ME, ECE, BE Capstone Design Programs

Polaris Defense

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Team 16: Polaris® Defense MRZR™ 2 Hybrid Variant Feasibility Study

Background / Purpose

Polaris Defense, a division of Polaris Industries, Inc., modifies the recreational vehicles, such as Sportsman® and RZR® in order to suit the harsh demands of Unites States military and foreign allies. Polaris Defense has tasked Team 16 with designing and building four of the major components of a hybrid powertrain for the current MRZR™ 2 chassis by:

1. Relocating and redesigning of fuel tank
2. A heat exchanger to cool the electric motor
3. Supplying auxiliary power for tools or weapons
4. Configuring and mounting the battery bank

To claim that this project is feasible the vehicle's weight must remain under 2,000 pounds for air transportation.

Project Deliverable #1: Redesigned Fuel Tank


Figure 1: Fuel Tank in Vehicle

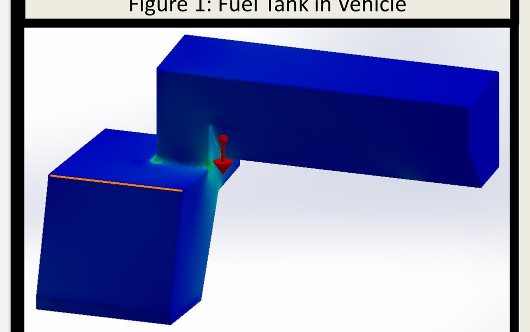


Figure 2: 8-G Load Finite Element Analysis

Overview

- Relocation and redesign of fuel tank due to addition of battery bank under the seats
- Chosen location allows for required 5 gallon volume tank and provides most protection
- For user safety, tank construction compliant with CFR Title 49 and manufactured by an A.W.S. certified welder

Analysis/Testing

- 8-G load simulation: Simulated body force loading of full tank when parachutes deploy
  - Maximum stress of 22 MPa, F.O.S. = 8.9
- Variable body force simulation: Simulated maximum forces observed during vehicle operation
  - Maximum stress of 3.5 MPa
- Pump Placement Test: Measured remaining fuel after fuel pressure dropped below 42.5 psi
  - .07 gal of fuel remained (.25 gal required)

Specifications

- 5052 Aluminum alloy
- 5 gallons
- 11.7 lbs.

Project Deliverable #2: Electric Motor Radiator

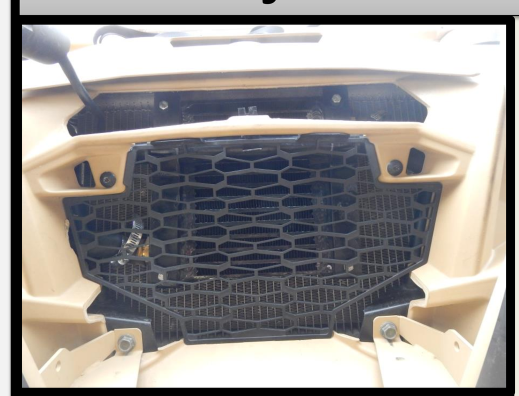
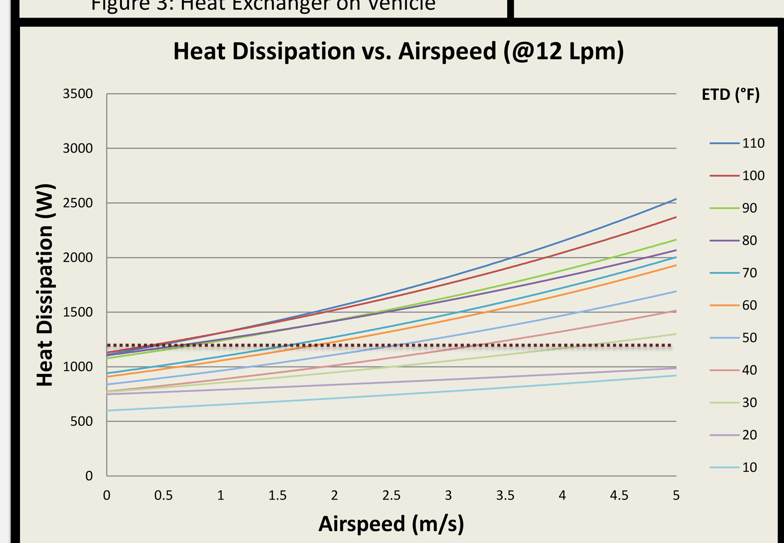


