Ecurie Piston Sport Auto – Car n.81
Design report

Design Overview

Our car, named Dynamix, is the first open-wheel single-seat racecar designed by the Écurie Piston Sport Auto (team from École Centrale de Lyon) for the Formula Student competition. To design this first car, we set our design aims in order to build a car which matches customer expectations. As the driver will be a week-end racer with little experience and budget but who wants to have fun on the track, the car has to be:

- Reliable with low maintenance, and ready to run at any time
- Simple and easy to drive to satisfy beginners
- Handy and having a predictable behaviour during every moment on the track
- Powerful and with an acceleration from 0 to 100 km/h in less than 4.5 s
- Sold at a reasonable price
- Safe

Keeping these objectives in mind, we developed a 255 kg car which is finally made of a tubular steel space-frame chassis, 13 inches tires and powered by a four-cylinder internal combustion engine. We conducted many tests on different tracks to ensure reliability, make adjustments and be sure to exploit the car's full potential.

Vehicle dynamics, suspension and steering system

Our goal was to build a car focused on handling, driveability and reactivity to give a feeling of control to the driver. In order to adapt the car to each driver on each track, many aspects are adjustable: static camber, toe, brake balance, limited slip differential, dampers and traction control. Even if the car is designed to be naturally understeering, these adjustments give the driver the possibility to change this and choose the right behaviour for each driving stage.

Tire choice

As this was our first FSAE car, the mass goal was set to 250 kg, so we chose 13 inch tires rather than 10 inch tires as we wanted enough space in the rim. With more space we can chose bigger brake discs to improve brake cooling and ensure better performance and reliability. Besides they allow more space for the uprights and suspensions, which therefore reduced packaging issues. The Hoosier tires were chosen because they were developed according to speeds and tire forces encountered in FS events.

Suspension

Then we focused on the whole suspension design to put the tire on the best conditions. Our suspension geometry is based on the use of unequal A-Arm suspension using spherical plain bearings rather than rubber bushes to improve geometry control and reactivity. To begin, we examined various existing Formula Student cars and set the following values: wheelbase (1610mm), front track width (1300mm) and rear track width (1250mm). Those values were chosen to give the car stability and limit mass transfer. The front track is wider than the rear track to avoid hitting cones with the inner rear wheel during tight corners. We then chose adjustment ranges for camber and toe based on tire data studies. Front kingpin axis inclination and offset, front caster and kinematic trail were chosen ensure stability and to limit self-centering effect because there is no power steering and turning the steering wheel has to be possible with relatively small effort. Wheel position was chosen to reach a 50/50 mass distribution and improve handling.

We chose not to design an anti-roll bar for the sake of simplicity, so we had to find a compromise between roll and ride rates. Ohlïns TTX25 mkII dampers were chosen because they offer lots of adjustments and are very lightweight. We chose pull rods suspensions to avoid buckling risk. We created our own 2D kinematic simulation with Geogebra in which we were able to change many parameters such as the length of the A-Arms or the location of the rod ends, and which allowed us to build a kinematic which respect the parameter values that we had initially set. We also studied the change of those parameters during steering and wheel traveling with DMU Kinematics Simulator. We decided to use pull rods and achieve a suspension kinematics design which matches wheel travel and rates specifications. When needed because of packaging issues, a compromise was found keeping in mind handling and driveability.

Upright and hub design

The uprights were designed to obtain the parameter values which we had determined for the suspension geometry. To help achieve this, we use shims to adjust camber and toe. The essential load cases (such as acceleration, braking and turn) were simulated in order to design an optimised structure which was a compromise between high resistance and small mass. An important safety margin was chosen to prevent breaking parts in case of minor shocks. Each assembly uses two angular contact bearings arranged back to back and pre-loaded by a lock nut to transmit both radial and axial load as well as titling moments. The uprights are designed to improve load path from the wheel to suspension with a very stiff assembly with the wishbone. Front and rear hubs are similar except for tripod housing interface to improve cost and the shims to adjust geometry are the same too. We used strong 7075 Aluminium alloy for both the uprights and the hubs in order to have lightweight yet resistant parts.

