

# NEWS MAGAZINE



20

20

S

T

Z

E

T

Z

O

C

1

**New Year, New Era**

2

**Summer Testing**

3

**Electrical System**

4

**Mechanical System**

5


**Autonomous System**

6

**Formula Student Germany  
Academy**

7

**Brand-new website**



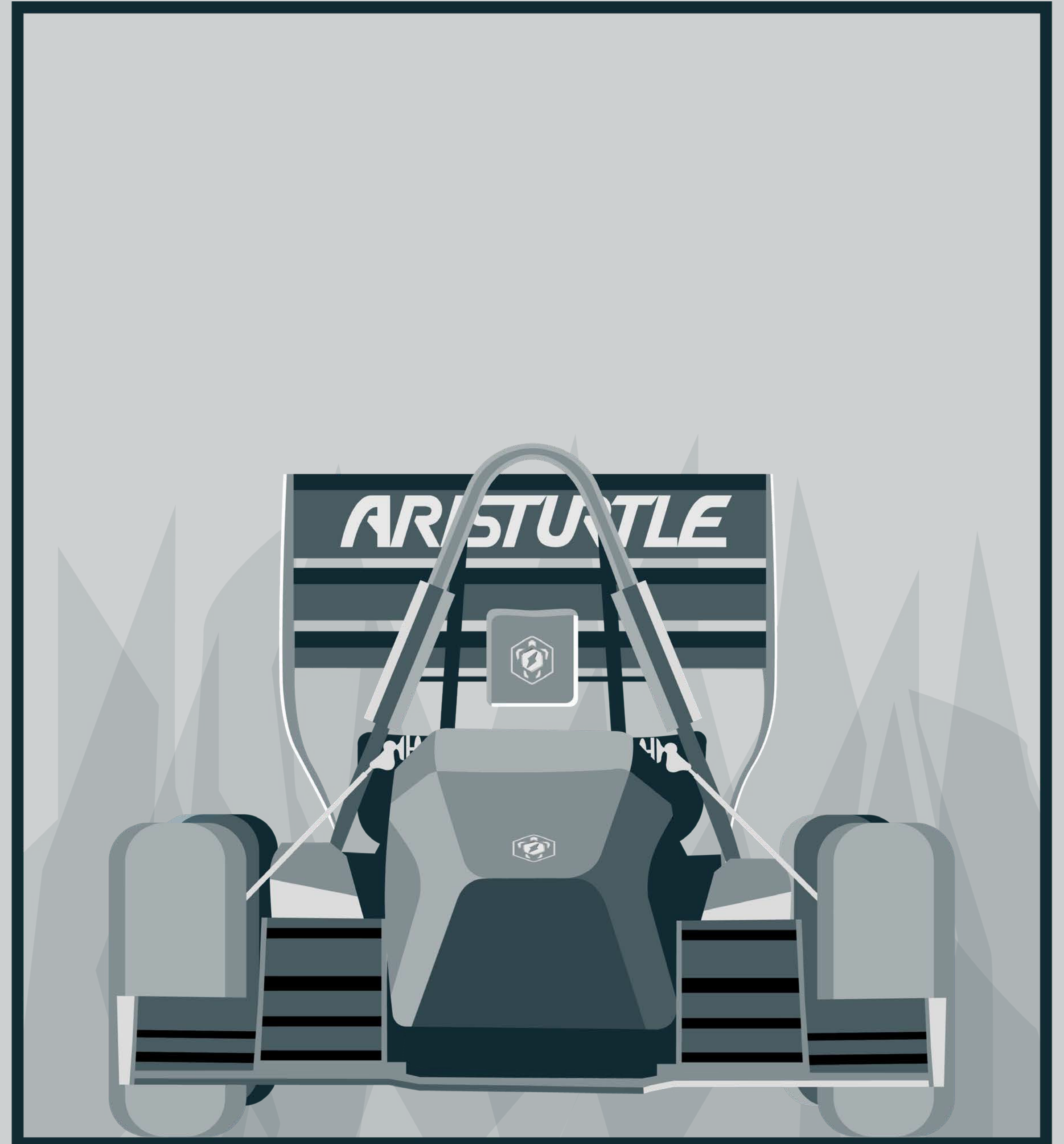
**“The art of progress is to  
preserve order amid  
change, and to preserve  
change amid order.”**

# A New Year, A New Era:

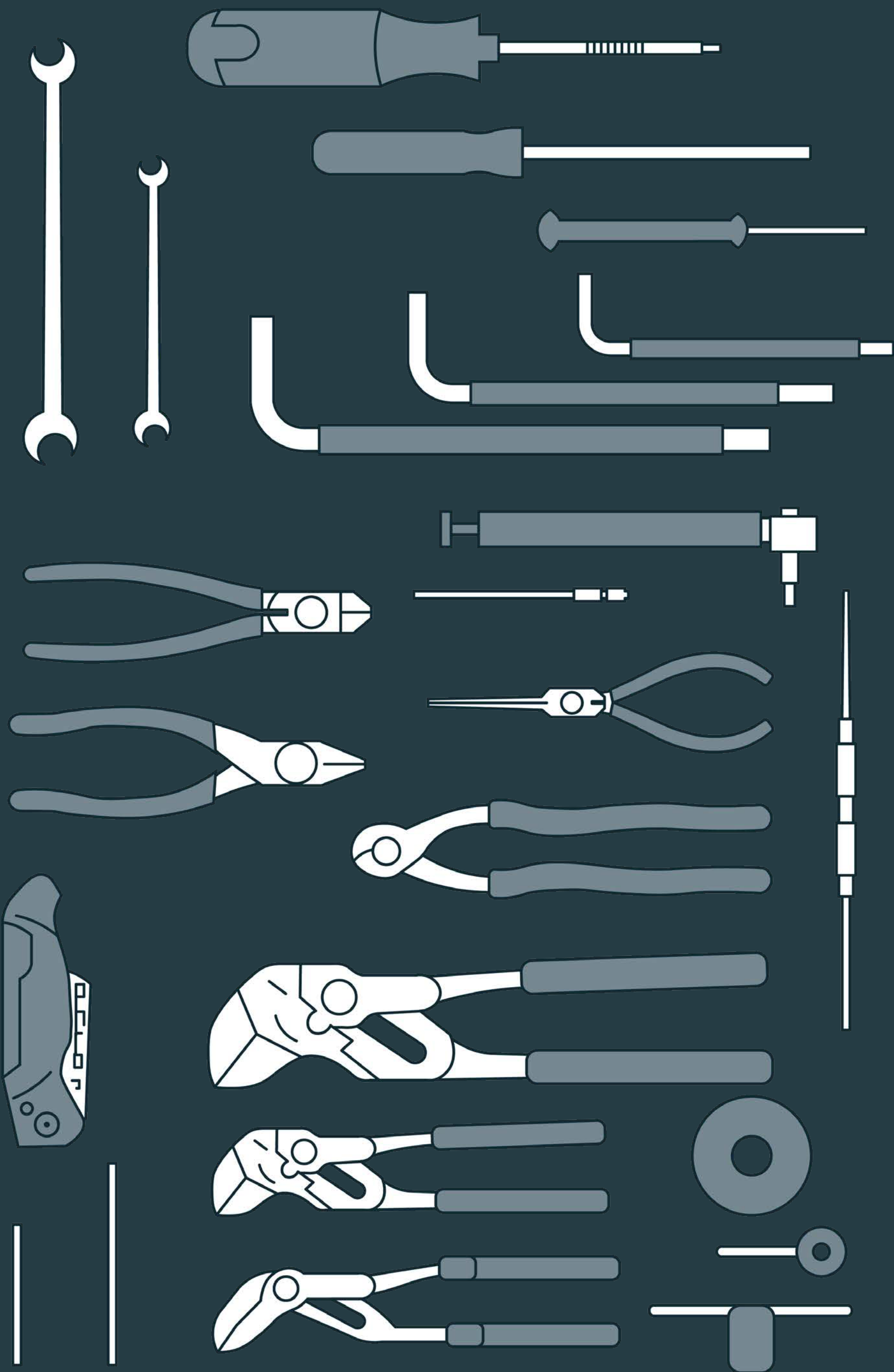
“The day after the storm”

2020 was full of moments to remember. From the stress during the design process in winter, until the cancellation of Formula Student Competitions due to the pandemic of Covid-19. The team has handled this challenging situation quite well. Team 2020 had to begin working from home, and for a long time our goal was to write reports about our projects. When we lost access to our workspaces, we immediately started working on possible concepts for team 2021. Lucky for us, the world technology allowed us to stay in touch with the rest of the team. Google Drive & Slack: Using these tools, Aristurtle almost was functioned as normal.

Simultaneously as we started working on concepts, the new board started planning the entire year on an organizational level. In late May, we had a fully digital Recruitment. This was a whole new experience and forced us to think out of the box. On late May, we finally got back into our workspace, Oikiskos which is located in the heart of Faculty of Engineering. Thus, we could finally start working as hard and dedicated as always in our favorite place.







# Summer Testing

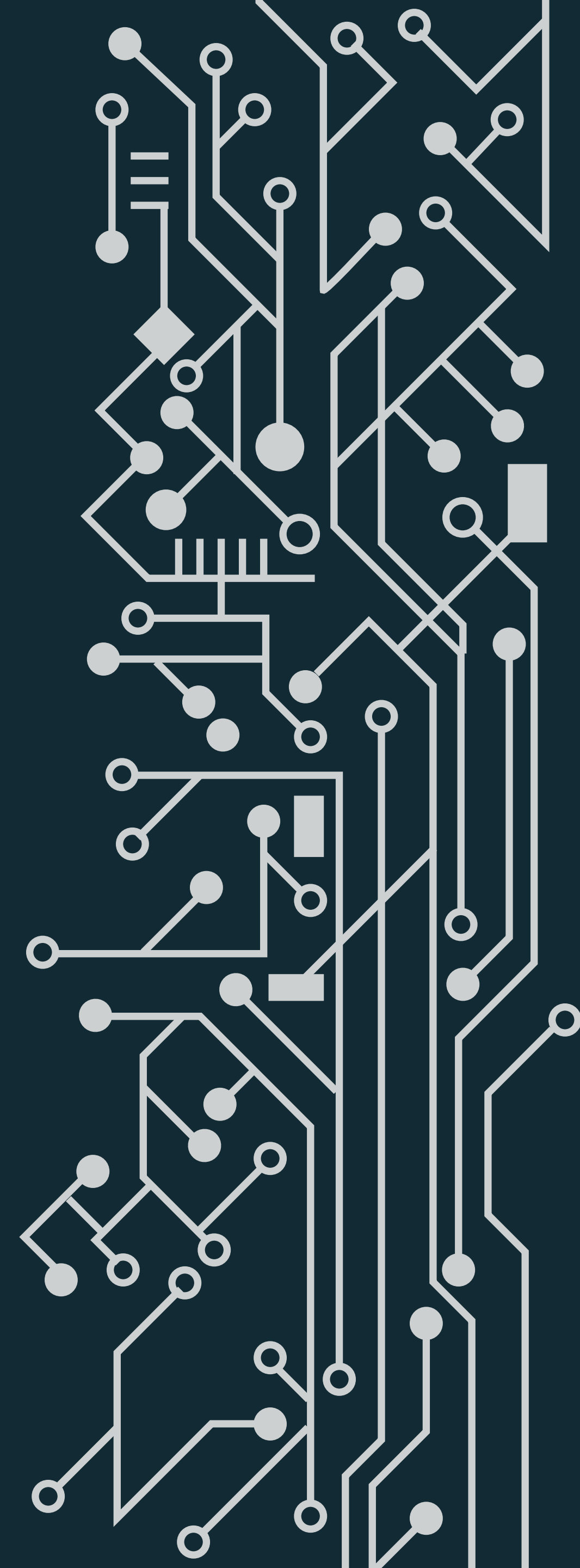
The goal of summer testing was to test concepts and ideas developed in the project year 2020 and during the summer, as well as validating physical models and load cases used in design. Since we unfortunately did not have the opportunity to produce a new race car this year, nor compete during the summer, we have spent the time developing concepts for next year's vehicle. Spending the summer for this purpose, we already have ideas for improvements for next year's solutions that we have larger to test. Another goal for this summer was the training of new members via seminars in appropriate and specifically programs which used by the team. The target was the quick and correct adaptation of the Team 2021 to the way of operation that Aristurtle follows.



# **The dream of building a racecar**

# Electrical System

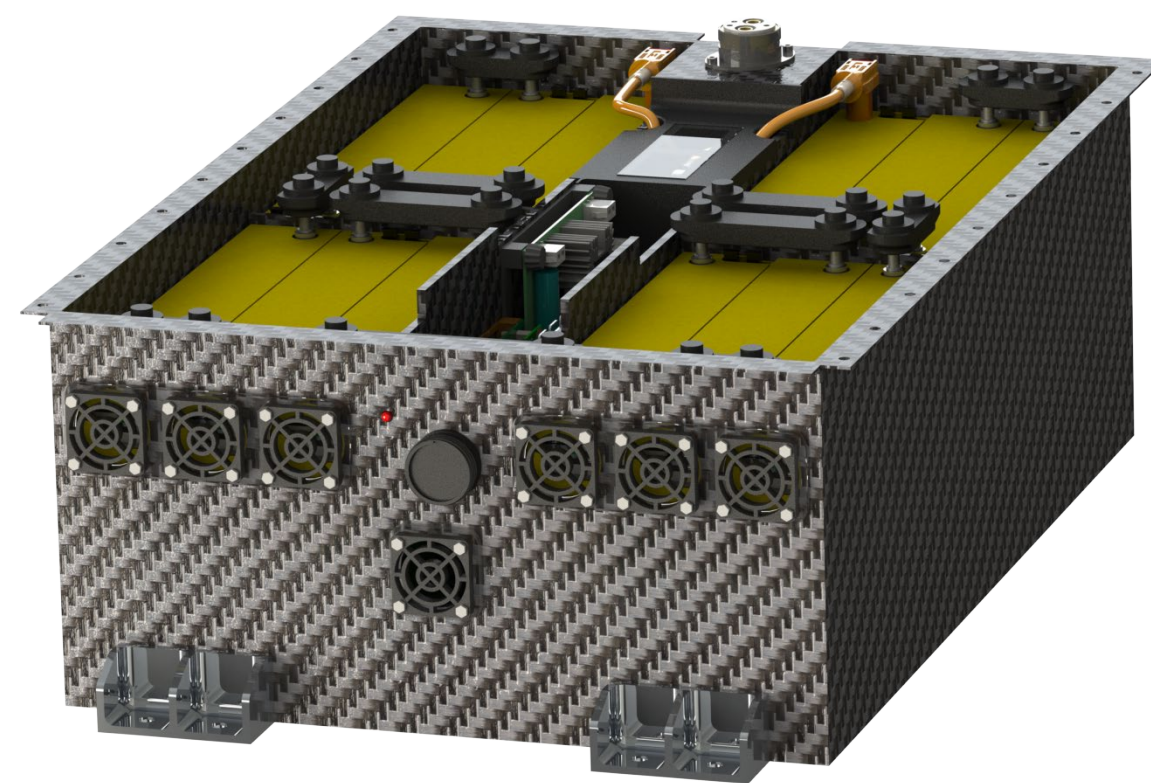
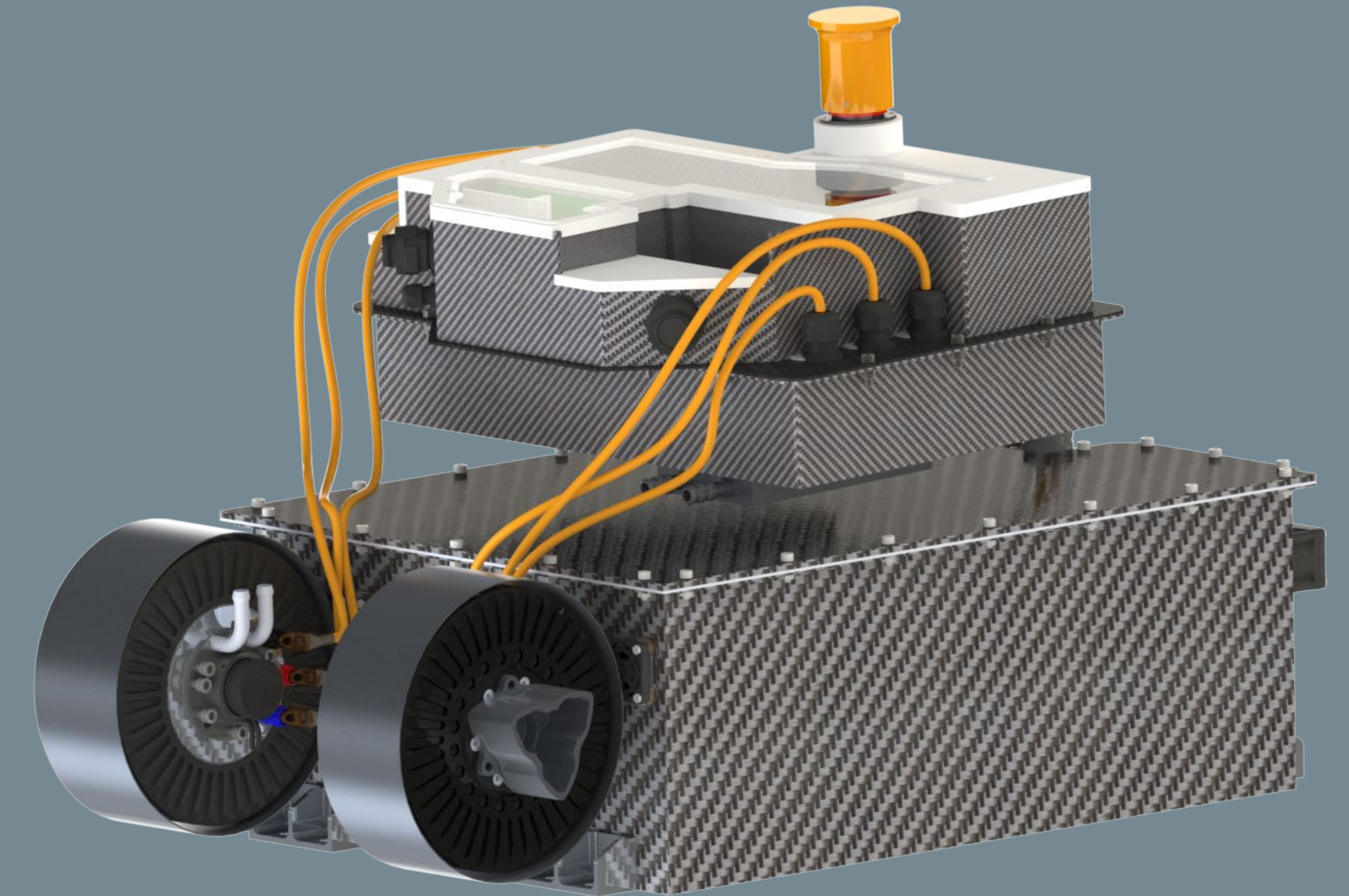
Last year ended with the fulfillment of many of Aristurtle's milestones, with most of them related to the High Voltage & Powertrain System and its integration to the vehicle. Ever since the announcement of the cancellation of last summer's competitions, the members of the subgroup have been renewed and the design goals for the new season have been set. Our main goal: the integration of the High Voltage system in such a way as to facilitate its entire adaptation to the Chassis of our new Racecar. The main directive for achieving this goal was the simplification and reliability in all the systems that make up the heart of every Electric Vehicle, always in collaboration with the Chassis and Suspension subgroups. A big contributor to the success so far has been the fact that the workflow and the management of the project have changed significantly. The adoption of the so-called Continuous Integration model, a practice commonly used in Software companies, seemed promising when the initial problem was subdivided into smaller ones, so that the cost of the above practice due to possible failures was kept to a minimum. In this way, every change or improvement is integrated and tested together with the rest of the system, greatly accelerating the development of the project.



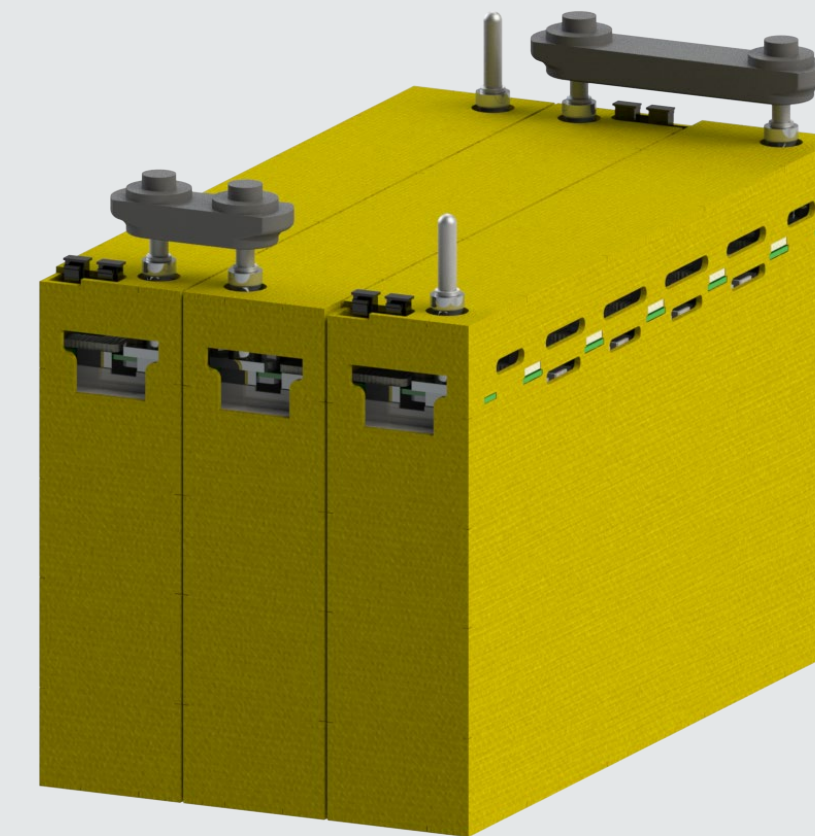


# Accumulator Container

Integrating the high voltage system in the vehicle's chassis was not a simple process. At Aristurtle, we understood from a very early stage the need for a unified logic in the way the car is designed and built and that is why we proceeded to design the car around the best possible arrangement and inter-connection of the High Voltage parts, as is the trend in the Automotive Industry. So we began by redesigning the Accumulator Container, finding smart solutions to problems regarding the packaging, the thermal behavior and, of course, its assembly and maintenance.



Taking advantage of the philosophy behind the design of the Accumulator Segments, which occurred during the previous season, we slightly modified some of the accumulator's parts to complete the puzzle of the general assembly with creating some important spatial symmetries in mind. Thus, we managed to design the Accumulator Container with symmetries on the X and Y axes, resulting in greatly simplified aspects such as the cooling system and the final assembly.

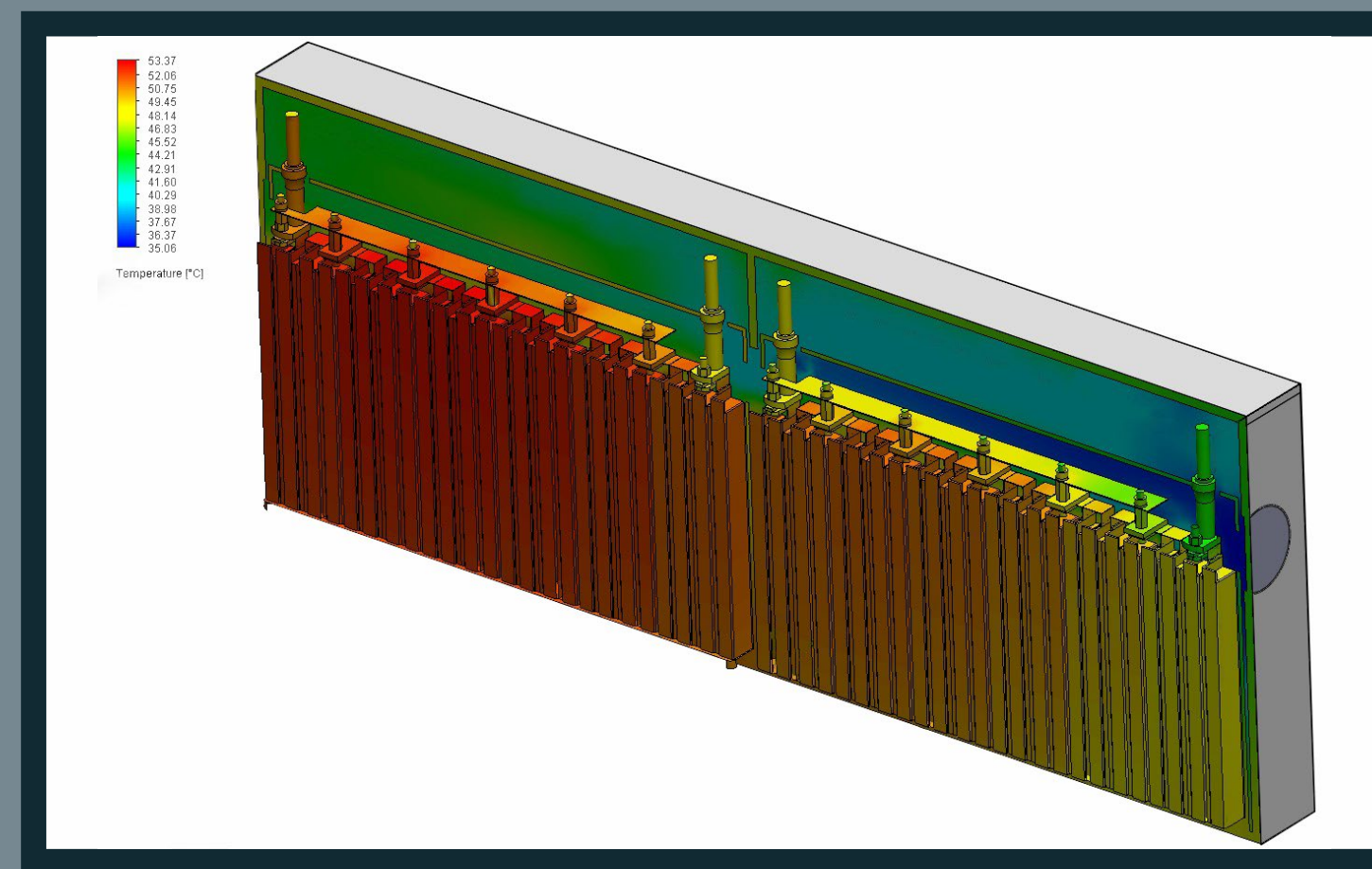
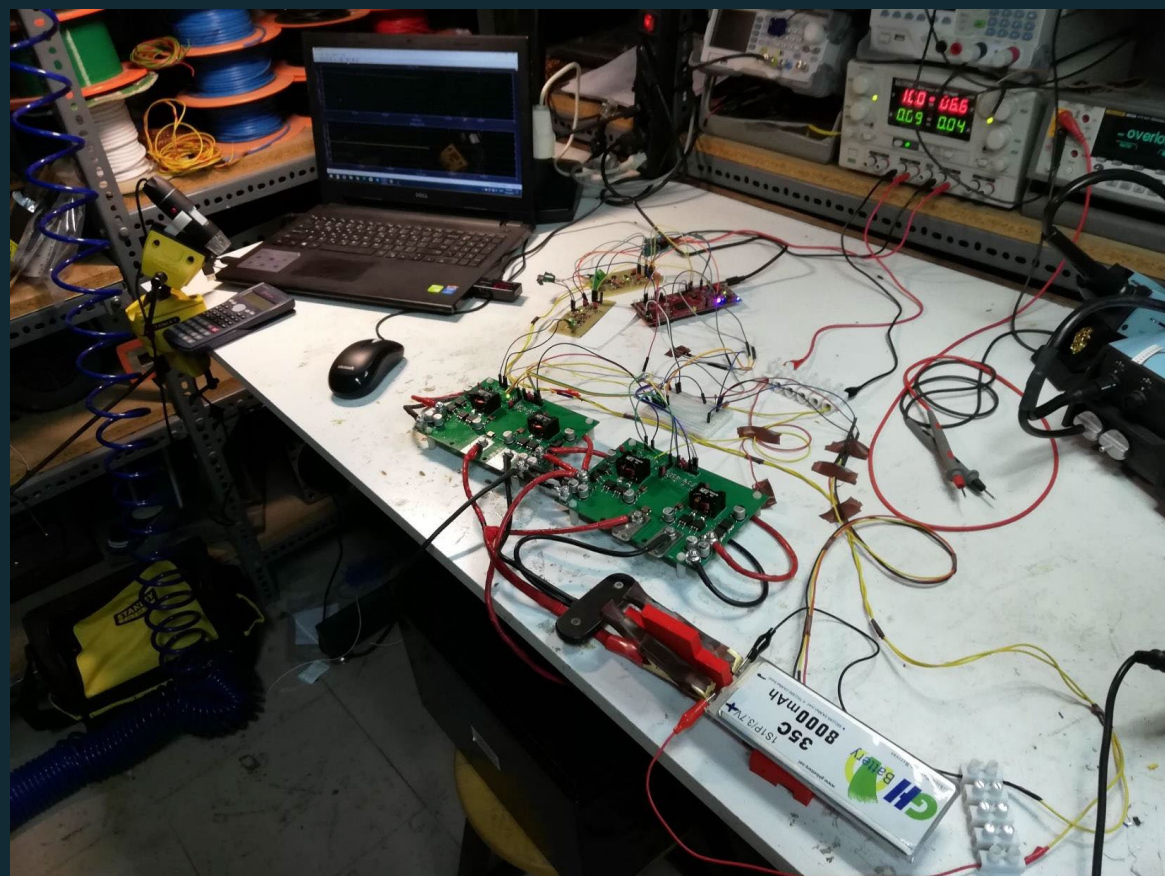


For the electrical connection of the parts in which the Container is divided, special copper connectors were used, permanently connected to the batteries, and aluminum custom-made busbars that are removed during storage or maintenance of the batteries. Ultimately, this effort ensured a fairly simple and reliable design resulting in the best resistance to weight ratio the team has ever produced so far.



