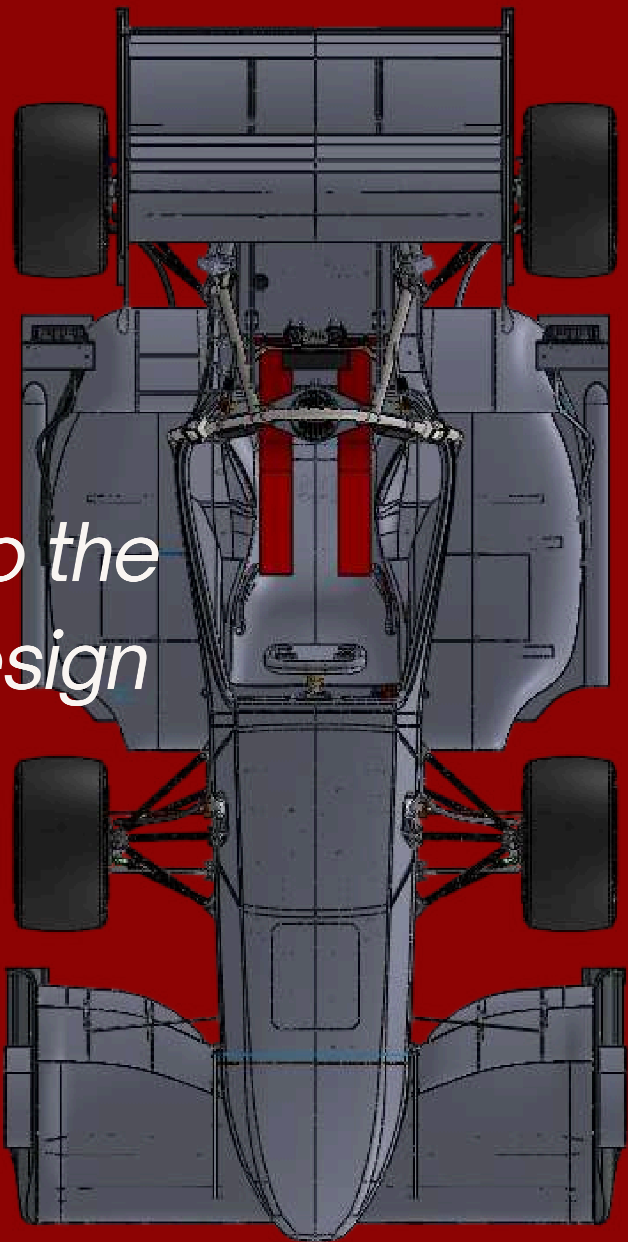
DESIGN MAGAZINE

MAR 2025



A deep insight into the team's design methods

What are the innovations of the FST14?

Read more about the upcoming prototype of FST Lisboa.

fst LISBOA

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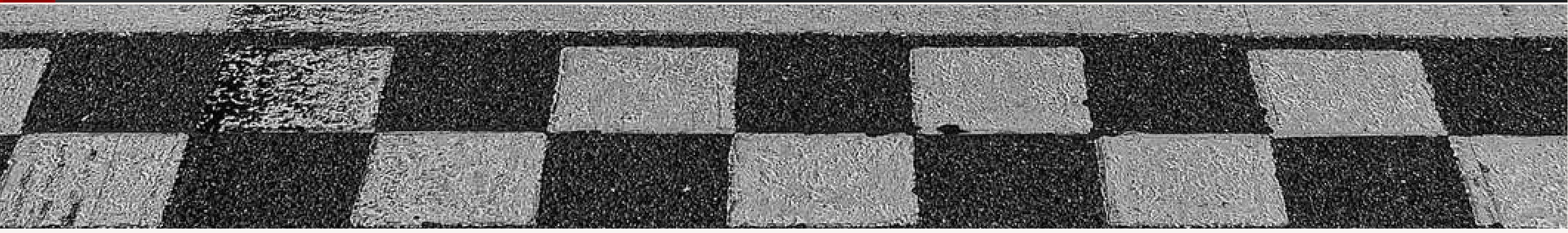
Content

A brief overview



The articles are divided by departaments. If you want to know the specifics of one, get to know where to find it in here.

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Design Magazine
FST Lisboa
Avenida Rovisco Pais, n.o1
1049-001 Lisboa, Portugal
Pavilhão Mecânica III, Piso 1 - Laboratório de Vibrações

E-Mail:
fstlisboa@fst.tecnico.ulisboa.pt

Editorial

This magazine showcases the development of our upcoming prototype, the FST14, focusing on its first stage: the **design**.

Rather than being highly technical, it is intended for all readers — engineers and enthusiasts alike — who are interested in the breakthroughs behind our next prototype.

Having this said, we present to you a wide variety of articles related to the design of the FST14, written by the department leaders, who share a common interest to improving the quality of FST Lisboa, year after year.

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Off to a Great Start

A message from our Team Leader

Behind every great engineering achievement, there is a team of dedicated individuals—people who pour their knowledge, creativity, and passion into making an idea come to life. At FST Lisboa, our greatest strength isn't just the cutting-edge technology or the innovative design of our car. It's the people—the engineers, designers, problem-solvers, and dreamers—who dedicate themselves to pushing the limits of what is possible.

This magazine isn't just about showcasing our latest prototype. It's about telling the story of the people who made it possible—the individuals who spent long hours testing, refining, and perfecting every detail. The ones who balanced demanding academic schedules with the intense workload of this project, driven by nothing more than their passion for engineering. But this passion goes beyond just engineering. It's a deep commitment to our team, to the shared vision that unites us, and to the project that represents who we are and what we strive to achieve together.

Whether it's the aerodynamicists refining airflow efficiency, the software engineers developing smarter control systems, the chassis team optimizing structural integrity, or any other, every department contributes to the bigger picture.

To our team members—this is your achievement. To our supporters, sponsors, and those who believe in our vision—this is the result of your trust. And to those who dream of being part of something bigger—know that this journey is as much about personal growth as it is about building a race car.

As we move forward, we carry with us the lessons learned, the challenges overcome, and the excitement for what's ahead. Because in the end, the true success of FST Lisboa isn't measured just in lap times or technical advancements, but in the people who make it all happen.

Nonetheless, the FST14 will undoubtedly be the fastest car we have ever built.

Welcome to the heart of our team.

by **Nuno Lynce**

Unleashing Performance

Innovation in Aerodynamics

Last year, the design of the front wing relied on a main plate with three flaps to generate a powerful vortex feeding into the diffuser. While this boosted the diffuser's efficiency, it also came with drawbacks, mainly energy losses in the vortex reducing airflow quality to critical areas like the rear wing. Furthermore, the diffuser's flap, with its abrupt transition from horizontal to vertical surfaces, caused undesirable airflow separation.

