2020 RYERSON FORMULA RACING DESIGN REPORT

Ryerson University – Car # 83 – Ryerson Formula Racing – fsae@ryerson.ca

Team Context

In 2019, the Ryerson Formula Racing car (RF19) placed 28th overall in Michigan with all new suspension, ergonomics, and a first-year aero package. With the graduation of two 5th year system leads, the team's composition shifted to more 1st-time system leads. This led to a decision to take a more modest step with the new car, RF20. RF19 was designed with the goals of Reliability, Drivability, Manufacturability, and Sustainable Design. It also had a 440lb weight target and a 2.4 CL target. To move forward to RF20, it was necessary to evaluate if these goals and targets correlated to real-world results. As far as Reliability, 400km of testing, alongside validating the wings with AutoX and Skidpad back-to-back test contributed to our success. However, we experienced catastrophic wheel stud failure 2 weeks before competition - luckily, with minimal secondary damage and no injuries. Further, inadequate torsional stiffness showed itself severely at Michigan with brand new tires and warm weather, switching from "playfulness" to severe instability on turn-in. These items forced conserving pace in Michigan, while also reducing driver confidence. The "validated" wings were later tested at a wind tunnel and found to yield 45% of their CFD performance. Finally, the performance of our 4-cylinder engine was impeded by inefficient sound suppression, that was inadequately planned. The conclusion was that our Performance Targets and Goals are only as good as the execution. With that in mind, the goals above were kept as "design themes", the weight target was abandoned, and an overarching emphasis on proper execution was put in place with a focus on training and development in preparation for the graduation of the final 4 experienced team members. An emphasis was also placed on financial sponsorship due to a reduction of university funds.

The overall car concept remained a 4-cylinder, aero car, with a steel tube frame, playing to our familiar territory so that we can focus on execution and teaching of the 1st time system leads. From performing a points-sensitivity as well as statistical analysis of competition results (using Optimum Lap), a realistic **overall competition target** was set at 9th place. This meant 4.3sec Acceleration, 5.3sec Skidpad, ~10th in AutoX and Endurance, and ~20th in Efficiency. In terms of Performance targets, this yielded:

1. Maintaining power/torque while reducing fuel usage from 4.7 to 3.8L.
2. Maintaining CL and CD at 2.4 and 1.2 respectively (CD having roughly ⅓ points effect of CL).
3. Achieving adequate torsional stiffness.

Goals

As mentioned above, the 4 main goals of the previous year were kept, mainly as a focal point for team members to constrain their scope and maintain a cohesive car. In terms of **Driveability,** the focus was placed on improving upper body comfort through re-evaluation in an ergonomics rig. **Reliability** was addressed by evaluating/replacing the failure points of RF-19 as well as improving the car testing procedure. A target of 700 km of testing was set. To reach it, Jan 1st was set as the completion date, with the help of **Manufacturability**. The main manufacturing delays last year were project management related - meaning, the designs were simple enough to build but were bottlenecked by supply chain or waiting on another sub-system. Designing and packaging parts in efforts to make them easier to reach, tune, validate, and sustain optimal function fell under **Sustainable Design**.

