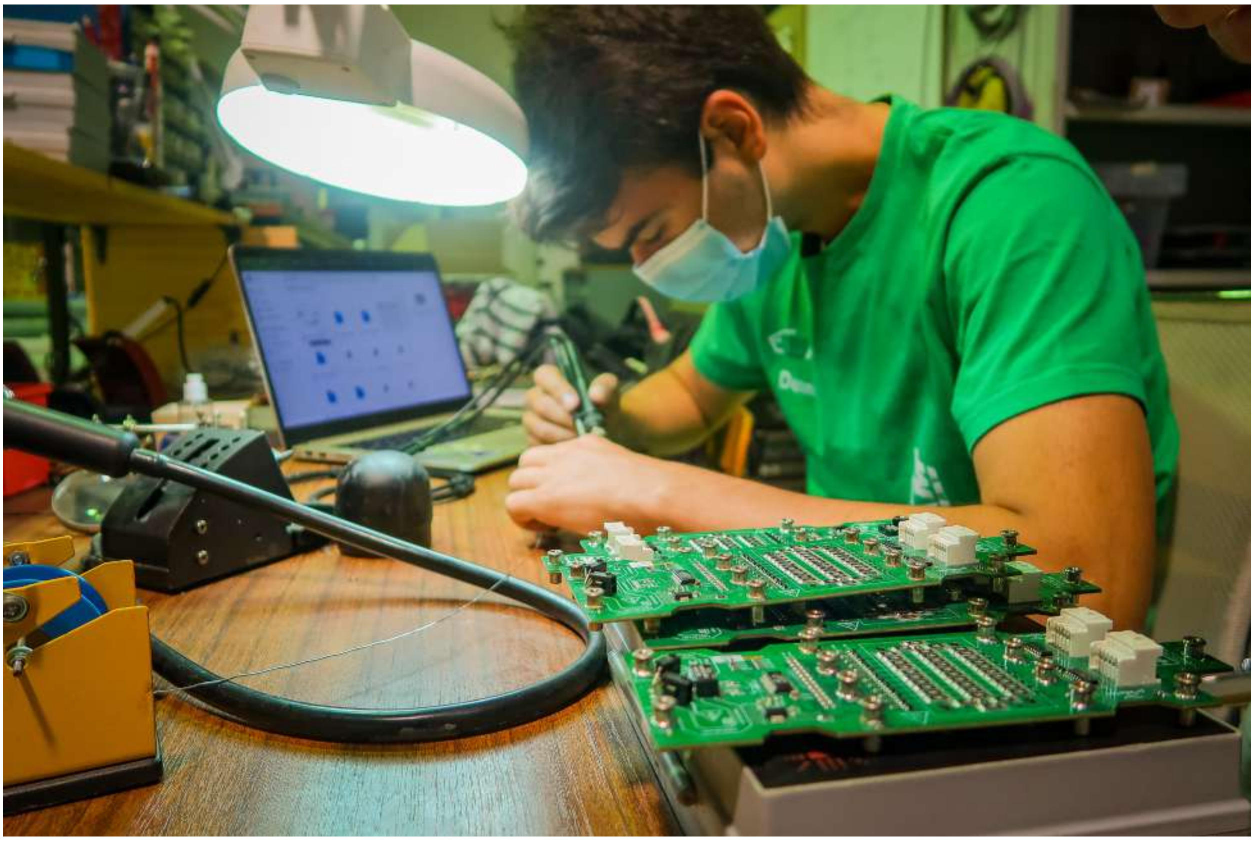


Figure 28: BMS Slaves - soldering.

ordered, some served as prototypes and others as final products that were installed in the car.

Some of the PCBs have up to 260 components so assembling them was a time-consuming process. At the end of the assembly process, a visual inspection was made by a member who did not solder the PCBs and tried to spot any soldering errors that could be easily fixed. All the circuits went through a checklist to verify the correct operation of the boards and detect errors such as soldering the wrong components and other common problems. Finally, all modules were installed in the electronics test bench to test features such as communication with other modules and high level operation to verify that the modules were ready to be integrated into the FST 10e.

Figure 29: BMS Slaves - soldering.

Figure 30: BMS Slaves - soldering.

Written by Miguel Lourenço
Electrical Systems Chief Engineer

Figure 31: FST 10e.

The Cooling Circuit

Powertrain

The water cooling system design for the FST 10e focused on saving weight while increasing the cooling performance, given that our last prototype had overheating related problems. This challenge required a significant concept change for the cooling circuit in its design stage, starting with the adoption of a closed system with removal of vents, reservoirs, and thus the catch can. The removal of the reservoir saves a lot of weight and reduces the pressure drop in the circuit, which means that we can save power and boost our overall performance. In order to be able to fill a closed-circuit an external reservoir is needed. Initially, this would be positioned between the radiator and the pump, using a Quick-disconnect coupling, that seals the circuit when the coupling is opened. However, during the circuit's assembly, the length of the coupling and fittings, combined with an easily foldable tube, didn't allow for that positioning, thus leading the team to opt for placing it before the radiator. This actually turned out to be a good solution, potentially better than the original one, since the reservoir is connected higher, allowing the air to be removed more easily. The only downside is that some air could get trapped in between the reservoir and the pump. However, the cap in the radiator allowed the removal of that air, solving the problem.

Regarding the pipework of the system, we exchanged the rubber tube, as it was implemented in our last prototype, for a silicone one. It is lighter, thinner and with better thermal properties. But when it came to its

Figure 32: Filling the cooling circuit of the FST 10e.

assembly, the bending radius of the tube was considerably large, meaning that it wasn't able to negotiate tight turns as the rubber tube was. Thus, its assembly had to be done cleverly in order to minimize the turning radius.

The FST 10e radiators were a huge step forward for the team, who counted on João de Deus for the manufacture of our unique and custom made radiators! These are made of aluminium, providing them with very good thermal properties and additional weight saving. However, the radiators' fins were too exposed to debris that could be found on track and collide with these components once the car is moving, leading to the potential damage of these components. The solution found by the team was to use a grill to protect them when maximum performance is not required.

The position of the radiator was also changed to the back of the car for better aerodynamics, maintaining a good airflow through it, and with the key addition of radiator fans. The duct that guides the air from the radiator outlet to the fan was 3D printed due to its complex geometry.

The manufacturing of the cooling sleeves was filled with ups and downs. Our initial plan was to bring to life the previously designed solution, which was based on increasing the heat transfer between the surrounding air and the cooling sleeves. Our plan included resorting to multijet fusion for the manufacture of these parts, for which a complicated geometry would not be a problem. This had to be abandoned due to the lack of funding for this specific 3D printing process, mov-

Figure 33: FST 10e's radiator ducts and fans.

ing on to attempt to manufacture the cooling sleeves using Luvocom PAHT. We kept pursuing 3D printing to manufacture these components because our goal was to make our car lighter and consequently faster without losing reliability.

This approach also didn't bring better results as we faced leaks, potential lack of structural integrity and unexpected results regarding the material's thermal expansion. However, understanding the weaknesses and strengths of the 3D printed cooling sleeves allowed us to better understand how to achieve an optimal solution.

We turned to aluminium and CNC machining for the next attempt as we were looking to avoid any more delays. The first step was to adapt the cooling sleeve's geometry to something that could be achieved by CNC machining. The use of aluminium solved both the structural integrity and leaks problem, but it was the assembly of these cooling sleeves that presented the real challenge, as the tight tolerances and the material's high Young Modulus proved to be problematic. Ultimately, temperature variations accompanied by thermal expansions and contractions solved our problem. As the cooling sleeves expanded and the motors housing made of aluminium contracted, we were able to install our solution.

