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TRABAJO FIN DE GRADO DESARROLLO DEL CHASIS DE UN VEHÍCULO ELÉCTRICO DE FORMULA STUDENT

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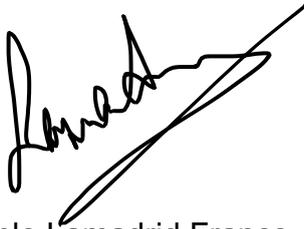
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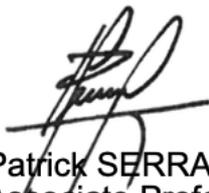
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DESARROLLO DEL CHASIS DE UN VEHÍCULO ELÉCTRICO DE FORMULA STUDENT

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Entidades colaboradoras: EPSA – Écurie Piston Sport Auto, ICAI – Universidad Pontificia de Comillas

RESUMEN DEL PROYECTO

Este trabajo de fin de grado está inscrito en el proyecto EPSA (*Écurie Piston Sport Auto*), equipo de Formula Student compuesto en su totalidad por alumnos de ingeniería de la École Centrale de Lyon, encargado del diseño y la producción de un vehículo eléctrico pensado para competir contra equipos de estudiantes de otras universidades en la edición del torneo FSUK 2022.

El equipo EPSA se divide en cuatro departamentos. Este proyecto pertenece a CHASEA (Chasis equipado y aerodinámico) y se basa en el desarrollo del chasis de un vehículo eléctrico de Formula Student. Dicho trabajo se ha desarrollado entre septiembre de 2021 y mayo de 2022, realizando, posteriormente, el documento escrito. Los objetivos principales de dicho proyecto, ordenados de manera cronológica, son los siguientes: análisis y elección de la estructura, entre un monocasco de carbono, una estructura tubular y una mixta, y del material empleado en la misma, readaptación del chasis para satisfacer las nuevas exigencias eléctricas, mayor volumen en la zona posterior del chasis, normativas de la temporada 2021-2022 (e.g., el piloto no debe tener la libertad de sacar los brazos del cockpit mientras que conduce) y para optimizar la ergonomía del piloto a través del sistema Ergo'Bench, integración entre los diferentes subsistemas adheridos al chasis a través de “chapas” que se encargan de fijar los diferentes elementos a la estructura tubular (e.g., la batería) y, por último, el proceso de producción en el que, por una parte, he desarrollado 30 planos de diferentes piezas del chasis y, por otra parte, he diseñado utillaje (9 sistemas) para facilitar el soldado a los alumnos de los institutos de mecánica que se encargan de dicho proceso.

Para realizar dicho trabajo, el proyecto se ha servido principalmente del útil de diseño 3D, CATIA V5. Además, hemos empleado herramientas organizativas como un referencial de piezas producidas y diseñadas (RSP y BOM), Monday para gestionar el avance de las tareas y Slack para comunicación interdepartamental.

Palabras clave: Formula Student, chasis, regulación, CATIA, planos, estructura tubular, École Centrale de Lyon

1. Introducción

Formula Student es una competición de concepción y desarrollo de vehículos en la que compiten alumnos de ingeniería de distintas universidades que construyen y conducen un monoplaza. Hay diferentes ediciones del campeonato, entre las que destacan Holanda, Italia, Reino Unido o Alemania. Es un torneo con una gran tradición (fundado en 1998), con grandes sponsors (e.g., Autodesk, Mathworks o BMW) y con más de 800 equipos presentes de forma anual.

Dicho es un torneo de desarrollo de vehículos entre futuros ingenieros evaluado en 2 pruebas: estáticas y dinámicas. Las primeras reparten un total de 325 puntos y están destinadas a vehículos tanto desarrollados como a proyectos conceptuales. Se evalúa a los equipos en tres pruebas: optimización de costes, diseño y una presentación de negocios. Las pruebas dinámicas otorgan 675 puntos y solo permiten la participación de vehículos plenamente funcionales. Los eventos se dividen en resistencia, autocross, eficiencia, skid pad y aceleración. En dichas pruebas, participan, de forma independiente, tres categorías de vehículos: vehículos de combustión interna, vehículos eléctricos y vehículos autónomos.

2. Definición del proyecto

Este Trabajo de Fin de Grado, ha participado en el departamento de la escudería encargado del diseño y producción del chasis.

Concretamente, se ha elegido, bajo 6 criterios, la estructura del chasis, así como el material, tan que cumpliera con las especificaciones mecánicas requeridas, se ha adaptado el chasis con la colaboración del departamento de baja tensión que nos ha proporcionado volúmenes sobre de los sistemas eléctricos, se han integrado 9 subsistemas distintos en el chasis a través de “chapas” de fijación a la estructura y se han desarrollado planos y utillaje para facilitar la producción. La motivación principal del trabajo ha sido, por una parte, la ambición de desarrollar sistemas óptimos con el fin de maximizar el rendimiento y la base sobre la que las futuras generaciones desarrollarán sus vehículos, y, por otra parte, trabajar con un grupo de alumnos de ingeniería altamente cualificados en un proyecto de gran envergadura bajo la tutela de la dirección pedagógica.

3. Descripción del proyecto

a. Análisis y elección de la estructura y del material

El primer objetivo del proyecto fue la elección de la estructura más adecuada a las capacidades del equipo. Formula Student permite elegir entre tres modelos de chasis, la estructura tubular, un monocasco de carbono o una estructura mixta.

Para dicha elección, fue crucial el trabajo previo de determinación de los KPIs (Key Performance Indicators) más determinantes. Desarrollé una lista de 6 KPIs, que ponderamos con el mismo peso y que considero cruciales en la elección del tipo de chasis:

- Precio y partnerships
- Masa/Rigidez
- Experiencia en el equipo
- Tiempo de concepción
- Tiempo de producción
- Innovación y progreso dentro del equipo

En el diagrama de decisión se demuestra que la estructura tubular es la más interesante. Sin embargo, este proyecto ha propuesto la transición hacia el monocasco de carbono.

	Tubular structure	Carbon monocoque	Hybrid structure
Price & Partnerships	5	1	3
Mass/Rigidity	2	5	3
Experience at the team	5	1	3
Conception time	4	2	3
Production time	2	4	3
Innovation and progress at the team	2	5	4
TOTAL	20	18	19

Figura 1. Elección de la estructura

Si nos fijamos en los KPIs externos al equipo, es decir, los que dependen de la estructura en sí: Masa/rigidez o tiempo de producción; el monocasco de carbono es el más interesante. Lo que nos hace ser reacios a dicha estructura son los elementos intrínsecos al equipo, como la experiencia o los partnerships. Por tanto, en el largo plazo, desarrollando conocimiento y una red de sponsors que puedan gestionar su producción, el monocasco de carbono mejoraría mucho el rendimiento del equipo.

Una vez elegido dicha estructura, tuve que definir el material a utilizar. La competición no deja mucho espacio a la creatividad en este aspecto, ya que la regla T 3.2.2. estipula claramente las especificaciones:

T 3.2.2: "Los tubos de acero debe ser de acero al carbono sin alea con un contenido máximo de 0,3% de carbono, 1,7% de manganeso y 0,6% de cualquier otro elemento."

Además de la composición, establecimos una serie de criterios de elección aconsejados por la institución de Formula Student:

- Mínimo límite elástico de 305 MPa
- Mínimo Módulo de Young de 200 GPa
- Mínima resistencia a tracción de 365 MPa

Además de estos criterios básicos, este proyecto estableció otros que fueran más allá como:

- Alargamiento a la rotura de al menos un 5%, es decir, un material dúctil para evitar rupturas brutales sin aviso de deformación plástica
- Máximo límite elástico posible para evitar la deformación plástica
- Máxima resistencia a tracción para reducir la posibilidad de ruptura
- Mínimo precio

Posteriormente, se analizaron los materiales que cumplían con las condiciones mínimas y que fueran ampliamente utilizados en la industria: acero 1040, acero 4130, acero inoxidable 304L y acero S355.

Material	Density (g/cm ³)	Tensile Strength(MPa)	Young Modulus(GPa)	Elongation at break(%)	Base metal price(EUR/kg)
Steel, SAE 1040 (Cold Drawn)	7.8	320/570	210	13	0.32
Steel, SAE 4130 Tempered	7.8	483/586	190	10	0.37
Stainless steel 304L	7.8	170/485	200	40	1.1
Steel S355	7.8	355/630	210	22	0.8

Figura 2. Elección del material

Finalmente, dichos criterios eran ampliamente satisfechos por el acero S355, que, aunque representa un coste algo mayor que los dos primeros, seguía pudiendo asumirse por el equipo y en el resto de las áreas es claramente satisfactorio.

b. Readaptación del chasis

Este año, uno de los objetivos principales ha sido la mejora de la ergonomía del piloto para optimizar su rendimiento. De ahí que haya desarrollado el sistema Ergo'Bench. Es un concepto simple, que cuenta con un volante, un asiento, unos pedales y una estructura que lo soporta todo y que permite modificar la inclinación y altura de todos los elementos a través de unos raíles guiados.

El objetivo era sentar a nuestros 3 pilotos y que nos dieran lo que ellos consideraban los parámetros idóneos para una conducción óptima. Una vez obtenidos dichos parámetros, y puesto que solo tenemos un monoplaza y los resultados fueron similares, determinamos los valores intermedios para cada parámetro con los que los pilotos afirmaban estar muy cómodos.

Estos parámetros eran:

- La inclinación del asiento
- La distancia al volante
- La distancia a los pedales
- La altura de los pedales
- La altura del eje del volante

Una vez elegida la estructura del chasis y obtenidas las medidas del volante, pedales y asiento, se desarrolló la readaptación del chasis.

Al haber elegido la misma estructura que en la temporada 20-21, decidimos partir de dicho chasis y adaptarlo a las exigencias de este año.

Había 3 nuevas exigencias a respetar en dicho proceso:

- Los tubos del lateral del cockpit no cumplían con la regla T 3.15.1, que establece que el piloto no tiene que poder sacar los brazos del cockpit mientras conduce.
- Como indica la regla A 6.12.2, los acumuladores, lo que se ve en la vista inferior, tiene que poder sacarse del chasis para cargar.
- El volumen ocupado por el sistema eléctrico en el rear-end del vehículo es superior al del motor de combustión.

c. Integración con los diferentes subsistemas

La tarea principal de este proyecto en la integración de los subsistemas en el chasis era la concepción de piezas que permitieran fijar los diferentes elementos de BASTIE y CHAIPE al chasis. Estas son piezas estandarizadas hechas en acero S355, que presentan orificios para poder atornillar los sistemas al chasis. Estos dos departamentos nos daban las especificaciones de las piezas a desarrollar y nosotros nos encargábamos de concebirlas.

Entre los elementos desarrollados, cabe destacar la pieza de inmovilización de la batería, la fijación de las luces o la adhesión de elementos al main hoop.

d. Proceso de producción

En el proceso de producción, externalizamos todo a institutos técnicos de Lyon. Cada uno de ellos se encarga de diferentes elementos, como la producción de los tubos, el ensamblado, etc.

La función de este proyecto es, por tanto, en el proceso de producción, la de realizar los planos para que pudieran producir las diferentes piezas. He realizado un total de 30 planos que se encuentran en el apartado Datasheets del documento largo. Hasta ahora, el 98% de las piezas han sido producidas.

Por otra parte, como la producción y el ensamblado estaban externalizados, hubo que desarrollar utillaje que facilitara el proceso. Estos son elementos en madera que se posicionan sobre el chasis e indican claramente donde ubicar un sistema. Esto tiene un doble objetivo, el de dar facilidad a los encargados de la producción, que no necesariamente son familiares con el vehículo, y el de aumentar la precisión del proceso.

4. Conclusiones

En este proyecto hemos desarrollado en detalle diferentes elementos y sistemas relativos al chasis de un coche eléctrico para la competición de Formula Student. A su vez, los objetivos principales estaban centrados en el desarrollo de la estructura en CATIA y en la mejora del proceso de producción y la integración entre departamentos. Uno de los principales retos ha sido el respeto de una estricta regulación con pequeño margen de maniobra.

La próxima ambición del proyecto EPSA es el de mejorar las prestaciones del vehículo para futuras competiciones de carácter eléctrico y preparar las bases de la competición autónoma en la que se adentrarán a partir de 2025. Este vehículo ha sido el primer monoplace totalmente eléctrico de la escudería, representando a la Ecole Centrale de Lyon.

DESIGN AND CONCEPTION OF THE CHASSIS OF AN ELECTRIC VEHICLE FOR THE FORMULA STUDENT COMPETITION

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Collaborating entities: EPSA – Écurie Piston Sport Auto, ICAI – Universidad Pontificia de Comillas

ABSTRACT OF THE PROJECT

This end-of-degree project is part of the EPSA (Écurie Piston Sport Auto) association, a Formula Student team made up entirely of engineering students from the École Centrale de Lyon, responsible for the design and production of an electric vehicle designed to compete against student teams from other universities in the FSUK 2022 edition of the tournament.

The EPSA team is divided into four departments. This project belongs to CHASEA (Equipped chassis and aerodynamics) and is based on the development of the chassis of a Formula Student electric vehicle. This work has been carried out between September 2021 and May 2022, subsequently carrying out the written document. The main objectives of this project, arranged chronologically, are the following: analysis and choice of the structure, between a carbon monocoque, a tubular structure and a mixed one, and of the material used in it, readjustment of the chassis to meet the new electrical requirements, greater volume in the rear area of the chassis, regulations for the 2021-2022 season (e.g., the driver must not be free to take his arms out of the cockpit while driving) and to optimize the ergonomics of the driver through the Ergo'Bench system, integration between the different subsystems adhered to the chassis through "plates" that are responsible for fixing the different elements to the tubular structure (e.g., the battery) and, finally, the production process in which, On the one hand, I have developed 30 plans for different parts of the chassis and, on the other hand, I have designed tools (9 systems) to facilitate welding for students at mechanics' institutes who are and are in charge of this process.

To carry out this work, the project has mainly used the 3D design tool, CATIA V5. In addition to that, we have used organizational tools such as a reference of produced and designed parts (RSP and BOM), Monday to manage the progress of tasks and Slack for interdepartmental communication.

Key words: Formula Student, chassis, regulation, CATIA, technical plans, tubular structure, École Centrale de Lyon

1. Introduction

Formula Student is a vehicle design and development competition in which engineering students from different universities compete to build and drive a single seater. There are different editions of the championship, among which the Netherlands, Italy, the United Kingdom, or Germany stand out. It is a tournament with a great tradition (founded in 1998), with great sponsors (e.g., Autodesk, Mathworks or BMW) and with more than 800 teams present annually.

This competition is a vehicle development tournament between future engineers evaluated in 2 tests: static and dynamic. The first one distributes a total of 325 points and are intended for both developed vehicles and conceptual projects. Teams are evaluated on three tests: cost optimization, design, and a business presentation. The dynamic tests award 675 points and only allow the participation of fully functional vehicles. The events are divided into endurance, autocross, efficiency, skid pad, and acceleration. In these tests, three categories of vehicles participate independently: internal combustion vehicles, electric vehicles, and autonomous vehicles.

2. Definition of the project

This Final Degree Project has participated in the team's department in charge of the design and production of the chassis.

Specifically, under 6 criteria, the structure of the chassis has been chosen, as well as the material, so that it complies with the required mechanical specifications. The chassis has been adapted with the collaboration of the low voltage department, which has provided us with volumes on the electrical systems, 9 different subsystems have been integrated into the chassis through fixing "plates" to the structure and plans and tools have been developed to facilitate production. The main motivation for the work has been, on the one hand, the ambition to develop optimal systems to maximize performance and the basis on which future generations will develop their vehicles, and, on the other hand, to work with a group of students highly qualified engineering staff in a large-scale project under the tutelage of the pedagogical director.

3. Description of the project

a. Analysis and election of the structure and the material

The first objective of the project was to choose the most appropriate structure for the team's capabilities. Formula Student allows you to choose between three chassis models, the tubular structure, a carbon monocoque or a mixed structure.

For this election, the previous work of determining the most decisive KPIs (Key Performance Indicators) was crucial. I developed a list of 6 KPIs, which we weigh with the same weight and that I consider crucial in choosing the type of chassis:

- Price and partnerships
- Mass/Stiffness
- Experience in the team
- Conception time
- Production time
- Innovation and progress within the team

The decision diagram shows that the tubular structure is the most interesting. However, this project has proposed the transition to the carbon monocoque.

	Tubular structure	Carbon monocoque	Hybrid structure
Price & Partnerships	5	1	3
Mass/Rigidity	2	5	3
Experience at the team	5	1	3
Conception time	4	2	3
Production time	2	4	3
Innovation and progress at the team	2	5	4
TOTAL	20	18	19

Figure 1. Election of the structure

If we look at the KPIs external to the team, that is, those that depend on the structure itself: Mass/rigidity or production time; the carbon monocoque is the most interesting one. What makes us reluctant to such a structure are the intrinsic elements of the team, such as experience or partnerships. Therefore, in the long term, by developing knowledge and a network of sponsors that can manage its production, the carbon monocoque would greatly improve the team's performance.

Once that structure was chosen, I had to define the material to use. The competition does not leave much room for creativity in this regard, as rule T 3.2.2. clearly stipulates the specifications:

T 3.2.2: " Steel tubes must be made of unalloyed carbon steel with a maximum content of 0.3% carbon, 1.7% manganese and 0.6% of any other element. "

In addition to the composition, we established a series of selection criteria recommended by the Formula Student institution:

- Minimum elastic limit of 305 MPa
- Minimum Young's Modulus of 200 GPa
- Minimum tensile strength of 365 MPa

In addition to these basic criteria, this project established others that went further, such as:

- Elongation at break of at least 5%, that is, a ductile material to avoid sudden breaks without notice of plastic deformation
- Maximum elastic limit possible to avoid plastic deformation
- Maximum tensile strength to reduce the possibility of breakage
- Minimum price

Subsequently, the materials that met the minimum conditions and were widely used in the industry were analyzed: 1040 steel, 4130 steel, 304L stainless steel and S355 steel.

Material	Density (g/cm ³)	Tensile Strength(MPa)	Young Modulus(GPa)	Elongation at break(%)	Base metal price(EUR/kg)
Steel, SAE 1040 (Cold Drawn)	7.8	320/570	210	13	0.32
Steel, SAE 4130 Tempered	7.8	483/586	190	10	0.37
Stainless steel 304L	7.8	170/485	200	40	1.1
Steel S355	7.8	355/630	210	22	0.8

Figure 2. Election of the material

Finally, these criteria were widely satisfied by S355 steel, which, although it represents a slightly higher cost than the first two, could still be assumed by the team and in the rest of the areas it is clearly satisfactory.

b. Adaptation of the chassis

This year, one of the main objectives has been to improve the ergonomics of the pilot to optimize his performance. That is why he has developed the Ergo'Bench system. It is a simple concept, which has a steering wheel, a seat, some pedals, and a structure that supports everything and that allows the inclination and height of all the elements to be modified through guided rails.

The objective was to seat our 3 drivers and have them give us what they considered to be the ideal parameters for optimal driving. Once these parameters were obtained, and since we only have one car and the results were similar, we determined the intermediate values for each parameter with which the drivers claimed to be very comfortable.

These parameters were:

- Seat tilt
- Distance behind the wheel
- The distance to the pedals
- The height of the pedals
- The height of the steering wheel axis

Once the chassis structure was chosen and the measurements of the steering wheel, pedals and seat were obtained, the chassis adaptation was carried out.

Having chosen the same structure as in the 20-21 season, we decided to start from that chassis and adapt it to the demands of this year.

There were 3 new requirements to respect in this process:

- The tubes on the side of the cockpit did not comply with rule T 3.15.1, which establishes that the pilot does not have to be able to remove his arms from the cockpit while he is driving.
- As the rule A 6.12.2 indicates, the accumulators, what is seen in the bottom view, must be able to be removed from the chassis to charge.
- The volume occupied by the electrical system in the rear-end of the vehicle is greater than that of the combustion engine.

c. Integration with the different subsystems

The main task of this project in the integration of the subsystems in the chassis was the design of parts that would allow the different elements of BASTIE and CHAIPE to be fixed to the chassis. These are standardized parts made of S355 steel, which have holes to be able to screw the systems to the chassis. These two departments gave us the specifications of the pieces to be developed and we oversaw conceiving them.

Among the elements developed, it is worth highlighting the battery immobilization piece, the fixing of the lights or the adhesion of elements to the main hoop.

d. Production process

In the production process, we outsource everything to technical institutes in Lyon. Each one of them oversees different elements, such as the production of the tubes, the assembly, etc.

The function of this project is, therefore, in the production process, to make the plans so that they could produce the different pieces. I have made a total of 30 plans that are in the Datasheets section of the long document. Until now, 98% of the parts have been produced.

On the other hand, as production and assembly were outsourced, tools had to be developed to facilitate the process. These are wooden elements that are positioned on the chassis and clearly indicate where to locate a system. This has a double objective, that of making it easier for those in charge of production, who are not necessarily familiar with the vehicle, and that of increasing the precision of the process.

4. Conclusions

In this project we have developed in detail different elements and systems related to the chassis of an electric car for the Formula Student competition. The main objectives were focused on the development of the structure in CATIA and the improvement of the production process and the integration between departments. One of the main challenges has been respect for strict regulation with little room for manoeuvre.

The next ambition of the EPSA project is to improve the performance of the vehicle for future electric competitions and prepare the bases for the autonomous competition that they will enter from 2025. This vehicle was the team's first fully electric single-seater, representing the Ecole Centrale de Lyon.

Acknowledgement

Foremost, the most deserved acknowledgement goes to the EPSA team of the École Centrale de Lyon. To the orchestra's director Patrick Serrafiero who organizes and guides the team towards improvement every year, to Valentin Baizeau, the team principal, to Garence Diaine, the president, to Guillaume Brault, the technical director and specially to the CHASEA department. Being able to work alongside such incredible colleagues and professionals has, on the one hand, helped me learn how a proper engineering project works in organization, production, management, risk minimization and processes optimization. On the other hand, I have had the opportunity to know people who share a passion of mine for motorsports, which has defined what I see today as an unforgettable experience.

I would not want to forget the people who made this experience possible, which is why I want to express my gratitude to the sponsors, the university's dean, Pascal Ray, and for sure the one who started this project, Monsieur Franck Debouck.

I cannot forget about my Spanish university, Universidad Pontificia Comillas - ICAI, for presenting me the opportunity of this double international degree that has allowed me to discover my passions, to develop my skills and to expand my vision. Ultimately, it is this experience that has let me join the EPSA team. I have to acknowledge the responsible for this experience: Damián Laloux Dallemagne who has presented us the project and guided us along the way.

Last but definitely not least, I would not be where I am, I would not have had the opportunities I have had, and I would not be the person I am today without my family, María José, Pedro Pablo and my sister, Paloma. They have been my mentors and the people I look up to. To my friends and to the people I have crossed along my way in my origin city: El Puerto de Santa María or in a different stage of my life at Madrid or Lyon. Every single one of them has played an important role in my development and education.

So to everyone here mentioned, **thank you**.

DOCUMENT I

REPORT



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Acronyms

AV	Autonomous Vehicle
BOM	Bill of materials
c.	circa (i.e., approximately)
CCAV	Centre for Connected and Autonomous Vehicles
CDCF	<i>Cahier des Charges Fonctionnel</i> (Objectives)
CHASEA	Chassis Equipé et Aérodynamique
e.g.,	Example
EPSA	Écurie Piston Sport Auto
EV	Electric Vehicle
EVCI	Electric Vehicle Charging Infrastructure
FS	Formula Student
FSUK	Formula Student UK
FSUS	Formula Student United States
GP	Grand Prix
HV	High Voltage
i.e.,	that is
I	Quadratic moment
ICAI	Instituto Católico de Artes e Industrias
ICE	Internal Combustion Engine
LV	Low Voltage
MIA	The Motorsport Industry Association
PAi	<i>Projet d'Application</i> (2 nd -year students project)
PE	<i>Projet d'Études</i> (1 st -year students project)
PO	<i>Procedure Organisationnel</i> (technical report of an element/system)
RSP	<i>Référentiel Standard de Production</i>
SAE	Society of Automotive Engineers
SDG	Sustainable Development Goals
TFG	Trabajo de Fin de Grado
TSAC	Tractive System Accumulator Container
UTC	University Technical College
WES	The Women's Engineering Society

PART I

REPORT



Chapter 1

Introduction

Every year, the Écurie Piston Sport Auto organizes different projects (PE and PAi) that are part of a program whose objective is to develop a vehicle to participate in a Formula Student competition. This project, which is usually done within an academic year, includes different actors, such as students, sponsors, partnerships and the pedagogical directors that guide us throughout the project.

Within the context of the sanitary situation due to COVID-19 we have experienced in the past years, the EPSA team decided, during the 2021 season, to design its first electric prototype and an electric test bench to ensure a safe electric transition. Our intergenerational organization promotes the transfer of technical and managerial knowledge from one class to the next one, an essential factor in the evolution of the team over the years.

Since September 2021, the EPSA team has therefore embarked on the design of Valkyriz and Bench 01. After the vehicle's specifications, the team members determined the concepts, architectures and configurations of the various subsystems during the preliminary design phase in the academic year 2021. The V-cycle then continued with the mechanical design of all the subsystems and their integration into the vehicle's main systems and into the final Valkyriz digital model. The ascent of the Valkyriz V-cycle was then carried out during this 2022 school year, and is still ongoing.

This report first presents some background information to help understand the Valkyriz project, its structure and organization, the EPSA team and the Formula Student competition. Then we move on to a detailed description of the technical work carried out this year. Finally, the development of the 2022 season will be detailed.

1.1. Structure of the report

This report has been structured following a generic to specific pattern. For the reader's understanding; the document starts with a detailed description of the FS competition, the points system, its history and the main procedures. This will allow the reader to have a big picture context of the final objective of the project.

The report will afterwards explain the EPSA team, developing its projects, organization, structure, work streams, performance objectives and financial management. Furthermore, there is an in-depth view of the 2022 season.

Then, the technical aspects of the project are explained throughout chapters 5, 6, 7 and 8. In this part of the report, there is a detailed view of the work on the equipped chassis, the tubular structure, the integration with other sub-systems and the production process.

Throughout these sections, everything explained represents the work done by this specific project developed by Pedro Pablo Lamadrid and not the work done by the whole team/a specific department. Everything hereby is therefore part of the TFG.

Finally, there is a superficial explanation of the simulation processes, which is not the main focus of this report. Then, a conclusion of the experience.

Afterwards, there are three sections whose main purpose is to let the reader have a full view of the project, with a detailed regulations area, the main datasheets used (materials' characteristics and all the technical plans designed) in the project and an annex with a long-list of images of the developed elements throughout the project (including jigs and screeds).

1.2. Motivation

The Formula Student competition is a multidisciplinary and demanding project that demands structures' conception, production and implementation via software such as CATIA, materials and constraints studies, the development of a business model, a tactical and strategic management of tasks and an electrical and security knowledge to correctly implement different systems. On top of that, the EPSA team has further objectives without which a vehicle is not presented to a competition, such as a minimal amount of testing (500 km).

As a final year engineering student, this project allows me to bring together all the skills and techniques that I have learned throughout my engineering degree, which is a unique opportunity to test yourself and push your limits before real world technical projects.

In addition to that, I got to work with a large group of people (+50) in a project that is defined by its complexity and demand. This helped me understand how to deal with enormous tasks by dividing them into manageable jobs, and how to organize a team.

Finally, I firmly believe in the search for further objectives and intellectual challenges that push limits to continue to improve. I am a car passionate and a motor-sport fan. This project has allowed me to discover vehicles and competitions from the inner side of it.

Therefore, I have multiple motivations to have chosen this project that has definitely made me progress technically and personally by developing different systems of the electric vehicle and by working in a large group of future highly-qualified engineers in a highly demanding project.

1.3. Working methodology

The methodology of the project has been similar in every department throughout the whole academic year. The structure is standardized, and it follows a top-down system, with a hierarchical structure. We tend to organize our working methodology as it follows:

- Regulations' introspection to determine the path of development to follow in each department as well as the tasks division

- Proposal of an architecture for the chassis and the different bindings with the other sub-systems
- Validation from the supervisors of the project (technical director, pedagogical direction and department coordination)
- Contact of the suppliers, production schedule and financial analysis for cost optimization
- Conception of the chassis
- Subsystems' implementation
- Production process

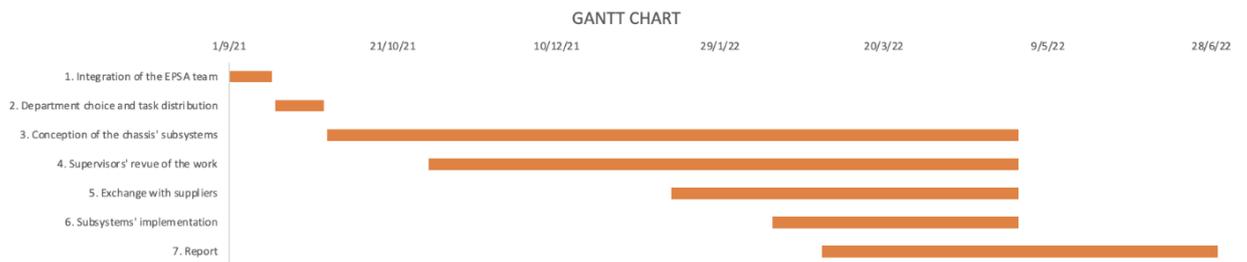


Figure 1. GANTT chart

Chapter 2

Sustainable Development Goals (SDG)

The Sustainable Development Goals are divided into 17 main areas, from which some of them have been widely developed throughout the project's scope. We could mention:

7. Affordable and Clean Energy

As the car we have developed is 100% electric, we promote between students, teachers, sponsors and spectators of the event, the renewable and more sustainable energies. This is definitely aligned with the team's objective of reducing its blueprint and making it more sustainable. On top of that, electric vehicles represent the future of the eco-friendly transportation. Working on a basic model allows us to motivate future engineers into helping in this transition.

8. Decent work and economic growth

Every single member of the team is necessarily catapulted in his motor-sport or transportation career. This project is the base from which every student has the opportunity to deepen into the subject and get a remarkable job in areas related to the vehicle industry. Throughout the year, there are several internship options that we receive to continue to work in a great environment and develop our engine / aerodynamics / suspension / etc knowledge in a dedicated company.

9. Industry, innovation and infrastructure

We are definitely at the pic of vehicle innovation, developing avant-garde cars with power units fully fuelled by electricity. It is an innovation competition whose intrinsic value is coming up with new creative ideas. As previously mentioned, EVs are one of the key challenges of our generation, at least in the early stage of our careers.

11. Sustainable cities and communities

One of the main objectives of the team is the inclusion of different student institutions in Lyon, which is why part of the production and assembly are done in collaboration with different assembly institutions whose students get to a real-life situation by building the car. There are several welding high schools that help us with the production process and that are further discussed in other sections.



Figure 2. Sustainable Development Goals

Chapter 3

Origin and context of the Formula Student Competitions

3.1. Origin of the Formula Student Competition

The Formula Student Competition first took place in 1998 (celebrating its 20th anniversary in 2018) and it is an annual student racecar contest organized by the Institution of Mechanical Engineers. The must-follow rule is that cars have to be both designed and built by engineering students.

The origin of the competition is in the Formula 1 engineering teams. When Honda engines were dominating Formula 1, the founding father, Soichiro Honda affirmed that its most talented young engineers had to rotate through the racing department in order to 'get their hands dirty'. It was their way of learning about priorities, to know how to manage time constraints and to be then fully prepared for the real designing and manufacturing tasks.

As this method was not practical, a partial alternative was parallelly developed for these young engineers to get the know-hows of a racing team and a project's management. Encouraged by the idea of a parallel curriculum at their engineering universities, a total of 114 filed entries for the first, 1998, event, with a total of 88 cars actually competing. This led to a rapid development and deploy of the tournament.

This first year's competition was very tight, and an experienced judging team of racing and car production industries were unable to narrow down the semifinalists to fewer than 23 cars. It was SAE International, in partnership with SAE UK who organized this first edition. It was co-sponsored by the SAE, MIRA and the IMechE, with industrial support from GKN, Ricardo, Jonathan Lee Recruitment and the MIA. Despite heavy rain, several hundred people made the trip and the US entries dominated the results: Texas Arlington won the acceleration and the overall best performance awards and Rochester the design competition and the presentation awards.

The design, fabrication and driving ability of the students helped gain visibility within the industry. It was the first step towards a high performing student competition.

Although the first official Formula Student competition took place in 1998 at MIRA, the rules of this modern tournament are actually the same as those of the original Formula SAE with

supplementary regulations.

The Formula SAE competition [1] is the father of the current FS. It started in 1980 by the SAE student branch at the University of Texas at Austin after a prior asphalt racing competition was proven unsustainable. In 1979, the only SAE Mini-Indy was held at the University of Houston. When the members of the new SAE student branch at the University of Texas learned that the Mini-Indy had died, they generated this new concept of an intercollegiate student engineering design competition.



Figure 3. University of Texas at Arlington. Formula SAE car, 1986

This competition then evolved to the actual format in 1998. The first Driver Training Event took place at *Three Sisters* near Wigan. This event was open to all teams who had finished building their FS car and wanted to practice on the track before the main event in July 2002. 2006 saw Ross Brawn, current Formula 1 technical director, become Patron of Formula Student. One year later, the event was moved to Silverstone. Finally, in 2008, the **Class 1A** category, the actual competition, was introduced.

3.2. Formula Student Competition

The Formula Student Competition is a tournament between universities from all around the world who design and manufacture a single-seat formula style race car within a date limit, with strict and complex regulations and with a severe judgement based on a number of criteria.

Students are allowed to receive advice and criticism from engineers or university professors, but the car must be entirely manufactured by them. They also have to be in charge of the fundraising. Nevertheless, most of the most successful teams have university-sponsored budgets. As the criteria is very diverse and evaluates different aspects of the car performance, we can see very different cars that focus on different parts of the competition as good performances could arrive without doing necessarily perfect in every aspect (e.g., a remarkable performance in the dynamic events could see a team win without doing so well in the static events).

Between the main ambassadors of the project, we can find David Brabham (an Australian professional racing driver and member of the Brabham family, a family highly linked traditionally to F1), Paddy Lowe (Former executive director of the Mercedes Formula One Team), Willem Toet, Leena Gade (a British race engineer who has served in the FIA World Endurance Championship and IndyCar race series), Dallas Campbell (a British actor), Mike Gascoyne (British Formula One designer and engineer) and James Allison (Chief Technical Officer of Mercedes-AMG Petronas F1 Team).

Some of the most notable judges have been Carroll Smith (he was a professional race car driver and engineer), Jon Hilton (Flybrid systems, ex Renault F1), Andrew Deakin (Renault F1), Neil Anderson, Alex Snook (Aptiv), Willem Toet (Sauber F1), Alex Hickson (GKN Aerospace Filton UK), Dan Jones (Flybrid Systems), Allan Staniforth, David Gould (Gould Racing), Pat Clarke, Nick Vaughan, Matt Wilkin (Brawn GP), Ben Michell (Dunlop tyres) and Claude Rouelle

(Optimum G).

The races are held in different countries such as Germany [2], the United Kingdom [3], the United States [4] or Italy [5].

3.3. Categories

As mentioned, there are several aspects taken into account in the evaluation and judgement of a FS car [6]. The performance of the car is important, but other qualities such as cost and manufacturing or the design are also analysed. This makes the competition a very demanding one in which every aspect of the car has to be thoroughly thought out to properly perform.

This different parts of the vehicle's performance are organised in two different categories of events: The static events and the dynamic events. Furthermore, cars are judged within their model. There are three different editions in which a team can compete: Autonomous car (the most recent one), electric vehicles (the most rapidly growing category) and thermal cars (the ones with which the competition began).

For each of these vehicle models (autonomous, electric and thermal), there are two competition classes that have evolved during time:

- **Formula Student Class (formerly Class 1):** Main event. Teams face each other with the designed cars. There are 6 categories of evaluation, and only judges can determine whether a team can compete or not in the dynamic events. Around 100-120 teams participate. The class, as it is, was developed in 2012. Racing teams participate in both static and dynamic events.
- **Concept Class (formerly Class 2):** This is, as its name indicates, a concept class for teams who only have a project and not necessarily a developed car. Here, teams are only evaluated on their business presentation, cost and design. The class, as it is, was developed in 2012. Teams only participate in static events.

3.3.1. Dynamic events

Dynamic events are divided into five different categories that are thoroughly thought out to test the students' ability to make the car effectively work on track. These events are the main part of the competition and where the most points are distributed, which is why performance on these events is crucial for a high-end result.

The dynamic events are:

- **Endurance:** The endurance event is the one in which the most points are given: **275**. This is a 22 kilometres long event on a similar track to the one in which the Autocross event is held. There are 2 drivers who do half of the distance each and who are imposed to do a pit stop. In order to gain any points, the car must finish the test, which is no easy task. Consistency and reliability are the main aspects of the event, as well as drivers' performance and pit crew rapidity. It is the final event of the week and the total time is determined by the sum of both drivers' time and the possible penalties (cutting corners, not respecting speed rules, etc). There are anywhere from 20 to 25 laps depending on the circuit.

- **Efficiency:** In this test, **100 points** are distributed. When speaking about efficiency, we refer to fuel's efficiency. Lap times and the usage of fuel are mixed to conclude the car's efficiency. Lower fuel consumptions are rewarded.
- **Autocross:** In this test, **150 points** are distributed. The car's dynamic ability is tested in a one lap sprint, in which two attempts are given with up to two different drivers. The objective of this event is to demonstrate the manoeuvrability on a small and tight course. This course will demand acceleration, cornering and braking. The circuit will have chicanes, hairpins and slaloms to test out every feature here mentioned, and it is tracked in order to get an average speed between 30 and 40 km/h. In the 1D class, it is the moment to demonstrate the effectiveness of the driverless vehicles while running in an unknown scenario.
- **Skid Pad:** **75 points** are given in the Skid Pad event. Lateral grip is the main aspect of this event in which a constant radius turn is made on a flat surface. There could either be one or two circles depending on the organization, each of them being of around 15.25 meters. Once again, the event is divided in two rounds, each of them being driven by a different driver. Each driver has two attempts. The ability to lateral speed up is what finally determines the score.
- **Acceleration:** There are **75 points** distributed in this event. The car must accelerate in a straight line, over a distance of 75 metres. There are two rounds, each of them with a different driver. Each driver has two attempts. This time, the score is not given by the best time but by the difference between the best and the worst times. This measures the vehicle's ability to accelerate.

This makes a total of 675 points distributed in the dynamic events:

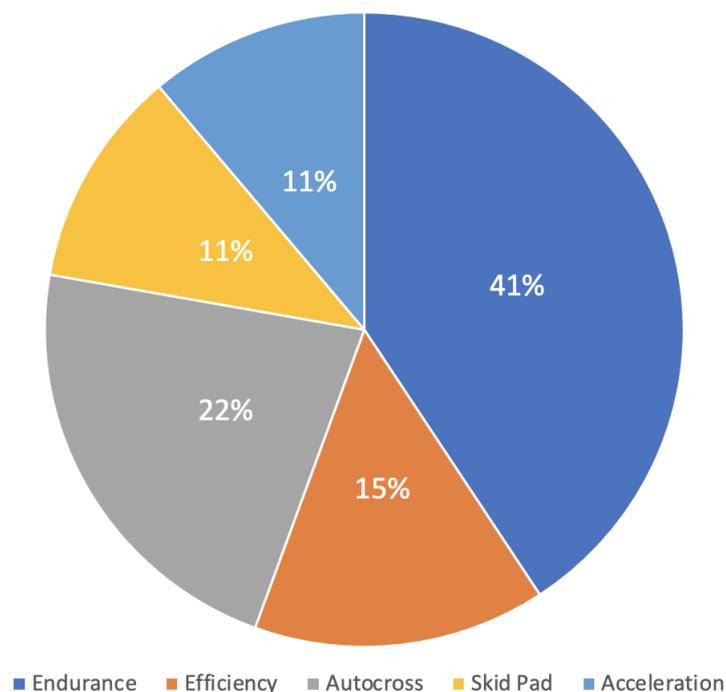


Figure 4. Points' distribution of the dynamic events

3.3.2. Static events

Static events are established to determine whether if vehicles can respond to the competition's requests or not. They also determine their respect of the regulations and the whole conception and production process. It is an optimisation and organisation inspection in which cars must demonstrate that they can take part in the dynamic events.

Teams are evaluated on non-technical criteria, as well as the quality of the assembly and its ability to perform and not break under different conditions. This category is divided in three main events:

- **Inspection event:** No points are rewarded in this event, it is only a test to verify if everything has been correctly assembled. The judges examine the different components of the car included in the inspection sheet. This control is done in three parts: Verification of electric and mechanical elements (driver's equipment included), a tilt test (a 45° tilt test to verify if the car loses oil or fuel and a 60° tilt test to verify if the car's grip has been properly calculated), a sound check of the volume of the thermal cars and a rain test in the case of electric cars. This is the pre-test to make sure the car can safely be tested on other aspects, so the first check every car will go through independently of the category they compete in or the type of vehicle it is.
- **Business Presentation:** In this event, teams will be able to get all the way up to **75 points**. It is an evaluation of the business plan developed by the team who will have to convince the executives of a company that their design meets the exceptional demands of the competition. These investors are theoretical and they play the role of judges. It is meant to demonstrate the ability of engineers to transform an idea into a business plan in which they will have to present sponsors, optimization processes, cost-cutting measures and comparisons between different procedures and the reason why they finally chose the one they are using.
- **Cost, Manufacturing and Sustainability report:** This last event gives **100 points** to those who deserve it. A fully detailed report that shows and justifies every cost the team has had will be judged by the jury. This report must identify materials used, a detailed explanation of production processes and the car's assembly. To end it up, students will complete a 'Real Case Scenario' event to reduce cost in specific areas based on different inputs given by the organization. Judges will then determine whether the quality/cost ratio is the appropriate or not, as well as the environmental footprint, the durability of the car and the quality of different mechanical components of the vehicle. This event is thought to demand the students to optimize processes instead of sticking to their first idea.
- **Engineering design event:** This event is rewarded with a maximum of **150 points**. Students will present their technical knowledge and know-hows to the judges. It is a multiple round event in which judgement gets harder along the way. Teams will get disqualified as rounds pass, and only the best ones will arrive to the final ones. This is also a great way to self-evaluate and learn through the feedback the judges give. It is a real engineering project's scenario, in which students will be asked high-demanding technical questions and hypothesis that they will have to answer and justify. Questions will be more specific as rounds go by.

