Queen's Formula Racing Design Report - 2018

After Queen's Formula Racing's (QFR) most successful year to date at Formula Student UK, the main challenge presented for 2018, was to build upon this success by learning from the mistakes made. From reviewing the car against competitors at the 2017 event, we highlighted the following areas to focus the team's resources to improve the yield of points at the competition:

- Skid pad (vehicle handling)
- Cost event
- Design event

Finishing 3rd last place in the skid pad event was a clear sign that there was much to be improved on. By analysing this result, and the factors that lead to it, it was found that the team lacked vehicle & driver testing, suspension adjustability and had a completely incorrect anti-roll system. This also contributed to the poor lap times in both the sprint and the endurance event which cost us a top 5 finish.

To improve on the poor result in the static events, valuable insights from the judges were used to identify the root cause of the issues. The feedback given highlighted environmental protection, sustainable material selection and a lack of documented evidence/analysis as being the team's biggest weaknesses. Throughout the design of the 2018 car these points were carefully considered.

Resource Allocation

To enable the team to efficiently target the imposed objectives, the available resources had to be carefully managed. To allow comparison between the available resources, each one was monetised, and each task/component was optimised for reduced cost. The assigned value placed on our resources was as follows:

- Student engineering time: £3.00 per hour
- Technician support time: £15.00 per hour
- Standard machine shop time: £30.00 per hour
- Advanced machine shop time (5-axis milling): £50.00 per hour

From benchmarking off-the-shelf lightweight alternatives to many components, the cost of each kilogram saved was set at £1,000 (or £1 per gram). This allowed continuous assessment throughout the design process if the task being undertaken was resource efficient which cut down on the amount of time spent "over engineering" components with respect to others.

Project Planning

Having identified a lack of testing as a major factor in the poor handling of the '18 car, the root cause was found to be a lack of project planning. A consistent failure to meet imposed deadlines was the main factor for the late completion of the 2017 car. With that in mind, a new schedule was proposed, slightly in advance of the previous year (to allow for a small slippage) but with very strict deadlines. As the effective time available for component design was reduced, less time was available for optimisation. This potential mass penalty was offset by the benefit gained from additional testing time. A simplified version of the schedule is presented in **Figure 1**, showing the various design stages (gateways) followed by manufacturing and testing.

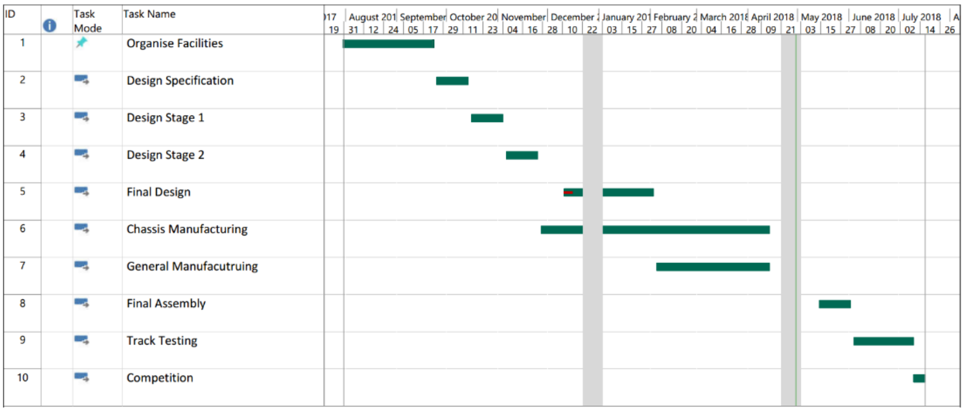

Figure 1 - QFR Project Plan 2018

To aid the design process and to highlight how the team members should be splitting their own resource, a design process was created for each team member to follow as shown in **Figure 2**. It was front heavy, with most of the time allocated for research and concept development. It should be noted, that a significant amount of time was left (15%) for evolution/tuning of the system. This is something often forgotten in years previous and has resulted in poor performance at the vehicle and subsystem level.