Written by Paula Cunha
Powertrain Department Leader

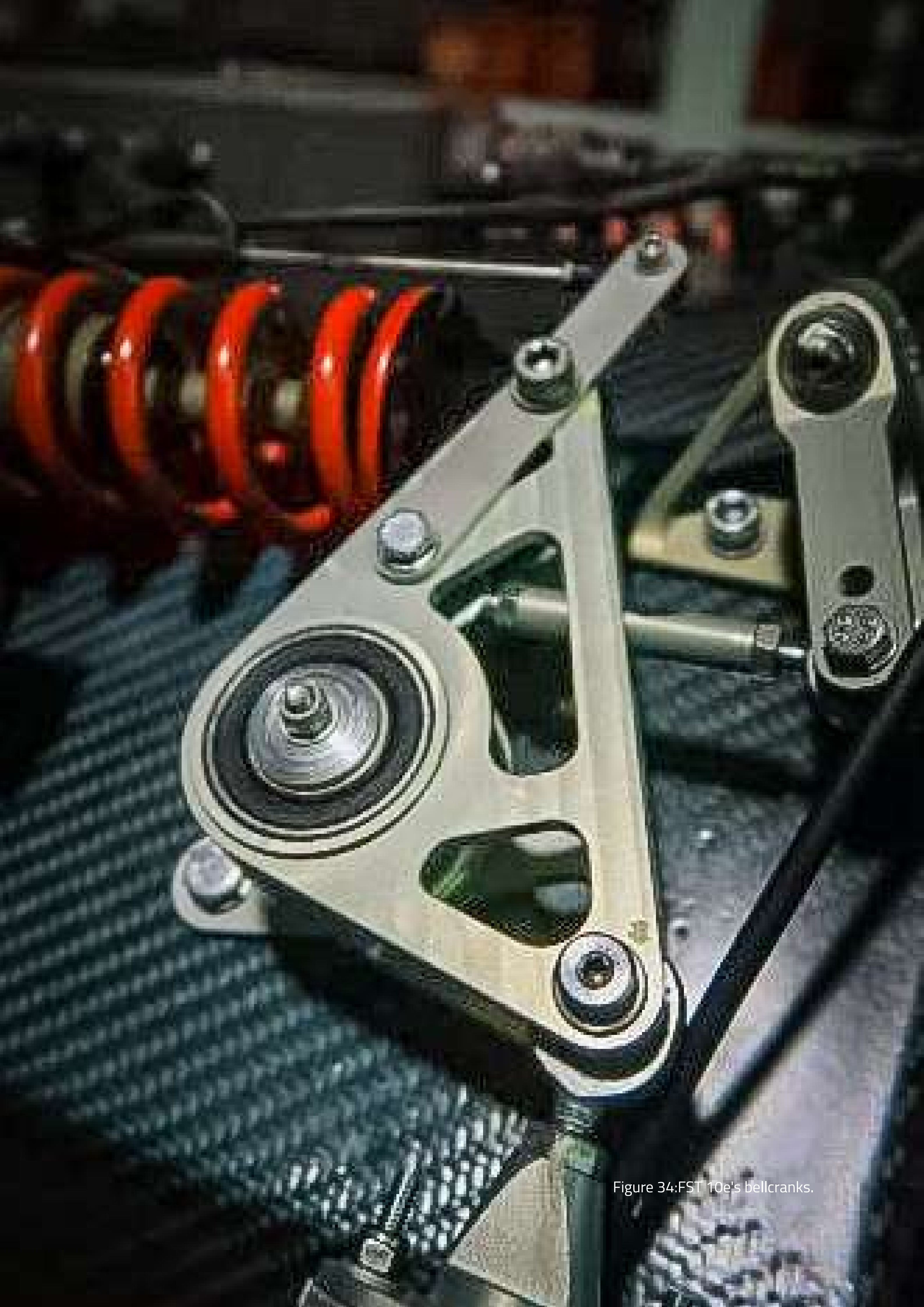


Figure 34:FST 10e's bellcranks.

The Impact Of Design Details on Manufacture & Assembly

Suspension

A-ARMS:

The A-arms make the connection between the wheel and the monocoque and are assembled in the suspension brackets. These components take part in the Lower Suspension system that endured significant changes for the FST 10e. These components are made of anodized aluminium and unidirectional CFRP (Carbon Fibre Reinforced Polymer) tubes, and the connections were done using epoxy adhesive. Each of these materials plays a role in the structural integrity of the Lower Suspension. The anodization of the aluminium parts improves their durability. Assuming the suspension links are only subjected to tensile stresses, the unidirectional CFRP tubes' fibre orientation provides the required resistance to the forces applied. The structural adhesive used was selected based on its application and adequacy to bond aluminium-CFRP joints.

Regarding the assembly of this system, this was done by making use of a mounting jig that assures the proper suspension geometry.

FST Lisboa's previous prototypes had a parallel relation between the majority of the spherical plain bearing inserts and the ground, making the brackets assembly something quite simple compared to the FST 10e's solution. For the FST 10e, we took into consideration the forces that act upon the A-arms' links and the angles on which it occurs and defined the best corresponding angle to be applied between these brackets and the ground. In theory, this allows us to make sure the forces act perpendicularly to the base of the bracket, ultimately leading to a better force distribution. Considering that the load direction is not the same for all the A-arms' links, there are several different mounting angles as the car is symmetric.

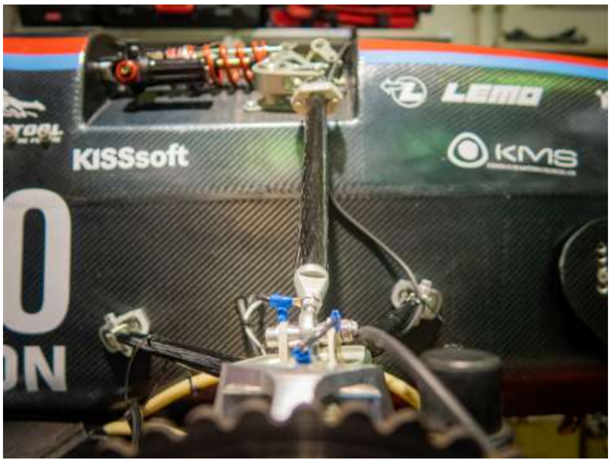


Figure 35: Front A-arms.

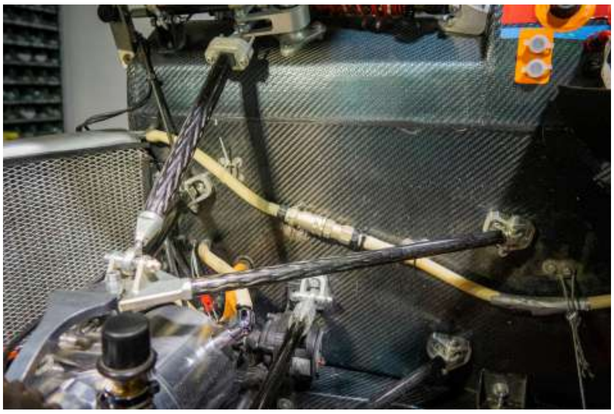


Figure 36: Rear A-arms.

DRIVETRAIN:

Taking into consideration the least positive aspects of last year's drivetrain system, efforts were made during the design phase in order to solve the most significant issues and lessen their relevance.

The overall packaging of the system was improved, as the suspension geometry took into consideration the assembling and maintenance processes. The radial distance of the suspension points relative to the upright's centre was increased in order to facilitate access to the system's fasteners, which proved a significant improvement in terms of assembly. As a result, the FST10e's drivetrain system is now substantially easier to assemble and disassemble, resulting in considerable time savings in maintenance for the team.

Regarding the FST 10e's transmission system, a very simple yet very effective innovation was done in comparison with the FST 09e. During the design phase, there was the addition of small superficial dots on the gears, more specifically, on the addendums and dedendums of the teeth that mesh with other gears. For

Figure 37: Drivetrain.

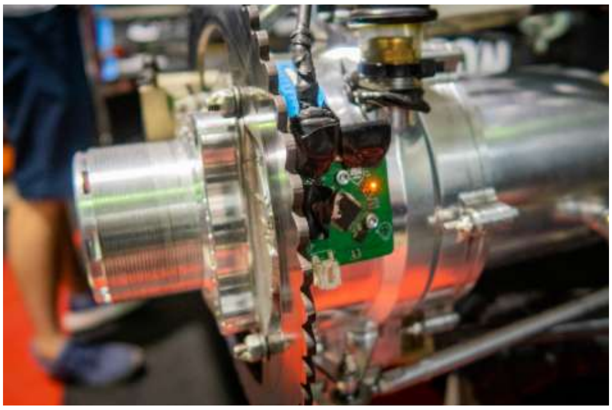


Figure 38: Drivetrain.