This makes a total of 325 points distributed in the static events. These events are suitable for all vehicles qualified. For those who participate in the Concept Class, these are the only events they can participate in:

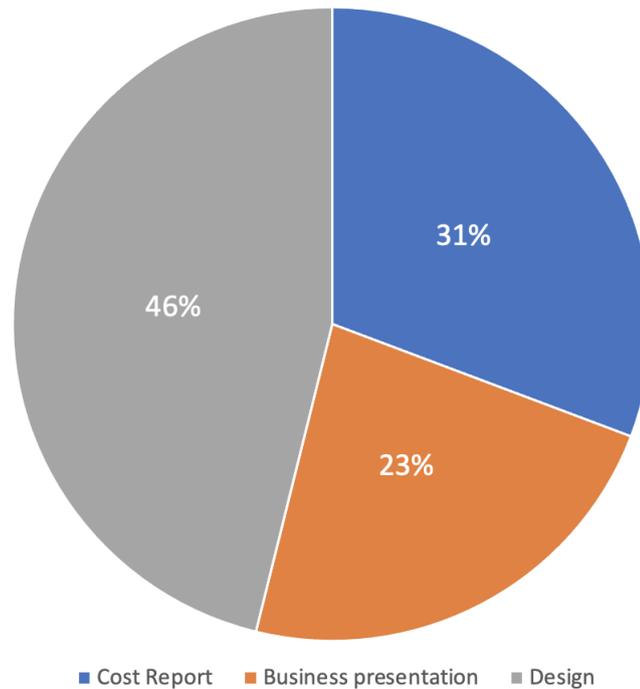


Figure 5. Points' distribution of the static events

The event's winner is the university that has the maximum number of points, being the maximum 1000. 66% of those points will be given away on the dynamic events, whereas the static events only represent 33% of them. The reason behind the points' distribution is rewarding the most advanced teams and not letting compete for the win to the concept class vehicles, as their vehicle as not yet even been developed. The keys to win are the following:

- Making a reliable vehicle with no possible issues that may disturb the vehicle's performance
- Optimizing every process and minimizing costs and fuel consumption while still having a remarkable performance
- Having a highly prepared team from a technical point of view
- Maximize possibilities through high-performing drivers

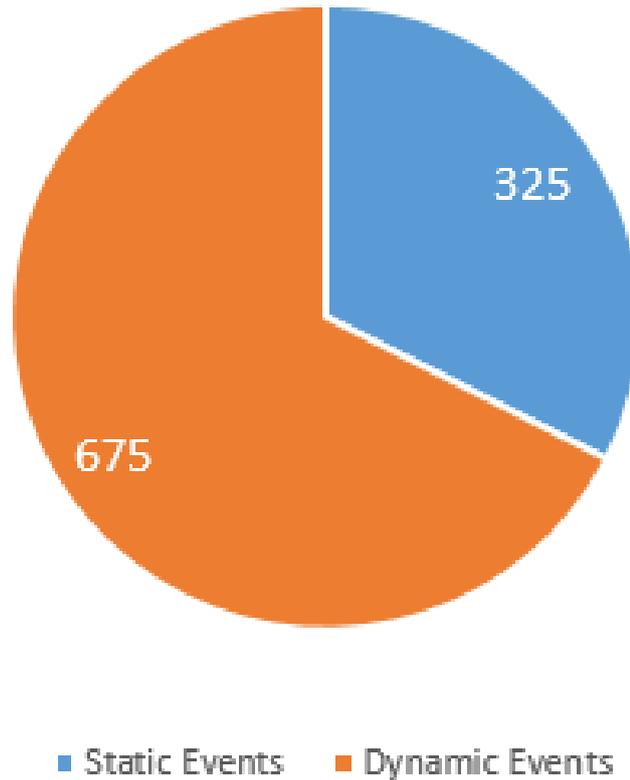


Figure 6. Total points' distribution

3.4. Sponsors

Sponsorships in the Formula Student competition [7] are seen as a very interesting investment, as over 4,000 students (130 teams - per edition) get together in an intense 4-day period followed closely by the main motor-sports businesses who look for young talent. All the motor-sport's eyes are put into this event, which makes it a clear sponsorship target for businesses in the motorsport and vehicle industries. These sponsorships usually have a double target:

- Visibility within the motorsports/vehicle sectors
- Recruiting the highest talented engineers that are interested in the industry and who will be the leaders of these areas in the future

The Formula Student's organization categorizes in three main groups their sponsors:

Partners	Sponsors	Supporters
MathWorks	AB Dynamics	AFBE-UK
Babcock	Altair	Anglo-American Oil Company
Autodesk	BMW Group	Cam Coat
Bentley	Cranfield University	CCAV
IPG	DLG Auto Services	Fisita
Saietta	GKN Automotive	Formula Careers
	Newton Europe	Get It Made
	Royal Automobile Club	Hoosier Tyre UK
	RS Grass Roots Education	Marc Brunel Recruitment
	Saietta Group	MIA
		Racecar Engineering
		Race Tech
		Racing Pride
		Silverstone UTC
		Student Motorsport
		WES

Table 1. Actual partners, sponsors and supporters of the FS competition

Partners hold a privileged position, sponsors are the standard version of partnership, and supporters are those businesses/institutions who collaborate in some way without being highly linked to the competition. Some main characters of the vehicle and motorsport’s industry take a main role in the development and organization of the competition. Some previous years’ sponsors include Scuderia Ferrari, Shell, Ford, Toyota, Williams Martini Racing or Airbus:



Figure 7. Previous competition sponsors

It is important to mention that sponsors are not the same for every Formula Student competition, and they may vary from one country to another. Either way, the sponsors here mentioned are the most remarkable and traditional ones. It is important to take into account that the main sponsors tend to participate in the FSUK or FSG editions, as they are the most visible competitions and the ones where the best teams participate in.

3.5. Incriptions

Every edition of the FS tournaments has a highly demanding inscription process, that has the same format for most of them. As more and more teams will join these competitions over the years, inscription skills are becoming a crucial aspect of the teams as they tend to increase in difficulty. Usually, teams have a specific person who prepares for the inscription processes and who is in charge of a clinical performance. Most of the time, teams tend to focus on the vehicle conception and production and forget about inscriptions. Without a proper preparation, a one-year-work vehicle could have nowhere to participate.

To qualify for competitions, which are more or less famous, you have to take part in qualification quizzes: certain stages (except Italy which operates on a first-come first served basis, and England which works on file) offer a quiz, put online at a specific time. The teams respond to them as accurately and as quickly as possible, which makes a classification according to these two criteria. The best ranked teams are admitted within the limit of spots available after payment of the competition fee.

Although FSUK is a great opportunity for the team to learn through new challenges (such as transportation logistics - we would have to transport the vehicle, materials, interchange elements and certain team members), rules and professionals, it was not the first option for the board of directors. The feedback we had received from the Invictus team (EPSA's 2021 members - thermal vehicle competition), were remarkably positive from the Formula Student Netherlands, where the welcoming and the advice received from the judges were extremely helpful. Therefore, this was the prioritized path by the team management regarding other competitions. Nevertheless, the EPSA team decided to participate in several quizzes to ensure the presence in at least one competition.

Inscription quizzes represent a great challenge, as they depend on rapidity, knowledge and, most importantly, the demand, the number of teams participating. Over 800 teams apply for a few spots in certain competitions, which makes the process extremely demanding. In our case, it is the Project Director who manages the inscription. As it is remarkably important to be fast, only one person can be in charge of answering the questions. This leaves a huge responsibility to this team member as our participation on a competition, as well as the costs associated, depends on his performance.

Nevertheless, the results were not as positive as expected, not achieving to enter the Formula Student Netherlands nor the Formula Student Germany or Italy competitions. The asymmetry in the proportion of electric teams and the number of available spots makes the qualification hardly achievable. As it is our first year participating in this event, it is of great relevance to learn from it as a team and transfer the feedback to our future generations and achieve greater results for next year's quizzes.

We were, therefore, forced to participate in the only competition where we had a spot, Formula Student United Kingdom. Although it was not our first option because of the logistics challenges it presented being a French team, it is one of the most recognized editions worldwide, which makes it a great growth opportunity for the team.

Chapter 4

EPSA - Écurie Piston Sport Auto

4.1. Introduction

EPSA [8] or Écurie Piston Sport Auto is a Formula Student team of 37 members from École Centrale de Lyon, a French Grand École located in Lyon. The FS team was created in 2001 with the idea of developing students knowledge and practical abilities in a real-world project. The competition is mainly focused on students who chose mechanical and electronic specific subjects. The engineering students design, implement, test and produce a vehicle (thermal combustion or electric depending on the year) that then competes in the FS tournament.

The EPSA Team has developed 4 technical courses [9] that were implemented in 2002, 2008, 2013 and 2019 respectively: TTIM (for two-seater vehicles with thermic propulsion), TIZY (for two-seater vehicles with hybrid propulsion), STUF (for single-seater vehicles with thermic propulsion) and ELIZ (for single-seater electric vehicles).

The student members are responsible for the design and conception phase, the budget administration and the sponsors' research. The production of the main elements of the vehicle are carried out by different educational institutions. While the conception is still being done, several professional high schools from Lyon are in charge of the manufacture of the different components.

4.2. History of the EPSA team

2003 to 2012: The EPSA team used to participate at the SIA championship, organized by the Automotive Engineers Society, whose target were the university students. The tournament's objective was to make compete different ecological vehicles' prototypes. Although the vehicles may seem more complex, they are actually easier to conceive and produce than the FS cars, as there was little to no regulation that limited the conception, so vehicles could be as simple or as complex as wanted.

The vehicles were judged, over several events, by a group of motor-sport experts. These events were composed of four static and four dynamic events.

The particularity of this championship was that cars had to have a 'Zero emission' mode. They would have to have a non-thermal engine. One of the dynamic events would consist on

doing a 1100 m course without using the thermal engine.

The regulation also placed emphasis on innovation in order to stimulate the imagination of future engineers.



Figure 8. EPSA's 2013 vehicle for the SIA championship

2012-2017: The 2nd-year students of the École Centrale de Lyon started to develop vehicles that would participate in the Formula Student competitions. The teams would be exclusively composed by second-year students, and the vehicles would be developed on a yearly basis.

2017-present: From 2017, the EPSA team has changed his working methodology. The team is now intergenerational, with students from first and second year of engineering and the third year students who are still interested in the project would have the possibility to collaborate as advisors. This has allowed to develop a better knowledge transmission system, as the students who work on a car on their first year can guide those who join the next year.

The EPSA team has developed different vehicles for diverse competitions, but every period is thought out the same way:

- the first year participating in a new competition/category, the team will develop a solid base, developing a vehicle with little innovation and not a high performance but ensuring the participation and the knowledge permeate to the next generations
- the following years, all the focus would be on the optimization of processes and performance

This procedure is translated in the distinctions the vehicles have obtained on each period:

Vehicle	Year	Competitions	Distinctions
Dynamix	2014	FS ATA 2014 FS UK 2015	Best Newcomer - FS UK 2015
Atomix	2015	FS ATA 2015 FS UK 2016	19th at the endurance event - FS UK 2016
Kinétix	2016	FS ATA 2016	8th at the cost event 10th at the Skid-pad event
Olympix	2017	FS ATA 2017	6th at the cost event
Vulcanix	2018	FS ATA 2018	4th at the cost event Team's record at the Skid Pad event
Optimus	2019	FSN 2019 FS ATA 2019	4th at the Business event - FSN 2019 & FS ATA 2019
Invictus	2020	FSN 2020	1st at the acceleration event
Valkiryz	2021	FS UK 2021	?

Table 2. EPSA's vehicles for FS

4.3. Roadmap of the EPSA team

The team, as every other competitive Formula Student team, is in a constant evolution. This allows the students to discover new technological challenges every year. This evolution is anticipated and organized to help students with the transition in a safe and solid way.

Transition to the electric vehicle: It was stipulated that it would take place in 2022. The first preparation PE took place in 2020 and it was named 'Battery pack'.

Transition to the driver-less vehicle: It will take place in 2025. The first PE has been developed throughout 2022 and it is focused on image recognition.

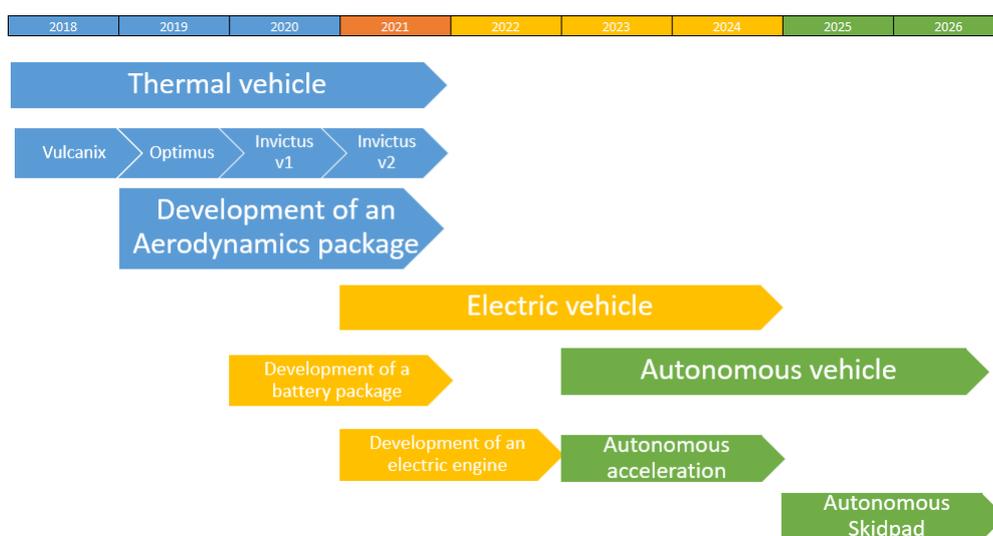


Figure 9. Roadmap EPSA

4.4. Team presentation

The Formula Student competition is very demanding, which is why the team's organization is crucial for an adequate performance. We are divided into four departments, that are supervised by the Board of directors. This structure allows 37 students to participate efficiently in the project while dividing the big tasks into smaller ones.

The organization of the EPSA Team for the first-ever fully electric vehicle is shown in **Figure 9**.

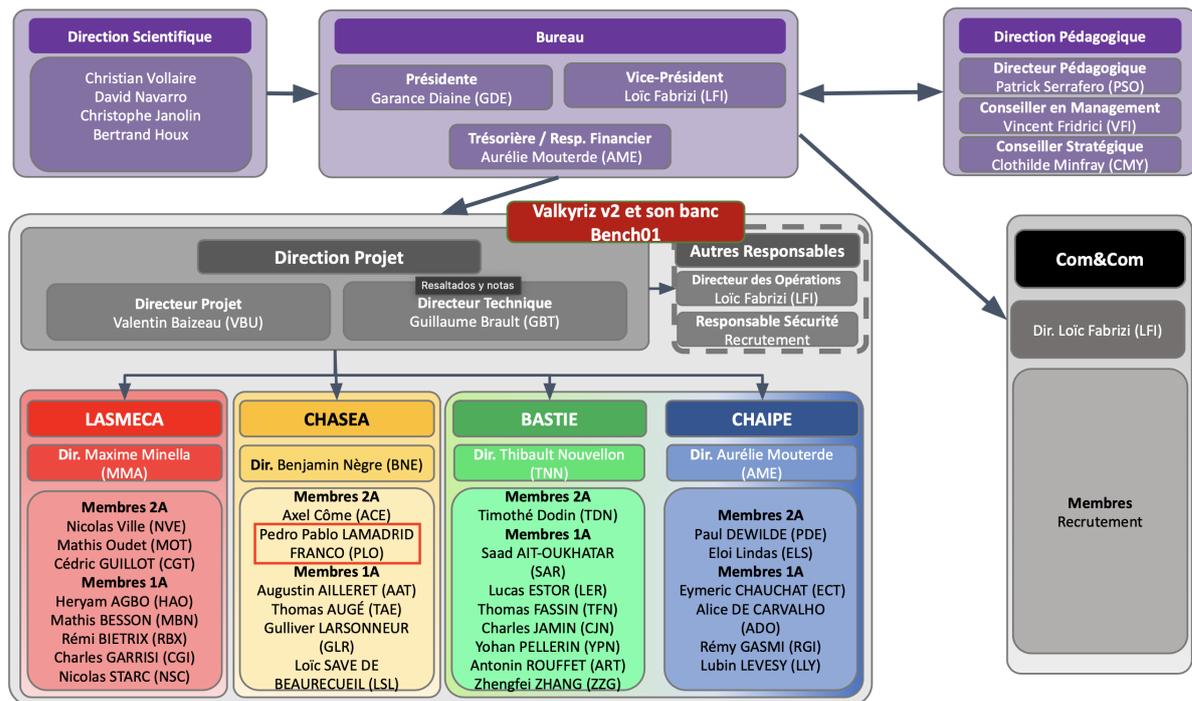


Figure 10. 2021-2022 EPSA's organization chart

To advise and guide the different departments, there are supervisors of the university: Mr. Serrafero, Mr. Fridici and Ms. Minfray. We also have a scientific direction composed of Mr. Vollaïre, Mr. Navarro, Mr. Janolin and Mr. Houx.

The students' structure is divided into two main sections: the board of directors and the different departments.

Board of directors:

- **Project's director (Valentin Baizeau):** He is responsible for achieving the objectives previously fixed in a given time and with a limited budget. He has to have a global view of the project and distribute tasks. He is also the person responsible for the inscription processes.
- **Financial director (Aurélie Mouterde):** She is responsible for the budget. She makes sure that the different departments stay within their budget that was allocated at the beginning of the project and assists the project's director for decision-making.

- **Technical director (Guillaume Brault):** He is responsible for the respect of the EPSA standards for the conception and production of the different systems. He ensures the appropriate quality of the tasks that have been done.
- **Performance responsible (Nicolas Ville):** He is present at the beginning and the end of the V cycle. He fixes the objectives at the beginning of the cycle and verifies that they are accomplished at the end.

Departments:

- **COM&COM** (*Commerce et Communication*) who has several roles which differ from technical positions. The main objective of this department is sponsorship and social network communication. It is therefore crucial to be constantly in contact with the technical team, in order to be aware of the project's progress, but also, and above all, to keep in touch with the outside professional world.
- **LASMECA** (*Liaison au sol mécatronique*) who is responsible for the suspension of the car as well as the tyres.
- **CHAIPE** (*Chaîne de Puissance électrique*) who develop the electric power transmission chain.
- **BASTIE** (*Banc Statique et Intelligence Embarquée*) who works on the onboard intelligence and the test bench.
- And the department we will focus on: **CHASEA** (*Chassis Équipé et Aérodynamique*) who design the chassis of the car. This last department is composed of 8 engineering students from École Centrale de Lyon, three of which are second-year students (Benjamin Negre, Axel Côme and Pedro Pablo Lamadrid) and five first-year students. This year we have followed the British Formula Student regulations.

4.5. Project's objectives and methodology

I have taken care to define the different objectives of my project. They are of different natures, whether they are objectives of results in competition, educational objectives, or development of the team.

The automotive sector is currently in the midst of an energy transition. The end of thermal engines, which is inevitable, will impose a new mode of propulsion. Electric is currently the most promising option, certainly far from perfect, but constantly improving. Tesla, Peugeot or Jaguar, the major car brands, now offer their electric models. EPSA having a pedagogical aim, it has become necessary for electric-powered vehicles to be sponsored by the Ecurie to enable engineering students to develop skills sought after in industry.

Currently, the EVs increase is mainly driven by a regulatory push (e.g., MOVES III [10] offers subsidies for EV buyers in Spain) and OEMs objectives (e.g., Mercedes and Renault to only sell EVs by 2030 and Audi by 2033). Currently, there are 170,000 EVs in Spain, while there are 20,000,000 ICEs. This reluctance to the transition is driven by the low EVCI density in Spain, that is slowly being counterattacked by regulation (e.g., every gas station must have an EVCI by 2023) and utilities projects (e.g., partnership between Cepsa and Iberdrola).

As this is the great challenge of our generation, at least on the early stage of our career, being able to start to know the EV world by developing a FS EV is a great opportunity.

4.5.1. Team's objectives

4.5.1.1. Competition's choice

Valkyriz was meant to participate this summer at the FSUK, at Silverstone. The decision to participate in the FSUK was made following our quizz results: our rankings were insufficient in other European competitions, in particular the Formula Student Netherlands.

4.5.1.2. Provisional performances

To size a vehicle, you must first determine the number of points you want to get in the competition. The team therefore defined, at the start of the project, the place it was aiming for in the ranking. For a first electric car, it was difficult to estimate what we were capable of. The approach was therefore to refer to the performance of the team in previous years. We felt that we would perform just as well in the static events, but that we would be slightly less dynamic. Furthermore, we wanted the transition to take place in complete safety. We, therefore, wanted our vehicle to be reliable, simple and durable rather than efficient. This way of work was aligned with the team's spirit of making reliable vehicles and to pass the information to the next generations for the optimization of the vehicle.

To ensure the reliability of the transition, we have established a road map for the 2021-2022 season.

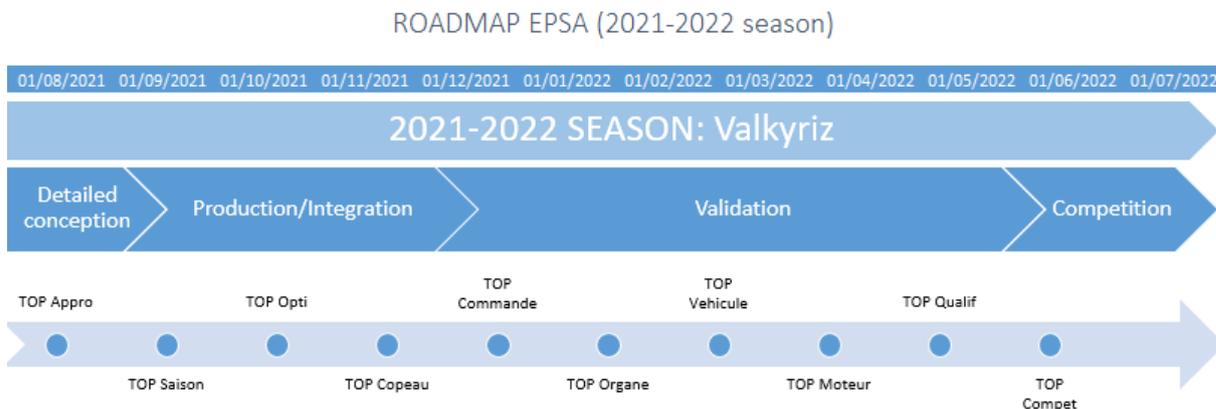


Figure 11. Road map for the 2021-2022 season

The project had to be staked so that the usual rhythm is maintained, i.e. approximately one milestone per month. The milestones of an EPSA project are called "TOP". These are project reviews during which the work provided is evaluated and verified by the Pedagogical Department and the Academicians.

Taking into account that it is the first ever electric vehicle developed by the EPSA team, we have set an objective of 450 points throughout the whole competition, which seems reasonable for a first-timer.

Once the provisional objectives were defined, the team has developed, by different models, the technical objectives.

So the team's objective, in terms of points, is described in the following table.

Static Events			
	Best EPSA results	Valkyriz expected results	Maximum points
Cost Event	94	75	100
Business Event	70	60	75
Design Event	116	80	150
Total static points	280	215	325
Dynamic Events			
Skid Pad	49	30	75
Acceleration	79	30	100
Autocross	64	40	125
Endurance	160	125	275
Efficiency	160	125	275
Total dynamic points	358	235	675
TOTAL	638	450	1000

Table 3. Points' objective for the 2021-2022 season

As it is clearly shown in the table above, we had high expectations on the static events, expecting results that are on average c. 20% lower than our best result, while we expected a worse performance on the dynamic events, with a c. 40% lower result than the best one.

4.5.2. Personal objectives

The objectives of the project, on a personal basis, are divided into several categories that we could resume in:

- Material and constraints analysis via simulations and the characterization of the elastic limit and rupture's constraint for the materials' decision and the structure choice within a decision matrix
- Structure's design and conception while respecting the rules via CAD CATIA (i.e., redefinition of the rear-end of the vehicle, of the cockpit and triangulation of different areas of the tubular structure)
- Integration with the different sub-systems of the vehicle (i.e., conception of screeds for the fixation of different elements to the chassis)
- Analysis and supervising of the production process divided into the laser-cutting processes and the 3D processes (e.g., development of jigs for welding easiness)

4.5.3. Methodology

The methodology of the project is similar in every department, and it consists on:

1. Regulations' introspection to determine the path of development
2. Proposal of an architecture for the chassis and the different bindings with the other sub-systems
3. Validation from the supervisors of the project
4. Contact of the suppliers and financial analysis for cost optimization
5. Vehicle's conception
6. Vehicle's production
7. Vehicle's testing

4.5.3.1. Main resources

The resources we have used in the development and implementation of the vehicle can be divided into two main categories:

Organization: Being a project with over 60 people involved, it is crucial to respect the proposed tasks division and permanently inform about the evolution of the work. To do so we use a platform called Monday [11]. Monday allows to have a global vision of the tasks in a single e-place and to visualize them in a simple way. Our organization of the work space allows every team member to consult his/her objectives actualized on a weekly basis and to provide update on the status of their current tasks. The fact of asking members to introduce the evolution in the objectives introduces a contract between the members and the management team. He lets the direction know that he knows what has to be done and the deadline. Tasks, deadlines, responsible and evolution must be added into the platform.

The screenshot displays the Monday.com interface with a sidebar on the left containing a navigation menu. The main area shows three task lists. The 'Commande' list has four items, all with a 'Done' status. The 'Dimensionnement' list has three items, all with a 'Done' status. The 'Durites' list has one item with a 'Done' status. A red box highlights the 'Dimensionnement' section.

Section	Sub item	Owner	Status	Estimated Time (h)	Due date
Commande	Passer la commande du radiateur	[Avatar]	Done	1 h	déc.-1, 2021
	Passer la commande du ventilateur	[Avatar]	Done	1 h	déc.-1, 2021
	Passer la commande de la pompe	[Avatar]	Done	1 h	déc.-1, 2021
	Passer la commande du vase d'expansion (offert par Radiasoudure?)	[Avatar]	Done	1 h	déc.-17, 2021
Dimensionnement	Choisir la pompe de refroidissement	[Avatar]	Done	1 h	oct.-3, 2021
	Réaliser une matrice de décision entre les 3 pompes proposées	[Avatar]	Done	1 h	oct.-12, 2021
	Dimensionner le vase d'expansion	[Avatar]	Done	1 h	déc.-17, 2021
Durites	Vérifier si des durites hors du châssis c'est rule compliant	[Avatar]	Done	1 h	nov.-3, 2021

Figure 12. Monday example

Monday is not the only platform we use for organization purposes. We also use Slack [12] for internal communication. Slack is a team organization software that allows to manage instructions, determine current state of a task, do polls, and intercommunicate between different departments throughout the creation of channels that establish chats within departments and between them.

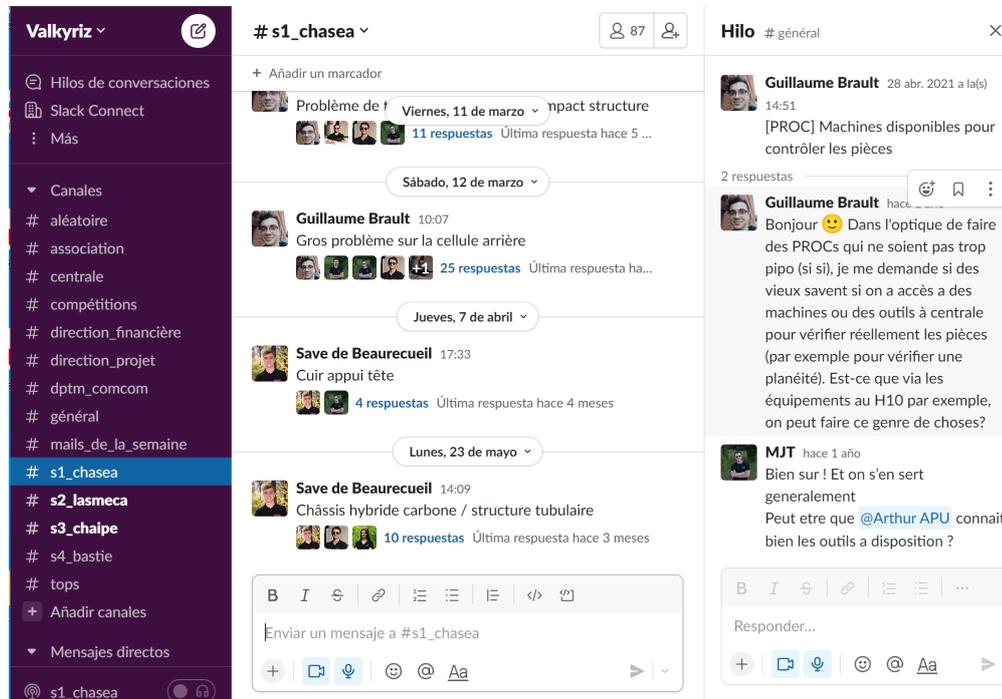


Figure 13. Slack example

We also have an internal 'Wikipedia' called EPSAbox [13] in which we report the current state of the project's development as a whole for everyone to have a global vision of the vehicle. EPSAbox is one of the main intergenerational platforms, as it is on it that we publish technical procedures for every element developed within an academic year. Everyone has a profile, and it is the way of getting in touch with people who have been EPSA members in previous years, as you have their contact and also what they have done for the team, the documents they have uploaded. Everyone has to publish, at least, two POs, which allows having a detailed vision of every year's work.

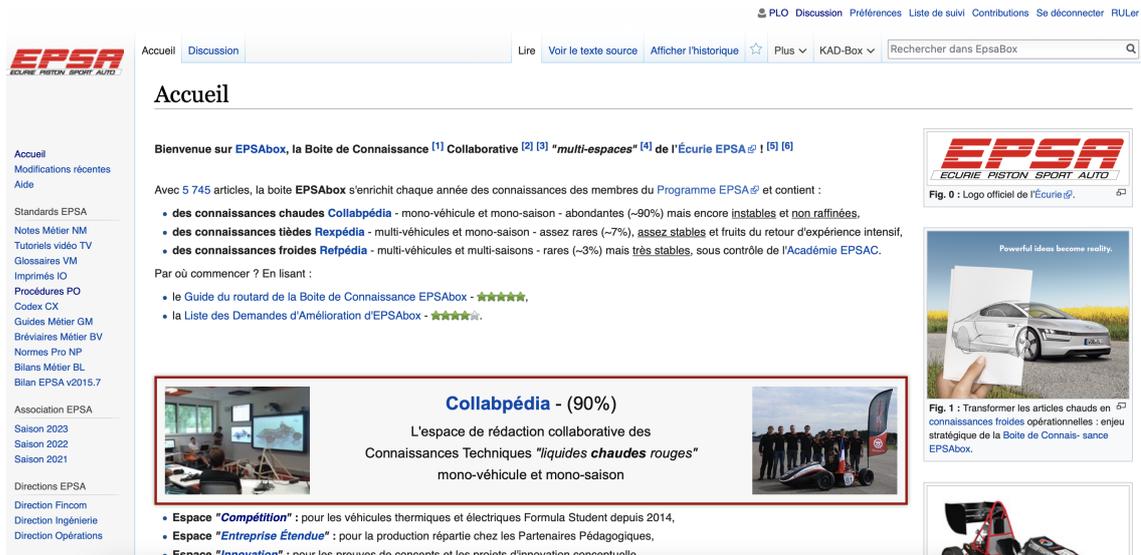


Figure 14. EPSABox example

Software: CATIA V5 [14] is our main resource. We develop the different elements, implement them into the vehicle, we make the technical plan for the suppliers and the welders, and we do constraints simulations. We design, as well, external elements (such as screeds or jigs) to the vehicle to help people who do not belong to the project, have a better understanding of the car. We have also used Fluent for aerodynamics purposes and fluids analysis. Almost every aspect of this project has been developed using CATIA.



Figure 15. CATIA logo

4.6. Financial management and logistics

4.6.1. Resources

Each year, EPSA can count on the financial support of various educational and industrial partners. This support is essential to the sustainability of the team, as it constitutes all the cash inflows used for the manufacture of the vehicles that we produce. Most of these entries come directly from the apprenticeship tax, which is why the association has been running an annual

tax collection campaign for years with its network companies and sponsors (this process will be detailed later).

As described above, the transition to electricity that EPSA wanted to implement this year is a transition that takes place over two years: this is why we will present the sources of financing for the team over the period from September 2021 to August 2022.

We are therefore going to describe the two types of financing the team has:

- **The recurring financing:** This is the financing on which the team can, a priori, count from season to season. They have been renewed for years and have not yet destined to decrease.
- **The exceptional financing:** These are the funds requested exceptionally this year by the team to complete its transition to electric. These funds have not intended to be renewed from one year to another and are the subject of files or presentations issued to the various financial partners of the team.

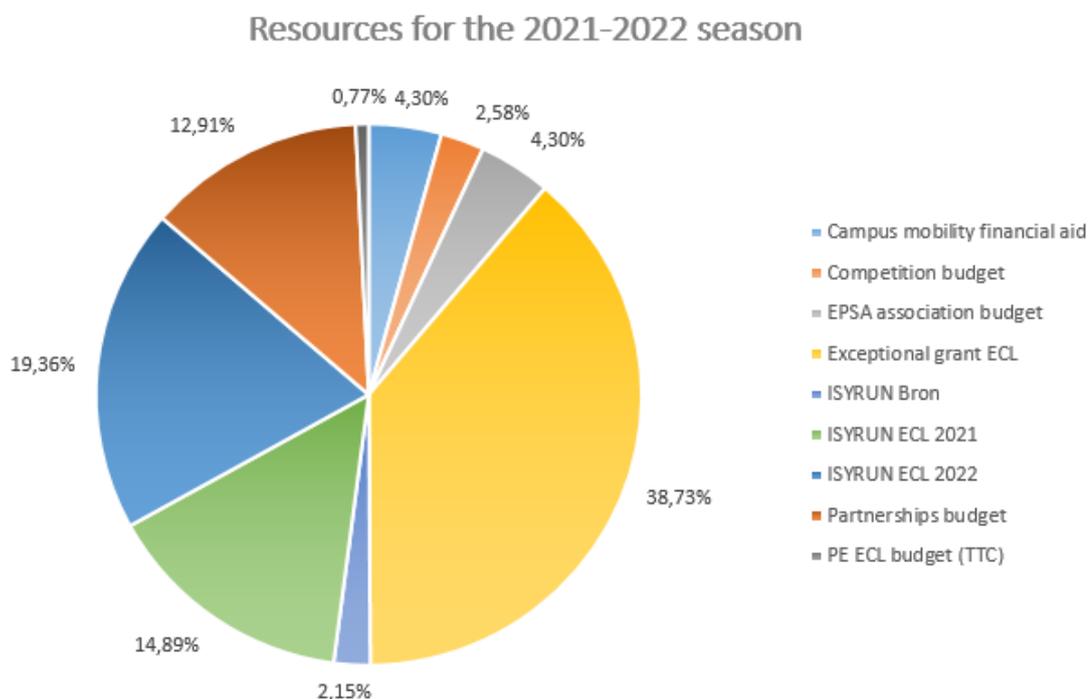


Figure 16. Resources for the 2021-2022 season

The recurring financing

Our main source of funding has always been the École Centrale de Lyon since the creation of the team. Indeed, for several years we have been conducting a campaign to collect learning taxes in partnership with the university. On the other hand, the university provides the EPSA team with a budget entitled **ISYRUN ECL** dedicated to the ordering of components and materials, which is necessary for the manufacture of our vehicles.

For the past few years, this budget has amounted to **EUR 45,000 including tax** per year and has been renewed in January.

We can also count on the participation of our second major partner: the Emile BEJUIT automotive trades high school located in Bron. This budget, entitled **ISYRUN Bron**, amounted until now to EUR 24,000 including tax, of which EUR 12,000 including tax was directly allocated to maintenance of the garage located directly on their campus. The remainder of the budget is used to spend orders for components and materials. However, since the beginning of our season, this budget has been reduced to **EUR 10,000 including tax** per year, which leaves **EUR 5,000 including tax** available to spend on some orders. This budget is renewed in June/July.

In addition to these two partners, we count on the support of four other educational institutions that allocate part of their budget to the project led by the EPSA team. These budgets are not used directly for placing orders, but for the training of students and for the manufacture of parts directly integrated into our vehicles. In 2022, since the 2021 season did not produce a vehicle, these budgets were doubled:

- **Budget ISYRUN La Giraudière [15] (EUR 10,000 with taxes, from which EUR 5,000 are usable):** this is the amount that corresponds to the production school La Giraudière. This includes the chassis production.
- **Budget ISYRUN La Mâche [16] (EUR 10,000 with taxes from which EUR 5,000 are usable):** this is the amount that comes from the school La Mâche.
- **Budget ISYRUN Boisard [17] (EUR 10,000 with taxes from which EUR 5,000 are usable):** This allows the financing of the production of different sub-systems such as those from the LASMECA department.

The exceptional financing

However, as illustrated below, the recurring financing collected by the team is not enough to ensure our transition to electric. This is why we have had calls on several of our partners to help us take this step. This is a usual procedure done for specific and exceptional, but planned situations. The transition towards the electric was a planned one in the team's road-map, as well as the one to autonomous driving in 2025. Sponsors accept these exceptional budget allocations while adequate previous organization has been done.

The mobility campus based at the Aragon Picasso high school in Givors supported us financially with up to **EUR 10,008 including tax** to participate in our electric transition. Nevertheless, this source of funding demands the production of a report on the design of a battery.

In September 2020, we also submitted an application for funding to the École Centrale Lyon amounting to EUR 30,000 including tax. This request resulted in the drafting of a more complete file submitted at the beginning of April 2021 to the ECL with an update of the budget following the changes in architectural choices and funding sources for the Bench 01 test bed. Finally, the subsidy granted by the Ecole Centrale Lyon following this request for an exceptional budget amounts to **EUR 90,000 including tax**.

Finally, the team also participates in the financing of this transition to electric by **EUR 10,000 including tax** thanks to the association's own funds. This sum constitutes an exceptional

financial effort on the part of the team in order to participate in the order of our first battery of the vehicle.

Financing sources	Amount	Comments
Exceptional financing by the ECL	EUR 90,000	Budget for orders
ISYRUN ECL 2021	EUR 34,678	Budget for orders:
ISYRUN ECL 2022	EUR 45,000	Large flexibility in the suppliers and elements
ISYRUN Bron 2022	EUR 5,000	Budget for orders: Less flexibility in the suppliers than ECL
ISYRUN La Giraudière 2021	EUR 5,000	Budget for the production
ISYRUN La Giraudière 2022	EUR 5,000	of mechanical parts
ISYRUN La Mâche 2021	EUR 5,000	Budget for the production
ISYRUN La Mâche 2022	EUR 5,000	of mechanical parts
ISYRUN Boisard 2021	EUR 5,000	Budget for the production
ISYRUN Boisard 2022	EUR 5,000	of mechanical parts
Competition budget	EUR 6,000	
EPSA association financial aid	EUR 10,000	
Mobility campus financial aid	EUR 10,008	Budget for orders
PE Budget ECL 2021	EUR 900	
PE Budget ECL 2022	EUR 900	
TOTAL	EUR 232,486	

Table 4. Total budget for the 2021-2022 season

4.6.1.1. Project expenses

Regarding the budget of our educational partners ISYRUN La Giraudière, La Mâche and Boisard, the details will not be given in this report: indeed, these partners are working on mechanical parts from the Valkyriz vehicle that are very close to the parts manufactured for Invictus. The report will rather focus on ordering parts on the ISYRUN Centrale budget, on the ISYRUN Bron budget and on the associative budget where the majority of expenditure on orders will be carried out.

A detailed costing of the ISYRUN budget allocated to the manufacture of Valkyriz was carried out in mid-season: we can thus approximate that the latter will constitute an outflow of EUR 98,400 including tax. Finally, as detailed below, the last expenses incurred for the manufacture of the bench static Bench 01 provide a price of approximately EUR 105,400 including VAT.

We have to take into account on our budget:

- the inscription fees for the competition that can add up to EUR 7,300 with taxes.
- the expenses for the pedagogical platforms at the Automobile Bron's High School that are EUR 2,300 with taxes.
- The EPSA team always leaves a budget of EUR 10,000 for the following year.
- Finally, we have allocated a 5% of the budget towards possible risks and inflation.

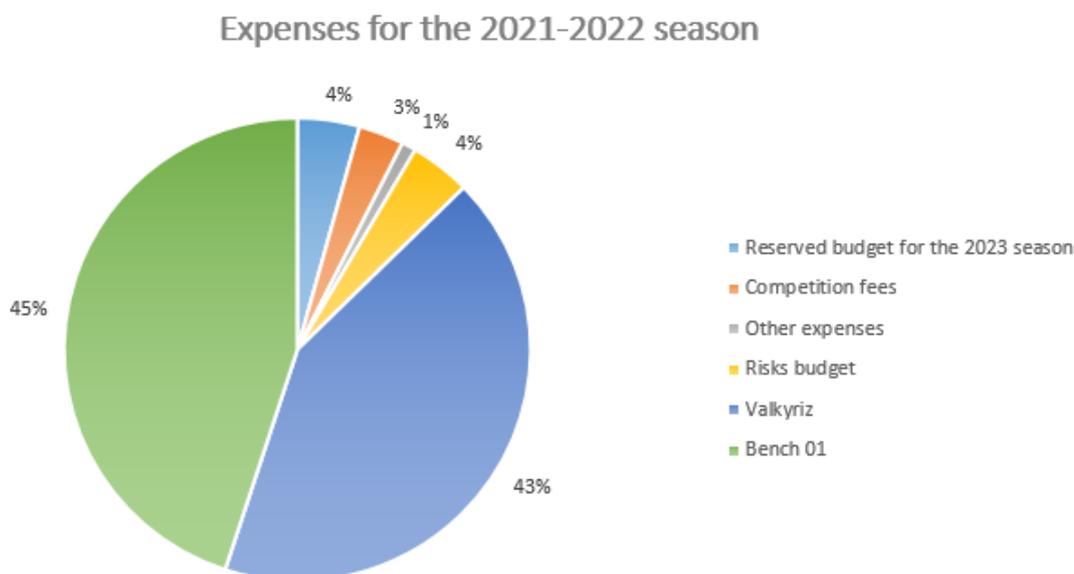


Figure 17. Expenses for the 2021-2022 season

4.6.1.2. Methodology for monitoring orders and expenditure on the various budgets

The orders’ monitoring and the day-to-day expenditures are managed with the financial department from the École Centrale de Lyon: Fatima Elboukhrissi for ISYRUN Centrale, Béatrice Chervet for the PE budget and Mari-Hélène Levée for the exceptional budget allocation.

This year’s orders’ monitoring has been done by naming one member responsible for each supplier. In an Excel table, grouping all the references of the orders to be done and already receives, each department manages their orders, just as exemplified by Figure 13.

Budget	Oreca							RESPO	CGT	
ISYRUN Centrale	Produit	Référence	Département concerné	Lien achat	Quantité	Prix unitaire TTC	Réduction	Rentré dans le devis/panier de commande sur internet	Réceptionné	Lieu de Stockage
	hamais pilote		CHASEA	hamais sparco	1	316	0,25	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
	moyeux escamotables		CHASEA	moyeux escamo	1	260	0,45	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
	Durites de frein		LASMECA	durites de frein	6	8,2	0,45	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
	Stickers et planche		LASMECA		7			<input checked="" type="checkbox"/>	<input type="checkbox"/>	
					Total €TTC	407,06				
					Frais de livraison €	12,57		Commande terminée	<input type="checkbox"/>	
					Total €TTC final	419,63				

Figure 18. Excel table for order monitoring

This way, a global budget is asked to every member responsible for each supplier, who is also in charge of managing the creation of an account for the supplier at ECL. The financial director supervises that everything is done accordingly to the ECL internal regulation. She is also responsible for, with the budget done, deciding which elements are finally ordered to the supplier and which are not.

4.6.1.3. Current financial state of the project

As to where the project is right now for the Valkyriz vehicle and within the budget that was accepted by the team and the different partners, over 84% of the budget has been expended.

Department	Expended budget	Allocated budget	Budget remaining
LASMECA	EUR 17,250.92	EUR 29,487	EUR 12,236
CHASEA	EUR 13,071.66	EUR 13,345	EUR 274
BASTIE	EUR 2,278.64	EUR 2750	EUR 471
CHAIPE	EUR 50,035.74	EUR 52,634	EUR 2,598
Others	EUR 167.9	EUR 262	EUR 94
TOTAL	EUR 82,804.86	EUR 98,478	EUR 15,673

Table 5. Current financial situation

Several elements have been delivered, such as the differential, the engine, the controller, the high voltage cables, the low voltage batteries, the chassis, the pedal system, between others.

Chapter 5

Formula Student Competition and EPSA in 2022

5.1. Introduction

The car we are currently working on for this season is named Valkyriz. It was meant to compete in Formula Student United Kingdom in 2022. It is the first 100% electric vehicle developed by EPSA and his technical partners. The main performance objectives with this vehicle are: 0 to 100 km/h in less than 4 seconds and a driving autonomy of 35 minutes, while having its mass reduced to 250 kg. This translates to the points' objectives previously mentioned, in Chapter 3.

The end of the 2021 season was defined by the design of the objectives to be achieved by the 2022 team with Valkyriz.

5.2. Objectives' organization in 2022

Taking into account that we had as a baseline last years' project, the correct establishment of objectives was crucial to our performance, as several subsystems were already developed while others were underdeveloped or had to be modified. Therefore, we have established executive meetings every month called 'TOP'. They are meetings in which we review the main data and technical gaps as well as the point of advancement of the project. These meetings were guided by the Pedagogical Direction and the project advisers. This year's TOPs were established as it follows:

- **TOP Project (April 2021):** Objectives and Progress Politics definition
- **TOP Model (May 2021):** Objectives formalization for the vehicle's performance. Establishment of budget and financial statements
- **TOP Pre dimension (June 2021):** Formalization of the functional objectives in terms of the vehicles' dimensions
- **TOP Appro (June 2021):** Procurement strategy
- **TOP Season (September 2021):** Official season debut with sponsors and pedagogic partners

- **TOP Synthesis (October 2021):** Checkpoint to ensure a correct evolution of the vehicle's conception
- **TOP Copeau (November 2021):** End of the detailed conception. The team has to demonstrate that the vehicle can be sent to production
- **TOP Organe (January 2022):** Production ending. Systems must be verified, and the assembly kit must be available
- **TOP vehicle (February 2022):** Systems are verified and the integration of the different sub-systems starts
- **TOP Engine (March 2022):** End of the integration process and start of the test phase

Although the initial objective was established as presented above, the reality has been slightly different, but within the expected possible delays. Being this year's vehicle the first electric one, there were, as expected, a few block points that represented delays. This is why, since January, TOPs were delayed by 15 days each to be able to respect the objective of each meeting.

5.3. Engineering Methodology

5.3.1. The introduction of an engineering methodology at the EPSA team

Given the scale of the project in financial and human terms, it is important to put in place a rigorous methodology to guide the development of each prototype. This allows for the establishment of benchmarks against which the status of the project can be assessed. The model adopted by the team this year is the V-cycle. This has been the system the team has used for the last years, and it is divided in 2 sections: system engineering, the downward flow, and integration engineering, the upward flow.

