Rensselaer Formula Hybrid's competition vehicle for 2019 builds off of the design inaugurated last year as VMR-X. Rensselaer Formula Hybrid (RFH) strives to complete design projects from the initial raw materials to the finished product; as few commercial-off-the-shelf parts are utilized in the design to maximize hands-on experience and learning. Improvements to the car will facilitate a competitive and reliable vehicle. With the hardware changes focusing on the removal of the engine, new front suspension, redesigned front uprights, and front outboard motor assemblies, VMR-X has the capability to be an important learning experience for the team due to the advancements made in the past two years. Adjustments of the placement of the motor controllers and minor battery pack changes were made this year as well after debugging and addressing major issues experienced last year that prevented the vehicle from running. A new aerodynamic package is also implemented to expand the vehicle's capabilities and improve performance.

VMR-X is an electric-drive vehicle consisting of four independently controlled motors powering the wheels through 7:1 planetary gear boxes. A team-designed and fabricated lithium ion battery pack sits below the driver and powers these four motors. VMR-X provides a low center of gravity and efficient space utilization by being constructed from a steel 4130 spaceframe design. The control system has since been debugged to address issues experienced last year that prevented the car from running. Team resources were reallocated this year to ensure that this system functioned properly to control the team-designed telemetry and drive-control for VMR-X. The aerodynamics kit features all carbon fiber structures designed and analyzed using CFD software and built using in-house mold making and carbon fiber layup processes. This includes front and rear wings, radiator pods, and undertray.

The powertrain system for VMR-X consists of four NeuMotors 8000 series brushless DC motors. Each motor is coupled at a 7:1 speed reduction planetary gearbox manufactured by Sesame Motion Corporation. Each motor is governed by a Kelly BLDC motor controller. This system is all powered by a team designed and assembled 3.8kWh lithium ion battery pack. The pack consists of 440 18650 cells in a 22s20p configuration. The cells are assembled within an envelope under 20" x 14" x 3" and situated below the driver to aid in lowering the center of gravity of the vehicle.

This battery assembly is actively cooled by two CNC milled aluminum cooling plates that have been designed utilizing CFD analysis to efficiently and effectively remove heat generated by the cells. During high load on the cells this will be vital to ensuring safe operation of the battery pack. The cooling plates have since been retrofitted with aluminum sheet metal to seal the plates better to eliminate previously discovered leaks. The cooling plates attempt to maintain the cells at constant and consistent temperature throughout to provide safe operation and maximum power draw.

Monitoring of the battery pack is accomplished by a proprietary accumulator management system (AMS) that communicates with various sensing equipment distributed throughout the pack. A new AMS has been installed for this year's competition vehicle and connects with 44 cell temperature sensors and 23 voltage sense lines to monitor cell module voltages and state-of-charge as well as providing a platform for continual cell balancing. All sensors have redundant pairs to allow for the swapping of sense lines in the event of component failures.

All accumulator hardware, safety equipment, AMS, and cooling plates are packaged within a newly expanded, welded aluminum enclosure and mounted below the driver directly to a chassis flange and protected by "toboggan rails" on either side. These chassis tubes protect the enclosure from any unfortunate obstacle encountered below the car. An opening in the firewall above allows for easy post-installation maintenance.

The VMR-X low voltage system is controlled by a DirectLogic 205 PLC to integrate the safety-critical electronics and the startup and shutdown systems. The high speed capabilities of the controller precisely gather and process wheel speed data to distribute to the control center of the car for accurate tractive control. This control center is known as $RFHB^3$ and is another example of team-built, debugged, and tested hardware and software to control various functions of the vehicle. This board monitors several performance characteristics such as wheel speed, suspension position, driver input encoders and hardware in the pedalbox and on the dashboard, a six degree of freedom Inertial Measuring Unit, and a GPS receiver. This information is not only used to continually compute tractive power distribution to the drive motors during racing but is also collected and stored on an SD card for analysis after test runs and racing. Tractive settings are predetermined and will be developed based on testing and will have specialized modes for each of the dynamic Formula Hybrid events.

The $RFHB^3$ processing and computations are performed by a Microchip SAMD21G18 ARM-core microprocessor to communicate with the sensory system on the vehicle through various analog, digital, and serial devices. These signals are then interpreted and the $RFHB^3$ will control the four motor controllers through an isolated DAC. Previously the $RFHB^3$ was not reading any of the sensors or encoders properly to be able to interpret any data from them. This made it impossible to understand how the car behaved during any testing run.