The Front Wing

This year's front wing reimagines efficiency. Featuring two main plates and a single flap, the updated design strategically avoids the wing's inner zone to eliminate counterproductive effects on overall aerodynamics. The addition of dual aerodynamic surfaces ensures smoother airflow, reducing inefficiencies caused by flat surface interactions. In parallel, the diffuser flap has been redesigned with a seamless transition between its horizontal and vertical elements, eliminating flow disruptions and delivering a significant performance boost.

The Rear Wing

The rear wing has also seen substantial refinements.
By reshaping the main wing and fine-tuning its flaps, we were able to optimize its effectiveness.

Thanks to the improved vortex generation at the front wing, more energized air now reaches the rear wing, enhancing its performance. An additional flap shifts the aerodynamic balance rearward, improving corner exit stability and reducing lift-induced drag - a game changer for handling and speed.

Structural Breakthroughs

Structural innovations are just as impressive as our aerodynamic breakthroughs. The wings are now supported by **swan necks**, which distribute loads more evenly without adding excessive weight. This solution minimizes the need for bulky internal structures, ensuring that the car stays light and agile.

The front wing swaps heavier foam materials for carbon spars bonded with adhesives. This approach maximizes carbon's potential by leveraging its surface area and inertia, delivering remarkable strength while shaving off weight.

Swan Necks and Front Wing

Flap Diffuser

Similarly, the diffuser now boasts a curved flap reinforced with foam and precision 3D-printed ribs, achieving a perfect balance of durability and efficiency. In the rear wing, carbon components provide robust support with minimal weight impact, underscoring our commitment to cutting-edge materials engineering.

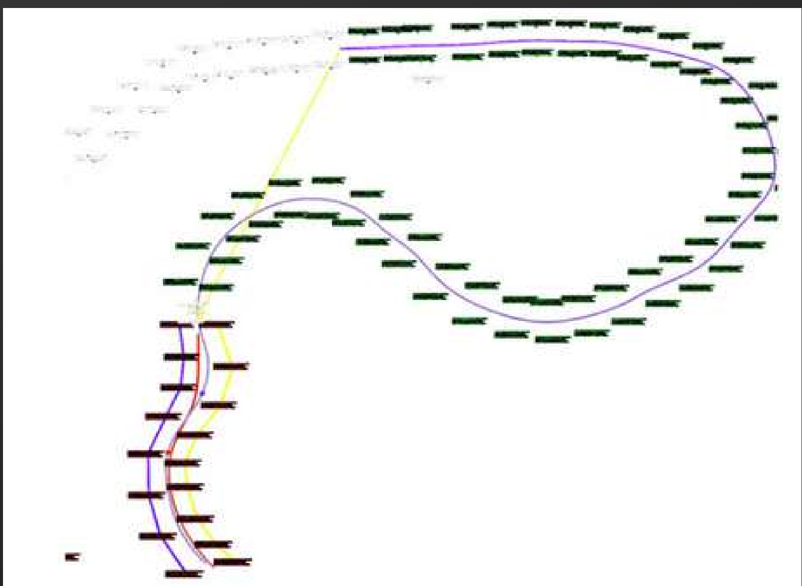
Every component has been meticulously analyzed and refined to enhance handling, speed, and efficiency. These upgrades are more than just technical improvements, they are a testament to FST Lisboa's relentless pursuit of excellence.

A New Approach

Innovation in Autonomous Systems

In the FST12 season, one of the goals was the implementation of the state-of-the-art control technique, Model Predictive Control (MPC). In the pursuit of enhanced performance with this controller, a discrepancy in the velocity achieved during the mapping process was observed when compared to the case of a complete centreline being available.

Therefore, one of the objectives for achieving higher speeds during the track mapping process is to develop a path planner capable of calculating paths with greater centerline lengths.



Slam Map

Our current algorithm is based on Delaunay triangulations. However, the developments made with this implementation have not allowed for an increase in the calculated centerline length per iteration within reasonable computational times. As a result, one of the goals for the FST14 Autonomous Systems (AS) department is to complete the implementation of the Eclipser algorithm, which was initiated last year.

This algorithm is designed to generate a path for autonomous vehicles based on the vehicle's current position and orientation, as well as the location of cones (optionally color-coded) in the SLAM map. The algorithm is stateless, meaning it does not rely on previous results. Each time it is executed, the only data reused is the last generated path, which is referenced only if the path calculation fails.

Here are the steps the algorithm follows:

01

Landmark Sorting

The algorithm first sorts the landmarks separately on the right and left of the vehicle. It selects the starting indexes for each configuration based on the distance and angle of the landmarks relative to the car (implemented in **fsdpp_cone_sorting**).

02

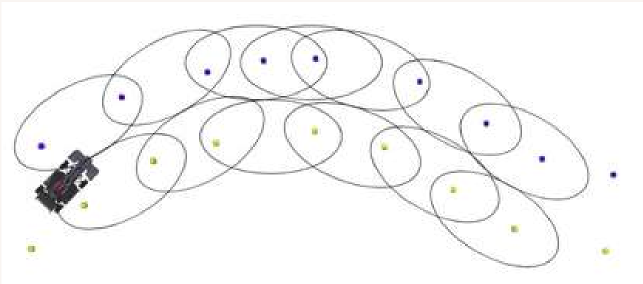
Adjacency Matrix Creation

An adjacency matrix is created where each row represents a landmark from the current SLAM detection. The matrix has 1s in columns corresponding to the 5 closest landmarks to the landmark in that row, and 0s for the others.

03

Configuration Generation

The algorithm creates possible configurations by drawing ellipses around pairs of starting landmarks using their relative direction vectors. Additionally, ellipses are drawn based on the angle between two vectors to help detect corner configurations. If any landmarks fall within these ellipses, they are added to the stack for later processing. This continues until no more landmarks are inside any ellipses.



Step 3: ***Configuration Generation***

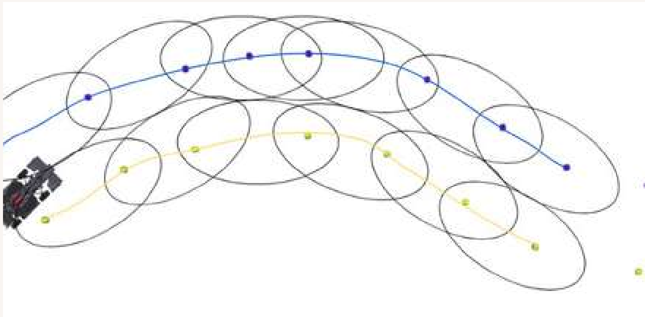
04

Configuration Evaluation

Once all possible configurations are generated, the algorithm selects the best one using a cost function (**fsdpp_cost_function**). The cost function evaluates several factors, such as:

- Direction of the landmark vectors
- Number of landmarks
- Angle changes between landmarks

The evaluation is performed for both the left and right sides. Conflicts between the two sides are resolved by checking if a landmark exists in both configurations. The final configurations are calculated after resolving any conflicts.