Performance Targets and Car Specs

Beginning with **Vehicle Dynamics**, the system primarily accommodated Aero needs - ride height control. Based on preliminary aero-maps, ride frequencies and roll rates were set. From previous experience, the testing and Michigan course surfaces were not sufficiently bumpy to warrant a softer setup, both for comfort and for grip. Tire choice was evaluated (see Drivability section below) with the use of TTC Data. Track width was set based on a basic quasi-steady-state MATLAB lap simulator, where the track parameters (corner radii) were adjusted to emulate the tighter line afforded by a narrower track width (while scaling down grip based on load sensitivity). Based on the roll rates, a torsional stiffness target of 1300Nm/deg was set, as, 4x the roll rate (Deakin). The target was reached in SW simulations, although reduced to 1100Nm/deg due to geometry-based front bellcrank compliance initially not accounted for. In the physical test, it was found to be 970Nm/deg. In terms of **Powertrain**, the main focus was reliability and tuning of the existing package, to reduce noise and use less fuel. A noise test was performed, comparing different mufflers. The test was aided by an Architecture professor with professional sound measuring equipment. It was realized that some mufflers performed very well at low rpm but substantially worse at high rpm, likely related to the size of the perforations in the internal duct of the mufflers, as well as the effective length. Interestingly, a significant portion of the energy emission in the FFT frequency plot was high frequency, likely coming from the engine/valve-train directly, and not the muffler. This meant further trials with sound-deadening cowlings were to be explored during testing. In terms of **Ergonomics,** the driver position was reclined to lower the CG, aid wing airflow and provide more driver comfort, given the 65 deg back angle in RF19 was uncomfortable. **Aerodynamics** was designed with a 3-element front wing and 5-element rear wing to meet the target CL of 2.4. A front and rear wing package was chosen due to the validation performed using skidpad and AutoX tests, showing significant gains. The airfoil behavior in rapid velocity change was also considered, to not induce sudden separation. After prototyping hollow and closed-cell foam wing profiles, a foam wing profile with steel end ribs was chosen to improve stiffness and manufacturability. A cloud computing sponsorship was acquired, allowing nearly complete mesh convergence in Star CCM+, with a highly detailed car on a rolling road (~20 Million Cells). In terms of **Electrical**, the component location was carefully considered to reduce the length of heavy-gauge wires. A data logger was also acquired to assist in data acquisition and process efficiency. .

Driveability

In terms of **Vehicle Dynamics**, a switch was evaluated to new 16in Hoosier tires, with the use of TTC data, from the current 18x7.5 R25Bs. While the 18's were originally chosen for their forgiving (wide) peak, they seldom reached their ~55C operating temperature during chilly Michigan conditions especially in the AutoX, Skidpad, and Acceleration events. While a switch to the softer LC0 compound was an option, their substantially worse relaxation length and load sensitivity made them less desirable than the R25B's. Peaking slightly lower, the heat up benefit of the 16x7.5 R25Bs eventually would fall short of the 18s in later endurance laps but excel in all other events. A 5.7mm Kinematic Trail was selected minimizing steering effort while maintaining high-speed stability. Through this, a secondary objective of not drowning out the tire feedback (MZ) and allowing for a tight 3.4 steering ratio was achieved. This was validated during summer testing by decreasing caster, monitoring high-speed stability and “understeer prediction” on a skidpad. To independently set steer-camber, moderate kingpin offset was set. The previous car did not have anti-roll bars, compromising front wing height as well as making the car difficult to tune steady-state. A front and rear anti-roll bars were implemented. During testing, if the rear bar is sufficient, the front will be removed.

Under **Ergonomics**, an adjustable steering wheel was prototyped and tested with various grip angles, offsets, diameters, and open v.s. closed thumb design. Feedback from alumni and experienced drivers lead to removing specific pressure points and not over-constraining the driver in the wheel. The final design included a carbon-balsa plate with Nylon 3D printed grips wrapped with bicycle bar tape to reduce vibration. Driver positions were tested using an ergonomic rig with the adjustable wheel, pedals, and seat fitted to a simulator setup. This allowed each driver to practice actual dynamic testing with various seat and wheel configurations. A 50 degree back angle was chosen to balance visibility with comfort, while also not constricting powertrain packaging. The steering wheel angle was set to 70deg, which while not as comfortable as 80deg, allowed for the use of a single u-joint. From experience with both variations, we opted to live with the slight non-linearity in favor of reduced deadzone. A seat plug was molded off one of the drivers using expandable foam, after which a fiberglass female mold was made in order to layup the carbon fiber seat. Having spent 2 years troubleshooting a pneumatic shifting system it was abandoned, both in terms of reliability and with a relatively tall gearing chosen downshifting to a hairpin is a non-issue. The gearing was partially set as a simpler solution to the shifting problem from a driver control point of view.