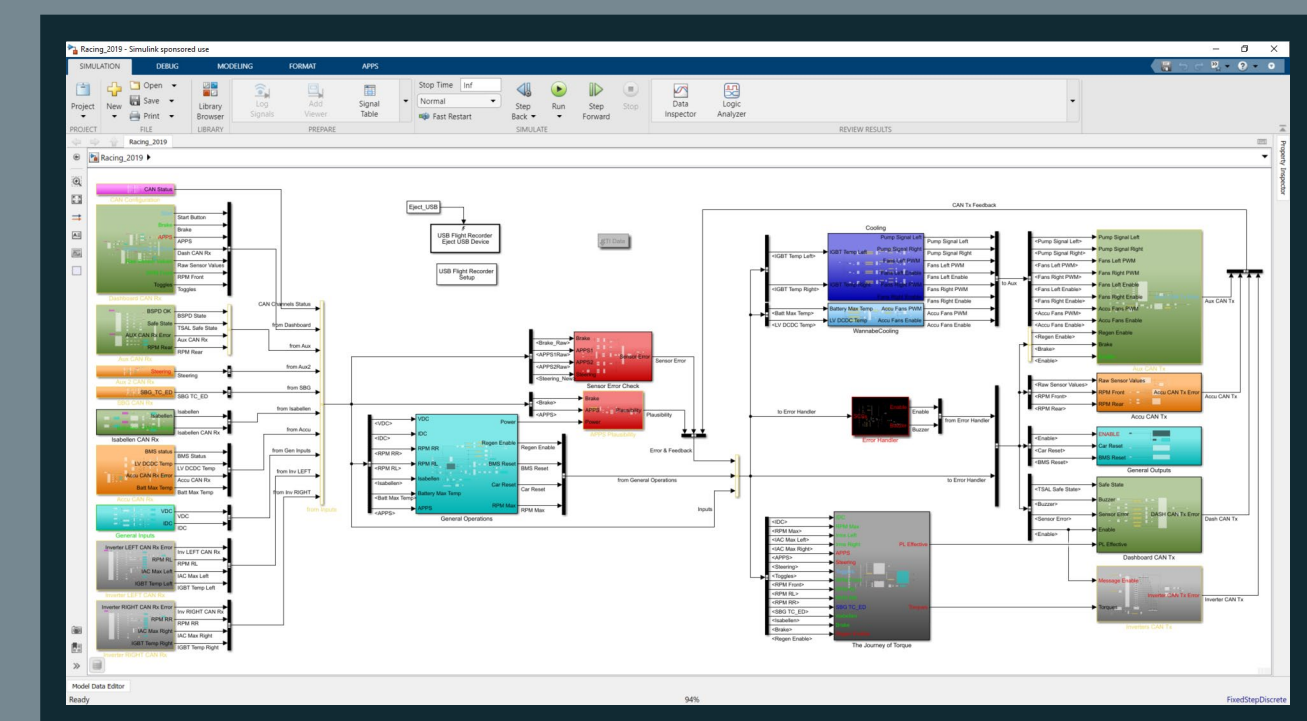
# Battery Cells & Thermal Analysis

One of the greatest enemies of Lithium-Ion Batteries in all electric vehicles, and therefore a limiting factor of performance, is temperature. Using an algorithm suitable for the estimation of the parameters that determine the electrical and thermal behavior of the battery and by conducting experiments to both find and verify these values, we were able to develop a fairly accurate model for our batteries. In this way, Aristurtle aims to measure the total energy that can be utilized from each cell for the various required operating conditions and to better utilize the battery and its capabilities. Finally, a research was conducted on the most efficient way to connect the battery cells, not only reducing heat loss, but at the same time reducing the weight of the previous design.



constructed, very similar to the final design, fully equipped with temperature sensors on both the body and the electrical contact point of the batteries. Bearing all that in mind, we designed an air-cooled heat dissipation system that is digitally controlled by the Vehicle's ECU in order to keep the temperature of the batteries below safety critical levels. To verify all of the above, but also to draw additional useful conclusions, the team will conduct a discharge experiment on a part of the Accumulator Container.

Using the High Voltage Simulation Model designed back in 2019, we proceeded to a separate study and analysis for the High Voltage Cables, where we reduced the total length and cross section of the entire wiring. We ended up with a fairly light wiring that weighs only 655g compared to the 1280g that the same wiring weighed in our previous car.



By making use of the aforementioned thermal battery model and exploiting existing track data from our previous participations in the Formula Student competitions, for the first time we proceeded to time-varying thermal analyses of both air flow and thermal behaviour inside our accumulator container. To verify the results, but also to extract experimental data regarding the temperature distribution inside the vehicle battery box, an experimental Accumulator Container was



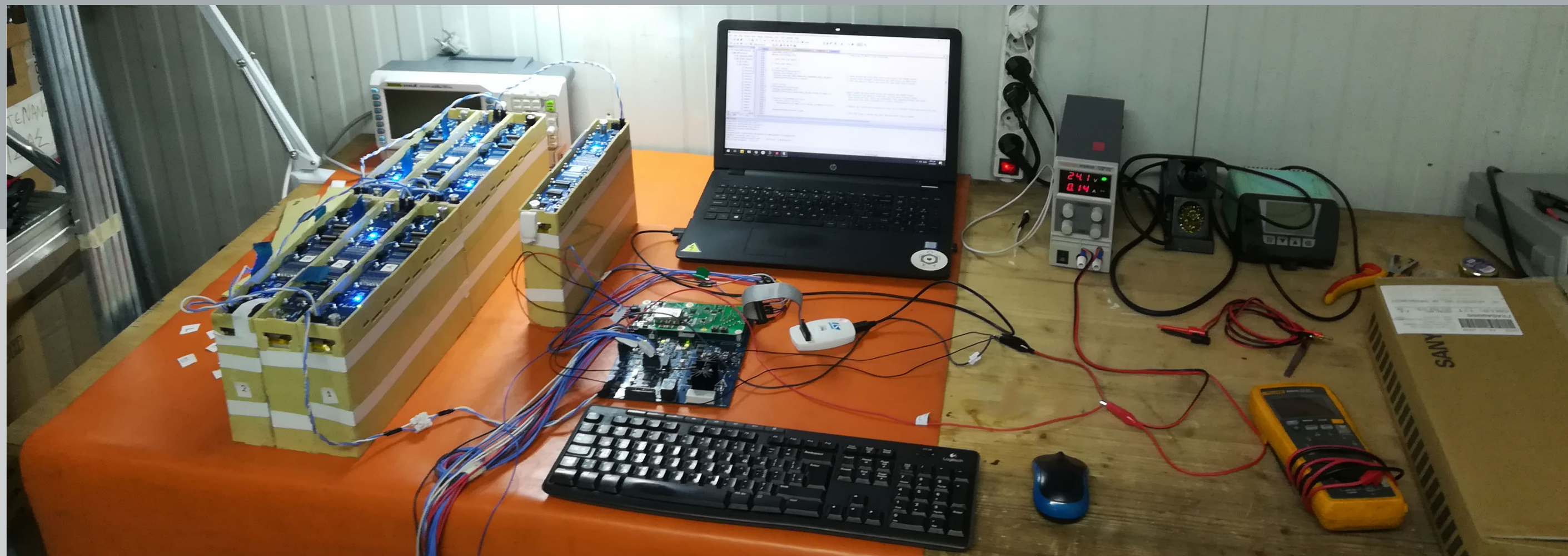
# Battery Management System

Electric Vehicle Applications with High Voltage Battery packs based on Lithium Ion chemistry batteries demand the implementation of a Battery Management System (BMS). The BMS protects the battery by preventing it from operating outside its safe operating area (deep discharging, over charging or operating in temperatures over the recommended values).

Continuing the tradition of previous years, using one of the best PCB (Printed Circuit Board) Design Software - Altium Designer, Aristurtle has developed its own BMS based on the centralized topology architecture, Master-Slave. The whole BMS is integrated inside the 600V maximum Voltage Accumulator Container, including 12 Slave PCBs that are responsible for the monitoring of crucial safety parameters such as the temperature and the voltage level of every cell group. The system's tasks are carried out by a microcontroller which also fulfills the needs of robust and reliable communication with the slaves PCBs, using a differential signal protocol isoSPI from Analog Devices.

Intrinsically, battery specifications, like the internal resistance or the maximum capacity, decay as they are used due to limited duty cycles. This phenomenon calls for the remedy we implemented a Passive Cell Balancing circuit in the Battery Management System. This feature eliminates the diversities between the batteries as it has the ability to equalize the voltage of every battery cell group in order to optimize the charging process. As a result, the overall performance of the car stays at the highest level as the battery pack delivers the maximum possible power.

Moving forward from the design period, the team proceeded into the debugging period by the time the High Voltage sub-team had finished the assembly of the most significant parts of the Accumulator Container. During this process, all the necessary functionalities were tested so as to result in the activation of the Shutdown Circuit in case of emergency by the use of non-programmable logic circuits placed in the master's PCB, the Fusebox.





# Charger

Given the team's new energy storage system, it was necessary to implement a new charger for our batteries. Beyond the necessary protective circuits, the charging system consists of a charger from ELCON and a PCB designed by team members, which performs all necessary functions for charging with the aid of the custom-made sTurtle microcontroller. This microcontroller is responsible for communicating with the Battery Management System (BMS) but also for sending appropriate commands to the charger for the safe charging of the cells. In addition, via serial communication with a computer, it is possible to monitor the charging status like Voltage, Current and Temperature of the cells by the user, critical information when using lithium ion batteries.

The assembly of the charger was completed by the team successfully, as ascertained after tests carried out together with the rest of the required electronic systems, as well as with the safety circuit of the vehicle, simulating the normal operation.

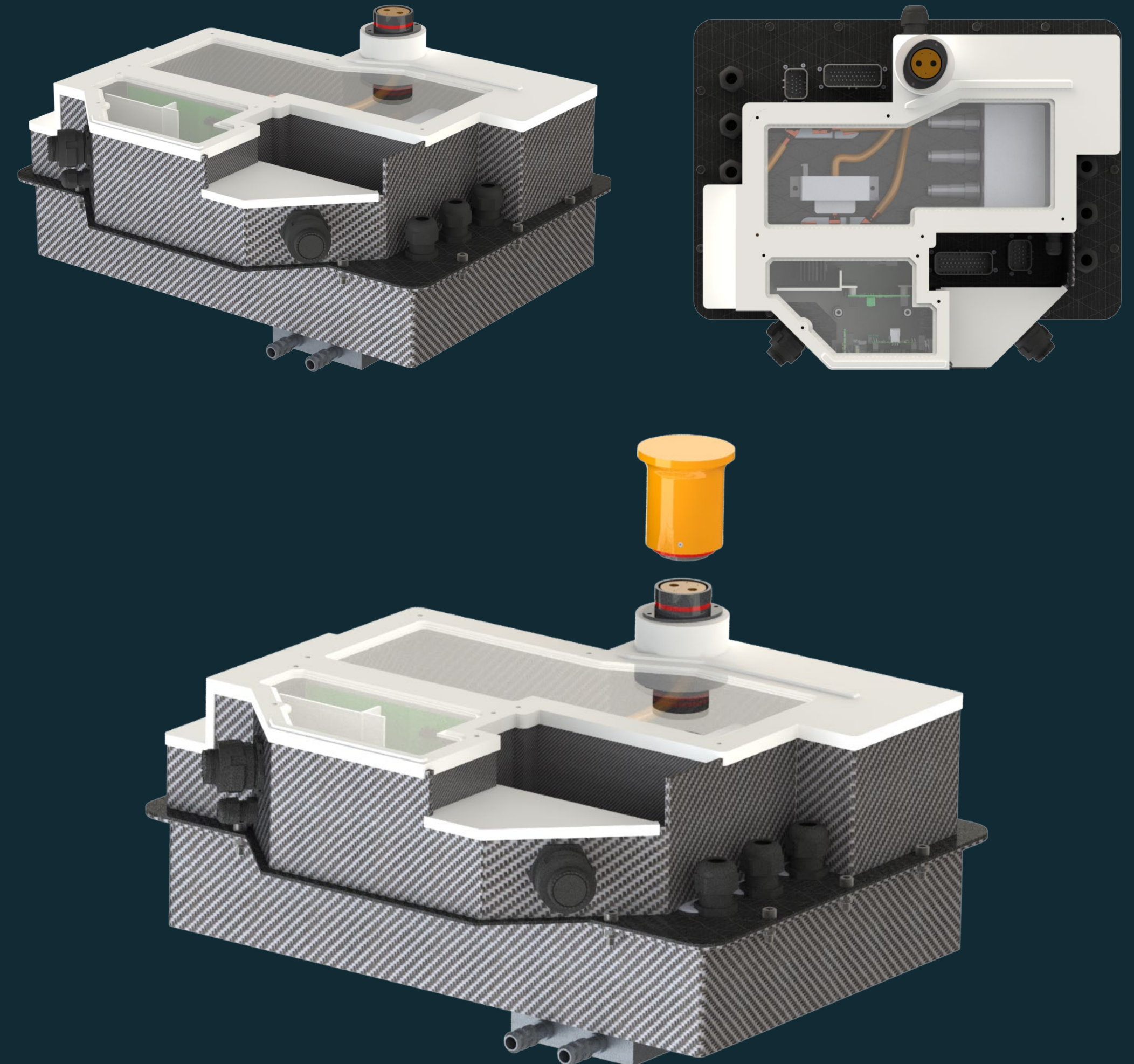




Maintaining and expanding the Compact Design of the Accumulator, we designed a central unit that contains all High Power Distribution and Control Systems, as well as most parts of the Vehicle's Shutdown Circuit. The lower compartment houses only the Power and Control Electronics of the two Inverters, while the upper one encloses the High Voltage Disconnect (HVD), the Power Distribution busbars and the Energy Meters required by the competitions. A separate compartment contains the self-developed PCBs of the TSAL (Tractive System Active Light), the BSPD (Brake System Plausibility Device) as well as the uController that is responsible for sensor data collection throughout the vehicle. The HPDUs (High Power Distribution Unit) casing is manufactured in-house mostly using Carbon Fiber reinforced Plastic and some 3D Printed parts and fittings, replacing the cast-aluminum stock casings of the Inverters and the fully 3D printed Splitter Box. The use of Composite Materials along with the compact and thoughtout placement of all components result in a total weight reduction of 25% or 2.5 kg compared to the previous design.

Besides the big weight reduction, reducing the volume occupied by all these components inside the Chassis is also very important. This was achieved mostly by the design of an all-encompassing casing, but was further magnified by the development of custom parts in place of bought ones, as was the case for the HVD. The modification of a conventional High Voltage Connector to a simple Disconnecting Device lead to the replacement of the previous HVD and the reduction of its footprint by 65%.

# High Power Distribution and Control Unit

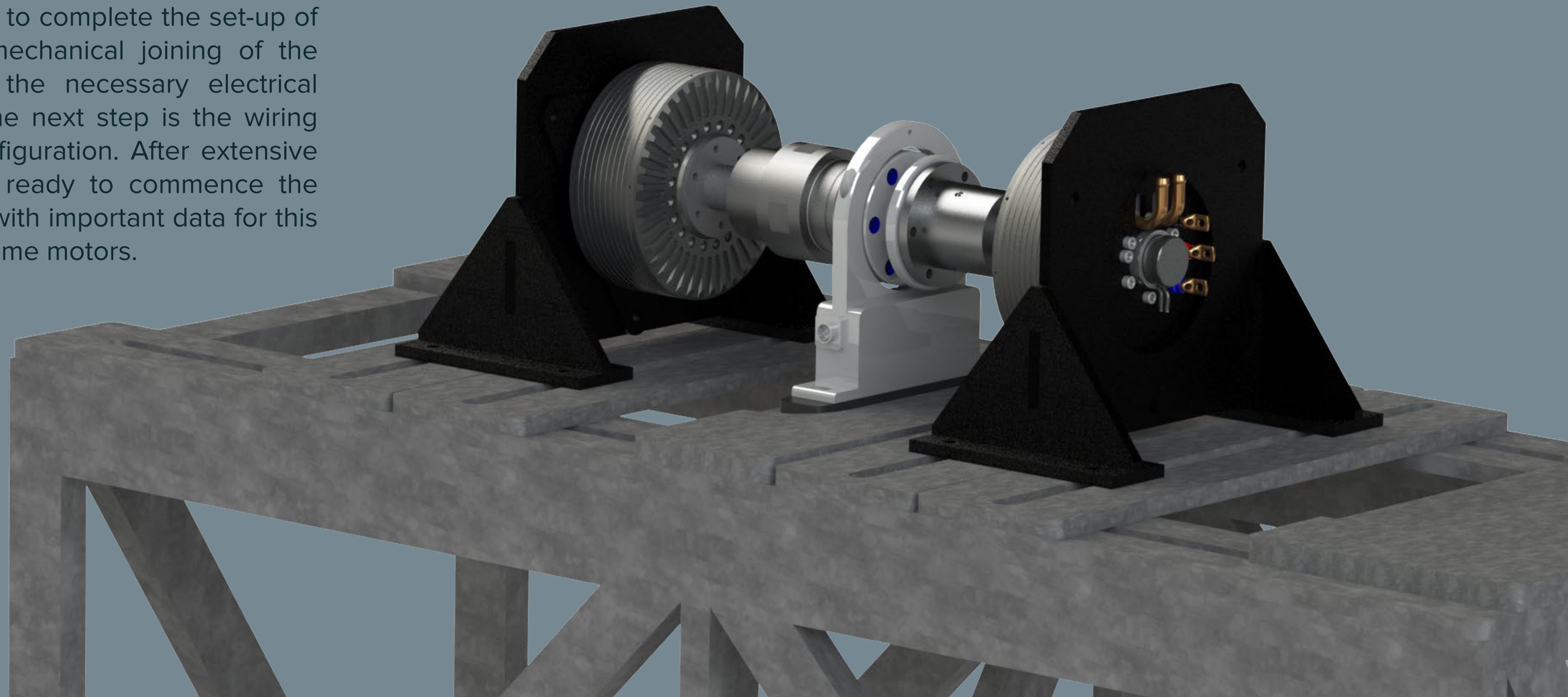




# Dynamometer

For the first time, the team proceeded to the construction of a custom-made dynamometer configuration for our new Electric Motors in order to obtain the necessary Torque - Power and Efficiency data. In order to obtain the required data from the motors it was required to implement an accurate measurements system. This system consists of a number of sensors, one PCB and a microcontroller. More specifically, three current sensors, sponsored by LEM, and one torque meter were used, while the PCB is responsible for the voltage measurement of the motors' 3 phases, the collection of the torque meter's data, and also their transmission to the microcontroller. Simultaneously, the microcontroller communicates via CAN with the inverters to receive the speed and temperature values, as well as additional vital information about the system. Finally, all of the received data is logged on a PC with the use of MATLAB.

The team worked at the Laboratory of Electric Machines of the University the last few months to complete the set-up of the experiment. Following the mechanical joining of the motors and the completion of the necessary electrical connections with the inverters, the next step is the wiring harness of the measurement configuration. After extensive preliminary testing, we are now ready to commence the experiment which will provide us with important data for this and all future vehicles using the same motors.



# Shutdown Circuit

As it has already been mentioned, the integration of a reliable and robust shutdown circuit severely contributes to defining a car as safe to drive. This circuit consists of numerous safety systems, including the BMS, which can independently control the Accumulator electromechanical isolation relays. These relays are normally open, which means that energy is permitted to flow outside of the Accumulator only if there are no errors and the Electrical System Officer intentionally closes the respective Master Switches of the car. Aristurtle has already tested every system of the Shutdown using our first version PCBs for the upcoming season. Parts that are included inside the Accumulator Container were tested more intensively due to the increase complexity of the circuits that need to interface with the Charger as well as the rest of the car, such as the Isolation Monitoring Device (IMD), a device sponsored by Bender GmbH. Moreover, the Brake System Plausibility Device (BSPD) has already been tested in real racing conditions as it is integrated in previous race car, Thetis. The BSPD has been designed by the Low Voltage sub-team using non-programmable logic circuits, which monitors the behavior of the car concerning the actuation of the brake and acceleration pedal simultaneously.



The vehicle dashboard is the medium through which the driver can communicate with the race car's electronic system. It contains both buttons and switches, as well as the necessary indicators, which allow the driver to learn and affect the vehicle's operation. The new dashboard design was made keeping in mind the goal to minimize the required space and the integration of all required electronic components in the same housing. In addition to those means of control that exist on the dashboard panel, we decided to add a series of buttons on the steering wheel, which will allow the driver to alter specific settings of the driver assistance systems.

The transmission of these commands to the ECU is performed by a new, custom-made microcontroller PCB, designed around a TMS320 processor from Texas Instruments. Its ability for more complicated calculations along with its very easy programming, with the use of Simulink, were the main reasons that we decided to utilize this new microcontroller in our vehicle. The one present in the dashboard is tasked with the collection and processing of data collected from the vehicle sensors present in the front of the vehicle and the driver interface, the control of the dashboard screen and the connectivity of the dashboard to the rest of the vehicle.

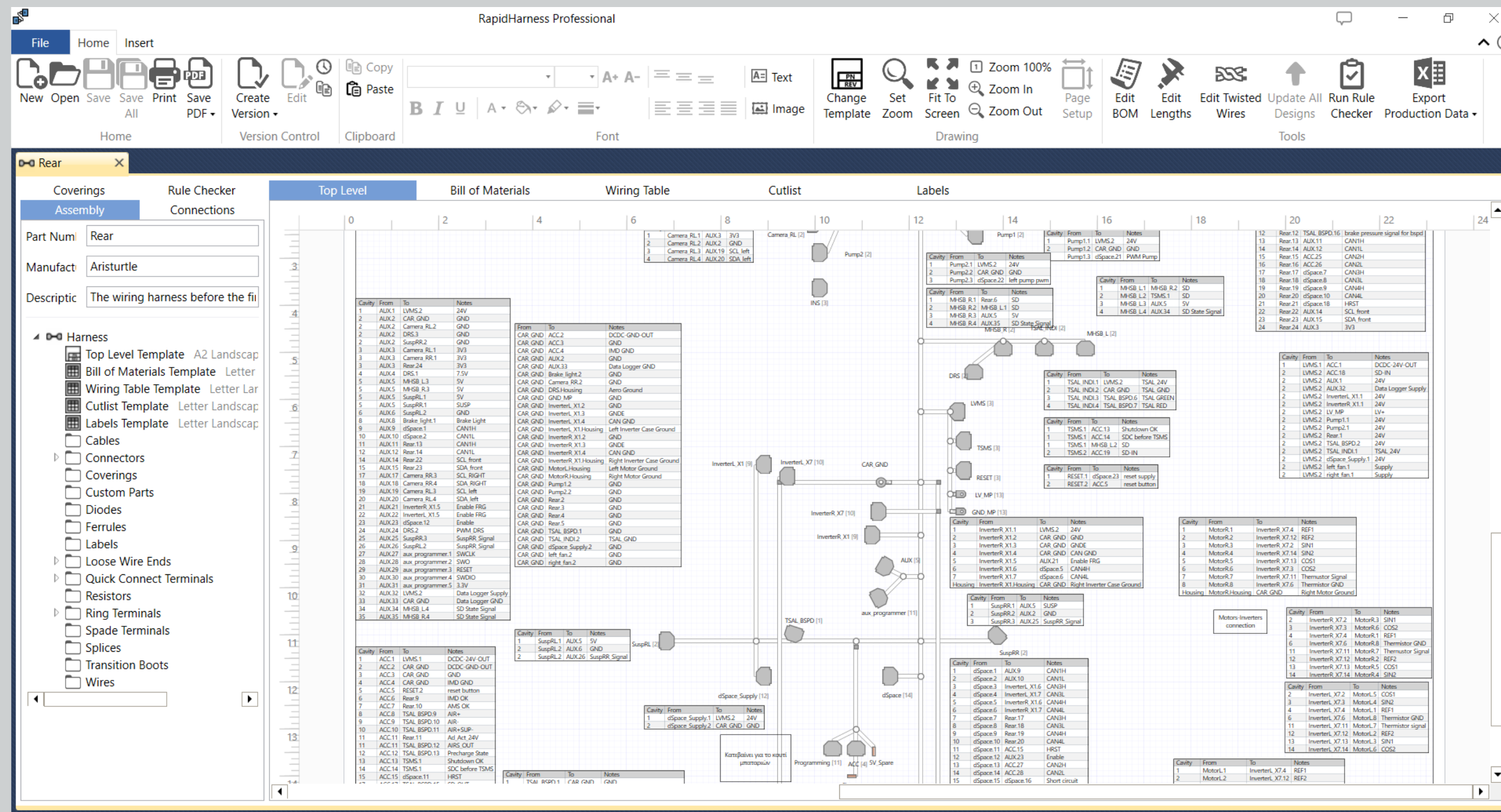
The screen that is used, the ADU from ECU Master, is an important addition to the dashboard, as it provides the driver with useful information regarding the vehicle settings, the speed, acceleration and power consumption. Additionally, it is planned to display lap timekeeping data to the driver when performing tests on track, using inputs from our custom-made lap time measurement system, which was developed during the spring of 2020.