Step 5: ***Cone Matching***

05

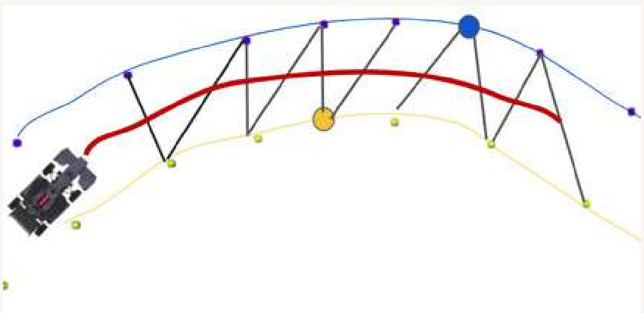
Cone Matching

After the best configurations are selected, the algorithm matches the cones from the left and right configurations (**fsdpp_cone_matching**). It checks if there are any matching cones and combines the two sides. In cases where a landmark is missing on one side or if a configuration doesn't exist for one side, the algorithm generates virtual cones to predict the missing configuration or landmark.

06

Centerline Calculation and Smoothing

Once the cones are matched, the algorithm calculates the center points of the matched cones and generates the centerline. The centerline is then smoothed using a spline library .



Step 6: ***Centerline Calculation and Smoothing***

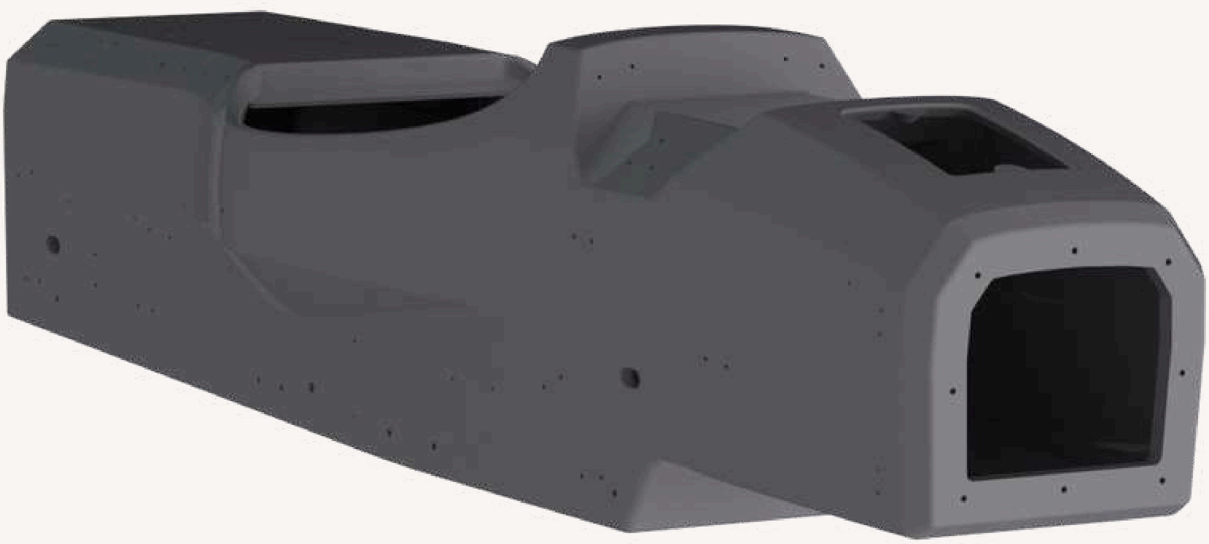
Redefining Strenght and Agility

Innovation in Chassis

The Chassis Department at FST Lisboa has made substantial advancements this year, focusing on optimizing the monocoque design and developing cutting-edge components to enhance structural performance and reduce weight.

Monocoque Geometry Redesign

In response to the shift towards a low-profile configuration, the geometry of the monocoque has been completely redesigned. This new approach prioritizes aerodynamic efficiency by lowering the center of gravity and improving stability during high-speed maneuvers. The streamlined profile ensures minimal air resistance while maintaining the structural integrity required for competition-level performance.



The design of the new Monocoque

Structural Analysis and Enhancements

A meticulous structural analysis was conducted to refine the monocoque's performance:

01

Suspension Mounting Point Optimization

Detailed studies were performed to understand the impact of suspension point positioning on the monocoque's rigidity. By optimizing these points, the chassis now delivers improved force distribution, enhancing overall handling and responsiveness.

02

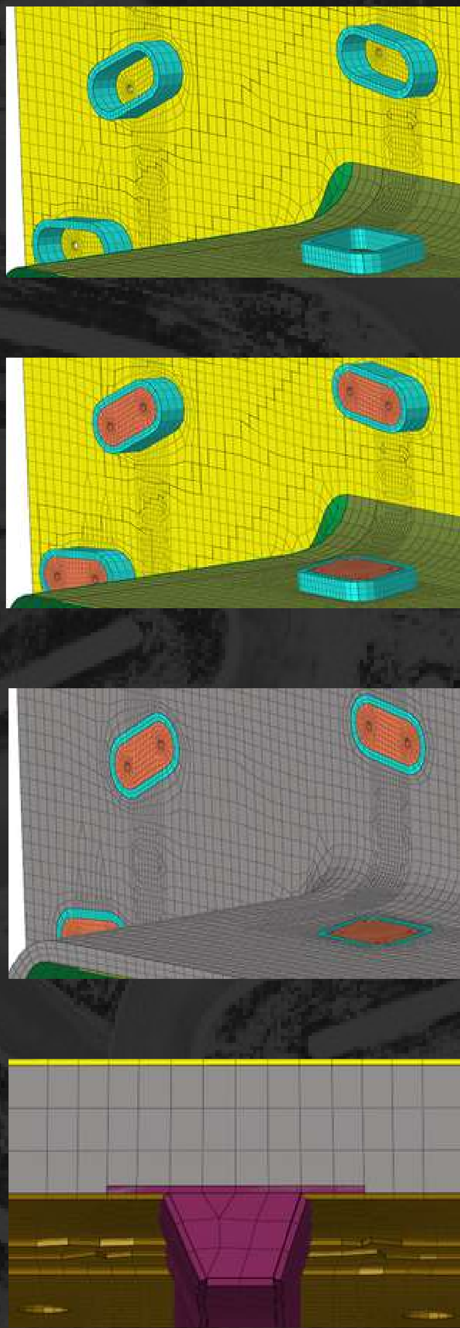
Integration of Stiffeners

Lightweight stiffeners were strategically integrated into the monocoque to reinforce critical areas around the suspension points. This innovation reduces mass without compromising local rigidity, achieving an ideal balance between strength and weight efficiency.

03

Local Modeling for Precision

To refine these enhancements, we employed a local modeling approach, enabling precise simulations of specific regions of the monocoque. This technique provided invaluable insights, ensuring targeted improvements without adding unnecessary complexity.