The **Powertrain** system was largely maintained for this year, with a focus on engine tuning to widen the powerband through acquiring a dyno tuning sponsorship. The aforementioned gearing change was simulated in Optimum Lap, showing a lap time penalty of 0.15 seconds on the 132sec Michigan endurance course while reducing the number of shifts from 118 to 66. Further, pulling each gear all the way to 14k (~2k past ideal shift point) results in another 0.2sec penalty, but gear shifts are down to 42. For the driver, ⅓ of the shifts, especially in AutoX, was substantially beneficial.

Reliability

On RF-19, 4 titanium wheel studs (RCV branded) sheared during a ~90km/h sweeper with a bump. Upon observation, some titanium studs had thinner wall thickness than others contributing to fatigue failure. Previously, we experienced torque related shearing (35Nm), and as such, it was hypothesized that the lower torque spec later set (30Nm) allowed for slippage at the shear surface, and subsequent stud bending. This year, RF-20 is equipped with 7/16 inch diameter solid steel studs, as well as a tighter fitting centering spigot.

The lubrication system has plagued the car’s reliability for years. On RF-19, an internal flexible baffling system in the oil pan solved this issue by effectively trapping oil near the pickup during cornering, braking, and acceleration. This solution was developed on the previous car, with continuous testing to ensure function, even under spike accelerations.

In terms of the aero package, care was taken to reduce failure points. In previous years, threaded inserts holding the endplate tended to spin/pull out and had caused an endplate to fall off in yaw during testing sessions. On another occasion, upon cone impact, a front wing mounting rib (Carbon-Nomex) fractured. To solve both issues, waterjet steel ribs were used and the mounting holes were tapped. A special structural adhesive was used to bond the ribs to the airfoil instead of only epoxy. An undertray was designed for RF-20, but with timeline delays and carbon sponsorships being canceled, it was postponed to be a summer testing item. At the time of this report, the first test day was performed (Mar 1), while the rolling chassis deadline was met at a record time (Dec 21), but electrical and engine issues delayed testing.

Manufacturability

An emphasis was placed on avoiding complex processes, specifically for machining. The uprights were designed to accommodate a 3-axis mill, despite a 5 axis CNC available, to reduce lead time. Further, laser cutting and water jetting were employed whenever possible, with bend lines etched, all in an effort to eliminate manual measurement and positioning. The frame jigging was done using laser-cut templates, forming an “exoskeleton” around the frame, which were cut with a “tab and slot” pattern to fit together easily. In terms of suspension tabs, the arms were welded first. The arm consisted of 6.35mm thick waterjet “ghosts” acting as bearing housings that slotted into pre-notched tubes. The tight fit of the ghosts and symmetry (relative to the tube midplane) resulted in little to no weld deflection and no jig requirement. The bearings were mechanically retained using a welded washer, forming a shoulder alongside a reamed press-fit hole. The entire frame, from tube profiles to painted frame, took a record time of 2 weeks, largely due to having all of the laser cut jigs and a-arm components ready to go at once.