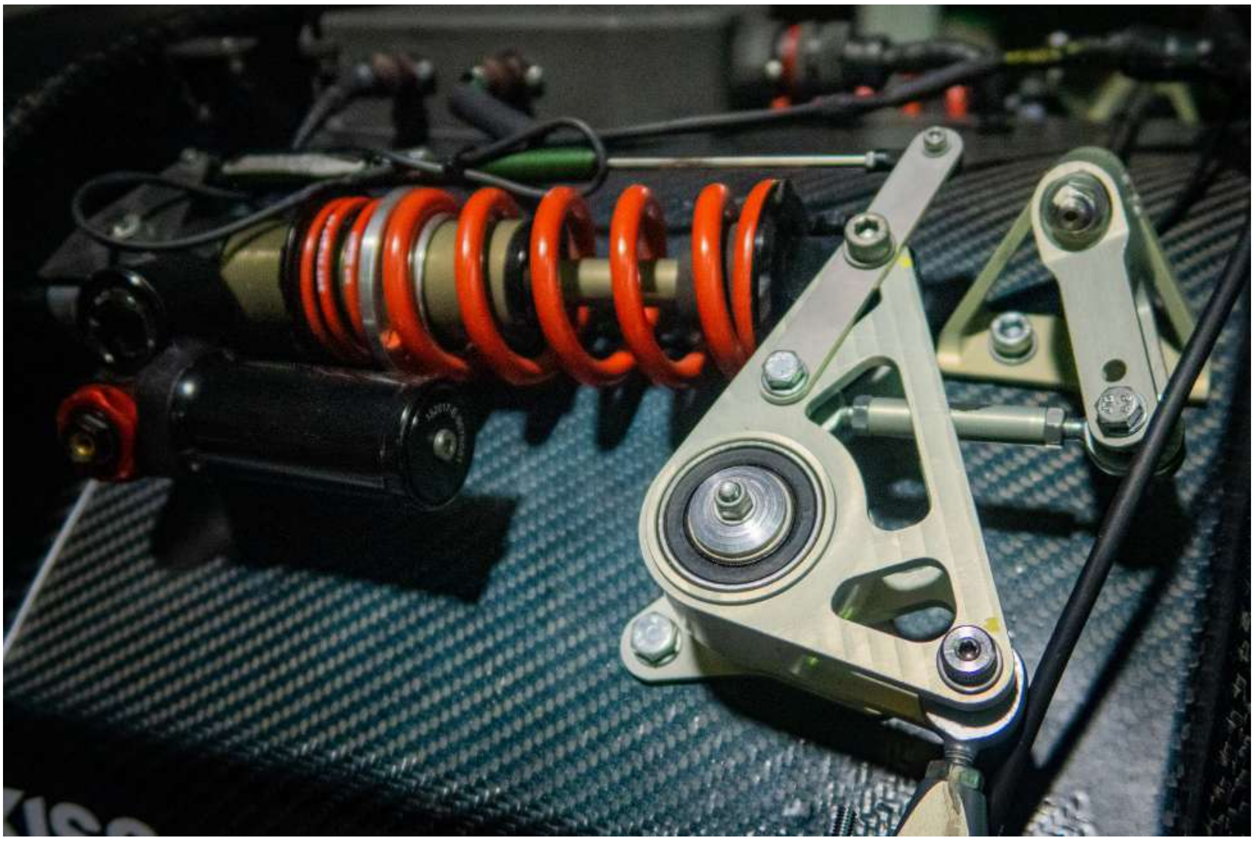


Figure 39: Bellcranks.

example, the sun, which meshes with 3 planets, has 3 small dots that correspond to the 3 teeth in which they mesh together.
This small change came to simplify the manufacture quite a bit since we only needed to align the dots of the different gears and we immediately knew that we were meshing them perfectly. It is indeed a great example of how such a simple design change can help so much the manufacturing process.

BELLCRANKS:

Bellcranks are often found on racing cars, and the FST 10e is no exception. They allow forces coming from the pushrod/pullrod to be redirected to the spring and damper system, enhancing its the overall aerodynamic performance of the car. One of our great priorities is minimizing weight. Add that to the tight tolerances necessary for the bearing slots and the final design becomes extremely complex, which is why the bellcranks are manufactured using CNC machining. The FST 10e's bellcranks underwent an anodization process to improve the surface resistance to corrosion.

Written by Tomás Salgado (Lower Suspension Responsible), André Lopes (Upper Suspension Responsible) e Rúben Alves (Transmission Responsible)

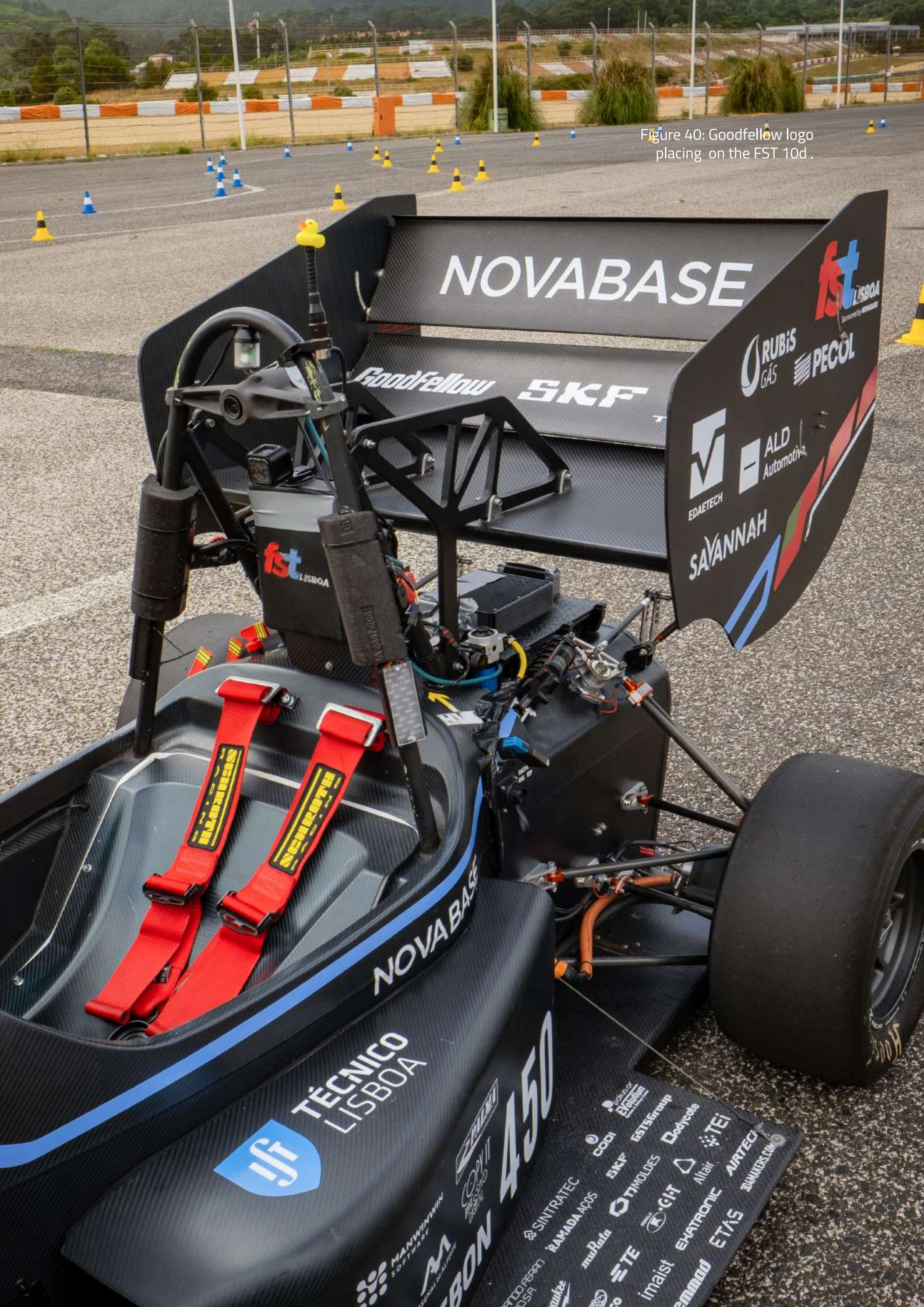


Figure 40: Goodfellow logo placing on the FST 10d .