Figure 3: Heat Exchanger on Vehicle

Overview

- The hybrid MRZR™ 2 utilizes a liquid cooled electric motor that generates a maximum of 1200 W of heat
- System utilizes the API MA-3.5 for high cooling performance versus weight
- Creates redundancy by using a system independent from the existing engine cooling system
- Frontal location provides maximum air flow and limits fan usage
- Protect users from potential harm by isolating cooling system



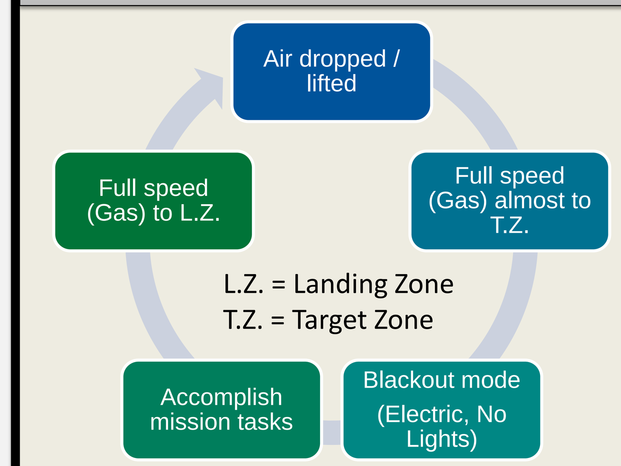
Analysis/Testing

- Cooling performance test: measured temperature drop across radiator at various airspeeds and entering temperature differences (ETD)
- The curves in the graph illustrate radiator performance – any system that dissipates more than 1200 W will cool the motor without the need for the fan to switch on
- Heat Dissipation Equation: $\dot{Q} = \dot{m}c_p(T_i - T_o)$