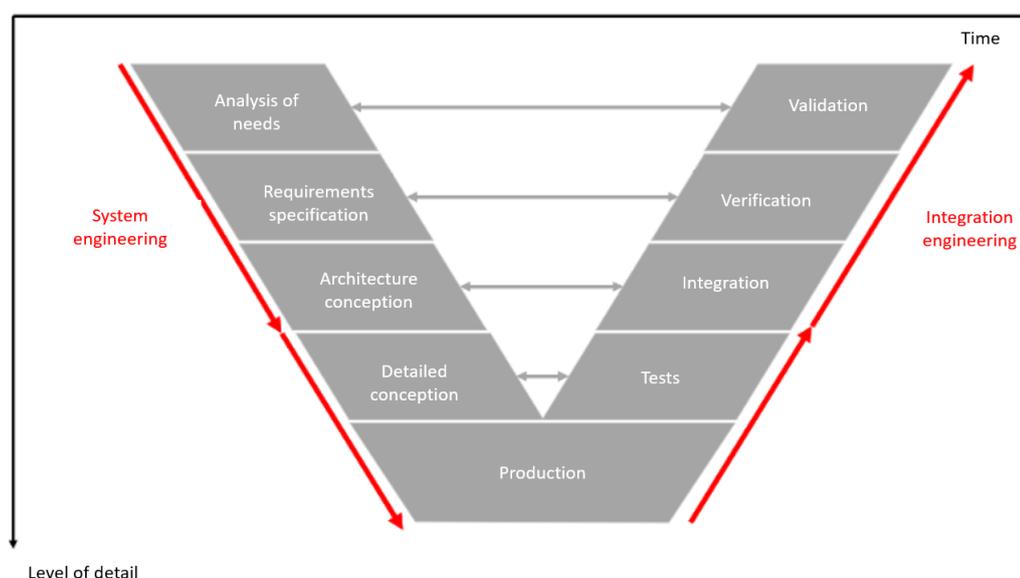


Figure 19. V cycle diagram

The V-cycle is a model formalized in the 1980s. Originating from the world of industry, it conceptualizes the development stages of a product, from the formalization of the customer's

needs to the validation of its conformity with the specifications. In a simplified way, the "V" diagram represents for each stage the level of detail required in a qualitative way.

A first series of stages, the downward flow, aims to detail the product up to its realization. The second series of steps, the bottom-up flow, aims to validate the product until its acceptance by the customer. It mainly includes a series of tests until it can be validated that the product meets the needs and requirements.

5.3.2. Ensuring vehicle's coherence

Each vehicle is designed according to a guideline, defined by the team of engineering student at the beginning of the project. The aim here is to set objectives for all the systems on the vehicle in order to guide the choices made in the design of the single-seater. Indeed, whatever the objectives set are, the car must be coherent as a whole. This respect for the objectives initially set is also assessed during the Formula Student Design test. Thus, the Valkyriz vehicle is intended to be reliable, simple and durable:

- **Reliable**, in order to place the safety issues linked to high voltage electricity at the heart of our considerations
- **Simple**, to minimize the risks inherent in adding technologies to the vehicle. The critical path is to develop the new vehicle powertrain, we don't want failures to come from systems already implemented on the team's vehicles
- **Durable**, as we want the development of Valkyriz to be easily transferred to future generations. Consequently, it is necessary to be able to pass on all of these global objectives to each system and sub-system of the vehicle, and to be able to use them in the future. To achieve this, it was necessary the standardization of the engineering processes, through the implementation and improvement of the tools that are proving their worth year after year at EPSA

Standardization is therefore a necessity to ensure consistency in the design of a vehicle, but also to allow the EPSA to be improved each season. The structuring procedures of the team are gathered in documents called PO (operational procedure), which detail for example the organization of a season or the procedure for checking a newly integrated system. In addition to that, we have a number of standard tools for organizing our work or for centralizing information. As an example, we will detail some of the main tools used this year:

- **Cahier des Charges Fonctionnels**: The specifications (or CDCF) make it possible to establish the link between the client's needs and the designer (in this case, the engineering student). From the specifications, it is possible to design the system and check that it meets the requirements imposed by its environment

Fonction primaire	Fonction secondaire	Niveau	Critère	Flexibilité	Article du règlement
	FS1.1 : Doit disposer d'un Main Hoop, Front Hoop, Front Bulkhead et Side Impact Structure	Sécurité	x	0%	T3.1.1
	FS1.2 : Pouvoir déplacer le véhicule lors de la compétition : pushbar	Sécurité	x	0%	T.13.1.1
	FS1.3 : Permettre au pilote de sortir en moins de 5 sec	Sécurité/Compétition		0%	T.4.11.1
	FS1.4 : Protéger le Pilote en cas de retournement de la voiture	Sécurité		0%	T.4.3.4
FP1 : Respect du règlement	FS2.1 : LAS	Rigidité en torsion	5x rigidité suspensions (1400Nm/deg)	20%	
FP2 : Respecter les Cas de Charges	FS2.1 : Motorisation	Rigidité en flexion (surtout la transmission secondaire)	40000 N	10%	
	Budget Financier	Ne pas dépasser le budget	environ 10000€	20 %	x
	Budget Massique	Peint et équipé	35kg		20% x
FP4 : Attentes de la Direction de Projet	Délais	Pas de retard	3 mois de production, de décembre à mi février		10% x
FP5 : Déplacement	Invictus doit pouvoir rentrer dans la remorque	Largeur véhicule	<1.2 m		0% x

Figure 20. Cahier des Charges example

- Bill of Materials (BOM):** The BOM lists each part present on the car (including screws and bolts) and gives an overview of its main characteristics. Each part has a status and a person responsible to enable the progress of the design to be monitored. This tool allows monitoring with precision, gathering every element of the vehicle, but its effectiveness depends on the rigour of the team in filling in the data.

Assembly	Part Number	Component (25 chars max)	Comment (40 chars max)	Owner	Qty	Etat du design	Bought/Made	Material	Process	Masse UNITAIRE théorique (g)	Masse théorique TOTALE (g)
FR_A0300		Pedal (Accelerator)			1					X	1 888,80
	FR_03001	Frame throttle		VBU	1	Dimensionné	Made	Acier S355		882,00	882,00
	FR_03002	Footrest		VBU	1	Dimensionné	Made	Acier S355		196,00	196,00
	FR_03003	Throttle pedal stick		VBU	1	Dimensionné	Made	Acier S355		263,00	263,00
	FR_03004	Throttle fixing rail		VBU	2	Dimensionné	Made	Acier S355		173,00	346,00
	FR_03005	Throttle fixing rail wedge		VBU	2	Dimensionné	Made	Acier S355		12,00	24,00
	FR_03006	Throttle Threaded Rod		VBU	2	Dimensionné		Acier S355		23,00	46,00
	FR_03007	Front Throttle Fixing Rail Wedge		VBU	2	Dimensionné		Acier S355		12,00	24,00
	FR_03008	Negative Throttle Mechanical Stop		VBU	1	Design terminé		Acier S355		17,00	17,00
	FR_03009	Positive Throttle Mechanical Stop		VBU	1	Design terminé		Acier S355		22,00	22,00
	FR_03010	Throttle pedal bearing		VBU	2	Dimensionné		Bronze		4,00	8,00
	FR_03011	Springs		VBU	2	Composant choix		Acier		6,00	12,00
	FR_03012	Potentiometer		VBU	2	Composant choix		Acier		15,00	30,00
	FR_03013	Rear Threaded rods		VBU	1	Dimensionné		Acier		5,00	5,00
	FR_03014	Front Threaded rods		VBU	1	Dimensionné		Acier		4,00	4,00
	FR_03015	Axle Throttle Pedal Spacer		VBU	1	Composant choix		Acier		5,00	5,00
	FR_03016	M4x25 Screw		VBU	2	Composant choix		Acier			0,00
	FR_03017	M4 FHC Screw		VBU	2	Composant choix		Acier			
	FR_03018	M6x30 Screw		VBU	4	Composant choix		Acier			0,00
	FR_03019	M8x30 Throttle Pedal shoulder screw		VBU	1	Composant choix		Acier			
	FR_03020	Nuts_M3		VBU	12	Composant choix		Acier		0,40	4,80
	FR_03021	Nuts_M4		VBU	4	Composant choix		Acier			
	FR_03022	Nuts_M6		VBU	8	Composant choix		Acier			0,00
	FR_03023	Nuts_M8		VBU	1	Composant choix		Acier			
	FR_03024	WASHER 4x9		VBU	2	Composant choix		Acier			
	FR_03025	WASHER 6x12		VBU	12	Composant choix		Acier		0,30	3,60
	FR_03026	WASHER 8x16		VBU	1	Composant choix		Acier			

Figure 21. BOM example

- Référentiel Standard de Production - RSP:** The RSP is to the production phase what the BOM is to the design phase. The parts are classified by manufacturing location and their progress is reported individually. These two documents may appear to be redundant, but their difference lies in the different way in which the parts are classified: by system or by producer. Thus, it is easier to feed two documents in parallel than one that would be not practical to use. In addition, the RSP can be shared with producers who wish to update it directly.

Département	Matériaux	Nuances	Nomenclature	Description	Quantité	Volume enveloppe (en mm)	Opérations	Statut	Responsable	Vérificateur
LASMECA	Acier	35NCD16	SU_06003	ball joint spacer M6 5.5mm	80	10,2*10,2*5,5		Pièce vérifiée	MMA	GBT
LASMECA	Acier	35NCD16	SU_06002	pivot joint spacer	4	15*15*20		Pièce vérifiée	MMA	GBT
LASMECA	Delrin		EN_01005	Bearing housing	1	108*108*22		Pièce vérifiée	MOT	GBT
LASMECA	Alu	20174	EN_01010	Sprocket spacer	1	16,5*38*38		Pièce vérifiée	MMA	GBT
LASMECA	Alu	7075 T6	WT_02002	Front brake bell	2	82*82*5		Pièce vérifiée	MOT	GBT
LASMECA	Delrin		EN_04001	Chain tensioner (Excentric Right)	1	160*160*22		Pièce vérifiée	CGT	GBT
LASMECA	Delrin		EN_04013	Chain tensioner (Excentric Left)	1	160*160*21		Pièce vérifiée	CGT	GBT
LASMECA	Acier	S235	BE_01005	Oreille de fixation	4			Pièce vérifiée	NVE	GBT
LASMECA	Alu	7075 T6	BE_01006	Renfort supérieur	2			Pièce vérifiée	NVE	GBT
LASMECA	Acier	35 NiCrMo 16	EN_01002	Flanged shaft	1	92*92*84		Production terminée	CGT	GBT
LASMECA	Acier	S235	BE_01002	bâti fixation droite	1			En production	NVE	GBT
LASMECA	Acier	S235	BE_01003	bâti fixation fond	1			En production	NVE	GBT
LASMECA	Acier	S235	BE_01004	bâti fixation gauche	1			En production	NVE	GBT
CHASEA	Acier	S355	FR_03003	Throttle Pedal Stick	1			MEP envoyée	LSL	NVE
CHASEA	Acier	S355	FR_03001_8	Frame Throttle cylindre	2			MEP envoyée	LSL	NVE
CHASEA	Acier	S355	FR_04002	Brake Pedale Stick v2	1			MEP envoyée	PLO	NVE
CHASEA	Acier	S355	FR_04005	Master Cylinder Wedge	2			MEP envoyée	PLO	NVE
CHASEA	Acier	S355	FR_04010	Distribution Brake Axle Tread	2			MEP envoyée	PLO	NVE
CHASEA	Acier	S355	FR_04012	Brake Distribution Ball Joint	1			MEP envoyée	PLO	NVE

Figure 22. RSP example

5.4. Main changes

The 2022 season could be described by one word: changes. We have made the transition from the ICE vehicle to the EV, having to adapt every system of the previous vehicle.

But another great change in the project scope was the participation in the FSUK. Logistics make a great difference between the participation in FS Italy or Germany (where the vehicle is transported via truck) and FSUK where greater challenges are set. The vehicle has now to be transported by train or ship.

And, although it represents a constant change, the team is different to the one that developed the Invictus vehicle last year. Taking into account that the French academic year ends in April, it represents a remarkable challenge that the team has to face every year.

5.4.1. The electric vehicle

The guiding principle behind the design of Valkyriz is to make the vehicle as risk-free as possible. This is why many technologies that are usually used to try to make the vehicle more efficient have been removed or simplified. To give just a few examples: the rear anti-roll bar implemented on the last two vehicles, has been removed, the differential chosen is less developed than those used in previous years and finally, many systems are over-dimensioned. Performance is not the objective for a first-timer, but reliability is.

As a result, the car will be particularly heavy this year. While previous classes tried to bring their cars under 200 kg, Valkyriz will weigh over 240 kg. Remaining under the 250 kg objective previously fixed.

Despite a return to face-to-face work after the lockdowns of last season, the pandemic greatly hampered our work. In particular, a global crisis in raw materials and electronic components is considerably slowing down the supply of the parts needed for the vehicle, while significantly increasing their cost. The team has no control over this crisis, which is affecting even the major car manufacturers, and has often been forced to find ad hoc solutions to supply itself.

Regardless of the planning difficulties, Valkyriz is in the process of being born and will certainly be functional, even though it is not yet ready to be launched.

In addition, this season saw the completion of the Bench 01 project, which was conducted in parallel to Valkyriz. The Bench 01 project aims at optimizing the electric battery and components of the vehicle.

5.4.2. Progress Politics for the 2021 season

On top of the competition and performance objectives, the team fixes, every year, new Progress Politics objectives that define the improvement of the team in a transversal way. In a matter of coherence of these objectives throughout the years, the improvement axis have to be resumed by a single word that has to start with the letter P. Here are defined the 10P that were the main focus of the team this year on an extra-technical level:

- **Project:** The management dynamics, the deadline respect, the budget optimal allocation, the quality insurance and the integration of checkpoints

- **Pedagogic:** The inter generation dynamics and data transmission, the formation and motivation of new joiners and the coordination with the pedagogical direction team
- **Prospection:** New industrial sponsors recruitment and the interview of the already existing ones.
- **Planning:** The timeline dynamics, the respect of plannings, the continuous reporting, the optimization of the usage of hours*person.
- **Procedure:** The synthesis of real-time knowledge
- **Process:** The performance, solidity and innovation measures and production organization
- **Product:** The performance, solidity and innovation of the vehicle's prototype
- **Partners:** The recruitment of new production sponsors
- **Pilot:** The training of new pilots and preparation of future ones
- **Podium:** The performance of the team in FS

5.4.3. FS United Kingdom

FSUK is a student design competition organized by the Institution of Mechanical Engineers which challenges students teams to design, develop, fabricate, and build a small Formula-style race car. Formula Student UK brings together more than 80 teams from around the world to compete at the Silverstone circuit. The project is backed by key figures in the industry, such as Ross Brawn.

This year's event has taken place from 6-10 July 2022

5.4.3.1. Differences between FS editions

FSUK is one of the few editions that offer the Concept Class competition for teams that have not yet produced the vehicle but have a design and are working on the conception. This makes it one of the most remarkable competitions in the FS environment, as it is the one in which the most universities participate in.

On top of that, the FSUK is always one step ahead of other FS editions in terms of technological level. As every FS tournament is still focused on ICE vehicles, FSUK already has a big focus on EVs, offering a wide range of EVCI facilities for vehicles charging and with a broader regulation for this type of vehicles. It is also a pioneer on AVs, hosting a wide range of universities competing in that category.

In terms of regulation, there are several differences between FS editions, but as they do not represent major changes on the vehicle's structure, we will not get into detail in this report.

Chapter 6

Equipped chassis and aerodynamics overview

6.1. Introduction

As previously described, the project's main focus is the conception and implementation of the chassis, the integration with the rest of the sub-systems and the verification of the production process. The Formula Student competition imposes a severe set of specifications that are renewed every year and then published for the students. This chapter will focus on a general overview of the chassis and sub-systems. The reason of this conception is developed in the rules section.

6.2. Responsibilities

The main responsibilities of this project within the scope of the EPSA vehicle are:
The objectives of the project are divided into several categories that we could resume in:

- Material and constraints analysis via simulations and the characterization of the elastic limit and rupture's constraint
- Structure's design and conception while respecting the rules via CAD CATIA and ergonomics design
- Integration with the different sub-systems of the vehicle (i.e. High-Voltage battery)
- Analysis and supervising of the production process divided into the laser-cutting processes and the 3D processes.

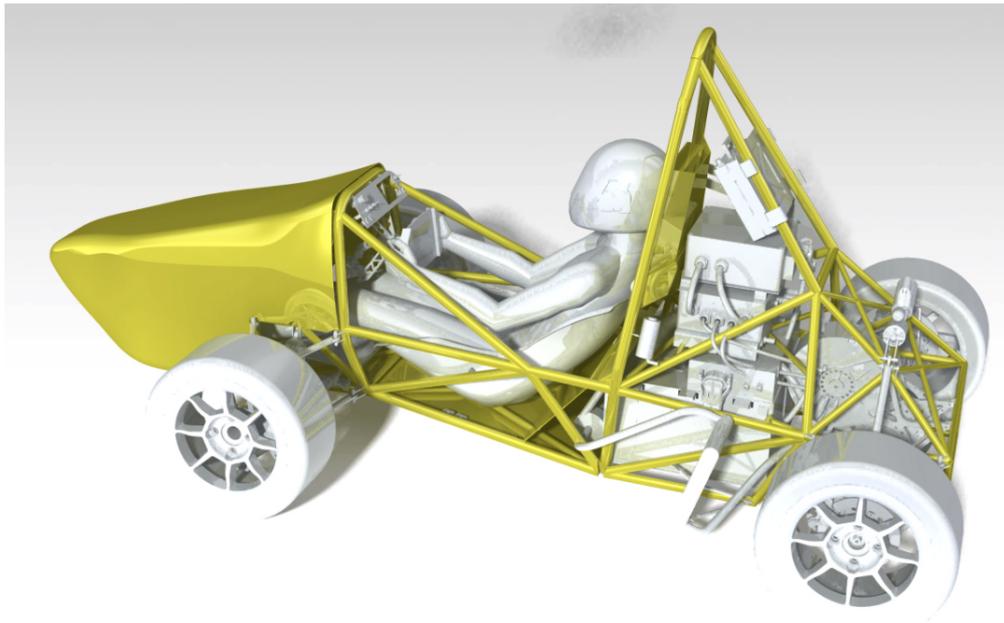


Figure 23. Digital rendering of all subsystems related to the Equipped Chassis and Aerodynamics, without the bodywork.

Once the global objectives were defined, we established the technical aspects we had to respect:

Function	Sub-functions	Criteria	Level	Unit	Flexibility
FP1: Support subsystems	FP1-1: Determine the fixation points	Envelop volume	Available volume for the battery: 0.1-0.2 m ³	m ² and m ³	
	FP1-2: Ensure the position of those points	Accessible and safe cockpit	Isolated firewall		
	FP1-3: Dress the vehicle	Sponsors visibility and aesthetics	Enough surface to show every sponsor	m ²	none
FP2: Support the pilot	FP2-1: Comfortable ergonomics	Pilot's vision	Pilot's evaluation		none
FC2: Respect of the director's objective	FC2-1: Respect of the massic budget	Total mass of the equipped chassis	57,5	kg	"±0/-5"
	FC2-2: Respect of the financial budget	Money	20000	€	min
	FC2-3: Respect of the working budget	Hours/Person	3000	Hours	10%

Table 6. Precise objectives of the CHASEA department

The chassis has to be continuously reactive to changes in the vehicle, as every sub-system's change will force the chassis to evolve. This is why the first and last version of the chassis differ drastically. This has to be done while respecting the rules and the objectives fixed by the board of directors of the team.

6.3. System's verification

Concerning the tubular structure, several checks are needed:

- **Material check:** The mechanical characteristics of the materials vary according to the origin of the supply. There could be possible heat treatments or mechanical stresses applied to the tube (for example when bending the poles), it is necessary to obtain from the tube supplier the "material certificate" which provides information on these values with great precision.

This is useful to check that the theoretical elastic limit corresponds to that announced by the supplier and make the numerical simulation carried out more precise and dynamic.

Pos. Item	Stück Number	Maße Dimensions	Gesamtlänge Length total	Gewicht Weight	Schmelzen-Nr. Heat No.	Prüfdruck Test pressure	Rohr-Nr.-Gruppe Tube number group	Vielfachlängen Multiple lengths
[A07]	[B08]	[B10]	mm	m	[B07]	[D04]	[B14]	[B15]
0040	1207	25,000 X 1,500 mm	6000,00	7242,00	6278	628438		

Figure 24. Material certificate example (1/2)

Pos. Item	Proben-Nr. Specimen No.	Schmelzen-Nr. Heat No.	Probenabmessung Specimen dimensions	Streckgrenze Yield strength	Zugfestigkeit Tensile strength	Dehnung Elongation
[A07]	[C00]	[B07]	[C14]	[C11]	[C12]	[C13]
0060	000001	628438	25,00 X 1,50	737	859	29,00
0060	000002	628438	25,00 X 1,50	731	853	28,00
0060	000003	628438	25,00 X 1,50	730	851	29,00

Figure 25. Material certificate example (2/2)

- Geometrical verification:** The manufacture of the chassis is carried out in two stages: the first is pointing, the second is tube welding. Once the second stage is engaged, it is no longer possible to go back and to modify dimensions, hence the need to check them carefully before giving the agreement to the students welders to initiate welding. The general framework for geometric verification of the tubular structure of the vehicle is therefore:
 - Production by the student of an A0 plan and a set of annexed plans, grouping together all the dimensions necessary for welding the tubular structure.
 - Pointing of the tube by the student welders of La Giraudière according to the dimensions defined on the A0 plan and the accompanying plans provided



Figure 27. Example of an experimental montage for the rigidity test.

The test can be repeated by fixing the front and applying the load to the back. It is also possible to determine the contribution of the battery container to the overall rigidity by carrying out this torsional stiffness test with and without the container.

We then have the necessary data to determine experimentally the torsional stiffness of the tubular structure. The last step is then to compare these results with those obtained in simulation to conclude on the coherence of the whole.

6.4. Production

The production process has been completely outsourced, externalized. To do so, we have worked with the team's educational partners, most of them being specialized high schools.

The production has therefore been done by several high schools:

- **The production school of La Giraudière** is in charge, each year, of carrying out the welding of the chassis and the yokes (equipment to which the other subsystems will be attached).
- **La Mâche**, carries out all the laser cutting and folding of the vehicle each year for the project, as well as then the production of other parts.
- **La Fabrique** [18] is responsible for other elements
- **The production garage of the École Centrale de Lyon** for modifications or simple elements.

The technical procedure we followed for the production phase is the following:

- Detailed plans of every element for an easy and safe production
- Design of jigs to facilitate welding.

6.4.1. Technical plans

Every single element of the chassis has been represented on a technical plan, with its measures, tolerances and clipping planes.

The verification of the technical plans followed a standard process: first, we design the part according to the rules and the objectives of the team, then we do the plan, and finally, a second person (normally the technical director) checks that the plan is consistent and correct. Therefore, we were able to ensure that the plans sent respected the production norms and standards required by the partners and the competition.

In total, this project carried out 30 plans. To categorize the advancement, we distinguish 4 possible states of an element: part produced and verified, part produced, part in production, plan sent, but part not produced. Currently, from the elements that this project was responsible for :

- 25 parts have been produced and verified.
- 4 parts have been produced without verification.
- 1 part are being produced
- 0 parts whose production has not yet started.

On top of that, for properly addressing the tubes, a numbering file was developed by this project, with a number given to each and every tube of the structure, that was then given to every supplier:

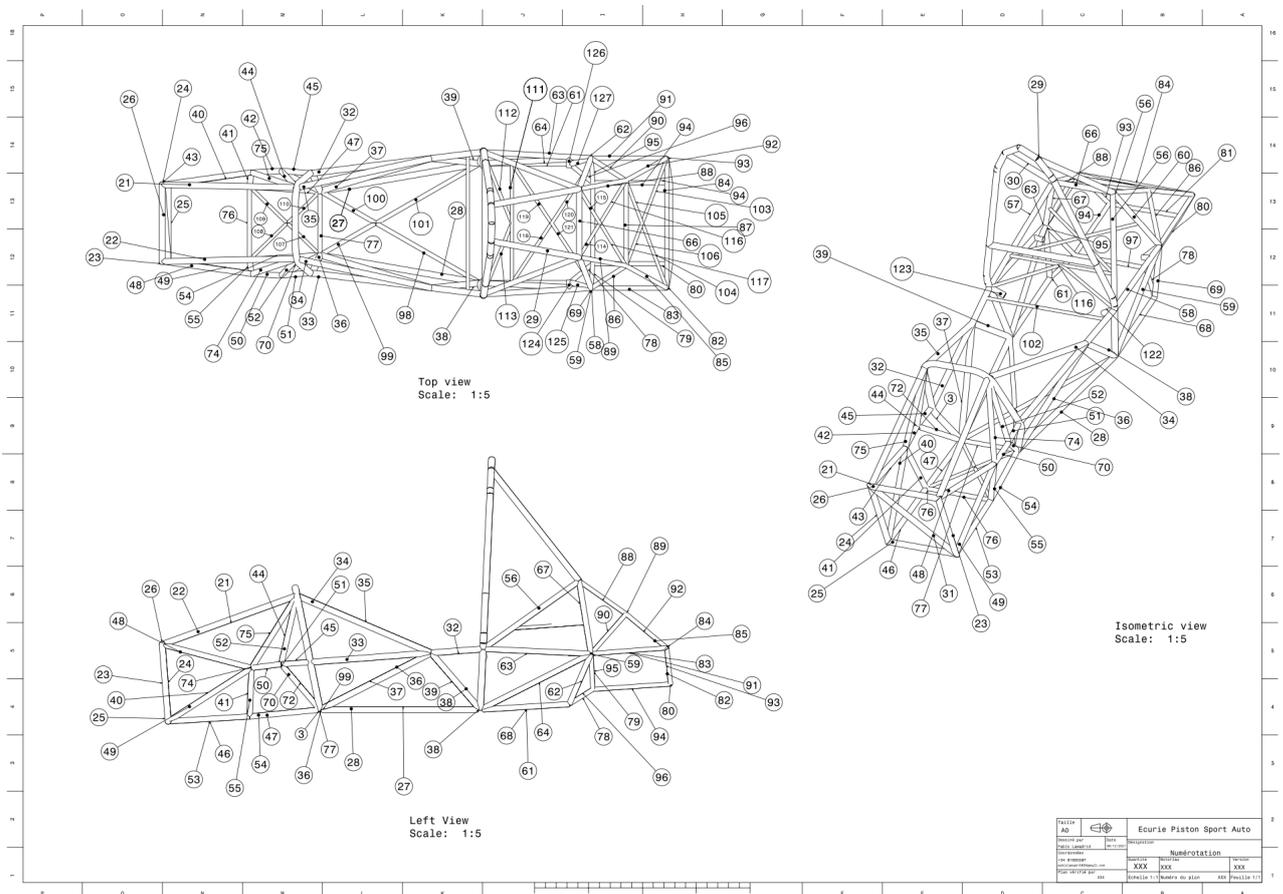


Figure 28. Numbering file

This numbering file has been the base above which all the contacts with the suppliers and welders were done. The main problem the chassis team members have had over the past years have been the gap between the knowledge and understanding of the vehicle they had against the one the partners had.

When working on a project for several months, everything seems intuitive, but it may not be as simple for those who do not necessarily have a technical background and who see the elements for the first time. Therefore, I proposed the idea of developing a numbering file that we would send to every partner.

The reason behind it is the following. When working with our welding partners, although measures were correct, they did not have a notion of the big picture. They did not know where each element fitted within the vehicle and the consequences of an erratic welding. Now, every time we contact a welder, we refer to an element by its number, which allows them to know the exact purpose of the element, its position within the chassis and the nearby sub-systems.

6.4.2. Design of jigs

In terms of jigs design, this project was responsible for nearly all of them, especially for placement jigs on the equipped chassis. These are wooden plaques designed to be easily placed on the chassis and which allow, in a fairly intuitive way, to place the screws and elements. Among these jigs, we can find the one of the tub, the harness, the main hoop or the one of the HV battery. The process of verification is the same as presented for the technical plans. These jigs were made with the laser cutter from the Ecole Centrale de Lyon. They are produced in 6 mm thick wood.

The main objective of these jigs, that the team members produce, is to facilitate the work of the production high schools that we have a partnership with. Instead of reading and understanding the technical plans, all they have to do is place the jig as indicated (while being supervised by a team member) and this element will automatically let the welder know with mm precision where he has to place the different elements welded/screwed to the chassis.

Every jig produced is added in the Annex.

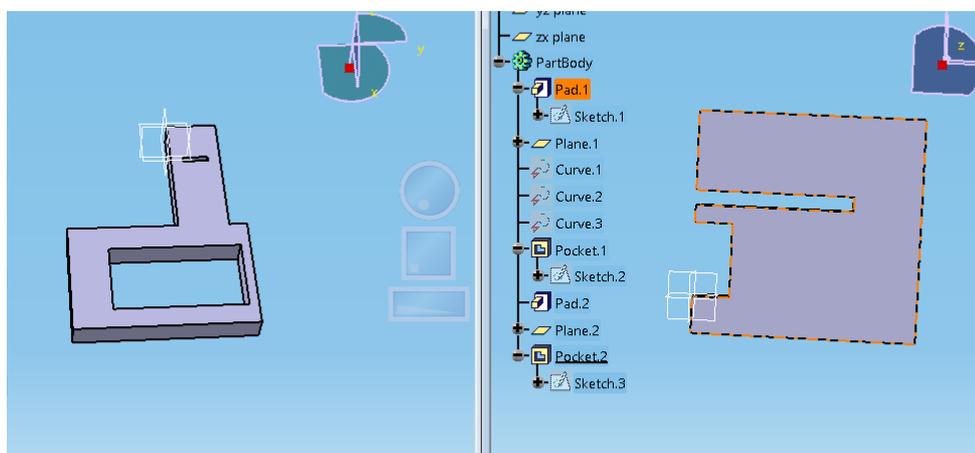


Figure 29. Jig example: Elements design

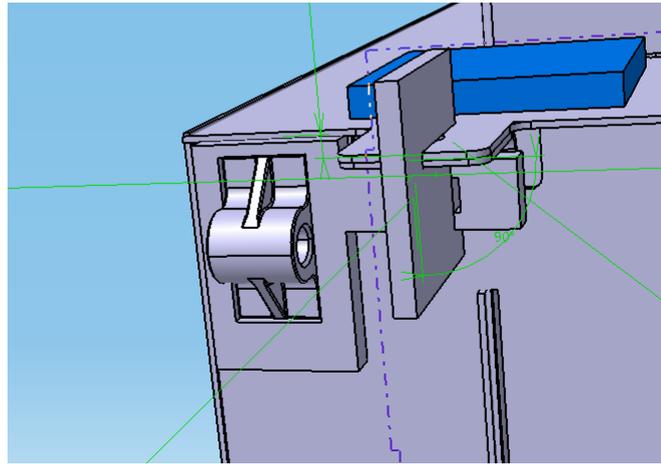


Figure 30. Jig example: On the structure

Chapter 7

Tubular Structure

7.1. Introduction

The chassis is "the fabricated structural assembly that supports all functional vehicle systems. This assembly may be a single welded structure, **multiple welded structures**, or a combination of composite and welded structures", as of what the FS rules establish.

The first task we had as the chassis developers was the type of structure we wanted to use. Therefore, we established some criteria that would determine which option was the most suitable in our case. These criteria were the following:

- Price and whether we have a partner who is used to producing this type of structure or not
- Ratio mass/rigidity
- Historical use by the EPSA team. The know-how and experience the team has concerning each possibility.
- Conception time
- Production time
- Innovation and progress at the EPSA team

To analyse each possibility we did not produce any element, we limited our analyses to research and the teams' knowledge. These criteria gave us the following results concerning each possible structure:

	Tubular structure	Carbon monocoque	Hybrid structure
Price & Partnerships	5	1	3
Mass/Rigidity	2	5	3
Experience at the team	5	1	3
Conception time	4	2	3
Production time	2	4	3
Innovation and progress at the team	2	5	4
TOTAL	20	18	19

Table 7. Structure decision criteria

Each aspect was evaluated in a 1-5 scale, being 1 the worst note and 5 the best one.

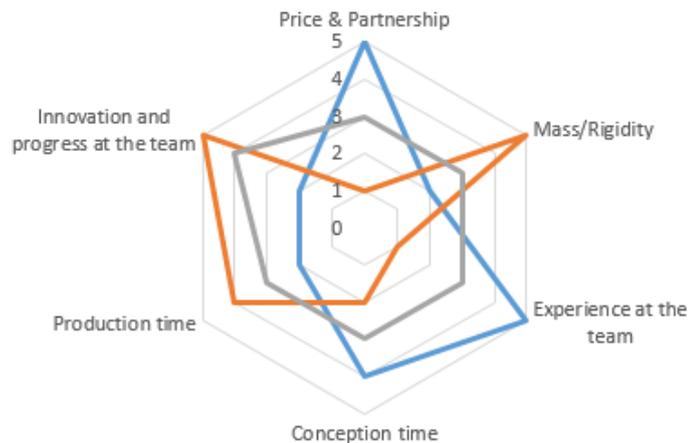


Figure 31. Diagram: Blue series = Tubular structure, Orange series = Carbon monocoque and Gray series = Hybrid structure

Although in terms of mass/rigidity, production time and innovation, the carbon monocoque is probably the best option, if we take into account other factors such as the experience in the team or our partnerships, the tubular structure seems to be the best option.

Nevertheless, it is interesting to bear in mind that the first option is the most suitable one with 20 points, but the hybrid structure and the carbon monocoque would seem more reasonable options if the team had enough experience. This makes us believe that we should have a tendency to transition, in future generations, towards one of these two structures, as performance and time costs would be reduced drastically.

7.2. Material choice

The Formula Student rules leave very little space to manoeuvre in terms of materials, as they fix conditions to ensure that any chassis that sticks to the rules will not have plastic deformation problems.

T 3.2.2: "Steel tubing has to be made from unalloyed carbon steel with a maximum content of 0.3 carbon, 1.7 manganese and 0.6 of any other element."

Steel is the most used material in the industry of vehicles due to its low cost, availability and its ease to be moulded, shaped and welded.

The conception process has been the following:

- Material choice
- Conception of the chassis that followed the rules
- Simulations to verify no plastic deformation
- Rearrangement of the chassis to minimise constraints.

We established some criteria, that were proposed by the organisation, the steel of our choice had to accomplish:

- Minimum yield strength of 305 MPa.
- Young modulus of at least 200 GPa.
- Minimum tensile strength of 365 MPa.

If this criteria were accomplished by several materials, we would then choose based on:

- Percentage of elongation at break (we do not want our material to have a sudden break, without prevention, which is why we wanted our material to be at least at a 5% elongation at break, so a ductile material).
- Highest yield strength
- Highest tensile strength
- Lowest price

After researching the main options, used in the automotive industry and that respected the rules, we ended up with 5 possible materials (technical description of mechanical properties in Annex): **SAE 1040**, **SAE 4130**, **304L** and **S355 steel**.

Material	Density (g/cm ³)	Tensile Strength(MPa)	Young Modulus(GPa)	Elongation at break(%)	Base metal price(EUR/kg)
Steel, SAE 1040 (Cold Drawn)	7.8	320/570	210	13	0.32
Steel, SAE 4130 Tempered	7.8	483/586	190	10	0.37
Stainless steel 304L	7.8	170/485	200	40	1.1
Steel S355	7.8	355/630	210	22	0.8

Table 8. Materials' analysis

We then decided to use the **steel S355**. Even though its price is higher than the two first options, we can still afford it and it is well above the rest of materials in terms of mechanical properties, which is why we chose to use the steel S355 for every element of the chassis, whose composition is: 0.2% carbon, 1.6% manganese, 0.55% Silice and traces of other elements, which is aligned with the rule **T 3.2.2.** presented above.

7.3. Structure's conception

Once the material was chosen, we started the conception phase. It initially consisted in designing a tubular structure based on the structure of the previous vehicle of the EPSA team, Invictus, while respecting the rules and adapting it to our electric needs.

As of the regulations' definition, the subsystems of the car are divided into: **BR-Brake System**, **EL-Electrical**, **EN-Engine&Drivetrain**, **FR-Frame&Body**, **MS-Miscellaneous**, **Finish**

& Assembly, ST-Steering System, SU-Suspension System, WT-Wheels, Wheels Bearing & Tires, FS-Fasteners.

The chassis department is focused on the FR-Frame&Body and the MS-Miscellaneous, Finish & Assembly, that according to the regulations are divided into:

Miscellaneous, Finish and Assembly - MS	Frame & Body - FR
Driver's harness	Aerodynamic devices
Firewall	Body attachments
Headrest/restraints	Body material
Mirrors	Body processing
Paint - Body	Clutch
Paint - Frames	Floor pan
Seats	Frame / Frame tubes
Impact attenuator	Mounts Integral to Frame
Shields	Pedals
Brake Light Housing	Shifter
	Shifter cable / Linkage
	Throttle controls
	Tube End Preps
	Tubes cuts / bends

Table 9. FR-FrameBody and MS-Miscellaneous, Finish and Assembly

The tubes on the structure must be triangulated as of the regulations' demand, in order to transfer the efforts in traction and compression instead of flexion. This structure maximises the torsional rigidity of the car, as we only have traction and compression, as described in the image below:

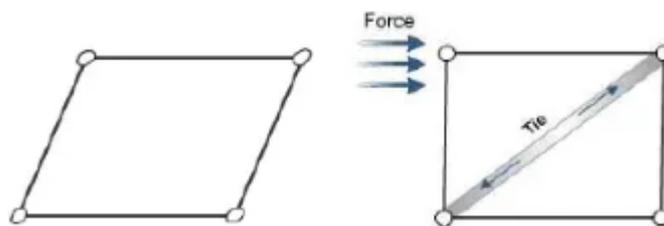


Figure 32. Advantage of using a triangulated structure

Triangles are the most used shape in engineering, from bridges design to aeroplanes, because materials can, normally, resist much more force in traction/compression, than what they can do in torsion. When applying a force to a triangle, the stress will distribute within the structure, that will principally suffer traction and compression.

As the rule **T 1.1.11** establishes, the tubular structure must be triangulated as follows:

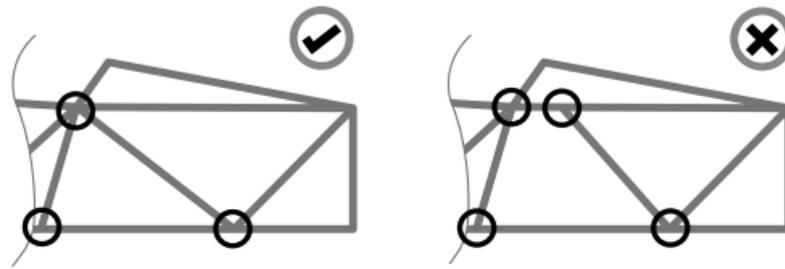


Figure 33. Node-to-node triangulation of chassis members (left correct and right incorrect)

The conception was then based on the previous year's chassis, which helped us reduce the design time, the verification process and production ambiguities.

Nevertheless, several modifications had to be done to adapt it to these year's objectives.

7.3.1. Main chassis changes

Ergo'Bench: Pilot ergonomics

This year, the department aimed to place pilot ergonomics at the top of its priorities, because it can be difficult to drive some of our vehicles due to the placement of the bucket seat, the pedals or steering wheel. A driver cannot perform if the vehicle does not have efficient driver ergonomics. To solve this problem, we imagined an ergonomic bench, called Ergo'Bench. This will allow future generations to design their vehicle around driver ergonomics efficiently. This bench consists of a seat, a harness, a steering wheel and a pedal set. All the elements will be able to move around to have the most ergonomic configuration for the drivers of the team. The measurements can be taken directly on the bench using integrated rulers and protractors. After having tested all the drivers and gathered all the data, the ergonomics manager will be able to design, for future vehicles, high-performance driver ergonomics.

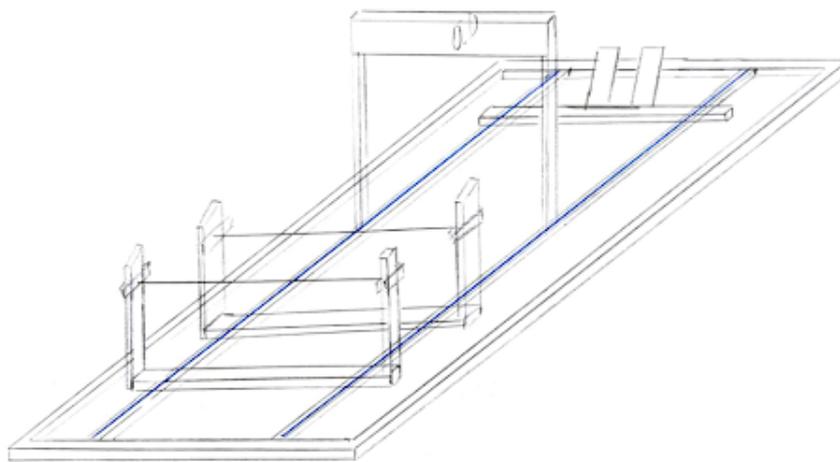


Figure 34. Ergo'bench diagram

While using the Ergo’bench to optimize the pilot’s position, we still have to respect the guidelines fixed by the organization in terms of distances and angles of the different tubes of the chassis and the different sub-systems:

Function	Sub-functions	Criteria	Values	Unit	Flexibility	Rules articles
FP1: Ensure the pilot's confort	FP1-1: Be sitted in a comfortable position	Baquet's inclination	35.5°	°	+/-3	x
		Distance from the baquet to the front hoop	52.5 cm (big jigs) 47.5 cm (small jigs)	cm	+/-2	x
	FP1-2: Have well-positioned pedals	Height of the pedals	10 cm from the baquet	cm	+2/-0	x
		Distance from the baquet to the pedals	105 cm (big jigs) 95cm (small jigs)	cm	+/- 5	T 4.3.4
	FP1-3: Have a well-positioned steering wheel	Height of the steering wheel	380 mm from the origin of the model	mm	+/-20	T 3
		Steering wheel's inclination	18°	°	x	x
		Distance from the steering wheel to the front hoop	11 cm	cm	+/- 1	T 2.6.6
	FP1-4: Have a well-organised control pannel	Commands position	Depends on the pilot	x	x	x
	FP1-5: Not being uncomfortable by the harness	Harness position	52 cm from the origin of the model	cm	x	x
FP1-6: Have a good lateral vision	Lateral vision angle	100° from each side	°	x	T 4.10.1	
FC1: Respect of the rules	FC1-1: The vehicle must be evacuable	Quickness of the pilot to get out of the car	5	s	x	T 4.11.1
	FC1-2: The helmet must be well-positioned	Helmet's position regarding the tubular structure		mm	Binaire	T 4.3.1
	FC1-3: The harness and the seat-belt must be well located	Angles with the horizontal		°	Binaire	T.5.5.5

Figure 35. Objectives and rules for Ergo’Bench

Once the Ergo’Bench was fully functional, we used it to take measures for each of our pilots:

	Baquet’s inclination	Steering wheel depth	Pedals depth	Pedals height	Steering wheel axis height
TLS	41°	30 cm	90 cm	5.5 cm	48 cm
MJT	41°	29 cm	93 cm	5.5 cm	51.5 cm
NVE	41°	25 cm	81 cm	5.5 cm	51.5 cm

Table 10. Pilot’s measures

Once the measures were done, we chose to retain some specific parameters that could suit the three drivers:

Baquet’s inclination	Steering wheel depth	Pedals depth	Pedals height	Steering wheel axis height
41°	26.5 cm	85 cm	5.5 cm	50 cm

Table 11. Used parameters

The three pilots agreed on the measures and affirmed that they were 'very comfortable' with the configuration.