The Sponsor Check Goodfellow

Goodfellow is a leading global supplier of metals, alloys, ceramics, glasses, polymers, compounds, composites and other materials to meet the research, development and specialist production requirements of science and industry. The Company has an extensive range of 70,000 catalogue products in multiple forms available off the shelf, most subject to free delivery within 48 hours and with no minimum order quantities.

With over 6000 customers supported by a worldwide network of offices, agents and distributors Goodfellow also offers a comprehensive range of bespoke processing services, effectively operating as an extension of the production team in order to develop custom fabricated components in any quantity required. Our in-house team is comprised of fellow scientists and engineers with extensive knowledge of materials and processing – through their technical expertise and a supporting range of specification tools the company has built an unrivalled reputation for helping to find solutions to even the most challenging of research problems. All our products are also underpinned by the ISO 9001 quality accreditation.

Goodfellow is pleased to offer a new line of additive manufacturing (AM) materials and services which can be expertly tailored to the design, function and product life of your application.

Figure 41: Honeycomb reinforcing structure provided by Goodfellow.

AM MATERIALS

Goodfellow's growing line of AM raw materials reflects evolving AM technology: advances in technology put more rigorous demands on materials, and advances in materials fuel advances in AM technology. Our technical experts fully understand this synergy and can help you make the best material selection for your AM process and application. We currently offer the following categories of raw materials for a range of AM processes:

> Metal, alloy and ceramic powders
> Metal and alloy wires
> Polymer monofilaments

TECHNICAL SUPPORT:

For the members of the Goodfellow technical team, no question is too big or small; they're here to help everyone realise their project or application's full potential. Whole Goodfellow's standards materials are list on websites and brochures, the team can advise on custom-made materials and solutions.

AM SERVICES

With thorough knowledge of the latest AM processes, Goodfellow can provide comprehensive AM services, from initial drawing to post-production finishing. Specifically, Goodfellow can:

> Fine-tune your component design or create the design for you.

Figure 42: Honeycomb Aluminium provided by Goodfellow reinforcing the FST 10e's monocoque.

> Assist in choosing the best AM process for achieving your desired results.
> Produce finished parts for you using AM technology or, if more appropriate, traditional manufacturing methods.
> Provide materials or finished parts in quantities from prototype to large-volume production.

CATEGORIES:

> Materials
> 3D printers & printing

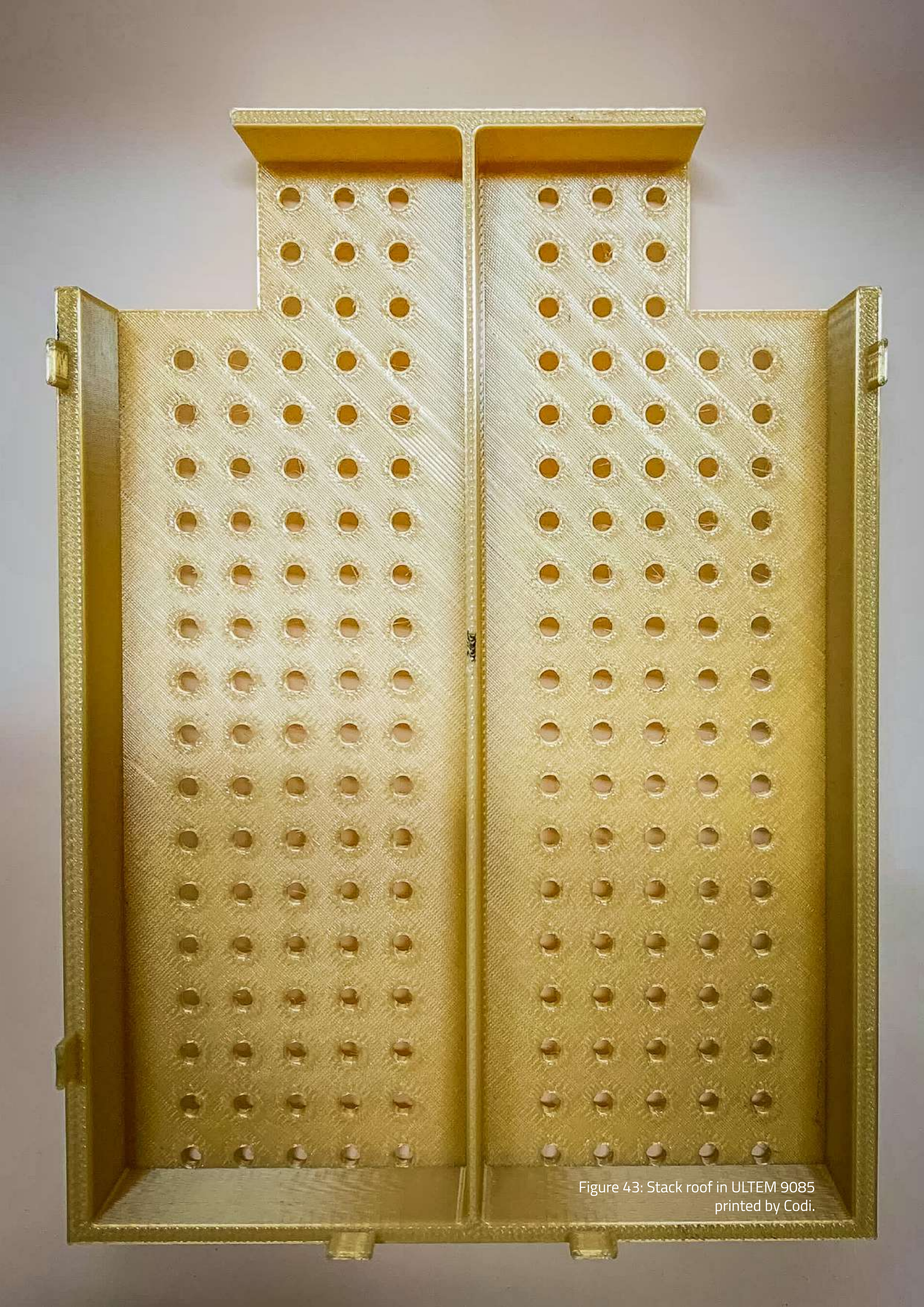


Figure 43: Stack roof in ULTEM 9085 printed by Codi.

In House 3D Printing

R&D Project

In house 3D printing allows us to better design several components of the car, by testing and iterating designs. Also allows the manufacture of parts with complex geometries with ease, enabling us to print functional components with good tolerances for our prototypes. Manufacturing with this technology gives us the freedom to print with various types of polymers and reinforced polymers which pose as real substitutes of aluminium or laminates for structural components, with the advantage of being able to modify some mechanical properties by changing printing settings, making each part unique and personalized for the intended use.

The team focused on 3 primary aspects to improve the performance of the in house 3D printing manufacturing. Firstly, we implemented design solutions more suitable for Fused filament Fabrication (FFF) printing, with different approaches to the locking mechanism in electronic boxes with the implementation of gutters.

As stated before, the team also started experimenting with other engineering-grade materials, such as filaments reinforced with carbon fibre or kevlar, enabling us to print structural components using 3D printing rather than milling aluminium parts. These filaments are more suitable for automotive purposes than previous alternatives and they have shown exceptional properties and great performances. All our filament comes from our sponsor 3D4Makers, that besides having common 3D filaments for hobbyists also has incredible engineering-grade filaments.

Figure 44: FST 10e accumulator's NACA duct.

The integration of fibres in these types of filaments changes their physical and mechanical properties, for example, ABS Kevlar is 12% lighter compared to regular ABS and 18% compared to PETG.

Lastly, we studied the possibility of 3D printing moulds. We still have a long way to go, but with some successful cases already. Worth mentioning the moulds for the stack casing of the accumulator and moulds for ducts in Kevlar, which proved to be incredibly durable and able to be reused up to 6 times.

Our parts are manufactured with 2 different 3D printing technologies, FFF and SLS (Selective Laser Sintering). In house we can print with FFF and the majority of printed parts are jigs and fit test models to validate designs, but we also print most of our end-use parts in this technology. Some specific parts are printed with SLS technology due to geometry aspects or property needs, which is the case for some ducts and boxes, due to their complex geometries. For this 3D printing technology, we count on our sponsor Sintratec. SLS printing benefits from not needing supports which enables printing with no constraints.

