Rensselaer Formula Hybrid – 2017 Design Report

As a general philosophy, Rensselaer Formula Hybrid (RFH) strives to build as much of each year's vehicle from scratch, with an emphasis on raw material to finished product design. This is firstly to increase the quality of individual learning received by team members, and secondly to ensure complete design freedom in order to build a vehicle that precisely meets our goals and requirements. This ideology has led to the development of VMR-2, RFH's most technically-advanced vehicle in our team's nine year history.

VMR-2 is a hybrid class vehicle, with an Agni 95R electric motor driven in parallel to a 250cc Kawasaki EX250-L engine, controlled by an AEM EMS-4 electronic control module, via chain-drive to a custom differential powering the rear wheels. The vehicle's control system runs primarily off a piece-built PLC system, which additionally communicates with a custom telemetry monitoring framework and a team-designed battery management system, monitoring a custom lithium-ion battery pack.

Building off the team's past experience in modular battery pack design with A123 lithium ion cells, VMR-2's accumulator demonstrates an enormous increase in design quality and efficiency. With high energy density and a positive impact on vehicle mass properties in mind, a compact, centralized design consisting of 440 Samsung INR18650-30Q cells was formulated.

With tight packaging and vehicle-fit in mind, a cell layout of 4 segments with 22 total series 20-cell modules was decided upon. Adjacent modules are interconnected via pure-nickel plates, with each cell individually tab-welded to an integrated 30-amp fuse, designed by the team through intensive testing and verification procedures. With only enough spacing between cells to allow for sensor wiring, the cells, housing, fusing, and module connectors were packed into a layout just under 20"x14"x3".

In order to safely and accurately monitor the battery pack, the team decided that an entirely custom Accumulator Management System (AMS) was the best option. The final design saw a network of 44 temperature sensors and 22 dual-purpose voltage measurement and module balance lines routing to four "Segment Monitoring Boards", which parse data off to a main motherboard for safety response, external communication, and continuous data logging. Additionally, all sensors and voltage-sense lines were redundantly doubled, allowing for failsafe quick-swapping given a sensor failure. All circuit design, PCB design, and programming was done entirely by team members from the ground up as per the RFH philosophy.

With such tight packaging and high-current expectations, heat management became a realm of concern. As such, the team developed a cooling plate, form-fit to the battery pack outline. Based on expected current draw and resistance losses, the team determined the amount of energy the cooling system would have to dissipate. This requirement was used as a boundary condition to model the cooling plate with Solidworks Flow Simulation. The design was iteratively revised to minimize the steady state temperature and the variation in temperature over the surface of the plate to ensure consistent characteristics and long lifetimes for the cells in the pack. The finished design was cut on a CNC mill from 6061 Aluminum as a compromising between thermal properties and mass. Based on simulation data, an Alphacool VPP655-PWM pump was selected to provide sufficient volumetric flow rate and pressure through the cooling plate and external radiator.

VMR-2's logic control system centrally consists of an Automation Direct Do-more H2 Micro modular PLC. This system was chosen due to its versatility, robustness, and programming simplicity. Individual modules can be swapped and replaced as requirements are added and removed from the vehicle's GLV design, allowing for future-proof flexibility. In its current configuration, the PLC serves as the vehicle's main communication and control hub. External logic systems send necessary data to the PLC for processing, and critical commands are either directly acted upon, or passed to additional GLV-controlled sub-systems such as the dashboard, AMS, and telemetry box. The PLC is also responsible for reading and error-checking pedal input before sending a scaled control signal to the main motor controller.

For effective driver control and communication, a compact, three-part dashboard system was developed for VMR-2. One panel was dedicated to startup/shutdown actuation, while a central panel provided simple, selectable feedback on important vehicle measurements, such as engine RPM and battery pack temperature, through an array of quick-referenceable RGB LEDs. The third panel houses a Java-programmed Android Moto360 touchscreen watch face for infinitely customizable info display and system-wide control.