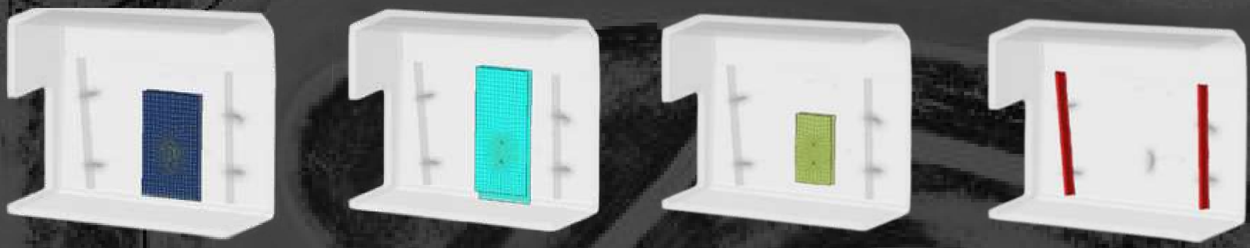


***Local Stiffness Iterations** - Model Details*

04

Torsional Rigidity Optimization

Iterative design cycles focused on increasing the monocoque's torsional rigidity were performed. These efforts resulted in a chassis capable of withstanding extreme dynamic loads while maintaining superior performance in cornering and acceleration.



*Stiffeners and Reinforcement Geometry and Placement for **Rear** Suspension*

*Stiffeners and Reinforcement Geometry and Placement for **Front** Suspension*

Carbon Wheel Development

To further elevate performance, a new carbon wheel design has been introduced. This innovative component addresses the need for reduced unsprung mass, which is critical for improving vehicle dynamics. The wheel's design leverages advanced computational analyses to ensure optimal rigidity and strength, all while achieving significant weight savings. The result is a highly efficient component that meets the rigorous demands of racing conditions.

In the Core of Control

Innovation in Driver Interface

FST Lisboa's Driver Interface department has reimagined how the driver interacts with the car, focusing on ergonomics, braking, and steering systems in order to ensure that the car responds intuitively to the driver's commands while integrating solutions for performance and safety.

Driver's Seat

Ergonomics: Perfecting Driver-Car Interaction

Ergonomics defines how seamlessly the driver and car operate as one. This year, we have refined the essential elements of this interaction:

Seat: The seat was meticulously redesigned to provide optimal support and reduce fatigue, especially during long or intense driving sessions. Its contours and materials ensure stability in high-speed cornering while maintaining comfort.

Seat Positioning: Adjustability has been prioritized, enabling drivers of all sizes to achieve a posture that aligns perfectly with the controls, reducing strain and improving reaction times.

Pedal Positioning: The pedal layout was restructured to ensure a natural, ergonomic movement. This change not only enhances precision but also minimizes energy expenditure during extended use.

Brake System: Merging Control and Automation

Braking is a cornerstone of performance and safety, and we have focused on integrating manual precision with autonomous capabilities.

EBS Integration:

The inclusion of a pneumatic system with two pistons allows the autonomous braking system to interact seamlessly with the hydraulic line. This setup enables smooth transitions between manual and autonomous braking, ensuring safety without sacrificing control.

Hydraulic Braking Line:

This system extends from the pedals to the four wheels, delivering consistent and reliable braking force. The hydraulic circuit translates driver input into efficient deceleration, maintaining stability in high-performance scenarios.

Pedal Box:

The layout was reimagined to enhance ergonomics and provide better feedback to the driver. This ensures responsive braking under any condition.

Steering System: Simplifying Complexity

The major updates of this season's steering system focused on efficiency and adaptability.

New Steering Actuator:

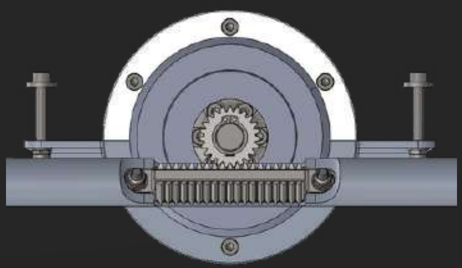
A simplified design now operates with just one gear instead of the previous three. This reduces weight and mechanical complexity while maintaining precision.

Unified Housing:

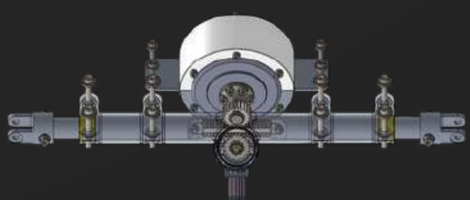
The actuator housing, previously composed of three separated parts, was redesigned into a single unit. This change enhances durability and ensures consistent performance under load.

REIC Module:

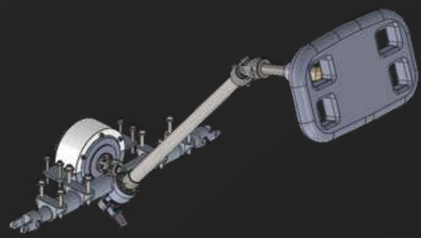
A new integrated control system combines manual and autonomous steering modes.



Steering Actuator Rack



Two Rack System



Steering ISO

These advancements allow the car to excel in a variety of conditions, making the steering system not only more intuitive but also more reliable.

Redefining Data Aquisition

Innovation in Electronics and Software

This year, FST Lisboa is focusing on developing state-of-the-art sensors. As we phase out the mandatory sensors and equipment required for competition, our focus will shift towards enhancing performance across various domains, such as tire performance, velocity estimation, and suspension load determination. These improvements aim to optimize the car's overall efficiency and handling, pushing the boundaries of technology in the competition.

Suspension Load Cells

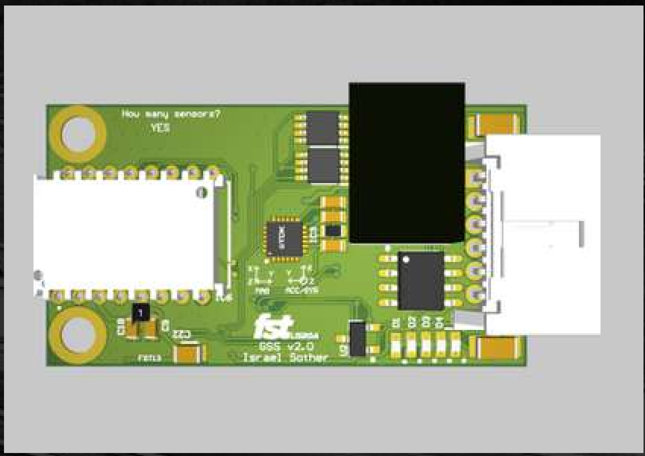
With the objective of determining the forces that act in the suspension while driving, several solutions were tested.