Steering system

The steering system was designed to have a minimal bend radius of 3.2 meters for the front exterior wheel. The geometry was designed based on a near-linear behaviour law which is acceptable and the static Ackermann has been chosen at the value of 92%, due to a simple study of the behaviour of the tires. The column was designed accordingly with two universal joints to obtain a linear steering ratio.

Frame and body

Frame

For purpose of reliability and solidity, we chose a tubular space frame design using AISI 4130 steel, with the main focus on stiffness and safety rather than weight. First, a basic CAD model containing space for systems and cockpit templates was created using CATIA. 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. The frame was analysed using ANSYS finite element analysis (FEA) in order to optimise the tubular structure, and with a lot of back and forth between CAD and FEA and a great attention to the rules, the triangulation and tubing diameter and thickness were determined in order to obtain a chassis stiffness of five times the suspension stiffness to avoid excessive distortion under high dynamic load. We also used the alternative frame rule requirements and crash situations, although it wasn't necessary, in order to maximise safety by having a final frame structure which can resist even extreme load cases. Laser cutting was used to produce accurate frame members and engrave each tube with a unique number. The frame was then welded from the bottom to the top on a welding table.

Body

We chose to design a bodywork which mainly covered the front of the vehicle up to the main roll bar, leaving the rear exposed, in order to simplify the design and avoid collisions with the engine and drivetrain elements at the rear of the vehicle. Carbon fibre was the material chosen for the body because it has a low volumetric mass and therefore allowed for a lightweight design. Body pieces design is very simple with no aerodynamics research, and it is therefore less expensive and easy to repair by customers.

Powertrain

Engine

Considering our global design objectives, the criteria for the engine were the reliability, the available power and torque, the mass and dimensions, but also the possibility to buy spare parts easily and the engine response. Although we initially considered using light and compact mono-cylinder or two-cylinder engines (such as the Aprilia 550 SXV engine), we finally chose to use a powerful four-cylinder that would guarantee customer satisfaction in terms of engine response. Besides, the power to weight ratio will be better with a four-cylinder engine, even if a lighter engine could have allowed for a lighter design of other parts. The Honda CBR600RR was chosen because of its well-known solidity and its maximum power RPM which is lower than other models, meaning that the intake restrictor will have a lesser influence. In order to preserve its reliability we chose to not make internal modifications to the engine other than changing the clutch. Indeed we replaced the original clutch with an anti-dribble clutch in order to cancel engine braking effects and allow clutchless downshifting.

Exhaust and intake air system

The air intake and exhaust systems were designed together in order to aim for maximum torque at 9500 RPM after a study on the impact of the 20mm restrictor. For the exhaust, the 4-2-1 configuration was chosen to gain power through Kadenacy effects. As the firing order is 1-2-4-3, the first connections are made between cylinders in phase opposition: 1-4 and 2-3. In order to take advantage of acoustics and improve engine filling, the length of the intake manifold was also optimized for the same engine speed.

The air intake system has been designed to be able to integrate all the corresponding elements required for the engine to function, including inlet flange, gasoline injectors and the throttle body, which is made by AT Power and meets all the required specifications. As geometrical constraints were important, we designed a part of our intake air system using carbon fibre in order to create the complex geometry required for the plenum. Other parts of this system were designed with aluminium to limit cost of the intake system. The exhaust manifold is made of 1.2mm thick stainless steel tube which is solid enough, yet less expensive than titanium.

Fuel system

A custom tank was made using stainless steel and has a capacity of 8 litres, which is sufficient to complete the whole endurance event with a good safety margin. The fuel system is completed by an external fuel pump, a fuel filter, a pressure regulator and a check valve on the cap. Stock primary injectors are mounted on the new intake system and are big enough to supply the engine without a second ramp. The injectors were mounted to aim for the inlet valve.