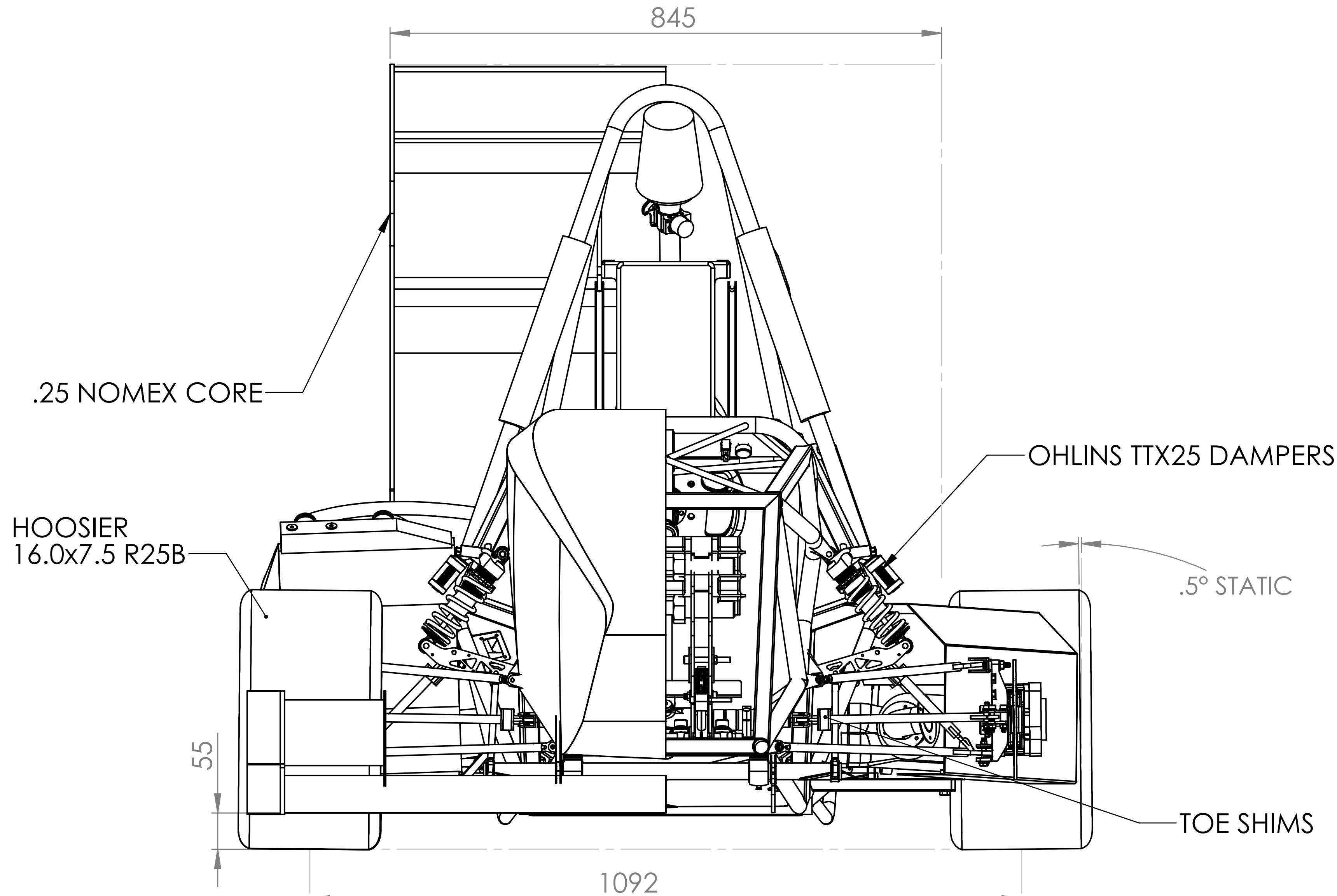
In terms of Aerodynamics, the internal structure of the wing elements were changed from a hollow configuration with internal ribs to a full foam core. This vastly eased manufacturing while increasing the weight from 16lbs to 19lbs for the full aero package. This was because fewer layers of carbon fiber and epoxy were needed to achieve an equivalent stiffness.

Sustainable design

Sustainable design makes parts easy to reach and sustain optimal function. Both serviceability and data acquisition (DAQ) play into this goal. The focus was put on reducing servicing time, standardizing fastener sizing, and implementing smart tuning. In terms of repeatability, ride height and toe were switched from a rod end arrangement to a laser cut 3-bolt (M3) flange, with aluminum shims. An additional benefit was the elimination of manual machined threaded inserts, in favour of reamed ghosts.

DAQ was integrated into all the vehicle systems to measure and tune for performance. Some of the sensors include brake temperature, wheel speed, suspension travel, steer angle, brake pressure, and radiator inlet and outlet temperature. A large data analysis emphasis was put on linking driver input sensors to car sensors to help train the driver, as well as isolate car characteristics from driver technique. A data logger was donated by a sponsor (Kvaser) to improve data collection efficiency and increase the amount of data that can be collected.