Past RFH dynamic vehicle testing has been largely qualitative and of the "stop-watch, pencil, and paper" variety. To match VMR-2s significantly increased technicality, the team decided that more direct testing measurements were crucial to precise testing and verification. As such, a custom vehicle telemetry system, dubbed RFHB^2 (Rensselaer Formula Hybrid Black Box) was developed.

After brainstorming all possibly-relevant telemetry measurements, a suite of 27 total individual sensors was decided upon to provide finite measurement of everything from front and rear independent 3-axis acceleration and vehicle tilt to 4-wheel rotational speed readings, suspension position monitoring, GPS location, and tire temperature. With such vehicle-specific needs, the RFH philosophy was once again enacted and an entirely custom motherboard PCB was designed, integrating the network of on- and off-board sensors, with two separate intercommunicating ATMEGA328 microprocessors logging live telemetry to an on-board SD card and wirelessly transmitting select data via RF for "pit-lane" style team monitoring.

To ensure that the system could benefit the team for years to come, RFHB^2 was designed with future-expandability in mind. The initial motherboard contains space for 13 additional external discrete digital or analog sensor additions, while an open I^{2}C line invites countless add-ons, including the ability to stack multiple motherboards should the need arise.

Additionally, the I^{2}C line adds the ability to communicate with external vehicle control system, enabling cockpit-display of critical telemetry information during testing, as well as the availability of finite vehicle response for active dynamic control systems such as the in-development RFH active suspension system.

2017 officially marked the first year of a specifically aerodynamic-minded approach to body kit design, resulting in a particularly ground-up undertaking for the team. The body kit was designed to sleekly conform to the geometry of VMR-2's chassis, while providing a low-drag leading-edge profile, and consists of four fiberglass panels, allowing for easy access to various vehicle components without the need for complete body kit disassembly.

As a rear-wheel drive vehicle, VMR-2 possesses a general rearward mass bias to provide the most traction to the driven wheels to benefit sequences of high acceleration from low speeds or standstill. To counteract this bias during high-speed and turning intensive events, a high-downforce front wing was iteratively designed through dynamic analysis using ANSYS Fluent. The final dual-airfoil design was formed with carbon fiber around a foam core, with two thin aluminum wing-spars for an ideal balance of structural rigidity and low-mass, providing a simulated 287.4 N of added downforce at 72 km/h.

For the front wing, hood, and nose-cone, all layup molds were CNC-routed in foam using a team-built and programmed tabletop router system, assembled from standard stepper motors, an aluminum guide-track, and a vertically mounted Dremel tool. Side panel molds were instead CNC-routed from a single piece of MDF as the geometry necessitated a stronger mold base to withstand vacuum forces during layup.

VMR-2's suspension consists primarily of a double-wishbone configuration at both the front and rear of the vehicle, with 100% Ackerman steering geometry, as a performance compromise to satisfy both the relatively low-speed turns expected during the autocross dynamic event and the longer, high-speed turns during the endurance event.

The suspension uprights were CNC machined from single aluminum blocks with a slim profile design. To allow for on-the-fly camber adjustments, the upright suspension linkages were designed as separate parts, with easy adjustment possible by use of low-profile "shims". After an initial prototype with welded sheet-steel links was deemed unsatisfactory, intense FEA-aided refinement lead to a beautifully integrated structural design from solid aluminum 7075. Thus, the team broke-in a new campus CNC mill and self-programmed the computer-aided manufacturing of VMR-2's final upright links.

While a parallel a-arm setup for the rear of the vehicle was found to work well geometrically, the effective ground-level roll center caused some concern for cornering response due to excessive body roll. But rather than implement a standard anti-roll bar, the RFH suspension team decided some further innovation was in order, leading to the development of VMR-2's active rear suspension system.

