EPSA TEAM – CAR N. 81
DESIGN REPORT

The 2015 car, named Atomix, is the second open-wheel Formula Student prototype designed by the EPSA team from the Ecole Centrale Lyon (France). The main objective was to build a light but strong and reliable car, capable to succeed in all static and dynamic events. Our team, initially composed of 21 Bachelor students, started the design from scratch in September 2014 and delivered a 220 kg car in August 2015. After that, 10 team members optimized the car to compete in the Formula Student UK 2016 Event. A tubular steel space-frame chassis, a four-cylinder internal combustion engine, a body and double wishbones in carbon fiber and a custom monitoring system are the key elements of our new car.

SUSPENSION

For the second FSAE car of the team we chose 10 inch tires instead of 13 inch as chosen on the previous vehicle in order to save weight with a controlled loss of lateral performances as proven by the analysis of tire data, in spite of the increase of packaging and heat issues. The steering system was designed in order to be able to take every possible turn successfully with the best grip possible (anti-Ackerman geometry).

The suspension system is composed of non-parallel A-ARMs of unequal length. Their positions were chosen in order to correctly place the roll centers and to obtain the right amount of camber in curve to optimize the work of the tires.
Pushrod lied to the lower A-Arm (front) and to the upper A-Arm (rear) actuates rockers connected to Ohlins TTX25 mk2 dampers. Low motion ratios were designed to reduce the stiffness of the springs.
The static camber and toe angle can be modified from -4° to 0° by shims on uprights, and from -2° to 2° by adjustable rods length. Two adjustable roll bars allow to reach the roll stiffness needed, and to change the car’s behavior by changing the front/rear roll stiffness ratio.

The uprights were designed to obtain the parameter values which we had determined for the suspension geometry. Furthermore, the uprights must carry the hubs and bearings, and also be resistant to all the stresses and forces coming from the A-arms suspensions and the bearings. The essential load cases (such as acceleration, braking and turn) were simulated in order to design an optimized structure which was a compromise between high resistance and small mass.

The hub was designed as a single part, and our aim was to make it as compact as possible in order to fit in the wheel rim while being adapted to other elements like the bearing and the brake disc. We used strong 7075 Aluminium alloy for both the uprights and the hubs in order to have lightweight yet resistant parts.

Composite materials were used to build the rods and the A-Arms. A process to glue carbon tubes with aluminum part was studied and characterized with tests, so the safety could be proved before mounting the parts on the vehicle. This new process saved **5** kg of unsprung mass compared to an equivalent steel solution.

FRAME AND BODY

Frame

For production facilities and rules compliance we chose a tubular space frame design using AISI 4130 steel. First, a basic CAD model containing space for systems and cockpit templates was created using CATIA V5. Frame dimensions were then created using adjustable parameters in order to quickly adapt to the evolution of other systems, especially engine and suspension mounting points. A first wooden frame was built to conduct an ergonomic study to determine certain dimensions such as roll hoop height. Then the frame was analyzed using ANSYS finite element analysis (FEA) in order to optimize the tubular structure, and with a lot of back and forth between CAD and FEA and a great attention to the rules, and to the triangulation in order to

minimize the weight of the frame as in the whole car design. Tubing diameter and thickness were determined in order to obtain a minimum displacement for the suspension components brackets.
To ensure a complete safety for the pilot we design our frame to also be compliant with the alternative frame requirements and crash situations, although if it wasn't necessary. As a result our frame can resist to extreme load cases for safety and is stiff enough to not interact with the suspension stiffness.

Body

We chose to design a body which mainly covered the front of the vehicle up to the front roll bar, leaving the rear exposed, in order to simplify the design, facilitate the cooling and avoid collisions with the engine and drivetrain elements at the rear of the vehicle. The front is made by a nose and a lot of small slabs. This nose can be easily taken off to facilitate the work on the car. Carbon fiber was the material chosen for the body because of its low volumetric mass, which therefore allowed a lightweight design.
The side parts are designed as a compromise between the cooling system and the elegant shape we wished to give at our car.
This elegance goal is at the origin of fluid but dynamic curves.