# Dashboard





# Wiring Harness



This year, we decided to revamp the process of designing the vehicle's low voltage wiring harness. Armed with the Rapid harness software, a 2-dimensional design tool, we already have a better supervision of all the signals transmitted on the race car, as the software provides a clear picture of the harness structure. The next step is to take the 2D plan and import in a 3-dimensional model of the vehicle, which will allow for the exact determination of wire lengths and the beginning of the construction of the actual wiring harness.



# Electronic Control Unit

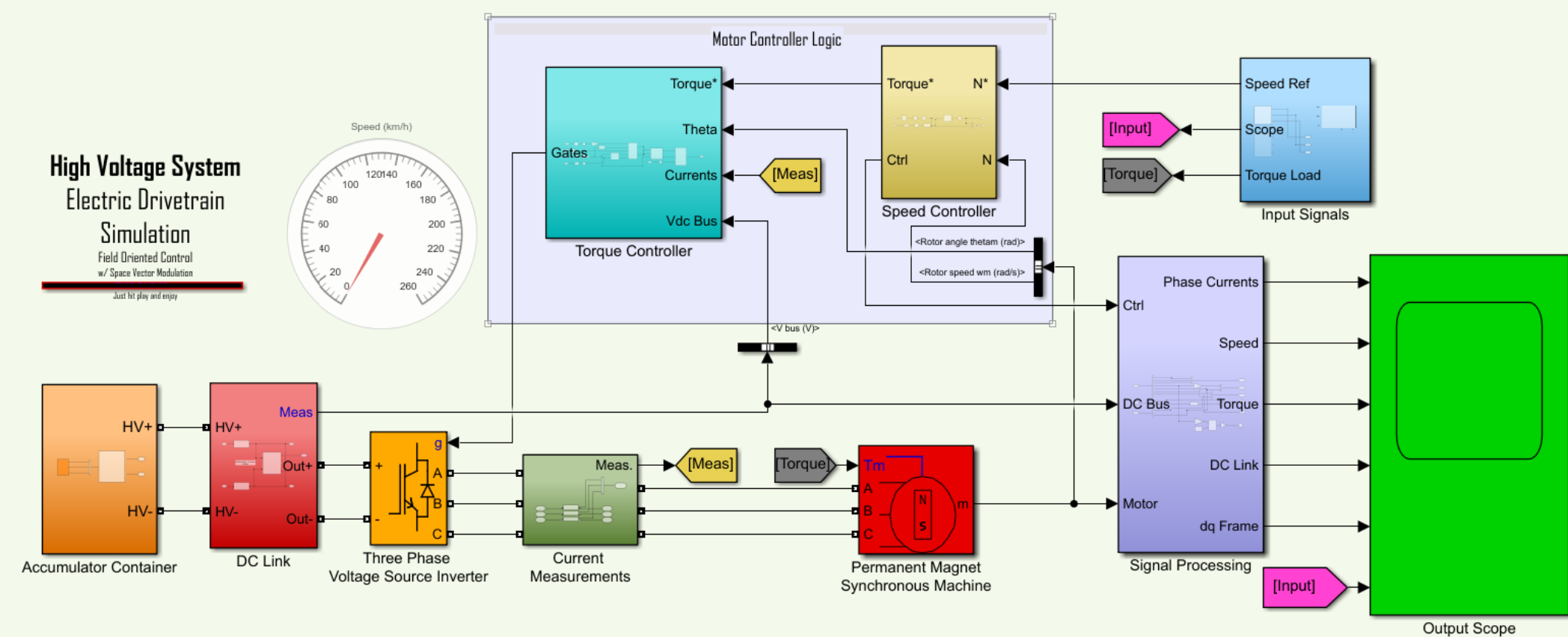
One of the most important pieces of the vehicle control is the central electronic control unit, or ECU, which in Aristurtle's vehicles is a dSPACE MicroAutoBox II. Because it is responsible for vital operations such as the motor torque reference generation and the checking of the correct operation of the vehicle's electronic systems, its programming must always be optimized, especially since it hosts several systems that actively affect the vehicle performance.

In pursuit of this goal, within 2020 we made significant changes, one of which was the complete redesign of the communication with the inverters, utilizing Simulink's Stateflow feature, a tool for creating finite state machines. This allows us to have unlimited control over the inverter settings, even when the vehicle is on the move, which opens new and interesting possibilities for the control of our motors.

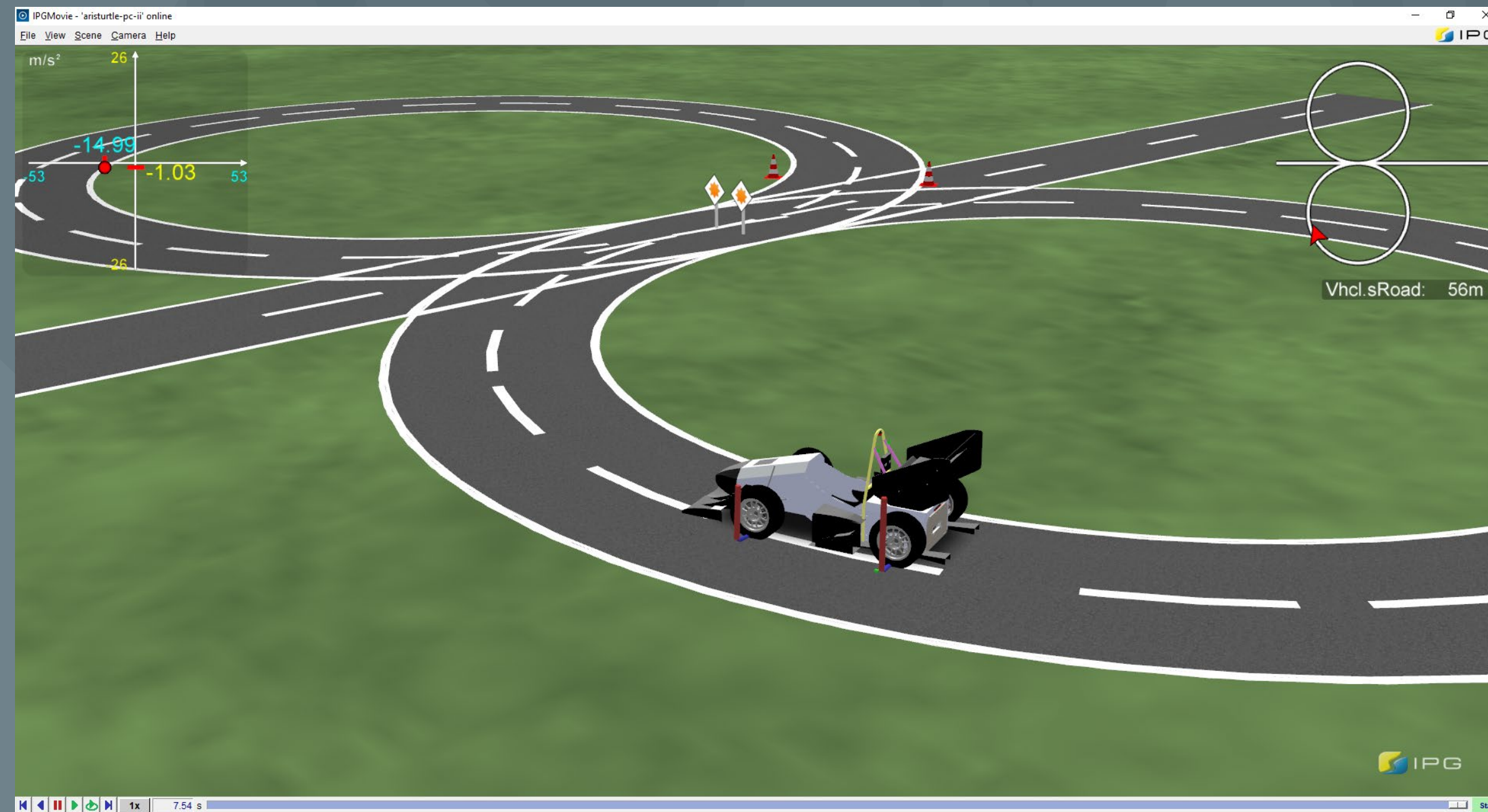


# Driver Assistance Systems

Continuing the effort to increase vehicle performance, during the spring, we developed a traction control system. The main goal of this addition to the vehicle ECU programming is the avoidance of excessive wheel slip situations. After studying the available experimental tire data, we have determined the optimum performance conditions for our tires, based on dynamic conditions such as load transfer and slip angle. With the help of the required sensors, we have thus created a feedback control logic which reduces the motor torque and thus the wheel slip to those levels which produce the maximum force between the tire and the road. The modeling of this system has taken place in Mathworks' Simulink environment, which makes the process much easier, while some preliminary tests have also been performed within the IPG CarMaker software, utilizing its very useful Simulink integration.







A system that was redesigned this year was the vehicle's electronic differential. Taking advantage of the existence of two separate motors and our ability to control each one separately, we have designed a system to electronically divide the required torque between them. The logic behind this system is based on the prediction of the route that the driver wishes to follow, based on the vehicle speed, yaw rate, lateral acceleration, steering wheel rotation angle and other kinematic variables. Using this live data, we designed a system in Simulink and simulated its effects within IPG CarMaker with very promising results. Additionally, we have allowed for the setting of driver-specific parameters, which allow the driver to alter the behavior of the electronic differential to suit different track requirements and driver behaviors.

Last, but not least, we developed our own regenerative braking logic, which has been integrated within the ECU application. The system relies on the reversal of the energy flow, thus returning energy to the batteries and simultaneously braking the vehicle, as is common practice both in commercial and racing electric vehicles. Using a finite state machine, and based on the vehicle speed, we generate a negative torque from the motors which is filtered through the electronic differential, to ensure improved cornering, even when not pressing the accelerator pedal. This system has been tested both in simulation and on the track with the results being very close to what we had calculated. We achieved an energy recuperation of about 10% of the expended energy.

These three systems are expected to significantly increase our vehicles' performance. Especially regarding regenerative braking, it is a very big step towards increasing the efficiency of our vehicle and granting us a higher range, both very useful for the Endurance and Efficiency event of Formula Student Competitions.

# Mechanical System

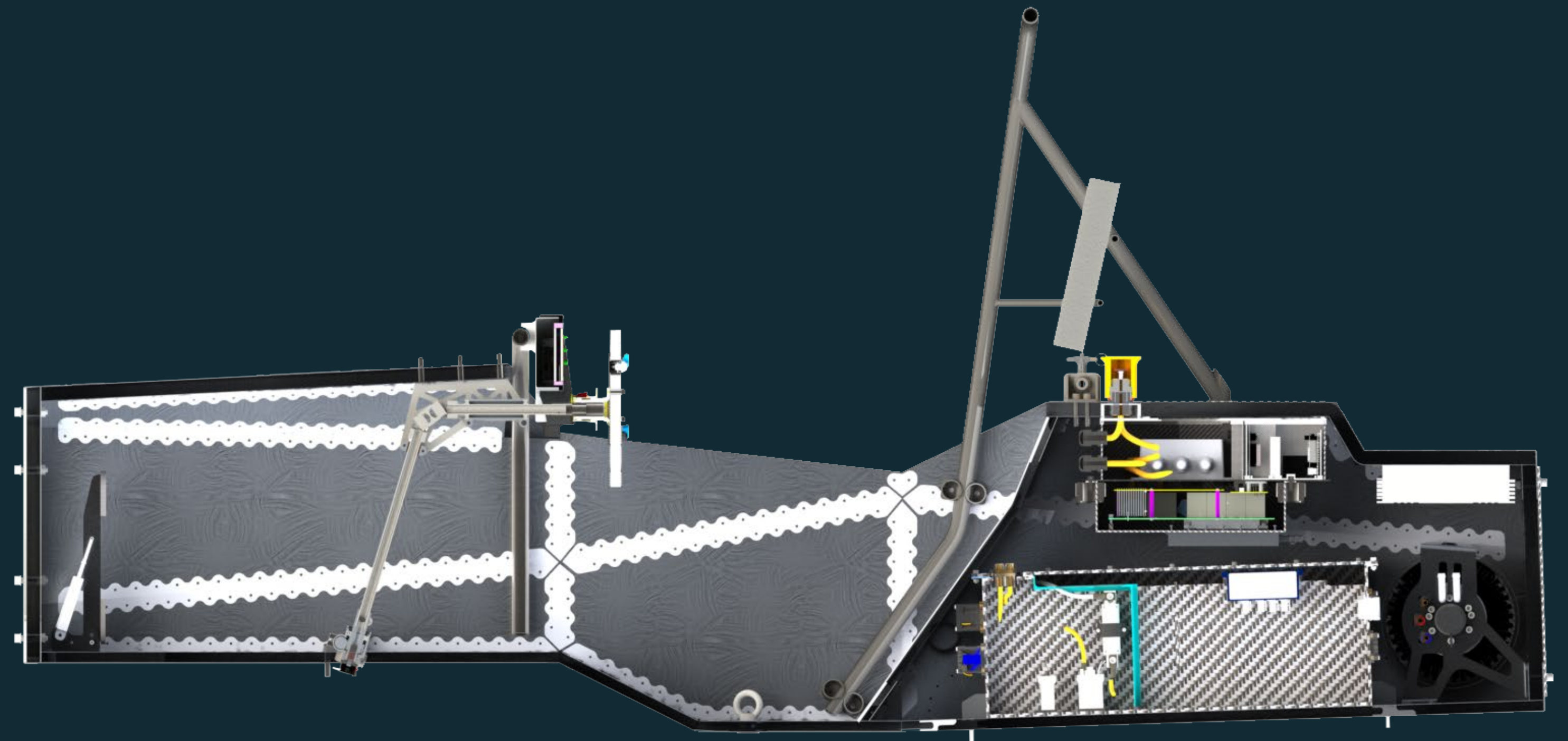
Parallel to the development of the High Voltage and Low Voltage Systems, the sub-teams responsible for the Mechanical Systems of the vehicle worked hard to research and design the Chassis, Suspension, Drivetrain, Steering and Braking Systems, as well as all other structural parts that comprise the vehicle, from the ground up. At the same time, the Aerodynamic Package was fully re-designed, in a way that the aerodynamic needs of the car could be satisfied, while constant communication between Suspension and Aerodynamics divisions defined the goals for the vehicles desired dynamic behaviour. Besides, our ultimate goal is the development and manufacture of a Racing Car, which of course requires the synergy of all discrete systems instead of optimizing each system separately.



# Frame & Composites

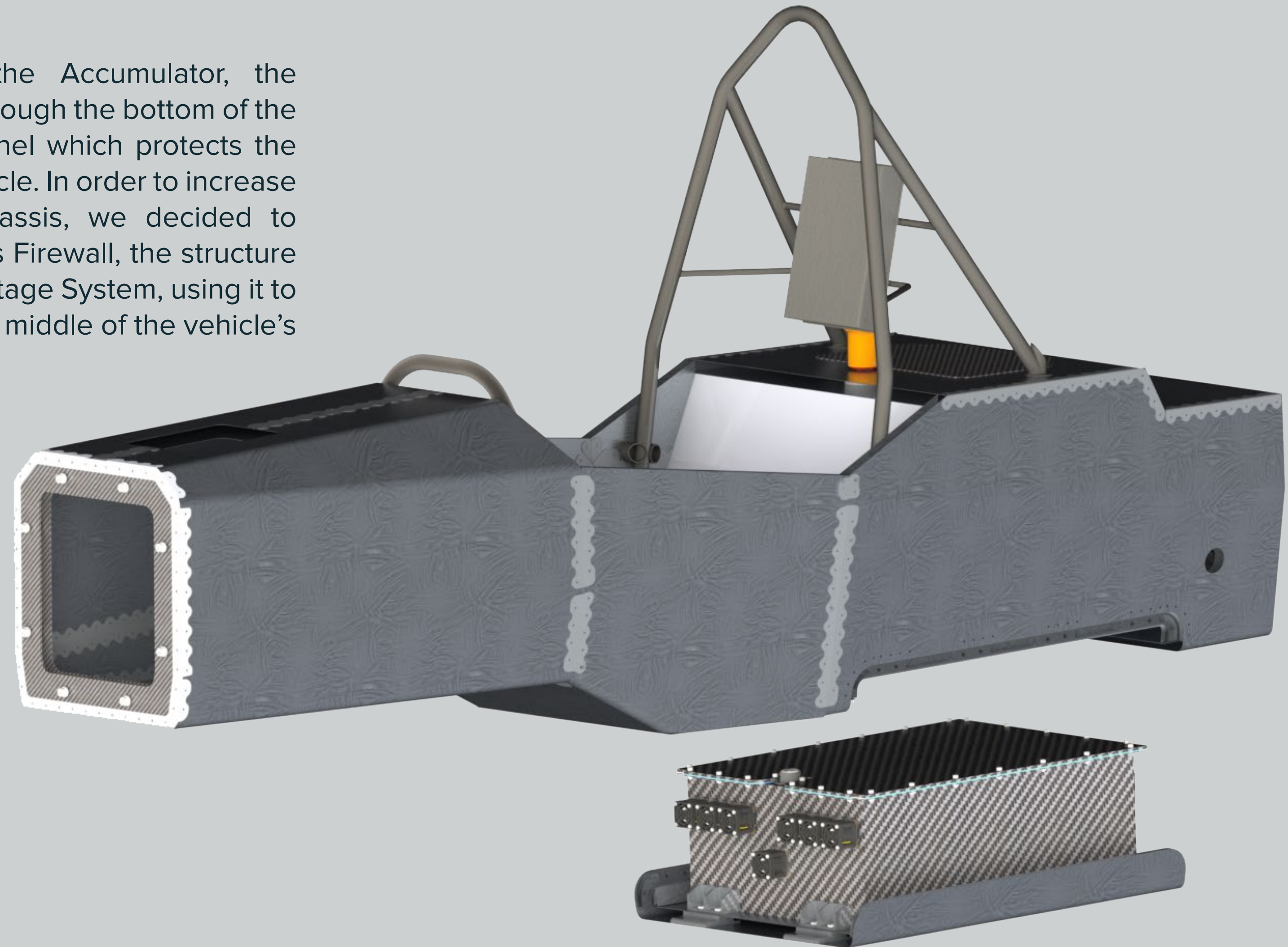
With the ergonomics of the car defined around each driver's height and desired driving stance, the chassis was designed so that it would encompass the High Voltage System, while providing ease of access for assembly and maintenance of all its components. The chassis' geometry was shaped aiming to reduce the unused space in its interior, especially in the cockpit and the rear part of the vehicle, where the Assembly of the Tractive System is contained, closely hugging the drivers body and shaving off extra weight.

The driving position was chosen using an Ergonomics Jig which helped us measure the best inclination of the driver's seat, as well as the positioning of the accelerator and braking pedals. The pedal assembly was redesigned to reduce weight and volume by 15% and 10% respectively, saving a lot of space in the chassis' interior, while ensuring a continuous and safe contact of the driver with the vehicle.





As the motors are located behind the Accumulator, the Accumulator Container is now removed through the bottom of the chassis, using a detachable structural panel which protects the container and solidly attaches it to the vehicle. In order to increase the torsional stiffness of this year's chassis, we decided to reinforce the material used in the vehicle's Firewall, the structure that separates the driver from the High Voltage System, using it to form an intermediate bulkhead around the middle of the vehicle's wheelbase.





Composite Materials play an important role in the development of many parts of the vehicle, with the obvious example being the aerodynamic package. However, materials such as Carbon Fiber and Kevlar will be used in a lot of structurally critical parts. Firstly, the two bulkheads that define the forwardmost and rearmost plane of the chassis and protect the driver and the High Voltage System from direct impact collisions will be fabricated using a lightweight Carbon, Kevlar and aluminum sandwich. In this way, we managed to further reinforce these areas while reducing their weight by 40% by opting to use composites over conventional materials, such as aluminum.



All of the alternative materials used in the vehicle are thoroughly destructively tested to affirm their strength and stiffness, as well as ensure their conformity with the Formula Student Rules. Such testing requires high precision testing machines and we are glad to be sponsored by Gete (GATS), who kindly give us unlimited support by providing access to their testing machines throughout the past 5 years!

One of the greatest achievements of the season will be Aristurtle's first ever fully Composite Accumulator Container, made out of a Carbon-Nomex Sandwich. Moving from an aluminum Accumulator Container to a Composite one results in a 60% weight reduction (around 7 kg), while at the same time offering greater overall rigidity due to the exceptional mechanical properties of carbon fiber. In conjunction with the innovative design for the connection of the accumulator segments and the research on their cooling system, one could say that the Accumulator Container is one of this year's Design Highlights!

It is also very important to properly seal the Accumulator Container, as well as the other housings such as the High Power Distribution Unit and the Dashboard of the car. In order to achieve the necessary waterproofing, products sponsored by Saint-Gobain are used, for the purpose of sealing from water, moisture and dust.



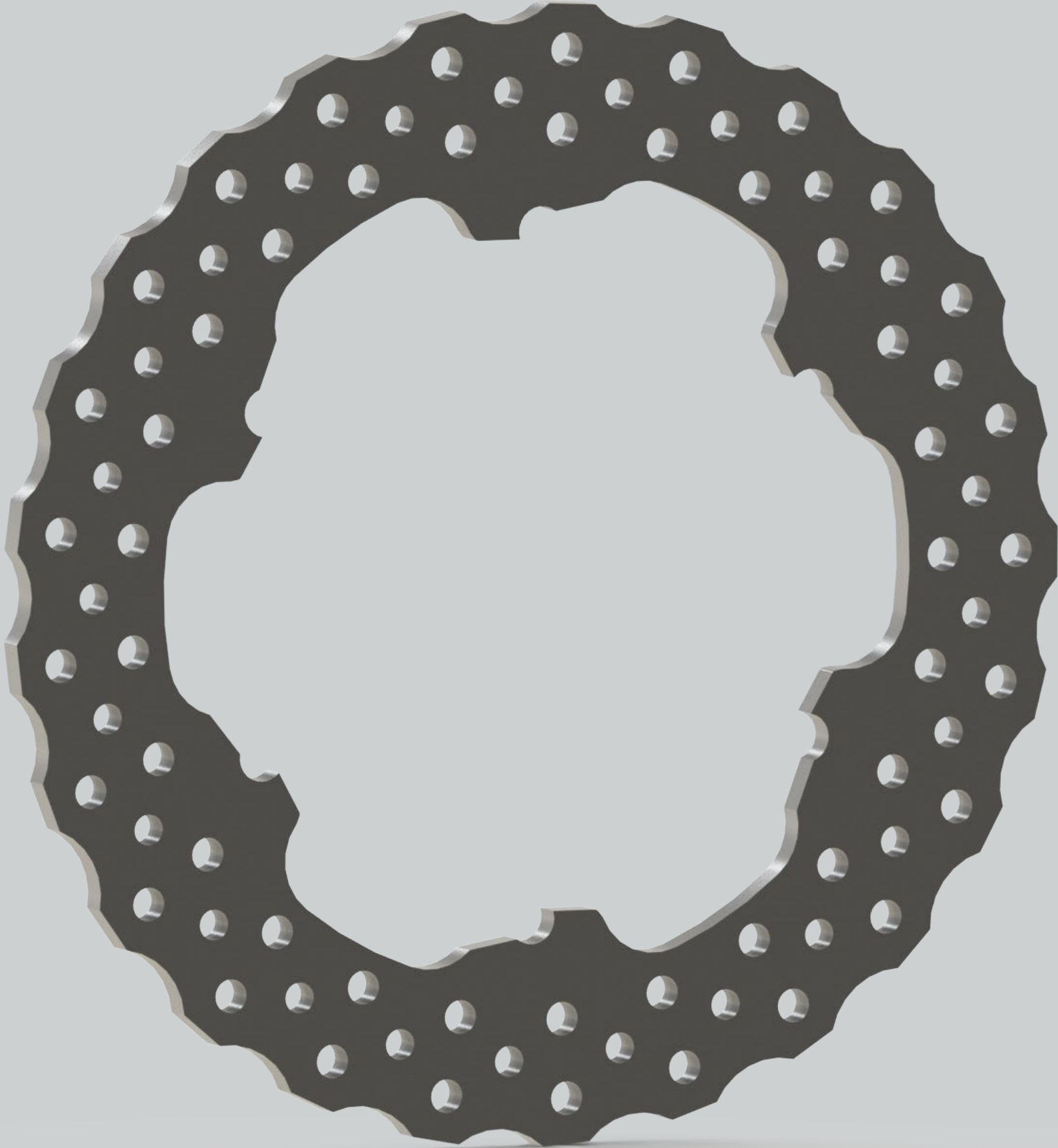
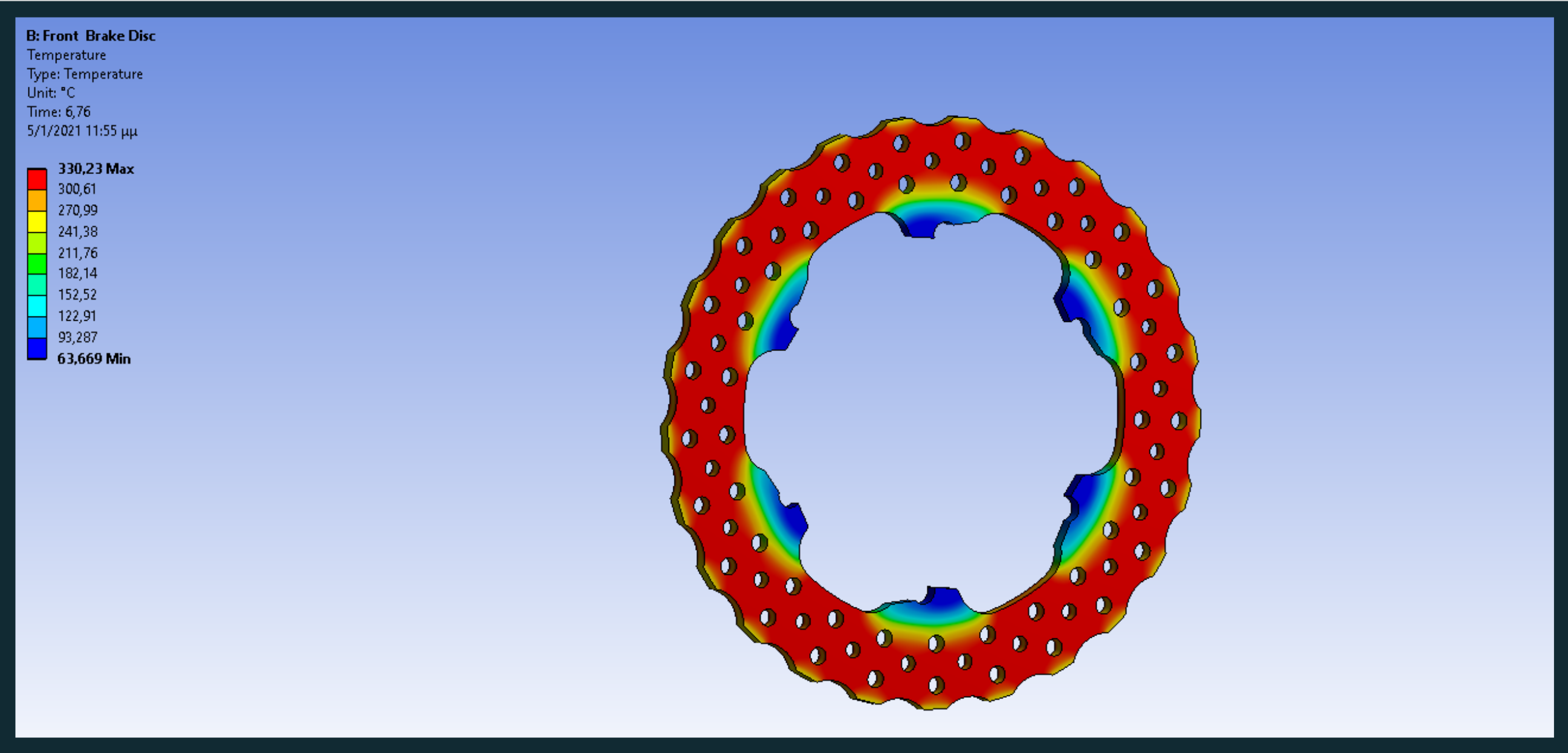
# Mechanical Design

The suspension and unsprung characteristics are designed by the Suspension sub-team but the Mechanical Design sub-team takes over the design and integration of all the structural components of the subsystems on the chassis. So the newfound sub-team is called to design the structural components of the suspension, brake and steering systems and also to conduct structural, dynamic and thermal analysis in order to be sure of the quality and integrity of our designs. Furthermore the Designers are called to implement and evaluate other various components that are placed in our race car.