After working through two prototype system designs, first involving a servo-motor and custom gearbox coupled to the vehicle's rear bell-cranks, and later an electronic linear actuator acting as a secondary "active pushrod", it was determined that the geometrical constraints and required actuation force necessitated a hydraulic system. As such, the team developed a mechanical actuator consisting of a linear hydraulic piston-cylinder attached to a secondary bell-crank (for both geometrical and force advantage) at each rear wheel powered by a DC motor driven hydraulic pump, with flow controlled by a series of solenoid valves and a primary servo-valve.

This setup thus allows for independent, dynamic rear suspension control, primarily in the form of "picking up" the inside wheel during cornering to counteract body roll. Additionally, driver-selectable suspension response settings include the option to temporarily pull both rear wheels up, effectively lowering the vehicle's rear ride height and stiffening suspension response to ensure ideal performance during straight-line acceleration trials.

To ensure stable and robust system response, the suspension control law was developed with the help of Matlab's Simulink modeling software. System measurements and estimations regarding dynamic forces and body roll during various cornering situations were input, while reported hydraulic part specifications provided a highly accurate insight into expected response. Utilizing a combination of feedback from RFHB^2's bell-crank potentiometers, front and rear accelerometers, and wheel-speed hall effect sensors, fed to a custom active suspension controller via I^{2}C protocol, a PID control scheme was designed to provide fast and stable suspension response during cornering.

As of this design report being written, the active suspension system is still within its initial prototyping phase, with a ready-for-competition product a few weeks out. As such, the system may or may not be presented on VMR-2 for use in competition events.

With the mentioned primary design aspects in conjunction with a plethora of improved manufacturing details, RFH has produced a 2017 competition vehicle that displays the greatest increase in year-to-year technological achievement ever produced by the team. We proudly present VMR-2 as a grand culmination of the incredible combined abilities of each and every member of Rensselaer Formula Hybrid.