Design Process

20%	30%	10%	15%	10%	15%
Problem Definition / Research	Concept Development	Evaluate and Analyse	Manufacture	Verify	Evolve / Tune

Figure 2 - QFR '18 Design Process

Design/Competition Targets

A benchmark review of the competition and the results from the 2017 event lead to the following targets being set. Each target has been optimised for points, using the monetised resource method to calculate how our resources could be most efficiently put to use.

- Mass: 199.5 kg
- CoG Height from the Ground: 265 mm
- Power: 63 kW (84.5 bhp)
- Torque: 53.4 Nm
- Testing: 200 km
- Endurance Fuel Consumption: 2.55 L
- 75 m sprint time: 3.90 s
- Skid pad time: 5.30 s
- Design Event Score: 130
- Cost Event Score: 75
- Business Presentation Score: 70

Our analysis has shown that if all of the design and static event competition targets were meet, a point score in the range of 730 to 750 would be achieved, placing QFR in the top three teams.

Overall Vehicle Concept

The most important decision in the design process is without doubt the powertrain configuration. Every year an increasing number of competitors move to an electric powertrain highlighting the advantages it offers. To asses the right option for QFR, each powertrain configuration was evaluated for both four motor electric drive systems but also alternative ICE configurations. It was shown that although an EV powertrain is now of a higher performance than our current ICE, the team lacks the financial capital, (> £30,000) to fund such a change in the short term. Alternative ICE's were investigated however none offered a greater power, weight and efficiency balance as our current award-winning Yamaha R6. For this reason it was decided to use the continued success of the Yamaha R6 to save financial capital over a number of seasons in order to fund a move to an electric powertrain in the longer term.

A target mass of 199.5 kg drove the design stage, with every aspect of the vehicle being assessed for its performance. A steel space frame was chosen over an Aluminium or Composite alternative which greatly helped aid the manufacturing process, which significantly reduced the build time. This reduction in build time allowed for more time testing the vehicle on the track allowing drivers to gain more experience. In all design stages improving manufacturability was essential to reduce production time and stay within the build plan.

The new pull rod suspension system was selected over other systems, which are compared in **Figure 3**. Swept back wishbones allowed the chassis to have fewer members and as a result, be lighter. The material for the suspension and ARB was chosen based on strength requirements from excel analysis tools using equations such as Euler's buckling theory and Tresca's shear stress for the ARB in torsion.

			Strength	Stiffness inc. compliance	Mass	Centre of gravity	Design risk	Set-up adjustability	Space efficiency / packaging	Cost	Aerodynamics	Total Score	Rank
		Weighting factor	22.2	19.4	16.7	13.9	11.1	6.9	4.2	4.2	1.4	-	-
Solution #	Solution Name												
1	Current Push-rod		3	3	3	3	3	3	3	3	3	300	3
2	Pull-rod, inboard shocks		3	3	3	5	2	1	1	3	5	297	4
3	Pull-rod, outboard shocks		3	3	3	5	3	3	3	3	3	328	1
4	Direct acting		3	4	3	4	3	1	2	1	2	306	2
5	Push-rod, parallel outboard shocks		2	2	3	4	2	3	3	3	4	263	5
6	Push-rod, shocks behind peddle-box		2	2	2	3	2	2	2	3	5	222	6

Figure 3 - QFR '18 Pull rod suspension and Anti-roll system

Overall Integration of Development

A comprehensive flow chart was used by the team to ensure smooth delivery of the final car assembly and meet all deadlines. Stage 1 engineers were involved by carrying out extensive workshop preparation to certify all essentials tools were in place which could have been a road block when assembling the vehicle.

Using an advanced CAD model allowed interference detection to be completed and build guide sheets to be created to aid physical manufacture when in the workshop and jigging components. This was vital as it gave confidence of where to position components before they were welded or braised, ensuring reduced rework and thus reducing manufacture time.

Driver Environment and Low Voltage System

To aid the driver vehicle integration, reducing the mechanical play throughout the car was a key design target, especially in the steering and pedals. The adjustable pedal box allowed the drivers to be confident behind the controls supplemented with adjustable brake bias. A higher seating angle helped to improve the visibility for the driver with new side supports designed to help secure the driver in position when cornering.