Drivetrain

To avoid frequent gear shifts, we decided to use only three gears from 0 to 100 kph. We therefore kept the integrated transmission of the Honda engine and the final drive ratio was chosen by simulation to improve acceleration. The chain drive offers the possibility to change this very easily. A limited slip differential was chosen to improve traction during cornering and to limit understeering and tire wear. The Drexler differential was chosen for its small mass, and steel axles were chosen for their strength and resilience. Chain tensioning is achieved with variable length link rods, a simple solution which offers continuous adjustment. The differential position was chosen to minimize tripod operating angle, taking into account wheel travel and chain tensioning.

Electrical system

A Lithium Iron Phosphate battery was chosen for its high power to weight ratio, and its 7.8 Ah capacity is widely sufficient to overcome any situation. We chose to use a DTAFast ECU as its software is very user-friendly and even beginner drivers could make adjustments to engine mapping and other functions. This ECU uses throttle/rpm injection and timing maps with compensation depending upon water temperature, air temperature, throttle transients and manages shift cut, launch control and traction control. A wideband lambda sensor enables closed-loop control if desired. In order to achieve a clean and proper electrical wiring system, a colour-coded wiring diagram was created and followed throughout the installation process. 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 so that only low-power relay signals pass through the firewall and into the cockpit.

Cockpit/Controls/Brakes/Safety

Ergonomics and control

Results from ergonomic studies were used to determine the seat angle, steering wheel position and pedal angles to provide a good driving position. To adjust for different driver sizes, we designed an adjustable pedal assembly which allows for up to 120mm fore-aft adjustment, and the steering wheel can be placed closer to the driver with a 40mm spacer. The seat comes from a go-kart and its mounts can be replaced easily to adapt seats of different types or sizes. We chose a two-pedal design and a hand-actuated clutch system, which can be placed on either side of the cockpit to suit different drivers. With this solution, the driver has the possibility to brake and accelerate without moving his feet left or right, and thus eliminates the time needed to switch from one pedal to another. The hand clutch gives the driver better control during the start phase, and the shift paddles with clutchless gearshifts allow the driver to keep both hands on the steering wheel during the race at all times.

The dashboard has a simple design and layout yet contains several useful instruments to help the driver, such as an RPM-tachometer, shift-light and gear indicator, as well as essential indicators used to monitor the state of the car, including a water temperature gauge, fan indicator and oil pressure warning light.

The steering system is designed to have a ¾ maximum revolution on the steering wheel, which allows the driver to keep his hands permanently in the same position on the steering wheel, even in sharp turns. The rack is just behind the pedal assembly and is protected by an aluminium cover so that the driver cannot touch any moving parts.

Brakes

To ensure good braking performance and endurance, we chose competition brakes from Beringer composed of floating cast iron discs (230mm diameter) and dual piston calipers (32mm bore front and 27mm bore rear) actuated by identical master cylinders through braided hose. This package is designed to give powerful and enduring braking under racing conditions. 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 let the driver easily adjust the front and rear distribution to suit his driving.

Safety

Simulations were made with the chassis to prove its solidity and protect the driver in case of a crash. The impact attenuator decreases the peak deceleration in case of frontal shock and the six-point harness retains the driver. Powerful brakes and predictable behaviour help to regain control the car after a driving mistake. The driver is separated from the engine cell with a 1mm aluminium firewall which is rigid, light, reflective to heat radiation and non-permeable to fluids. The cooling system and exhaust are designed so that the driver cannot touch them when getting in or out the car.