Figure 36. Ergo' Bench

Rules compliance

To use appropriately the developed Ergo' Bench, we had to take into account the main rules that could pose problems:

- **T 2.6.6:** "The steering wheel must be no more than 250 mm rearward of the front hoop. This distance is measured horizontally, on the vehicle centerline, from the rear surface of the front hoop to the forward most surface of the steering wheel with the steering in any position"
- **T 4.3.4:** "The figure has to be positioned in the vehicle as follows:
 - The seat adjusted to the rearmost position
 - The pedals adjusted to the frontmost position
 - The bottom 200 mm circle placed on the seat bottom
 - The middle circle positioned on the seat back
 - The upper 300 mm circle positioned 25 mm away from the head restraint"

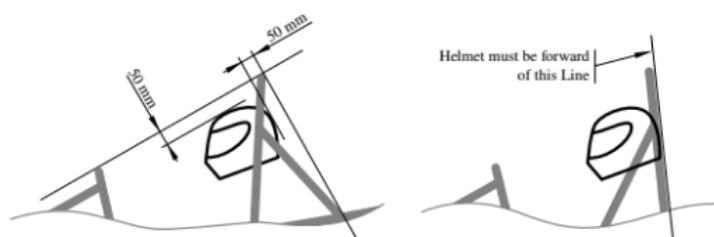


Figure 37. Minimum helmet distance

This distance was already respected by the previous chassis, so we will just leave it the same way:

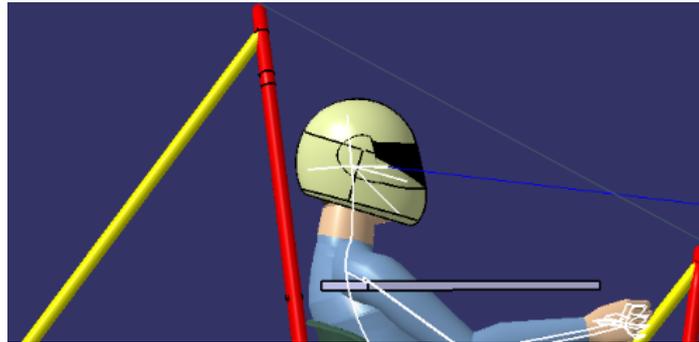


Figure 38. Helmet distance on Invictus

- **T 4.10.1:** "The driver must have adequate visibility to the front and sides of the vehicle. Seated in a normal driving position, the driver must have a minimum field of vision of 100° to either side. The required visibility may be obtained by the driver turning their head and/or the use of mirrors."
- **T 4.11.1:** "All drivers must be able to exit to the side of the vehicle in less than 5 s with the driver in the fully seated position, hands in the driving position on the connected steering wheel (in all possible steering positions) and wearing the required driver equipment as in T 13.3. The egress time will stop when the driver has both feet on the ground."
- **T 3.15.1:** "The side impact structure may consist of at least three tubes:
 - The upper member must connect the main hoop and the front hoop. It must be at a height between 240 mm and 320 mm above the lowest inside chassis point between the front and the main hoop.
 - The lower member must connect the bottom of the main hoop and the bottom of the front hoop
 - The diagonal member must triangulate the upper and lower member between the roll hoops node-to-node."

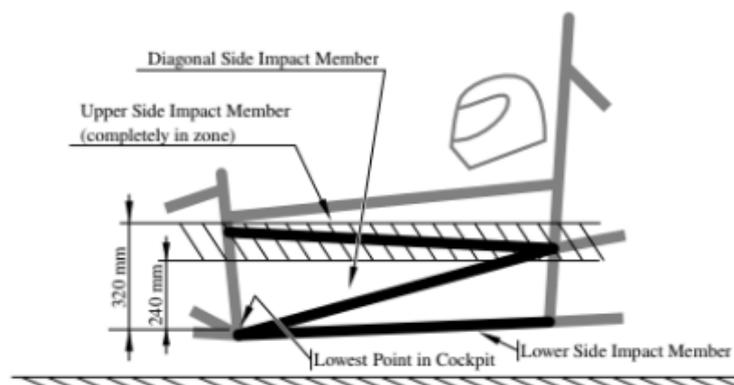


Figure 39. Side impact structure

- **T 4.9.1:** All vehicle controls must be operated from inside the cockpit without any part of the driver, (e.g., hands, arms or elbows), being outside the vertical planes tangent to the outermost surface of the side impact structure.

Regarding the previous vehicles of the team, we had some feedback from the judges that claimed that some tubes were not correctly triangulated, so some points of the rules were not fully respected, such as **T 3.15.1**. We have had to modify the structure to prohibit the pilot's arms to be out of the car while on the cockpit.

Assembly and disassembly of the HV battery

This year we had to integrate a new engine assembly into the vehicle which includes the battery and all its equipment. This new engine assembly being much larger than the one of a thermal car, the rear-end cell was subjected to many new constraints. The most decisive of all is the constraint of assembly and disassembly of the battery.

Indeed, the regulation of the FS competition requires regular assembly and disassembly of the battery, because no team is allowed to recharge its battery while on the vehicle. We then thought thoroughly before finally arriving at a dismantling solution from below the car using inserts arranged at the four corners of the battery.

A 6.12.2: "Accumulators must be removed from the vehicle and placed on the accumulator container hand cart for charging"

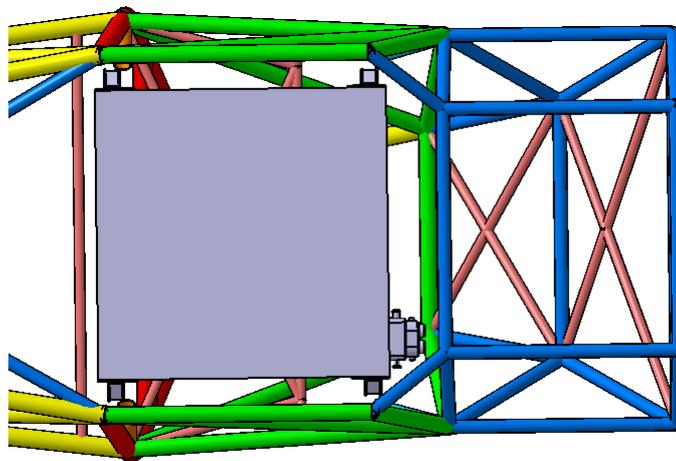


Figure 40. Bottom view of the rear cell with the battery

For practical reasons, the battery and every other sub-system concerning the electric engine (which are not a responsibility of CHASEA), were conceived as volumes envelopes. This way, we could design the rear-end of the vehicle without having the actual engine, which was finished several months after this analysis. The volume envelopes were supplied by the CHAIPE department.

Final tubular structure

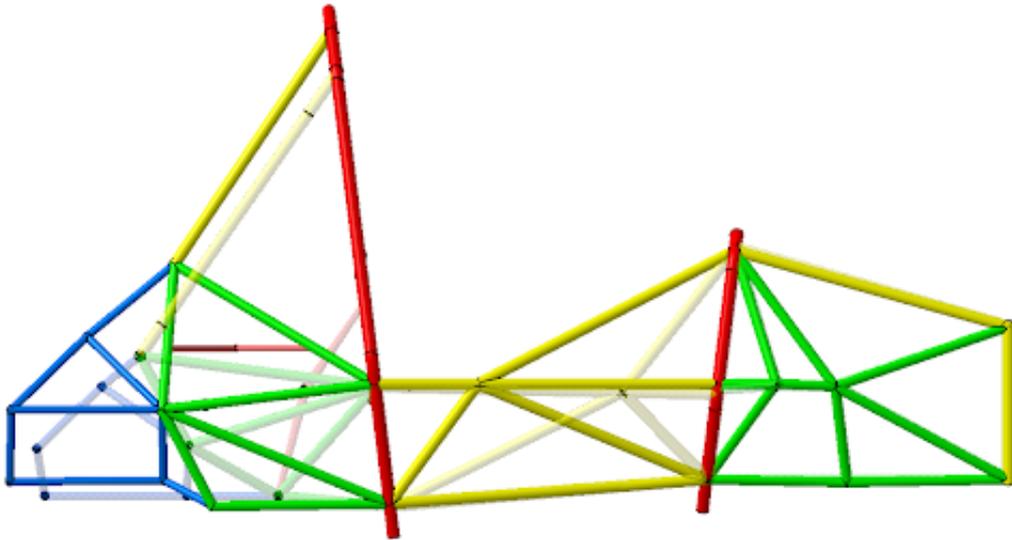


Figure 41. Comparison between Invictus (shaded) and Valkyriz

There are two main changes of the tubular structure:

- at the pilot's region, in which the triangulation was increased and the structure was modified to respect the rule **T 3.15.1**
- at the rear-end to allow the introduction of the HV battery, we had to increase the internal volume.

We have tried to maintain as many parts of the previous chassis as possible to minimise the conception and production time, as our time at the team is very limited (September to April), and taking into account that Invictus got the best results on the history of the EPSA team.

7.4. Unexpected block-points

One of the main challenges necessarily present when conceiving and producing a Formula Student vehicle are the block-points that come along during the conception but also after the production process is finished. During the whole year, we have dealt with unexpected moments of uncertainty where a quick response and a high precision are needed in order to keep the project alive.

The main block-point for the chassis team was the rear cell crisis. As the rules are complex, strict and high demanding, we ensure a thorough understanding of the regulation before the conception. Rules are divided by sub-system, so each department is in charge of developing their part of the vehicle while taking into account every aspect of the rules.

The block-point here was that one of the regulations for the chassis conception was hidden in the electrical section (within the *Tractive System Energy Storage - Mechanical configuration* paragraph):

EV 5.5.1.: All TSACs must lie within and be attached to the primary structure or any additional structures fixed to the primary structure which meet the minimum specification for

side impact structures, see table 4, no higher than the top of the side impact structure, see T 1.1.16.

Item or application	Minimum wall thickness	Minimum cross sectional area	Minimum area moment of inertia
Main and front hoops, shoulder harness mounting bars	2 mm	175 mm ²	11320 mm ⁴
Side impact structure, front bulkhead, roll hoop bracing, driver's restraint harness attachment	1.2 mm	119 mm ²	8509 mm ⁴
Front bulkhead support, main hoop bracing supports	1.2 mm	91 mm ²	6695 mm ⁴

Table 12. Tubes specifications

This rule specifies that we must protect the high voltage battery with the same tubes we use to protect the driver (identical specifications). As the production of the tubular structure was too advanced, we could not modify the tubes involved nor conceive new tubes, as both cost and time were scarce. Nevertheless, we had to find a solution to respect this point of regulation or the vehicle would not be able to participate in the FSUK.

After several discussions with the judges, we opted for a solution which consists in welding two plates between the tubes to improve the buckling resistance of the rear cell tubes.



Figure 42. Technical solution to comply with rear cell regulations

We have hollowed out the plates to be able to save weight on the total assembly of the chassis and to have access to the rear cell systems, the power unit and the electronics, which is crucial during the competition. Changes have to be done constantly, which means that conceiving the vehicle in a way that every main element of the car is easily accessible is very important.

Current tubes have a section which is too small, so their quadratic moment is too low. We will size the plates to increase the quadratic moment to comply with the regulation. With a simple calculation by hand, we determined the new quadratic moment (with plates) to be able to determine the thickness and the width of the plates.

Tubes	25x1.5	20x1.5
Diameter (mm)	25	20
Objective I (m ⁴)	8.51E-09	8.51E-09
I pre-plates (m ⁴)	7.68E-09	3.75E-09
Plate thickness (mm)	0.5	0.5
Plate width (mm)	20	20
I plate (m ⁴)	9.22E-10	4.96E-09
New I (m ⁴)	8.6E-09	8.71E-09

Table 13. Quadratic moment calculations

Our initial quadratic moment (without the plates) was, as shown in Table 11:

- **7.68E-09** m⁴ for the 25x1.5 tubes
- **3.75E-09** m⁴ for the 20x1.5 tubes

These results were calculated following the procedure developed hereby:

$$I = \iint_R \rho^2 dA$$

where

- dA is the infinitesimal area element
- ρ is the perpendicular distance from the axis BB'

Doing the calculations, our values were not aligned with the competition objectives, which led us to developing the plates to increase the quadratic moment of the tubes. To properly calculate the plates' characteristics, we followed these steps:

- We had to sum the quadratic moment of the plate to the one of the tubes, to do so we had to determine the quadratic moment of the plates taking as a reference the axe of the tubes
- This meant to do a translation of the moment of inertia of the tubes, obtaining the following expression:

$$I_{plate} = \frac{t \cdot w^3}{12} + \frac{t \cdot w \cdot (d + w)}{2}$$

with w (width of the plates - distance from the tube to the drilled area of the plate), t (thickness of the plates) and d (diameter of the tube)

- Once the expression is calculated, we have to adapt the width and the thickness of every plate so that the quadratic moment is satisfactory for every tube
- therefore, as exemplified in the table above, we could standardize the measures to obtain close enough quadratic moments for every tube

These results were seen as enough by the judges of the FSUK tournament who gave green light to our model that presents an error, regarding the quadratic moment, of:

- **1%** for the 25x1.5 tubes

- **2.4%** for the 25x1.5 tubes

But over all, the main block point of the season came right at the end and in the most critical moment. Although we knew that the pandemic would cause a delay in the supply of electronic elements of the vehicle, which is why we decided to make the commands in advance regarding other year's commands, we did not expect such an important delay.

To exemplify the problem, we commanded connectors for the LV system, for which the contract affirmed that they would be supplied in February. Nevertheless, they contacted us in March to tell us that they would not be available until the end of July (already too late for the competition).

This detail was responsible for not presenting the vehicle in this year's competition. Despite that, Valkyriz is perfectly functional now and will be present in future editions.

Chapter 8

Integration with other sub-systems

8.1. Introduction

The equipped chassis is the main system of the vehicle, onto which every other sub-system is attached. This explains why it is crucial to maintain a continuous communication channel with the other departments in order to develop the structure while taking into account the different parts that will be attached to it.

The relationship which each department is different, taking into account the different nature of each one of them. LASMECA is mainly focused on CATIA development, which leads to a better understanding of the structure's model, while BASTIE and CHAIPE are more focused on the electric part of the development, so they barely work with CATIA and are not familiar with the structure's update.

This has two implications. On the one hand, CHASEA does not have to focus on the integration part with LASMECA, as they continuously update us with what they modify, and they have freedom to integrate their sub-systems to the chassis while updating the members of our department.

On the other hand, the integration process of the sub-systems developed by CHAIPE and BASTIE have to be done by the CHASEA department. This is already taken into account on the design and conception phase, as we develop our tubular structure for it to be adapted to the sub-systems defined by these two departments.

8.2. Screeds

Once the different elements are placed on the chassis, our main objective is to fix them and make sure they will stay well positioned. To do so, we develop screeds.

Screeds are small plates made of steel S355, just as the rest of the chassis, that are welded to the tubular structure and that present one or multiple screw holes to screw the different subsystems to the chassis.

This project has developed 17 screeds that are mainly focused on the BASTIE department. Between the screeds that have been developed, we can mention, the lights' screeds, the fuse box screeds or the battery screeds. Every developed screed is presented in Annex.

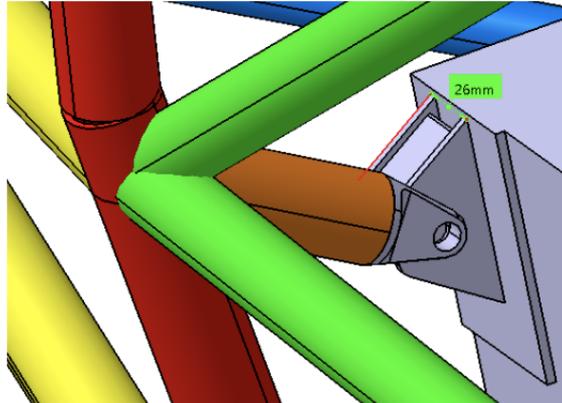


Figure 43. Container's screed

At the current state of the project, every screed has been designed, produced, verified, and all screeds have been welded.

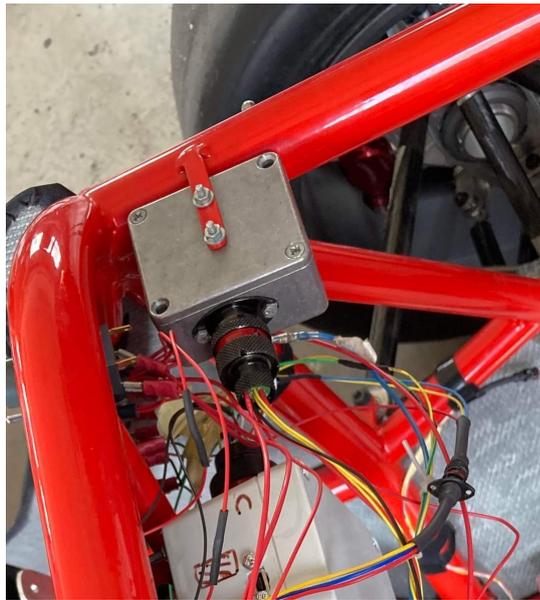


Figure 44. Fuse box screed

The advantage of having a proper inter-generational documentation is that certain analyses have been standardized, and they do not have to be redone. One example is the one of the screeds. Depending on the tube's diameter and the type of screed to use, we have a standard procedure to follow for them to be optimal, so no constraints analyses had to be done regarding the screeds.

During the duration of this project, screeds have been developed for the following elements of the vehicle:

- **Battery immobilization:** The electric battery is fixed to the chassis from the outside, so a heavy-weight resisting screed was developed to ensure the immobilization of the battery

- **Lights' screed:** The lights (front-end and rear-end) attached to the main hoop were fixed to a screed placed in the upper part of the main hoop
- **Buzzer screed:** The buzzer attached to the front-end of the cockpit was fixed by a standard screed
- **Bomb support:** The refrigerating bomb was attached to the rear-end of the chassis by a 4-fixation-points structure
- **Cables screeds:** Several cylindrical screeds were developed to be attached to different points of the chassis to guide and organize the cables
- **Main hoop screeds:** These are thought to fix different electrical subsystems to the main hoop

As the screeds are crucial elements of the structure without which the vehicle would not be able to be driven and taking into account that there are loads of screeds involved in the different sub-systems, a very precise and detailed datasheet has been developed to allow every member of the team to know whether they had screeds involved in the systems they were working on or not and the current state they were in (Produced or Welded).

In total, there have been 188 screeds developed by the EPSA team that have been resumed in the *Liste de Chapes* document:

Nom/Acroche	Quantité	Système	Masse	Masse totale	Masse mesurée (g)	Masse mesurée totale (g)	Epaisseur	Fabriqué	Soudé	Localisation	Num	IGS	PLAN
Boitier carte avant	3	EN	0,003	0,009			1.5mm	oui	oui		27		
3 MM													
power distribution box	4	EL	0,006	0,024	7	28	3mm	oui	oui	Bron	101	OUI	OUI
bracket jacking bar left	1	EN	0,042	0,042	42	42	3mm	oui	oui	Bron	102	OUI	OUI
bracket jacking bar right	1	EN	0,043	0,043	44	44	3mm	oui	oui	Bron	103	OUI	OUI
differential assy tube sup	4	EN	0,021	0,084	20	80	3mm	oui	oui	Bron	104	OUI	OUI
differential assy tube inf	4	EN	0,019	0,076	19,5	78	3mm	oui	oui	Bron	105	OUI	OUI
chain shield sup	1	EN	0,008	0,008	11	11	3mm	oui	oui	Bron	106	OUI	OUI
cooling system up	1	EN	0,021	0,021	21	21	3mm	oui	oui	Bron	107	OUI	OUI
cooling system down pliee	1	EN	0,048	0,048	46	46	3mm	oui	oui	Bron	108	OUI	OUI
											109 ??		
Regulateur de pression	1	EN	0,027	0,027	19	19	3mm	oui	oui	Bron	110	OUI	OUI
pédalier tube avant	4	FR	0,022	0,088	20,6	82,4	3mm	oui	oui	Bron	111	OUI	OUI
pédalier tube arrière	4	FR	0,021	0,084	20	80	3mm	oui	oui	Bron	112	OUI	OUI
pédalier support gaine	1	FR	0,022	0,022	22	22	3mm	oui	oui	Bron	113	OUI	OUI
Siege dessous	4	MS	0,004	0,016	4,75	19	3mm	oui	oui	Bron	114	OUI	OUI
Siège arrière	2	MS	0,003	0,006	4,75	9,5	3mm	oui	oui	Bron	115	OUI	OUI
pompe vers tubulaire	1	EN	0,004	0,004	6	6	3mm	oui	oui	Bron	116	OUI	OUI
Sur radiateur	3	pas soudé	0,003	0,009	0		3mm alu				117	NON	NON
Shifter	1	EN	0,015	0,015	11	11	3mm	oui	oui	Bron	118	OUI	OUI
chain shield inf	1	EN	0,023	0,023	23	23	3mm	oui	oui	Bron	119	OUI	OUI
5mm													
Moteur	2	EN	0,039	0,078	48,5	97	5 mm	oui	oui	Bron	201	OUI	OUI
Basculeur de Suspension avant av	2	SU	0,039	0,078	0		5mm	oui	oui	Bron	202	OUI	OUI
Basculeur de Suspension avant arr	2	SU	0,039	0,078	0		5mm	oui	oui	Bron	203	OUI	OUI
Triangle arrière inf 1 (avant sup)	2	SU	0,031	0,062	0		5mm	oui	oui	Bron	204	OUI	OUI

Figure 45. Liste de chapes example

Chapter 9

Conclusions of the project

The objective of this last concluding chapter is to resume the key points and expertise obtained throughout this bachelor's thesis, focused on the design and conception of the chassis of an electric vehicle for the Formula Student competition.

My experience at École Centrale de Lyon has outperformed my expectations. I have lived two very intense, productive and life-changing years. This experience has, for sure, seen myself grow in my personal life and in different skills, but it has overall formed me in different technical areas throughout lessons, but also, and most importantly, through projects as the EPSA Formula Student team.

For a long time, I have wanted to join a Formula Student team, as a motorsport enthusiast. The 2021-2022 season seemed the perfect one, as it is the perfect closure for my bachelor's studies.

Since the first day in the team, I have always seen the professionalism every member has when delivering work. But I have also experienced a remarkable and very helpful environment. Everyone is open to helping you when you struggle, when you have to quickly get to know systems you are not familiar with, or when there are administrative procedures to be done.

This environment speaks by itself and has convinced me of the prosperous future the team will have. When analysing high performing teams or companies (e.g., Google), they are characterized by two things: the best professionals in the industry and a great environment. Those two factors are absolutely fulfilled by the EPSA team, which makes me believe that it is a matter of time that they dominate whatever competition they are in.

Regarding my personal experience, I have got to develop the basic skills in terms of organization, team work and on a technical basis for my future career. It is the best way to gain "industry experience" without the pressure of a real-world project, but with a strict schedule and tight deadlines. This project is a hint of what the motorsport industry looks like from the inside. Doing a gross approximation, the work we have done throughout the year is the base of what a Formula 1 team has to experience.

My main objectives have been the choice of the material to be used while respecting the regulation and the internal objectives, the redefinition of the rear-end of the chassis, the design of jigs and screeds for the integration with other sub-systems and the verification of the production

process that has been mainly externalized.

I have had the opportunity to learn to do a decision matrix and the most important criteria to select a material (e.g., EUR/kg or production cost), I have experienced the impact of triangulating a structure, I have challenged the difficulty of having to design jigs and screeds without guidelines and I have seen the relevance of properly verifying the vehicle's welding.

I have also learned how to master certain software packages that are crucial for different engineering sectors, such as CATIA or even communication and organization systems, like Slack. In other words, I have skyrocketed my career, all while having fun and learning from outstanding individuals.

One of the main challenges for the correct conception has been taking into account the rules developed by the FS competition regulation. Despite this, and due to an introspection of the regulations, the vehicle has been satisfactory. Nevertheless, certain issues that were not expected and that could not be fixed, as the delay in the supply due to the pandemic have led to the impossibility in the participation in the FS.

In conclusion, the EPSA project, as well as my experience at École Centrale de Lyon, has made me evolve as a person, but also as a professional. I have got an internal view of the motorsport industry and I have got to know outstanding engineering students that will eventually lead the sector.

This makes me feel grateful for the opportunity, but I also have the pride of having contributed to the first ever electric vehicle developed by the team and having helped to get over unexpected block points and challenges. I'm proud of the team I have been a part of, and I have to thank them and ICAI for the opportunity of going to Lyon.

Bibliography

- [1] F. S. organized by SAE International, “FSAE,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.fsaeonline.com/>
- [2] F. S. G. Institution, “FORMULA STUDENT GERMANY,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.formulastudent.de/fsg/>
- [3] F. S. U. FSAE, “FORMULA STUDENT UK,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.imeche.org/events/formula-student>
- [4] F. S. US, “FORMULA STUDENT US,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.formulastudentusa.com>
- [5] F. S. ATA, “FORMULA STUDENT ATA,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.formula-ata.it>
- [6] “POINTS,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.global-formula-racing.com/en/formula-student>
- [7] Imeche, “SPONSORS,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.imeche.org/events/formula-student/formula-student-sponsorship-opportunities>
- [8] P. Serrafiero, “EPSA,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.epsa-team.com/index.php/en/competitions/formula-student>
- [9] —, “HISTORY,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.epsa-team.com/index.php/en/garage>
- [10] G. de España, “MOVES III,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.idae.es/ayudas-y-financiacion/para-movilidad-y-vehiculos/programa-moves-iii>
- [11] “MONDAY,” 2022, last checked 21/08/2022. [Online]. Available: <https://monday.com/lang/es/>
- [12] “SLACK,” 2022, last checked 21/08/2022. [Online]. Available: <https://slack.com/intl/es-es/>
- [13] P. Serrafiero, “EPSABOX,” 2022, last checked 21/08/2022. [Online]. Available: <https://epsabox.kad-office.com/w/Accueil>
- [14] “CATIA,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.3ds.com/es/productos-y-servicios/catia/>
- [15] “LA GIRAUDIÈRE,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.lagiraudiere.fr>

- [16] “LA MACHE,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.ecolelamache.org>
- [17] “BOISARD,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.ecoleboisard.com>
- [18] “LA FABRIQUE,” 2022, last checked 21/08/2022. [Online]. Available: <https://lafabrique.biz>
- [19] “ANSYS,” 2022, last checked 21/08/2022. [Online]. Available: <https://www.ansys.com>

PART II



REGULATION



FSUK rules represent a very strict and complex framework that are thought to be one of the most developed frames to work upon on the FS competitions industry. It is because of that, that the EPSA team designs, verifies and produces its vehicles while respecting these rules. The regulation is composed of three categories that define the exact technical methodologies to cover for each of them:

- ICE
- EV
- AV

The regulation is structured following the next criteria :

- Administrative regulations
- General technical requirements
- Internal combustion engine vehicles
- Electric vehicles
- Driverless vehicles
- Technical inspections
- Static events
- Dynamic events

The rules that are hereby presented have been mentioned throughout this document. In the next pages, there is an extract of the electric vehicle part of the regulation regarding the mentioned edition from the FSUK official website.

FSUK EV Regulation



T GENERAL TECHNICAL REQUIREMENTS

T 1 DEFINITIONS

T 1.1 Chassis Definitions

- T 1.1.1 Chassis – The fabricated structural assembly that supports all functional vehicle systems. This assembly may be a single welded structure, multiple welded structures or a combination of composite and welded structures.
- T 1.1.2 Cockpit – The volume which accommodates the driver which is defined by the top of the vehicle, the floor closeout, the inner side of the bodywork, the front bulkhead and the firewall.
- T 1.1.3 Chassis member – A minimum representative single piece of uncut, continuous tubing or equivalent structure.
- T 1.1.4 Front bulkhead – A planar structure that defines the forward plane of the chassis and provides protection for the driver’s feet.
- T 1.1.5 Front bulkhead support – A structure that defines the side of the chassis from the front bulkhead back to the top of the upper side impact structure and the bottom of the front hoop.
- T 1.1.6 Front hoop – A roll bar located above the driver’s legs, in proximity to the steering wheel.
- T 1.1.7 Impact Attenuator (IA) – A deformable, energy absorbing device located forward of the front bulkhead.
- T 1.1.8 Main hoop – A roll bar located alongside or just behind the driver’s torso.
- T 1.1.9 Monocoque – A chassis made of composite material.
- T 1.1.10 Node-to-node triangulation – An arrangement of chassis members projected onto a plane, where a co-planar load applied in any direction, at any node, results in only tensile or compressive forces in the chassis members as shown in figure 1.
- T 1.1.11 Primary structure – The primary structure is comprised of the following components:
- Main hoop
 - Front hoop
 - Roll hoop braces and supports
 - Side impact structure
 - Front bulkhead
 - Front bulkhead support system

T1 Definitions

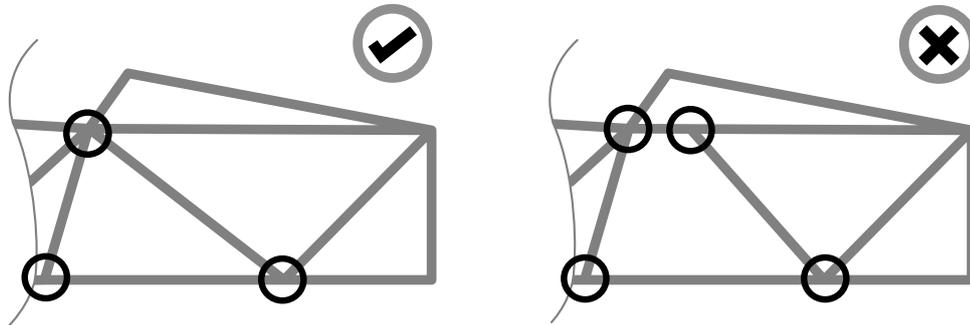


Figure 1: Node-to-node triangulation of chassis members (left correct and right incorrect).

- All chassis members, guides and supports that transfer load from the driver's restraint system into the above mentioned components of the primary structure
- [EV ONLY] structures mentioned under EV 4.4.2 and EV 5.5.2
- [CV ONLY] structures mentioned under CV 1.3.2

- T 1.1.12 Roll hoops – Both the front hoop and the main hoop are classified as “roll hoops”
- T 1.1.13 Roll hoop bracing – The structure from a roll hoop to the roll hoop bracing support.
- T 1.1.14 Roll hoop bracing supports – The structure from the lower end of the roll hoop bracing back to the roll hoop(s).
- T 1.1.15 Rollover protection envelope – Envelope of the primary structure and any additional structures fixed to the primary structure which meet the minimum specification defined in T 3.2 or equivalent.
- T 1.1.16 Side impact structure – The area of the side of the chassis between the front hoop and the main hoop and from the chassis floor to the height as required in T 3.15 above the lowest inside chassis point between front hoop and main hoop.
- T 1.1.17 Surface envelope – The surface envelope is the surface of the union of the rollover protection envelope, see T 1.1.15, and the volume defined by top of the roll bar and the outside edges of the four tires, see Figure 2.

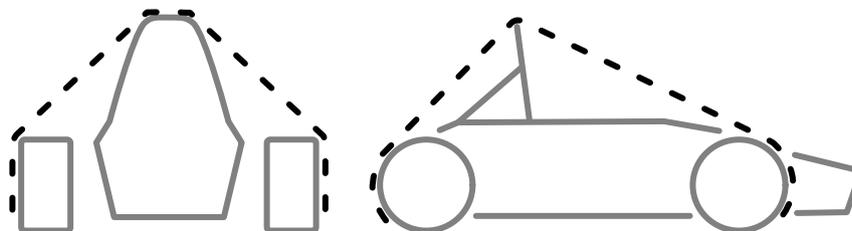


Figure 2: Surface Envelope without the rollover protection envelope, see T 1.1.15

T 1.2 Material Defintions

- T 1.2.1 Fire Retardant – A material meeting one of the following standards:

T2 General Design Requirements

- UL94 V-0 for the minimum used material thickness

Equivalent standards are only accepted, if the team shows equivalence and this is approved by the officials prior to the event.

T1.2.2 Coolant – A substance used for heat transfer by convection.

T1.3 Electrical Definitions

T1.3.1 Direct Connection – Two devices or circuits are directly connected if the connection is not routed through any common PCB and does not include any devices or functionality other than overcurrent protection or connectors.

T1.4 Driving Mode Definitions

T1.4.1 Manual Mode – A vehicle is in manual mode when driven by a human driver. In this case the ASMS must be off (AS deactivated).

T1.4.2 Autonomous Mode – A vehicle is in autonomous mode when the AS is activated. When a vehicle is in autonomous mode, there must be no person inside the vehicle.

T2 GENERAL DESIGN REQUIREMENTS

T2.1 Vehicle Configuration

T2.1.1 The vehicle must be designed and fabricated in accordance with good engineering practices.

T2.1.2 The vehicle must be open-wheeled, single seat and open cockpit (a formula style body) with four wheels that are not in a straight line.

T2.1.3 Open wheel vehicles must satisfy the following (see also figure 3):

- The wheel/tire assembly must be unobstructed when viewed from the side.
- No part of the vehicle may enter a keep-out-zone defined by two lines extending vertically from positions 75 mm in front of and 75 mm behind the outer diameter of the front and rear tires in the side view of the vehicle, with steering straight ahead. This keep-out zone extends laterally from the outside plane of the wheel/tire to the inboard plane of the wheel/tire assembly.

T2.2 Ground Clearance

T2.2.1 The minimum static ground clearance of any portion of the vehicle, other than the tires, including a driver, must be 30 mm.

T2.2.2 Sliding skirts or other aerodynamic devices that by design, fabrication or as a consequence of moving, contact the track surface are prohibited.

T2 General Design Requirements

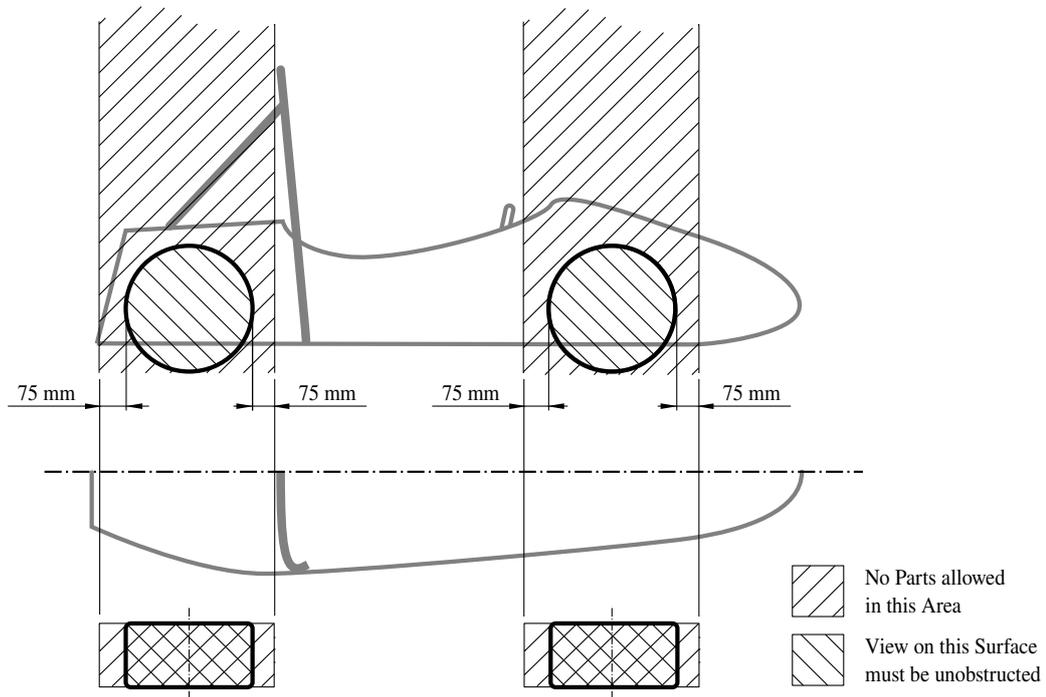


Figure 3: Keep-out-zones for the definition of an open-wheeled vehicle.

T2.3 Bodywork

- T2.3.1 There must be no openings through the bodywork into the cockpit other than that required for the cockpit opening. Minimal openings around the front suspension and steering system components are allowed.
- T2.3.2 Enclosed chassis structures and structures between the chassis and the ground must have two venting holes of at least 25 mm diameter in the lowest part of the structure to prevent accumulation of liquids. Additional holes are required when multiple local lowest parts exist in the structure.
- T2.3.3 All edges of the bodywork that could come into contact with a pedestrian must have a minimum radius of 1 mm.
- T2.3.4 The bodywork in front of the front wheels must have a radius of at least 38 mm extending at least 45° relative to the forward direction, along the top, sides and bottom of all affected edges.

T2.4 Suspension

- T2.4.1 The vehicle must be equipped with fully operational front and rear suspension systems including shock absorbers and a usable wheel travel of at least 50 mm and a minimum jounce of 25 mm with driver seated.
- T2.4.2 All suspension mounting points must be visible at technical inspection, either by direct view or by removing any covers.

T2 General Design Requirements

T2.5 Wheels

- T2.5.1 Any wheel mounting system that uses a single retaining nut must incorporate a device to prevent loosening of the nut and the wheel. A second nut (“jam nut”) does not meet these requirements.
- T2.5.2 Wheel lug bolts and studs must be made of steel or titanium. The team must be able to show good engineering practice and providing adequate strength by calculations. Wheel lugbolts and studs must not be hollow.
- T2.5.3 Aluminum wheel nuts may be used, but they must be hard anodized and in pristine condition.

T2.6 Tires

- T2.6.1 Vehicles must have two types of tires as follows:
- Dry tires - The tires on the vehicle when it is presented for technical inspection are defined as its “dry tires”.
 - Wet tires - Wet tires may be any size or type of treaded or grooved tire provided:
 - The tread pattern or grooves were molded in by the tire manufacturer or were cut by the tire manufacturer or their appointed agent. Any grooves that have been cut must have documentary proof that it was done in accordance with these rules.
 - There is a minimum tread depth of 2.4 mm.
- T2.6.2 Tires on the same axle must have the same manufacturer, size and compound.
- T2.6.3 Tire warmers are not allowed.
- T2.6.4 Special agents that increase traction may not be added to the tires or track surface.

T2.7 Steering

- T2.7.1 Steering systems using cables or belts for actuation are prohibited. This does not apply for autonomous steering actuators.
- T2.7.2 The steering wheel must directly mechanically actuate the front wheels.
- T2.7.3 The steering system must have positive steering stops that prevent the steering linkages from locking up. The stops must be placed on the rack and must prevent the tires and rims from contacting any other parts. Steering actuation must be possible during standstill.
- T2.7.4 Allowable steering system free play is limited to a total of 7° measured at the steering wheel.
- T2.7.5 The steering wheel must be attached to the column with a quick disconnect. The driver must be able to operate the quick disconnect while in the normal driving position with gloves on.
- T2.7.6 The steering wheel must be no more than 250 mm rearward of the front hoop. This distance is measured horizontally, on the vehicle centerline, from the rear surface of the front hoop to the forward most surface of the steering wheel with the steering in any position.
- T2.7.7 The steering wheel must have a continuous perimeter that is near circular or near oval. The outer perimeter profile may have some straight sections, but no concave sections.

T3 General Chassis Design

- T2.7.8 In any angular position, the top of the steering wheel must be no higher than the top-most surface of the front hoop.
- T2.7.9 The steering rack must be mechanically attached to the primary structure.
- T2.7.10 Joints between all components attaching the steering wheel to the steering rack must be mechanical and visible at technical inspection. Bonded joints without a mechanical backup are not permitted. The mechanical backup must be designed to solely uphold the functionality of the steering system.
- T2.7.11 Rear wheel steering, which can be electrically actuated, is permitted if mechanical stops limit the range of angular movement of the rear wheels to a maximum of 6°. This must be demonstrated with a driver in the vehicle and the team must provide the equipment for the steering angle range to be verified at technical inspection.

T2.8 Wheelbase

- T2.8.1 The vehicle must have a wheelbase of at least 1525 mm.

T2.9 Track and Rollover Stability

- T2.9.1 The smaller track of the vehicle (front or rear) must be no less than 75 % of the larger track.
- T2.9.2 The track and center of gravity of the vehicle must combine to provide adequate rollover stability.

T3 GENERAL CHASSIS DESIGN

T3.1 General Requirements

- T3.1.1 Among other requirements, the vehicle's structure must include:
- Two roll hoops that are braced
 - A front bulkhead with support system and IA
 - Side impact structures

T3.2 Minimum Material Requirements

- T3.2.1 Table 4 shows the minimum requirements for the members of the primary structure if made from steel tubing.
- T3.2.2 Steel tubing has to be made from unalloyed carbon steel with a maximum content of 0.3 % carbon, 1.7 % manganese and 0.6 % of any other element. All other steel grades are considered alternative materials and require additional testing and documentation (see T3.3).
- T3.2.3 Except for inspection holes, any holes drilled in any part which is a member of the primary structure must be considered in the SES.
- T3.2.4 The steel properties used for the calculations in the SES must be:

T3 General Chassis Design

Item or application	Minimum wall thickness	Minimum cross sectional area	Minimum area moment of inertia
Main and front hoops, shoulder harness mounting bar	2.0 mm	175 mm ²	11 320 mm ⁴
Side impact structure, front bulkhead, roll hoop bracing, driver's restraint harness attachment (except as noted above)	1.2 mm	119 mm ²	8509 mm ⁴
Front bulkhead support, main hoop bracing supports	1.2 mm	91 mm ²	6695 mm ⁴

Table 4: Minimum Material Requirements

Non-welded strength for continuous material calculations:

- Young's Modulus (E) = 200 GPa
- Yield Strength (S_y) = 305 MPa
- Ultimate Strength (S_u) = 365 MPa

Welded strength for discontinuous material such as joint calculations:

- Yield Strength (S_y) = 180 MPa
- Ultimate Strength (S_u) = 300 MPa

T3.2.5 Any tubing with a wall thickness less than 1.2 mm or a minimum area moment of inertia less than 6695 mm⁴ is considered non-structural and will be ignored when assessing compliance to any rule regarding the vehicle structure.

T3.2.6 If a member of the primary structure (except for the roll hoops) is a bent tube or made from multiple tubes an additional tube must support it. This support tube must:

- Have its attachment point at the position along the bend tube where it deviates farthest from a straight line connecting both ends.
- Be of the same dimension as the supported tube(s).
- Terminate at a node of the primary structure.
- Be angled no more than 30° from the plane of the supported tube(s).

T3.2.7 Any welded seams shape must not be mechanically altered in any way.

T3.3 Alternative Materials

T3.3.1 Alternative materials may be used for all parts of the primary structure and the TSAC with the following exceptions:

- The main hoop and the main hoop bracing must be steel
- The front hoop must be metal

T3 General Chassis Design

- Any welded structures of the primary structure must be steel
- However, the front hoop may be an aluminum welded structure

T3.3.2 If any other materials than steel tubing are used in the primary structure or the TSAC, physical testing is required to show equivalency to the minimum material properties for steel in T3.2.

T3.3.3 If alloyed steel as defined by T3.2.2 is used, the team has to include tests and documentation in the SES to show structural equivalency. This may include, but is not limited to:

- Receipts and data sheets of the used tubing materials
- Documentation about welding processes and filler materials
- Documentation about heat treatments
- Tests showing adequate strength and elongation at break in the welded condition

T3.4 Composite Structures

T3.4.1 If composite structures are used in the primary structure or the TSAC, the Flexural Rigidity (EI) of that structure must be calculated with the tools and formulas in the SES. The actual geometry and curvature of the panel may be taken into account for the main hoop bracing support, the front hoop bracing, the front bulkhead support structure, the shoulder harness bar, the TS and TSAC protective structure. For all other areas the EI must be calculated as the EI of a flat panel about its neutral axis. This panel must have the same composition as the structure used in the primary structure or the TSAC.

T3.4.2 If composite materials are used in the primary structure or the TSAC the SES must include:

- Material type(s)
- Cloth weights
- Resin type
- Fiber orientation
- Number of layers
- Core material
- Lay-up technique
- 3-point-bend test and shear test data

T3.4.3 For any laminate in the primary structure or the TSAC, the maximum weight content of parallel fibers, relative to the weight of all fibers in the laminate, is 50%. All fibers laid within any orientation $\pm 10^\circ$ count as parallel in this case.

T3.4.4 Wherever backing plates are required, they must be fully supported by the structure they are attached to.

T3.4.5 Backing plates must have a continuous perimeter that is near circular or near oval. The outer perimeter profile may have some straight sections, but no concave sections. Backing plates must not have any cut-outs within their outside perimeter except for the holes for bolts.

T3 General Chassis Design

T3.5 Laminate Testing

T3.5.1 If composite materials are used for any part of the primary structure or the TSAC the team must:

- Build a representative test panel which must measure exactly 275 mm × 500 mm that has the same design, laminate and fabrication method as used for the respective part of the primary structure represented as a flat panel. The sides of the test panel must not be laminated (core material must be visible).
- Perform a 3-point bending test on this panel

The data from these tests and pictures of the test samples and test setup must be included in the SES. In the pictures, the following must be identifiable: distance between the two supports, dimensions of the load applicator and test sample marking as per T3.5.4. The test results must be used to derive strength and stiffness properties used in the SES formula for all laminate panels.

Representative test panels for parts of the TSAC may use smaller dimensions, provided that the panel core thickness is 5 mm or smaller. This representative test panel must then measure 150 mm × 275 mm. In this case, the distance between the two test panel supports must be at least 200 mm and the load applicator must have a radius of at least 5 mm. T3.5.5 and T3.5.6 do not apply.

T3.5.2 If a panel represents side impact structure it must be proven that it has at least the same properties as two steel tubes meeting the requirements for side impact structure tubes for buckling modulus, yield strength and absorbed energy.

T3.5.3 Composite structures with different core thicknesses but otherwise identical construction may use material properties derived from a single test panel. The panel with the thicker core must be tested and the structure using derived material properties may not use a core thickness of less than 66 % of the tested panel.