POWERTRAIN

Engine Choice

The engine choice impacts the entire vehicle design, therefore it was made early. Considering our global design objectives, the criteria for the engine were the available power and torque, the mass and dimensions, but also the reliability and the possibility to buy spare parts easily. A four-cylinder was chosen to maximize the power-mass ratio, better than a mono or bi-cylinder. The Honda CBR600RR PC40 was chosen because of its endurance, reliability, and a previous experience with this type of engine in the team.
A new flat wet sump was made to move down the engine of 60mm and to make the gravity center of the vehicle lower. This flat sump is composed from different 5754 Aluminum laser cut parts welded together to avoid an expansive machining process.

Intake and exhaust air system

The intake and the exhaust systems were designed together to offer the maximum torque at 10000 rpm and to deliver a quite constant power in a wide band of rpm in order to facilitate the drivability.
The exhaust line has a 4-2-1 configuration, in order to facilitate the draining of the engine, and an acoustic study was made to take advantage of the Kadenacy effect. The line is made in stainless steel recovered by a heat treatment made of zirconium lowering the radiations in order to allow a compact packaging.
The intake system was designed to reach our performances goal by optimizing the air filling and to respond to the integration constraints. The throttle body with the inlet flange was bought (At Power) but the other parts were designed and made in rapid prototyping to be completely free in the shape decision and to facilitate the packaging. The manifold is conical for an equal air-distribution between the four cylinders. The rapid prototyped parts are made in Polyamide 12 to support fuel and depression as proven by tests before mounting such a critical system on the car.

Fuel system

A custom tank was made using 5754 Aluminum and has a capacity of 7 liters, which is sufficient to complete the whole endurance event. The fuel tank was designed to ensure a constant fuel supply in a curve by 1,8g during 6s with a false bottom working as a buffer volume.
We chose one of the lightest fuel pumps available on the market and added a fuel filter, a pressure regulator and a check valve on the cap. A single fuel injector rail was kept at the Honda original location.

Drivetrain

The power transmission between the gear box and the differential is achieved by chain. The limited slip differential (manufactured by Drexler) ideally distributes power to the wheels via drive shafts supplied by RCV Performance. The final ratio was chosen to be in the 3rd gear at the end of the 75m of the acceleration.

The chain tension can be adjusted thanks an eccentric system made in polymer (Delrin) moving longitudinally the whole differential.

COCKPIT/CONTROLS/BRAKES/SAFETY

Gear shifting

Gearbox shifting is done by using a brushless servomotor to control the selector drum angular position. All the shifting mechanism that comes with the engine has been replaced by a couple of gears to allow the servomotor to position the drum from the outside of the engine case. Thanks to this design, the shifting system has a closed-loop to make sure the gearbox is properly shifted. The servomotor is actuated by paddles on the steering wheel, and the shift system also cut the engine ignition on upshift to allow clutchless upshifting. The original clutch was replaced by a slipper clutch to cancel out the engine braking torque, in order to allow clutchless downshifting.

Dashboard

The dashboard has a simple design to bring only the necessary information to the driver and is made in carbon fiber. At the left of the steering wheel four warning lights are present for essential information (Power ON, fan ON, shift light and oil pressure failure) beside five push buttons (emergency stop, starter, neutral, gearshift system initialization and launch control) and one switch (ignition).
A-LCD screen at the right of the steering wheel gives to the pilot the information of the water temperature, the engine RPM and the engaged gear.
A special mode, used for the calibration, can be chosen with a display button. The displayed information are then the throttle position, the four suspensions and the steering rack positions, the battery voltage and the coolant temperature.

The display is only the emerged part of a custom made monitoring system based on Arduino electronic cards. Three cards plus the ECU discuss through a CAN-BUS. These cards are in the front, the middle and the back of the car. They are linked to all the car's sensors: the 2 undriven-wheels speed, the suspension displacement, the steering rack displacement, the engine temperature and the engine speed. All these pieces of information are loaded on a SD card placed at the back of the car and displayed on the dashboard. A card also supervised the gear shifting and the ECU can save data from the engine.