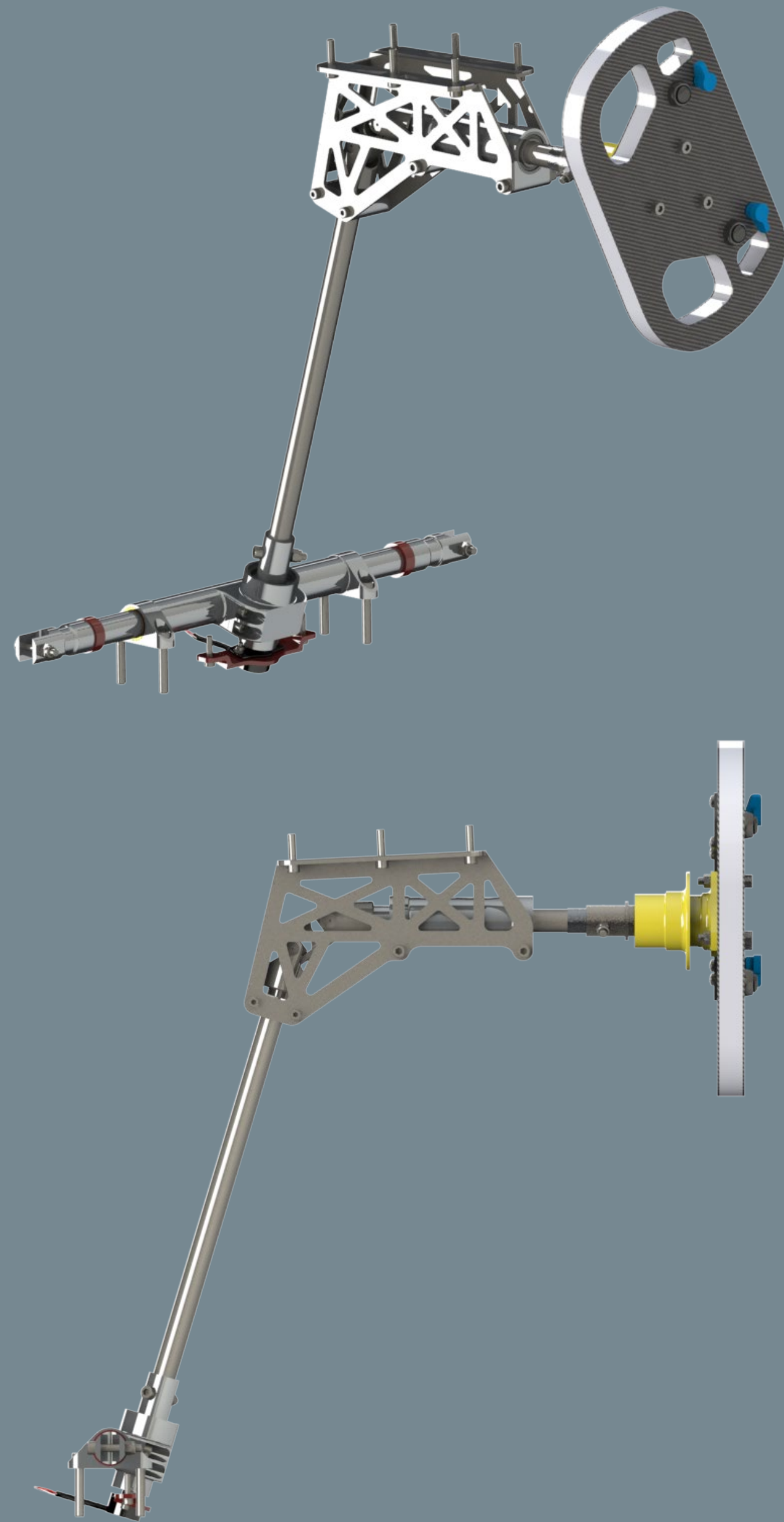


# New disc brakes

According to the new changes and requirements in our race car, the brake system needed to be synchronized with the new developments. Thus we were given the opportunity to optimize and re-consider some of the components of the system that required radical changes such as the disc brakes. The motive behind the new design was still the further reduction of weight and also the optimal dynamic behavior and performance of the system on the track. So with the help of repeated static, dynamic and thermal finite element analysis (FEM) and with continuous experimenting on our designs, we managed to achieve our goal of reducing weight while we also reduced the thermal fatigue that the disc brakes are subjected to.



# Steering system

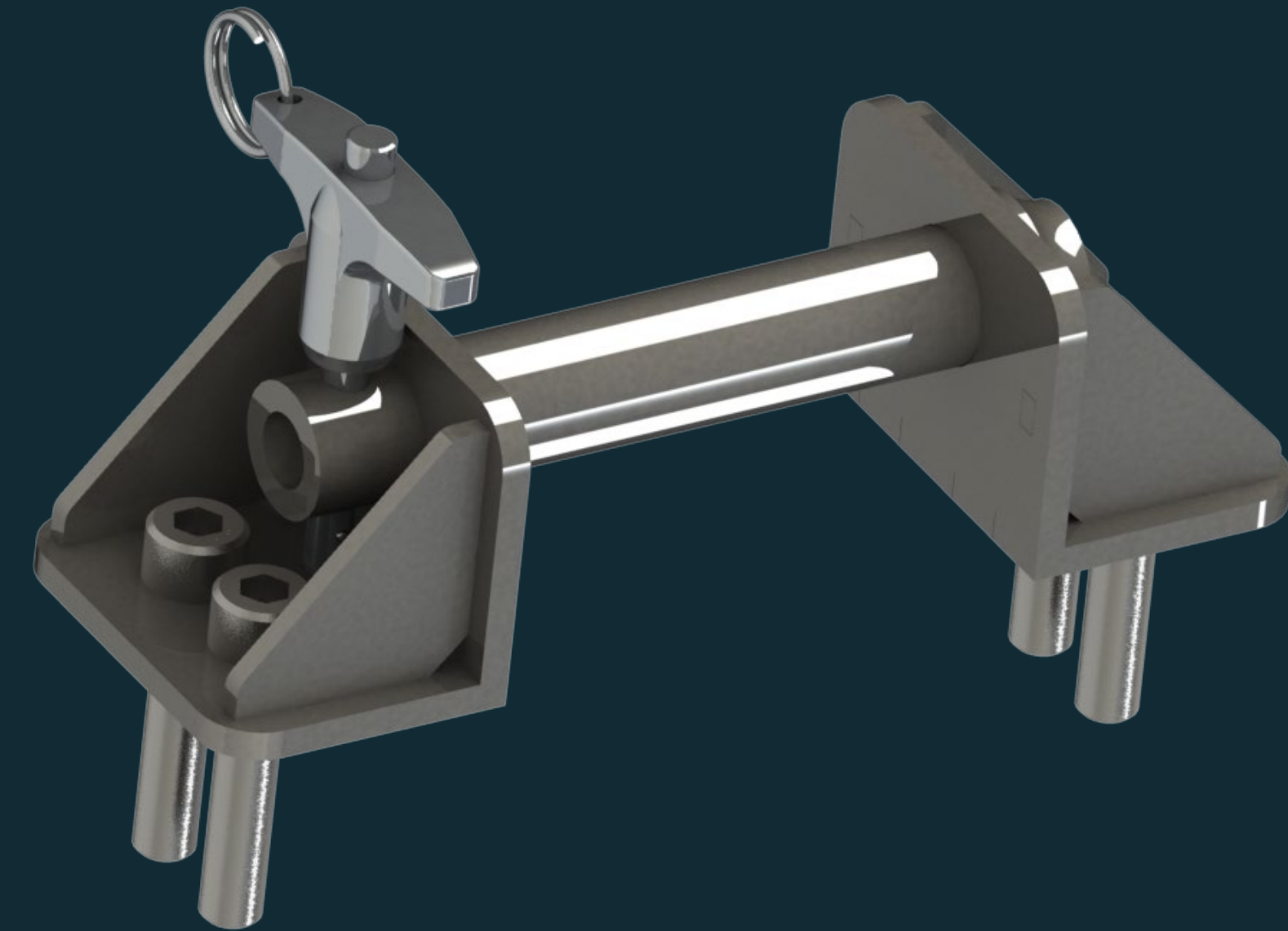
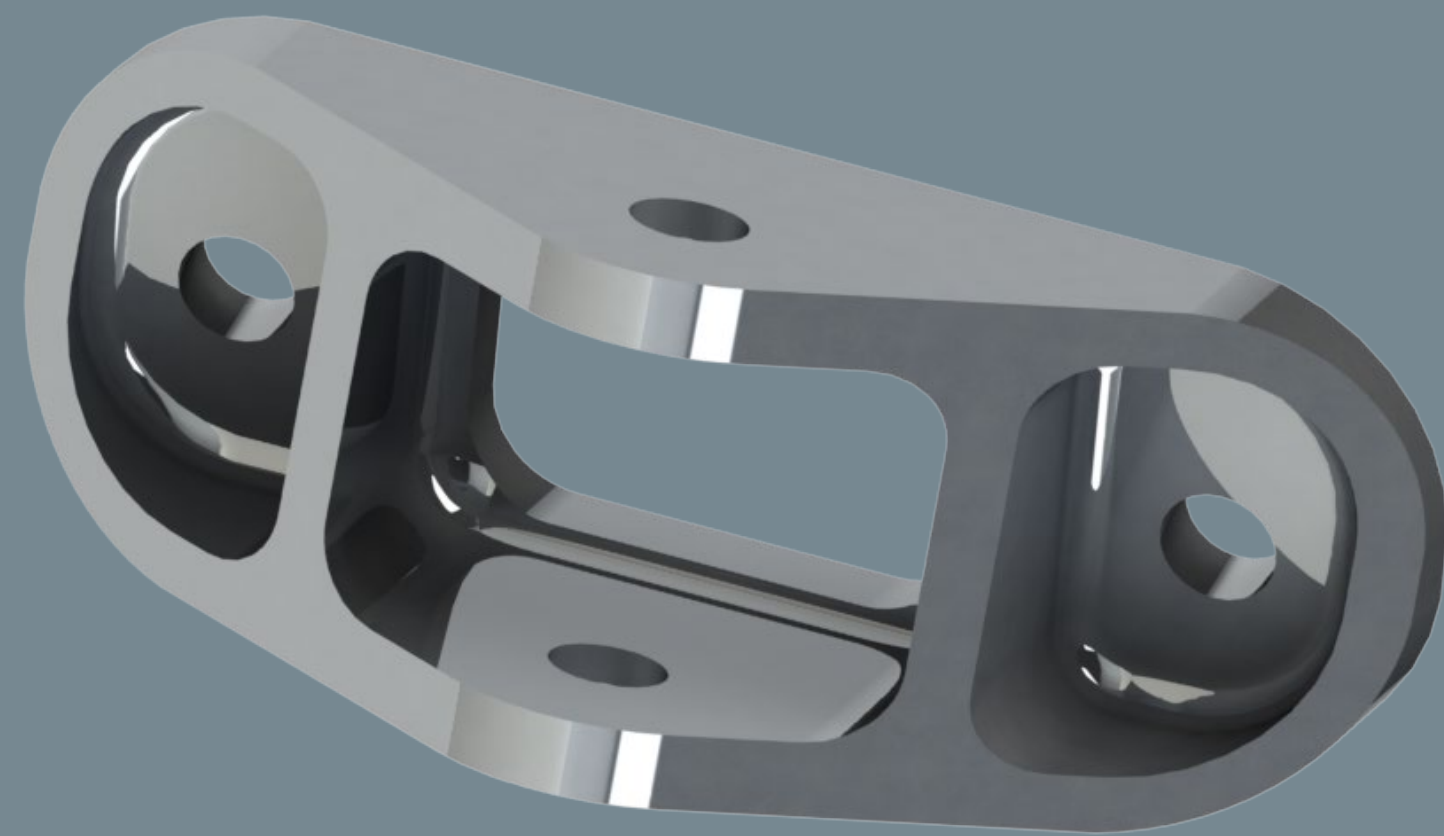


The design process of the steering system has been lengthy and painstaking; the attention to detail is great. This system consists of two main subassemblies, that of the steering rack and that of the steering shaft support. The former lies on the floor of the chassis and accommodates the rack and pinion dyad, which are housed inside a screwed-together rack base and pinion housing. Through their meshing, the rotary motion of the steering wheel is translated to oscillating movement of the rack and tie rods, which push/pull and turn the front wheels. Due to constraints in the steering geometry and the ergonomics of the vehicle, the movement of the steering wheel to the rack is transferred via a double universal joint so that the two eccentric axles of the system can be engaged. This change in the implementation of the system reduced further the weight of the structure as well as normalized the constraints due to space in the cockpit. In fact the design of the system didn't compromise the ergonomics or the robustness of the whole structure.



# Suspension and Driver's Harness mountings

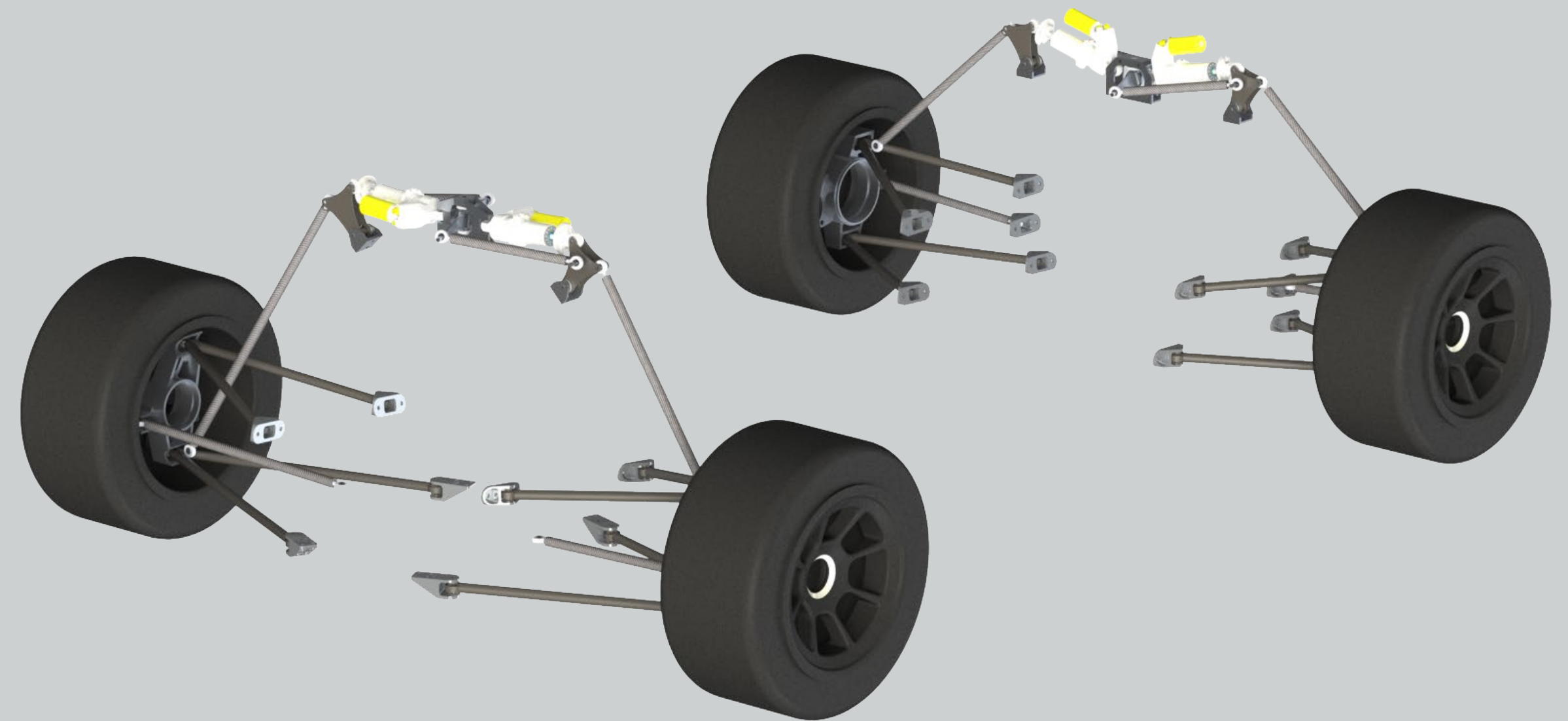
The brackets that attach the wishbones and other suspension components to the chassis had to be designed from scratch as the previous design was deemed unusable due to major changes in chassis and suspension geometry. Nine separate concepts were developed in total and each was evaluated for four loading scenarios (two different loading angles, pure tension and compression). The results lead to the final, improved design, reaching a satisfying outcome, easy to manufacture, rigid and lighter than any previous design.



This year's Shoulder Harness mounting is something innovative for Aristurtle, as the Harness will be mounted directly on the monocoque, instead of the Shoulder Harness Bar that was attached to the Main Roll Hoop. Two separate brackets and a single axis will support each of the two belts and will be attached to the chassis directly behind the driver's shoulders. This ensures the driver's safety and comfort as it no longer restraints his head's movement and creates a tight fit between the belts and his body. All components were designed in conformance with the strict safety demands of the FS Rules by performing detailed Strength Calculations and cross checking them with the Structural FEA results.

The new racing season of 2020-2021 started with strong momentum for our team as we put some new goals on the table in order to improve our under construction new race car. More precisely the Suspension sub-team in cooperation with the new sub-team of Mechanical Design improved and evolved the suspension, braking, steering and drivetrain systems. The general goals of the aforementioned sub-teams are the further reduction of weight and precisely of unsprung mass, the additional improvement of the dynamic behavior of our car and also the improvement of the reliability of the aforementioned vehicle systems. Analytically, we needed to design once again the suspension geometry from scratch because of the changes of the chassis and tractive system that triggered a weight transferring towards the front of the car which greatly improved the weight distribution between the two axles. A goal of the redesign is the furthermore improvement of the car behavior and the feedback it gives back to the driver. A more aggressive suspension design and also the analysis in computing environment helped us to achieve that goal. The aforementioned geometry of course includes the steering geometry which was designed and checked again in order to enhance stability, performance and greater feedback during cornering.

# Suspension

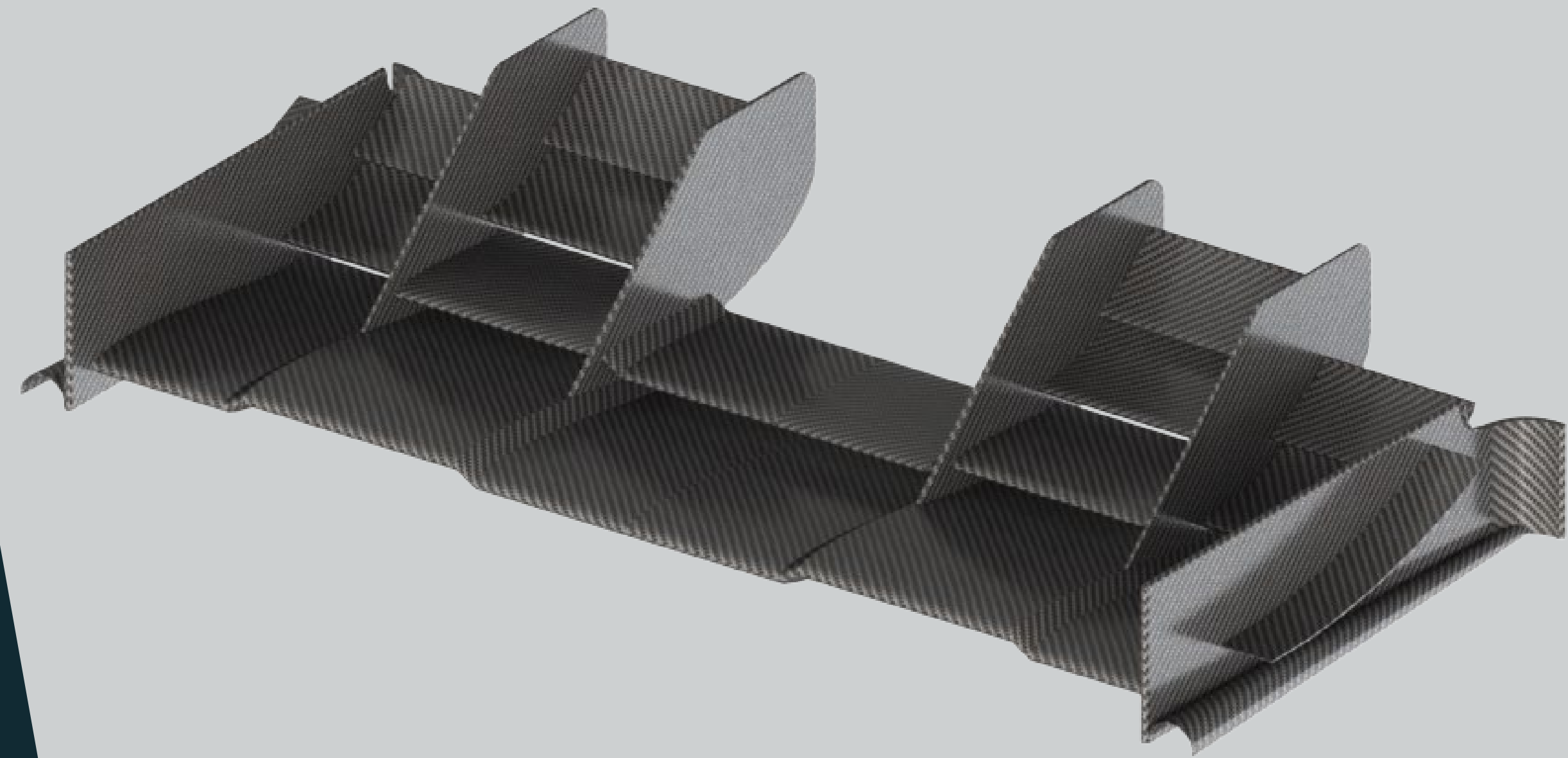




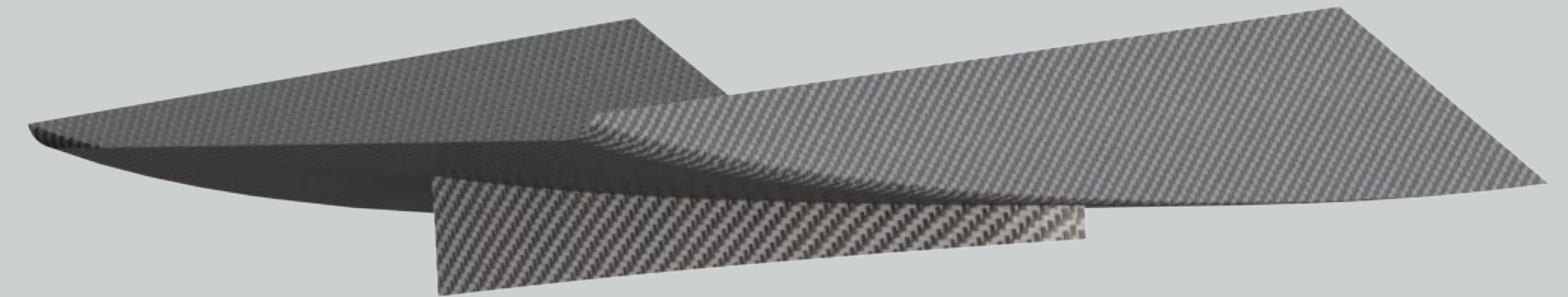
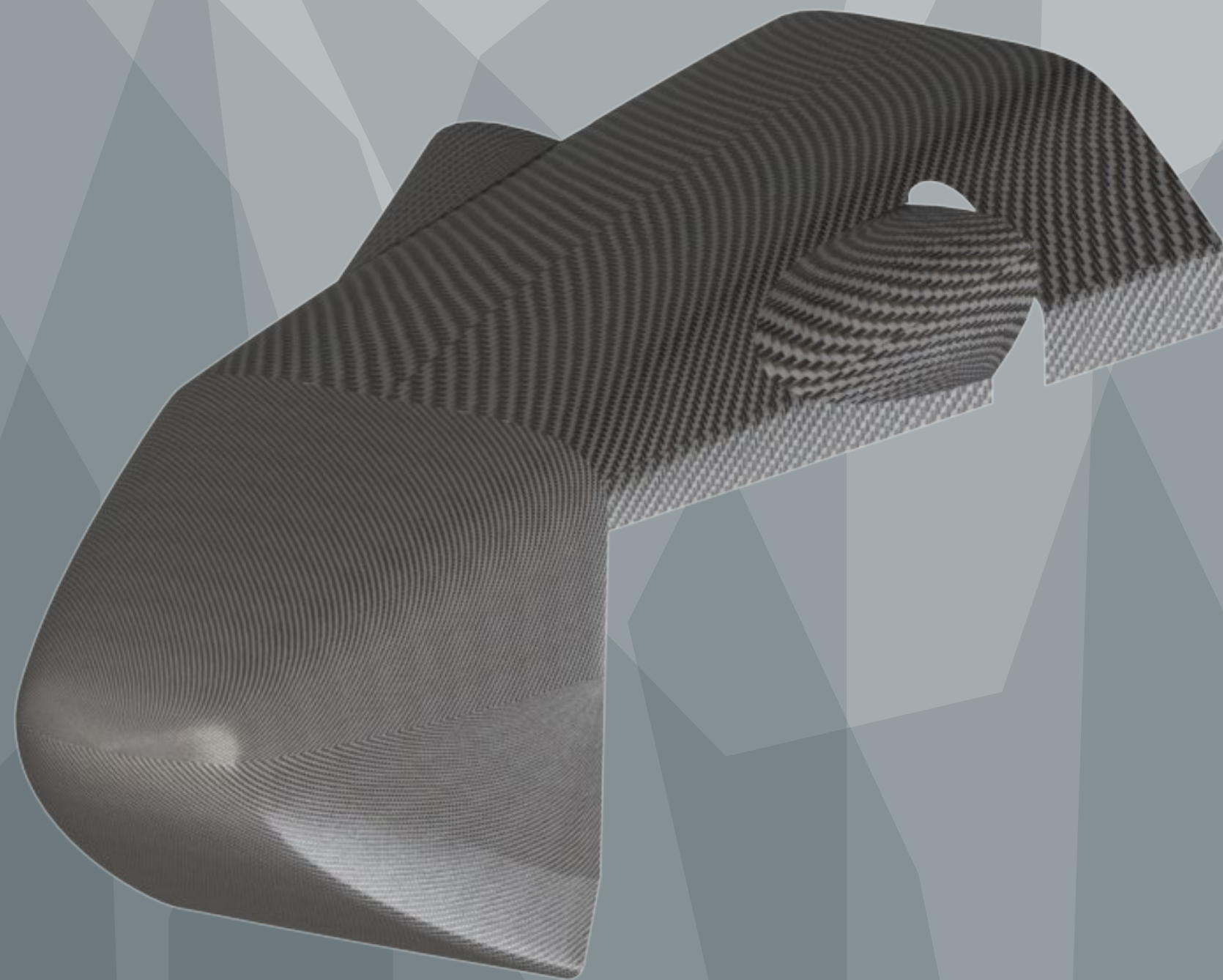
# Aerodynamics

In the course of a radical reconstruction of the aerodynamics department, we decided to completely redesign last years Aerodynamic Package. At first, in full coordination with the Suspension department, we set the goal of maximizing the produced downforce while keeping a delicate balance of the aerodynamic forces to ensure the good response of the vehicle in any dynamic scenario. Furthermore, utilizing the team's knowhow on Composites, as well as trying new material combinations and manufacturing methods we will manage to produce more complex geometries which in turn will improve the aero overall performance.