Tests and adjustments

As one of the main objectives is reliability, the first part of the tests was to check the solidity by practicing acceleration, skid-pad and sprint events. Engine mapping was then tuned on chassis dynamometer to maximize output torque. The end of injection was synchronized with the inlet valve opening to vaporize fuel on hot walls before admission stroke. We aim for a 0.88 lambda value at any moment the driver wants to accelerate and adjust injection timing to reach it. The spark advance map was optimized to improve torque while avoiding engine knocking. Data logging was very useful to control engine behaviour, and the throttle transients and shift cut compensations were adjusted to maintain the 0.88 lambda value during tip in or after a shift change. We also tuned launch control and traction control parameters to improve start and handling.

Static wheel loads were adjusted to be as close as possible to perfect left/right balance. We tested different tire pressures to find a compromise between grip and endurance on skid-pad and sprint tracks. Some adjustments were made to the differential bias ratio, as well as to the geometry and the dampers because understeering in cornering entry was initially very high.

A total of about 1,000 km of tests were performed to verify reliability and solidity.

Maintainability

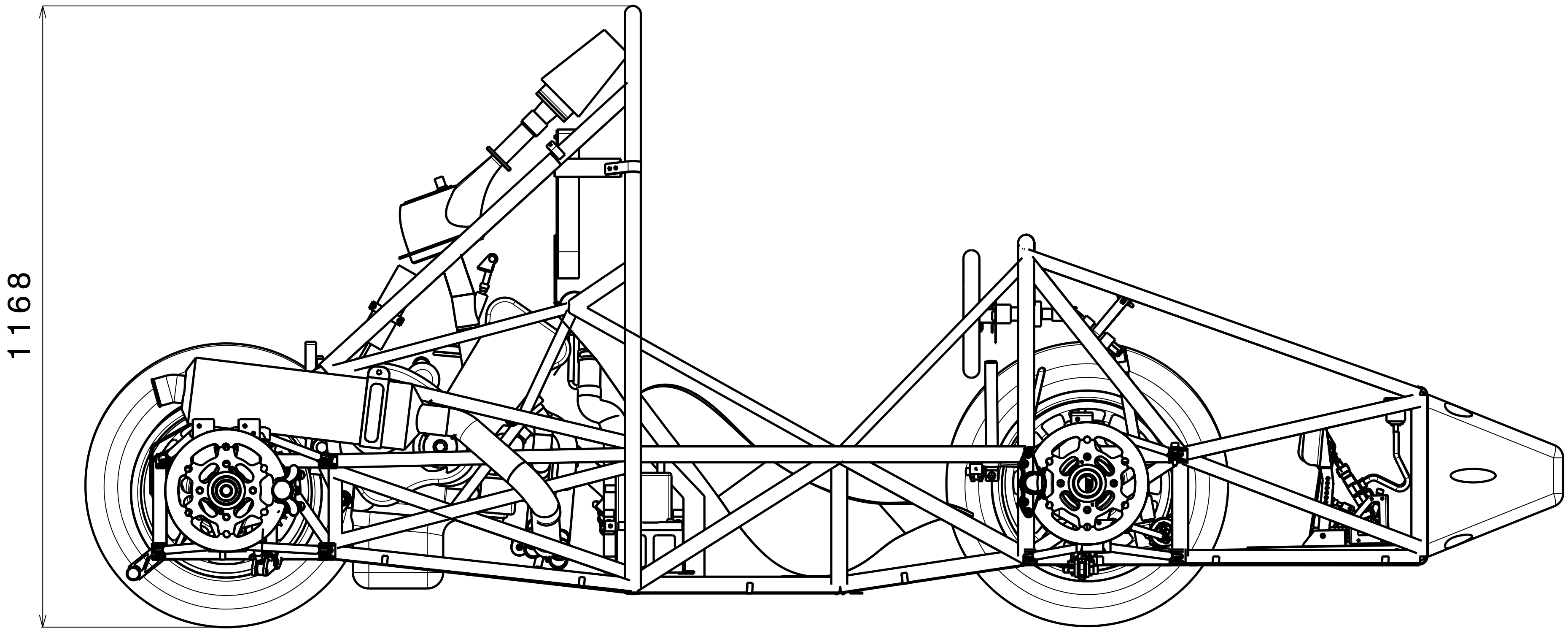
The car was designed to be assembled and maintained by a non-professional mechanic without the need for special tools. Components are easily accessible thanks to the steel spaceframe structure, as well as the absence of body at the rear of the car and a nose mounted with quick release fasteners. The stock Honda engine doesn't need frequent servicing, so the driver can do several races without any engine maintenance. Use of steel and aluminium parts enables low cost self-made repairs.