Strain Gauges

The initial solution explored was the strain gauge, with the decision to use at least one per suspension. Development began with lab testing on carbon tubes—the material used for the suspension. While the lab results were promising, real-world application in the car yielded no significant results. The issue was eventually traced to interference from the car's high-voltage systems, particularly the motors, which generated low-frequency electromagnetic noise. Despite several attempts to filter out the noise, the integration proved challenging. As a result, a new solution was developed: the use of load cells.

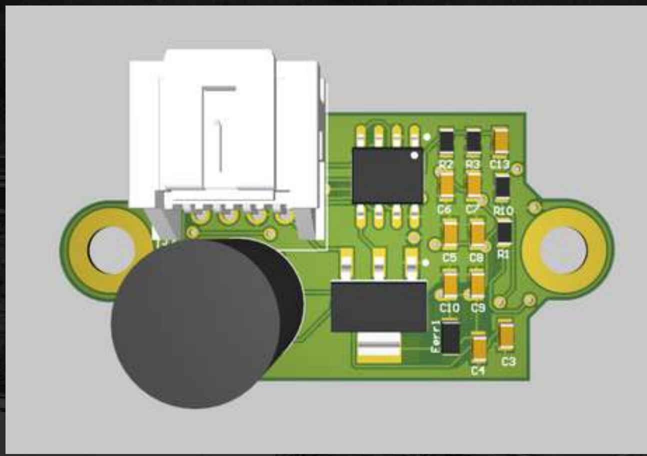
Load Cells

To implement load cells, a new steel suspension was designed with the load cell integrated into it. This design aimed to capture signals more effectively, minimize potential noise, and improve data quality. The PCB was positioned close to the load cell and engineered with a focus on low-noise design to enhance performance.



Ground Speed Sensor

To gather the necessary data for velocity estimation, a second version of the ground speed sensors is being developed, with a focus on improving: **Manufacturing Quality** and **Precision**.
For this, a new optical sensor has been selected. The sensor utilizes an optical array to capture images of the ground and measures the time between each shot. By combining these images with data from a height sensor and an IMU (Inertial Measurement Unit), the system calculates the distance a pixel has moved over the time interval. Using the displacement from the optical sensor, the height from the height sensor, and the accelerations from the IMU, the sensor can accurately determine the ground speed, accounting for any vehicle motion or angular shifts during operation.



Tire Infrared Temperature Sensor

To enhance tire performance analysis and understand the effects of different tire compounds, FST Lisboa has developed a new sensor to measure tire surface temperature while the car is in motion. The sensor selected is the MLX90621ESF-BAB-000-SP, which features a thermopile array with 16 elements in width and 4 in height. This sensor provides accurate, real-time temperature data across the tire's surface, offering valuable insights into tire behavior during dynamic conditions.
Although the PIC33 microcontroller supports I2C communication, the team had to develop a custom code library to interface with the MLX90621ESF-BAB-000-SP, as such a library had not been previously created. This integration allows for precise and continuous temperature monitoring, crucial for optimizing tire performance.

A Revolution in Inverters

Innovation in Powertrain

As FST Lisboa phases out the current AMK inverters, our focus shifts to a cutting-edge prototype grounded in the principles of real-time Ultra Short Horizon Model Predictive Control (RUSH MPC) from a foundational thesis. This change promises to redefine the efficiency and performance benchmarks of our powertrain.

The Status Quo: ***AMK Inverters***

The AMK inverters have been a reliable cornerstone of our powertrain, boasting a robust design and compatibility with the Formula Student framework. With features like a switching frequency of 8 kHz and a Field-Oriented Control (FOC) methodology, these inverters have enabled us to maintain consistent performance in demanding scenarios. However, their limitations have become evident as our performance goals evolved.

Key drawbacks include:

Low Switching Frequency:

The 8 kHz switching cap of the AMK inverters limits the precision of control and increases the total harmonic distortion (THD) in motor currents, resulting in reduced efficiency.

Simplistic Control Strategy

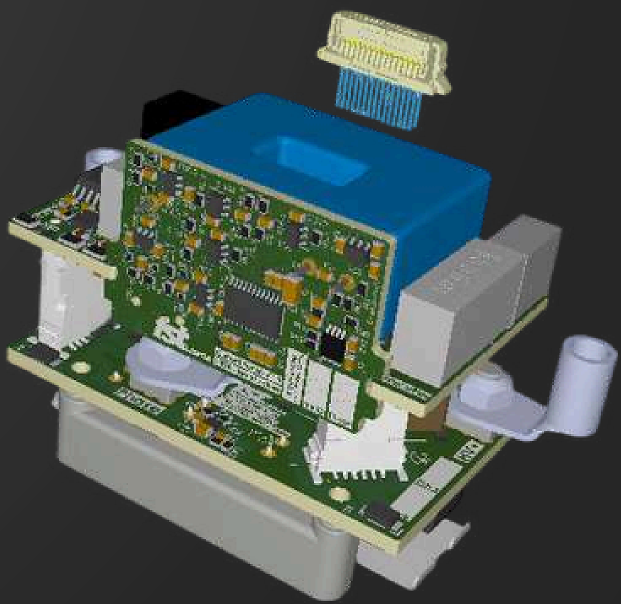
While FOC is effective, it lacks the dynamic responsiveness and efficiency of advanced control methods like Maximum Torque per Ampere (MTPA) strategies, critical for modern powertrain demands.

Heavier and Larger Design:

The reliance on Insulated-Gate Bipolar Transistors (IGBTs) necessitates larger DC link capacitors and heatsinks, leading to increased system weight and volume.

The Prototype Advantage: ***A New Era Of Inverters***

Our new inverter prototype, leveraging Silicon Carbide (SiC) MOSFETs and RUSH MPC, addresses the shortcomings of the AMK system while introducing transformative enhancements.



01

Increased Efficiency and Dynamic Response:

The adoption of SiC MOSFETs enables higher switching frequencies, reaching up to 50 kHz. This improvement not only reduces current THD but also enhances torque control precision, leading to smoother operation and greater overall efficiency. Furthermore, RUSH MPC offers unparalleled dynamic response, adapting to rapidly changing conditions with minimal delay—a critical factor in high-performance racing scenarios.