The low voltage wiring loom is protected from environmental factors such as heat and water thanks to high quality connectors and good wire management. A lightweight lithium ion battery is also used to help achieve the reduced target mass.

Chassis Design and Development

2018 has witnessed the largest amount of changes to a QFR vehicle in over ten years. In depth project work, coupled to discussions with 2017 design judges and the overall aim to solve handling issues, led to the design of a brand new pull rod, double wishbone suspension system, with a new fully adjustable hollow ARB system, as seen in **Figure 4**.

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Figure 4 - QFR '18 Pull rod suspension and Anti-roll system

The chassis sees further mass reduction on the 2017 design due to the new rear swept back wishbones. Members are all nodal, therefore forces are distributed directly into the T45 tubes permitting a high torsional stiffness of 1927 Nm/deg. Tubes were braised rather than welded to reduce the chance of fatigue fracture in the heat effected zone of the material.

The new steering system has focused on negating bump steer and reducing compliance in the column. A double UV joint column each positioned out of phase has been used to negate non-linear motion and hence improve driver confidence. The brake system includes bespoke steel disks optimised to reduce mass and thermal dissipation with aluminium callipers and allows for brake basis adjustments.

Powertrain Design and Development

QFR18 powertrain incorporates a YZF-R6 5SL engine with dry sump system, a heavily modified cam lift system and optimised intake plenums utilising unsteady gas flow dynamics within Virtual Engines software. Significant engine testing and optimised mapping has resulted in an increase in torque and power by 16%, producing a peak torque output of 58.4 Nm and peak power output of 82.3 bhp. An improvement in BSFC was also achieved by up to 34 g/kWh. Further engine testing undertaken develops potential mapping capability utilising cylinder deactivation to further increase fuel savings during endurance events under partial throttle applications, with an additional 10% BSFC saving potential.

Marrying of the M800 ECU and the pneumatic sequential gear system, allows pre-programmed limits for auto shift changes. Acceleration sprocket analysis along with ECU mapping and track testing have also developed and optimised traction and launch control along with auto up-shift parameters leading to further improvement in acceleration of the QFR Vehicle. A Drexler limited slip differential and CV joints are used to transmit power to the wheels while stub axle hubs designed in-house reduced the mass of hub and upright by 26% and 30% respectively over their predecessors.

Practical Design Aspects

Costing analysis has influenced design choices and compromises between performance and cost the QFR vehicle. The 2018 space frame chassis has a reduced the mass of 6% over its predecessor and uses standardised components such as top hats and bolts, improving ease of assembly and maintenance of the vehicle, along with the feasibility of mass production. Manufacture of MDF jigs for chassis and suspension tabs allowed accurate placement of chassis components while extensive use of a gantry water jet cutter was utilised for all sheet metal components on the vehicle reducing machining costs and lead times.

Servicing and adjustability of the QFR Vehicle drove development of suspension design, engine spacing, dry sump belt cover and accessibility of fixtures. Fully adjustable auto shift, traction and launch control settings allow amateur drivers to develop their skills further, while a fully modular high-quality wiring loom allows repairs and modifications on track. A risk analysis tracker was utilised throughout the year, assessed manufacturing and delivery times, highlighting highest risk parts with potential to halt progress on the QFR18 vehicle.

Application of Engineering Science

Extensive utilisation of Abaqus CAE software for FEA analysis on critical components on the vehicle have driven mass savings and stress concentration reductions, improving service interval times for unspring mass and suspension components.

Exploitation of strain gauge instrumentation allowed verification of strains on static components, like the pedal box and ARB levers (Figure 5 & 6), along with chassis and suspension members during dynamic track testing.