Working method

Designing a car is a complex task and we paid attention to be professional throughout the entire process. We used a knowledge management system similar to Wikipedia to keep records of our work so each team member could find needed information at any moment. We also have our own production management software which allows us to exchange information with our suppliers. We kept our objectives in mind during the design process to be consistent when we had to make choices.

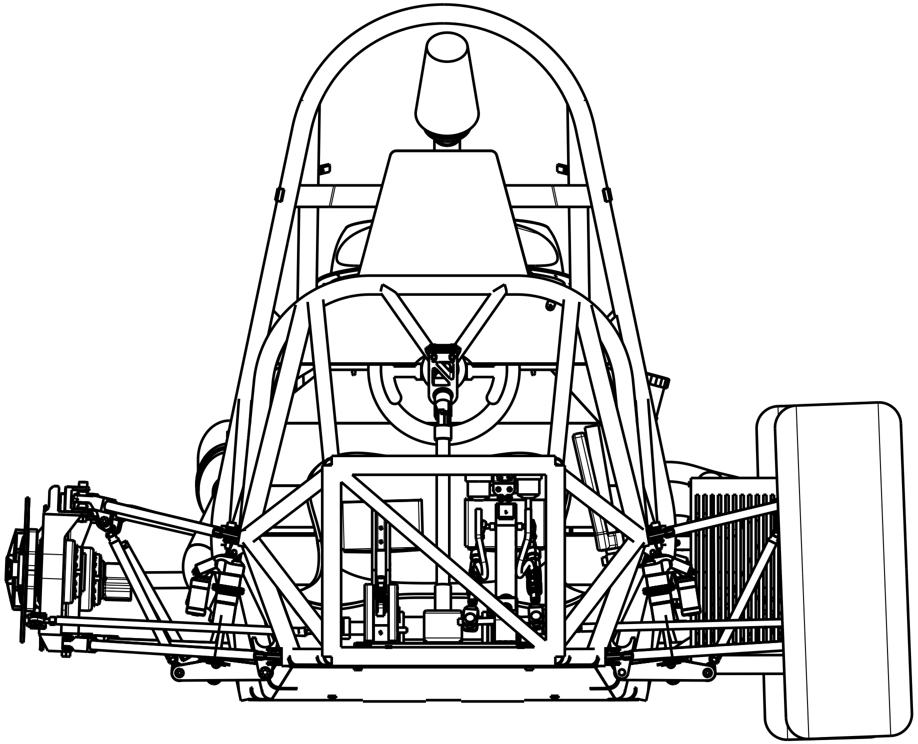
To ensure reliability of the whole car, each part needs to be solid enough to resist during the race. Each part on a load path was tested with the finite element method with Catia V5. The load cases are determined with severe and rare static situations. Critical parts were oversized to avoid reaching yield strength even with high dynamic loads.