Specifications

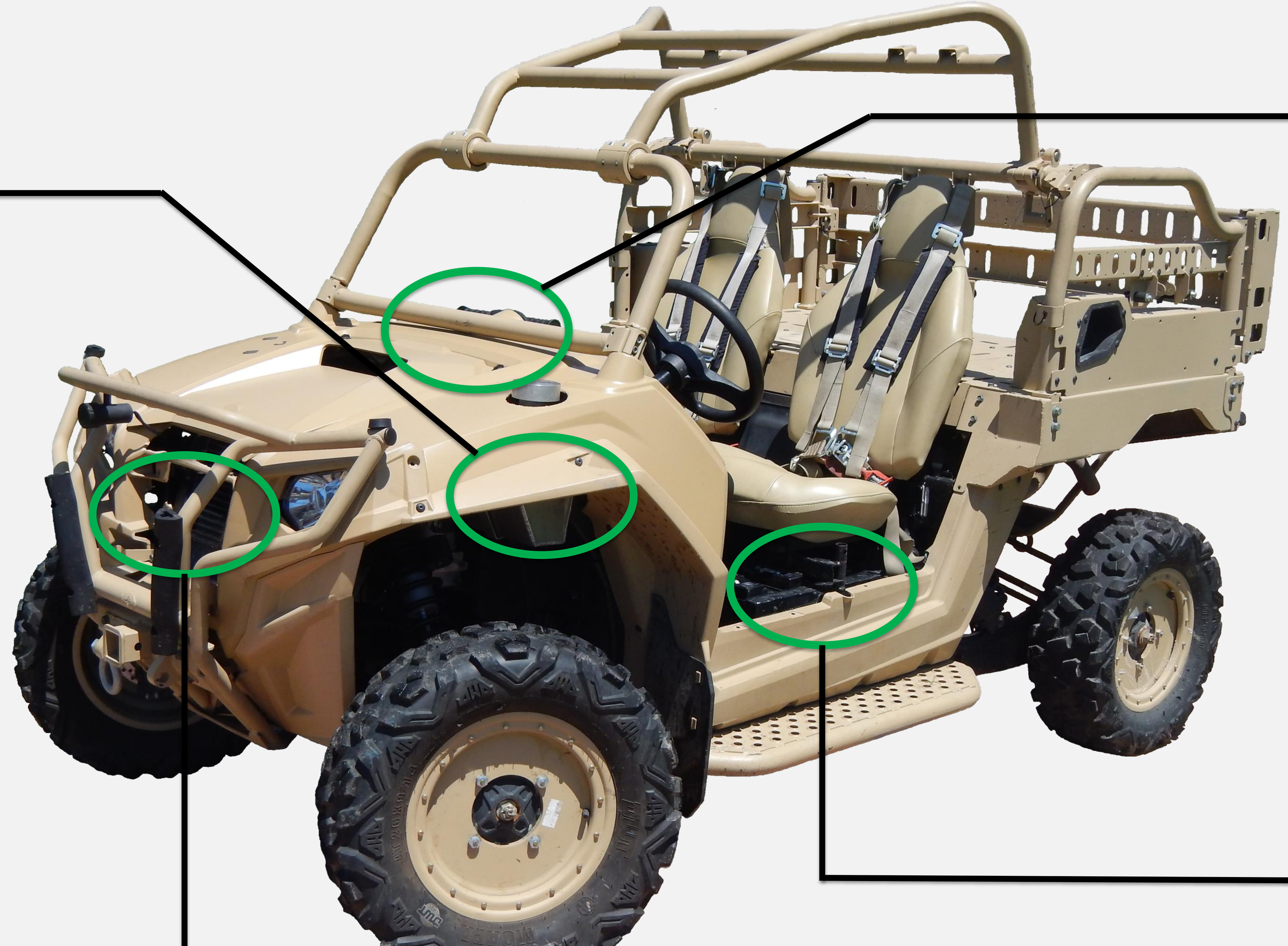
- 12 Lpm coolant flow rate
- MA 3.5 Radiator - 6lbs
- 50% ethylene glycol
- CM10 pump – 1.2lbs

Possible Mission Profile



Depicted is a combat scenario for the hybrid MRZR™. The military has determined that they are in need of a more stealth ground vehicle to infiltrate enemy territories.

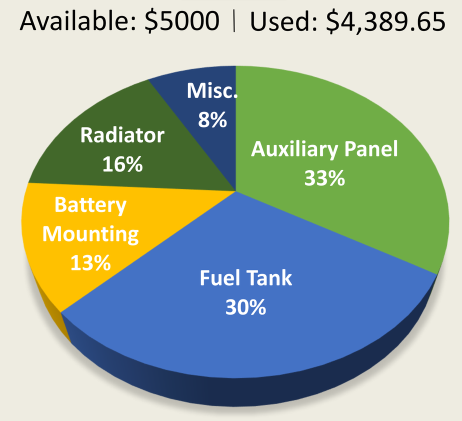
The U.S. Special Forces came to Polaris Defense hoping to take the current MRZR™ platform and modify it so they can run at optimum speed but also have the ability to be as quiet and dark as possible.