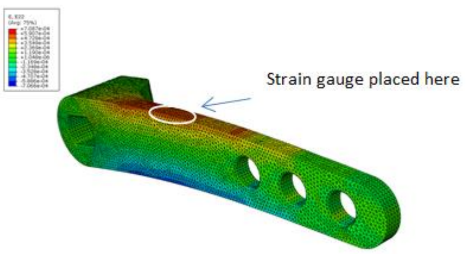


Figure 5 – Abaqus strain gauge testing

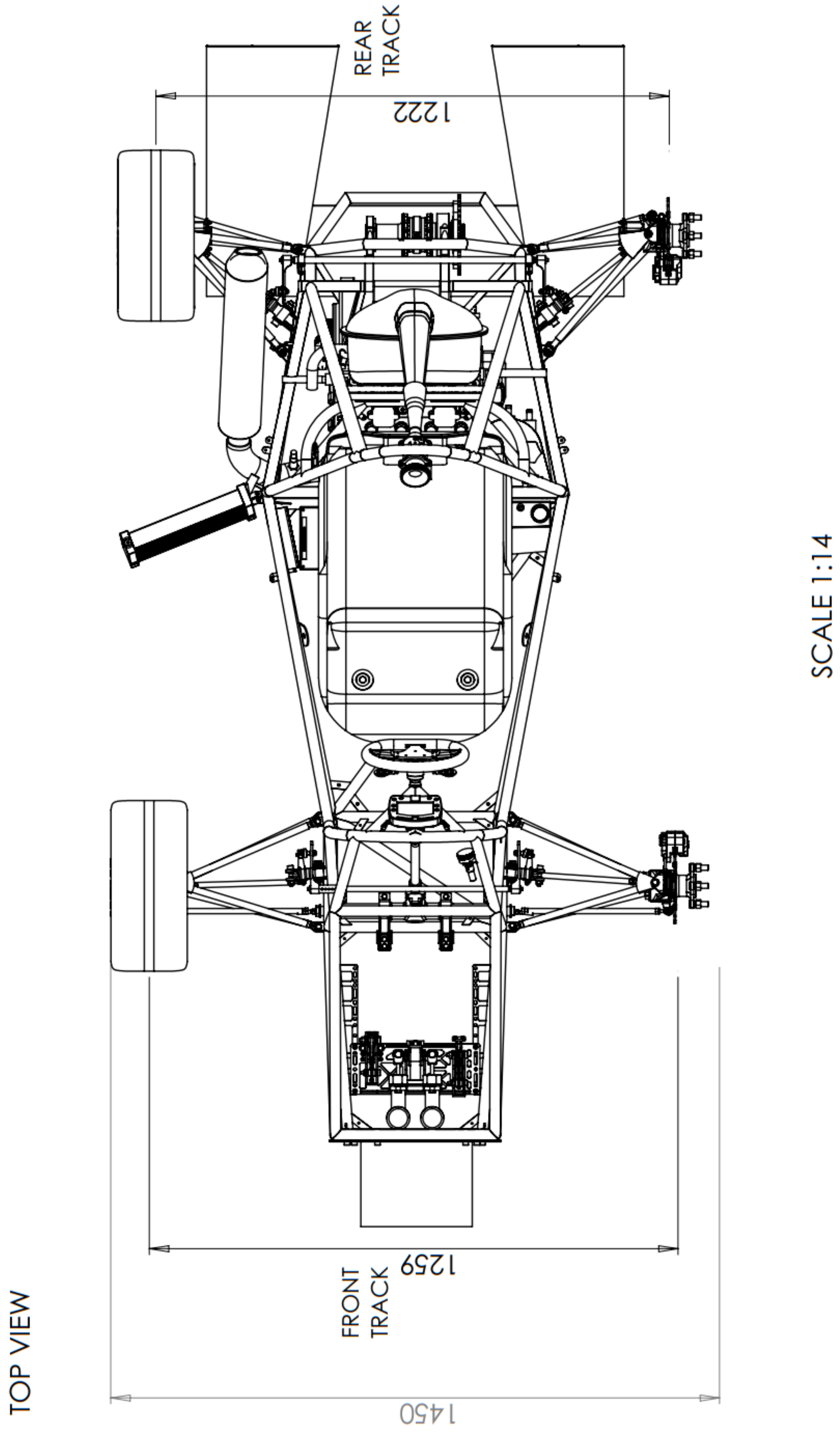
Figure 6 – Strain gauge testing on ARB lever

Effective communication and information sharing was achieved through employment of QFR Microsoft Sharepoint, Calendar, procurement and interactive task lists along with weekly operational and team meetings. This ensured that critical gateways were meet throughout the year.