Figure 1 – VMR-2 front view render

Figure 2 – VMR-2 side view render

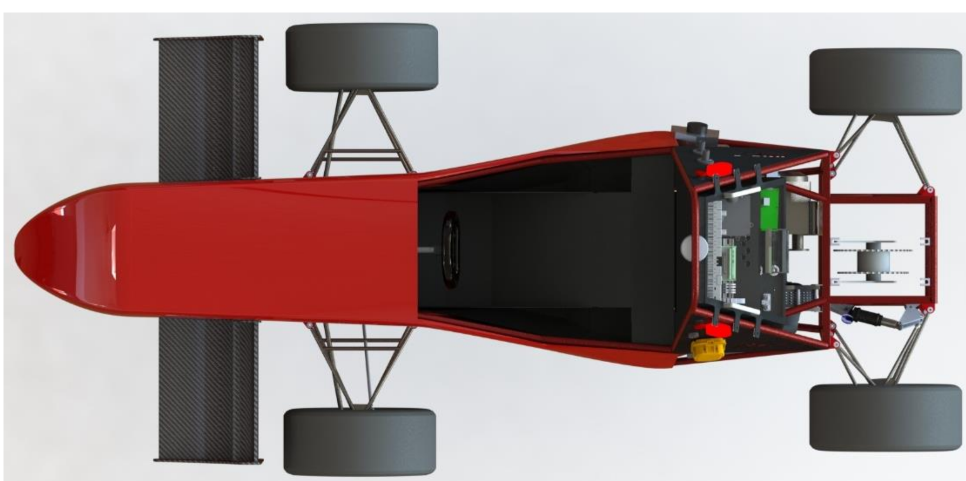

Figure 3 – VMR-2 top view render

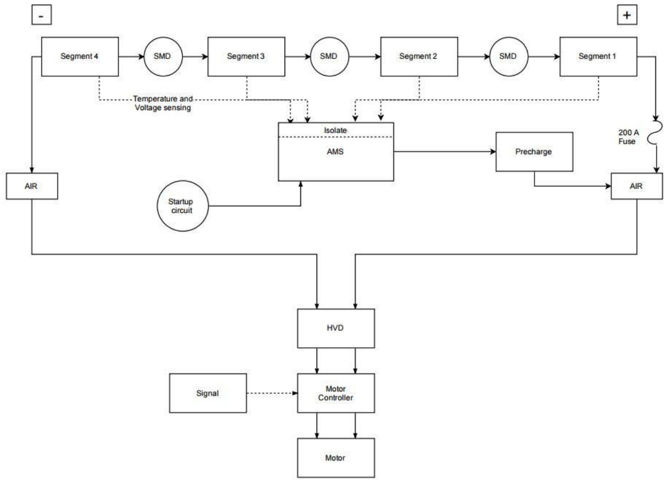

Figure 4 – HV Wiring Diagram

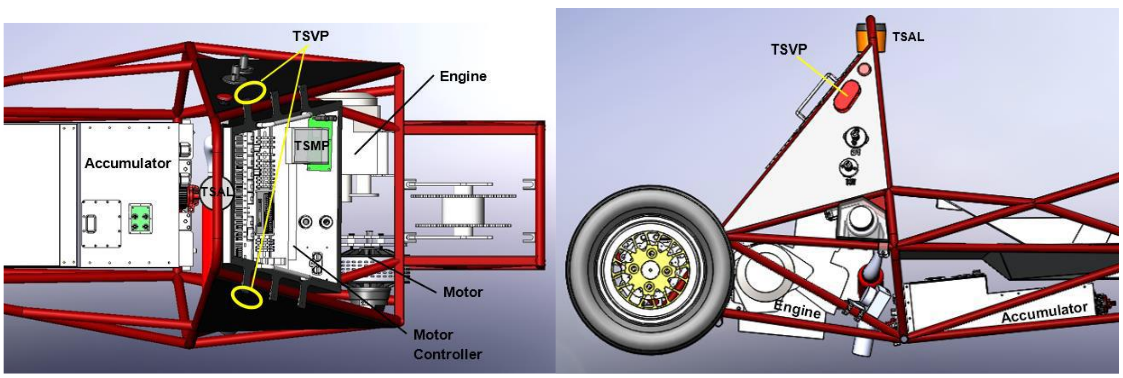

Figure 5 – Locations of major TSV components

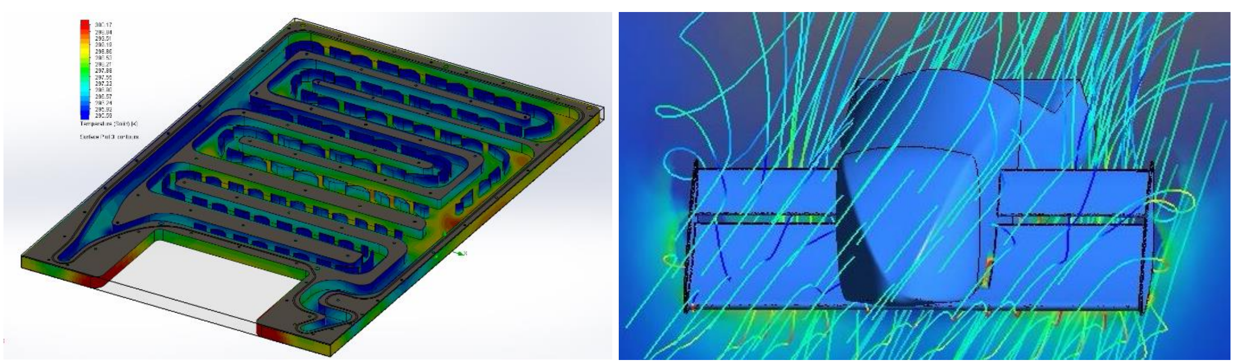

Figure 6 – Accumulator cold plate (left) & front wing (right) CFD analysis screenshots