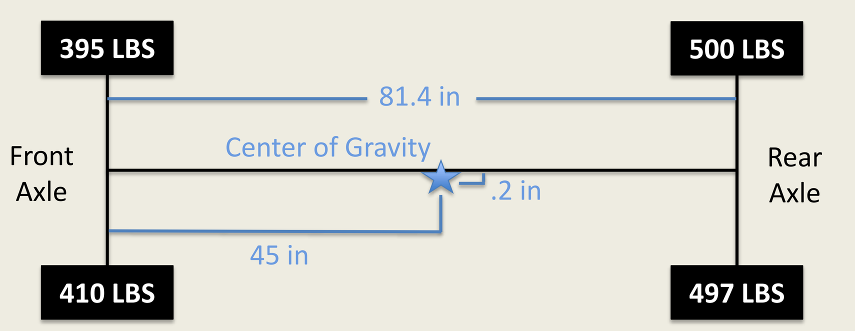
Project Summary

Budget

Available: $5000 | Used: $4,389.65



Vehicle Weight



Total Weight: 1802 lbs

Project Deliverable #3: Auxiliary Panel

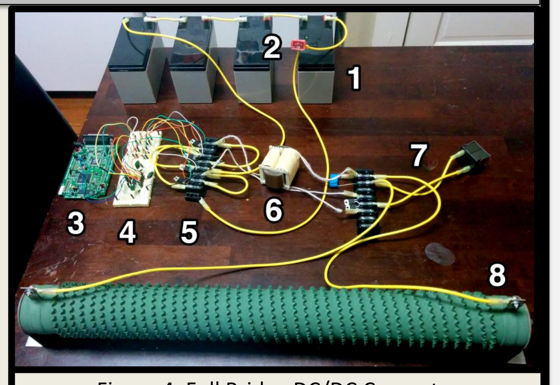


Figure 4. Full Bridge DC/DC Converter

1. 48 VDC Batteries
2. 50 A Fuse for Protection
3. Digital Signal Processor to Produce PWMs
4. Control Circuit with MOSFET Drivers
5. MOSFET Bridge Configuration
6. Center-Tap Configuration Transformer
7. Diode, Inductor, and Capacitor Filter Circuit
8. 2.5 kW Resistor Test Load

Overview

- Provide 48VDC and 5VDC outputs
- Provide reliable means to extract electrical energy from the battery bank in order to power various tools
- Supply stable and constant DC voltage despite
- Isolate outputs via transformer to provide safety to the end user

Analysis/Testing

- Efficiency

$$\eta = \frac{P_{out}}{P_{in}}$$

- Voltage Ripple

$$\Delta V_o = \frac{V_o}{16 * L * C * f^2}\left(1 - \frac{2 * V_o N_p}{V_{in} N_s}\right)$$

- Current Ripple

$$\Delta i_o = \frac{V_o}{L}\left(1 - \frac{V_o N_p}{V_{in} N_s}\right)\frac{1}{f}$$

- Switching Losses

$$\Delta P_{sw} = \frac{1}{2} V_{in} I_{srms} D$$

- Voltage Ripple Test
  - Measured peak to peak voltage ripple to be at a maximum of 10.5% of the output voltage
- High Power Test
  - Determined the 48 VDC converter is infeasible for the MRZR™ 2 package for high power

Specifications

- 2kW at 48VDC
- 10W at 5VDC
- 80-85% Efficiency
- 10.5% Voltage Ripple
- IP67 certified USB Ports
- 10% Current Ripple