Conclusion

The QFR18 vehicle has seen a huge upgrade to its suspension over its predecessors which, thanks to improvement project management, has allowed for track time testing to tune the whole system. Upgrades have been made to many of its main components and systems in order to achieve an ambitious weight reduction and improve reliability, serviceability and environmental protection.

Having capitalised upon misfortune by other top teams at the 2017 event, the goal for the 2018 car was to identify the team's strengths and weaknesses and build upon them. This has been achieved through a successful redesign of the suspension and incremental changes to the chassis and powertrain.


REAR TRACK
1222
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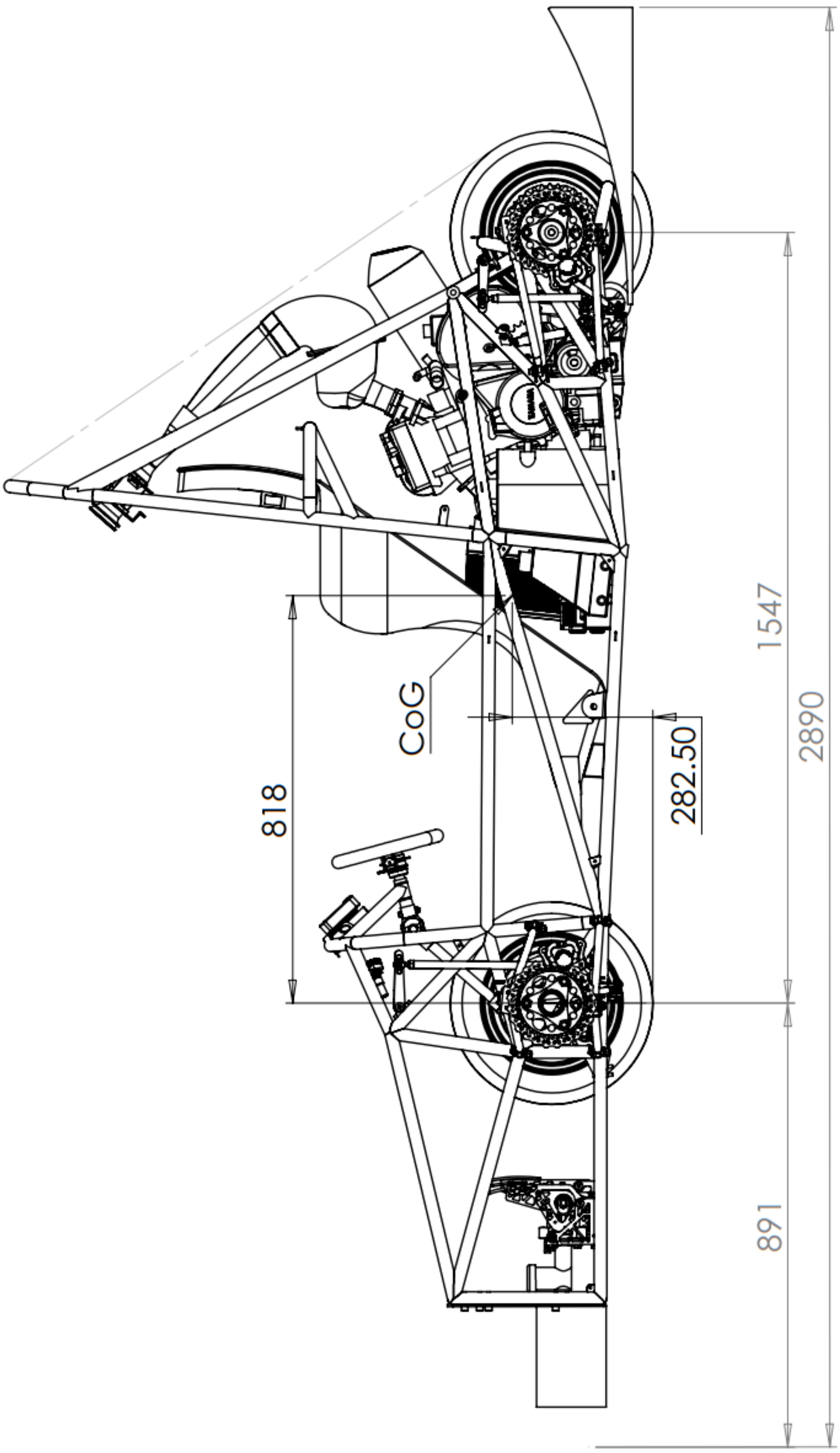
TOP VIEW