T3.5.4 The test samples must be presented at technical inspection. All samples must be marked with the following non-removable (e.g.: permanent marker or engraving, but no sticker) information: laminated structure acronym and date of testing.

T3.5.5 The distance between the two test panel supports must be at least 400 mm.

T3.5.6 The load applicator used to test any panel or tube must be metallic and have a radius of 50 mm.

T3.5.7 The load applicator must overhang the test piece to prevent edge loading.

T3.5.8 There must be no material between the load applicator and the test piece.

T3.5.9 Perimeter shear tests must be completed which measure the force required to push or pull a 25 mm diameter flat punch through a flat laminate sample. The sample must be at least 100 mm × 100 mm. Core and skin thicknesses must be identical to those used in the actual primary structure and be manufactured using the same materials and processes.

T3.5.10 The test fixture must support the entire sample, except for a 32 mm hole aligned co-axially with the punch. The sample must not be clamped to the fixture.

T3 General Chassis Design

T3.6 Structural Documentation

- T3.6.1 All teams must submit a Structural Equivalency Spreadsheet (SES) and Structural Equivalency 3D Model (SE3D).
- T3.6.2 The SES spreadsheet form can be downloaded from the competition website.
- T3.6.3 The SE3D must contain a three dimensional CAD model of the chassis including all members of the primary structure and all mechanical attachment details of the hoops and hoop braces in "IGES" file format not larger than 40 MB. [EV ONLY] The TSAC(s) and attachment must also be included.
- T3.6.4 Vehicles must be fabricated in accordance with the materials and processes described in the SES.
- T3.6.5 Teams must bring a copy of the approved SES to technical inspection.

T3.7 Roll Hoops

- T3.7.1 Both roll hoops must be securely integrated to the primary structure using node-to-node triangulation or equivalent joining methods.
- T3.7.2 The minimum radius of any bend, measured at the tube centerline, must be at least three times the tube outside diameter. Bends must be smooth and continuous with no evidence of crimping or wall failure. The minimum area moment of inertia, see T3.2, must be maintained in all areas, including the bends of the manufactured tubes.
- T3.7.3 In a plane perpendicular to the longitudinal axis of the vehicle and through the lower endpoints of the roll hoop, no part of the primary structure may lie below 30 mm of the endpoints of the roll hoop.
- T3.7.4 Roll hoops attached to a composite primary structure must be mechanically attached at the top and bottom of both sides of that structure and at intermediate locations if needed to show equivalency. The lower roll hoop tubing attachment points must be within 50 mm of the endpoints of the roll hoop.
- T3.7.5 Mounting plates welded to the roll hoops must be at least 2 mm thick steel or 3 mm thick aluminum, dependent of the roll hoop material.
- T3.7.6 Both roll hoops must have one 4.5 mm inspection hole in a non-critical straight location and its surface at this point must be unobstructed for at least 180°.

T3.8 Main Hoop

- T3.8.1 The main hoop must be constructed of a single piece of uncut, continuous, closed section steel tubing.
- T3.8.2 In side view the portion of the main hoop which is above its upper attachment point to the side impact structure must be inclined less than 10° from vertical.
- T3.8.3 In side view any bends in the main hoop above its upper attachment point to the primary structure must be braced to a node of the main hoop bracing support structure with tubing meeting the requirements of main hoop bracing.

T3 General Chassis Design

T3.8.4 In side view any portion lower than the upper attachment point to the side impact structure must be inclined either forward or not more than 10° rearward.

T3.9 Front Hoop

T3.9.1 The front hoop must be constructed of a continuous and closed section.

T3.9.2 If the front hoop is made from more than one piece it must be supported by node-to-node triangulation or an equivalent construction.

T3.9.3 In side view, no part of the front hoop can be inclined more than 20° from vertical.

T3.9.4 If the front hoop is a welded construction made from multiple aluminum profiles, the equivalent yield strength must be considered in the as-welded condition unless the team demonstrates and shows proof that it has been properly solution heat treated and artificially aged. The team must supply sufficient documentation proving the appropriate heat treatment process was performed.

T3.9.5 Fully laminating the front hoop to the monocoque is acceptable. Fully laminating means that the hoop has to be encapsulated with laminate around its whole circumference, see figure 4. Equivalence to at least four mounts compliant with T3.16.1 must be shown in the SES. The laminate encapsulating the front hoop must overlap by at least 25mm on each side. It must have the same lay-up as the laminate that it is connecting to.

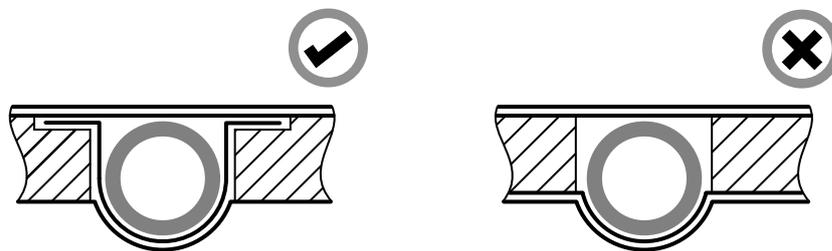


Figure 4: Front hoop laminating requirements

T3.10 Main Hoop Bracing

T3.10.1 The main hoop must be supported to the front or the rear by bracing tubes on each side of the main hoop.

T3.10.2 In side view the main hoop and the main hoop braces must not lie on the same side of a vertical line coincident with the top of the main hoop.

T3.10.3 The main hoop braces must be attached to the main hoop no lower than 160 mm below the top-most surface of the main hoop. The included angle formed by the main hoop and the main hoop braces must be at least 30°.

T3.10.4 The main hoop braces must be straight.

T3.10.5 The lower ends of the main hoop braces must be supported back to the upper attachment point of the main hoop to the side impact structure and to the lower attachment point of the

T3 General Chassis Design

main hoop to the side impact structure by a node-to-node triangulated structure or equivalent composite structure.

T3.10.6 If any item which extends outside of the primary structure is attached to the main hoop braces, additional bracing is required to prevent bending loads in a rollover situation.

T3.11 Front Hoop Bracing

T3.11.1 The front hoop bracing attaches on each side of the front hoop as well as the structure forward of the driver's feet. A minimum of two tubes without any bends must be straight on a line in side view of the frame.

T3.11.2 The front hoop bracing structure must be attached no lower than 50 mm below the top-most surface of the front hoop, see figure 5.

T3.11.3 If the front hoop is inclined more than 10° to the rear, additional braces extending rearwards are required.

T3.11.4 Composite front hoop bracing structures cannot be counted towards the front bulkhead support structures and vice-versa for the structural equivalency documentation.

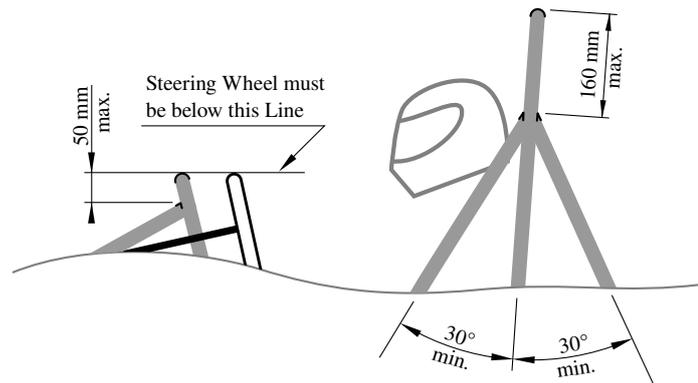


Figure 5: Front hoop bracing, main hoop bracing and steering wheel requirements

T3.12 Mechanically Attached Roll Hoop Bracing

T3.12.1 Any non-welded joint at either end of a bracing must be either a double-lug joint, see figure 6, or a sleeved joint, see figure 7. Spherical rod ends are prohibited.

T3.12.2 If threaded fasteners are used they are considered critical fasteners and must comply with T10.1.

T3.12.3 Double lug-joints must include a capping arrangement, see figure 6.

T3.12.4 In a double-lug joint each lug must be at least 4.5 mm thick and the pin or bolt must be 10 mm metric grade 8.8 minimum. The attachment holes in the lugs and in the attached bracing must be a close fit with the pin or bolt.

T3.12.5 For sleeved joints the sleeve must have a minimum length of 38 mm either side of the joint and be a close-fit around the base tubes. The wall thickness of the sleeve must be at least that

T3 General Chassis Design

of the bracing tubes. The bolts must be 6 mm metric grade 8.8 minimum. The holes in the sleeves and tubes must be a close-fit with the bolts.

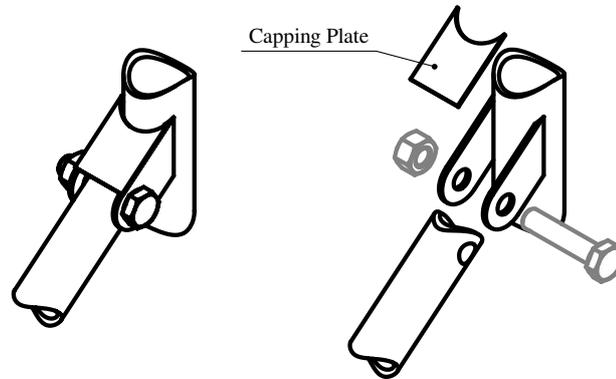


Figure 6: Double lug joint

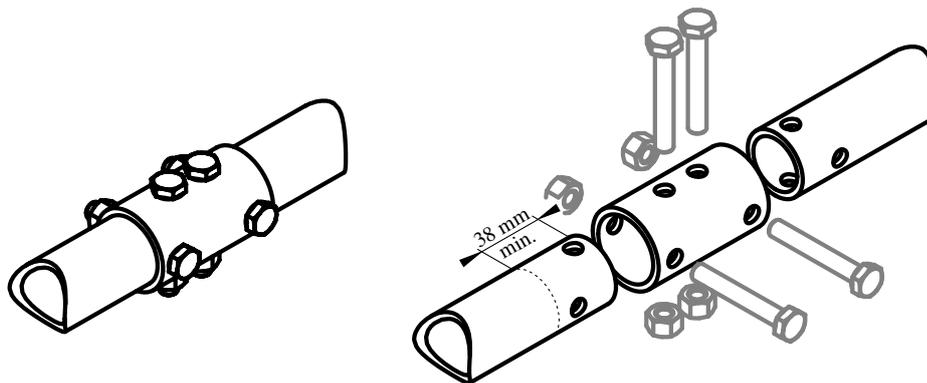


Figure 7: Sleeved joint

T3.13 Front Bulkhead

T3.13.1 Any alternative material used for the front bulkhead must have a perimeter shear strength equivalent to a 1.5 mm thick steel plate.

T3.13.2 If the front bulkhead is part of a composite structure and is modeled as an “L” shape, the EI of the front bulkhead about the vertical and lateral axes must be equivalent to a steel tube meeting the requirements for the front bulkhead. The length of the section perpendicular to the bulkhead may be a maximum of 25 mm measured from the rearmost face of the bulkhead.

T3.14 Front Bulkhead Support

T3.14.1 The front bulkhead must be supported back to the front hoop by a minimum of three tubes on each side; an upper member, a lower member and diagonal bracing to provide triangulation.

- The upper support member must be attached to the front bulkhead a maximum of 50 mm below the top-most surface of the front bulkhead, and attached to the front hoop a maximum of 50 mm below the upper side impact member. If the attachment point

T3 General Chassis Design

of the upper member is greater than 100 mm above the upper side impact member, node-to-node triangulated bracing is required to transfer load to the main hoop.

- The lower support member must be attached to the base of the front bulkhead and the base of the front hoop.
- The diagonal bracing must triangulate the upper and lower support members node-to-node.

T3.14.2 If the front bulkhead support is part of a composite structure, it must have equivalent EI to the sum of the EI of the six baseline steel tubes that it replaces and it must not be counted towards the composite front hoop bracing structures for the structural equivalency documentation (i.e. T3.11.4).

T3.14.3 The EI of the vertical side of the front bulkhead support structure must be equivalent to at least the EI of one baseline steel tube that it replaces.

T3.14.4 The perimeter shear strength of the monocoque laminate in the front bulkhead support structure must be at least 4 kN.

T3.15 Side Impact Structure

T3.15.1 The side impact structure must consist of at least three steel tubes, see T 3.2, on each side of the cockpit, see figure 8.

- The upper member must connect the main hoop and the front hoop. It must be at a height between 240 mm and 320 mm above the lowest inside chassis point between the front and main hoop.
- The lower member must connect the bottom of the main hoop and the bottom of the front hoop.
- The diagonal member must triangulate the upper and lower member between the roll hoops node-to-node.

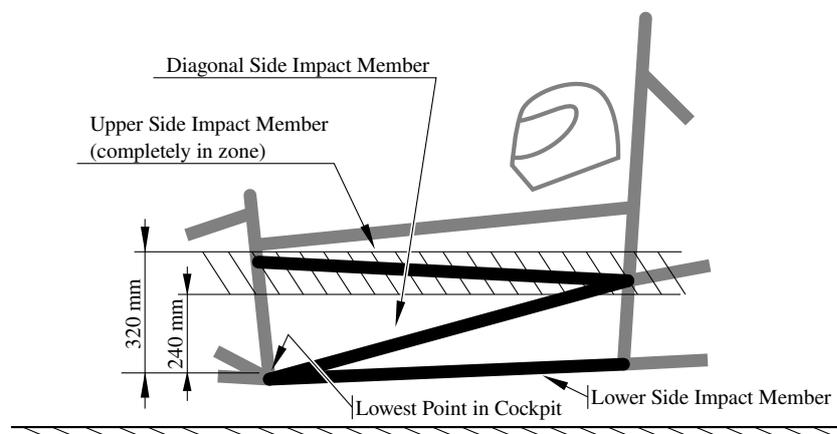


Figure 8: Side impact structure

T3.15.2 If the side impact structure is part of a composite structure, the following is required:

T3 General Chassis Design

- The region that is longitudinally forward of the main hoop and aft of the front hoop and vertical from the bottom surface of the chassis to 320 mm above the lowest inside chassis point between the front and main hoop must have an EI equal to the three baseline steel tubes that it replaces, see figure 9.
- The vertical side impact structure must have an EI equivalent to two baseline steel tubes and half the horizontal floor must have an EI equivalent to one baseline steel tube.
- The vertical side impact structure must have an absorbed energy equivalent to two baseline steel tubes.
- The perimeter shear strength must be at least 7.5 kN.

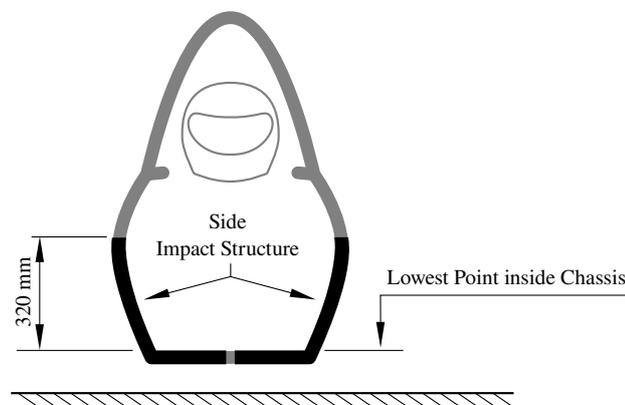


Figure 9: Side impact structure monocoque

T3.16 Bolted Primary Structure Attachments

- T3.16.1 If two parts of the primary structure are bolted together, each attachment point between the two parts must be able to carry a load of 30 kN in any direction.
- T3.16.2 Data obtained from the laminate perimeter shear strength test must be used to prove that adequate shear area is provided.
- T3.16.3 Each attachment point requires a minimum of two 8 mm metric grade 8.8 bolts and steel backing plates with a minimum thickness of 2 mm.
- T3.16.4 For the attachment of front hoop bracing, main hoop bracing and main hoop bracing support to the primary structure the use of one 10 mm metric grade 8.8 bolt is sufficient, if the bolt is on the centerline of the tube, see figure 10.
- T3.16.5 When using bolted joints within the primary structure, no crushing of the laminate core material is permitted.

T3.17 Impact Attenuator

- T3.17.1 Each vehicle must be equipped with an IA.
- T3.17.2 The IA must be:

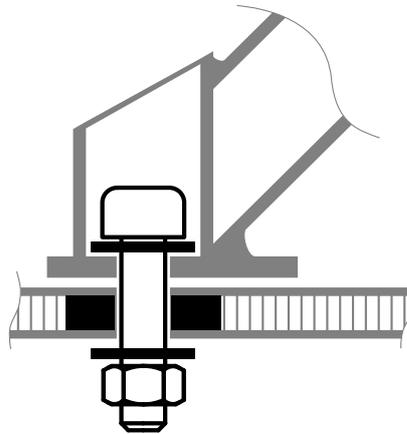


Figure 10: Bolted roll hoop bracing support

- Installed forward of the front bulkhead.
- At least 100 mm high and 200 mm wide for a minimum distance of 200 mm forward of the front bulkhead.
- Not able to penetrate the front bulkhead in the event of an impact.
- Attached securely and directly to the Anti Intrusion Plate (AIP).
- Not part of the non-structural bodywork.
- Designed with a closed front section.
- Cannot be wider or higher than the AIP.

- T3.17.3 On all vehicles, a 1.5 mm solid steel or 4.0 mm solid aluminum AIP must be integrated into the IA.
- If the IA and AIP (IA assembly) are bolted to the front bulkhead, it must be the same size as the outside dimensions of the front bulkhead.
 - If it is welded to the front bulkhead, it must extend at least to the centerline of the front bulkhead tubing in all directions.
 - The AIP must not extend past the outside edges of the front bulkhead.
- T3.17.4 Alternative AIP designs are permissible if equivalency to T3.17.3 is proven by physical testing as in T3.19.2.
- T3.17.5 If the IA assembly is not integral with the primary structure, i.e. welded, a minimum of eight 8 mm metric grade 8.8 bolts must attach the IA assembly to the front bulkhead. The IA may be attached to the AIP by a minimum of four 8 mm metric grade 8.8 bolts. The bolts are considered critical fasteners and must comply with T 10.
- T3.17.6 The attachment of the IA assembly must be designed to provide an adequate load path for transverse and vertical loads in the event of off-center and off-axis impacts. Segmented foam attenuators must have the segments bonded together to prevent sliding or parallelogramming.

T3 General Chassis Design

- T3.17.7 The attachment of the IA assembly to a monocoque structure requires an approved “Structural Equivalency Spreadsheet” per T3.6 that shows equivalency to a minimum of eight 8 mm metric grade 8.8 bolts.
- T3.17.8 A team may use one of the “standard” FSAE IAs, in order to avoid testing, provided that:
- if the front bulkhead width is larger than 400 mm and/or its height is larger than 350 mm a diagonal or X-bracing that is a front bulkhead support tube or an approved equivalent per T3.2, must be included in the front bulkhead. Or equivalent for monocoque bulkheads.
 - must use a 1.5 mm solid steel AIP that is welded along its full perimeter to a steel bulkhead or use a 4 mm solid aluminium AIP that is bolted to any bulkhead with a minimum of eight 8 mm metric grade 8.8 bolts
 - if the “standard” honeycomb IA is used, the IA must be of pre-crushed type
- T3.17.9 If the standard IA is used, but does not comply with the requirements of T3.17.8 physical testing must be carried out to prove that the AIP does not permanently deflect more than 25 mm.

T3.18 Impact Attenuator Data Requirement

- T3.18.1 All teams must submit an IA data report using the Impact Attenuator Data (IAD) template provided at the competition website.

T3.19 Impact Attenuator Test Requirements

- T3.19.1 The IA assembly, when mounted on the front of a vehicle with a total mass of 300 kg and impacting a solid, non-yielding impact barrier with a velocity of impact of 7 m/s, must meet the following requirements:
- Decelerate the vehicle at a rate not exceeding 20 g average and 40 g peak.
 - The energy absorbed in this event must meet or exceed 7350 J.
 - Teams using the standard IA are not required to submit test data with their IAD report, but all other requirements must be included.
- T3.19.2 During the IA test:
- The IA must be attached to the AIP using the intended vehicle attachment method.
 - The IA assembly must be attached to a test fixture that has geometry representative of the intended primary structure and equal or higher stiffness and strength. When alternative materials are used for the AIP, the test fixture must be a copy of the intended primary structure (i.e. materials, lay-up, joining methods).
 - There must be at least 50 mm clearance rearwards of the AIP to the test fixture.
 - No part of the AIP may permanently deflect more than 25 mm beyond the position of the AIP before the test.
- T3.19.3 Teams using IAs (typically structural noses) directly attached to the front bulkhead, which shortcut the load path through the bulk of the AIP, must conduct an additional test. This test

T4 Cockpit

must prove that the AIP can withstand a load of 120 kN (300 kg multiplied by 40 g), where the load applicator matches the minimum IA dimensions.

T3.19.4 Vehicles with aerodynamic devices and/or sensors in front of the front bulkhead must not exceed the peak deceleration of T3.19.1 for the combination of their IA assembly and the non-crushable object(s). Any of the following three methods may be used to prove the design does not exceed 120 kN :

- Physical testing of the IA assembly including any attached non-crushable object(s) in front of the AIP.
- Combining the peak force from physical testing of the IA assembly with the failure load for the mounting of the non-crushable object(s), calculated from fastener shear and/or link buckling.
- Combining the “standard” IA peak load of 95 kN with the failure load for the mounting of the non-crushable object(s), calculated from fastener shear and/or link buckling.

T3.19.5 Dynamic testing (sled, pendulum, drop tower, etc) of the IA may only be conducted at a dedicated test facility. This facility may be part of the university, but must be supervised by professional staff. Teams are not allowed to design their own dynamic test apparatus.

T3.19.6 When using acceleration data from the dynamic test, the average deceleration must be calculated based on the raw unfiltered data. If peaks above the 40 g limit are present in the data, a 100 Hz, 3rd order, low pass Butterworth (−3 dB at 100 Hz) filter may be applied.

T3.20 Non-Crushable Objects

T3.20.1 All non-crushable objects (e.g. pedals, master cylinders, hydraulic reservoirs) must be rearward of the rear most plane of the front bulkhead and at least 25 mm behind the AIP at any time, except for sensors, aerodynamic devices and their mountings.

T4 COCKPIT

T4.1 Cockpit Opening

T4.1.1 The size of the cockpit opening needs to be sufficient for the template shown on the left of figure 11 to pass vertically from the cockpit opening to below the upper side impact member when held horizontally. The template may be moved fore and aft.

T4.1.2 If the side impact structure is not made of tubes, the template must pass until it is 320 mm above the lowest inside chassis point between the front and main hoop.

T4.1.3 The steering wheel, seat and all padding may be removed for the template to fit. Any other parts may only be removed if they are integrated with the steering wheel.

T4.2 Cockpit Internal Cross Section

T4.2.1 The cockpit must provide a free internal cross section sufficient for the template shown on the right in figure 11 to pass from the cockpit opening to a point 100 mm rearwards of the

T4 Cockpit

face of the rearmost pedal in an inoperative position. The template may be moved up and down. Adjustable pedals must be in their most forward position.

T4.2.2 The steering wheel and any padding that can be removed without the use of tools while the driver is seated may be removed for the template to fit.

T4.2.3 The driver's feet and legs must be completely contained within the primary structure when the driver is seated normally and the driver's feet are touching the pedals. In side and front views, any part of the driver's feet or legs must not extend above or outside of this structure.

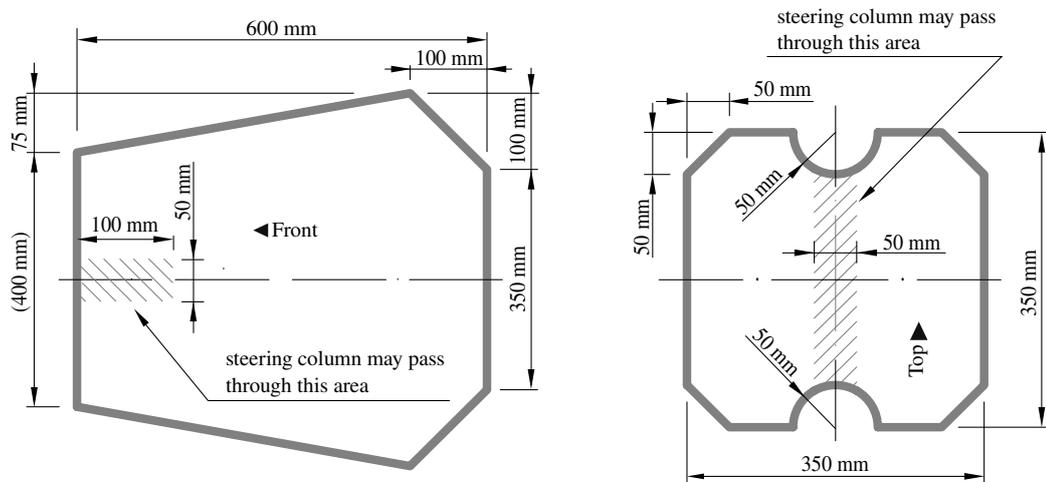


Figure 11: Cockpit opening template (left) and cockpit internal cross section template (right)

T4.3 Percy (95th percentile male)

T4.3.1 When seated normally and restrained by the driver's restraint system, the helmet of a 95th percentile male and all of the team's drivers must, see figure 12:

- Be a minimum of 50 mm away from the straight line drawn from the top of the main hoop to the top of the front hoop.
- Be a minimum of 50 mm away from the straight line drawn from the top of the main hoop to the lower end of the main hoop bracing if the bracing extends rearwards.
- Be no further rearwards than the rear surface of the main hoop if the main hoop bracing extends forwards.

T4.3.2 The 95th percentile male is represented by a two dimensional figure consisting of two circles of 200 mm diameter (one representing the hips and buttocks and one representing the shoulder region) and one circle of 300 mm (representing the head with helmet).

T4.3.3 The two 200 mm circles are connected by a straight line measuring 490 mm. The 300 mm circle is connected by a straight line measuring 280 mm with the upper 200 mm circle.

T4.3.4 The figure has to be positioned in the vehicle as follows, see figure 13:

- The seat adjusted to the rearmost position
- The pedals adjusted to the frontmost position

T4 Cockpit

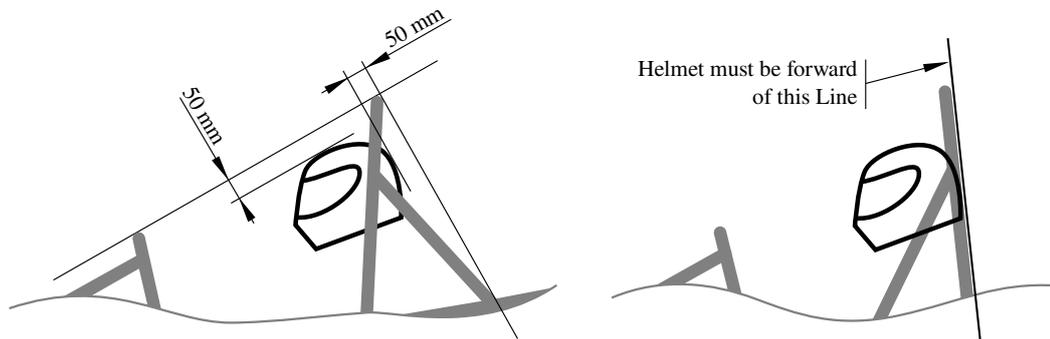


Figure 12: Minimum helmet clearance

- The bottom 200 mm circle placed on the seat bottom. The distance between the center of the circle and the rearmost actuation face of the pedals must be minimum 915 mm.
- The middle circle positioned on the seat back
- The upper 300 mm circle positioned 25 mm away from the head restraint.

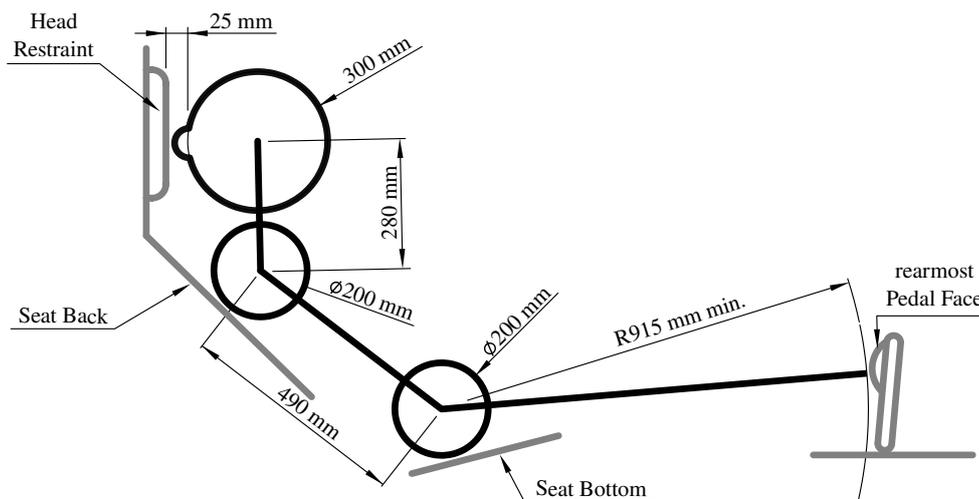


Figure 13: Percy placement

T4.4 Side Tubes

T4.4.1 If there is any chassis member alongside the driver at the height of the neck of any of the drivers in the team, a metal tube or piece of sheet metal must be attached to the chassis to prevent the driver's shoulders from passing under that chassis member.

T4.5 Non-Welded Driver's Harness Attachment

T4.5.1 Any harness attachment to a monocoque must be using one 10 mm metric grade 8.8 bolt or two 8 mm metric grade 8.8 bolts (or bolts of an equivalent norm) and steel backing plates with a minimum thickness of 2 mm.

T4 Cockpit

- T4.5.2 If the attachment of the drivers harness is not welded to a steel structure, it must be proven that the attachments for shoulder and lap belts can support a load of 13 kN and the attachment points of the anti-submarine belts can support a load of 6.5 kN.
- T4.5.3 If the lap belts and anti-submarine belts are attached less than 100 mm apart, these must support a total load of 19.5 kN.
- T4.5.4 The strength of lap belt and shoulder belt attachments must be proven by physical testing where the required load is applied to a representative attachment point with the lay-up and attachment brackets as in the chassis. The following requirements must be met:
- Edges of the test fixture supporting the sample must be a minimum of 125 mm from the load application point.
 - The width of the shoulder harness test sample must not be any wider than the shoulder harness panel height used to show equivalency for the shoulder harness mounting bar.
 - Designs with attachments near a free edge may not support the free edge during the test.
 - Harness loads must be tested with the worst case for the range of the angles specified for the driver's harness.

T4.6 Driver's Seat

- T4.6.1 The lowest point of the driver's seat must in side view not extend below the upper face of the lowest side impact structure member or have a longitudinal tube (or tubes) that meets the material requirements for the side impact structure (T3.2), passing underneath the lowest point of the seat.
- T4.6.2 Adequate heat insulation must be provided to ensure that the driver is not able to contact any parts of the vehicle with a surface temperature above 60 °C. The insulation may be external to the cockpit or incorporated with the driver's seat or firewall. The design must address all three types of heat transfer with the following minimum requirements between the heat source and the part that the driver could contact:
- (a) Conduction insulation by:
 - (i) No direct contact, or
 - (ii) a heat resistant, conduction insulation material with a minimum thickness of 8 mm.
 - (b) Convection insulation by a minimum air gap of 25 mm.
 - (c) Radiation insulation by:
 - (i) A solid metal heat shield with a minimum thickness of 0.4 mm or
 - (ii) reflective foil or tape when combined with T4.6.2.a.ii.

T4.7 Floor Closeout

- T4.7.1 All vehicles must have a floor closeout made of one or more panels, which separate the driver from the ground.

T4 Cockpit

- T4.7.2 The closeout must extend from the front bulkhead to the firewall.
- T4.7.3 The panels must be made of a solid, non-brittle material.
- T4.7.4 If multiple panels are used, gaps between panels may not exceed 3 mm.

T4.8 Firewall

- T4.8.1 A firewall must separate the cockpit from all components of the fuel supply system, hydraulic fluid (except brake system and dampers), flammable liquids, the low voltage battery and any TS component, see EV 1.1.1.
- T4.8.2 The firewall must cover any line of sight between the parts mentioned in T4.8.1 and any part of the tallest driver below a plane 100 mm above the bottom of the helmet.
- T4.8.3 The firewall must be a non-permeable surface made from a rigid, fire resistant material, see T 1.2.1, which must be rigidly mounted to the vehicle's structure.
- T4.8.4 Any firewall must seal completely against the passage of fluids, especially at the sides and the floor of the cockpit.
- T4.8.5 Pass-throughs for wiring, cables, etc. are permitted if grommets are used to seal the pass-through.
- T4.8.6 Multiple panels may be used to form the firewall but must overlap at least 5mm and be sealed at the joints. Any sealing material must not be vital to the structural integrity of the firewall.
- T4.8.7 [EV ONLY] The tractive system firewall between driver and tractive system components must be composed of two layers:
- One layer, facing the tractive system side, must be made of aluminum with a thickness of at least 0.5 mm. This part of the tractive system firewall must be grounded according to EV 3.1.
 - The second layer, facing the driver, must be made of an electrically insulating and fire retardant material, see T 1.2.1. The second layer must not be made of CFRP.
 - The thickness of the second layer must be sufficient to prevent penetrating this layer with a 4 mm wide screwdriver and 250 N of force.
- A sample of the tractive system firewall must be presented at technical inspection.
- T4.8.8 [EV ONLY] Conductive parts (except for the chassis) may not protrude through the firewall or must be properly insulated on the driver's side.
- T4.8.9 [EV ONLY] TS parts outside of the envelope, see EV 4.4.3, do not need a firewall.

T4.9 Accessibility of Controls

- T4.9.1 All vehicle controls must be operated from inside the cockpit without any part of the driver, e.g. hands, arms or elbows, being outside the vertical planes tangent to the outermost surface of the side impact structure.

T5 Driver Restraint System

T4.10 Driver Visibility

- T4.10.1 The driver must have adequate visibility to the front and sides of the vehicle. Seated in a normal driving position, the driver must have a minimum field of vision of 100° to either side. The required visibility may be obtained by the driver turning their head and/or the use of mirrors.
- T4.10.2 If mirrors are required to meet T4.10.1, they must remain in place and be adjusted to enable the required visibility throughout all dynamic events.

T4.11 Driver Egress

- T4.11.1 All drivers must be able to exit to the side of the vehicle in less than 5 s with the driver in the fully seated position, hands in the driving position on the connected steering wheel (in all possible steering positions) and wearing the required driver equipment as in T 13.3. The egress time will stop when the driver has both feet on the ground.

T5 DRIVER RESTRAINT SYSTEM

T5.1 Definitions

- T5.1.1 6-point system – Consists of a two-piece lap belt (minimum width 50 mm), two shoulder straps (minimum width 75 mm) and two leg or anti-submarine straps (minimum width 50 mm).
- T5.1.2 7-point system – Same as the 6-point system except it has three anti-submarine straps.
- T5.1.3 upright driving position – Position with a seat back angled at 30° or less from the vertical as measured along the line joining the two 200 mm circles of the 95th percentile male template as defined in T 4.3 and positioned per T 4.3.4.
- T5.1.4 reclined driving position – Position with a seat back angled at more than 30° from the vertical as measured along the line joining the two 200 mm circles of the 95th percentile male template as defined in T 4.3 and positioned per T 4.3.4

T5.2 Belts - General

- T5.2.1 All drivers must use a 6-point or 7-point restraint harness meeting the following specifications:
- All driver restraint systems must meet SFI Specification 16.1, SFI Specification 16.5, SFI Specification 16.6, FIA specification 8853/98 or FIA specification 8853/2016.
 - The belts must bear the appropriate dated labels.
 - The material of all straps must be in perfect condition.
 - There must be a single metal-to-metal latch type quick release for all straps.
 - All lap belts must incorporate a tilt lock adjuster (“quick adjuster”). A tilt lock adjuster in each portion of the lap belt is highly recommended. Lap belts with “pull-up” adjusters are recommended over “pull-down” adjusters.

T5 Driver Restraint System

- Vehicles with a “reclined driving position” must have either anti-submarine belts with tilt lock adjusters (“quick adjusters”) or have two sets of anti-submarine belts installed.
- The shoulder harness must be the “over-the-shoulder type”. Only separate shoulder straps are permitted (i.e. “Y”-type shoulder straps are not allowed). The “H”-type configuration is allowed.
- The shoulder harness straps must be threaded through the three bar adjusters in accordance with the manufacturer’s instructions.
- When a HANS device is used by the driver, FIA certified 50 mm wide shoulder harnesses are allowed.

T5.2.2 SFI spec harnesses must be replaced following December 31st of the 2nd year after the date of manufacture as indicated by the label. FIA spec harnesses must be replaced following December 31st of the year marked on the label.

T5.2.3 The restraint system must be worn tightly at all times.

T5.3 Belt, Strap and Harness Installation - General

T5.3.1 The lap belt, shoulder harness and anti-submarine strap(s) must be securely mounted to the primary structure. This structure and any guide or support for the belts must meet the minimum requirements of T3.2.

T5.3.2 The tab or bracket to which any harness is attached must have:

- A minimum cross sectional area of 60 mm² of steel to be sheared or failed in tension at any point of the tab, and
- A minimum thickness of 1.6 mm.
- Where lap belts and anti-submarine belts use the same attachment point, a minimum cross sectional area of 90 mm² of steel to be sheared if failed in tension at any point of the tab.
- Where brackets are fastened to the chassis, two fasteners of 8 mm metric grade 8.8 fasteners or stronger must be used.

T5.3.3 Harnesses, belts and straps must not pass through a firewall, i.e. all harness attachment points must be on the driver’s side of any firewall.

T5.3.4 The attachment of the driver’s restraint system to a monocoque structure requires an approved SES per T3.6. The lap belts and anti submarine belts must not be routed over the sides of the seat. Where the belts or harness pass through a hole in the seat, the seat must be rolled or grommeted to prevent chafing of the belts.

T5.4 Lap Belt Mounting

T5.4.1 The lap belt must pass around the pelvic area below the anterior superior iliac spines (the hip bones).

T5.4.2 The lap belts should come through the seat at the bottom of the sides of the seat to maximize the wrap of the pelvic surface and continue in a straight line to the anchorage point.

T5 Driver Restraint System

- T5.4.3 In side view, the lap belt must be capable of pivoting freely by using either a shouldered bolt or an eye bolt attachment.
- T5.4.4 With an “upright driving position”, in side view the lap belt must be at an angle of between 45° and 65° to the horizontal.
- T5.4.5 With a “reclined driving position”, in side view the lap belt must be between an angle of 60° and 80° to the horizontal.
- T5.4.6 The centerline of the lap belt at the seat bottom should be between 0 mm to 76 mm forward of the seat back to seat bottom junction as in figure 14.

T5.5 Shoulder Harness

- T5.5.1 The shoulder harness must be mounted behind the driver to a structure that meets the requirements of the primary structure. However, it cannot be mounted to the main hoop bracing or attendant structure without additional bracing to prevent loads being transferred into the main hoop bracing.
- T5.5.2 If the harness is mounted to a tube that is not straight, the joints between this tube and the structure to which it is mounted must be reinforced in side view by triangulation tubes to prevent torsional rotation of the harness mounting tube. Supporting calculations are required. Analysis method: Use 7 kN load per attachment and the range of angles in T5.5.5, calculate that the bent shoulder harness bar triangulation stresses are less than as welded yield strength T3.2.4 for combined bending and shear and does not fail in column buckling. If the team chooses not to perform the strength analysis T3.2.6 will apply.
- T5.5.3 The strength of any shoulder harness bar bracing tubes must be proved in the relevant tab of the team’s SES submission.
- T5.5.4 The shoulder harness mounting points must be between 180 mm and 230 mm apart, measured center to center.
- T5.5.5 From the driver’s shoulders rearwards to the mounting point or structural guide, the shoulder harness must be between 10° above the horizontal and 20° below the horizontal as in figure 14.

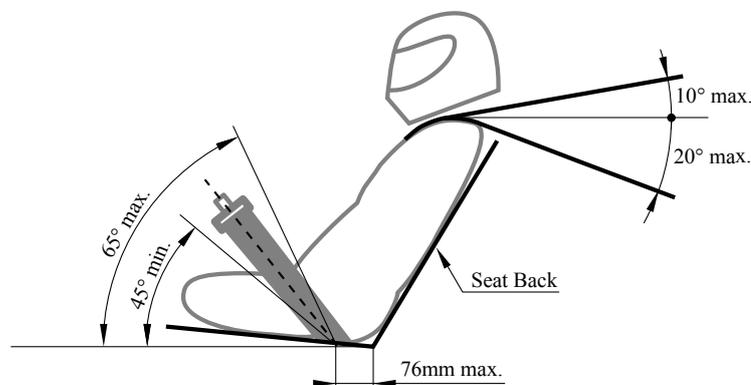


Figure 14: Lap belt and shoulder harness mounting

T5 Driver Restraint System

T5.6 Anti-Submarine Belt Mounting

- T5.6.1 The anti-submarine belts of a 6 point harness should be mounted in one of the following setups:
- With the belts going vertically down from the groin, or angled up to 20° rearwards. The anchorage points should be approximately 100 mm apart.
 - With the anchorage points on the primary structure at or near the lap belt anchorages, the driver sitting on the anti-submarine belts and the belts coming up around the groin to the release buckle.

T5.7 Head Restraint

- T5.7.1 A head restraint must be provided on the vehicle to limit the rearward motion of the driver's head.
- T5.7.2 The head restraint must:
- Be vertical or near vertical in side view.
 - Be padded with an energy absorbing material with a minimum thickness of 40 mm that meets either the SFI 45.2 standard, or is listed in the FIA technical list n°17 as a type B material for single seater cars.
 - Have a minimum width and height of 150 mm.
 - Be located so that for each driver:
 - The restraint is no more than 25 mm away from the back of the driver's helmet, with the driver in their normal driving position.
 - The contact point of the back of the driver's helmet on the head restraint is no less than 50 mm from any edge of the head restraint.
- T5.7.3 The head restraint and its mounting must withstand a force of 890 N applied in the rearward direction at any point on its surface.

T5.8 Roll Bar Padding

- T5.8.1 Any portion of the roll bar, roll bar bracing or chassis which might be contacted by the driver's helmet must be covered with a minimum thickness of 12 mm of padding which meets SFI spec 45.1 or FIA 8857-2001.

T5.9 Driver's Leg Protection

- T5.9.1 All moving suspension and steering components and other sharp edges inside the cockpit between the front hoop and a vertical plane 100 mm rearward of the pedals, must be shielded with solid material.
- T5.9.2 Covers over suspension and steering components must be removable to allow inspection of the mounting points.

T6 Brake System

T6 BRAKE SYSTEM

T6.1 Brake System - General

- T6.1.1 The vehicle must be equipped with a hydraulic brake system that acts on all four wheels and is operated by a single control.
- T6.1.2 The brake system must have two independent hydraulic circuits such that in the case of a leak or failure at any point in the system, effective braking power is maintained on at least two wheels. Each hydraulic circuit must have its own fluid reserve, either by the use of separate reservoirs or by the use of a dammed reservoir.
- T6.1.3 A single brake acting on a limited-slip differential is acceptable.
- T6.1.4 “Brake-by-wire” systems are prohibited in manual mode.
- T6.1.5 Unarmored plastic brake lines are prohibited.
- T6.1.6 The brake system must be protected from failure of the drivetrain, see T7.3.2, from touching any movable part and from minor collisions.
- T6.1.7 In side view any portion of the brake system that is mounted on the sprung part of the vehicle must not be below the lower surface of the chassis.
- T6.1.8 The brake pedal and its mounting must be designed to withstand a force of 2 kN without any failure of the brake system or pedal box. This may be tested by pressing the pedal with the maximum force that can be exerted by any official when seated normally.
- T6.1.9 The brake pedal must be fabricated from steel or aluminum or machined from steel, aluminum or titanium.
- T6.1.10 [EV ONLY] The first 90 % of the brake pedal travel may be used to regenerate brake energy without actuating the hydraulic brake system. The remaining brake pedal travel must directly actuate the hydraulic brake system, but brake energy regeneration may remain active.

T6.2 Brake Over-Travel Switch

- T6.2.1 A brake pedal over-travel switch must be installed on the vehicle as part of the shutdown circuit, as in EV 6 or CV 4.1. This switch must be installed so that in the event of a failure in at least one of the brake circuits the brake pedal over-travel will result in the shutdown circuit being opened. This must function for all possible brake pedal and brake balance settings without damaging any part of the vehicle.
- T6.2.2 Repeated actuation of the switch must not close the shutdown circuit, and it must be designed so that the driver cannot reset it.
- T6.2.3 The brake over travel-switch must be a mechanical single pole, single throw switch, commonly known as a two-position switch, push-pull or flip type, it may consist of a series connection of switches.