The suspension setup and kinematics on VMR-X were designed using a team-built MATLAB program that calculated suspension geometry and hardware dimensions. Adjustments of the CAD models of hardware to reflect changes in the MATLAB program ensure that the most current and accurate dimensions are modeled in the CAD assemblies based off of the specifications from the program. Tuning of the suspension using this program helps predict what results will be obtained when tuning the actual suspension components during testing of VMR-X on the race track. Understanding how different variables interact with each other is paramount to being able to adjust the proper component to get a desired outcome effect on the car performance. This tool was imperative to the redesign of all the front suspension components as well as front and rear anti-roll.

Components such as the new front uprights and damper mounts were machined from Aluminum 7075 and the new front bellcranks, front motor to gearbox adapters, and front and rear anti-roll rockers were all machined from Aluminum 6061. All components were designed and tested through the use of FEA to optimize load path distribution and packaging. The anti-roll rockers and damper mounts were CNC machined using CAM programmed by the team members that designed the parts using Autodesk Fusion 360.

VMR-X will have a fully redesigned aerodynamic package for competition in 2019. The front and rear wings are being redesigned and will continue to have rear wing active aerodynamics. New radiator pods will also be manufactured to accommodate the new undertray. All new components were analyzed using ANSYS Fluent with a rolling floor and spinning wheels to model the airflow around the car as realistically as possible and achieve the best performance from the aerodynamics package. Interior structural supports were designed and tested using the composites analysis tool in "SolidWorks Simulation".

The carbon fiber aerodynamic kit was completely manufactured in house using foam molds and a two part epoxy to wet out the carbon fiber. The molds were cut from XPS foam using a CNC router programmed by a team member, glued together, sanded to finish size, and hard coated with polyurethane. These molds were then filled with the epoxy wetted carbon fiber, covered in peel ply, cotton, and a vacuum bag and pulled to a vacuum and let to cure for several hours. Minor finishing work needed to be done after the parts were removed from the mold and then attached to the car.

Several major issues delayed the testing and ultimately the completion of VMR-X for competition in 2018; the first problems addressed in the current school year were those problems that hindered success last year. Successful testing of the motors and wiring and testing of $RFHB^3$ was one of the major obstacles overcome and allow us to focus on the critical design improvements for the current vehicle. Commutating the motors with the motor controllers proved to be a challenging task that took several months but was eventually resolved. Moving forward, testing the car and gaining more information about the design choices that were made will not only help the team to dial in the design of the car for this year but prove as a critical learning experience for the future of RFH.