02

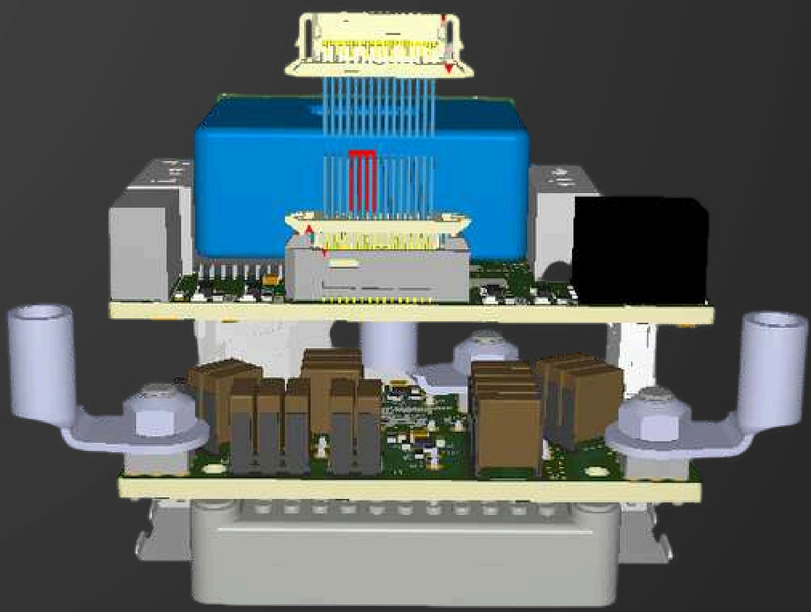
Compact and Lightweight Design:

The high efficiency of SiC MOSFETs reduces heat generation, enabling the use of smaller heatsinks. Combined with lower capacitance requirements, our new inverter design achieves a significant reduction in size and weight, boosting the power-to-weight ratio of the vehicle—a decisive advantage in Formula Student competitions.

03

Advanced Control Strategies

The integration of RUSH MPC facilitates real-time optimization of the motor's operation, ensuring maximum torque per ampere and reducing energy wastage. This advanced control approach not only improves performance but also extends the lifespan of components by minimizing unnecessary stress on the motor and inverter.



The new Inverter Prototype

Preliminary simulations and experimental results demonstrate:

01

Efficiency Boost:

A measurable reduction in power losses compared to the AMK system, validated by the reduction in current THD and switching losses when using SiC MOSFETs. Experimental data from steady state and dynamic load conditions corroborate these findings.

02

Improved Torque Control:

Enhanced dynamic response validated by torque step-response tests, which demonstrate the rapid adjustment capabilities of RUSH MPC under varying load conditions.

Driving Towards the Future

As we transition from the AMK inverters to our own inverter system with RUSH MPC and SiC technology, we are setting new standards for what a Formula Student powertrain can achieve. This advancement aligns with our team's commitment to innovative, sustainable and high-performance engineering.

Taking a Step Forward

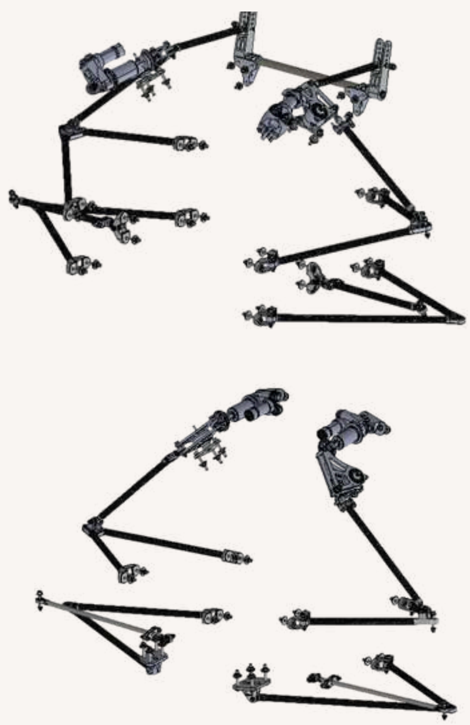
Innovation in Suspension

Evolution of a Winning Formula

Suspension

FST Lisboa's suspension system has remained largely consistent over the years, built on a foundation of carbon tubes bonded to aluminum inserts with a carefully chosen structural adhesive. While the core design concept remains the same, the geometry of the suspension is refined each year to meet specific performance goals for each season. This continuity has allowed the team to fine-tune the system for optimal handling, stability, responsiveness and structural integrity.

However, recent developments have seen a shift in how the team approaches suspension design. In the past, geometry was often the result of avoiding any issues in terms of interferences.



Suspension Overview

Nevertheless, in recent years, there has been an increasing reliance on structural analysis simulations to inform design choices.

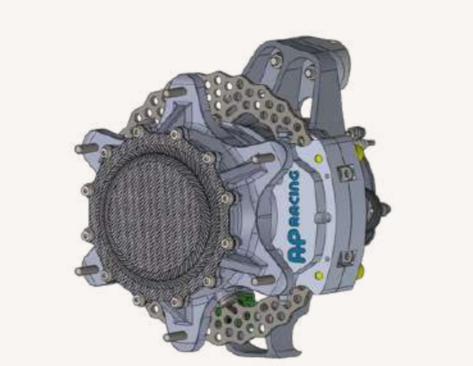
This means that, although a single department manages the mechanical design, inputs are not only drawn from the vehicle dynamics and the suspension departments, but also from the remaining mechanical departments. By using these simulations, the team has gained deeper insights into the trade-offs between different suspension configurations. As a result, the suspension system is better suited to the ever-changing demands of competitive racing.

Adapting to Regulatory Changes

Drivetrain

The drivetrain and wheel assembly are equally crucial to the car's performance, and 2024 brings several key refinements to these systems. Last season, the wheel assembly featured 10-inch rims and a compound planetary gearbox. A key innovation in the 2023 setup was the shift of output from the planetary gears to the outer ring, and the consequent redesign of the whole drivetrain packaging, from the hub to the upright, which now functions as the motor cooling sleeve.

These changes improved the packaging and reduced the weight of the system. For the 2024 season, regulatory updates have required slight modifications to the **drivetrain**, including a revised arrangement of bearings and oil seals. The switch to low-profile tires prompted adjustments to the suspension geometry and a slight increase in rim width, which introduced new challenges in the design of the new upright.