T6.3 Brake Light

- T6.3.1 The vehicle must be equipped with one brake light that is illuminated if and only if

T7 Powertrain

- the hydraulic brake system is actuated
- [EV ONLY] or the electric brake system is actuated, see EV 2.2.2

- T6.3.2 The brake light must meet the following requirements:
- A red light with a black background.
 - Rectangular, triangular or near round shape.
 - Minimum illuminated surface of 15 cm² with even luminous intensity.
 - Clearly visible from the rear in very bright sunlight.
 - When LED lights are used without a diffuser, they may not be more than 20 mm apart.
 - If a single line of LEDs is used, the minimum length is 150 mm.
- T6.3.3 In side view the brake light must be orientated vertical or near vertical and mounted between the wheel centerline and driver's shoulder level. Viewed from the back it should be positioned approximately at the vehicle's centerline.

T7 POWERTRAIN

T7.1 Transmission and Drive

- T7.1.1 Movement of the vehicle without a person in the vehicle and with the master switch(es) in the off position must be possible.

T7.2 Coolant Fluid and System Sealing

- T7.2.1 [CV ONLY] Water-cooled engines must only use plain water.
- T7.2.2 [EV ONLY] TS components may only use plain water, air or oil as the coolant, see T 1.2.2.
- T7.2.3 Cooling systems using plain water (except outboard wheel motors and their cooling hoses) must have a heat resistant, rigid and rigidly mounted cover which meets the requirements of T4.8.2.
- T7.2.4 Any cooling or lubrication system must be sealed to prevent leakage.
- T7.2.5 Separate catch cans must be employed to retain fluids other than plain water from any vents of the cooling system or engine lubrication system. Each catch-can must have a minimum volume of 10 % of the fluid being contained or 900 ml whichever is greater.
- T7.2.6 Any vent for systems containing plain water must have a catch-can with a minimum volume of 10 % of the fluid being contained or 100 ml, whichever is greater.
- T7.2.7 Catch cans, their mountings and all cooling or engine lubrication system hoses must be made of material that is permanently rated for temperatures of at least 120 °C or the temperatures the respective fluid may reach whichever is higher.
- T7.2.8 Catch cans must be rigidly mounted to the chassis and located rearwards of the firewall below the driver's shoulder level.

T8 Aerodynamic Devices

T7.2.9 Any catch can must vent through a hose with a minimum internal diameter of 3 mm down to the bottom level of the chassis and must exit outside the bodywork.

T7.3 Drive Train Shields and Guards

T7.3.1 The lowest point of any lubrication system can only be lower than the line between the lowest point of the main hoop and the lowest chassis member behind the lubrication system if it is protected from hitting the ground by a structure mounted directly to the chassis.

T7.3.2 Exposed rotating final drivetrain parts, chains and belts must be fitted with scatter shields. Scatter shields and their mountings must:

- Cover chains and belts from the drive sprocket to the driven sprocket/chain wheel/belt or pulley.
- Start and end parallel to the lowest point of the driven sprocket/chain wheel/belt or pulley.
- Be constructed of non-perforated 2 mm steel or 3 mm aluminum alloy 6061-T6.

T7.3.3 Scatter shields for high-speed rotating final drivetrain parts (such as electric motors, clutches, sprockets, gears etc.) that have an OEM casing that do not comply with T7.3.2 may be used, if material is added to achieve the minimum required thickness.

T7.3.4 [EV ONLY] When an electrical motor casing is rotating around the stator or is perforated, a scatter shield must be included around the motor. This scatter shield must be at least 1 mm thick and made from aluminum alloy 6061-T6 or steel.

T7.3.5 Scatter shields for chains and belts must be centered on the centerline of the chain or belt and remain aligned with the chain or belt under all conditions. The minimum width of the scatter shield should be at least three times the width of the chain or belt. The minimum material requirements are:

- For metallic chains and belts: 2 mm steel.
- For non-metallic chains and belts: 3 mm aluminum alloy 6061-T6.

T7.3.6 All fasteners attaching scatter shields, guards and their mountings must be 6 mm metric grade 8.8 or stronger and must comply with T10.1.

T7.3.7 Finger guards are required to cover any parts that spin while the vehicle is stationary. Finger guards may be made of lighter material, sufficient to resist finger forces. Mesh or perforated material may be used but must prevent the passage of a 12 mm diameter object through the guard.

T8 AERODYNAMIC DEVICES

T8.1 Definition Aerodynamic Device

T8.1.1 A specifically designed structure mounted on the vehicle to guide the airflow around the vehicle, increasing the downforce acting on the vehicle and/or lowering its drag. The mounting of this structure is not regarded as an aerodynamic device, unless it is intentionally designed to be one.

T8 Aerodynamic Devices

T8.2 Restrictions for Aerodynamic Devices

T8.2.1 Height restrictions:

- All aerodynamic devices forward of a vertical plane through the rearmost portion of the front face of the driver head restraint support, excluding any padding, set to its most rearward position, must be lower than 500 mm from the ground.
- All aerodynamic devices in front of the front axle and extending further outboard than the most inboard point of the front tire/wheel must be lower than 250 mm from the ground.
- All aerodynamic devices rearward of a vertical plane through the rearmost portion of the front face of the driver head restraint support, excluding any padding, set to its most rearward position must be lower than 1.2 m from the ground.

T8.2.2 Width restrictions:

- All aerodynamic devices lower than 500 mm from the ground and further rearward than the front axle, must not be wider than a vertical plane touching the most outboard point of the front and rear wheel/tire.
- All aerodynamic devices higher than 500 mm from the ground, must not extend outboard of the most inboard point of the rear wheel/tire.

T8.2.3 Length restrictions:

- All aerodynamic devices must not extend further rearward than 250 mm from the rearmost part of the rear tires.
- All aerodynamic devices must not extend further forward than 700 mm from the fronts of the front tires.

T8.2.4 All restrictions must be fulfilled with the wheels pointing straight and with any suspension setup with or without a driver seated in the vehicle.

T8.3 Minimum Edge Radii of Aerodynamic Devices

T8.3.1 All forward facing edges of aerodynamic devices that could contact a pedestrian must have a minimum radius of 5 mm for all horizontal edges and 3 mm for vertical edges.

T8.4 Aerodynamic Devices Stability and Strength

T8.4.1 Any aerodynamic device must be able to withstand a force of 200 N distributed over a minimum surface of 225 cm² and not deflect more than 10 mm in the load carrying direction.

T8.4.2 Any aerodynamic device must be able to withstand a force of 50 N applied in any direction at any point and not deflect more than 25 mm.

T9 Compressed Gas Systems and High Pressure Hydraulics

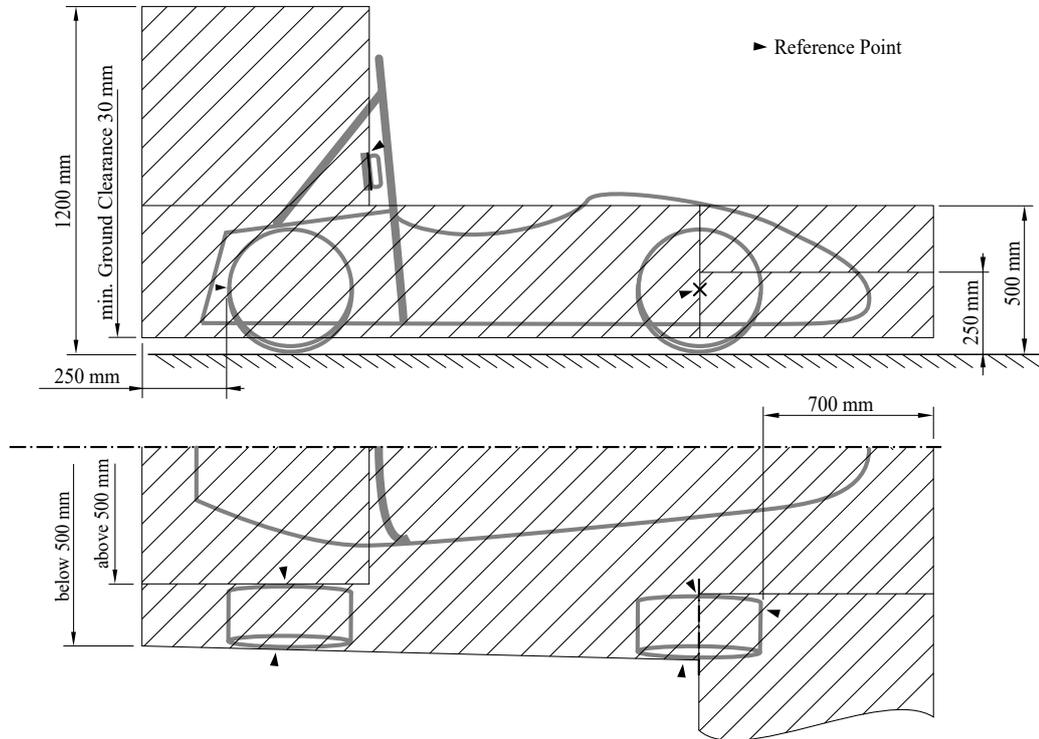


Figure 15: Maximum dimensions and positioning of aerodynamic devices. The positioning space is further restricted, see T 2.1.

T9 COMPRESSED GAS SYSTEMS AND HIGH PRESSURE HYDRAULICS

T9.1 Compressed Gas Systems

T9.1.1 Any system on the vehicle that uses a compressed gas as an actuating medium must comply with the following requirements:

- The working gas must be nonflammable.
- The pressure inside compressed gas systems must not exceed 10 bar.
- Compressed gas cylinders/tanks may exceed the 10 bar limit, if a pressure regulator, which limits the output pressure to a maximum of 10 bar, is mounted directly onto them.
- Gas cylinders/tanks must be of proprietary manufacture, designed and built for the pressure being used, certified and labeled or stamped appropriately.
- Gas cylinders/tanks and lines must be protected from rollover, collision from any direction, or damage resulting from the failure of rotating equipment.
- Gas cylinders/tanks and their pressure regulators must be located within the rollover protection envelope T 1.1.15.
- Gas cylinders/tanks and their pressure regulators, must be shielded from the driver. The shields must be steel or aluminum with a minimum thickness of 1 mm.

T 10 Fasteners

- Gas cylinders/tanks and their pressure regulators must be protected from damage by the driver or any moving parts.
- Gas cylinders/tanks must be securely mounted to the chassis, engine or transmission.
- The axis of gas cylinders/tanks must not point at the driver.
- Gas cylinders/tanks must be insulated from any heat sources.
- All used parts must be appropriate for the maximum possible operating pressure.

T 9.2 High Pressure Hydraulic Pumps and Lines

T 9.2.1 The driver and anyone standing outside the vehicle must be shielded from any hydraulic pumps and lines with line pressures of 2100 kPa or higher. The shields must be steel or aluminum with a minimum thickness of 1 mm. Brake lines are not considered as high pressure hydraulic lines.

T 10 FASTENERS

T 10.1 Critical Fasteners

T 10.1.1 Critical fasteners are defined as bolts, nuts, and other fasteners utilized in the primary structure, the steering, braking, driver's harness, suspension systems and those specifically designated as critical fasteners in the respective rule.

T 10.1.2 All threaded critical fasteners must be at least 4 mm metric grade 8.8 (OEM parts 3 mm metric grade 8.8) , equivalent or of that specified in the referencing rule, whichever is larger.

T 10.1.3 All threaded critical fasteners must be of the type hexagon bolts (ISO 4017, ISO 4014) or socket head cap screws (ISO 4762, DIN 7984, ISO 7379) including their fine-pitch thread versions. Alternative fasteners are permitted if the team can show equivalence.

T 10.1.4 Any bolted joint in the primary structure and mounting of the TSAC to the chassis using either tabs or brackets, must have an edge distance ratio "e/D" of 1.5 or greater. "D" equals the hole diameter and "e" equals the distance from the hole centerline to the nearest free edge of the tab or bracket. Any tabs attaching suspension members to the primary structure are not required to meet this rule.

T 10.2 Securing Fasteners

T 10.2.1 All critical fasteners must be secured from unintentional loosening by the use of positive locking mechanisms.

T 10.2.2 The following methods are accepted as positive locking mechanisms:

- Correctly installed safety wiring.
- Cotter pins.
- Nylon lock nuts (ISO 7040, ISO 10512, EN 1663 or equivalent) for low temperature locations (80 °C or less).

T 11 Electrical Components

- Prevailing torque lock nuts (DIN 980, ISO 7042 or equivalent, and jet nuts or K-nuts).
- Locking plates.
- Tab washers.

Any locking mechanism based on pre-tensioning or an adhesive is not considered a positive locking mechanism.

- T 10.2.3 A minimum of two full threads must project from any lock nut.
- T 10.2.4 All spherical rod ends and spherical bearings on the steering or suspension must be in double shear or captured by having a screw/bolt head or washer with an outer diameter that is larger than the spherical bearing housing inner diameter.
- T 10.2.5 Adjustable tie-rod ends must be constrained with a jam nut to prevent loosening.

T 11 ELECTRICAL COMPONENTS

T 11.1 Low Voltage System

- T 11.1.1 The Low Voltage System (LVS) is defined as
- [CV ONLY] all electrical circuits of the vehicle.
 - [EV ONLY] every electrical part that is not part of the TS, see EV 1.1.1
- T 11.1.2 The maximum permitted voltage that may occur between any two electrical connections in the LVS is 60 VDC or 25 VACRMS.
- T 11.1.3 [CV ONLY] The following systems are excluded from the LVS voltage limit, see T 11.1.2:
- High voltage systems for ignition
 - High voltage systems for injectors
 - Voltages internal to OEM charging systems designed for <60 VDC output.
- T 11.1.4 [EV ONLY] The LVS must not use orange wiring or conduit.
- T 11.1.5 [EV ONLY] The LVS must be grounded to the chassis.

T 11.2 Master Switches

- T 11.2.1 Master switches, see T 11.3, EV 6.2 and T 14.7, must be a mechanical switch of the rotary type, with a red, removable handle. The handle must have a width of at least 50 mm and must only be removable in electrically open position. They must be direct acting, i.e. they must not act through a relay or logic.
- T 11.2.2 Master switches must be located on the right side of the vehicle, in proximity to the main hoop, at the 95th percentile male driver's shoulder height, as defined in T 4.3, and be easily actuated from outside the vehicle.

The center of any master switch must not be mounted lower than the vertical distance of the template's, see T 4.3, middle circle center to the ground surface multiplied by 0.8.

T 11 Electrical Components

- T 11.2.3 The “ON” position of the switch must be in the horizontal position and must be marked accordingly. The “OFF” position of the master switch must also be clearly marked.
- T 11.2.4 Master switches must be rigidly mounted to the vehicle and must not be removed during maintenance.
- T 11.2.5 Master switches must be mounted next to each other.

T 11.3 Low Voltage Master Switch

- T 11.3.1 An LVMS according to T 11.2 must completely disable
- [EV ONLY] power to the LVS
 - [CV ONLY] power from the Low Voltage (LV) battery and the alternator to the LVS
- T 11.3.2 The LVMS must be mounted in the middle of a completely red circular area of ≥ 50 mm diameter placed on a high contrast background.
- T 11.3.3 The LVMS must be marked with “LV” and a symbol showing a red spark in a white edged blue triangle.

T 11.4 Shutdown Buttons

- T 11.4.1 A system of three shutdown buttons must be installed on the vehicle.
- T 11.4.2 Each shutdown button must be a push-pull or push-rotate mechanical emergency switch where pushing the button opens the shutdown circuit, see EV 6.1 and CV 4.1.
- T 11.4.3 One button must be located on each side of the vehicle behind the driver’s compartment at approximately the level of the driver’s head. The minimum allowed diameter of the shutdown buttons on both sides of the vehicle is 40 mm. The buttons must be easy reachable from outside the vehicle.
- T 11.4.4 One shutdown button serves as a cockpit-mounted shutdown button and must
- have a minimum diameter of 24 mm
 - be located in easy reach of a belted-in driver
 - be alongside of the steering wheel and unobstructed by the steering wheel or any other part of the vehicle
- T 11.4.5 The international electrical symbol consisting of a red spark on a white-edged blue triangle must be affixed in close proximity to each shutdown button.
- T 11.4.6 Shutdown buttons must be rigidly mounted to the vehicle and must not be removed during maintenance.

T 11.5 Inertia Switch

- T 11.5.1 An inertia switch must be part of the shutdown circuit, see CV 4.1 and EV 6.1, such that an impact will result in the shutdown circuit being opened. The inertia switch must latch until manually reset.

T 11 Electrical Components

- T 11.5.2 The device must trigger due to an omnidirectional peak acceleration of ≤ 8 g for a half sine test pulse of ≥ 50 ms length and ≤ 13 g for a half sine test pulse of ≥ 20 ms length. The “Sensata Resettable Crash Sensor” should meet those requirements.
- T 11.5.3 The device must not include any semiconductor components.
- T 11.5.4 The device must be rigidly attached to the vehicle. It must be possible to demount the device so that its functionality may be tested by shaking it.

T 11.6 Brake System Plausibility Device

- T 11.6.1 A standalone non-programmable circuit, the BSPD, must open the shutdown circuit, see EV 6.1 and CV 4.1, when hard braking occurs, whilst
- [EV ONLY] ≥ 5 kW power is delivered to the motors.
 - [CV ONLY] the throttle position is more than 25 % over idle position.
- The shutdown circuit must remain open until power cycling the LVMS or the BSPD may reset itself if the opening condition is no longer present for more than 10 s.
- T 11.6.2 The action of opening the shutdown circuit must occur if the implausibility is persistent for more than 500 ms.
- T 11.6.3 The BSPD must be directly supplied, see T 1.3.1, from the LVMS, see T 11.3.
- T 11.6.4 Standalone is defined as there is no additional functionality implemented on all required Printed Circuit Boards (PCBs). The interfaces must be reduced to the minimum necessary signals, i.e. power supply, required sensors and the shutdown circuit. Supply and sensor signals must not be routed through any other devices before entering the BSPD.
- T 11.6.5 To detect hard braking, a brake system pressure sensor must be used. The threshold must be chosen such that there are no locked wheels and the brake pressure is ≤ 30 bar.
- T 11.6.6 [EV ONLY] To measure power delivery, a DC circuit current sensor only must be used. The threshold must be chosen to an equivalent of ≤ 5 kW for maximum TS voltage.
- T 11.6.7 It must be possible to separately disconnect each sensor signal wire for technical inspection.
- T 11.6.8 All necessary signals are System Critical Signal (SCS), see T 11.9.
- T 11.6.9 [EV ONLY] The team must prove the function of the BSPD during technical inspection by sending an appropriate signal that represents the current, in order to achieve ≤ 5 kW whilst pressing the brake pedal. This test must prove the functionality of the complete BSPD except for any commercially available current sensors.
- T 11.6.10 [EV ONLY] The BSPD including all required sensors must not be installed inside the TSAC.

T 11.7 Low Voltage Batteries

- T 11.7.1 LV batteries are all batteries connected to the LVS.
- T 11.7.2 LV batteries must be securely attached to the chassis and located within the rollover protection envelope, see T 1.1.15.

T11 Electrical Components

- T 11.7.3 Any wet-cell battery located in the cockpit must be enclosed in a non-conductive, water proof (according to IPX7 or higher, IEC 60529) and acid resistant container.
- T 11.7.4 LV batteries must have a rigid and sturdy casing.
- T 11.7.5 Completely closed LV battery cases must have an overpressure relief. Venting gases must be separated from the driver by a firewall.
- T 11.7.6 Ungrounded terminals must be insulated.
- T 11.7.7 LV batteries must be protected from short circuits, not more than 100 mm from ungrounded terminals.
- T 11.7.8 Battery packs based on lithium chemistry other than lithium iron phosphate (LiFePO₄):
- Must have a fire retardant casing, see T 1.2.1.
 - Must include overcurrent protection that trips at or below the maximum specified discharge current of the cells.
 - Must include overtemperature protection of at least 30 % of the cells, meeting EV 5.8.3, that trips when any cell leaves the allowed temperature range according to the manufacturer's datasheet, but not more than 60 °C, for more than 1 s and disconnects the battery.
 - Must include voltage protection of all cells that trips when any cell leaves the allowed voltage range according to the manufacturer's datasheet for more than 500 ms and disconnects the battery.
 - It must be possible to display all cell voltages and measured temperatures, e.g. by connecting a laptop.
 - Must meet EV 5.8.10
 - Signals needed to fulfill these requirements are SCS, see T 11.9.

T 11.8 Accelerator Pedal Position Sensor

- T 11.8.1 T 11.8 only apply for electric vehicles, see chapter EV, or internal combustion vehicles using Electronic Throttle Control (ETC), see CV 1.6.
- T 11.8.2 The APPS must be actuated by a foot pedal.
- T 11.8.3 Pedal travel is defined as percentage of travel from fully released position to a fully applied position where 0 % is fully released and 100 % is fully applied.
- T 11.8.4 The foot pedal must return to the 0 % position when not actuated. The foot pedal must have a positive stop preventing the mounted sensors from being damaged or overstressed. Two springs must be used to return the foot pedal to the 0 % position and each spring must work when the other is disconnected. Springs in the APPS are not accepted as return springs.
- T 11.8.5 At least two separate sensors must be used as APPSs. Separate is defined as not sharing supply or signal lines.
- T 11.8.6 If analog sensors are used, they must have different, non-intersecting transfer functions, . A short circuit between the signal lines must always result in an implausibility according to T 11.8.9.

T11 Electrical Components

- T11.8.7 The APPS signals are SCSs, see T11.9.
- T11.8.8 If an implausibility occurs between the values of the APPSs and persists for more than 100 ms
- [EV ONLY] The power to the motor(s) must be immediately shut down completely. It is not necessary to completely deactivate the tractive system, the motor controller(s) shutting down the power to the motor(s) is sufficient.
 - [CV ONLY] The power to the electronic throttle must be immediately shut down.
- T11.8.9 Implausibility is defined as a deviation of more than ten percentage points pedal travel between any of the used APPSs or any failure according to T11.9.
- T11.8.10 If three sensors are used, then in the case of an APPS implausibility, any two sensors that are plausible may be used to define the torque target and the 3rd APPS may be ignored.
- T11.8.11 It must be possible to separately disconnect each APPS signal wire to check all functionalities.
- T11.8.12 A fully released accelerator pedal in manual mode must result in:
- [EV ONLY] A wheel torque of ≤ 0 Nm
 - [CV ONLY] An idle position or lower throttle set-point. This may only be exceeded during a gearshift for a maximum of 500 ms.

T11.9 System Critical Signal

- T11.9.1 SCS are defined as all electrical signals which
- Influence actions on the shutdown circuit, see CV4.1 and EV6.1.
 - Influence the wheel torque.
 - [EV ONLY] Influence indicators according to EV5.8.8, EV4.10 or EV6.3.7.
 - Influence indicators according to T15.3.3.
- T11.9.2 Any of the following SCS single failures must result in a safe state of all connected systems:
- (a) Failures of signals transmitted by cable:
 - Open circuit
 - Short circuit to ground
 - (b) Failures of analog sensor signals transmitted by cable:
 - Short circuit to supply voltage
 - (c) Failures of sensor signals used in programmable devices:
 - Implausibility due to out of range signals, e.g. mechanically impossible angle of an angle sensor.
 - (d) Failures of digitally transmitted signals by cable or wireless:
 - Data corruption (e.g. checked by a checksum)
 - Loss and delay of messages (e.g. checked by transmission time outs)

T 12 Vehicle Identification

Signals might be a member of multiple signal classes, e.g. analog signals transmitted by cable might be a member of T 11.9.2.a, T 11.9.2.b and T 11.9.2.c.

If a signal failure is correctable, e.g. due to redundancy or worst case values, the safe state must be entered as soon as an additional non correctable failure occurs.

- T 11.9.3 The maximum allowed delay of messages according to T 11.9.2.d must be chosen depending on the impact of delayed messages to the connected system, but must not exceed 500 ms.
- T 11.9.4 Safe state is defined depending on the signals as follows:
- signals only influencing indicators – Indicating a failure of its own function or of the connected system
 - low voltage battery signals – At least one pole is electrically disconnected from the rest of the vehicle
 - [EV ONLY] For all others signals – opened shutdown circuit and opened AIRs
 - [CV ONLY] For all others signals – opened shutdown circuit and stopped engine
- T 11.9.5 Indicators according to T 11.9.1 with safe state “illuminated” (e.g. absence of failures is not actively indicated) must be illuminated for 1 s to 3 s for visible check after power cycling the LVMS.

T 11.10 Sensors & Electrical Components Mounting

- T 11.10.1 All sensors and components must be securely mounted. For all mounts, T 2.3.3 applies.
- T 11.10.2 Sensors and components may not come into contact with the driver’s helmet under any circumstances.
- T 11.10.3 All sensors and components must be positioned within the surface envelope, see T 1.1.17, or within the box defined in T 8.2.
- T 11.10.4 Passive antennas that are exclusively acting as such with the longest side <100 mm may additionally to T 11.10.3 protrude from the surface envelope, see T 1.1.17.
- T 11.10.5 The body of any video/photographic camera which is not exclusively used as sensor for the AS unit must be secured at a minimum of two points on different sides of the camera body. If a tether is used to restrain the camera, the tether length must be limited so that the camera cannot contact the driver.

T 11.11 Legal & Work Safety

- T 11.11.1 All sensors must fulfill the local legislative specifications (i.e. eye-protection classification for laser sensors, power limitation for radar sensors, etc.) in the country of competition.

T 12 VEHICLE IDENTIFICATION

T 12.1 Vehicle Number

- T 12.1.1 Each vehicle will be assigned a number at the time of its entry into a competition.

T13 Vehicle and Driver Equipment

T 12.1.2 Vehicle numbers must appear on the vehicle at the front and both sides as follows:

- Height: At least 150 mm high;
- Font: Roman Sans-Serif characters. Italic, outline, serif, or shadow numbers are prohibited.
- Stroke width and spacing between numbers: At least 20 mm.
- Color: Either white numbers on a black background or black numbers on a white background.
- Background shape: The number background must be one of the following: round, oval, square or rectangular. There must be at least 25 mm between the edge of the numbers and the edge of the background.
- Clear: The numbers must not be obscured by parts of the vehicle.

T 12.2 University Name

T 12.2.1 The university name must be written fully. Only the following abbreviations in the university name are accepted, if the city name is written fully:

- University → Uni
- Technical University → TU
- University of Applied Sciences → UAS
- Berufsakademie → BA
- If the university officially uses an abbreviation in their proper name, this abbreviation is accepted.

T 12.2.2 The university name must be displayed and written in Roman Sans-Serif characters of at least 50 mm high on both sides of the vehicle.

T 12.2.3 The characters must be clearly visible at a distance and placed on a high contrast background.

T 12.3 Timing Equipment

T 12.3.1 All vehicles will get timing equipment provided by the competition organizers.

T 13 VEHICLE AND DRIVER EQUIPMENT

T 13.1 Push Bar

T 13.1.1 Each team must have a removable device (called the push bar) that attaches to the rear of the vehicle and allows two people to push and pull the vehicle while standing erect behind the vehicle.

T 13.1.2 The push bar must have a red color.

T 13.1.3 The university name must be written on the push bar. The characters must be clearly visible and placed on a high contrast background.

T 13 Vehicle and Driver Equipment

- T 13.1.4 The push bar must be capable of slowing and stopping the forward motion of the vehicle and pulling it rearwards.
- T 13.1.5 An approved fire extinguisher, see T 13.4.1, must be mounted to the push bar such that it is quickly accessible.
- T 13.1.6 [EV ONLY] Two pairs of high-voltage insulating gloves and a multimeter with two 4 mm banana plug test leads rated for 1000 V CAT III or better must be attached to the push bar. The HV gloves must be protected by a case or similar means from mechanical damage, humidity and sunlight. It must be possible to open the case without using tools.

T 13.2 Quick Jack

- T 13.2.1 Each team must have a removable device (called the quick jack) that lifts up the vehicle, so that all driven wheels are at least 100 mm off the ground and the vehicle is adequately supported. All non driven wheels must not touch anything else than the ground.
- T 13.2.2 The lifting of the vehicle with the quick jack must be possible by one person and not require actions other than positioning and operating the quick jack itself.
- T 13.2.3 In the lifted position the vehicle must stand securely and stable and the quick jack must be locked and secured. This must function without the support of a person or additional weights.
- T 13.2.4 The quick jack must have a red color.
- T 13.2.5 The university name must be written on the quick jack. The characters must be clearly visible and placed on a high contrast background.

T 13.3 Driver Equipment

- T 13.3.1 The equipment specified below must be worn by the driver anytime while in the cockpit with the engine running or with the tractive system active for electric vehicles and anytime between starting a dynamic event and either finishing or abandoning a dynamic event. Removal of any driver equipment during the event will result in disqualification.
- T 13.3.2 A well-fitting, closed face helmet that meets one of the following certifications and is labeled as such:
- Snell K2010, K2015, K2020, M2010, M2015, M2020, SA2010, SAH2010, SA2015, SA2020, EA2016 or newer
 - SFI 31.1/2010, 31.1/2015, 31.1/2020, 41.1/2010, 41.1/2015, 41.1/2020 or newer FIA 8860-2010, FIA 8860-2018, FIA 8859-2015 (with SA 2015), FIA 8858-2010 (with SA(H) 2010) or newer
- Open faced helmets and off-road helmets (helmets without integrated eye shields) are not approved. All helmets to be used in the competition must be presented during technical inspection where approved helmets will be stickered.
- T 13.3.3 A balaclava which covers the driver's head, hair and neck, made from acceptable fire resistant material as defined in T 13.3.11, or a full helmet skirt of acceptable fire resistant material.

T 13 Vehicle and Driver Equipment

- T 13.3.4 A fire resistant one piece suit, made from a minimum of two layers that covers the body from the neck down to the ankles and the wrists. The suit must be certified to one of the following standards and be labeled as such:
- SFI 3.2A/5 (or higher)
 - SFI 3.4/5 (or higher)
 - FIA Standard 8856-2000
 - FIA Standard 8856-2018
- T 13.3.5 Fire resistant underwear (long pants and long sleeve t-shirt). This fire resistant underwear must be made from acceptable fire resistant material as listed in T 13.3.11 and must cover the driver's body completely from neck down to ankles and wrists.
- T 13.3.6 Fire resistant socks made from acceptable fire resistant material as defined in T 13.3.11, that cover the bare skin between the driver's suit and the boots or shoes.
- T 13.3.7 Fire resistant shoes made from acceptable fire resistant material as defined in T 13.3.11. The shoes must be certified to the standard and labeled as such:
- SFI Spec 3.3
 - FIA Standard 8856-2000
 - FIA Standard 8856-2018
- T 13.3.8 Fire resistant gloves made from acceptable fire resistant material as defined in T 13.3.11. Gloves of all leather construction or fire resistant gloves constructed using leather palms with no insulating fire resisting material underneath are not acceptable.
- T 13.3.9 Arm restraints are required and must be worn such that the driver can release them and exit the vehicle unassisted regardless of the vehicle's position. Arm restraints must be commercially manufactured according to SFI Standard 3.3 or equivalent.
- T 13.3.10 All driver equipment covered in T 13.3: must be in good condition. Specifically, it must not have any tears, rips, open seams, areas of significant wear or abrasion or stains which might compromise fire resistant performance. The officials reserve the right to impound all non-approved driver equipment until the end of the competition.
- T 13.3.11 For the purpose of this section some, but not all, of the approved fire resistant materials are: Carbon X, Indura, Nomex, Polybenzimidazole (commonly known as PBI) and Proban.
- T 13.3.12 T-shirts, socks or other undergarments made from nylon or any other synthetic material which will melt when exposed to high heat are prohibited.

T 13.4 Fire Extinguishers

- T 13.4.1 Each team must have at least two dry chemical/dry powder fire extinguishers with a minimum firefighting agent capacity of 0.9 kg.
- T 13.4.2 The following are the minimum accepted ratings:
- USA, Canada and Brazil: 10BC or 1A 10BC
 - Europe: 34B or 5A 34B

T 14 Autonomous System

- Australia: 20BE or 1A 10BE

Extinguishers of larger capacity (higher numerical ratings) are acceptable.

- T 13.4.3 Aqueous Film Forming Foam (AFFF) fire extinguishers are prohibited. Halon extinguishers and systems are prohibited.
- T 13.4.4 All extinguishers must be equipped with a manufacturer installed pressure/charge gauge.
- T 13.4.5 Except for the initial inspection, one extinguisher must readily be available in the team's paddock area, and the second must accompany the vehicle wherever the vehicle is moved. Both extinguishers must be presented with the vehicle at technical inspection.
- T 13.4.6 Hand held fire extinguishers are not permitted to be mounted on or in the vehicle.

T 14 AUTONOMOUS SYSTEM

T 14.1 Definitions

- T 14.1.1 Each vehicle must implement a full AS according to T 14, to run in autonomous mode.
- T 14.1.2 [CV ONLY] The following definitions apply to maintain the same wording as for Electric Vehicles:
- Ready-to-drive (R2D) – Engine is running and a gear is engaged.
 - TS active – Engine is running but gearbox is in neutral (also assumed for TS not active).
 - TS activation button – The engine start button is the equivalent.
 - Accumulator Isolation Relay (AIR) - The fuel pump relay (see Figure 20) is the equivalent.

T 14.2 Teleoperated driving

- T 14.2.1 Teleoperated driving is not allowed.

T 14.3 Data logger

- T 14.3.1 The officials will provide a standardized data logger that must be installed during the competition. Further specifications for the data logger and required hardware and software interfaces can be found in the competition handbook.
- T 14.3.2 The intent of the data logger is to understand and reproduce the system state in case of failure. This includes a basic set of signals defined in the competition handbook and the set of vehicle-individual signals that have to be monitored by the Autonomous System Brake (ASB) to ensure redundancy and fault detection.

T 14 Autonomous System

T 14.4 Remote Emergency System

- T 14.4.1 Every vehicle must be equipped with a standard RES specified in the competition handbook. The system consists of two parts, the remote control and the vehicle module.
- T 14.4.2 The RES must be purchased by the team.
- T 14.4.3 The RES has two functions:
- When the remote emergency stop button is pressed, it must open the DV Shutdown Circuit (SDC) defined in T 14.5.
 - When the “Go” button is pressed, the preselected autonomous mission is started.
- T 14.4.4 The RES vehicle module must be directly integrated in the vehicle’s SDC with one of its relays hard-wired in series to the shutdown buttons.
- T 14.4.5 The RES relay, which is integrated into the SDC, may be bypassed by a normally closed relays, when driving manually. The relay must be directly supplied by the ASMS, see T 14.7, and must have either a forcibly guided or a mirrored normally open contact which is directly connected in series to the ASMS.
- T 14.4.6 The antenna of the RES must be mounted unobstructed and without interfering parts in proximity (other antennas, etc.).

T 14.5 Shutdown Circuit

- T 14.5.1 If the SDC is opened by the AS or the RES, it has to be latched open by a non-programmable logic that can only be reset manually (either via a button outside of the vehicle, in proximity to the ASMS, or via LVMS power cycle).
- T 14.5.2 The SDC may only be closed by the AS, if the following conditions are fulfilled:
- Manual Driving: Manual Mission is selected, the AS has checked that ASB is deactivated (No autonomous brake actuation possible).
 - Autonomous Driving: Autonomous Mission is selected, ASMS is switched on and sufficient brake pressure is build up (brakes are closed).

T 14.6 Signals

- T 14.6.1 Any signal of the AS is a SCS. If failures lead to loss of environment perception and/or localization, the system must react accordingly.

T 14.7 Autonomous System Master Switch

- T 14.7.1 Each vehicle must be equipped with an ASMS, according to T 11.2.
- T 14.7.2 The ASMS must be mounted in the middle of a completely blue circular area of ≥ 50 mm diameter placed on a high contrast background.
- T 14.7.3 The ASMS must be marked with “AS”.
- T 14.7.4 The power supply of the steering and braking actuators must be switched by

T 14 Autonomous System

- LVMS
- ASMS

Other than stated in T 11.2.1, non-programmable logic may be used as part of the ASMS.

- T 14.7.5 When the ASMS is in “Off” position, the following must be fulfilled:
- No steering, braking and propulsion actuation can be performed by request of the autonomous system.
 - The sensors and the processing units can stay operational.
 - The vehicle must be able to be pushed as specified in A 6.7.
 - It must be possible to operate the vehicle manually as a normal CV or EV.
- T 14.7.6 It is strictly forbidden to switch the ASMS to the “On” position if a person is inside the vehicle.
- T 14.7.7 After switching the ASMS to the “On” position, the vehicle may not start moving, until R2D is entered (Figure 16).
- T 14.7.8 The ASMS must be fitted with a “lockout/tagout” capability to prevent accidental activation of the AS. The ASR must ensure that the ASMS is locked in the off position whenever the vehicle is outside the dynamic area or driven in manual mode.

T 14.8 Steering Actuation

- T 14.8.1 Steering system actuation (movement) must only happen if the vehicle is R2D.
- T 14.8.2 The steering system may remain active during an emergency brake maneuver while the vehicle is in movement.
- T 14.8.3 Manual steering must be possible without manual release steps (e.g. operating manual valves / (dis-) connecting mechanical elements) while the ASMS is switched “Off”.

T 14.9 Actuator Decoupling

- T 14.9.1 It is not allowed to remove any parts of the autonomous system for dynamic events.
- T 14.9.2 The actuators may be disconnected for manual driving if:
- no parts including bolts, clips, etc. are removed for disconnection i.e. they must never lose the physical contact to the disconnection mechanism.
 - the disconnection mechanism cannot block manual operation in any position.
 - the disconnection mechanism is securely locked in both positions.

T 14.10 Autonomous System Status Definitions

- T 14.10.1 The Emergency Brake System (EBS) is considered to be “activated”, if the power supply path defined in T 15.2.2 is cut after passing the initial checkup sequence (T 15.3.1). Brakes may only be released after performing manual steps.

T 14 Autonomous System

T 14.10.2 The status of the AS must be determined according to the flowchart in Figure 16.

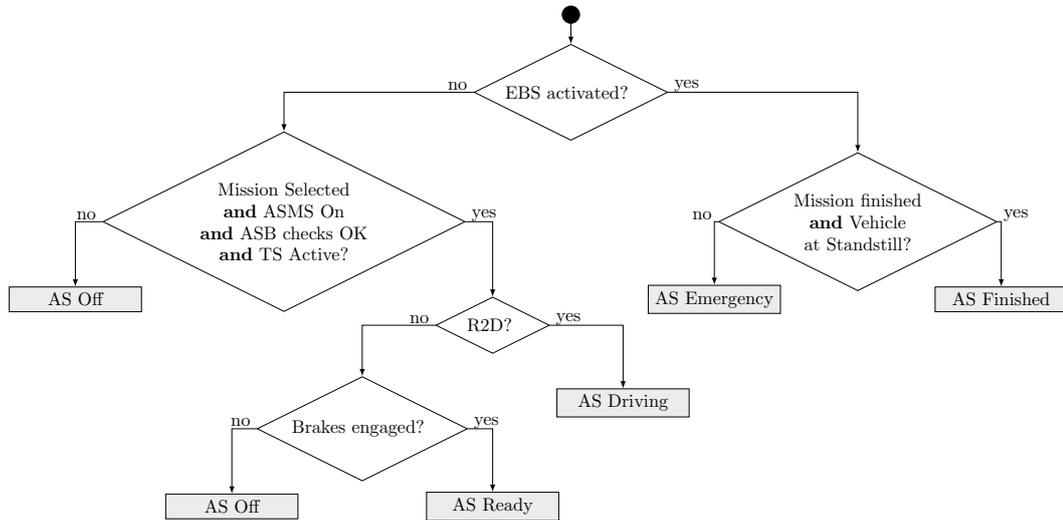


Figure 16: AS Status Flowchart

T 14.10.3 R2D may only be activated by the “Go” signal from the RES, after the system has remained in “AS Ready” for at least 5 s.

T 14.10.4 Performing manual steps, other than activating the TS, at the vehicle while the ASMS is switched “On” is prohibited.

T 14.11 Autonomous System Status Indicators

T 14.11.1 The vehicle must include three ASSIs that must indicate the status of the AS (as defined in T 14.10) correlating to illumination as shown:

AS Off	AS Ready	AS Driving	AS Emergency	AS Finished
off	yellow continuous	yellow flashing	blue flashing	blue continuous

The ASSIs may not perform any other functions.

T 14.11.2 One ASSI must be located on each side of the vehicle behind the driver’s compartment, in a region 160 mm below the top of the main hoop and 600 mm above the ground. The third ASSI must be located at the rear of the vehicle, on the vehicle centerline, 160 mm below the top of the main hoop and more than 100 mm above the brake light.

T 14.11.3 Each ASSI must have a dark background and a rectangular, triangular or near round shape with a minimum illuminated surface of 15 cm². The ASSIs must be clearly visible in very bright sunlight. When LED lights are used without a diffuser, they may not be more than 20 mm apart. If a single line of LEDs is used, the minimum length is 150 mm. At least one ASSI must be visible from any angle of the vehicle.

T 14.11.4 The status “AS Emergency” has to be indicated by an intermittent sound with the following parameters:

- on-/off-frequency: 1 Hz to 5 Hz

T 15 Autonomous System Brake

- duty cycle 50 %
- sound level between 80 dBA and 90 dBA, fast weighting in a radius of 2 m around the vehicle.
- duration between 8 s and 10 s after entering “AS Emergency”

T 14.12 Autonomous Missions

T 14.12.1 The AS must at least implement the following missions:

- Acceleration
- Skidpad
- [DC ONLY] Autocross
- [DC ONLY] Trackdrive
- EBS test
- Inspection
- Manual driving

T 14.12.2 The inspection mission will be used during technical inspection while the vehicle is jacked up and all wheels are removed.

T 14.12.3 The inspection mission is defined by slowly spinning the drivetrain and actuating the steering system with a sine wave. After 25 s to 30 s the mission is finished and the transition to “AS Finish” must be initialized.

T 14.12.4 The selected mission must be indicated by the Autonomous Mission Indicator (AMI).

T 14.12.5 The AMI must be easy readable and can either be part of the dashboard or located next to the ASMS. If an e-ink display is used, it must be visible that the shown mission is up-to-date. AMI is considered SCS!

T 14.13 Autonomous System Form

T 14.13.1 Prior to the competition, all teams must submit a clearly structured documentation of their entire AS (including ASB) called ASF.

T 15 AUTONOMOUS SYSTEM BRAKE

T 15.1 Technical Requirements

T 15.1.1 To run in autonomous mode, the vehicle must be equipped with an ASB that features an EBS as part of it (see T 15.2).

T 15.1.2 All specifications of the brake system from T 6 remain valid.

T 15.1.3 The tractive system is not considered to be a brake system.

PART III



DATASHEETS



Technical plans are crucial in the conception of any engineering system, but moreover, in the production of a highly complex project involving several members and external parties. Conception is done around the idea that every other already developed part is correct. With the exact measures of the technical plans of the elements surrounding the new to-be-developed components, these are conceived. It is therefore of great importance to consciously do them and to have them verified by the technical directors, who have a broader vision of the project.

On top of that, these, as well as .DXF documents, are the only information our production partners have to develop the elements. The CATIA model, the simulations and the time spent is worth nothing if the measures in those technical plans are not coherent.