Engine management and data logging are done with an MS3 Pro ECU. The stock R6 charging system charges a Shorai LiFePO4 Battery mounted on a quick-release compartment. The wiring harness was designed to take in multiple sensors from every corner of the car. To record all the data, general-purpose sensor modules were designed to acquire and process digital and analog sensor inputs and then send them to the ECU over the CAN bus for logging. The functionality of the sensor modules can be customized and extended through firmware. The use of CAN-connected sensor modules allows us to exceed the physical pin limitation of the ECU. With the new data logger, that limitation is no longer a problem.



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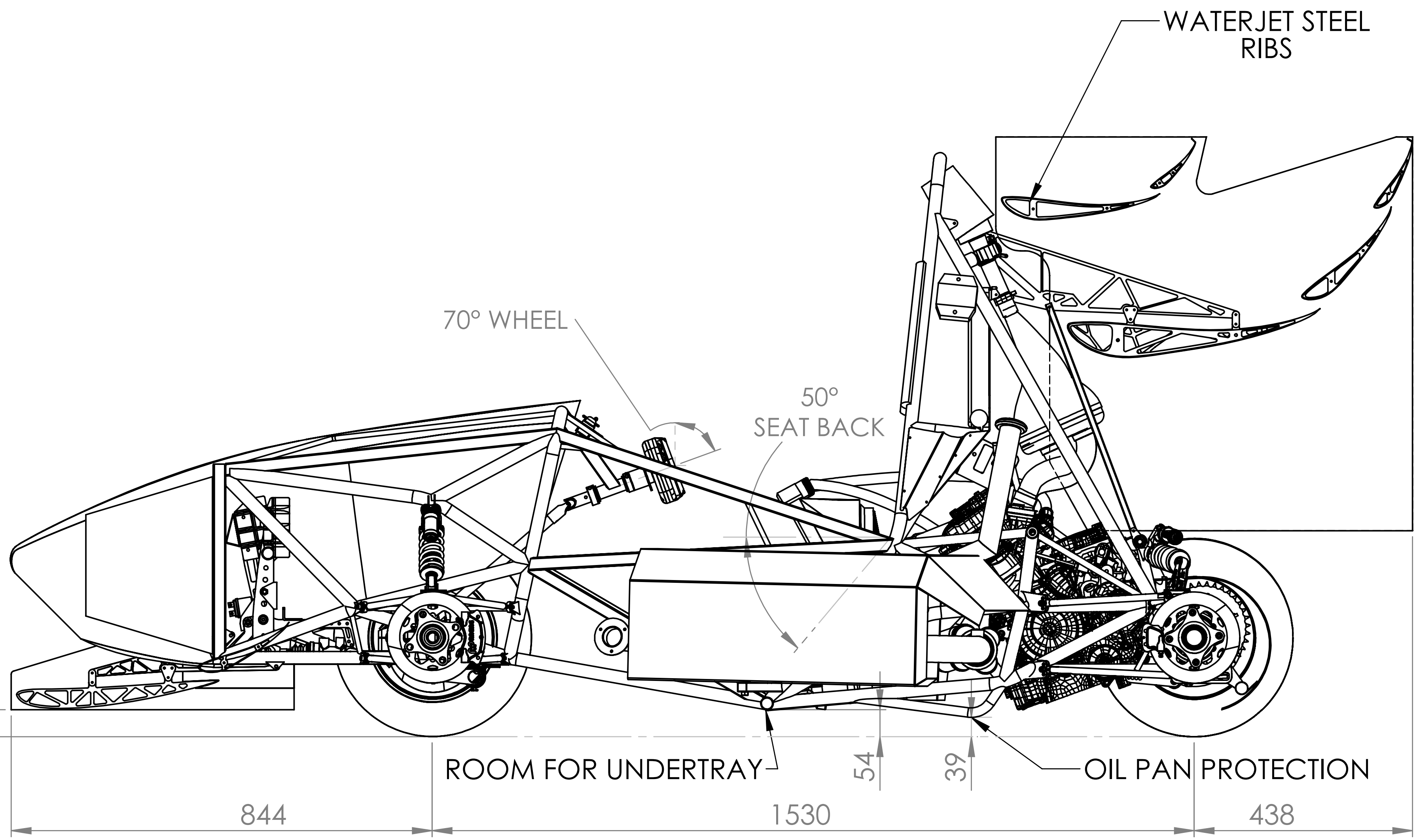