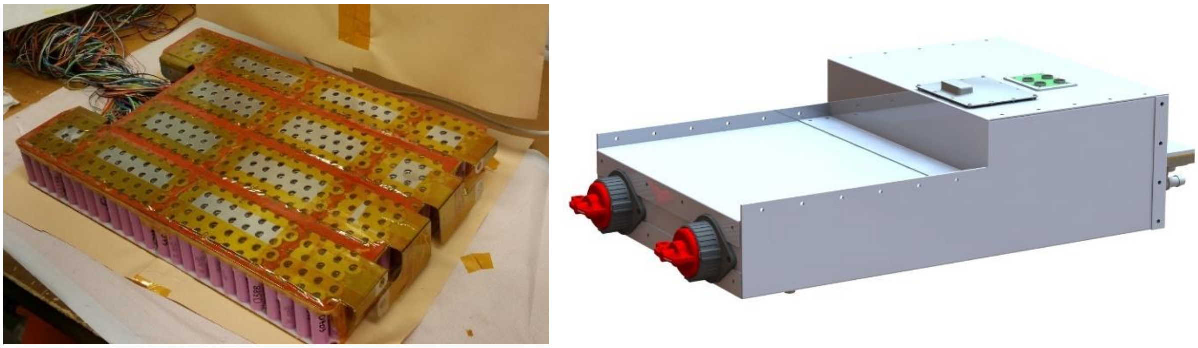

Figure 7 – Battery pack cell configuration (left) & final accumulator design render (right)

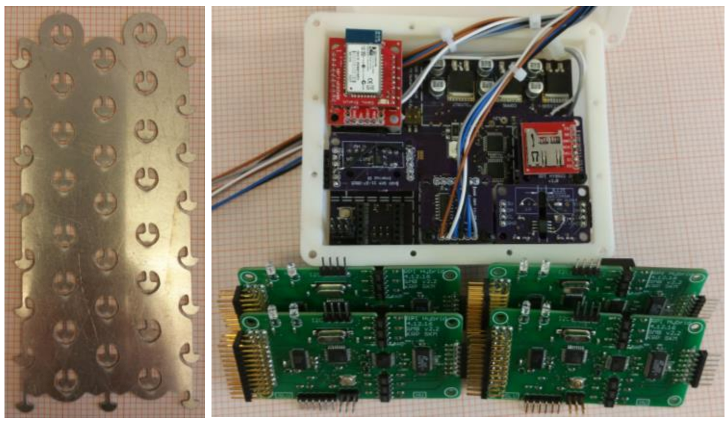

Figure 8 – Collector plate with integrated fuses (left) & custom AMS system (right)

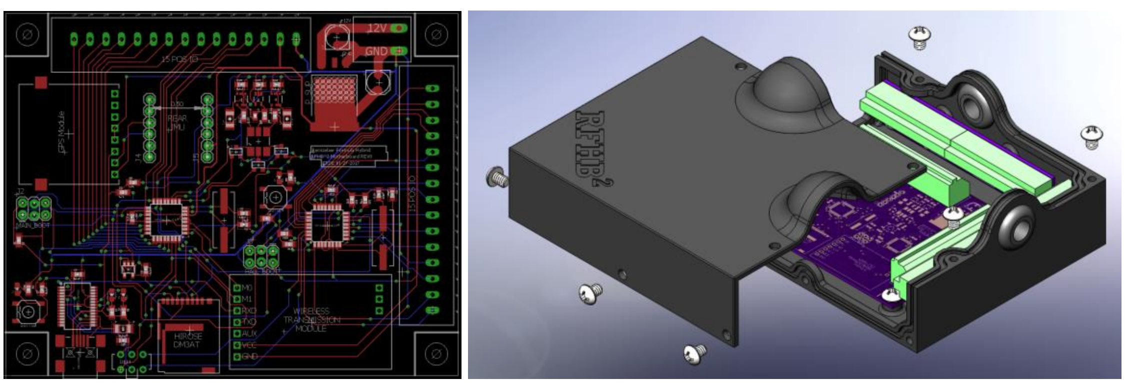

Figure 9 – RFHB² motherboard layout (left) and full system mockup (right)

Figure 10 – CNC-milled aluminum 7075 upright links (left) & main electronics box design render (right)