The first device the airflow comes in contact with is the Front Wing, which effectively tunes the flow distribution to the rest of the aero package and is responsible for the production of 25-30% of the total downforce. The front wing also feeds adequate airflow to the Undertray and using a new and bold design approach, manages to reduce the overall drag of the vehicle by directing the airflow away from the spinning front wheels.



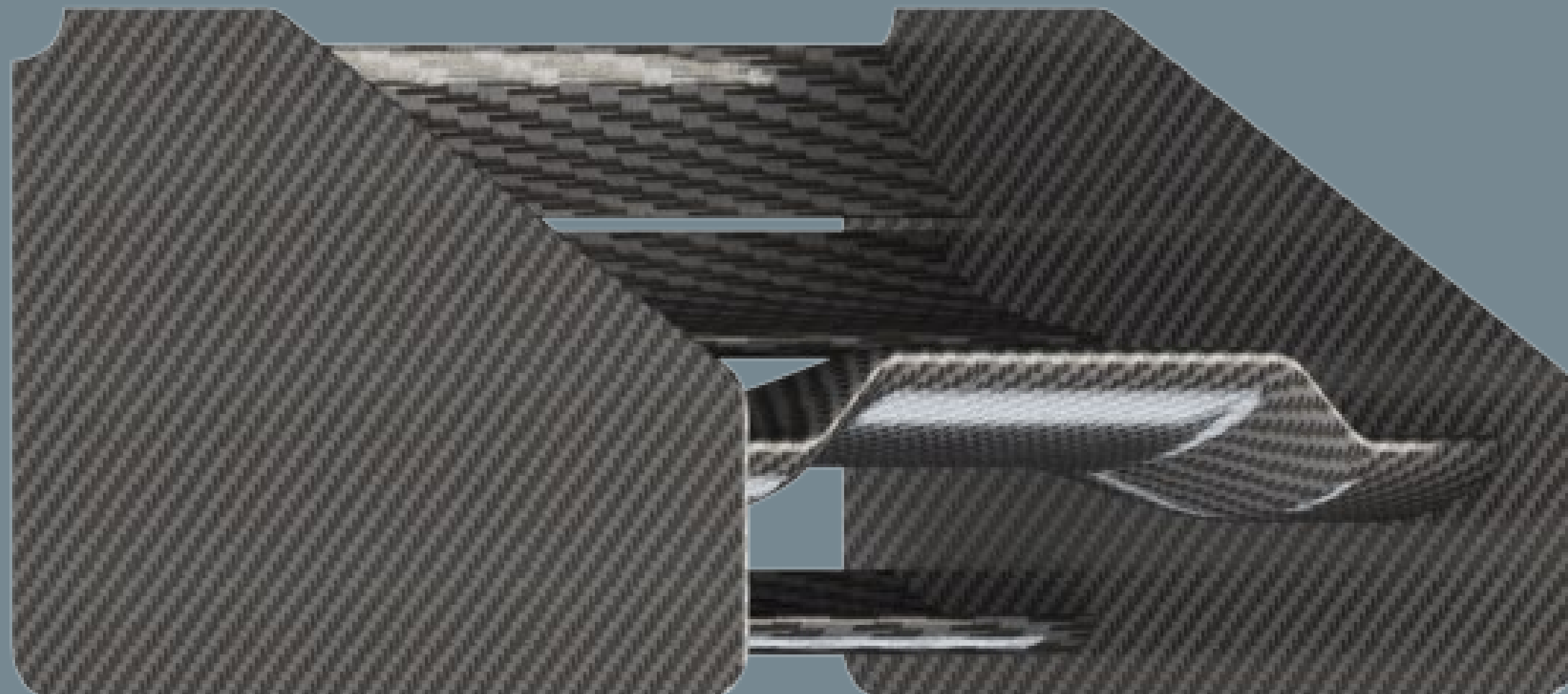
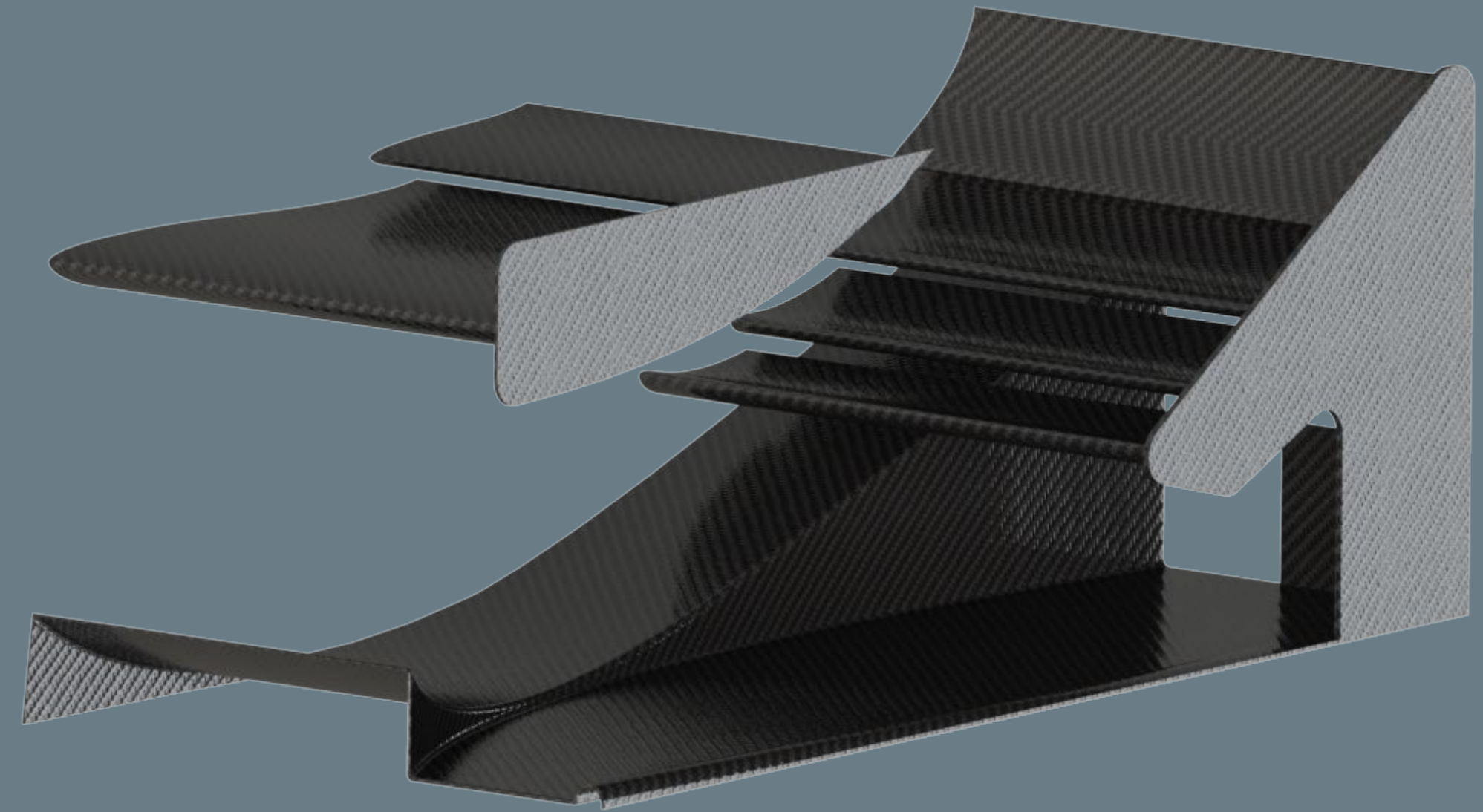
The Nose-cone and the front Suspension Cap also play an important role in drag reduction. The uptilted Nose-cone achieves to increase Undertray airflow with minimal unwanted lift gain, while a different implementation of the Suspension Cap's geometry aims to further reduce drag by better guiding the air around the front Spring-Damper assembly.



The Undertray helps in smoothing out the flow beneath the chassis and, using an air splitter, feeds airflow directly to the sidepods' floor. Its inverse-wing shape increases the produces downforce especially when coupled with the upturned chassis floor and the diffuser, which achieves a uniform increase in pressure, normalizing the airflow.

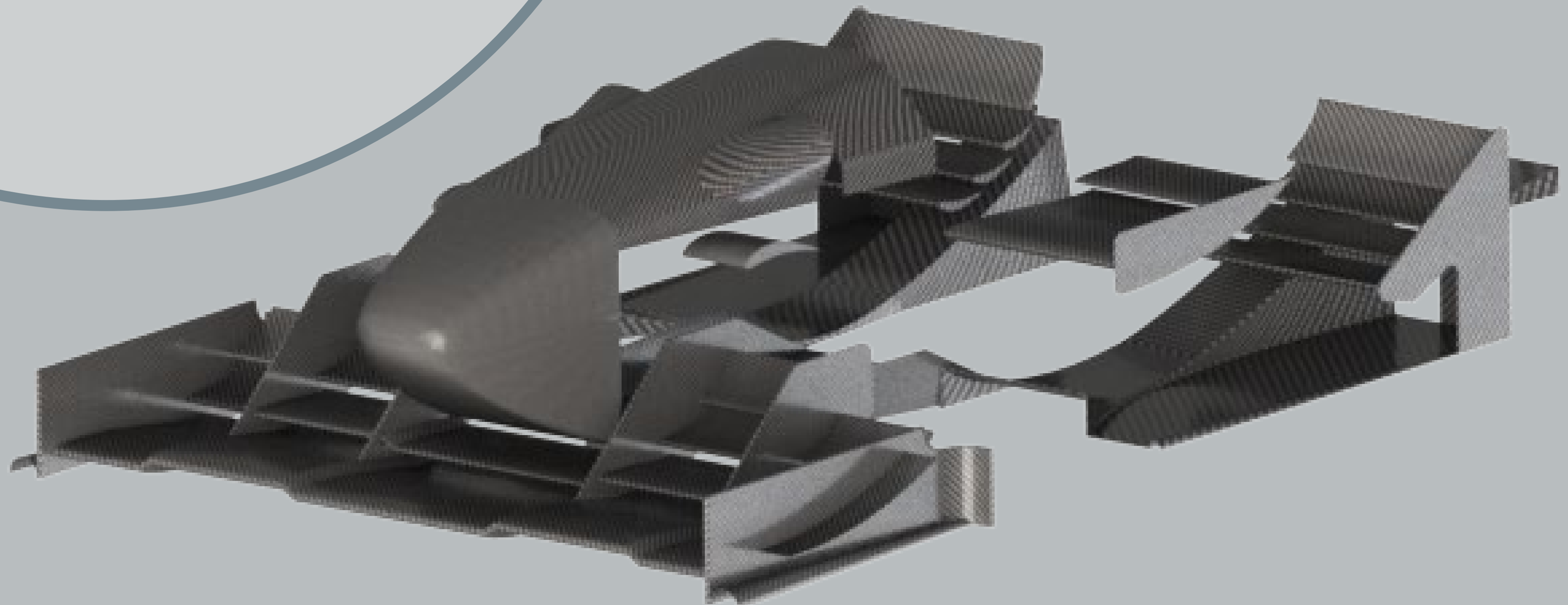
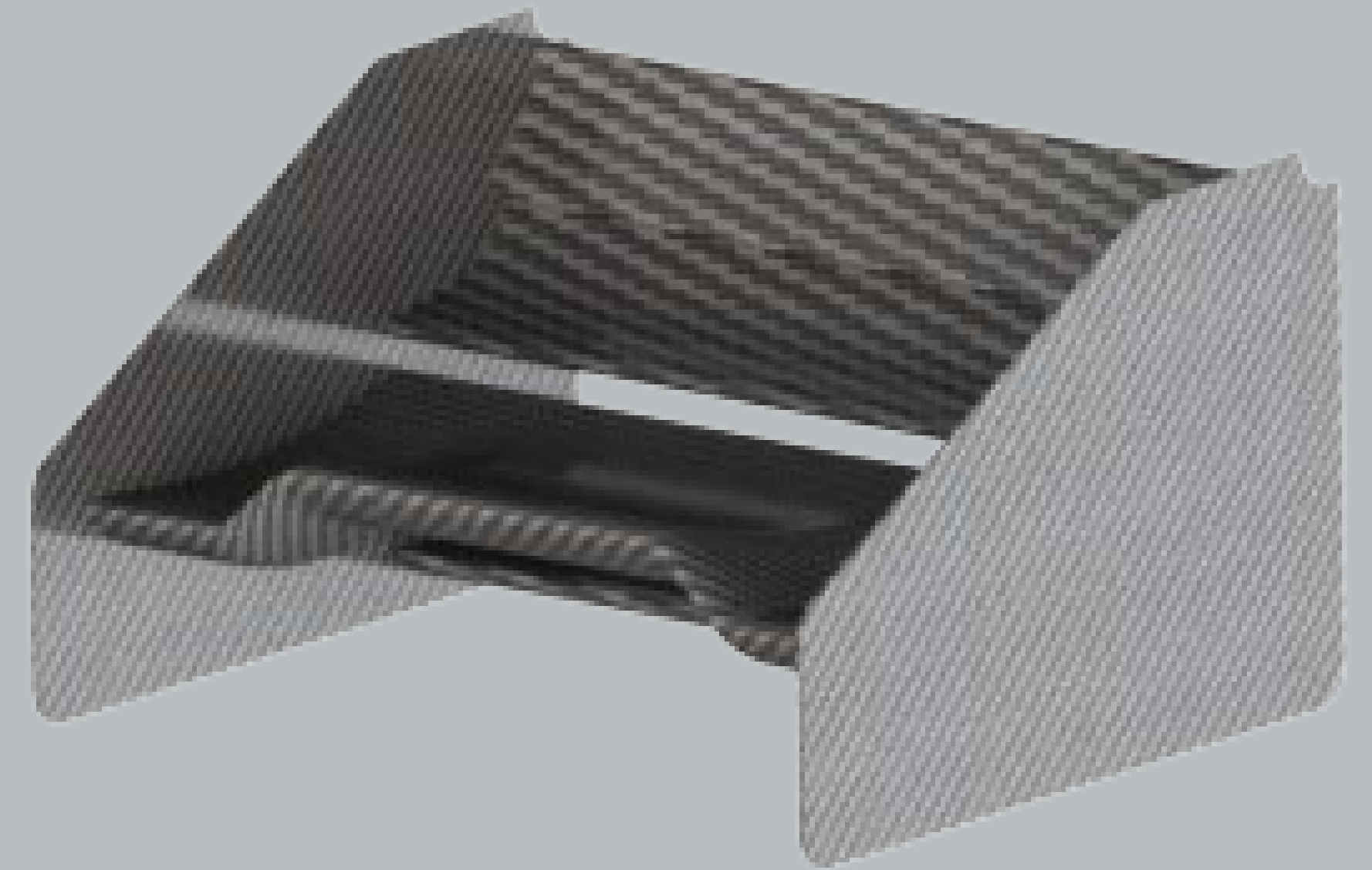


At the two sides of the vehicle lie the Sidepods. They use and form the airflow coming from the front part of the car, assisted by the additional winglets placed directly next to the drivers compartment and serve a dual purpose; Producing downforce and directing more airflow to the Rear Wing.



The Rear Wing was redesigned, with the major change being the main flap's variable cross section, which aims to exploit the flow passing above the drivers helmet. In addition to the change of the main flap, two of the remaining 3 flaps of the rear wing will have a varying angle of attack, functioning as a Drag Reduction System or DRS, as it is well known from F1.

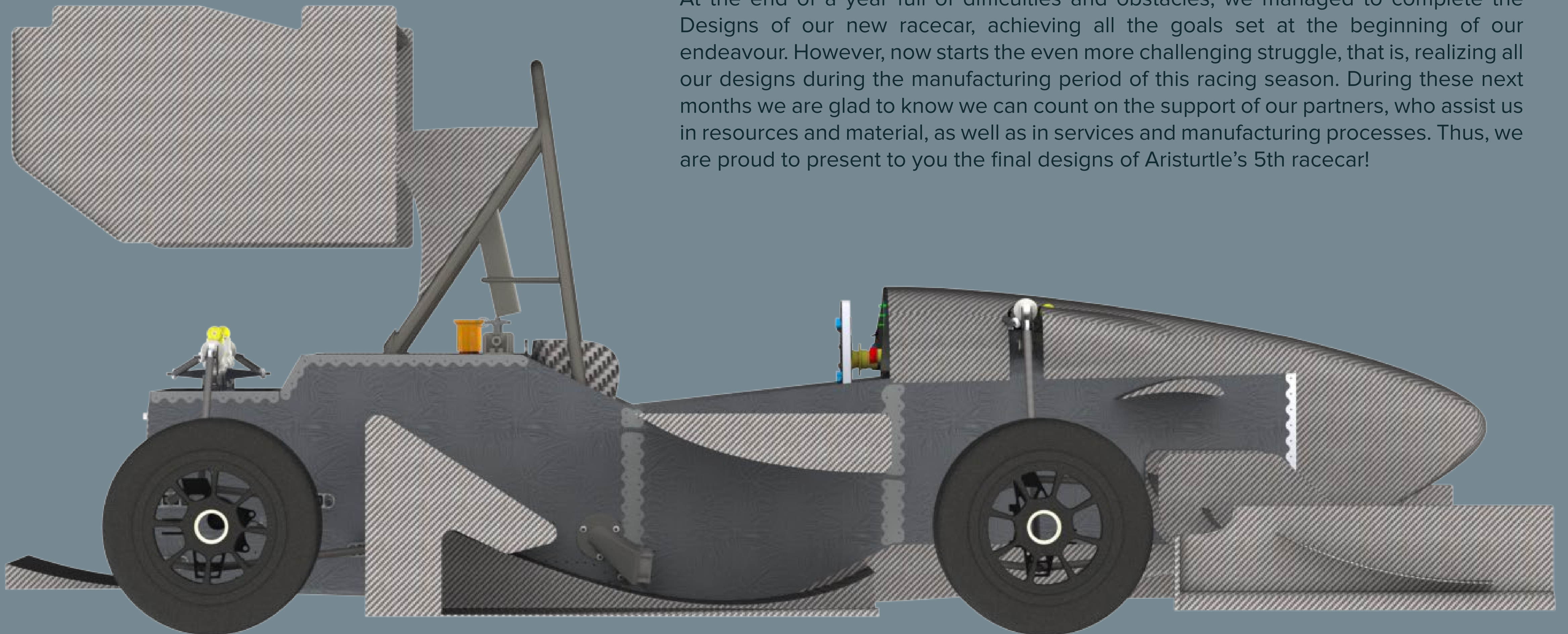
Having having gone through the bulk of the iterative design process, the Aerodynamics Department will continue with further CFD Analyses in various scenarios, in order to ascertain the best dynamic behaviour of the vehicle in a spectrum of movement and positioning combinations. Along with the aero map's setup, the manufacturing of the first aero parts will commence, starting with the mold shaping and finishing.



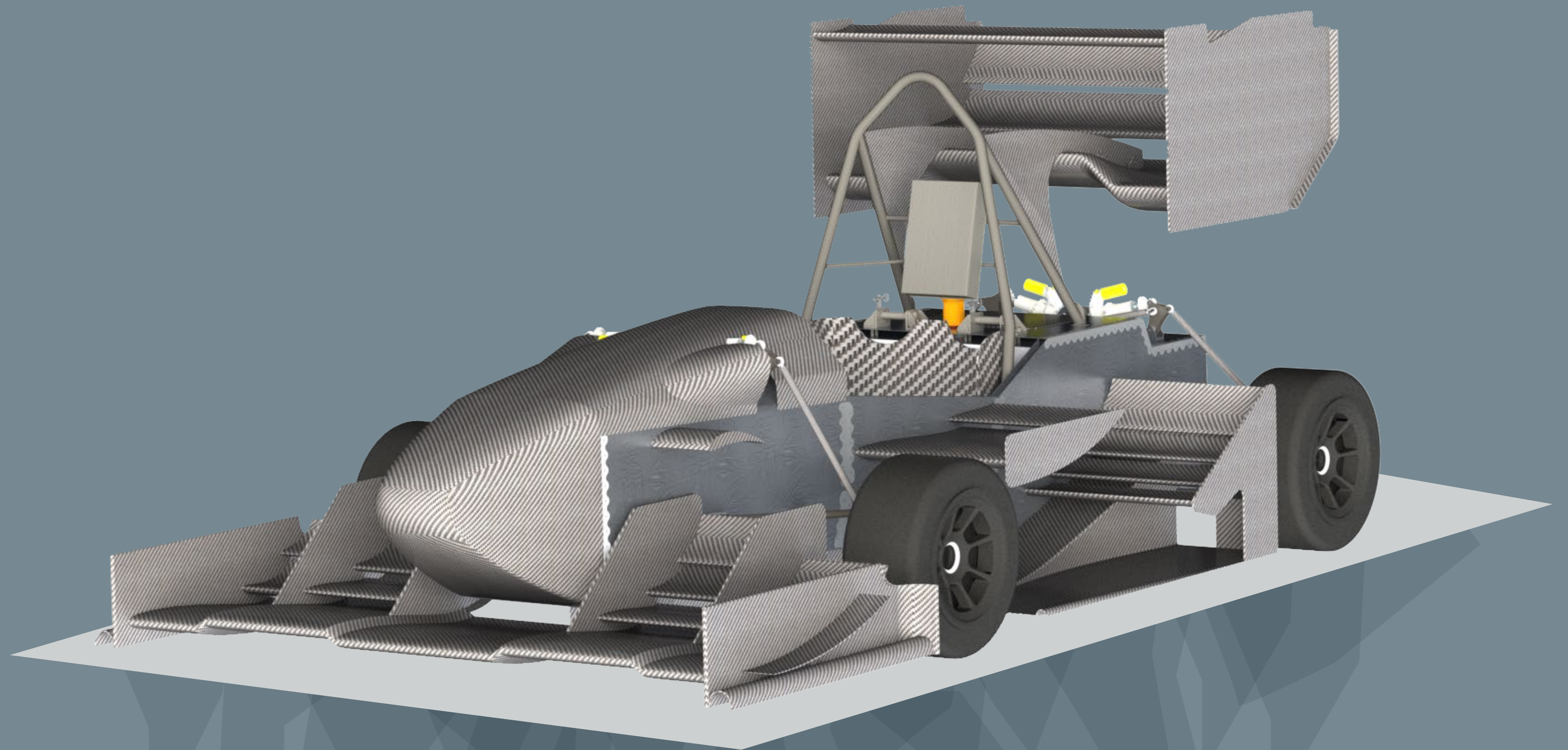


# Final designs of Aristurtle's 5th racecar

At the end of a year full of difficulties and obstacles, we managed to complete the Designs of our new racecar, achieving all the goals set at the beginning of our endeavour. However, now starts the even more challenging struggle, that is, realizing all our designs during the manufacturing period of this racing season. During these next months we are glad to know we can count on the support of our partners, who assist us in resources and material, as well as in services and manufacturing processes. Thus, we are proud to present to you the final designs of Aristurtle's 5th racecar!













# Autonomous System

Following the trend of formula student competitions and the automotive industry in general, Aristurtle made its first steps into autonomous driving in mid 2019. Our first season was an instructive period, where much of the research and experimentation towards developing a driverless car was conducted, but finished abruptly due to the pandemic.

Armed with a year's worth of experience, this season we made decisive steps towards our goal, by freezing the design period early and rapidly implementing the core subsystems, leaving a wide time window for testing and incremental improvements.





# Software

Designing the software for an autonomous vehicle combines the challenges of developing cutting-edge technologies and a reliable real-time system at the same time. After a year of research and experimentation, this season's goals are implementation and rapid prototyping. This workflow allows us multiple test iterations, a much needed feature when diving into the depths of an emerging industry.