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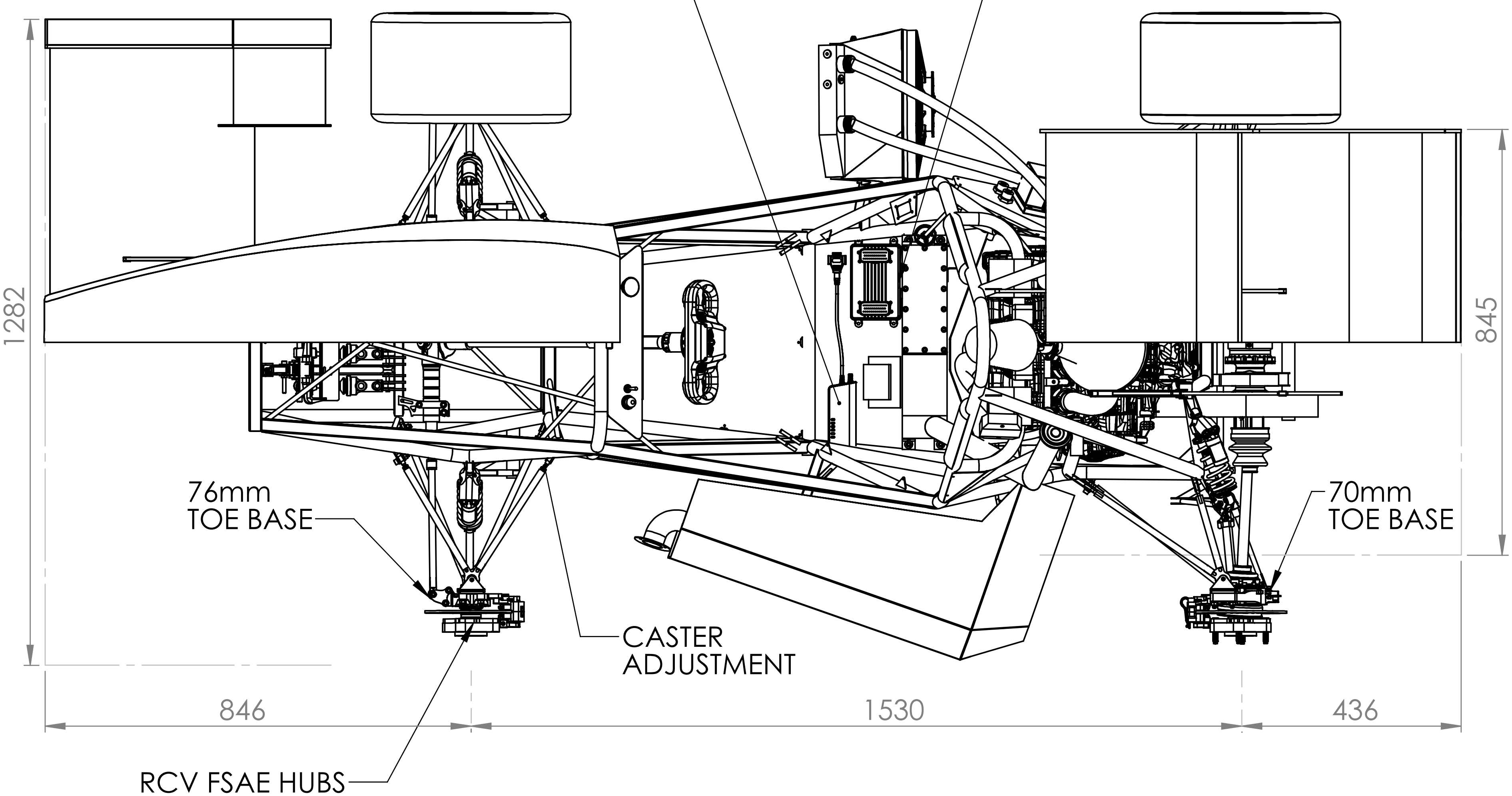