Brakes

Two independent brake circuits were used: one for the front and one for the rear. A balance bar is used with the brake pedal in order to easily adjust the front and rear distribution. Stainless Steel discs (diameter 195mm, thickness 5mm) manufactured by Beringer are mounted on the four wheels. Two different sizes of calibers are mounted on the car : Beringer dual piston calipers with a 32mm bore on the front ; AP-Racing dual piston calipers with a 25.7mm bore on the rear.

SYSTEMS MANAGEMENT/INTEGRATION

Electrical system and safety

Two electrical systems are present, the former for data acquisition, the latter for the engine. The engine electrical system is built from scratch to connect a programmable ECU (DTAFast S60) and to only keep the basic sensors (crank and camshaft positions, TPS, water temperature, oil failure). In order to achieve a clean and proper electrical system, a color-coded wiring diagram was created. The wiring is mainly protected and guided using spiral wrap, which simply needs to be unwrapped in order to access the wires in case of any electrical failure. All electrical elements are fuse protected and the battery, power devices and relays are all placed behind the firewall. This means that only low-power relay signals pass through the firewall and through the cockpit.

Team management and organization

Our team was initially composed of 21 students who designed and produced the car for two years. Then 10 of them optimized the car for one more year. Two main leaders were present, one for the resources and administrative management and another one for the technical aspects. Each member of the team was responsible of a specific system of the car, following them from the first concept to the integration and optimization in the car. A great motivation and solidarity in the team allowed us to overcome any unexpected problems we encountered throughout the project, especially in the final phase.

MANUFACTURABILITY/FIELD SERVICEABILITY

According to our wish to make a lightweight car, we tried to limit the use of steel in the car. That is why steel is only used for the tubular frame and for the welded bindings, to facilitate the welding and to be compliant with the standard frame rules.
In order to limit the machining time and costs, the laser cut and welded solutions were preferred for steel and aluminum parts.

As we have designed and manufactured a large number of our components, many of our parts are unique. To manufacture these parts, we worked with students from several nearby technical schools. This was an interesting and fulfilling experience for us, thanks to the professional relationships we developed with these students.

TESTING AND SETUP SESSIONS

Our car went through various testing sessions in order to get the vehicle to behave perfectly and to use all the potential hidden in tire behaviour, vehicle dynamics and engine management.