Although we enhanced the range of materials we can print using FFF, we still can't print with filaments like Ultem, imperative for accumulator components. These special parts need to comply with strict regulations and withstand the most adverse conditions, needing the material to meet the standard UL94 V-0 f. To manufacture these parts we count on our sponsor CODI.

Both these technologies present unparalleled advantages compared with other manufacturing processes and are essential to our manufacturing processes.

Written by Diana Sanchez
3D Printing Responsible

Figure 45: Reservoir of the FST 10d's water cooling circuit printed in PA 12.

02 DR

RIVERLESS

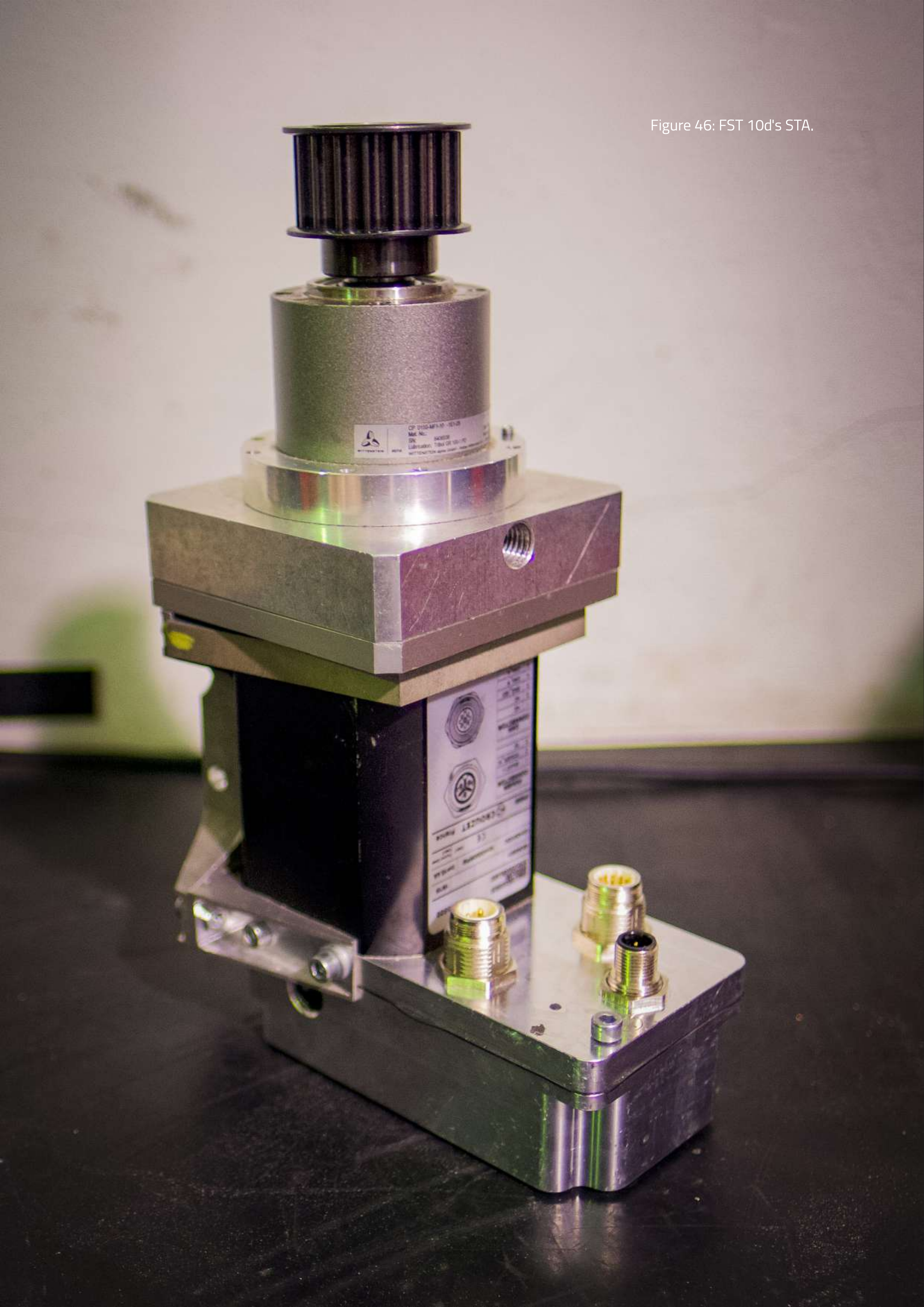


Figure 46: FST 10d's STA.

Steering With No Hands: Parte II

Mechanical Hardware

It's easy to understand that the autonomous steering system is crucial to a driverless vehicle. The newly designed Steering Actuator's (STA) manufacture and assembly proved to be a new challenge for the team.

The manufacturing process started with the adaptation of the previous steering system. The vast majority of the changes made were in the steering housing, which had to be machined to allow new components to be fitted in and to allow the motor support to be assembled here.

There was also the need for machining the motor support, hugger and two brackets, which constituted 90% of the manufacturing. The material choice for these components was aluminium due to its reduced weight, while also having enough strength to withstand the stresses associated with this application. All these components were machined by our sponsors as great precision was needed in order to avoid unwanted compliance issues later on.

Figure 47: Motor holder.

Figure 48: Prototypes of the new STA interfaces.

With all this complete, the next step was getting the remaining parts: The pulleys, fixation rings (for the pulleys), belt and, most importantly, the motor. These components allow the column to turn on its own. The motor creates the motion, it gets converted through the gearbox, and the pulleys transmit this to the column, allowing the wheels to turn as if it was a driver turning the steering wheel.

Once we had all the parts and the assembly process began, we faced a big holdback. The gearbox design changed at the end of the design phase compromising the initial fixing solution. Even though it was possible to attach it to the motor using an interface plate, it was not possible to fit the cockpit template required by the competitions. This meant a new and rule compliant fixation design had to be made, resulting in a new support which was 25% thinner, with smaller bolts (M6 instead of M8) and had the screw holes rotated 45°. With these changes, we fixed all the problems.

At the end of the assembly process, we faced another problem. However, this was expected to happen. The fact that the original non-autonomous system was very compact in addition to the small space available in the monocoque made it extremely hard to assemble some components, which is clear in the screw holes on the steering housing, connecting it to the motor support.

To sum up, this was a surprisingly challenging task, which was expected, mainly because it was the first year the team manufactured an autonomous vehicle.

Written by João Gaspar
STA Responsible

Figure 49: STA interfaces.

Figure 50: Motor/motor interface.

Figure 51: FST 10d's EBS.

Braking With No Foot: Part II

Mechanical Hardware

The FST10d is the first autonomous car made by FST Lisboa, which makes its EBS the first emergency brake system in the history of the team. It was challenging but rewarding to come up with a reliable design to ensure the performance of such an important safety device from scratch.

We didn't have any experience on the matter, therefore the knowledge of what was being done in the industry, as well as the experience of other FS teams, was of great importance.

The FST10d EBS consists of a pneumatic circuit, coupled with a mechanical lever mechanism, that when triggered either by the opening of the Shutdown Circuit or a manual pneumatic valve, actuates the hydraulic brake lines of the car with enough pressure to stop it. The team designed and manufactured a mechanical "cage", that provides support for the actuators and transmits the forces from the pneumatic to the hydraulic system. There is a gas spring mounted on the 'cage' that ensures the system's redundancy.

The manufacturing process of this system's parts was planned to be easy and quick, in order to maximize the testing period and make adjustments or substitute parts along the way. This meant using easy to find and easy to machine materials, that would ensure the mechanical sturdiness and reliability an EBS needs to perform accordingly.

The main materials used were aluminium and steel. The aluminium was used for almost every component due to its good mechanical properties and low density. Was used to manufacture levers, cage's lateral walls and shafts.