Hereby, there are presented the 30 technical plans that were developed by this project during the academic year. These technical plans correspond to:

- 25 FR-Frame & Body
- 3 MS-Miscellaneous, Finish and Assembly
- 2 EL-Electrical

Technical plans



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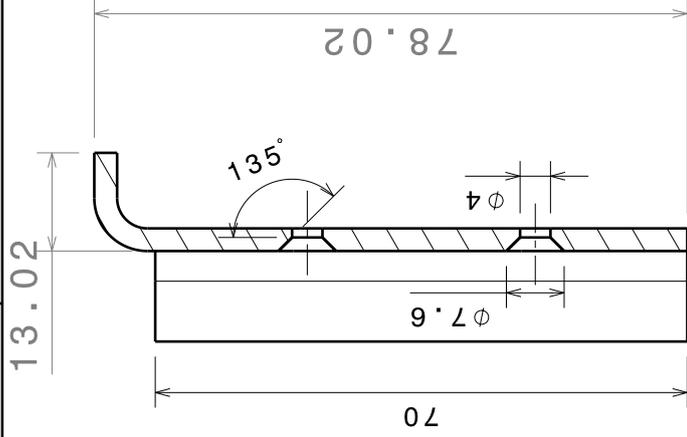
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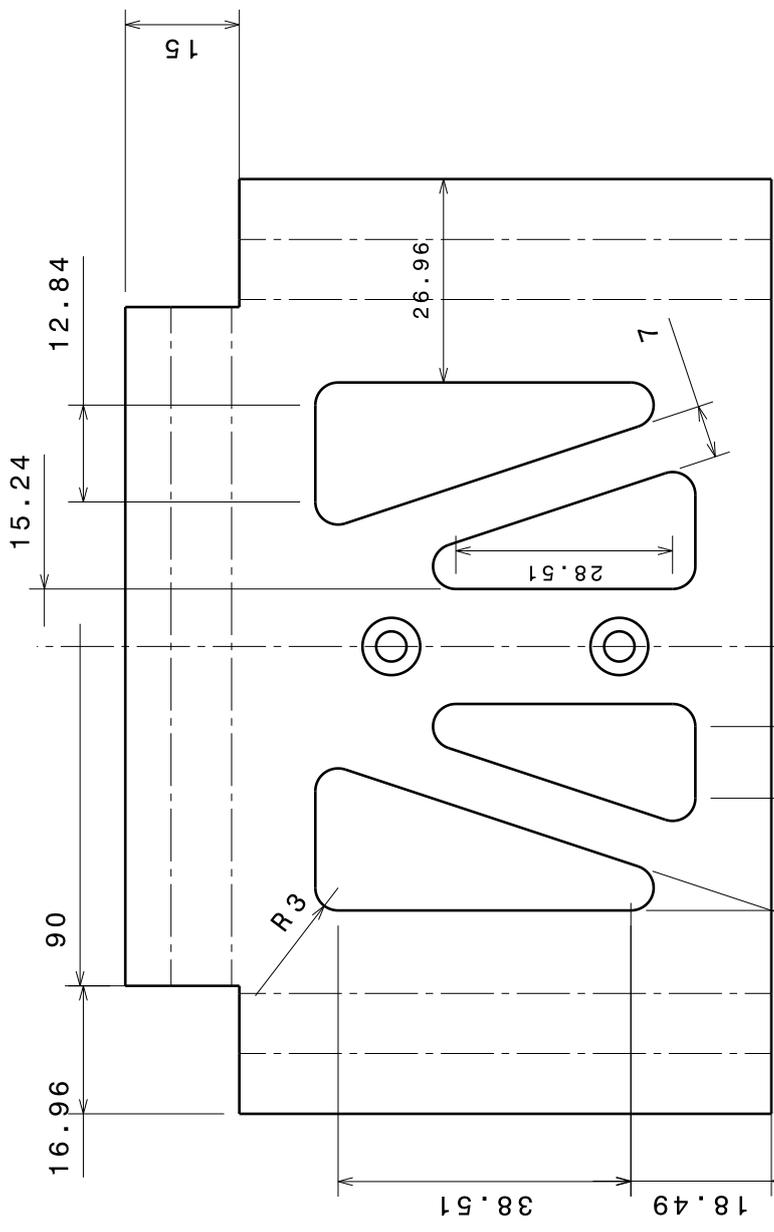
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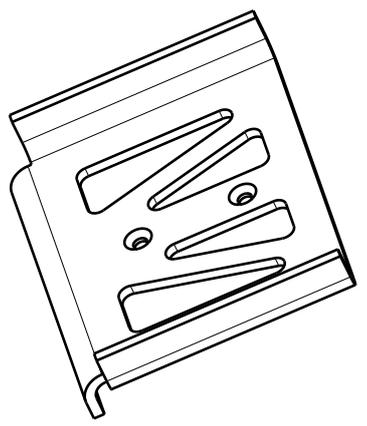
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Section view A-A
Scale: 1:1



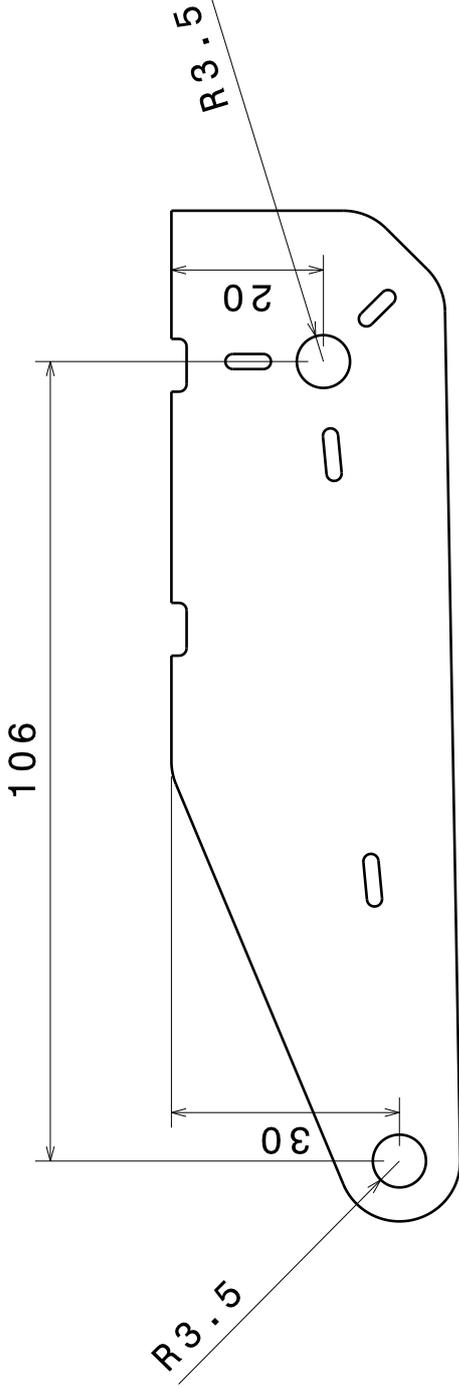
Unfolded view
Scale: 1:1



Isometric view
Scale: 1:2

Ecurie Piston Sport Auto			
Désignation		Footrest	
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Echelle 1:1		Numéro du plan FR_03002	
Feuille 1/1			
Taille	Dessiné par	Date	Plan vérifié par
A4	Pablo Lamadrid	05/10/2021	Guillaume Brault
Coordonnées		PabloLamadrid00@gmail.com	
		+34 618695587	

Tôle épaisseur: 3mm



Vue de face
Echelle : 1:1

Tolérances générales : ISO 2768 -mK

Taille A4		Ecurie Piston Sport Auto	
Dessiné par Pablo Lamadrid	Date 12/10/2021	Désignation Plaque Pédale Frein 1	
Coordonnées Tel : +34 618695587 pablo.lamadrid00@gmail.com		Quantité 2	Matériau Acier S355
Plan vérifié par Guillaume Brault		Echelle 1:1	Version 1.0
		N° du plan FR_04001_1	Feuille 1/1

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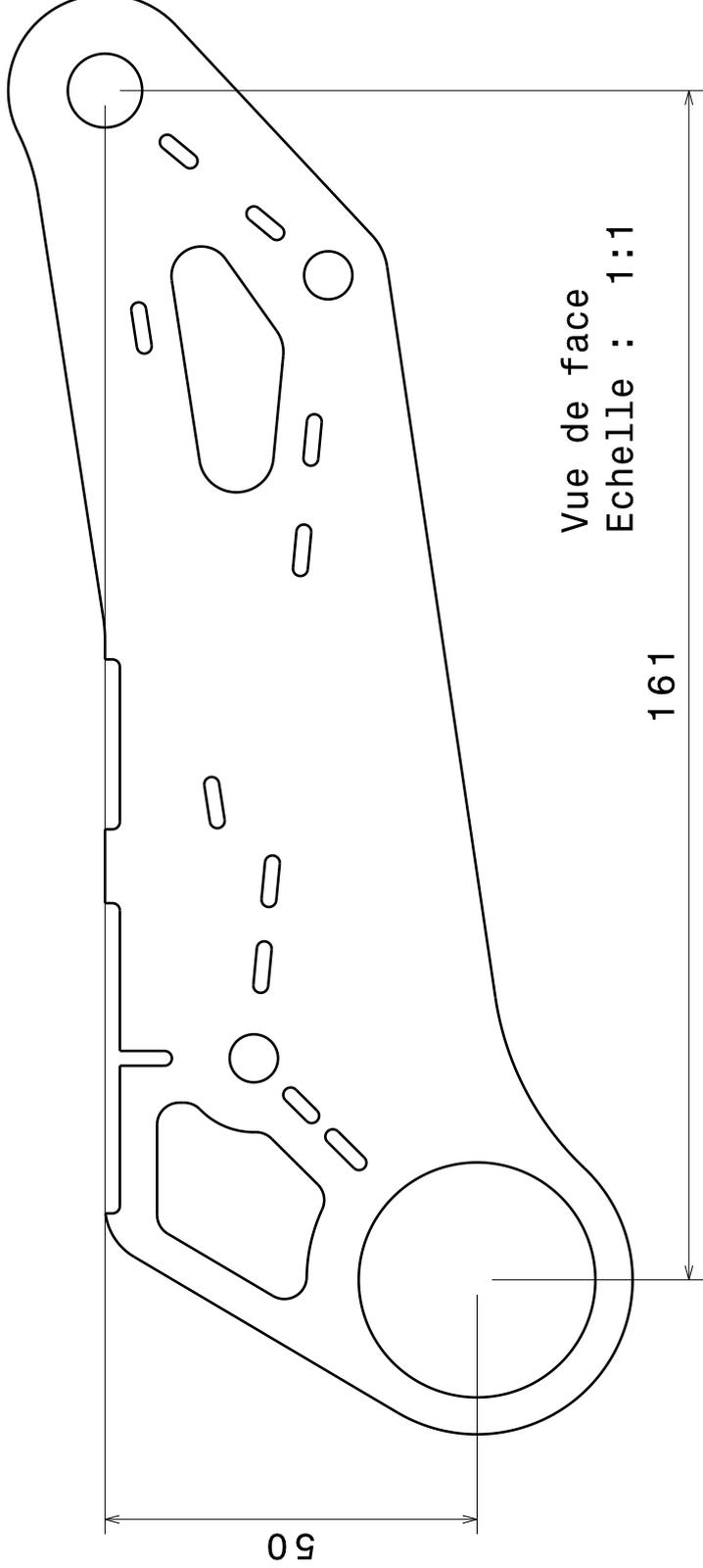
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A B C D

Tôle épaisseur: 3 mm



Vue de face
Echelle : 1:1

161

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Tolérances générales : ISO 2768-mK

Taille A4		Ecurie Piston Sport Auto	
Dessiné par Pablo Lamadrid	Date 12/10/2021	Désignation Plaque Pédale Frein 2	
Coordonnées Tel : +34 618695587 pablo.lamadrid00@gmail.com		Quantité 2	Version 1.0
Plan vérifié par Guillaume Brault		Matériau Acier S355	Echelle 1:1
		N° du plan FR_04001_2	Feuille 1/1

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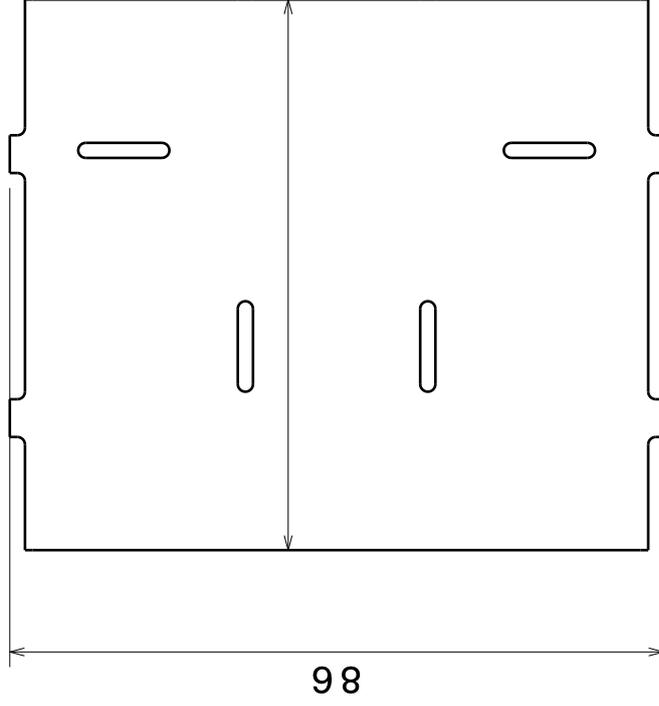
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Tôle épaisseur: 3 mm

Vue de face
Echelle : 1:1

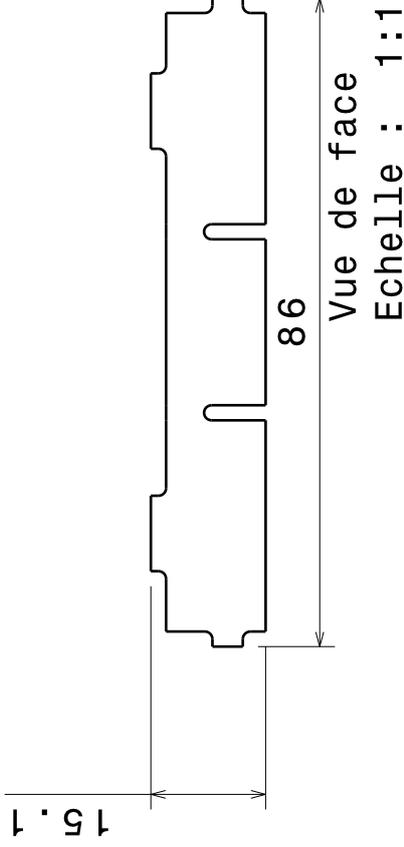
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Dessiné par Pablo Lamadrid	Date 12/10/2021	Désignation Plaque Frein 3	
Coordonnées Tel : +34 618695587 pablo.lamadrid00@gmail.com	Quantité 1	Matériau Acier S355	Version 1
Plan vérifié par Guillaume Brault	Echelle 1:1	N° du plan FR_04001_3	Feuille 1/1

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Tôle épaisseur: 3 mm



Tolérances générales : ISO 2768 -mK

Taille A4	
Dessiné par Pablo Lamadrid	Date 12/10/2021
Coordonnées Tel : +34 618695587 pablo.lamadrid00@gmail.com	
Plan vérifié par Guillaume Brault	

Ecurie Piston Sport Auto

Désignation

Plaque Pédale Frein 5

Quantité

1

Matériau

Version

Echelle 1:1

N° du plan

Feuille 1/1

FR_04001_5

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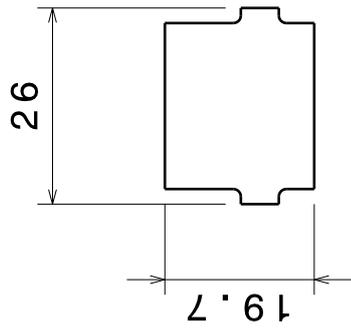
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Tôle épaisseur: 3 mm



Vue de face
Echelle : 1:1

Tolérances générales : ISO 2768 -mK

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Dessiné par Pablo Lamadrid		Désignation Plaque Pédale Frein 6		
Date 12/10/2021	Quantité 1	Coordonnées Tel : +34 618695587 pablo.lamadrid00@gmail.com	Matériau Acier S355	Version 1.0
Plan vérifié par Guillaume Brault		Echelle 1:1	N° du plan FR_04001_6	Feuille 1/1

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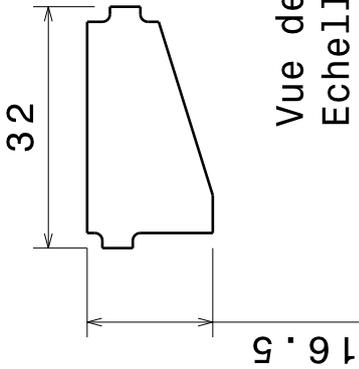
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Tôle épaisseur: 3 mm



Vue de face
Echelle : 1:1

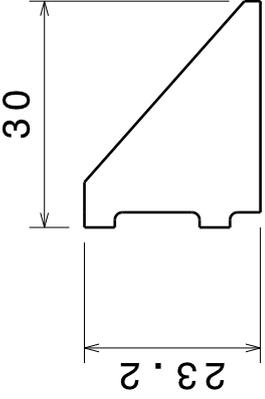
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Taille A4		Ecurie Piston Sport Auto	
Dessiné par Pablo Lamadrid	Date 12/10/2021	Désignation Plaque Pédale Frein 7	
Coordonnées Tel : +34 618695587 pablo.lamadrid00@gmail.com	Quantité 2	Matériau Acier S355	Version 1.0
Plan vérifié par Guillaume Brault	Echelle 1:1	N° du plan FR_04001_7	Feuille 1/1

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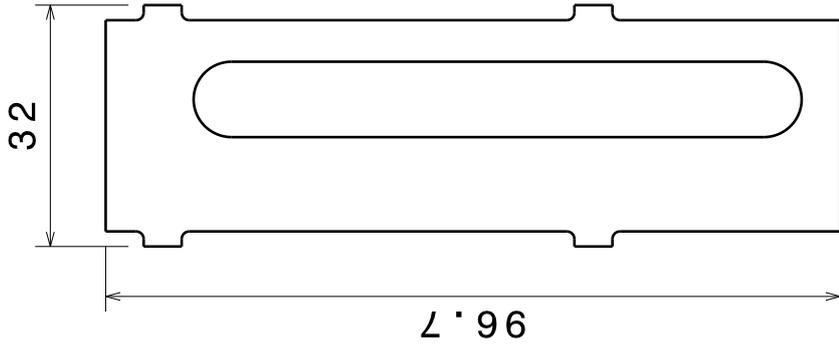
Vue de face
Echelle : 1:1

Tôle épaisseur: 3 mm

Tolérances générales : ISO 2768 -mK

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Dessiné par Pablo Lamadrid	Date 12/10/2021	Designation Plaque Pédale Frein 8	
Coordonnées Tel : +34 618695587 pablo.lamadrid00@gmail.com	Quantité 2	Matériau Acier S355	Version 1.0
Plan vérifié par Guillaume Brault	Echelle 1:1	N° du plan FR_04001_8	Feuille 1/1

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Tôle épaisseur: 3 mm

Vue de face
Echelle : 1:1

Tolérances générales : ISO 2768 -mK

Taille A4		Ecurie Piston Sport Auto	
Dessiné par Pablo Lamadrid	Date 12/10/2021	Désignation Plaque Pédale Frein 9	
Coordonnées Tel : +34 618695587 pablo.lamadrid00@gmail.com	Quantité 2	Matériau Acier S355	Version 1.0
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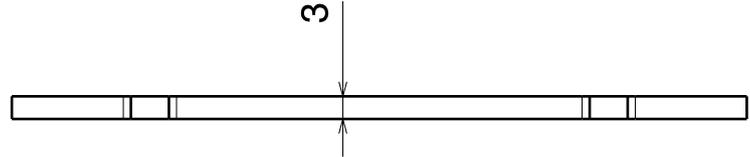
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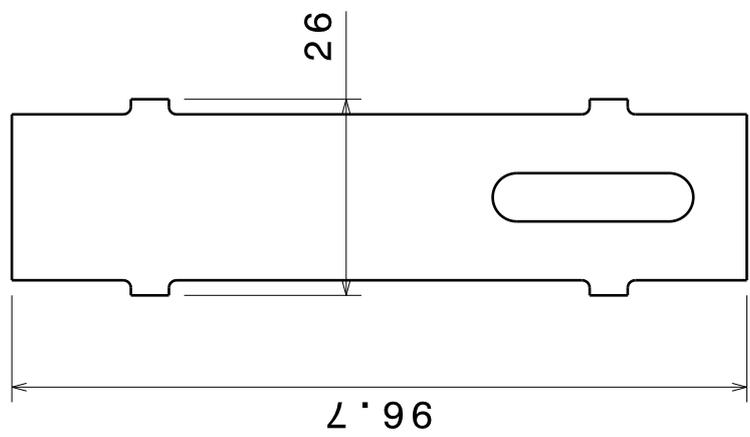
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Left view
Scale: 1:1



Front view
Scale: 1:1

Taille A4				Ecurie Piston Sport Auto	
Dessiné par		Date 12/10/2021		Désignation Plaque pédale frein 10	
Coordonnées Tel: +34 618695587 Pablo.lamadrid00@gmail.com		Quantité 1		Matériau Acier S355	
Plan vérifié par Guillaume Brault		Echelle 1:1		Version 1.0	
				N° du plan FR_04001_10	
				Feuille 1/1	

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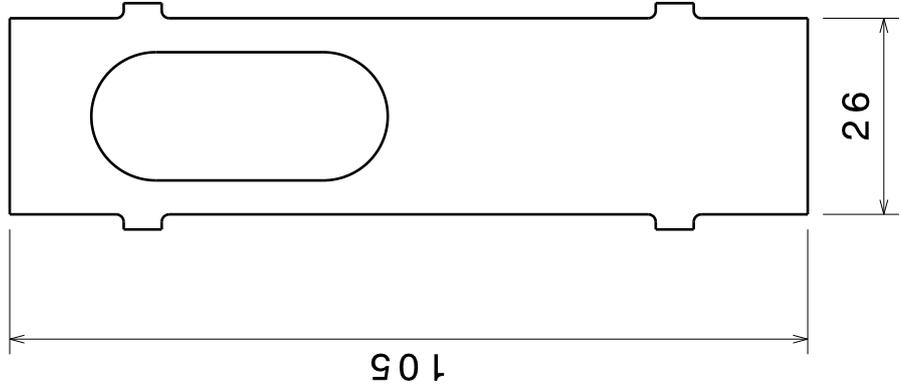
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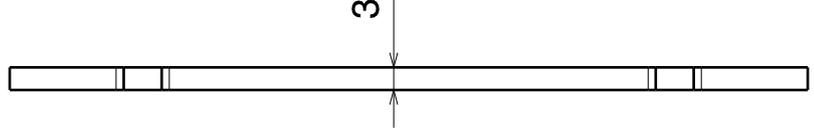
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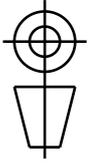
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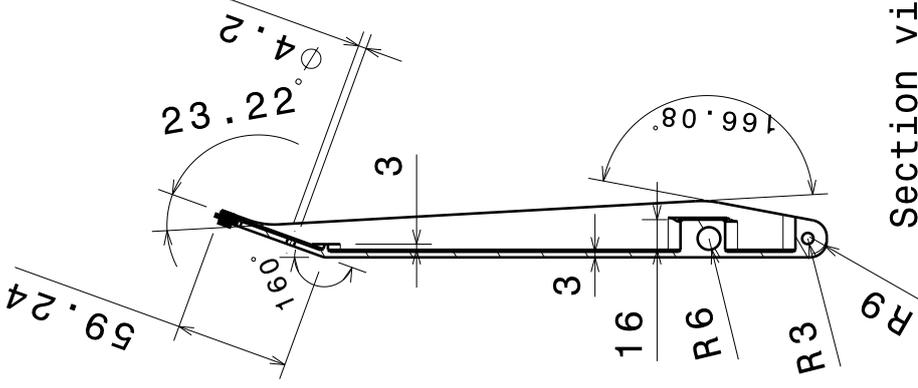
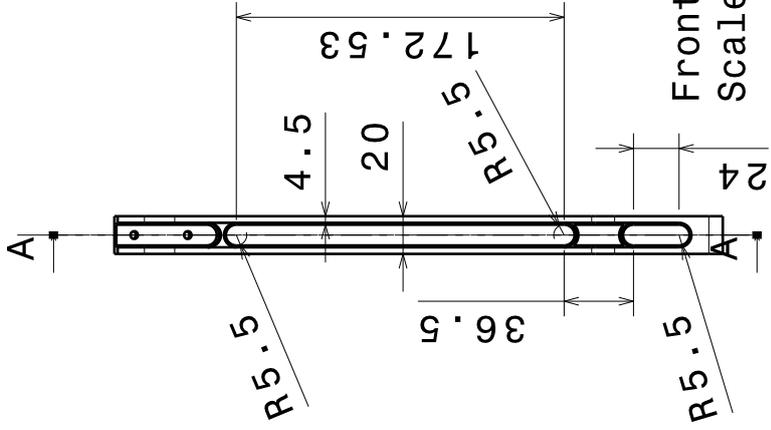
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Left view
Scale: 1:1

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Coordonnées tel: +34 618695587 pablo.lamadrid00@gmail.com		Version 1.0	Echelle 1:1 N° du plan FR_04001_11 Feuille 1/1
Plan vérifié par Guillaume Brault			

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Taille A4	
Dessiné par Pablo Lamadrid	Date 13/11/2021
Coordonnées +34 618695587 pablo.lamadrid00@gmail.com	
Plan vérifié par XXX	

Ecurie Piston Sport Auto	
Désignation Brake Pedale Stick	
Quantité 1	Matériau Acier S355
Version 1	
Echelle 1:1	Numéro du plan FR_04002
Feuille 1/1	

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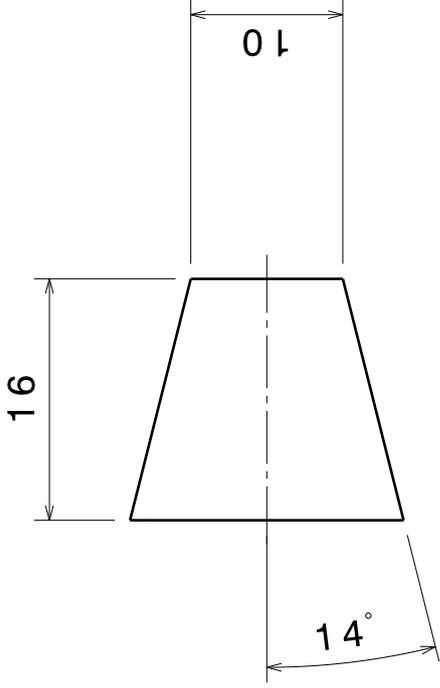
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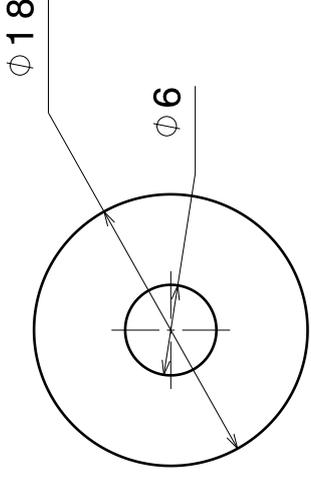
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Front view
Scale: 2:1



Left view
Scale: 2:1

Taille A4	
Dessiné par Pablo Lamadrid	Date 06/11/2021
Coordonnées +34 618695587 pablo.lamadrid00@gmail.com	
Plan vérifié par Nicolas Ville	

Ecurie Piston Sport Auto	
Désignation Master Cylinder Wedge	
Quantité 2	Matériau Acier S355
Version 1	
Echelle 1:1	Numéro du plan FR_04005
Feuille 1/1	

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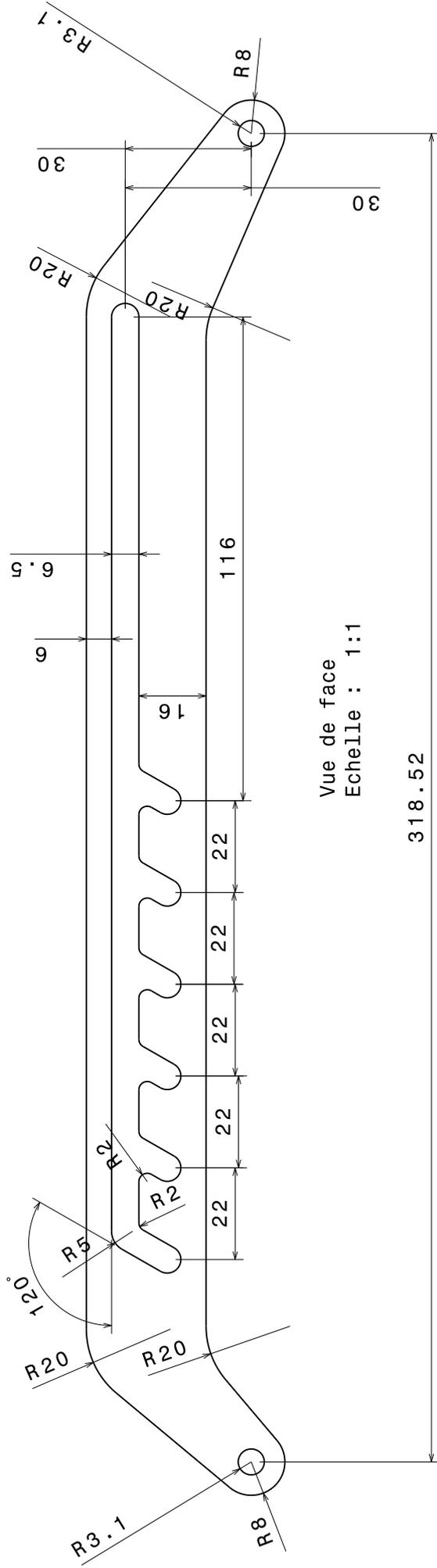
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Vue de face
Echelle : 1:1

318.52

Tôle épaisseur: 3mm

			
Taille A3		Dessiné par Pedro Pablo Lamadrid	
Date 06/11/2021		Coordonnées +34 618695587 pablo.lamadrid00@gmail.com	
Désignation Brake Fixing Rail		Plan vérifié par Guillaume Brault	
Quantité 002		Matériau S355	
Version 1		Echelle 1:1 N° plan FR_04006	
Feuille 1/1		A	

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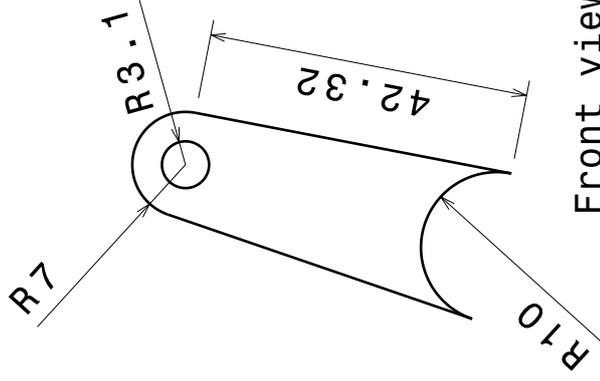
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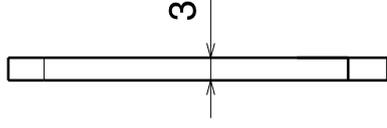
1

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Front view
Scale: 1:1



Left view
Scale: 1:1

Taille A4	
Dessiné par Pablo Lamadrid	Date 06/11/2021
Coordonnées +34 618695587 pablo.lamadrid00@gmail.com	
Plan vérifié par Guillaume Brault	

Ecurie Piston Sport Auto

Désignation

Brake Fixing Rail Wedge

Quantité

2

Matériau

Acier S355

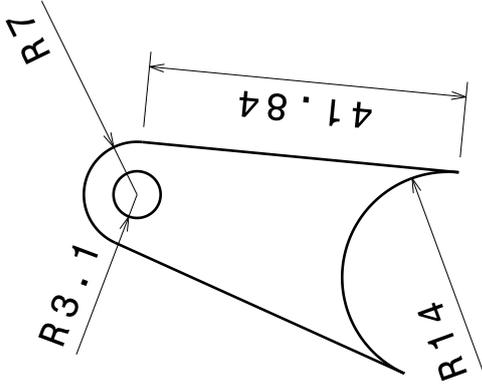
Version

1

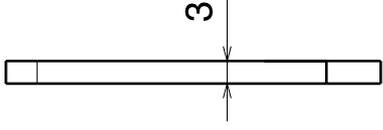
Echelle 1:1

Numéro du plan FR_04007

Feuille 1/1



Front view
Scale: 1:1



Left view
Scale: 1:1

Taille A4	
Dessiné par Pablo Lamadrid	Date 06/11/2021
Coordonnées +34 618695587 pablo.lamadrid00@gmail.com	
Plan vérifié par Guillaume Brault	

Ecurie Piston Sport Auto		
Désignation Front Fixing Rail Wedge		
Quantité 2	Matériau Acier S355	Version 1
Echelle 1:1	Numéro du plan FR_04008	Feuille 1/1

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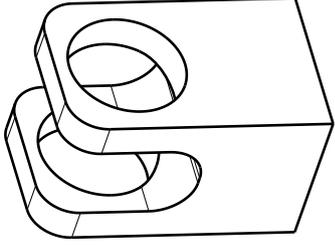
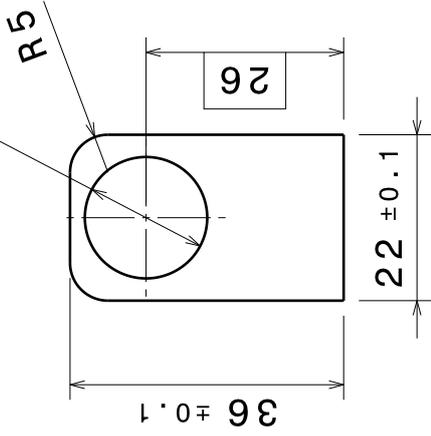
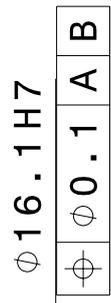
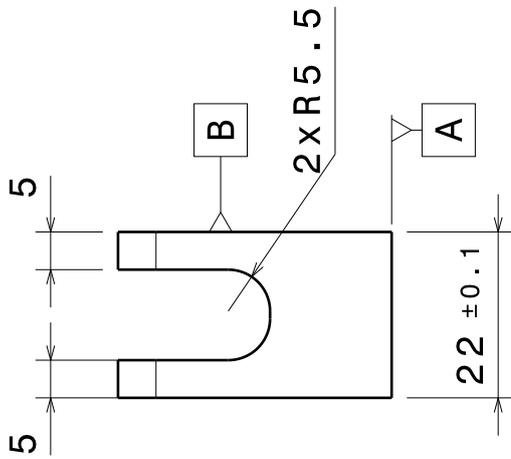
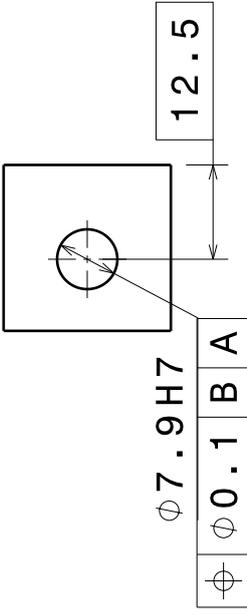
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4 3 2 1



Front view
 Scale: 1:1

Taille A4		Ecurie Piston Sport Auto	
Dessiné par Pablo Lamadrid	Date 06/11/2021	Désignation Distribution Brake Axle Tread	
Coordonnées +34 618695587 pablo.lamadrid00@gmail.com		Quantité 2	Version 1
Plan vérifié par Nicolas Ville		Matériau Acier S355	Echelle 1:1
		Numéro du plan FR_04010	
		Feuille 1/1	

A

4 3 2 1 4

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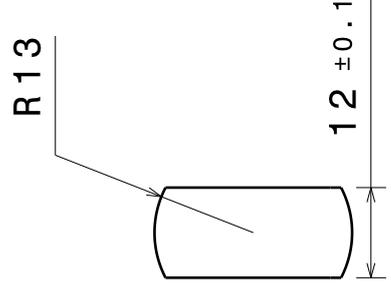
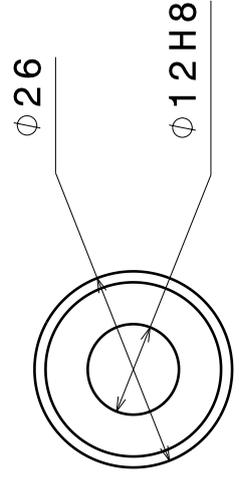
4 3 2 1 4

A

∞

C

D



Front view
Scale: 1:1

Taille A4			
Dessiné par Pablo Lamadrid		Date 06/11/2021	
Coordonnées +34 618695587 pablo.lamadrid00@gmail.com			
Plan vérifié par Nicolas Ville			
Ecurie Piston Sport Auto			
Désignation Brake Distribution Ball Joint			
Quantité 1	Matériau Acier S355	Version 1	
Echelle 1:1	Numéro du plan FR_04012		Feuille 1/1

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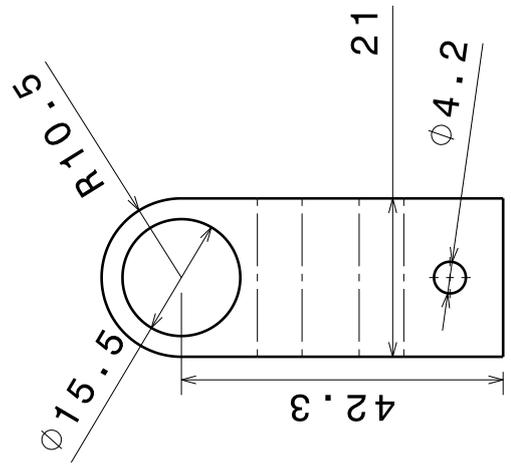
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A

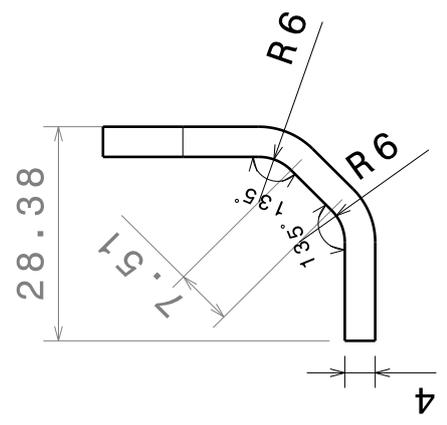
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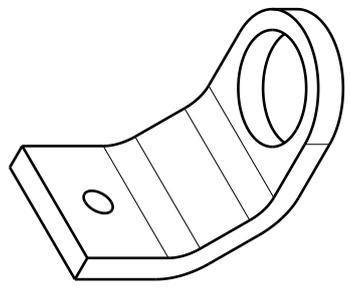
D



Vue dépliée
Echelle : 1:1



Vue de droite
Echelle : 1:1



Vue isométrique
Echelle : 1:1

Taille A4	
Dessiné par Pablo Lamadrid	Date 06/11/2021
Coordonnées tel. : +34 618695587 pablo.lamadrid00@gmail.com	
Plan vérifié par Guillaume Brault	

Ecurie Piston Sport Auto		Désignation	
		BOTS Support	
Quantité 01	Matériau Acier S355	Version 1.0	
Echelle 1:1	Numéro du plan FR_04013	Feuille 1/1	

A

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C

D

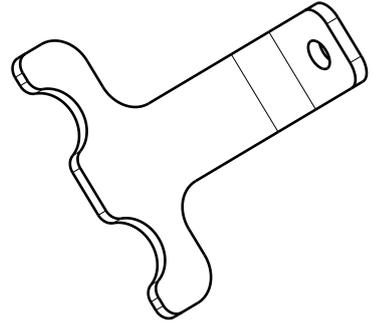
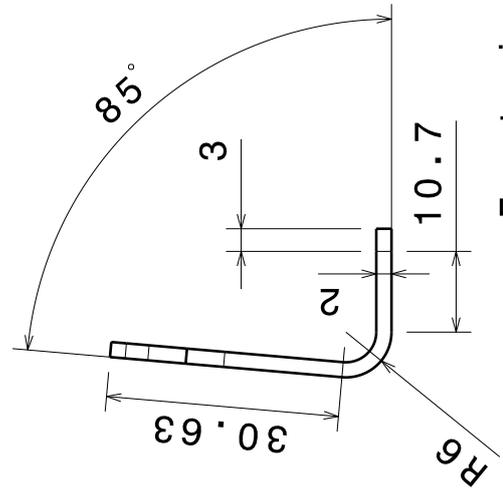
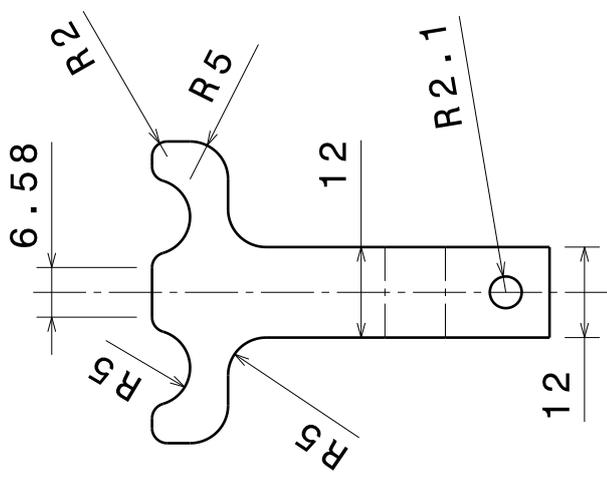
4

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Auxiliary view A
Scale: 1:1

Taille A4		Ecurie Piston Sport Auto	
Dessiné par Pablo Lamadrid	Date 14/11/2021	Désignation Brake Pedale Hose Wedge	
Coordonnées +34 618695587 PabloLamadrid00@gmail.com	Plan vérifié par Guillaume Brault	Quantité 1	Version 1
		Matériau S355	
		Echelle 1:1	Numéro du plan FR_04015
			Feuille 1/1

4

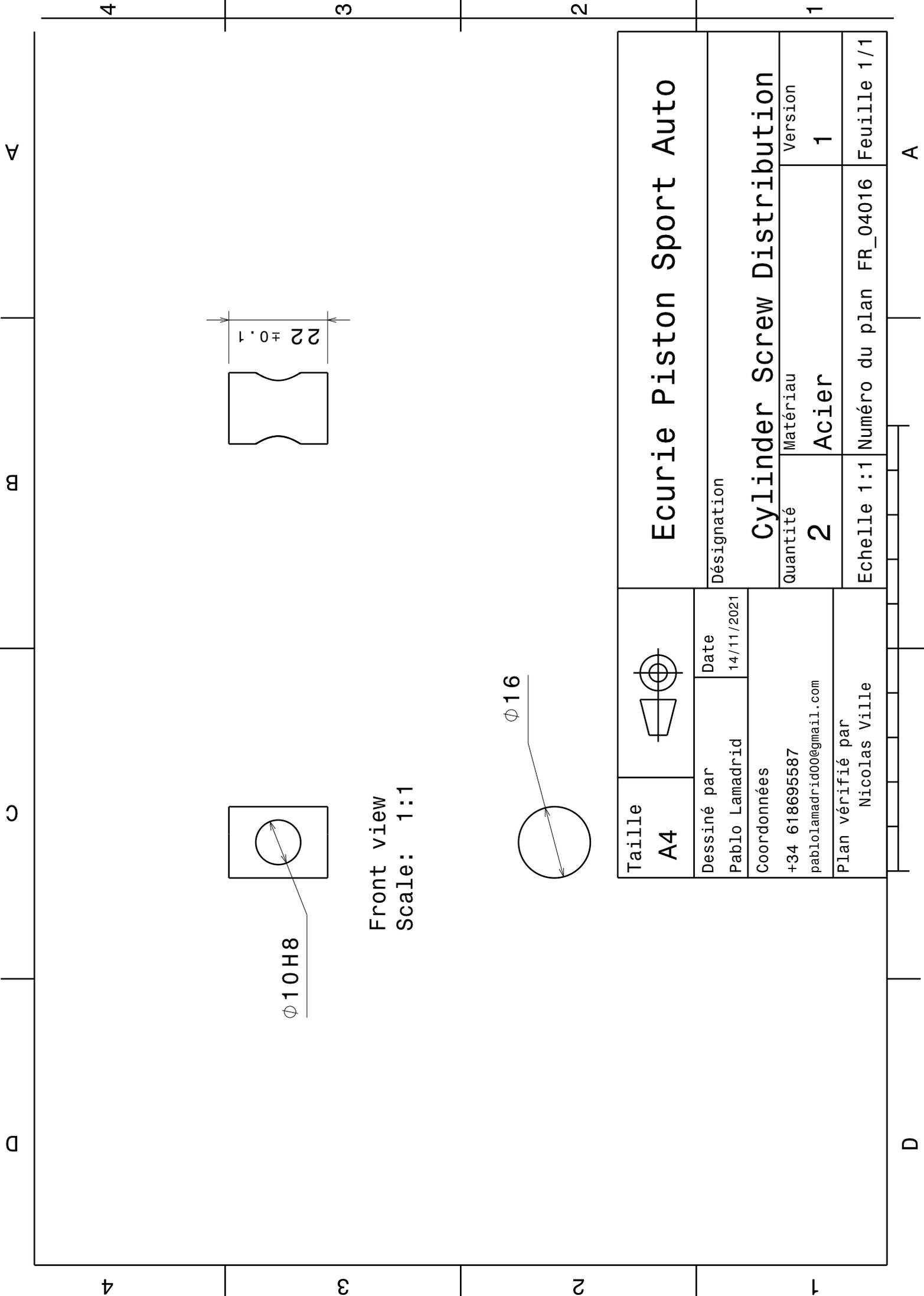
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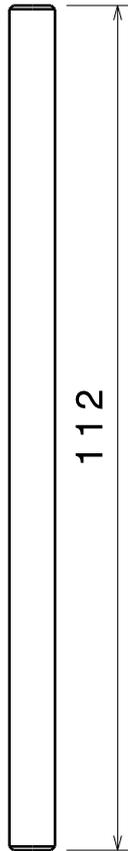