Side View

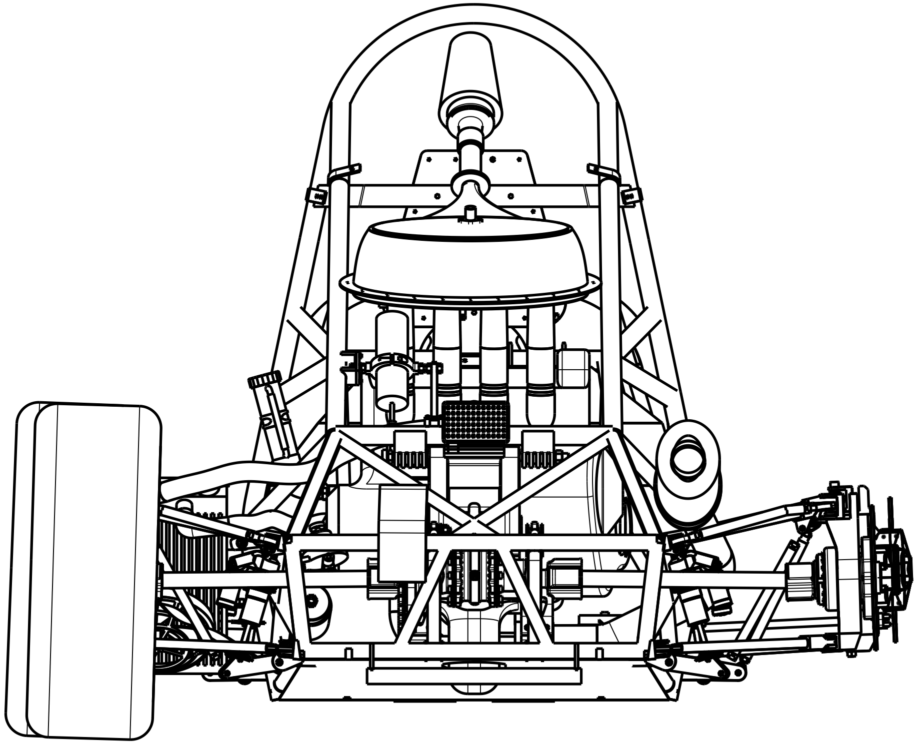


Size A4	Ecurie Piston Sport Auto - Car n.81
Scale 1:12	Ecole Centrale de Lyon