Engine setup

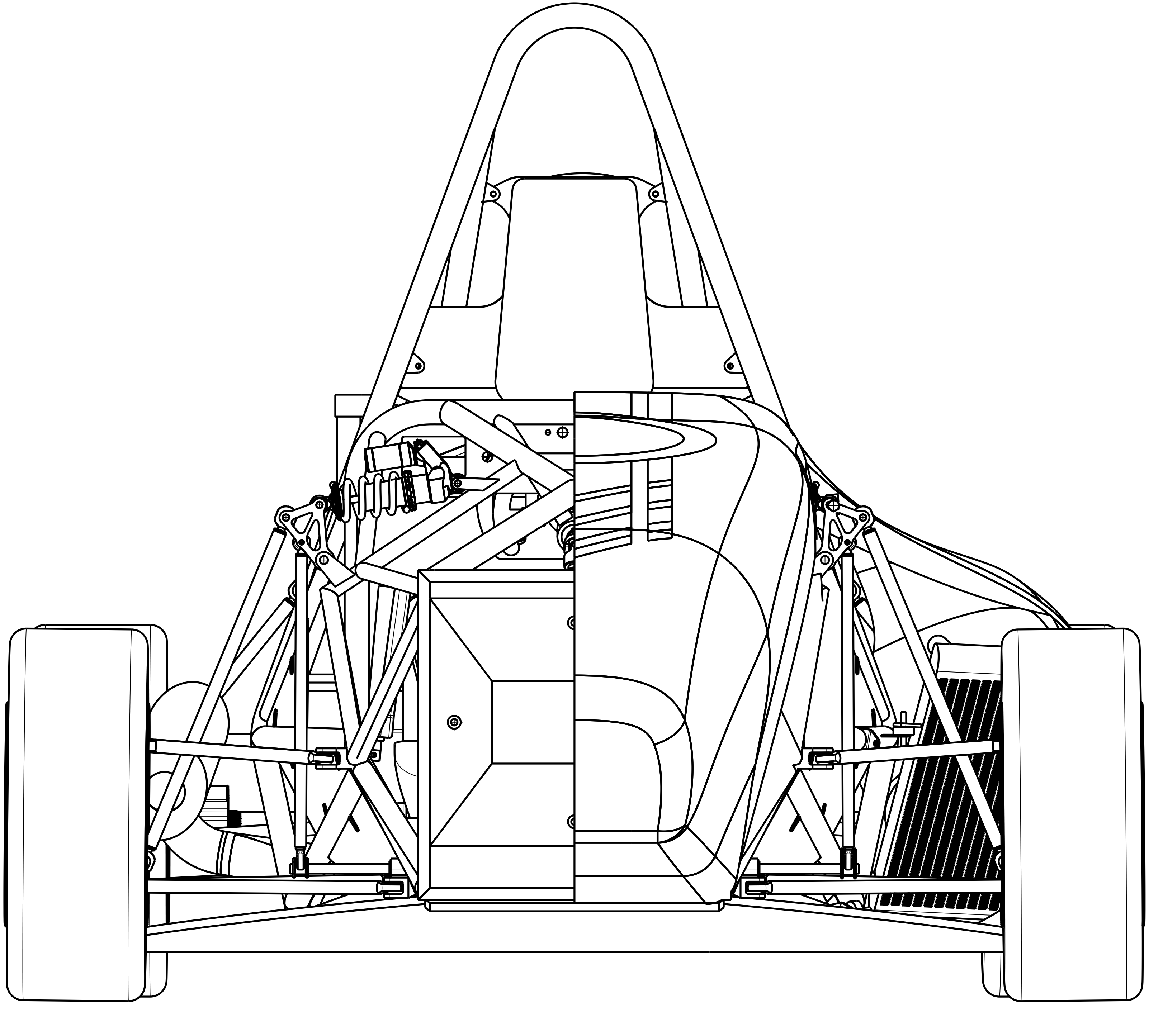
The car went to dyno testing to get all the power and torque by changing the fuel injection time map (mapped by throttle position sensor and RPM). This dyno session allowed us to start working on engine transient response with multiple fuel compensation for gear shift ignition cut as well as throttle tip in and tip out. All this work has been done using the DTA S60 ECU acquisition system, especially with lambda sensor values paired up with RPM and throttle position sensor. By this mean, Atomix' fuel map was also validated as the lambda sensor value stayed close to the target lambda map we designed for fuel efficiency without power loss when it is needed.