4 3 2 1 4 3 2 1 4 3 2 1

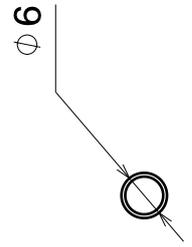
A A A A

0.5 x 45°

0.5 x 45°



112



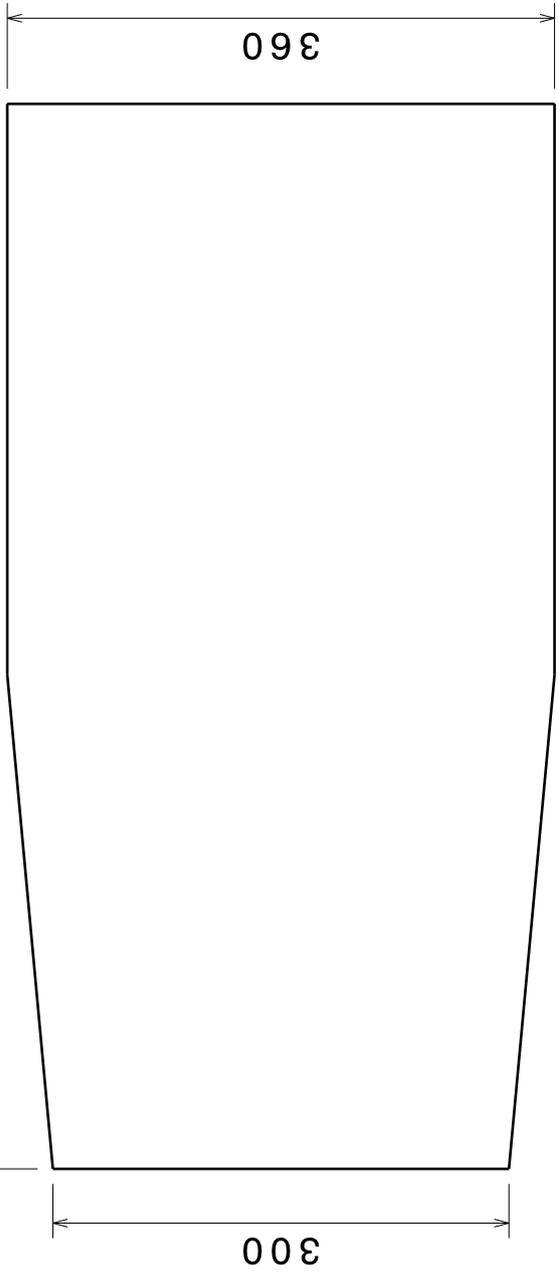
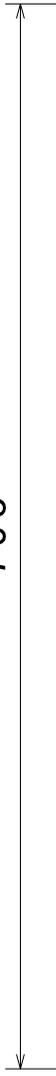
Front view
Scale: 1:1

Taille A4				Ecurie Piston Sport Auto	
Dessiné par Pablo Lamadrid		Date 14/11/2021		Désignation Brake Threaded Rod	
Coordonnées +34 618695587 pablo.lamadrid00@gmail.com		Quantité 2		Matériau Acier S355	
Plan vérifié par Nicolas Ville		Echelle 1:1		Version 1	
				Numéro du plan FR_04018	
				Feuille 1/1	

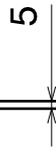
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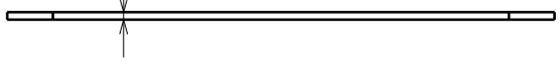
360



5

Front view
Scale: 1:5

Left view
Scale: 1:5



Taille A4				Ecurie Piston Sport Auto	
Dessiné par		Date 12/10/2021		Désignation	
Coordonnées tel: +34 618695587 pablo.lamadrid00@gmail.com		Quantité 1		Front plate	
Plan vérifié par XXX		Matériau Aluminium 2017 t4		Version 0.1	
		Echelle 1:5		Numéro du plan FR_06001	
				Feuille 1/1	

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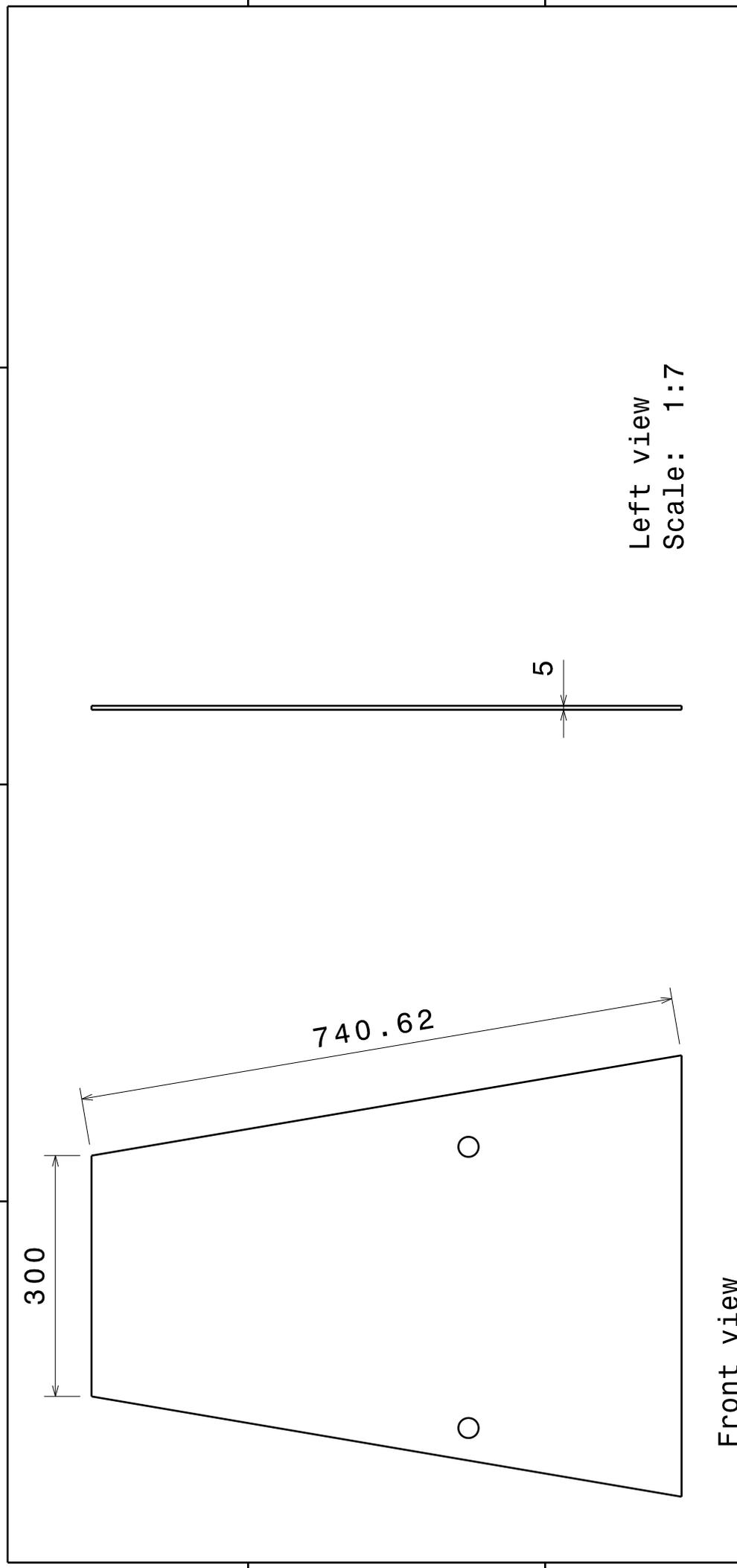
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A B C D



Left view
Scale: 1:7

Front view
Scale: 1:7

Ecurie Piston Sport Auto		Désignation		Cockpit plate	
Taille A4		Date 12/10/2021	Quantité 1	Matériau Aluminium 2017 t4	Version 0.1
Dessiné par	Coordonnées tel: +34 618695587 pablo1amadri.d00@gmail.com		Echelle 1:7		Numéro du plan FR_06002
Plan vérifié par XXX		Feuille 1/1			

4 3 2 1 A D

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B

C

D

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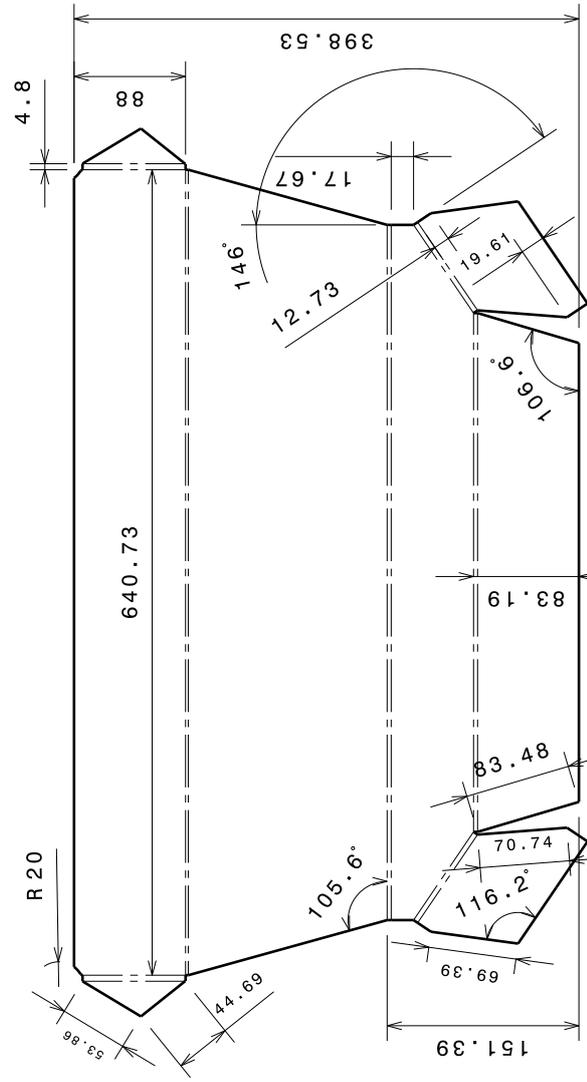
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4

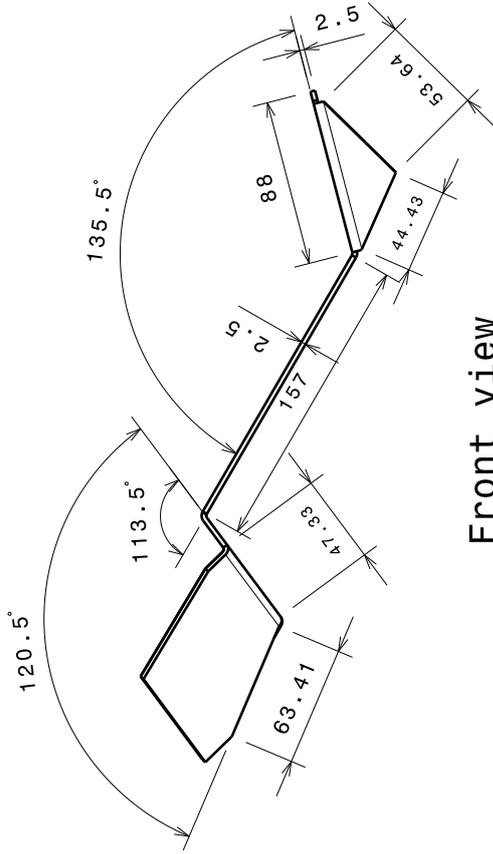
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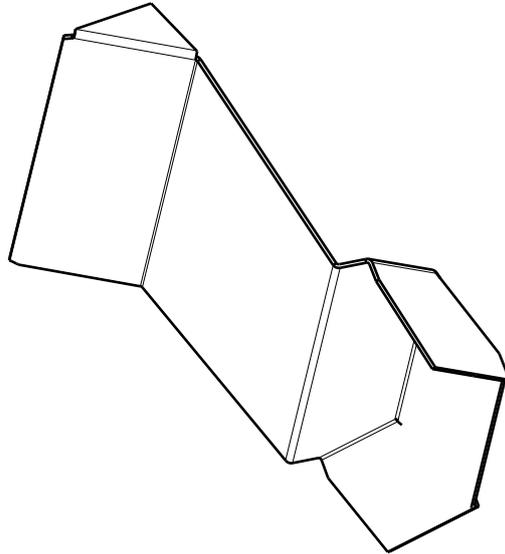
1



Vue dépliée
Échelle: 1:6



Front view
Scale: 1:4



Isometric view
Scale: 1:5

Ecurie Piston Sport Auto

Désignation

Paroi pare feu - milieu

Quantité

1 Aluminium AG3

Version

1.0

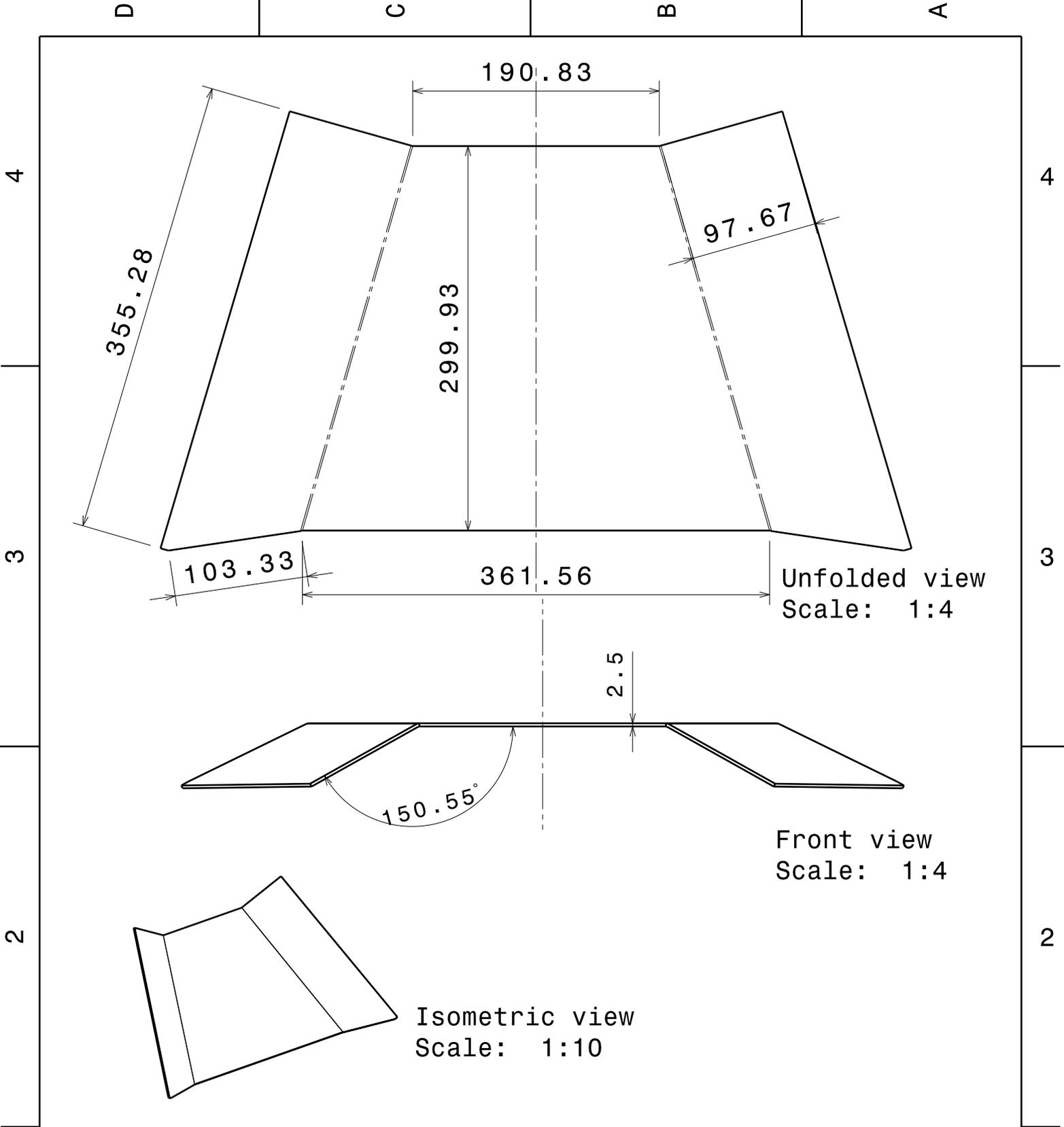
Plan vérifié par
Guillaume Brault

Echelle 1:1 Numéro du plan MS_04001

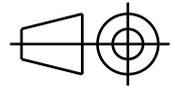
Feuille 1/1

D

A



Taille
A4



Ecurie Piston Sport Auto

Dessiné par
Pablo Lamadrid

Date
28/09/2021

Désignation

Coordonnées
pablolamadrid00@gmail.com
+34 618695587

Paroi pare feu - Upper part

Plan vérifié par
Guillaume Brault

Quantité
1

Matériau
Aluminium AG3

Version
1.0

Echelle 1:4

Numéro du plan MS_04002

Feuille 1/1

1

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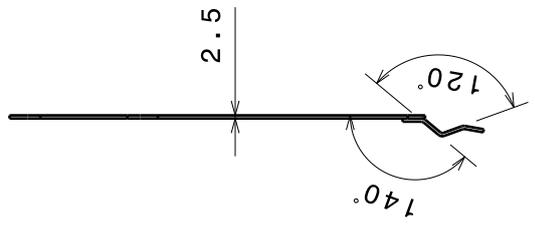
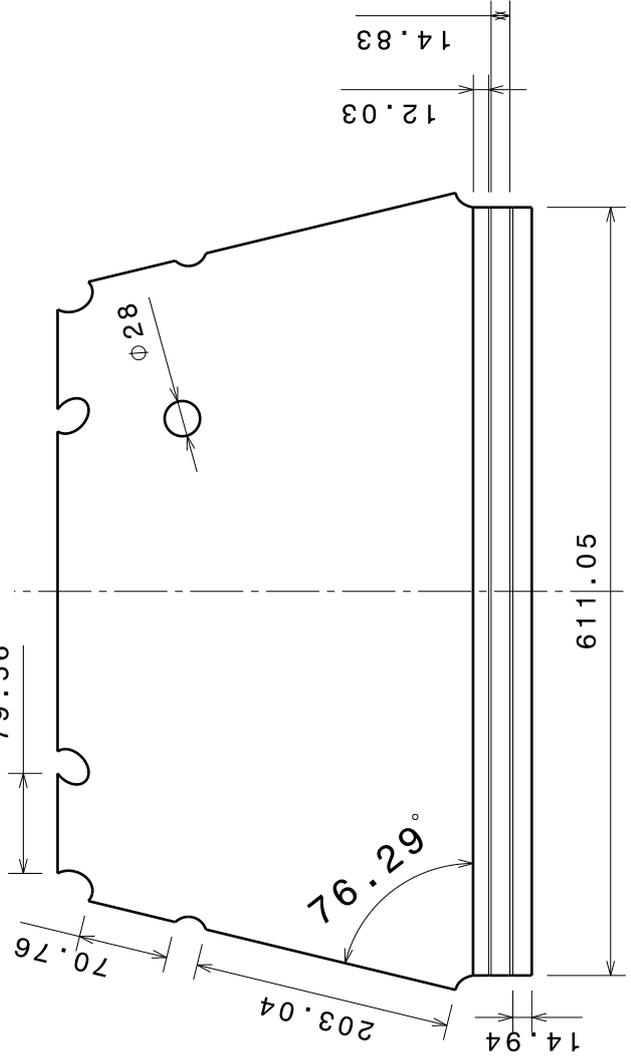
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Taille A4	
Dessiné par Pablo Lamadrid	Date 04/10/2021
Coordonnées pablo.lamadrid00@gmail.com +34 618695587	
Plan vérifié par Guillaume Brault	

Ecurie Piston Sport Auto	
Désignation Paroi pare feu - Lower part	
Quantité 1	Matériau Aluminium AG3
Version 1.0	
Echelle 1:6	Numéro du plan MS_04003
Feuille 1/1	

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PART IV



ANNEX



Simulations



Introduction

Although it is not the main focus of my project, simulations have played a crucial role in the vehicle's development, and they have greatly influenced my work throughout the academic year.

In terms of materials and stress analyses, we have divided the organization into two main studies: A Von Mises stress analysis for the whole structure in the wireframe version of the vehicle and then a specific analysis of the different components other than tubes.

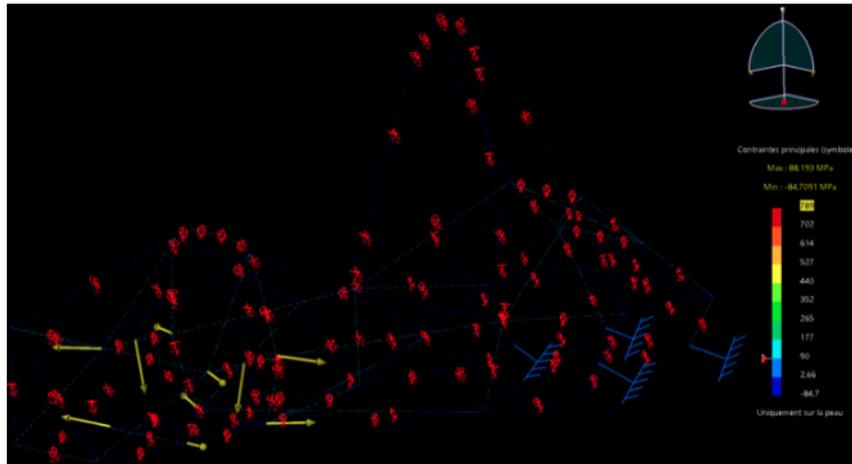


Figure 46. Von Mises' constraints analysis (Maximal constraint: 90 MPa)

Through simulations, we have:

- verified that the material chosen is adequate in terms of constraints. As the steel S355 has a elasticity limit of 355 MPa, we ensure no plastic deformation. The elongation at break is of 22%, so we are sure that there will not be a sudden break
- done an iterative conception process. The members in charge of the simulations came back to the members who conceived in CATIA to analyse possible improvements and repeated the cycle again

Specifications

The simulation aspect of the project has been done via ANSYS [19]. ANSYS is an engineering simulation software empowering the design and delivery of transformational products. ANSYS solver is presumably a better one than CATIA one, which is why we decided to go in that direction.



Figure 47. Ansys - Engineering simulation software

Nevertheless, team members have used other software packages for different purposes, such as Fluent or the Simulations block of CATIA.

Developed jigs



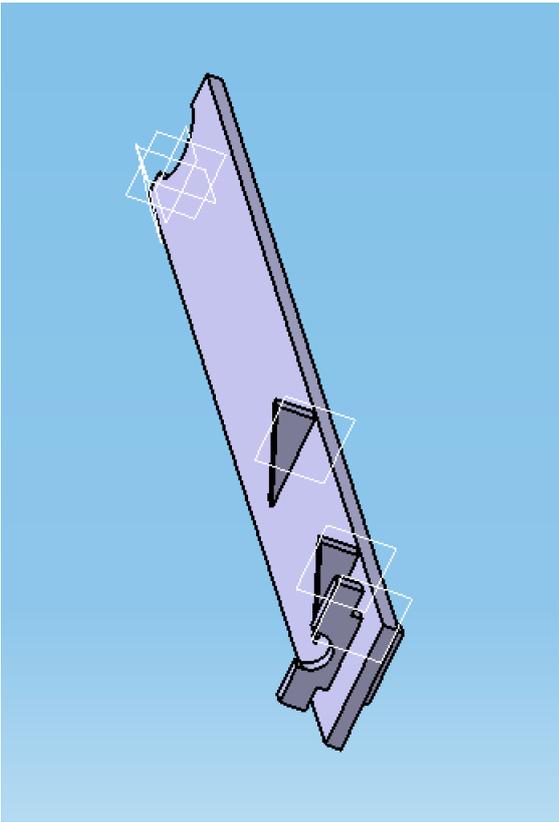


Figure 48. Main hoop jig (1/2)

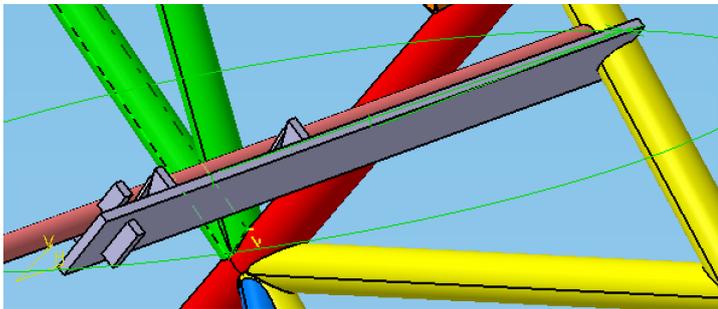


Figure 49. Main hoop jig (2/2)

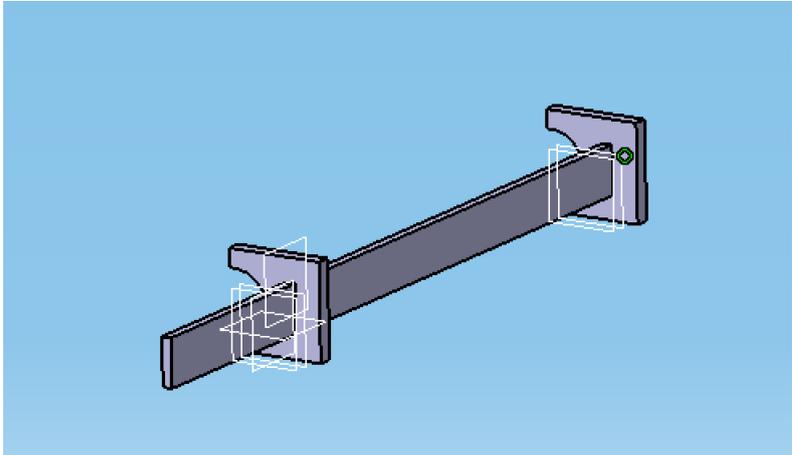


Figure 50. Baquet haut jig (1/2)

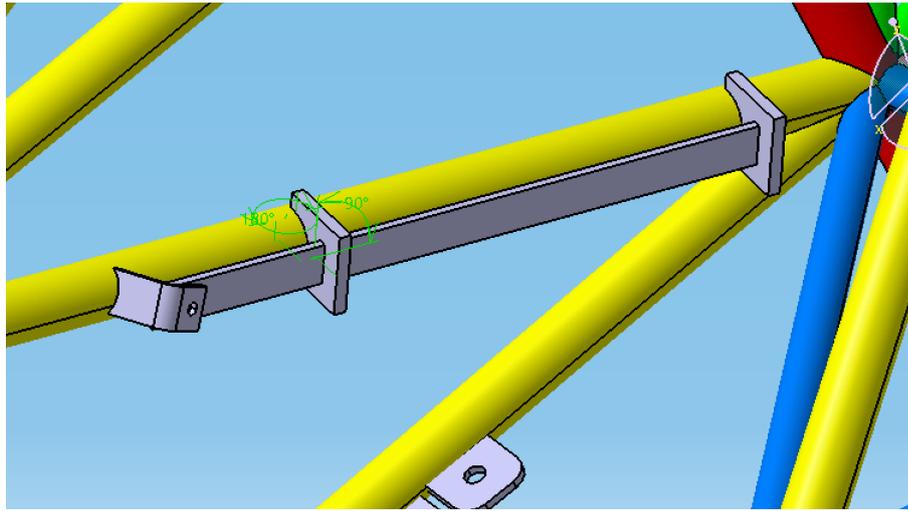


Figure 51. *Baquet haut jig (2/2)*

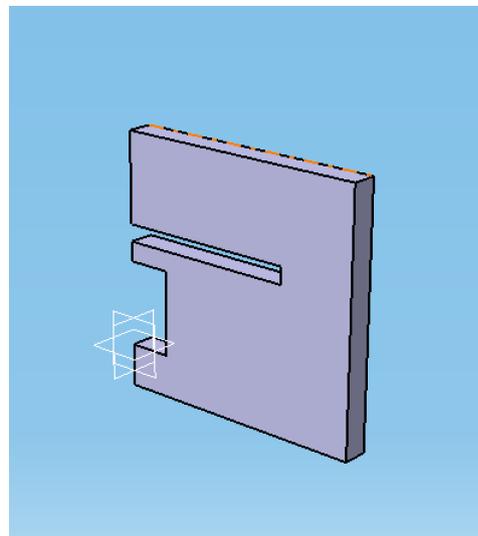


Figure 52. Battery jig

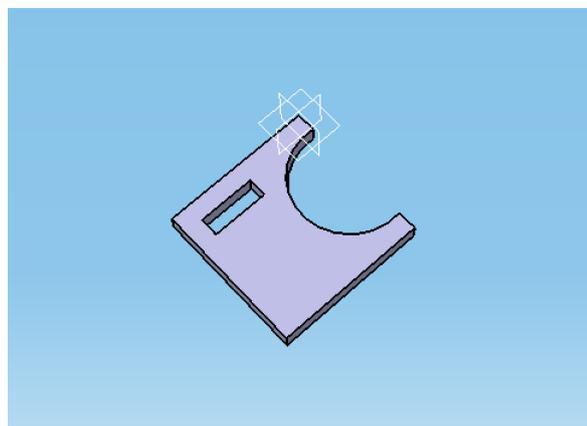


Figure 53. Fusible box jig

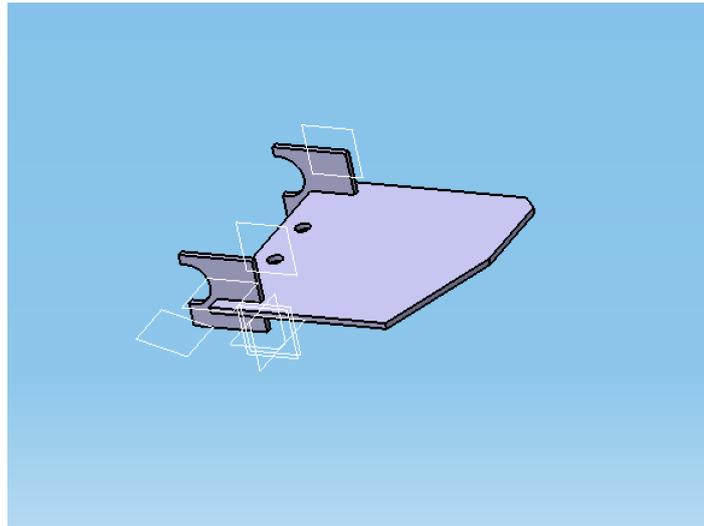


Figure 54. Harness jig (1/2)

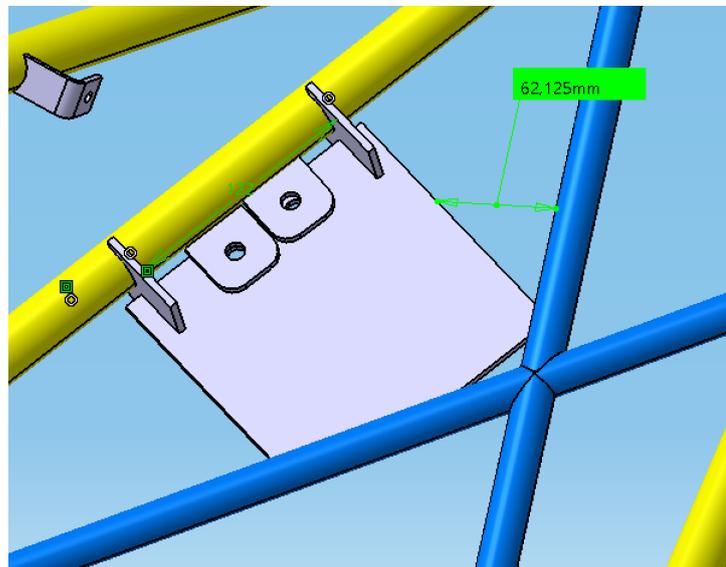


Figure 55. Harness jig (2/2)

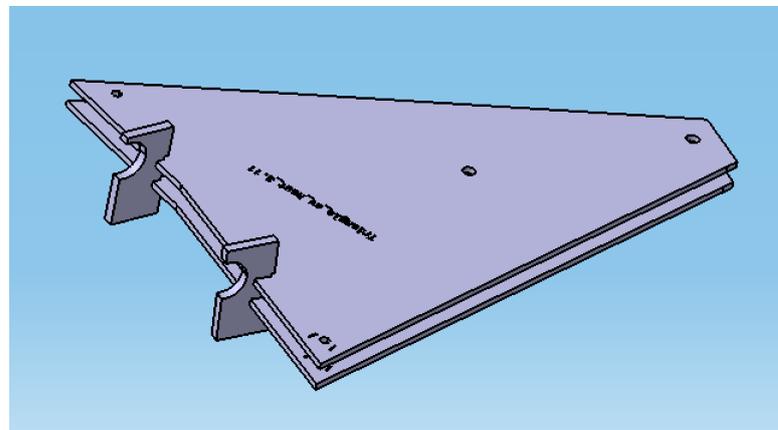


Figure 56. Avant-haut jig

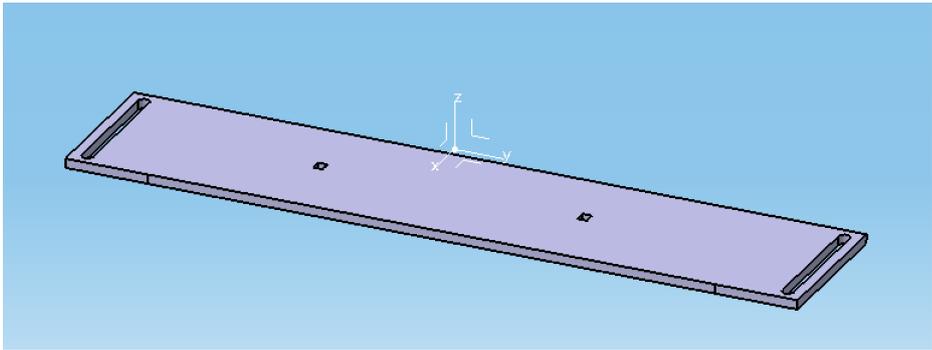


Figure 57. BAR jig

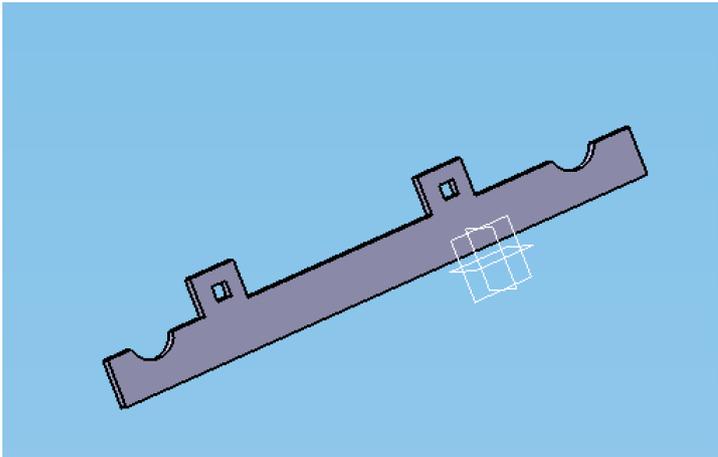


Figure 58. Rocker jig

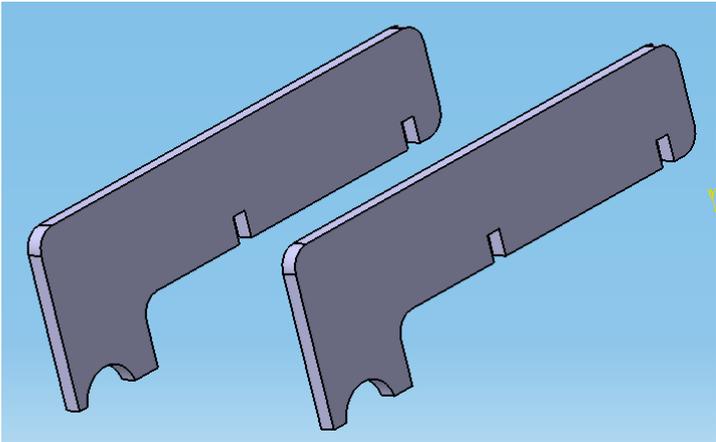


Figure 59. Harness brake jig

Developed screeds



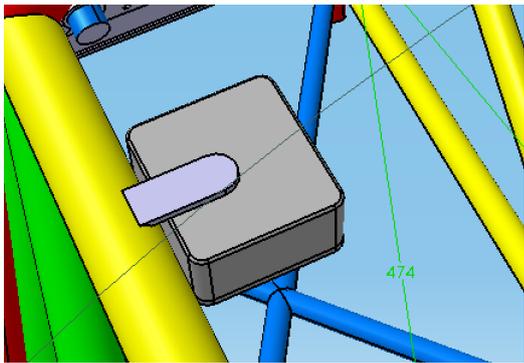


Figure 60. Buzzer screed(1/2)

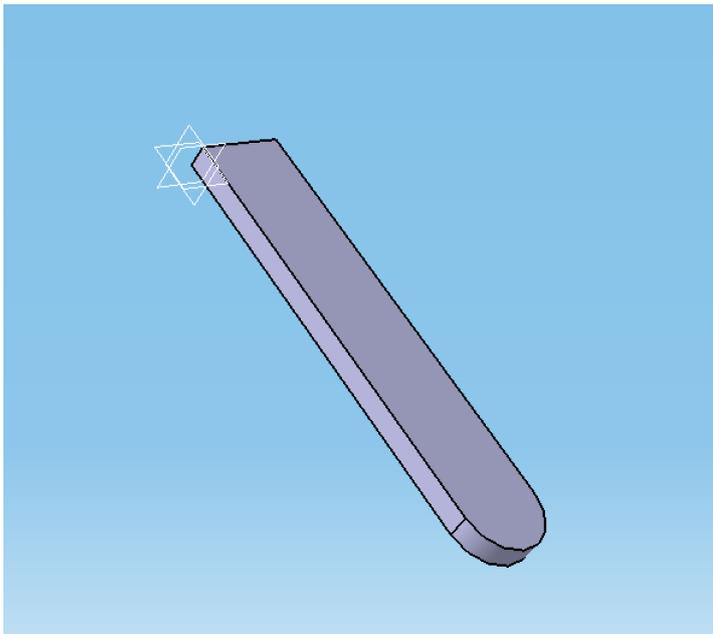


Figure 61. Buzzer screed (2/2)

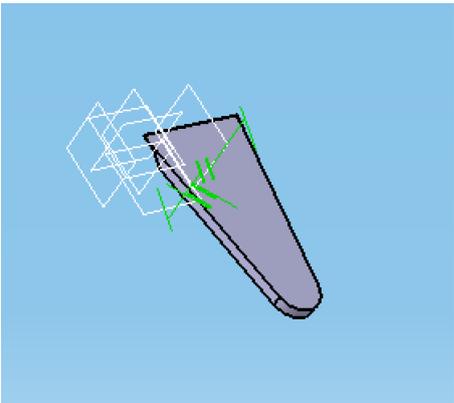


Figure 62. Battery screed (1/3)

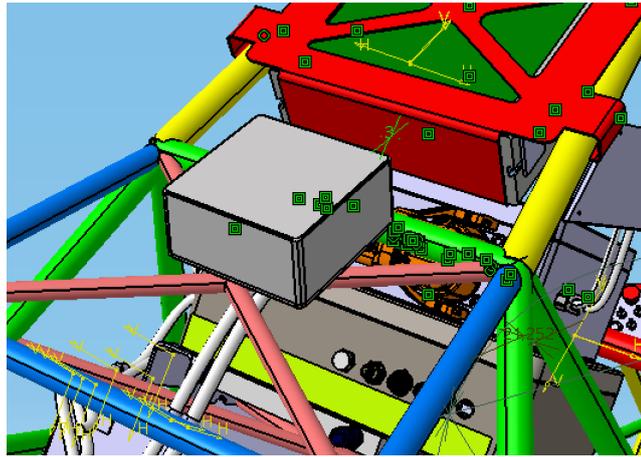


Figure 63. Battery screed (2/3)

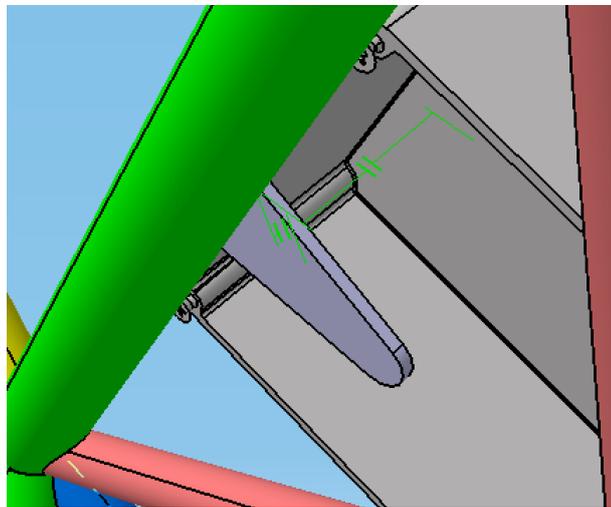


Figure 64. Battery screed (3/3)

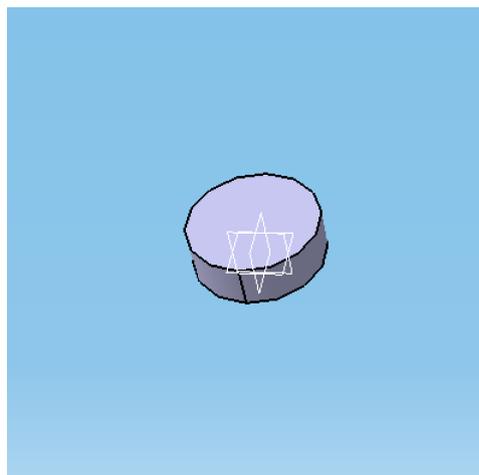


Figure 65. Cables screed 1590U x 10

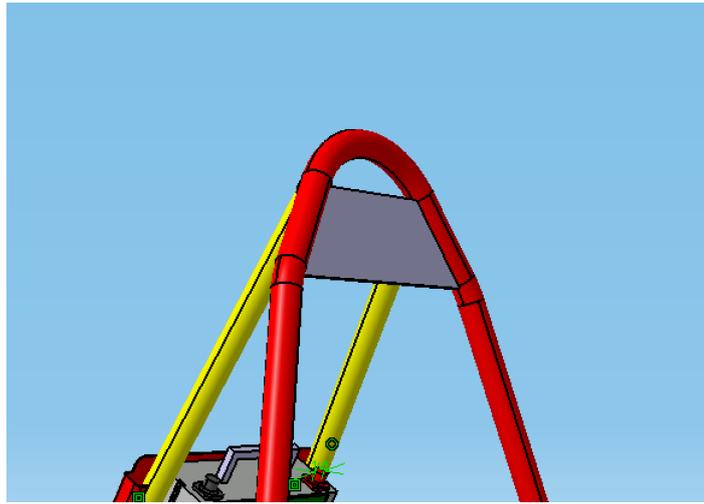


Figure 66. Lights screed

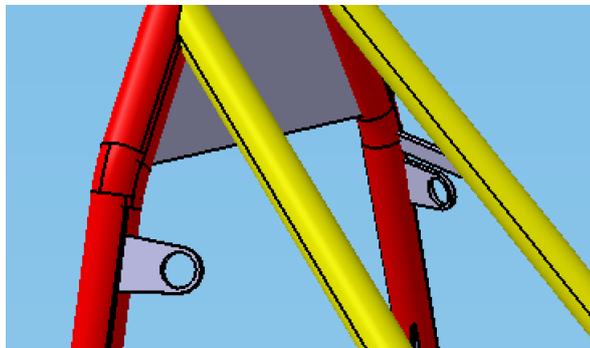


Figure 67. Main hoop screeds - *there are 3*

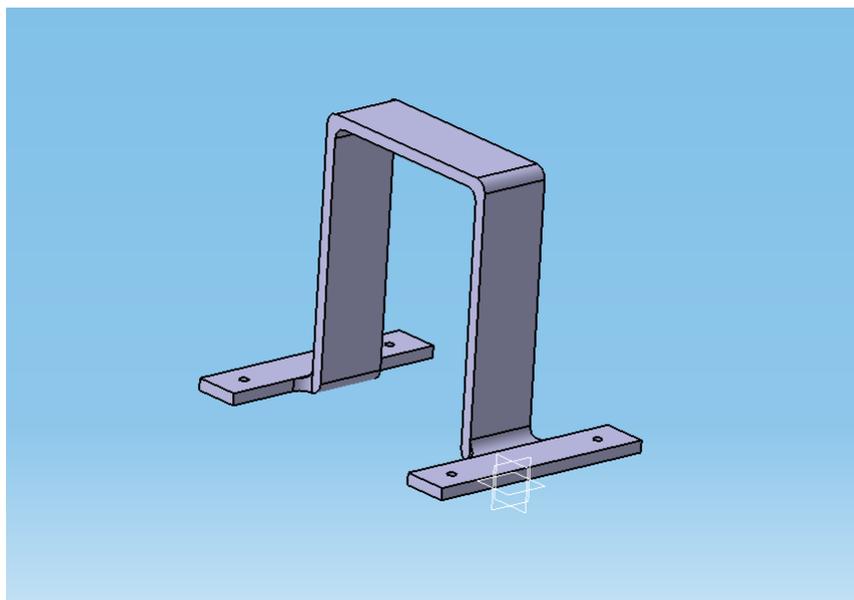


Figure 68. Bomb support