Front View



Rear View



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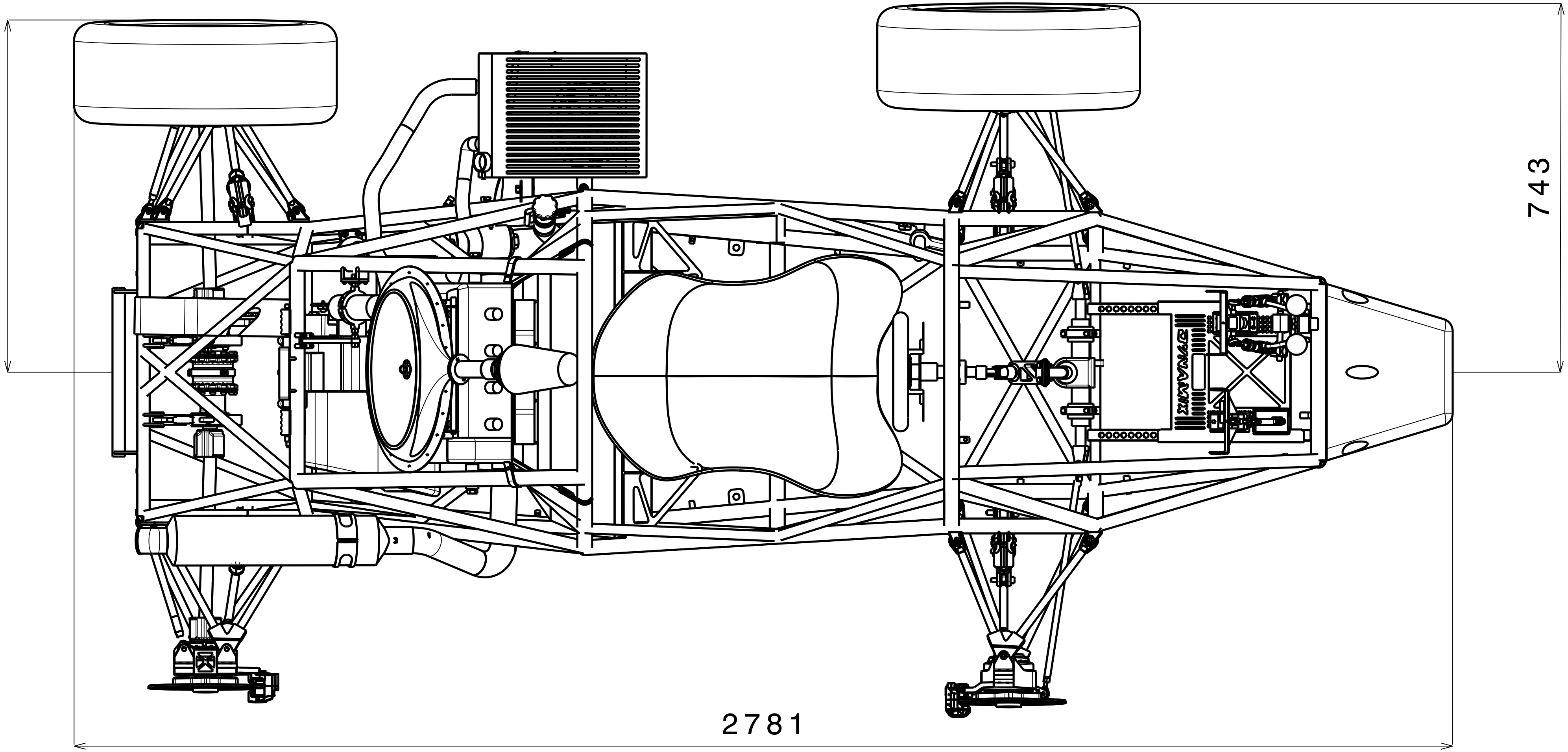
Top View