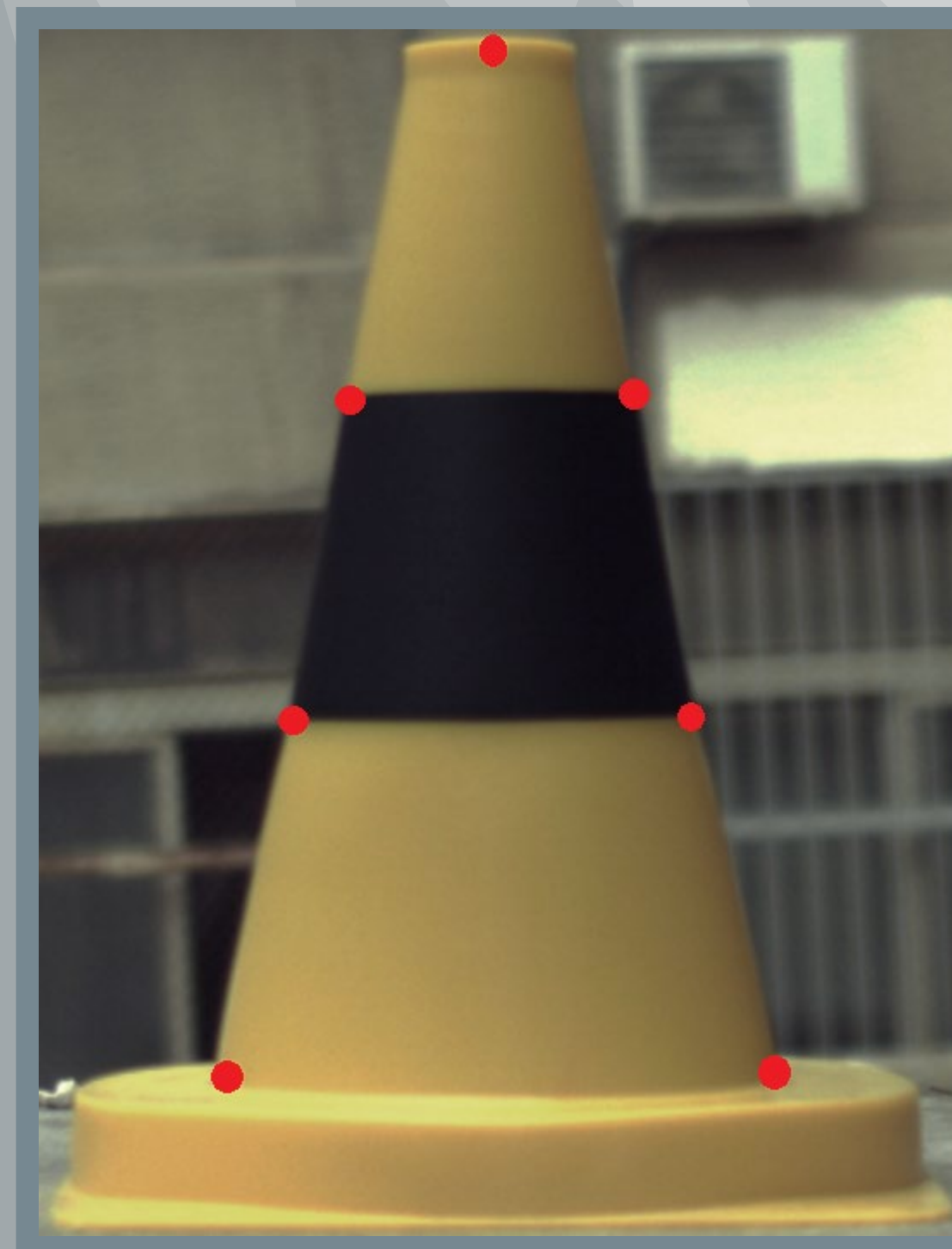
Software development was also easy to adapt in periods of quarantine, since testing is possible at any level in our self-developed ROS2+Gazebo simulation and data collected from the real world.

# Cameras

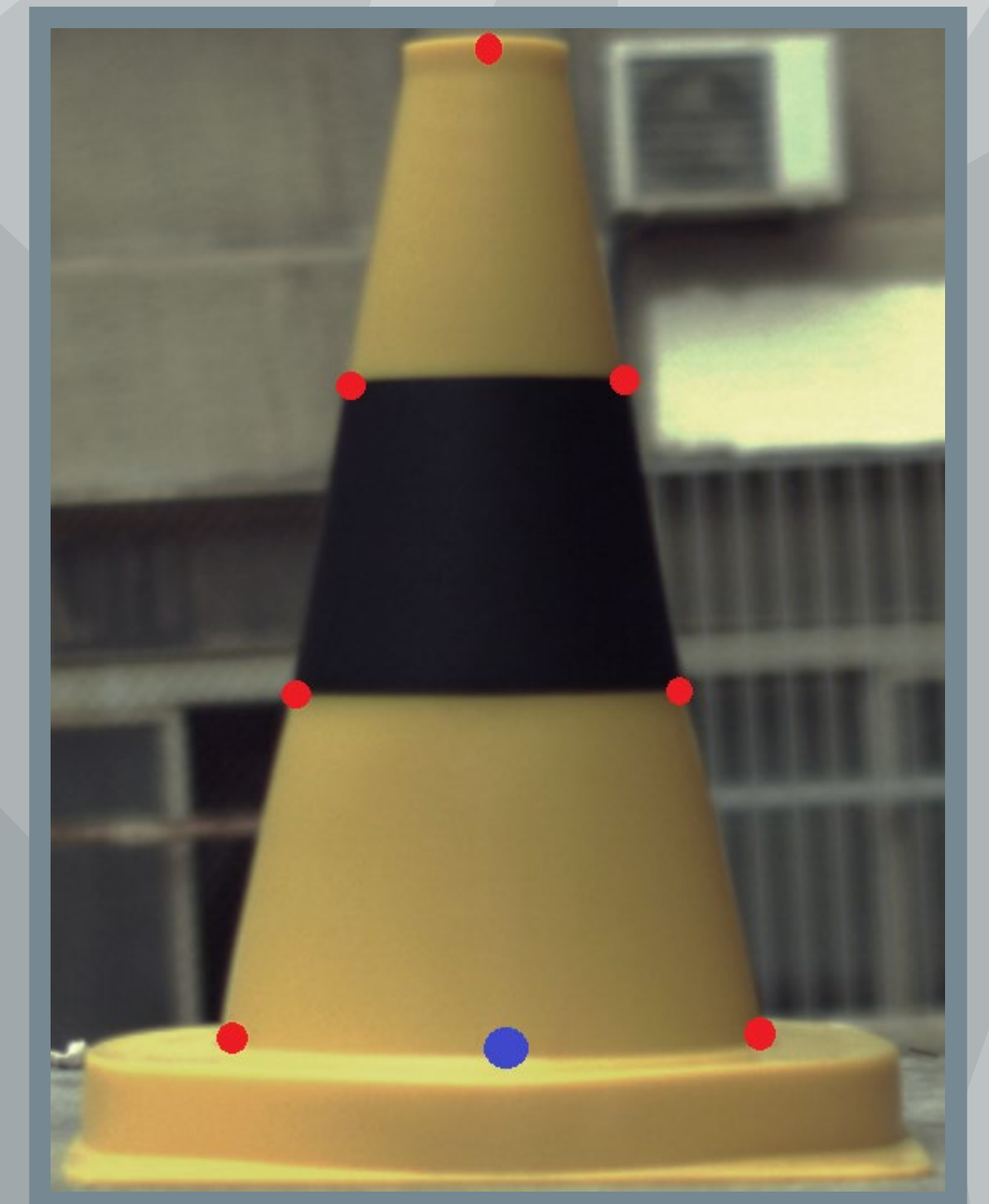
At the start of the season, the camera perception pipeline was redesigned from the ground up. First each cone is localized in a bounding and classified with the help of the state of the art object detection neural network, YOLO. Then, another convolutional neural network regresses 7 key points in each cone. Using those points and a-priori knowledge of their position relative to the cone, we can run a Perspective-n-Point algorithm to precisely estimate the pose of the cone with respect to the camera. RANSAC is applied to the input of PnP to avoid errors due to potential badly estimated key points.



Cone localization: YOLOv4



Keypoint regressor



Cone base center estimation with PnP

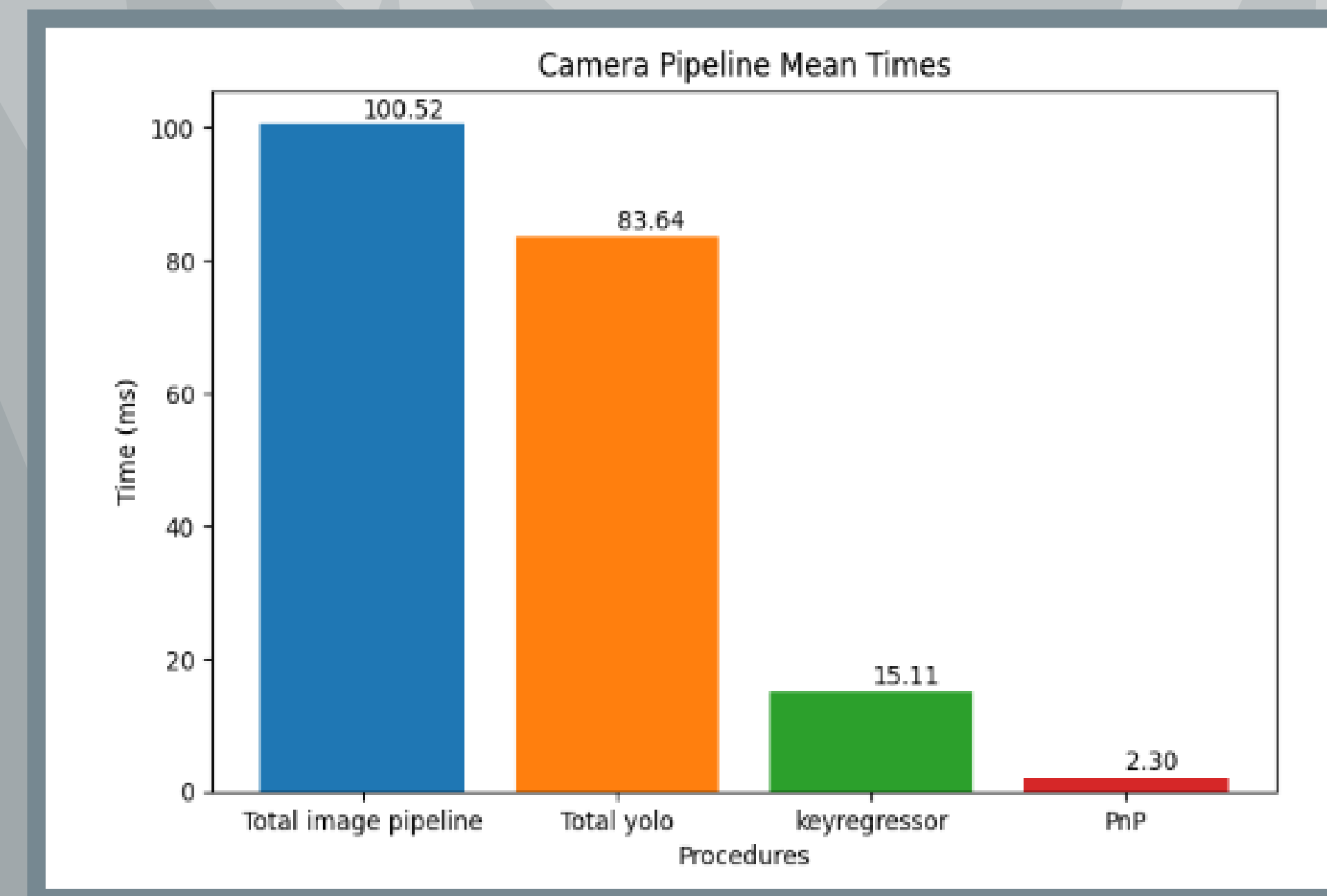
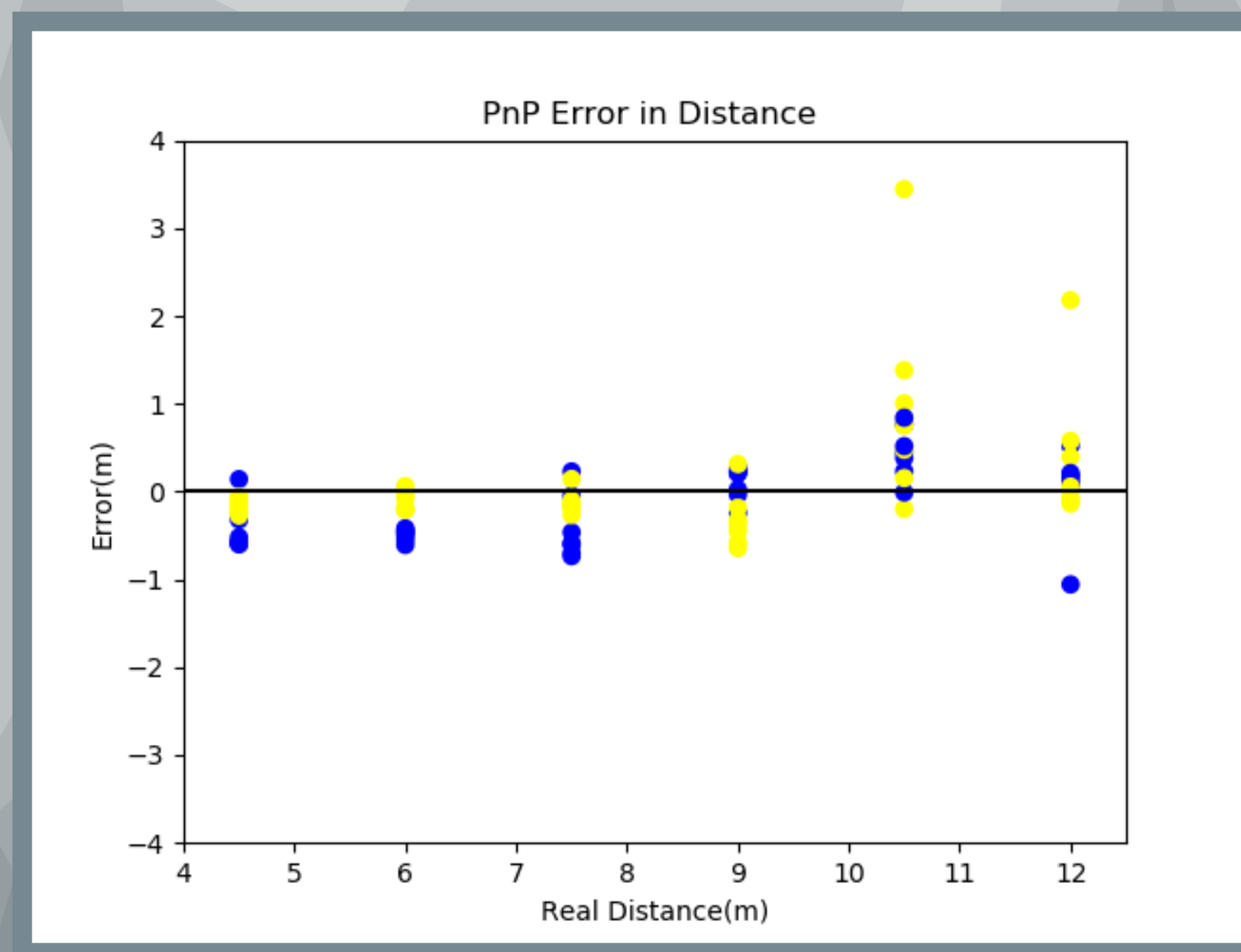


After a basic implementation was completed, the pipeline was incrementally improved and fine tuned considerably in order to meet the demanding nature of real time perception in an unknown environment. We migrated from YOLOv3 to YOLOv4, a simple adjustment which increases the mAP of the detector network by over 10%. Aristurtle is also now a proud contributor of the new and refined FSOCov2 project, increasing the size and quality of our training dataset.

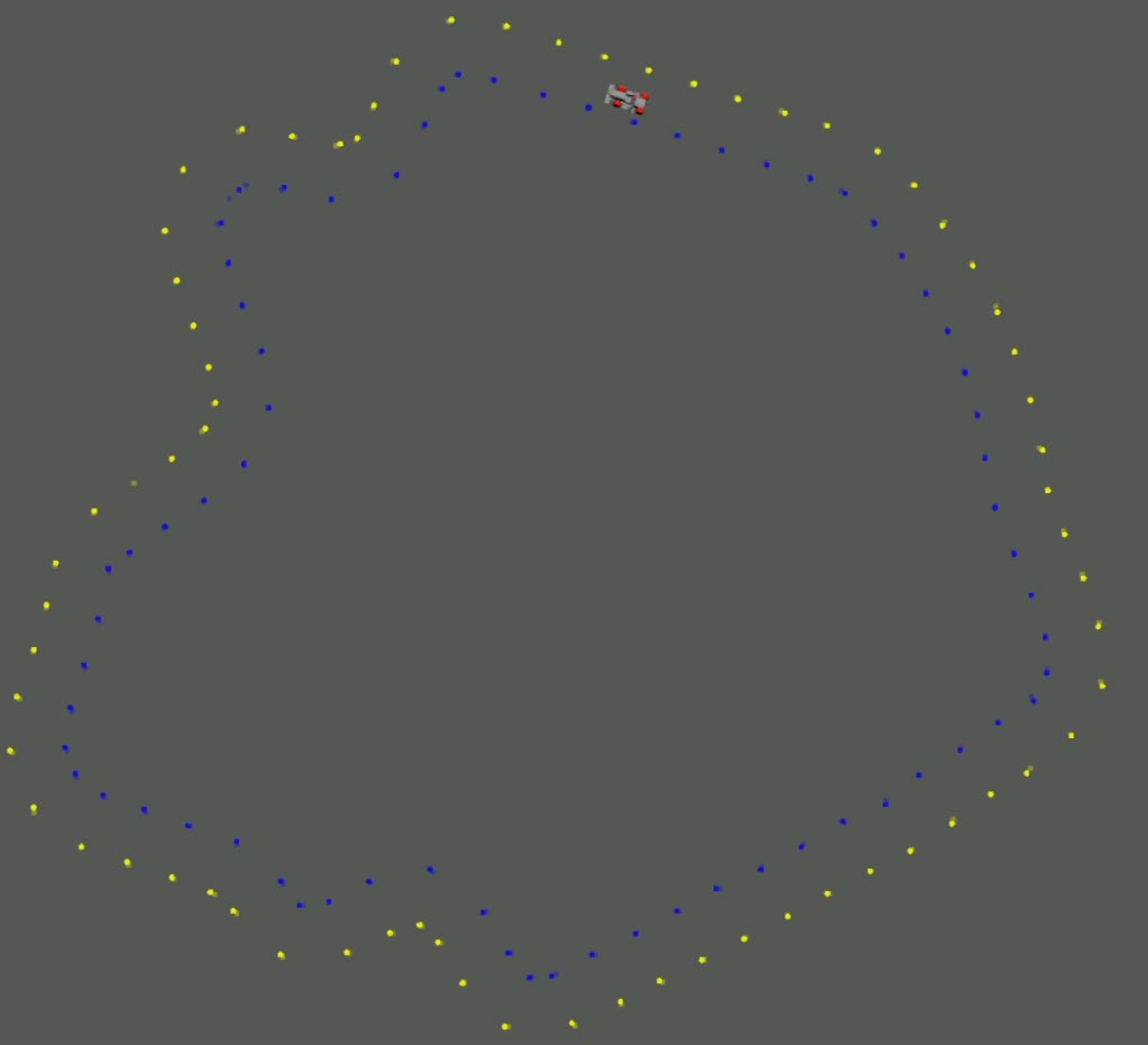
Both YOLOv4 and keypoint regressor networks were deployed to TensorRT, NVidia's network inference engine for optimal inference times on NVidia hardware, reducing the total processing time by up to 8 times relative to the initial implementation.

Furthermore, by calibrating the networks with test images at build time, we can enable inference at INT8 precision, dropping each network's inference runtime further by a factor of 2.

When applying all the optimizations mentioned, we could achieve an accuracy of 30cm ( $1\sigma$ ) with a processing time of approximately 100 milliseconds, at up to 10 meters distance on Jetson TX2. Through our recent collaboration with Cincoze, we will become able to use a fanless rugged computer equipped with a PCIe GPU, giving us approximately 4 times better floating point performance.



The new architecture also provides a powerful interface, accepting image input from a device, still images, videos and cameras simulated in gazebo, allowing for flexible and automated testing and benchmarking.



# Localization & mapping

Of course instantaneous measurements are not sufficient in order to create long term and performant plans for controlling the vehicle. Using accumulated environment measurements from our cameras and lidar, we can create a map of the perceived environment through SLAM algorithms. Over the span of the last few months we examined a new approach to localization and mapping, a graph based SLAM. Eventually, a custom implementation based on g2o (Kummerle, Grisetti et al.) was developed. Some of its highlights are:

- the incorporation of color information in the vertices, a novelty avoiding the need to match color information to the map at a separate step which is vulnerable to misassociation.
- Negative detection information
- Only updates when a new input is sufficiently novel; does not waste computational power.
- Up to 70 milliseconds total update time

Again, a lot of care went towards testing. A simulated test environment was developed, which provides freedom in specifying simulated environment perception and position estimation input latencies and artificial noise. The algorithm remained robust against a multitude of different configurations including tricky track layouts and conservative levels of input latency at noise. The implementation is ready for testing on real data once social gatherings become safer.



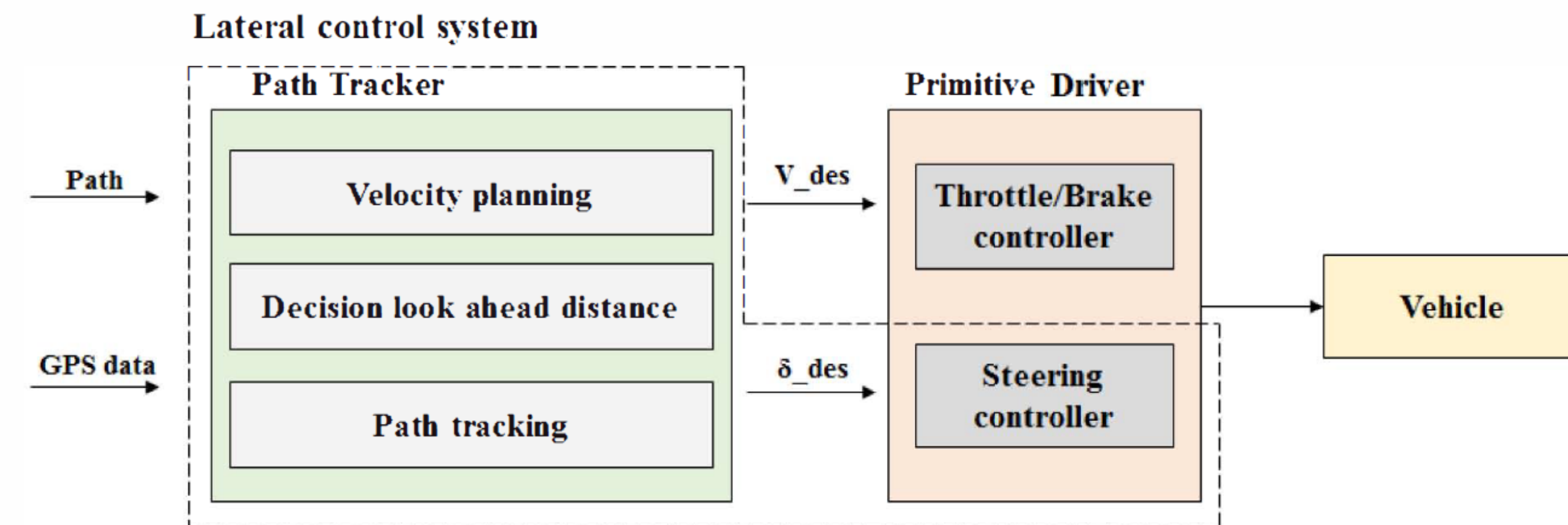
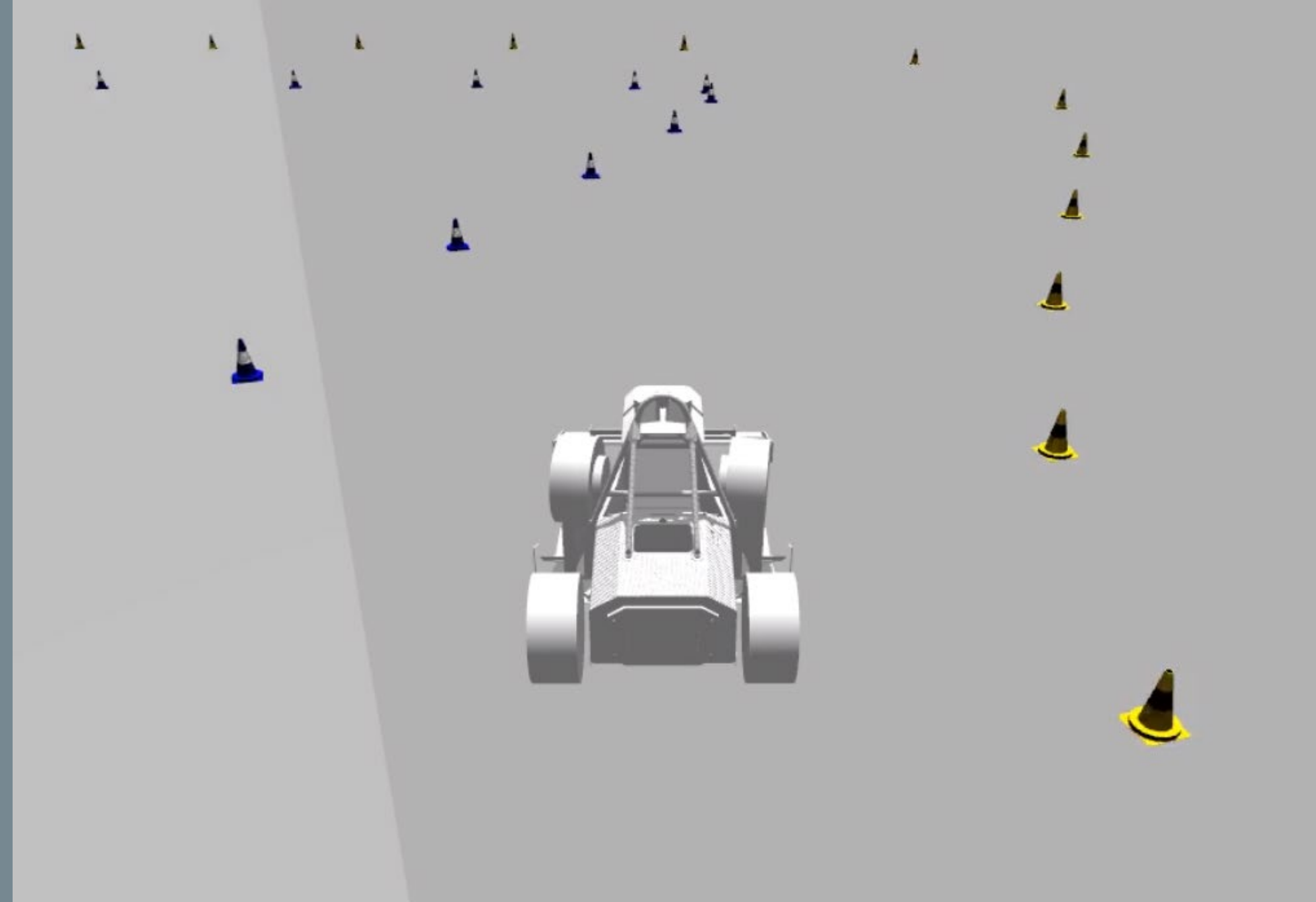
# Control

Now that a map of the environment has been created, we are finally able to plan a driving strategy and command our actuators.