Drivetrain Overview

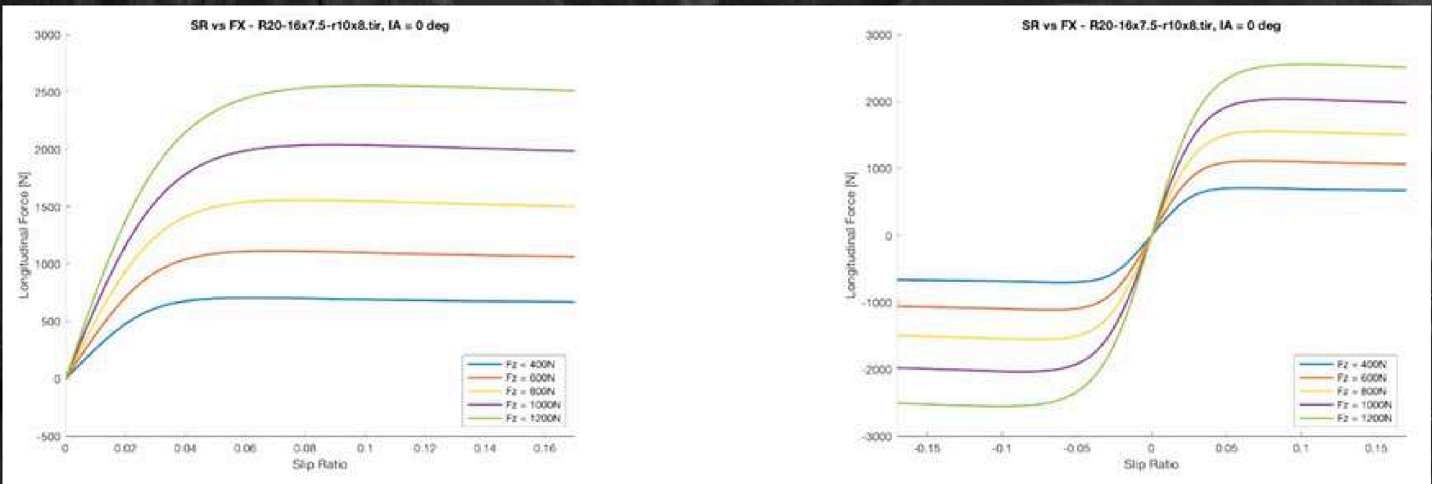
Drivetrain Packaging

Additionally, the gear ratio of 12.65 has been optimized to suit the new tire radius, based on simulations that factor in the different events of a Formula Student competition, maximizing the scoring potential. With a well-established suspension design and meticulously optimized drivetrain adjustments, these systems are engineered to keep the car firmly planted on the track, ensuring maximum grip and stability.

Innovative Simulation Tools

Innovation in Vehicle Dynamics

In recent years, we relied solely on theoretical simulations, which often resulted in unpredictable results during dynamic events. To address this, we have introduced an innovative approach to vehicle dynamics this year, implementing a suite of advanced simulation tools to optimize car handling, stability, and overall performance. These models are no longer based solely on theoretical predictions but are enriched with real-life data from previous competitions and tests. By integrating sensor data directly into the simulator, we have significantly enhanced simulation accuracy and reliability.



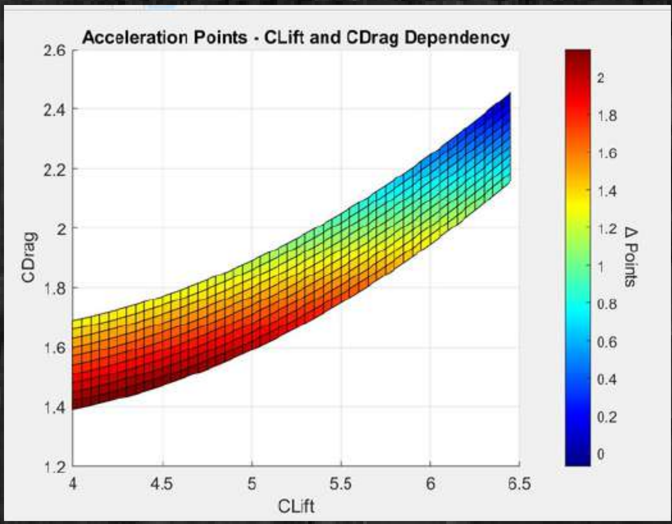
*Tires Graphics - **Slip Ratios vs Força Longitudinal for different Vertical Forces***

Steady-State Cornering Simulator

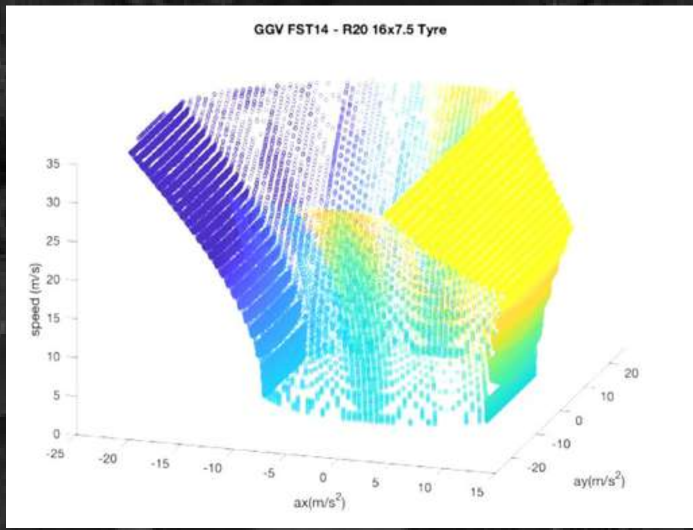
This simulation is designed to analyze constant-radius, constant-speed cornering, focusing on key aspects such as mass distribution, aerodynamic balance, and chassis stiffness. These parameters, which are deeply linked to the car's dynamic performance, are crucial for optimizing cornering ability and maintaining stability at high speeds.

Point-Mass Simulator

This straightforward model simulates fundamental parameters, including center of mass (CM), center of gravity (CG) height, wheelbase, efficiency, and gear ratios. Because these factors remain largely unaffected by dynamic behavior, the point-mass approach excels in scenarios such as acceleration events, providing clear, actionable insights.



Aerodynamics Study *- Point = function of Clift and Cdrag*



Graphic GGV *(GGV = Acceleration x Acceleration x Velocity) of the Hoosier R20 16x7.5-10 tires*