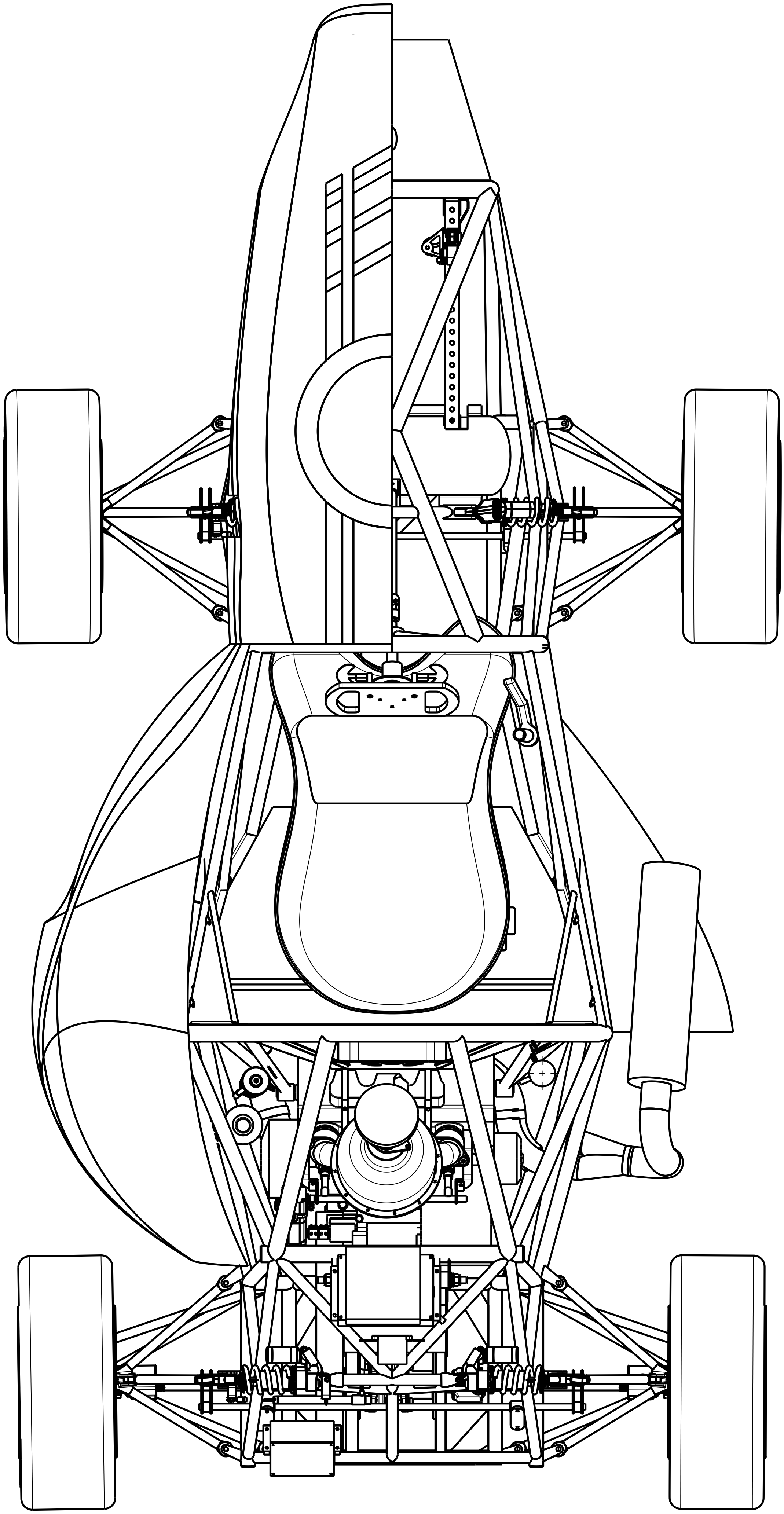
Suspension setup

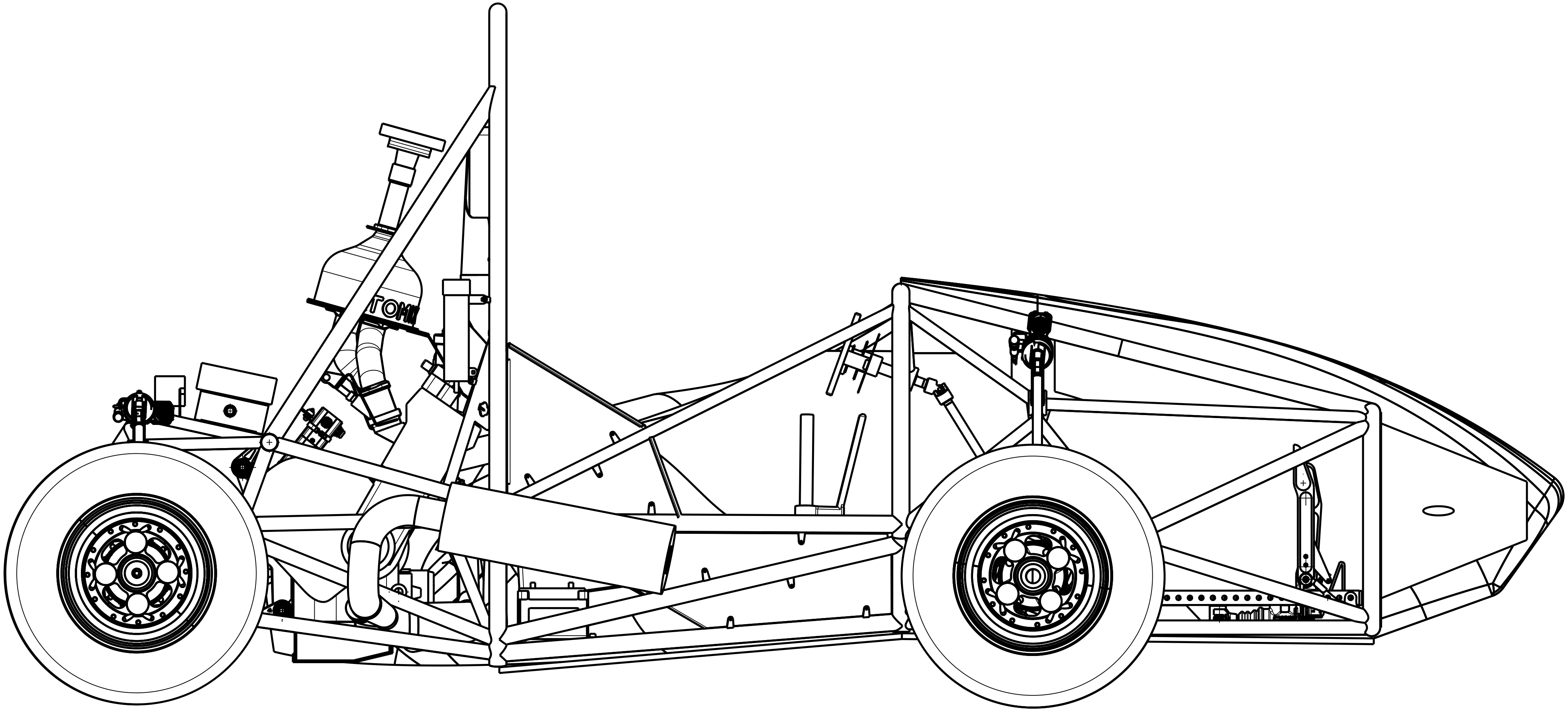
In the mean time, a large suspension setup campaign was followed, in order to get the most responsive car and to get the most of grip from the tires. At first, weight distribution was adjusted to have a perfectly balanced car, then toe and camber were set following the same goal of fast response and high grip. Track testing was essential to have a balanced load transfer which was reached by changing the anti-roll bars setup. Furthermore, suspension geometric setup was validated by temperature measurement on the tire, to be sure that pressure wasn't too high or too low, and that camber and toe settings allowed the tire to work on its full width. At last, damping valves were adjusted using the spring-damper displacement sensors placed on each of them in order to have a responsive car (not overdamped) and yet still stable in every situation (no overshoot).

Driver training

After all these setup sessions, Atomix different drivers drove the car in order to get used to its behaviour, and suspension system was adjusted to provide a more preventive behaviour in cornering. With these setups, all the drivers trained for their different event, so much that Atomix was on track for more than 300 km (approx 180 miles).