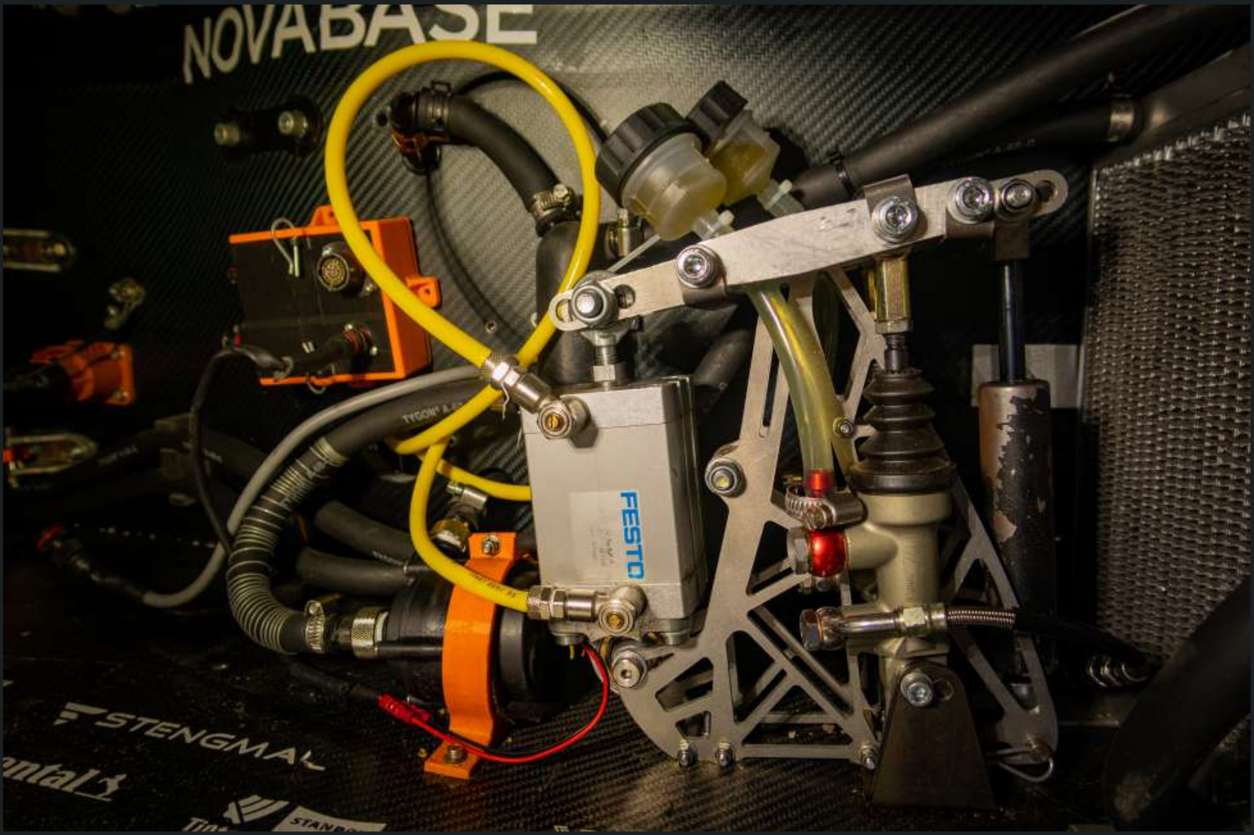


Figure 52: FST 10d's EBS.

Steel was used in the components under the most stresses like the master cylinders' support shafts and lateral shaft supports to avoid single shear.

The two materials were chosen because of their easy machinability using various processes, allowing to obtain a great variety of shapes. This allowed for optimized parts, with less weight and better accessibility to every part of the system, important in the process of maintenance. The manufacturing processes selected were laser cut and water jet for the cage lateral walls, steel supports and levers; milling for the supports and levers adjustments; lathe for shafts and pins and bending for steel supports.

Thanks to our sponsors, the laser cut and water jet were done rapidly and with great surface finish, the others were done by the team itself, which led to greater preparation with spares for intensive testing.

Written by João Alves
EBS Responsible

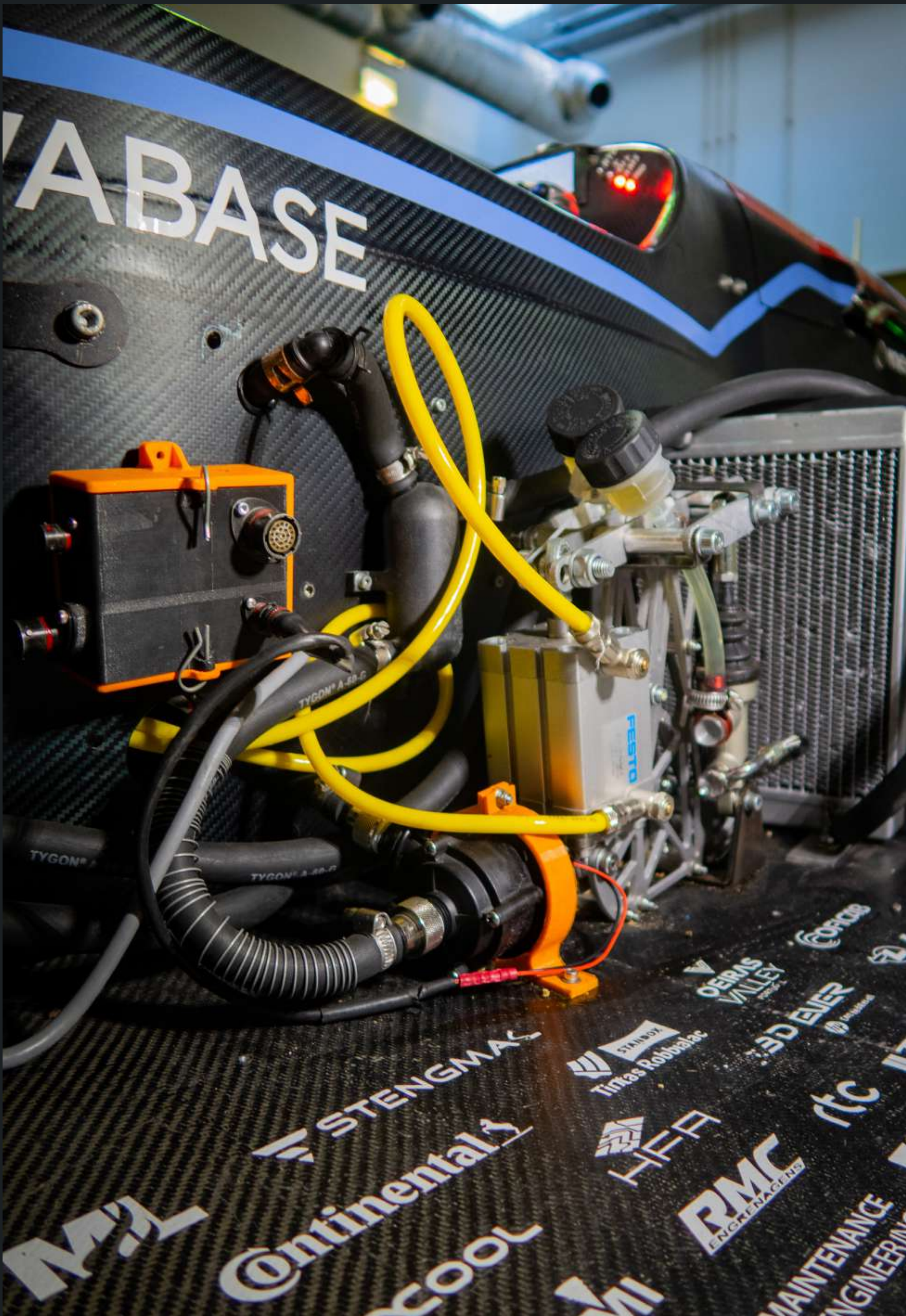


Figure 53: FST 10d's EBS.

Figure 54: FST 10d.

From FST 09e to FST 10d

Mechanical Integration

The FST 10d is an adaptation of the team's last prototype, the FST 09e, into an autonomous vehicle. This meant that several components had to be integrated into the original design, which presented many difficulties as the implementation of these components wasn't considered in the original design of the FST09e.

The goals for the team's first driverless vehicle were focused on reliability, accessibility and ease of manufacture, and the integration of these systems was directly influenced by these same goals.