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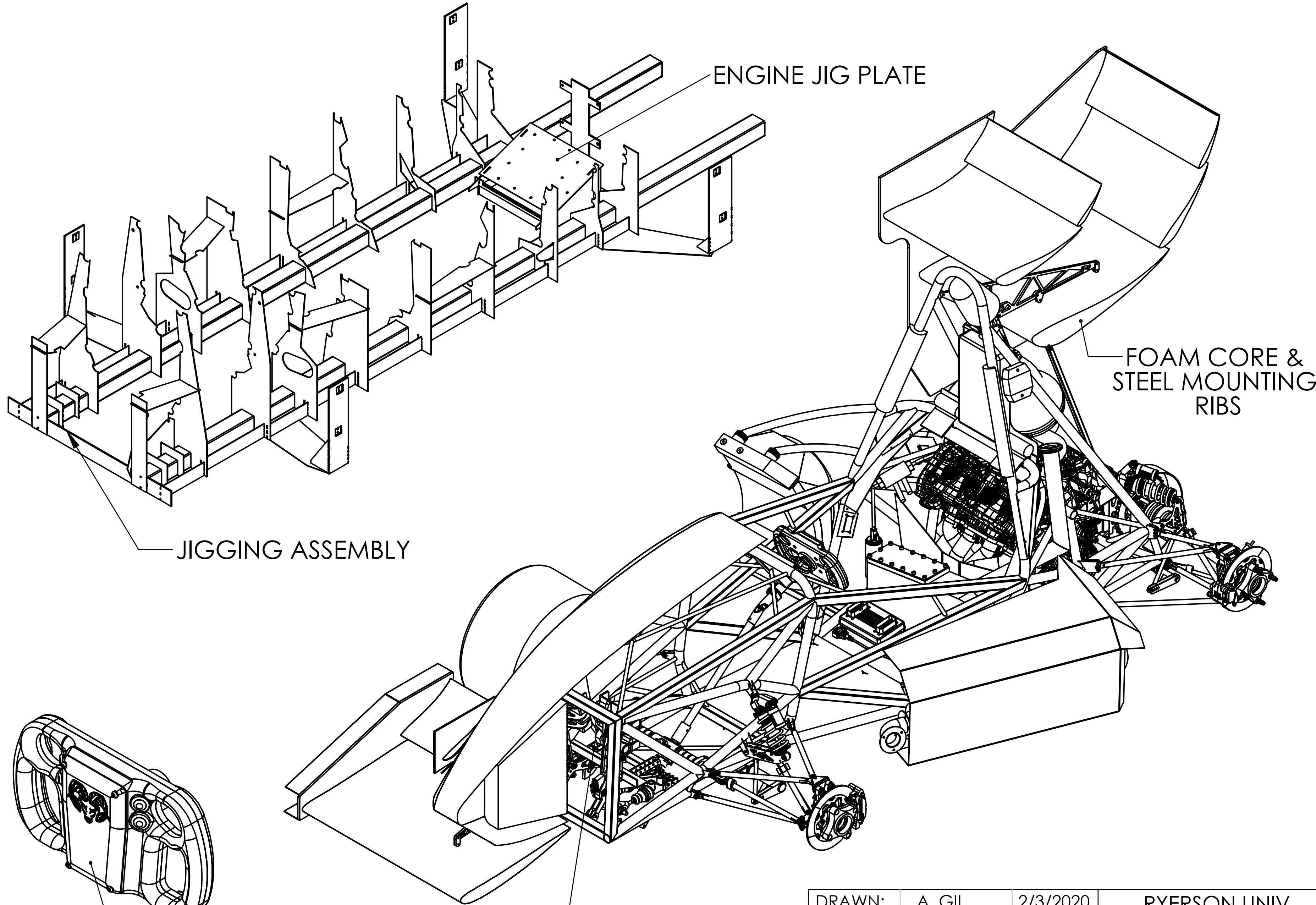

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		SCALE:1:12	SHEET 4 OF 4