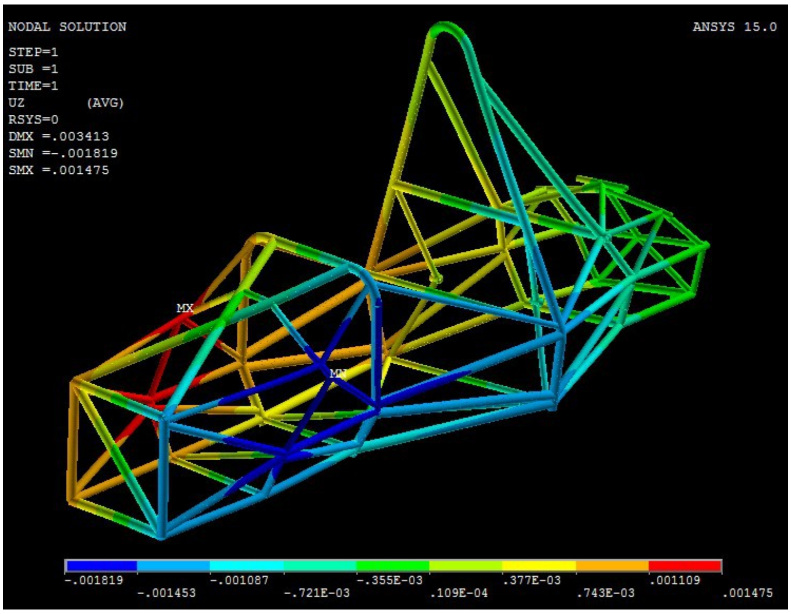


Figure 1 : Torsion simulation from the front frame

Figure 2 : Traction test for A-Arms fabrication process validation

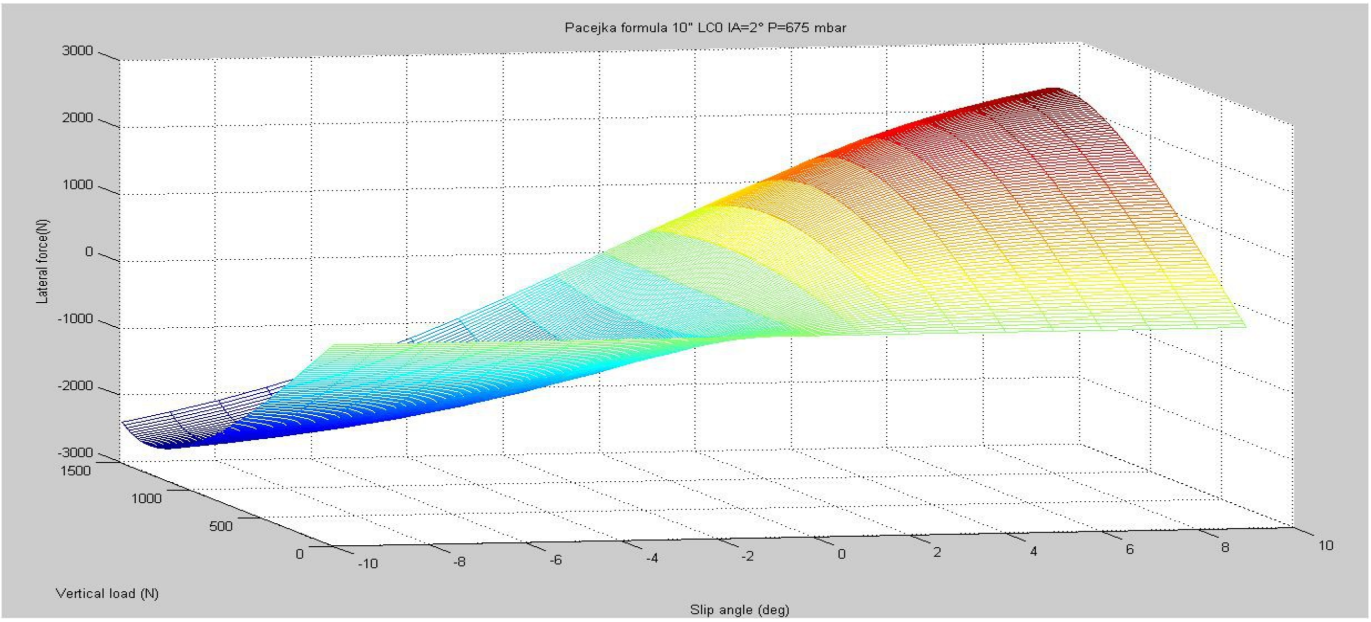


Figure 3 : Results of tires modell for vehicle dynamic simulation

Figure 4 : Testing session