The core of the AS (Autonomous System) is the PC unit that controls the car. It is a large and heavy component and its positioning can alter the weight balance of the vehicle quite dramatically. Its integration required some consideration regarding the cooling, as the unit being used relies on a set of fins arranged in order to passively cool the PC components. Sensor location was also a factor, as longer cables can create signal loss or pick up more noise from the already electronically packed chassis. Several locations for the PC were considered and a trade-off between accessibility, cooling performance and vehicle balance was defined. The considered location, the car's sidepods, is a great fit due to its water-tightness capacity and it also minimizes GC shift. To anchor the PC to the monocoque, a set of two ribs were designed, featuring topology optimization in order to minimize weight allied with an aerospace-grade aluminum alloy. These parts were manufactured using water-jet cutting, a very common and accessible technique.

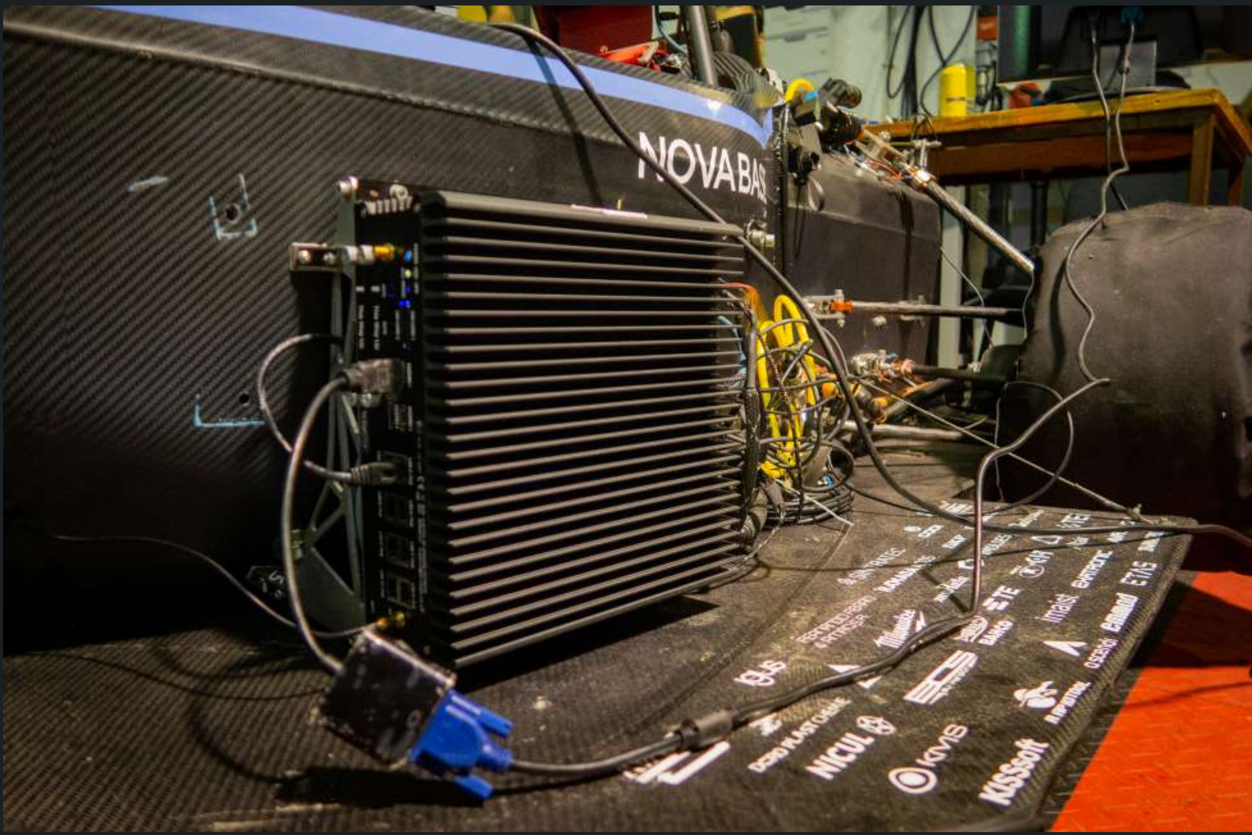


Figure 55: FST 10d's processing unit.

The emergency communication with the AS is done through the RES (Remote Emergency System). In this system, information sent by the team is received by the antenna and then the emergency system is activated. The placement of this antenna had to be done in order to give the best reception, so a high point in the Main Hoop was chosen, offering both range and protection for the antenna. Since the antenna is not a heavy component, a simple support in PETG was designed to keep it in position.

Figure 56: FST 10d's camera support.

Careful sensor integration is a big part of the success of an autonomous vehicle as it is very important to correctly correlate the real-world position of the sensors and the coordinates of these sensors in the AS's counterparts. This is especially relevant in computer

Figure 57: FST 10d's LiDAR.

vision systems, like the LiDAR and the camera. The main goal for the integration of these two was to find the right location on the vehicle where these could be mounted for the best performance.

The main camera is mounted on the Main Hoop of the chassis, as this structure is rigid and can be used to securely attach the camera at an eye-level height. This attachment was designed using the benefits of 3D printing and SLS technology. To minimize weight and aerodynamic drag, this mounting system was created using aerodynamic neutral flaps and a streamlined tear-shaped body. To create a rigid and durable attachment, PA 12 (polyamide) sintering was used, since this method allows for even more complex shapes and structures to be printed without geometrical limits.

For the LiDAR, the considerations were similar, and the optimal location found was in the front of the car, below the nose. This guarantees that there are little to no obstructions between the sensor and the cones it's meant to detect. This delicate sensor is "protected" by the front wing of the car with a support made with PETG, which prevents any cone or other object from hitting the LiDAR. Once again, water-jet cutting was used to manufacture the anchor system, using topology optimization to create a safe and light structure.

Written by Pedro Marques
Mechanical Integration Responsible

Figure 58: FST 10d.

FST 10d's Stationary Testing

Software Development

After many months of continuously developing the autonomous system software pipeline and testing it in both simulation and recorded sensor data, the anticipation of testing it on the car was building up. We wanted to see our software in action! However, before any sort of dynamic testing can happen, a good amount of stationary testing must occur.

Naturally, a collection of other variables influenced this possibility: the readiness of the car's electronics, the maintenance of its powertrain and the integration of the steering actuator motor. This last one was the biggest challenge.

Fortunately, prior to having the steering actuator, we could already start testing part of our software on the car by attempting to control the powertrain. With our in-car computer running a simulation, we could see both rear wheels responding to the software commands and validate their behaviour against the live simulation.

Having finally acquired the steering actuator itself - delayed by the pandemic - the challenge of integrating it on the car arose. On the hardware side, some of our previous integration design and planning had to be reviewed; on the software side, we had to establish communication between our software and the actuator, as well as explore the most fitting way to control it.

After some brainstorming and a couple breakthroughs, bench testing of the steering actuator was underway. With the unit outside the car, we were successful in controlling it via CAN,

Figure 59: FST 10d's stationary testing set up.

and soon after, we employed the same testing procedure as with the powertrain: running a simulation and validating the steering actuator responses.

With these individual tests concluded thus far, and having finally integrated the steering actuator into the car, the ultimate testing was nearing: controlling both the powertrain and steering simultaneously through our autonomous software.

After months of preparation, we were ready. Following the same procedure, our autonomous software processed the inputs of a simulation and computed the steering and throttle outputs, which were then being relayed to the steering actuator and the powertrain, resulting in both these systems responding simultaneously.

This sort of testing allowed us to validate a big part of our autonomous software. It served to show that we were on a good path and soon the dynamic testing could begin.

However, a third system was still missing in the car - the Emergency Brake System (EBS). This system was designed and developed with the help of our Chassis department and as soon as it was ready, bench testing began. Being a pneumatic system, a pressurized air supply was needed. At first, a pressurized air line available in our workshop was used to test the system but it was quickly replaced by a small pressurized air tank, which would then be used in the car. Throughout testing, some iterations and modifications were made to the system as well as to its position in the car. Having been originally thought to

Figure 60: FST 10d software testing.

reside in the left-hand side of the vehicle, it was later moved to the right-hand side, where additional space was available for the required tubing and valves. Once this system was fully operational and well tested, it was time to take the car out of the workshop as it was finally ready for the dynamic testing season to start.

Written by Miguel Gonçalves
Autonomous Systems Scrummer

Figure 61: FST 10d's rear.