The Main Innovation

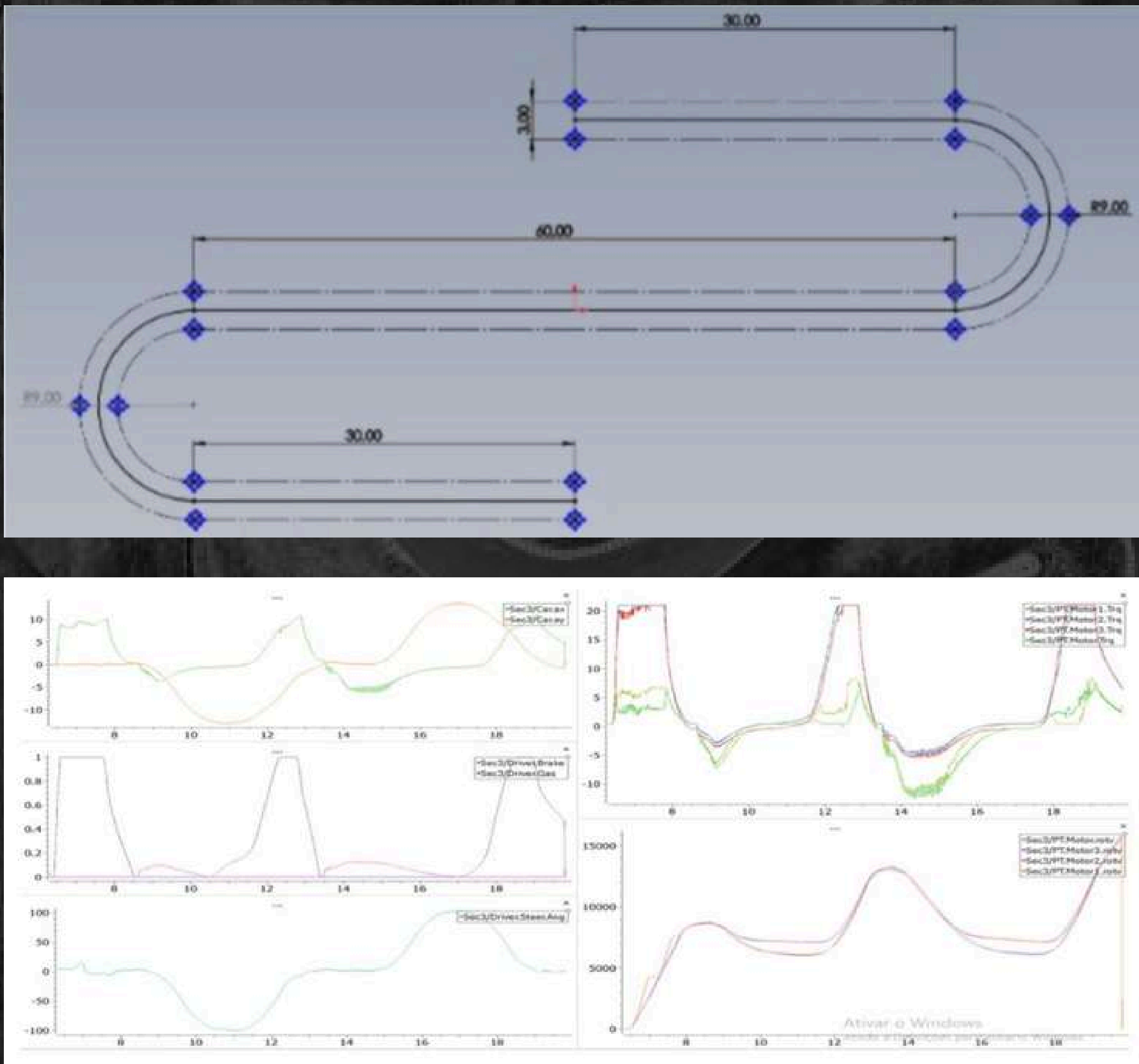
Multibody Transient Simulator

At the core of this year's simulation strategy is the Multibody Transient Simulator, representing a significant leap forward for the Vehicle Dynamics department. Unlike simpler models that focus solely on steady-state performance, this advanced tool captures the car's behavior during transient states. It simulates the car's response to dynamic changes such as entering or exiting corners, hard acceleration, or sudden braking. These transient moments are critical to overall performance, as they involve complex interactions between the chassis, suspension, weight distribution, and aerodynamic effects.

How it works:

What sets this simulator apart is its ability to model the full mechanical and dynamic interactions of the car in real-time. It analyzes how forces act on various components, including the chassis, wheels, and tires, and how these forces influence the car's behavior during rapid transitions. This includes changes in steering angles, acceleration, deceleration, and even moments of instability, such as when the car begins to lose grip in a corner.

Previously, the team relied solely on theoretical simulations, leading to unpredictability in dynamic events. To improve, we enhanced simulation accuracy using real-life data from competitions and tests, increasing reliability by integrating sensor data directly into the simulator.



Analysis of an S-Shaped sequence of turns *- Multibody Simulator*

In conclusion, the new system provides unprecedented levels of detail, enabling us to model the interactions between subsystems with remarkable accuracy. These advancements mark a transformative step for the Vehicle Dynamics department, bringing us closer than ever to achieving peak performance on the track.

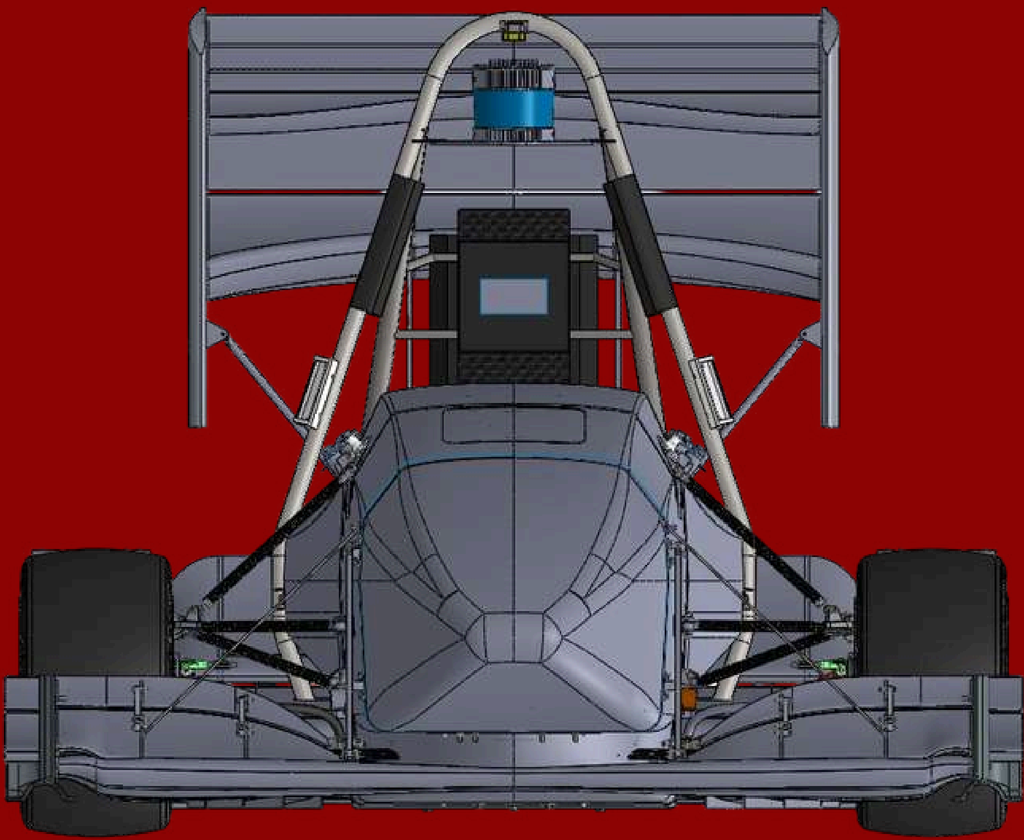
by **Fábio Bemposta**

The (Almost) Finish Line

As you may have noticed after reading through this magazine, its content is not purely technical. Our goal is not only to share insights into the engineering behind the FST14 but also to spark your interest in this year's prototype.

While the design stage involves extensive theoretical studies, an equally crucial part of the FST14's development is the fabrication of its components—a process already well underway. Over the next few months, the team will be fully dedicated to this phase, refining every detail to bring the project to life. This work will continue until the end of May, right before the highly anticipated Rollout, where months of effort will finally be unveiled.

If this magazine has piqued your curiosity about this year's FST Lisboa project, we invite you not only to explore the upcoming Manufacture Magazine, but also to witness the final result firsthand at the Rollout and the subsequent Formula Student Competitions' results.



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