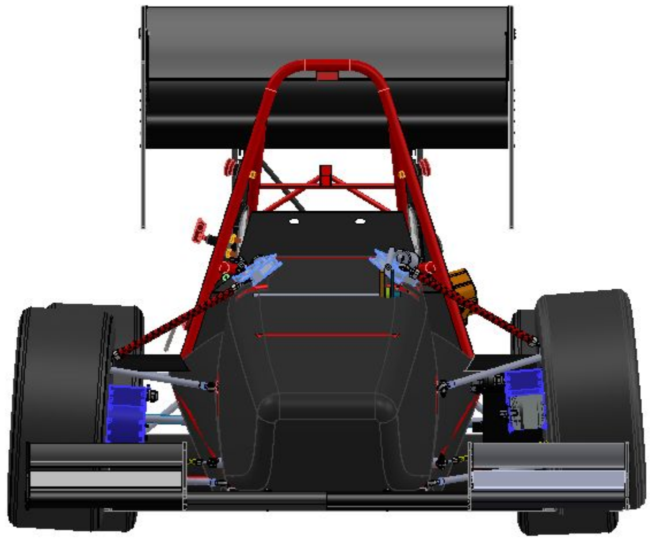

Figure 1 – VMR-X front view render

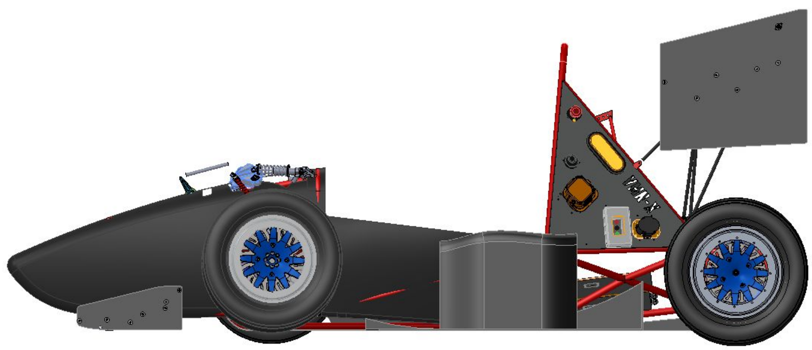

Figure 2 – VMR-X side view render

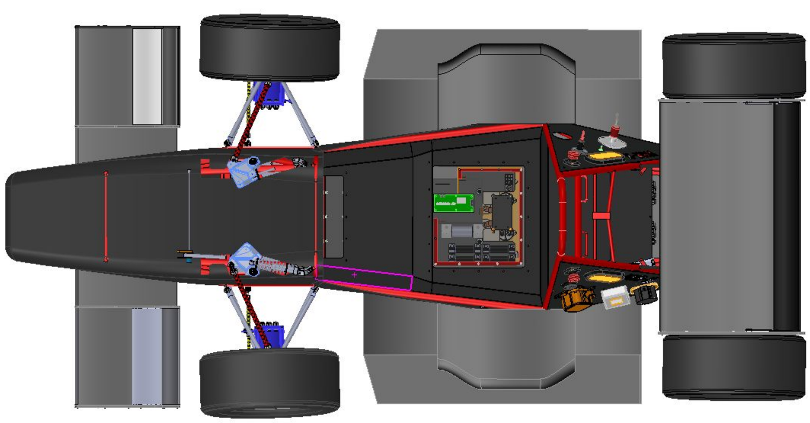

Figure 3 – VMR-X top view render

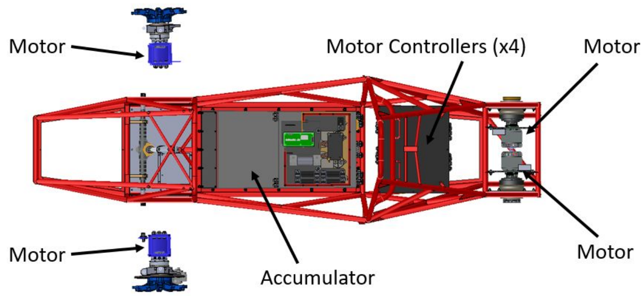


Figure 4 - Major TSV Wiring Components

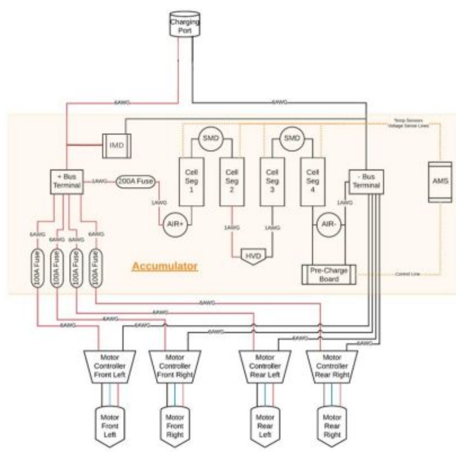


Figure 5 – HV wiring diagram

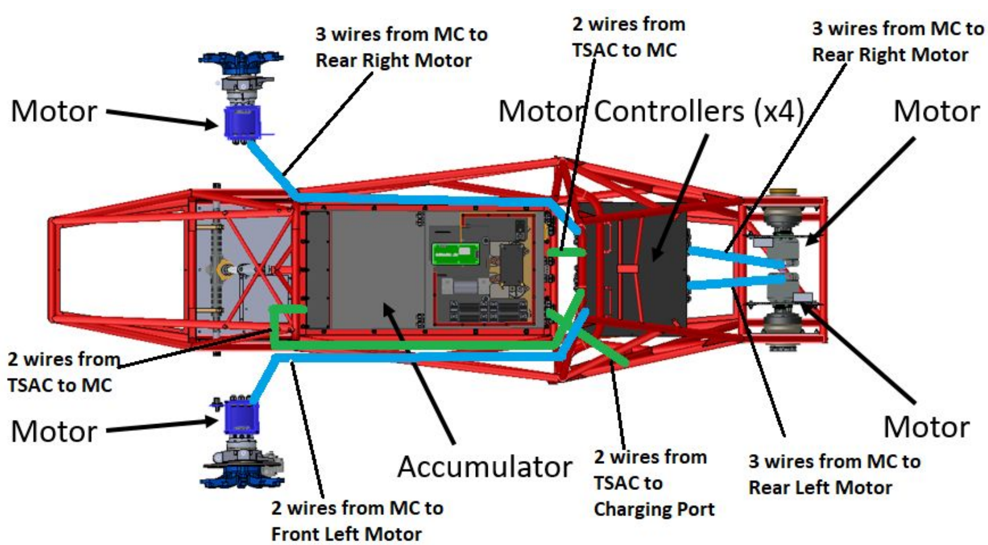


Figure 6 - HV schematic overlay on VMR-X