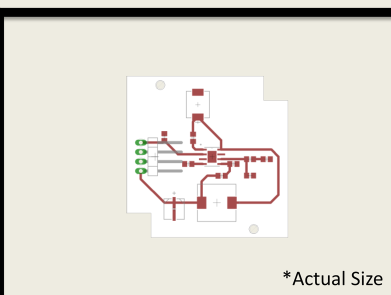


Figure 5. Buck DC/DC Converter Board

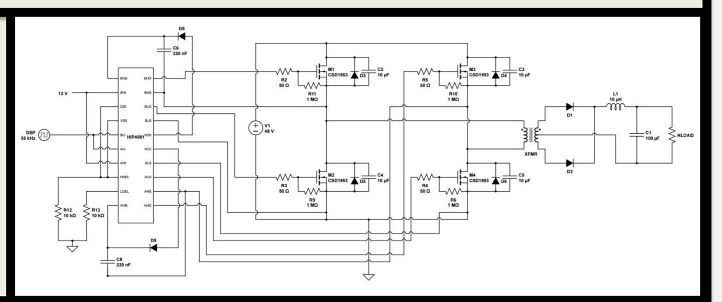


Figure 6. Full-Bridge DC/DC Converter Schematic

Project Deliverable #4: Battery Mounting System

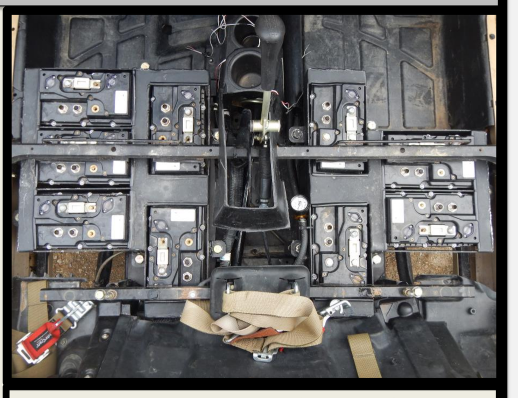


Figure 7. Battery Bank in Vehicle

Overview

- Configure and secure bank of nine batteries
- Mount two independent steel plates to the existing chassis
- Create removable top for easy access to the batteries
- Secure top to the platform with 10 half-inch zinc-coated Grade 8 bolts
- Dampen vibrations and noise with Poron foam

Analysis/Testing

- Fatigue Life Estimation

$$n = \left(\frac{0.1}{N_1} + \frac{0.3}{N_2} + \frac{0.6}{N_3}\right)^{-1}$$

- Max Loading (Air Drop)

$$\sigma_{max} = \frac{\beta_1 q b^2}{t^2}$$

- Weld Strength (AWS Standard)
  - Calculated unit load: 49 lb/in (AWS allowable unit load: 7.93E3 lb/in)
- Quarter Car Model: Simulation determined maximum suspension travel and sprung mass accelerations
  - Maximum suspension travel of 12.1"
  - Maximum stress of 6.98 MPa from 8.7 $^{m}/_{s^2}$ sprung mass acceleration
  - Compared maximum stress to S-n curve; determined infinite fatigue life of system
- Dynamic Test: Drove vehicle with strain gauges attached to frame
  - Validated quarter car model by comparing results with collected data
- Bead Bend Weld Quality Test
  - Steel and Aluminum welds both stronger than 0.66(S_y)
  - Weld quality confirmed

Specifications

- 6061-T6 Aluminum Top
- A1011 Steel Platform
- 230 total lbs. (including batteries)

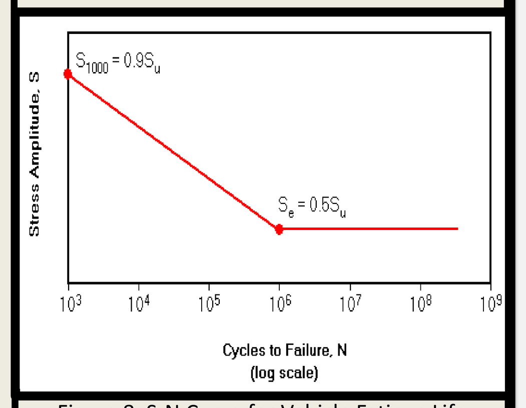


Figure 8. S-N Curve for Vehicle Fatigue Life

Timeline

Team was Formed / Met with Sponsor — Research and Design — Component Analysis — Component Revisions / Procurement of Parts — Component Construction — Final Construction / Initial Testing — Final Testing / Presentation

August 2014 | September | October | November | December | January 2015 | February | March | April | May

Project Commencement — Presented to Polaris — Design Presentation — Manufacturing Began — Surpassed 50% of Budget — MRZR™ 2 Arrival — Vehicle Completed — Prototype Presentation

Sponsors: Brian Van Batavia – Polaris Industries Inc.

Advisers: Dr. Charalampopoulos, Dr. Zhou