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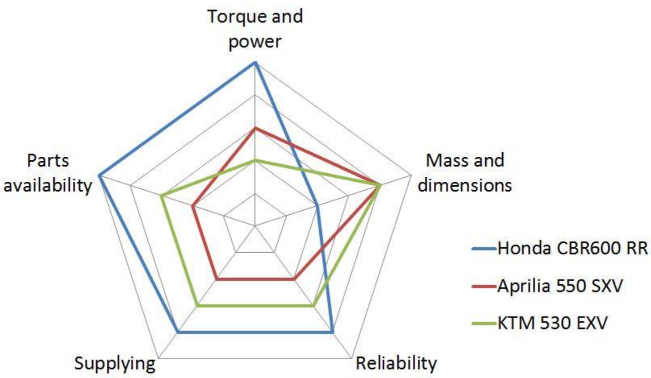

Figure 1: Engine selection diagram

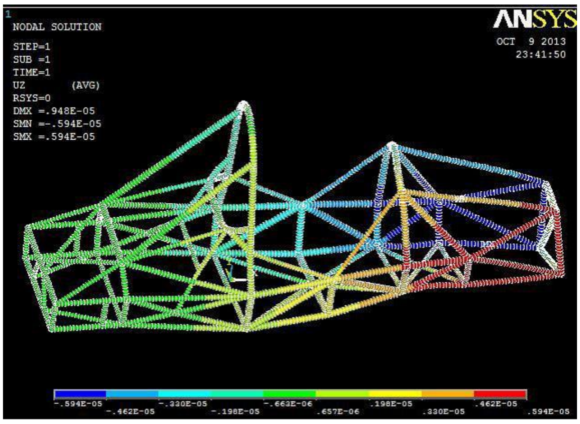

Figure 2: Torsional test of the front of our frame with Ansys

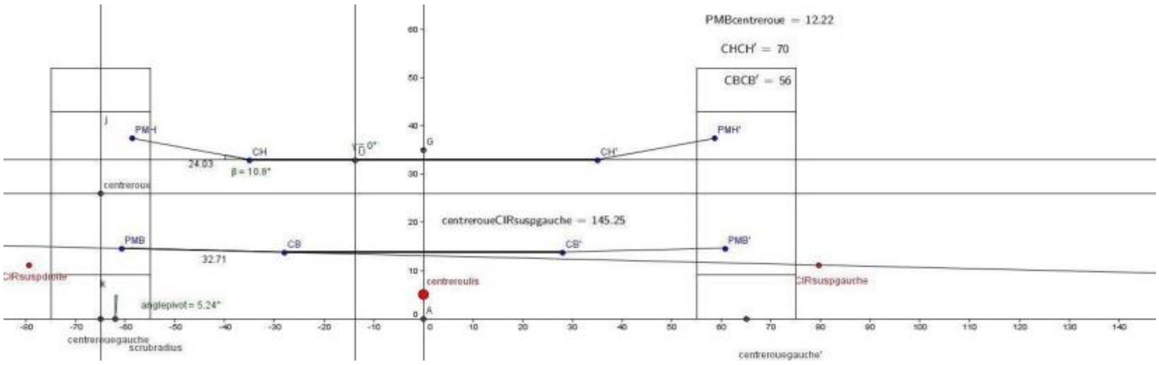

Figure 3: 2D kinematics simulation of the suspension

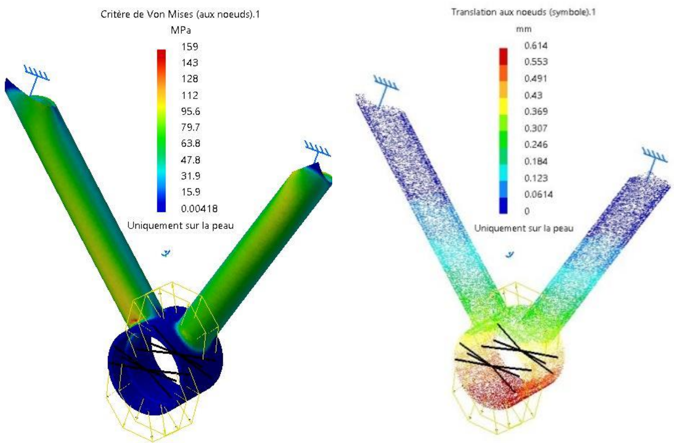

Figure 4: Steering wheel mount analysed with FEA

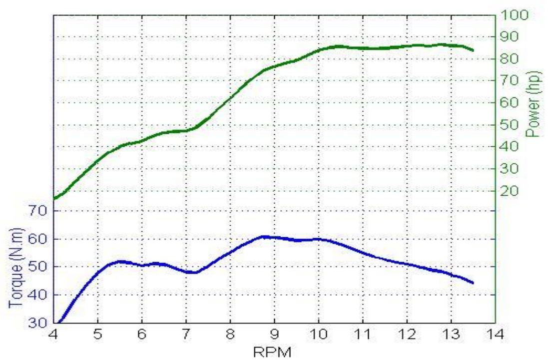

Figure 5: Engine curve after adjustments on dynamometer

Figure 6: Test phase

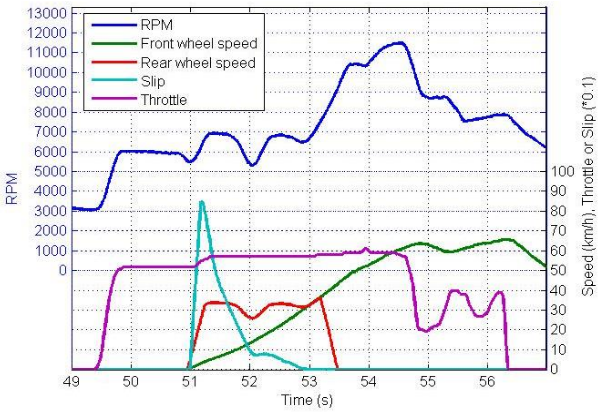

Figure 7: Data logging during launch control