The Sponsor Check: Rubis Gás

The energy that inspires us

WHO ARE WE?

Rubis Energia Portugal belongs to a French international group, with presence in Europe, Africa and the Caribbean, that has been operating for over 25 years in the energy sector and which emerged in Portugal in 2014 with the business of LPG (Liquefied Petroleum Gas) distribution, commercially known as propane and butane. With the mission of becoming a reference brand in gas distribution, Rubis supplies thousands of customers from the most diverse sectors of activity: hospitality, restaurants, health, industry, agriculture, commerce and domestic consumption, through the three business segments - Packaged, Bulk (including Auto-gas) and piped.

Through its commercial brand - Rubis Gás - it supplies around 4,000 customers daily in the bulk area, and more than 25,000 in the piped segment. Rubis Gás also distributes and markets packaged gas at more than 15,000 points of sale throughout the country, supplying more than 500,000 customers, and it is the second player in the national LPG (Liquefied Petroleum Gas) market.

Rubis Gás won the position of leading company in 2020, in the "bottled gas" sector, according to ECSI - Portugal (European Customer Satisfaction Index), the National Customer Satisfaction Index.

As a leader, it faces the markets where it operates from a long-term sustainability perspective. This business philosophy is reflected in the investments in Portugal, from the acquisition of infrastructures, through the distribution and logistics network, to operations management.

In addition to investments, training and professional development are part of Rubis' DNA, which in Portugal is responsible for more than 1,500 direct and indirect jobs.

Rubis seeks to respond to all challenges, putting people at the centre of the organisation, promoting professional and personal development.

WHAT DEFINES US?

Aware of our role in the national market, our mission is to guarantee the supply of energy through high standards of quality, safety and sustainability, while constantly seeking ways to better serve our customers and partners. We work daily to be the consumer's first choice and to maintain our position as one of the most solid energy companies in the country. We are committed to achieving goals, exceeding expectations and creating solutions and processes that enable us to develop the business of our customers and partners, always with a proactive attitude towards market needs.

We believe that the balance between economic growth and environmental and social sustainability is fundamental, giving us the possibility to support the community around us.

At Rubis, we aim to contribute to improving the living conditions of the community through a policy of social responsibility and awareness-raising among our employees and partners. Every year, we give life to the campaign "Pedalar por uma Causa" (Pedal for a Cause), a social solidarity initiative that was born with the sponsorship of Rubis Gás to the green jersey of the Volta a Portugal bicycle tour, and which has helped different institutions from all over the country to achieve their projects.

The corporate culture of Rubis, based on responsibility and entrepreneurship, also intends to support innovative projects, such as the Formula Student team of the Instituto Superior Técnico, which we believe will contribute to the transformation of the automobile industry and to a significant advance in technology.

"La volonté d'entreprendre, le choix de la responsabilite"
Rubis Group motto

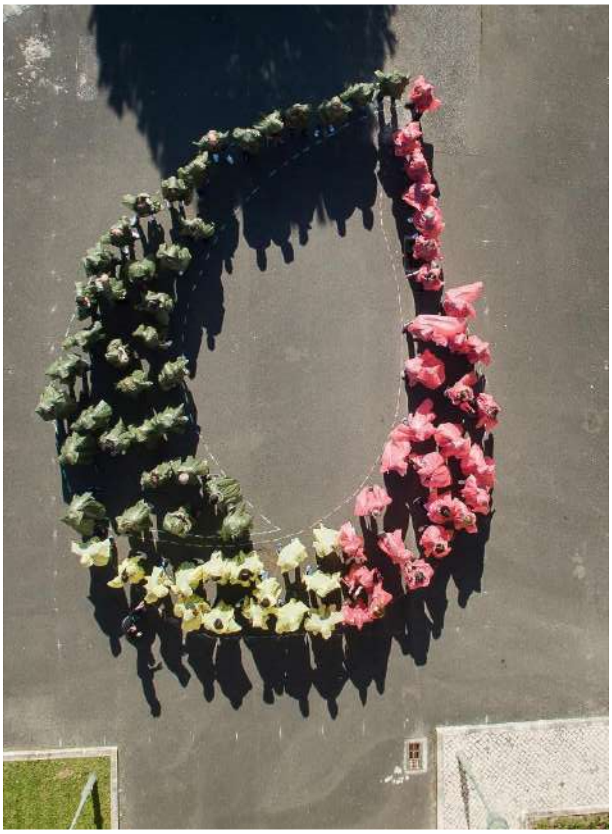


Figure 62: Rubis Gás logo.

Figure 63: Rubis Gás's advertisement.

Figure 64: PECOL's consumables.

The Sponsor Check Pecol

FIXING EXPERTS

Founded in 1983, PECOL - Sistemas de Fixação is part of a Portuguese Group based in Águeda, Portugal. Integrated in this solid business group, PECOL started its activity as a screw manufacturer, eventually expanding its business over the years.

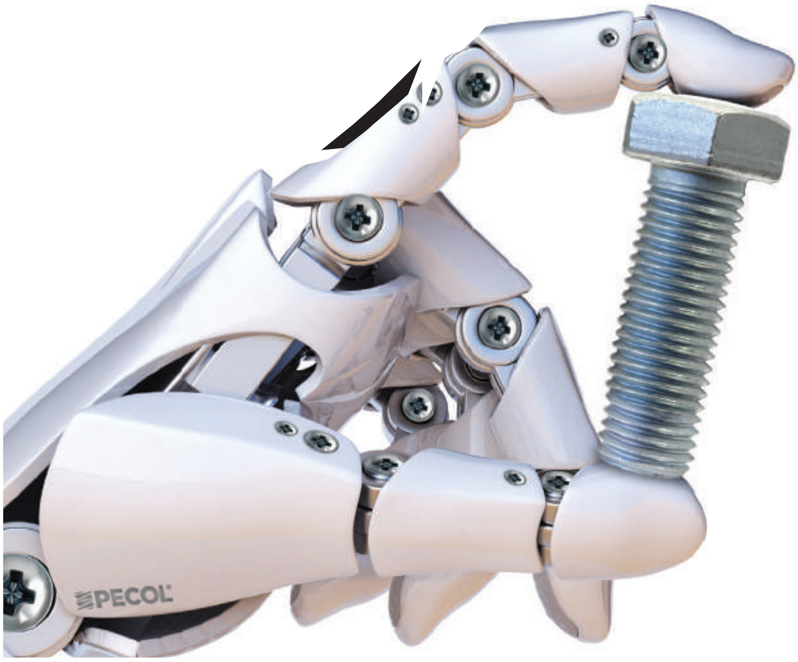
It is a reference company at European level, with a range of products and services in the area of fastening systems for all types of industries, providing its clients with the means of production and qualified engineering teams.

PECOL develops customised solutions for special parts, cold stamping and heat and surface treatments.

Today its areas of activity and know-how have been extended to Chemical Systems, Power Tools **(Pecol PowerTools)** and Personal Protective Equipment **(Pecol Safety)**, among others.

SUSTAINABILITY STRATEGY

AT PECOL, WE WORK DAILY TO ENSURE A BETTER TOMORROW. Sustainability plays an increasingly strategic role in our company, as we believe that it is the companies' duty to promote sustainable development and society welfare. It is our goal to minimise the impact created by our products throughout their life cycle from the raw materials used, through production, transport, packaging and disposal and recycling.



Our sustainability policy is underpinned by the following pillars:

- Eco-responsible production: use of renewable energy and waste management;
- Eco-friendly products: environment and health friendly raw materials - water based, biodegradable, without hazardous substances;
- Eco-responsible Packaging and Packaging: recycled, recyclable and reusable packaging that reduces waste;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TÉCNICO LISBOA
RUBIS GAS
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RAMADA AÇOS
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ascendi
CODI
BAHCO
TEi
rtc

Figure 65: FST 10e (left) and FST 10d (right).

Figure 66: FST 10s.

NOVABASE
TÉCNICO LISBOA

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ALD Automotive
RUBiS GÁS
GoodFellow
SAVANNAH
PECOL Sistemas de Fixação
TECDIGITAL

RAMADA AÇOS
AIRTECH
OEIRAS VALLEY
CODI
Milwaukee
FERNANDO FERRO & IRMÃO SA
KMS
TJMOLDES
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