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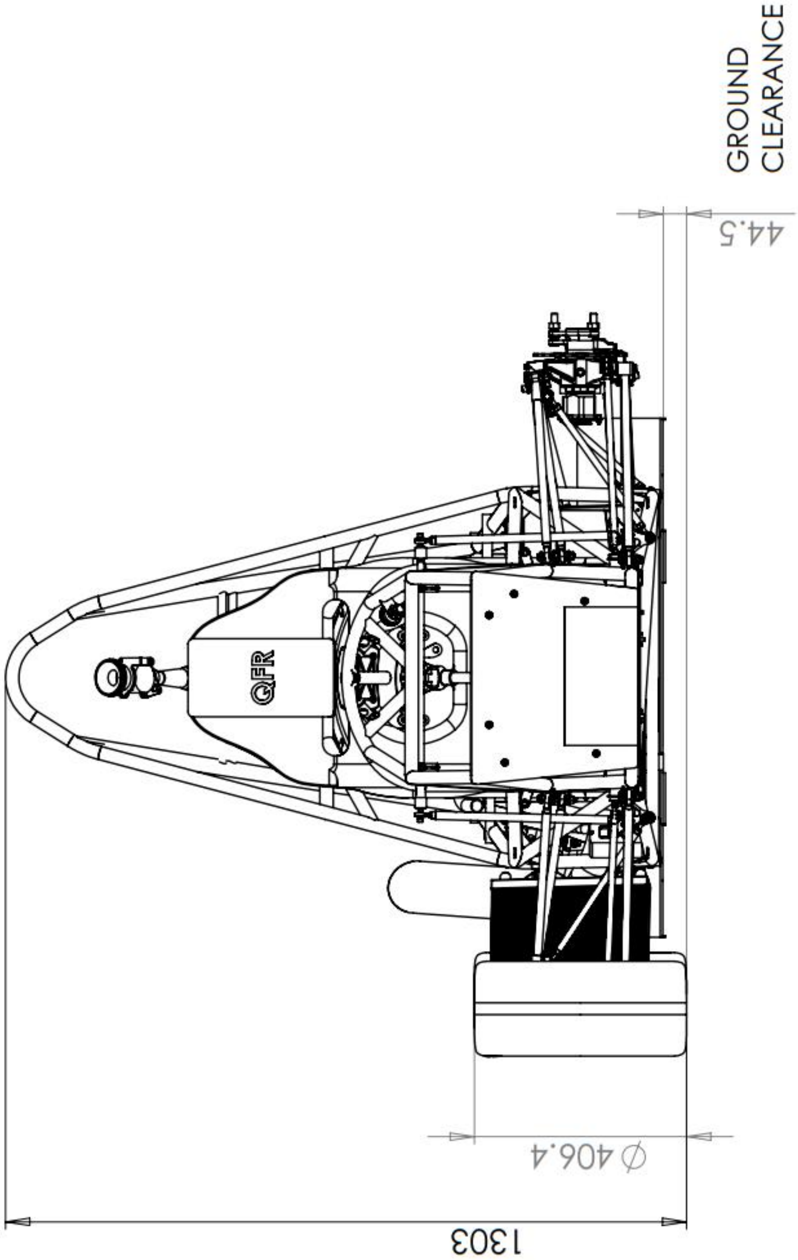
SIDE VIEW



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FRONT VIEW