An important prerequisite for effective vehicle control is an accurate vehicle model. A kinematic representation is accurate in low velocities but inaccurate otherwise. Conversely, a dynamic formulation which models slip angles and tire forces is much better at high speeds but practically unusable at low speeds. Our new model combines the two to bring the best of either the kinematic or the dynamic formulation, depending on the situation.

This semester we prototyped a modular approach for controlling the vehicle, using a path planner, a longitudinal and a lateral controller. The path planner receives a map from SLAM, and creates an array of goal points for the vehicle to follow. Those points are then fed into a pure pursuit lateral controller and a PID velocity controller that finally compute commands for the actuators based on the desired trajectory. The lookahead distance and desired velocity are made adaptive to the curvature of the path, similar to a human driver.

Thanks to our partnership with embotech this year, we are also working on a vehicle controller based on non-linear model predictive control, one of the most common and successful control methods for autonomous driving.



# LiDAR

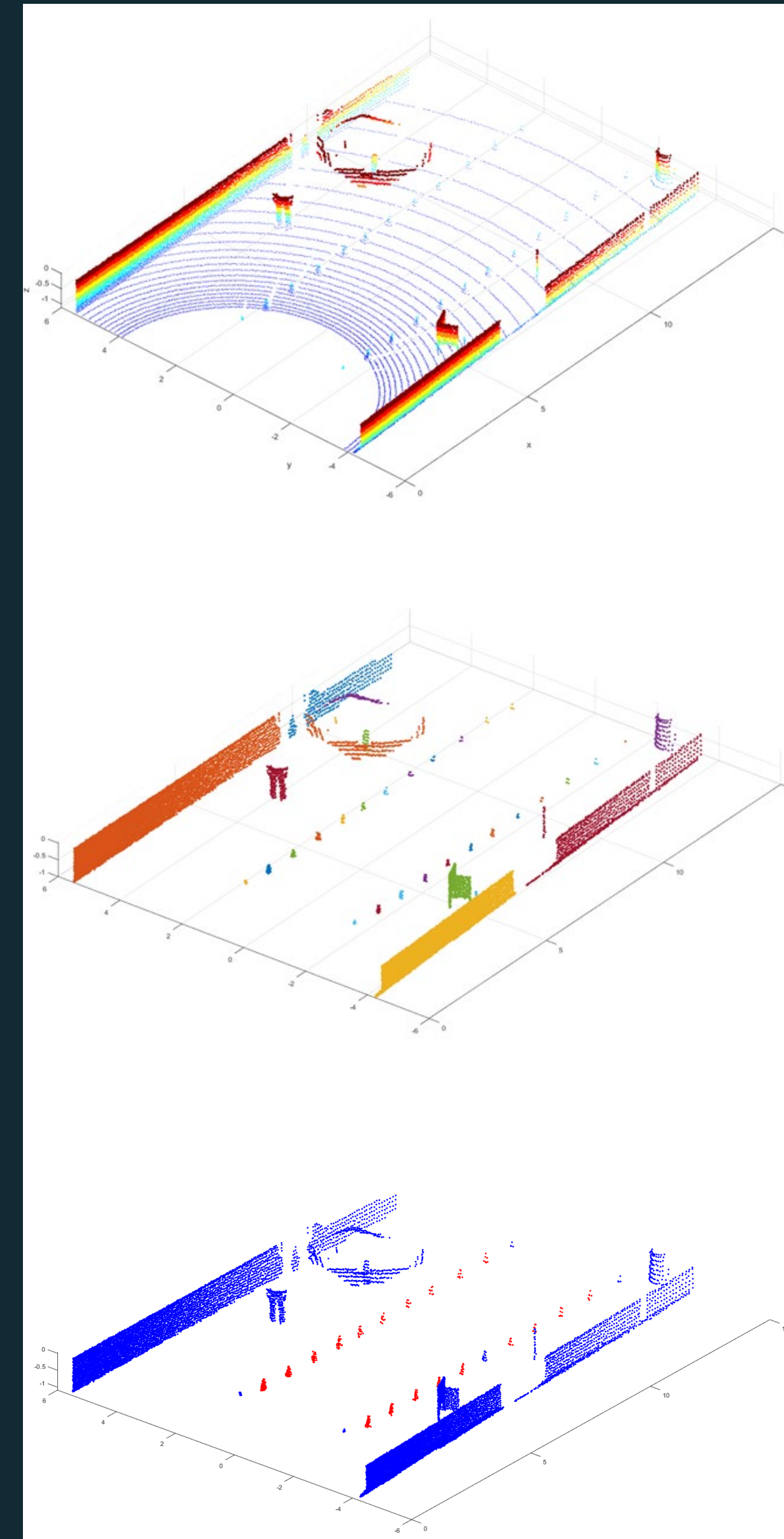
A LiDAR sensor (LIght Detection And Ranging) is a perception sensor for measuring distances by illuminating a target with a number of rays and measuring the time they need to reflect back to the sensor. With this method, one can make 3D representations of the environment by accumulating the points measured into a pointcloud.

LiDAR sensors are quickly becoming one of the most used perception sensors in the automotive industry and we decided to follow that tendency.

Having two perception sensor pipelines detect cones offers many advantages. First of all, it ensures that in case of a failure on one of the two sensors, there is a redundant system still running. Furthermore, the accuracy of the map generated by the SLAM algorithm increases the more perception sensors are used, allowing for more robust control and localization.

Last year, we modeled several LiDAR models in our simulation and examined possible locations to place the sensor. Careful study of the results led to our team acquiring an OS1-32 LiDAR model from Ouster. Since the specific variant captures points below its horizon, we decided to place the LiDAR below the top of the main roll hoop, along with the cameras using a common mounting.

This summer, the pipeline that detects cones from LiDAR pointclouds was designed and tested using MATLAB. At the start, a distinction is made over points that belong to the ground and points that belong to an object. After this step, ground points are discarded while each object is classified using its geometric features as a cone or non-cone object.



Raw pointcloud image generated from a LiDAR sensor

Pointcloud after ground removal

Pointcloud after cone classification. Objects in red as detected as cones while blue are detected as non-Cones





# Hardware and Electronics

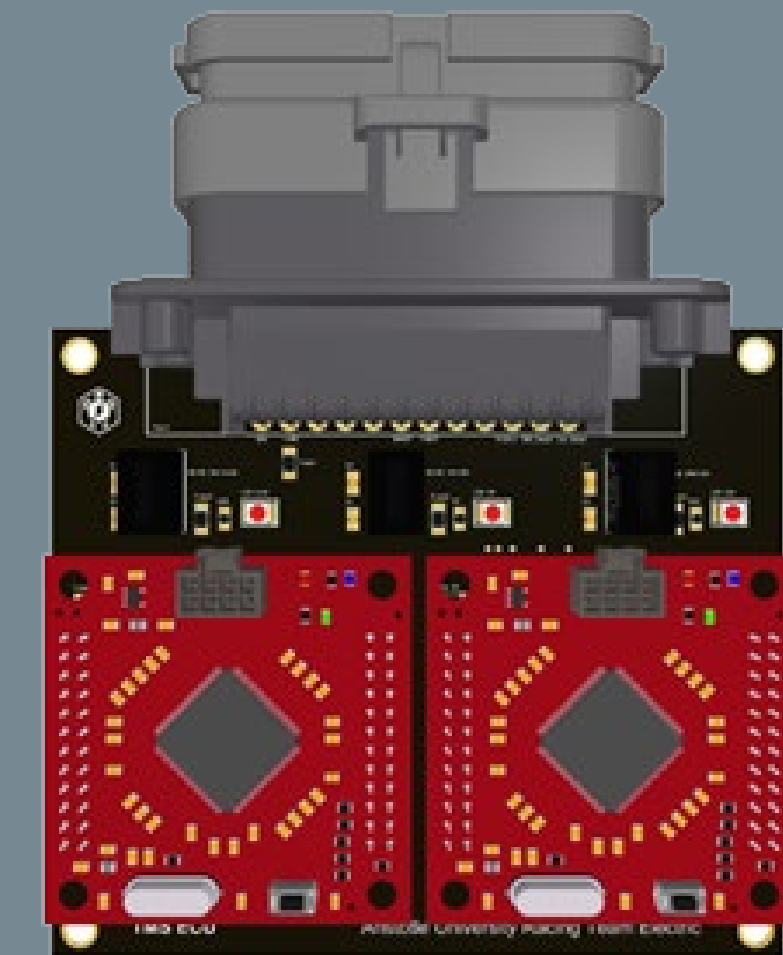
This category includes additions and revisions to the electronics of the vehicle. Since safety is critical in a driverless vehicle, many of these changes are made to ensure the vehicle's integrity, like the Emergency Brake System. Furthermore, new subsystems are added to provide our vehicle with the capabilities of the driver, like steering wheel actuation and brake pedal actuation. Finally, indicators that signal the vehicle's state are needed so a person can understand the car's condition from a distance.

# ECU

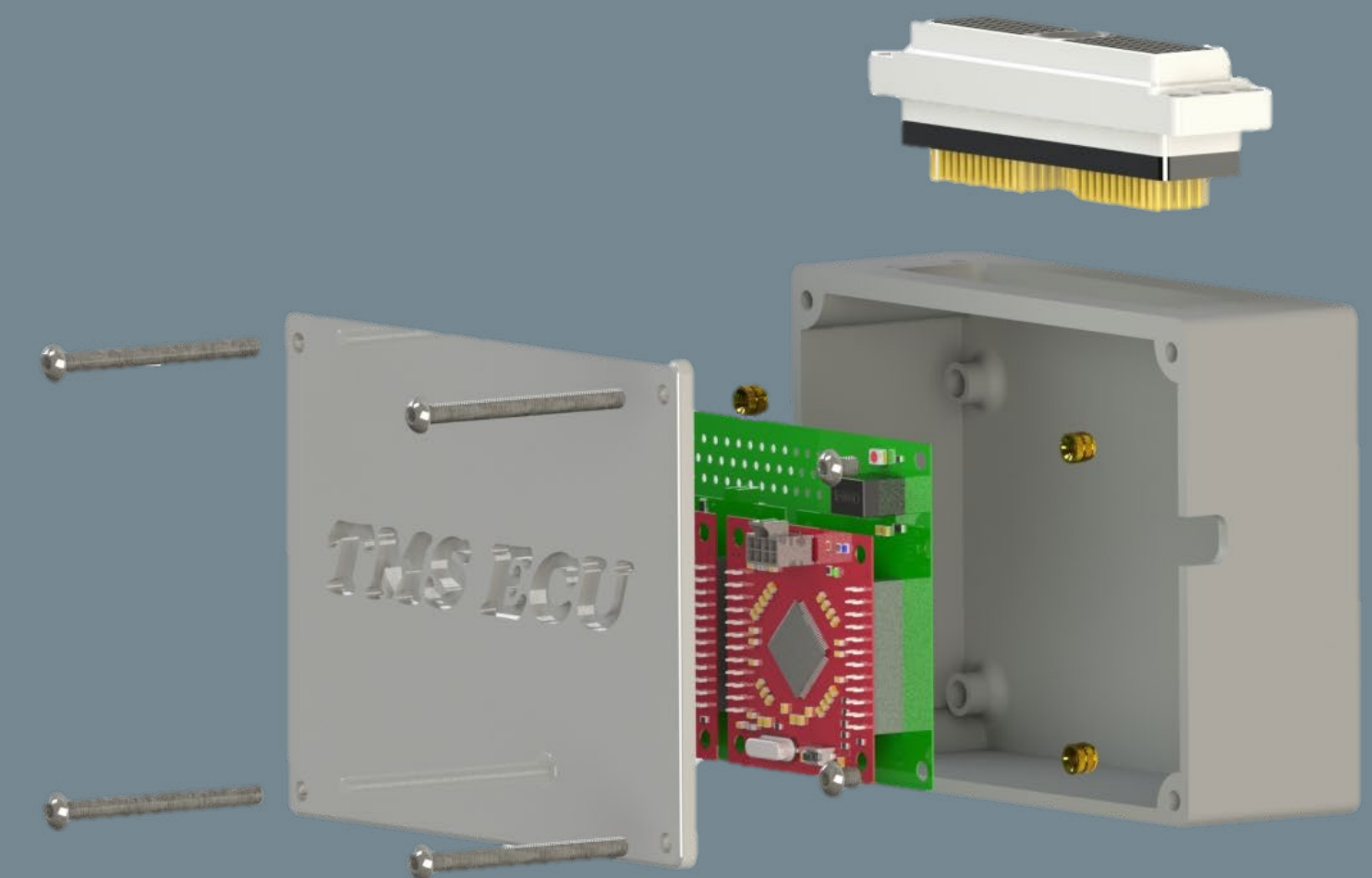
Thetis' powertrain remains electric. One of the main components of Electric Vehicles is the Electronic Control Unit (ECU) responsible for collecting information from the network of microcontrollers and sensors in the vehicle, and performing vital tasks such as commanding the motor controllers.

Thetis accommodated a dSpace MicroAutoBox as an ECU but since this specific model will be used on the new Electric Vehicle, we had to come up with a new plan for an ECU. We decided to use two self-designed TMsTurtle microcontrollers that host a TMS320, a microprocessor developed by Texas Instruments. The main reason that led to this choice is that the programming environment for the dSpace MicroAutoBox used by our EV team is Simulink. TMsTurtle can also be programmed through Simulink. This way, we can easily migrate, at a software level, from a dSpace ECU to a custom-made ECU while also tracking the changes made to the motor control pipeline by the members of our EV team.

A Printed Circuit Board (PCB) was designed to house the two microcontrollers. One MCU is responsible for communication with the rest of the vehicle through a Controller Area Network (CAN). The second MCU is used for communication with the motor controllers. A serial interface is implemented for communication between the two TMsTurtle.

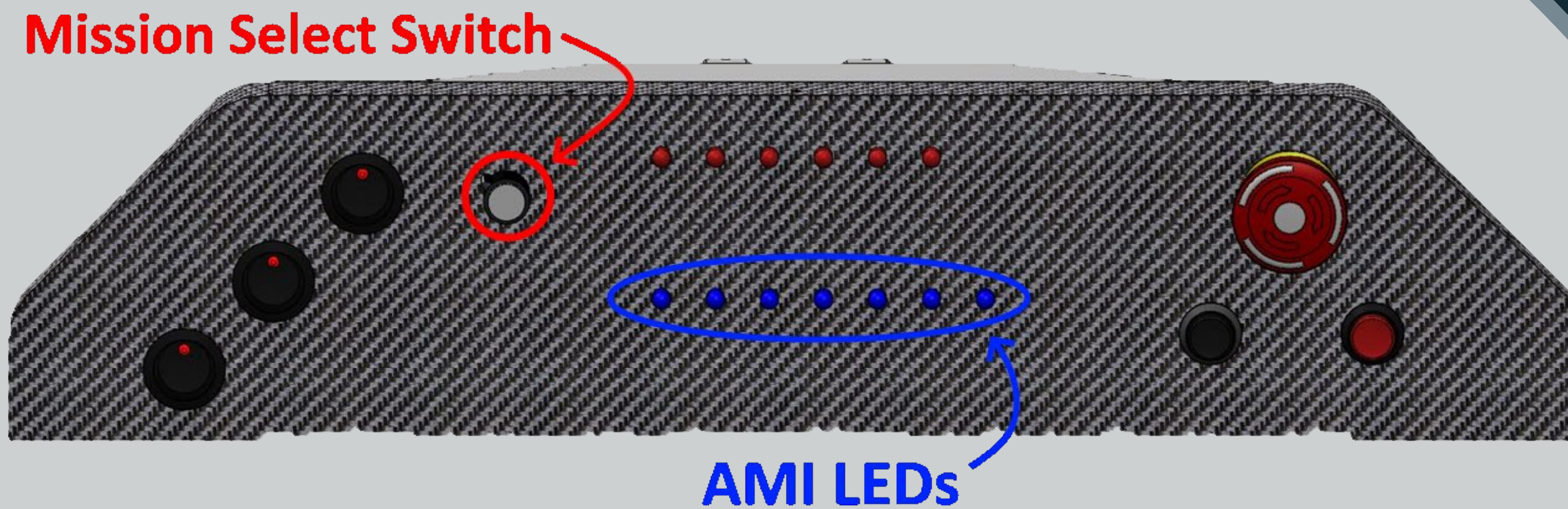


The ECU PCB with the two MCUs



A prototype casing designed for the PCB





LEDs and rotary switch position on the dashboard panel



AMI PCB location inside the dashboard housing

# Autonomous System Indicators

Two are the main indicators used on our vehicle: The Autonomous Mission Indicator (AMI) and Autonomous System Status Indicator (ASSI). The AMI indicates what mission is currently selected (e.g. Autocross event) and the ASSI indicates in what state is the vehicle in the selected mission. Each indicator utilizes a PCB.

The AMI indicators (LEDs) are located on the dashboard panel, in the cockpit. The AMI PCB is located inside the dashboard housing. An sTurtle (custom-made MCU based on STM32F4) is responsible for their operation.





The ASSI are located on each side of the vehicle behind the driver's compartment, coincident to the main roll hoop. They consist of high luminosity yellow and blue LEDs. Depending on the Autonomous System State, they flash or stay continuously illuminated. They are controlled from the APU.

ASSIs location on the main hoop with their respective casing



## Emergency Brake System

The vehicle needs to be equipped with a system that ensures the car will come to a safe stop in case of failure. This system is named Emergency Brake System (EBS) and has both mechanical and electronic components. The mechanical parts are responsible for the actuation of the brakes in case of emergency while the electronic parts are responsible for detecting a failure and controlling the actuator.

The mechanical part of the EBS was designed last year but due to the pandemic, was not implemented on the vehicle. However, this year the parts were assembled on the vehicle. The main components of the EBS are a pressure tank, an electric valve and a pneumatic cylinder which is attached to the brake pedal. The pressure tank is filled with compressed air and the valve is electrically supplied when there is no error, so no air passes to the pneumatic cylinder as long as there is not a system failure. As soon as an error comes up, the supply to the valve is cut and pressurized air flows to the pneumatic cylinder. The internal piston responds by pulling the brake pedal and thus the vehicle begins to slow down.



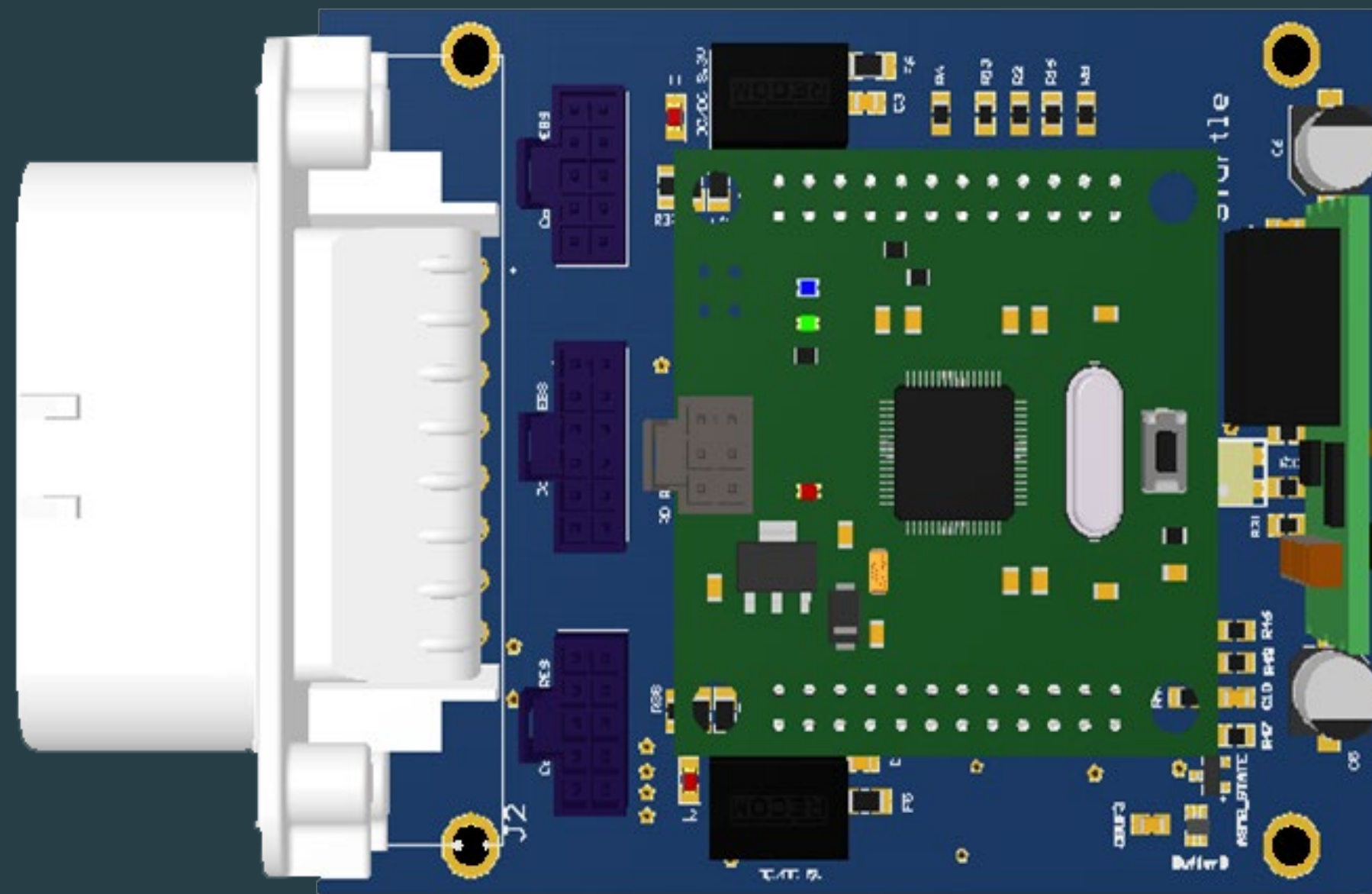
EBS Pressure tank installed on the rear part of the chassis



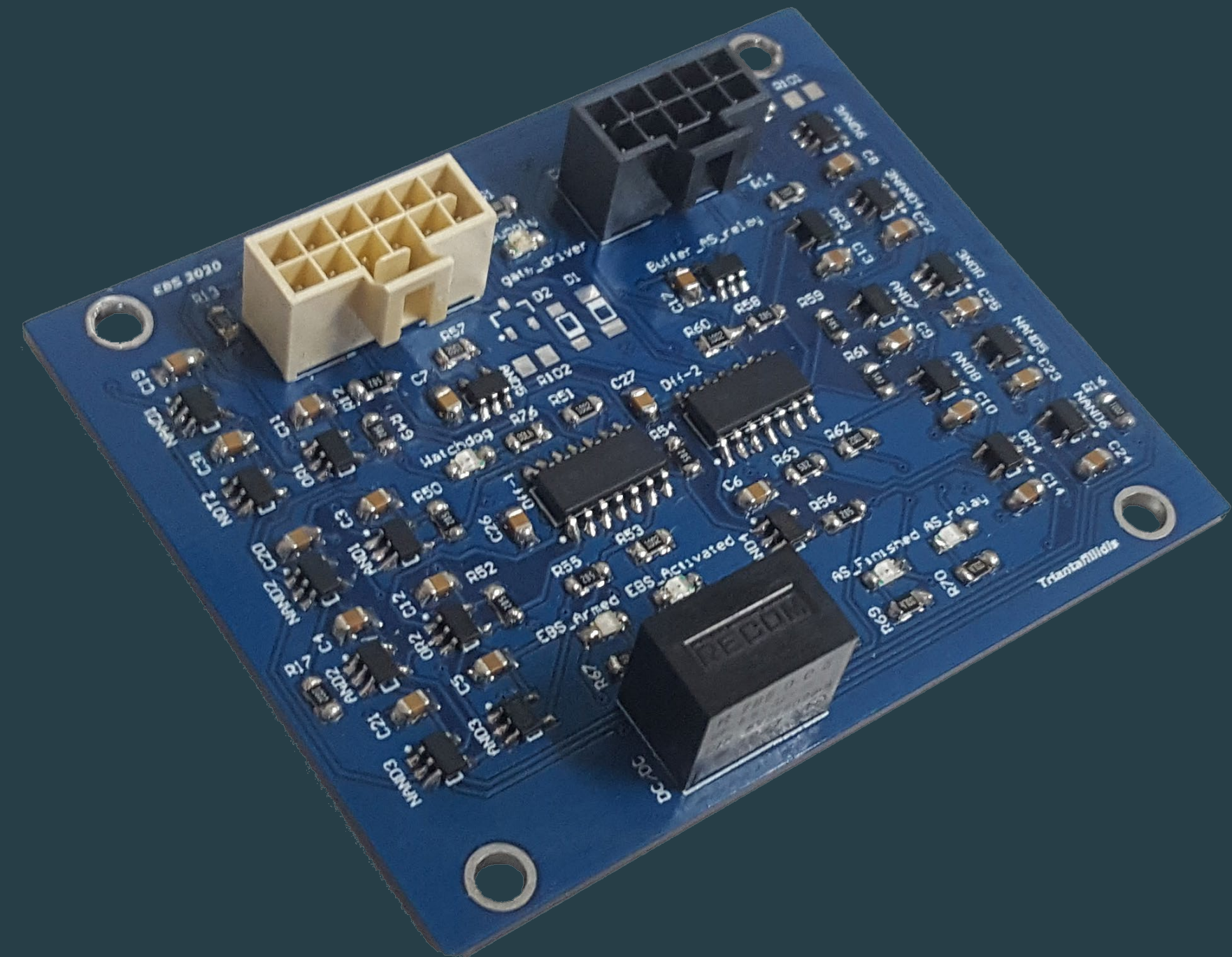
The electronic components are split into two PCBs: the EBS non programmable logic (EBS-NPL) and the EBS supervisor.

The EBS-NPL PCB was designed and tested last year. It receives signals from different parts of the vehicle and processes them using hard-wired electronics. In an event of a failure, the EBS-NPL will trigger the Shut-Down Circuit of the vehicle and enable the mechanical actuator (pneumatic cylinder).

The EBS Supervisor PCB is responsible for supplying some auxiliary signals to the EBS-NPL and publishing the state of the EBS to the rest of the system. In case of failure of the supervisor, the EBS-NPL PCB can still operate on its own and is capable of bringing the vehicle to a halt.



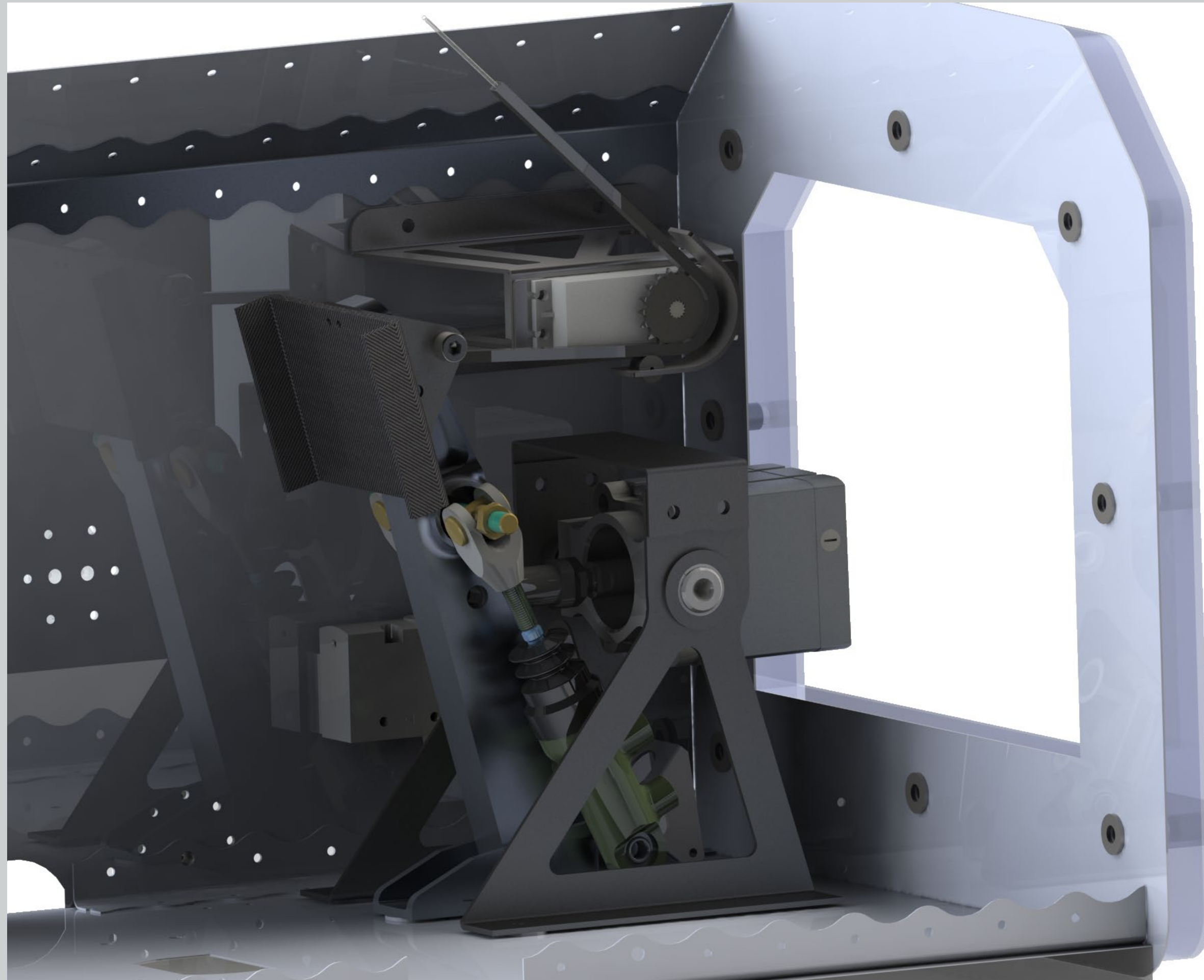
EBS Supervisor PCB



EBS Non-Programmable Logic PCB



# Brake Pedal Actuation



Servo motor and its mounting was placed on the top of the EBS pneumatic cylinder

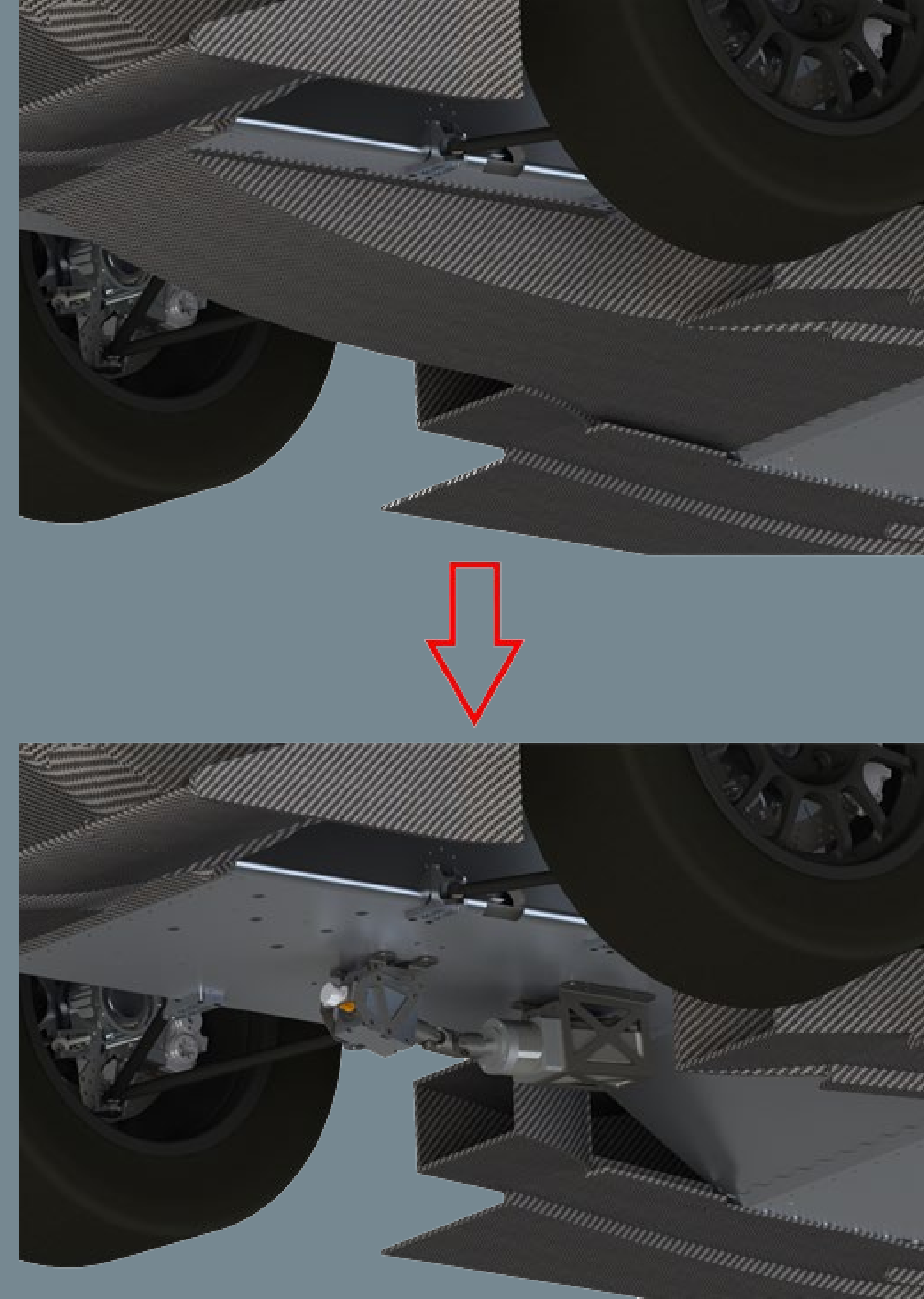
The brake pedal must be actuated at will by the autonomous system not just in case of a failure, but also during driving. For this reason, a different pedal actuation system must be implemented apart from the pneumatic setup.

We decided to use a servo motor attached to the brake pedal through a chain. In that way, by controlling the servo's rotary position, we can control the pedal's position. This motor is controlled by the microcontroller used in the EBS Supervisor PCB since, besides being a service brake, is also considered an EBS Redudancy system.

# Steering Wheel Actuation

A mandatory system for the operation of an autonomous vehicle is the steering control system, which is responsible for turning the physical steering wheel to the desired position. This system acts by receiving the desired position from the APU and activating the steering system to meet that position. Its functionality is based on a high torque NEMA stepper motor, a stepper motor driver and a position sensor which is tasked with reporting the actual position of the steering wheel. All the above is controlled by a sTurtle, housed on the Steering Actuation PCB, which makes sure the desired and actual steering position coincide. Crucial for the correct operation of the steering system is the ability of the motor to overcome the various forces from the tires and turn the steering system to the desired position in a reasonable time, just like a real driver would. The location of the stepper motor is under the floor closeout of the cockpit, inside the aerodynamic undertray.

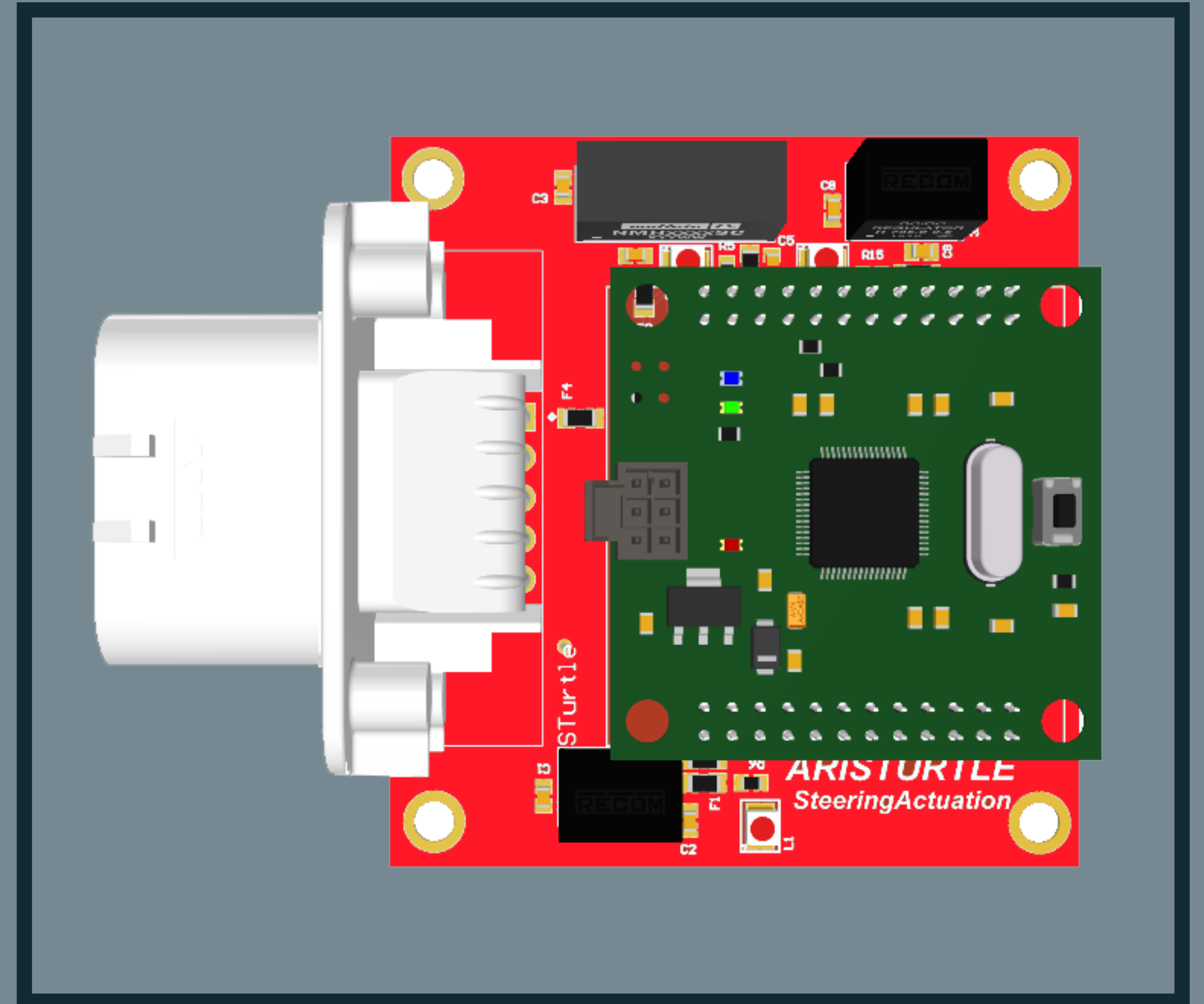
The performance was measured to be around 1.1s to cover the whole steering wheel's range (Maximum RPM = 40).







Stepper motor mounted to Thetis' chassis



Steering Actuation PCB

# Structure



Sensor positioning on the main hoop

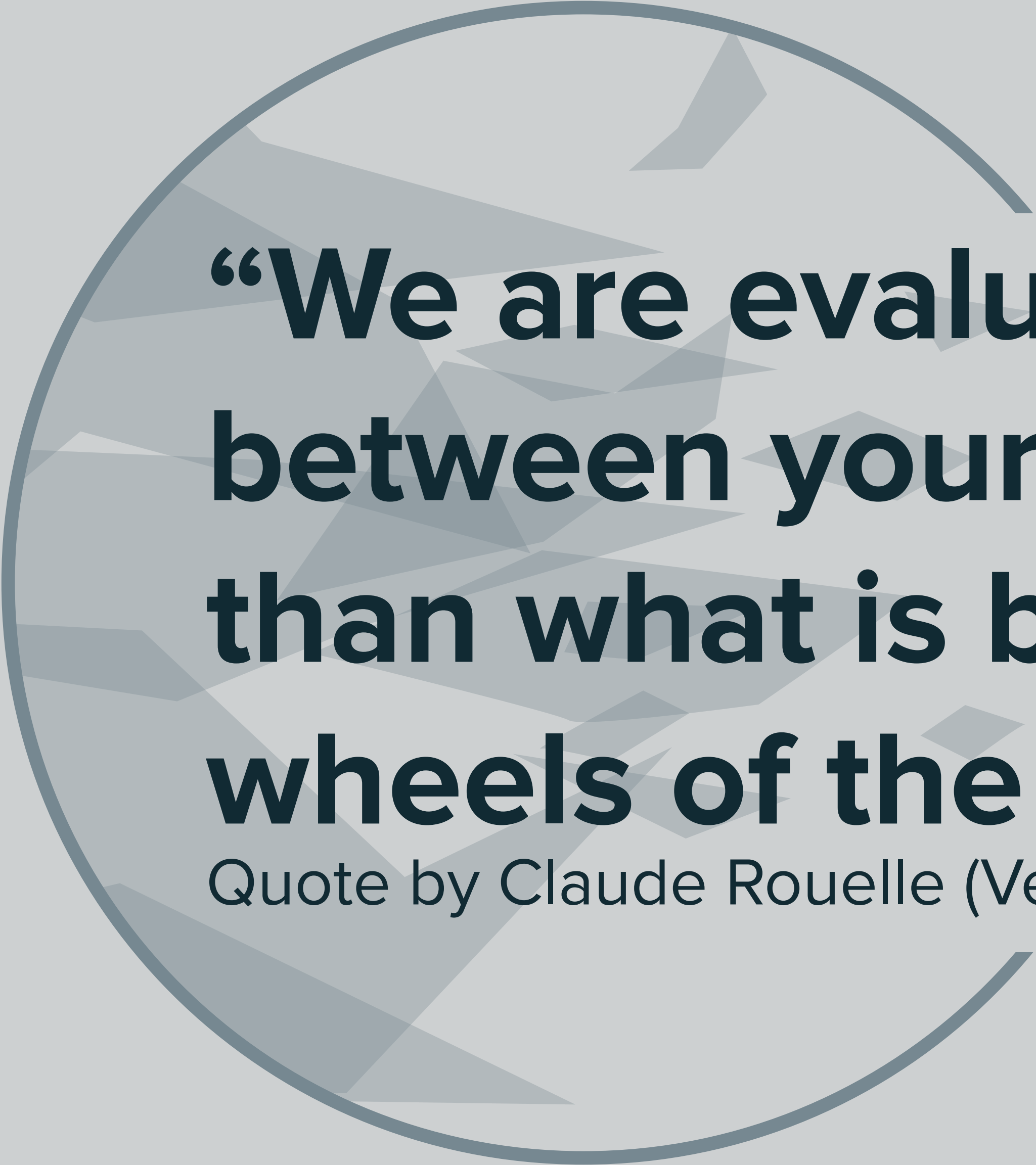
## Perception Sensor Mounting

Backed by our simulation results, the main roll hoop was chosen as the position for the dual camera setup and LiDAR sensor. As mentioned, a common casing-mounting was designed and made from 3D printed material (ABS), covered with an aluminum cap. Initially, a jig frame was 3D-printed to find the proper height and camera angles suited for our lenses.



3D printed casing with aluminum cap






**“We are evaluating what is  
between your ears, rather  
than what is between the  
wheels of the car”**

Quote by Claude Rouelle (Vehicle Dynamics Judge)

# Formula Student Germany


In early October the team had the opportunity to participate in the first virtual FSG Academy Main Workshop organized by the Formula Student Germany competition to officially kick the season off.





**FSG academy**


Favorite Quote (from Claude)
















Claude Rouelle  
Vehicle Dynamics Judge  
Source: FSG Website

"We are evaluating what is between your ears, rather than what is between the wheels of the car."

3



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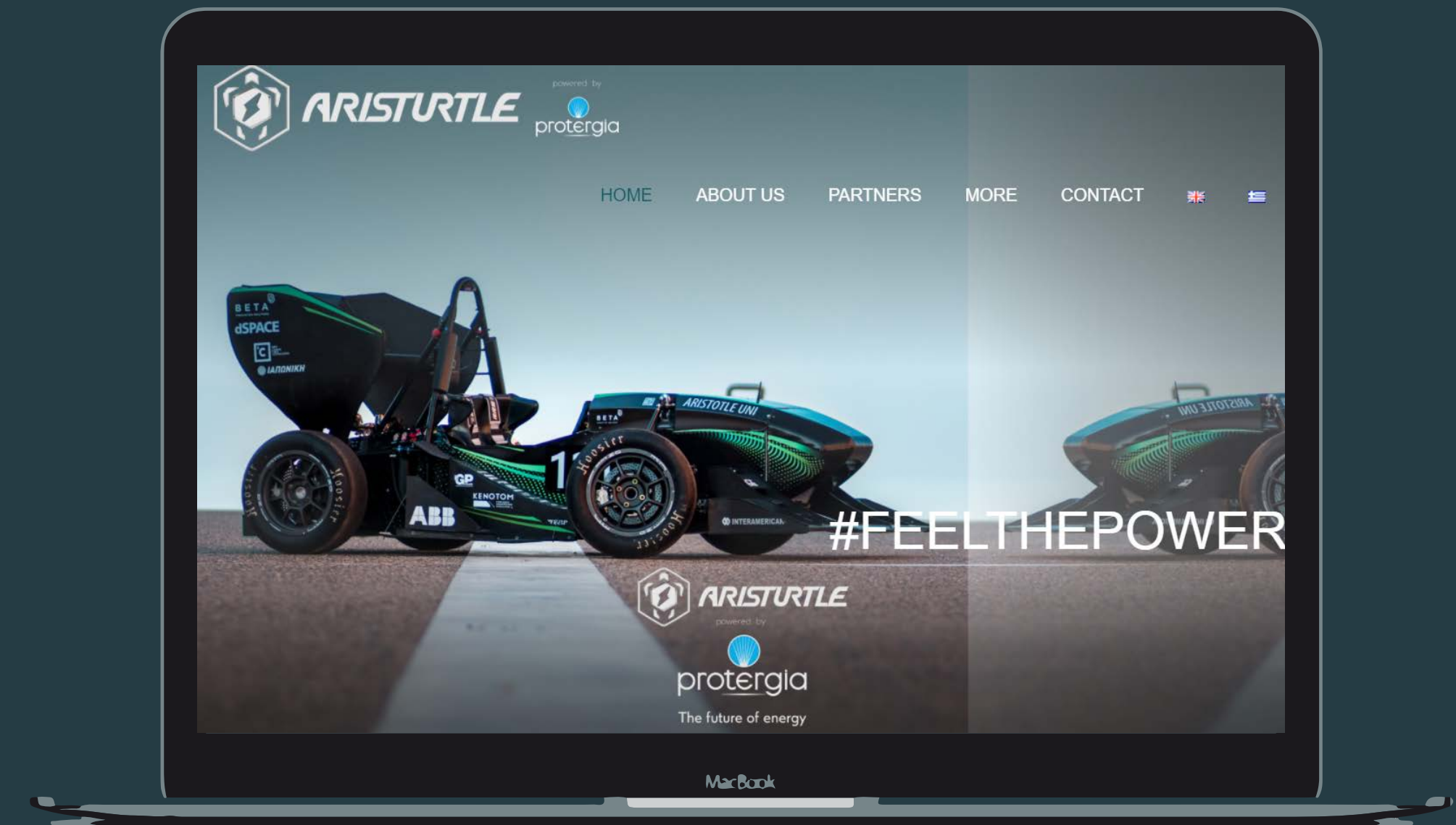
In early November the team participated in the Deep Dive Workshop on Simulation where top formula student teams talked about vehicle dynamics, CFD & FEA analysis.









# Check out for our brand-new website

After a few months of hard work and dedication, we are proud to officially announce the launch of our brand-new website. We hope that you will enjoy the fresh look and feel of our updated website.







**ARISTURTLE**powered by



### ELECTRIC VEHICLE




In 2013, a small number of undergraduate students from the department of Electrical and Computer Engineering of the Aristotle University of Thessaloniki founded Aristurtle with the vision of creating a single-seat race car that run solely on electricity. Three years later, they managed to turn their


**ARISTURTLE**powered by



### ARISTOTLE UNIVERSITY OF THESSALONIKI

The Aristotle University of Thessaloniki (AUTH) has been our biggest supporter since day one. From providing us with its facilities, to accompanying our team in the international Formula Student Competitions, the University has always pledged its maximum support

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### FORMULA STUDENT

Formula Student is a testing ground for the next generation of world-class engineers. Formula SAE is a student design competition organized by SAE International (previously known as the Society of Automotive Engineers). The competition began back in 1978 and is currently on of the largest students

[www.aristurtle.gr](http://www.aristurtle.gr)

## Protergia x Aristurtle aka Aristurtle powered by Protergia: Innovating Together.

In order for Aristurtle to achieve its goals, the help of assistants in the work of the team is always welcome, who can, through the support they provide, give their own impetus. Protergia, the Electricity and Natural Gas Division of MYTILINEOS, provides its own energy to the new car, as it is the exclusive premium sponsor of the team.

For Protergia, working with Aristurtle is an opportunity to contribute to development cutting-edge technologies, and at the same time to help team members succeed in bringing the next innovation in electric and autonomous driving. Protergia's vision is to innovate in electricity generation. Aristurtle's vision is innovation in electric propulsion. A common factor in Protergia x Aristurtle is the innovation in electricity. When electricity meets automotive: Protergia and Aristurtle usher in a new era in the electric vehicle industry. After all, the words innovation and evolution are keywords for both Protergia and Aristurtle. In addition, Protergia has already paved its own path in electric propulsion, as it is distinguished for its pioneering and innovative spirit. Thus, it has proceeded to the installation of four electric vehicle recharging stations at its headquarters, with the ultimate goal of the gradual electrification of its corporate fleet. At the same time, has started to create its own network of recharging points through the installation of chargers in more than 50 locations throughout Greece and has created combined 'green' products for electricity supply & charger subsidy to owners of electric vehicles.





# Thank you Sponsors!

A significant part of the reason why Aristurtle manages to evolve and participate in numerous competitions each year has to do with our sponsors. With their continuous assistance our team is able to focus entirely on the design and manufacturing of our vehicles. They allow us to turn our vision of a race car into reality. In terms used within the motorsport community they are the energy that pushes us forward and gives us the power to strive for greatness. We can only be eternally grateful for the trust they have invested in us and for supporting us every step of the way! It is only thanks to them that we manage to reach our goals!

To every single one of our sponsors, thank you for being part of Aristurtle's family!

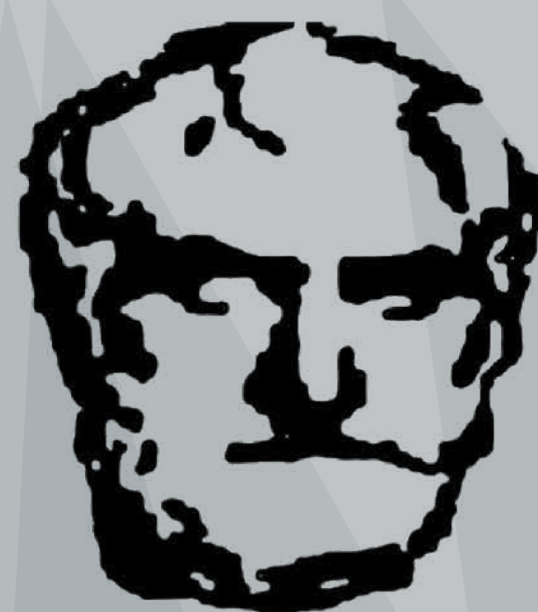




Aristotle University of Thessaloniki



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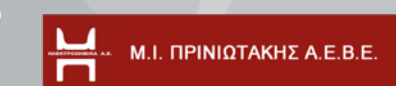
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**JAM Sport**  
SUSPENSION SYSTEMS





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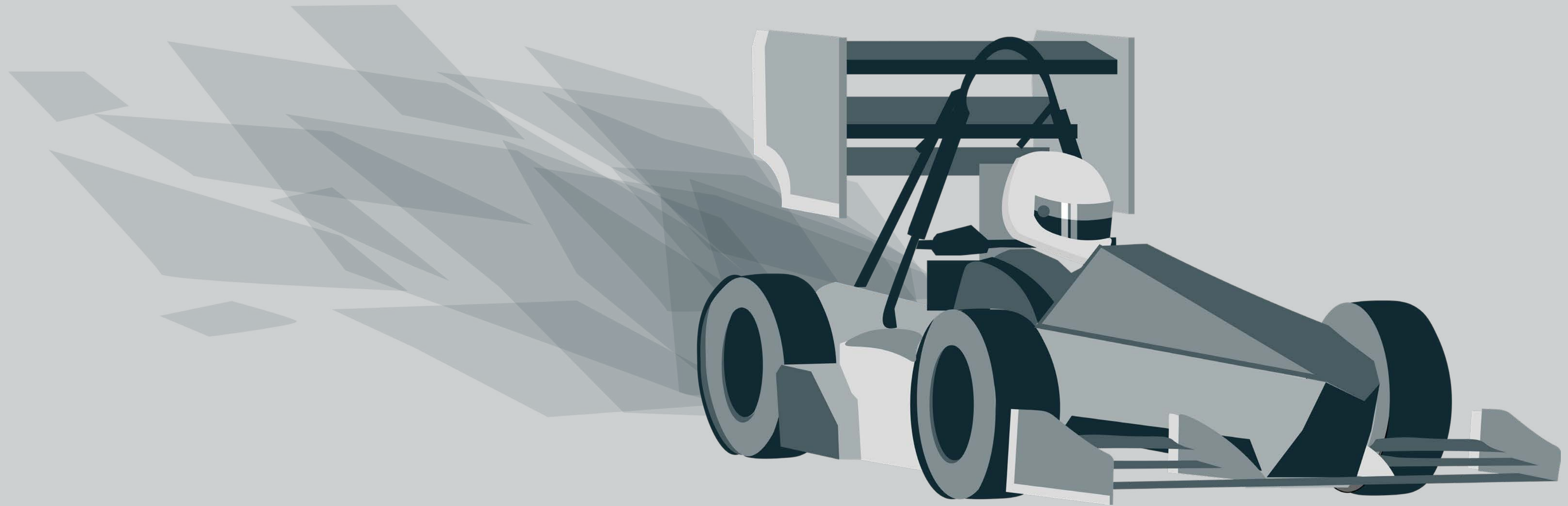
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# Till the next race



**#feelthepower**