Vehicle #65

Baja SAE Design Report

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ABSTRACT

Baja SAE was established in Fall of 2015 at the University of Colorado at Boulder. The team's intent is design and fabrication of a rugged and marketable off-road vehicle. This report serves to highlight key areas of design for vehicle #65 in competition at Baja California in May 2016.

TABLE OF CONTENTS

INTRODUCTION

Vehicle #65 has been optimized for success in the Baja endurance challenge. After having consulted automotive design literature, previous SAE competitors, and an independent study on the Baja challenge, the team has developed the knowledge base to field a competitive vehicle in the program's first year. Key design features include 'one-size-fits-all' ergonomics, modular components, a fully adjustable suspension, and substantial rollover protection for the driver.

DESIGN OBJECTIVES

Design intent has been oriented towards large factors of safety and well-understood systems. With regard to the competition, completion of the endurance challenge has been given priority over performance in minor events. Effort has been directed away from specialty challenges like rock crawl and acceleration in favor of a vehicle fully capable of completing four hours on the track. This motivation implies diminished efforts towards weight reduction and vehicle performance, however overall quality and durability have benefitted.

VEHICLE CONCEPTS

In all respects, vehicle #65 is a first-generation prototype. By necessity, concept generation and revision have taken place without direct reference to a legacy of previous designs. During initial project ramp-up, several major designs were considered and discarded as different resources were consulted.

Three different suspension options dominated early discussion, with MacPherson, trailing arm, and A-arms in contention. A-arm designs eventually won out, owing to improved manufacturability, reduced cost, and mechanical simplicity. Other concept revisions were primarily motivated by FEA testing. A myriad of frame, upright, and A-arm designs were validated and revised with comprehensive loading conditions.

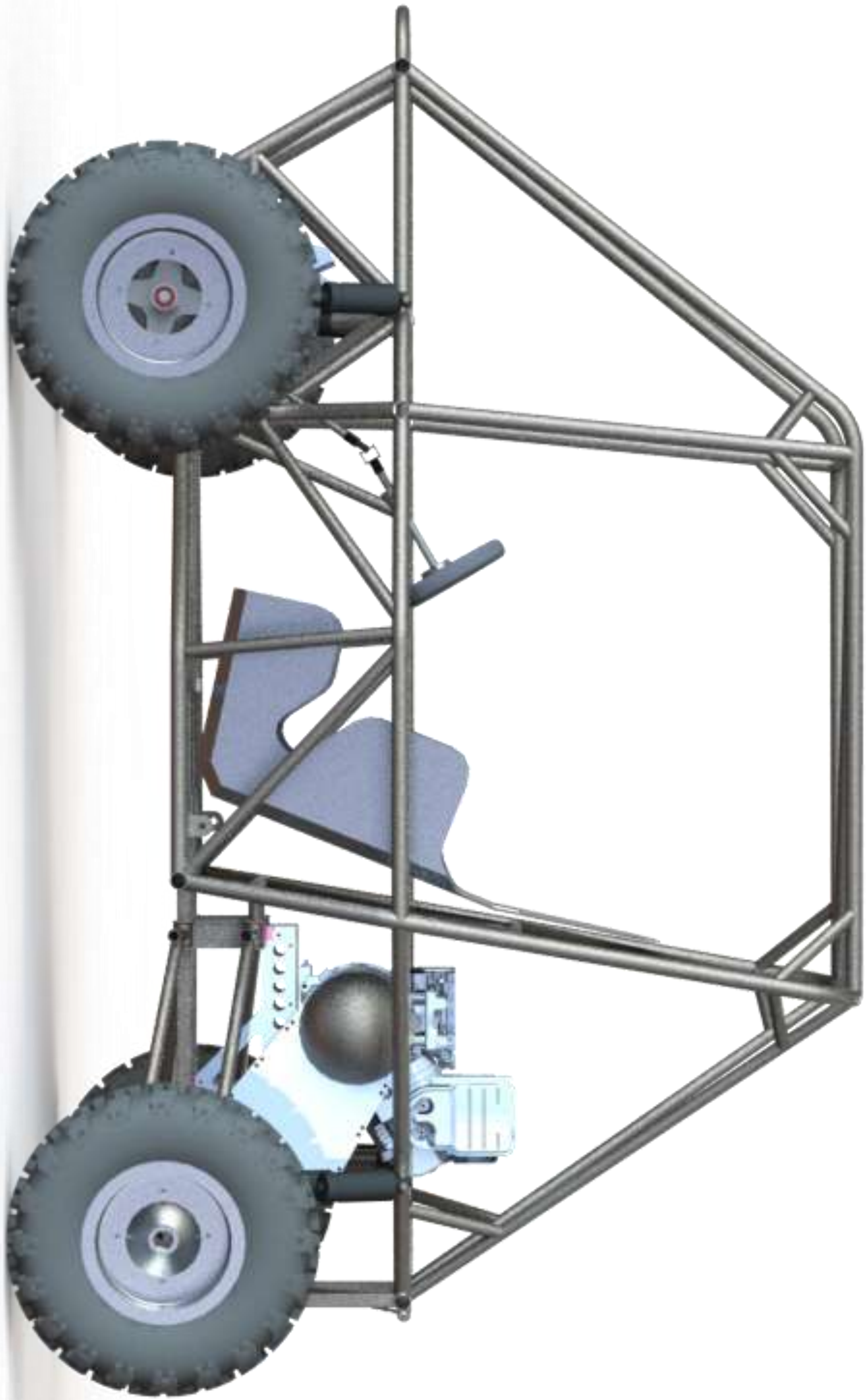
TESTING

Due to the first-year environment, testing opportunities have been limited by schedule and project budget. Designs have primarily been validated through extensive FEA analysis, however limited testing has thus far motivated ergonomic and structural improvement.

ISOMETRIC VEHICLE RENDERS – FRONT VIEW

Top View

Side View



FRAME

The chosen design is a triangulated space frame comprised of both round and rectangular tubing. Tubing varies throughout the chassis depending on structural needs of that area, as well as severity of possible failure modes. Tube choice also depended on the mounting required.

Chassis Design - This chassis would be considered a 'non nose' design because front bracing members extend to the front bumper. This choice was made in order to maximize internal space, as well as increase space on the sides of the car for easier entry and exit during emergency egress.

Frame Weight - With a measured weight of 121 lbs, the bare frame is above average in weight. This stems from design intent focused on the goal of ensuring successful event completion, limited manufacturing time and experience, and a large chassis accommodating several team members proportioned well outside the national average.

Tubing Selection – Primary frame members are fabricated from 4130 alloy 1.25" OD 0.065" thick circular tubing. Selection began with a comparison of bending strength among tube profiles and materials. This tubing was selected after it proved lighter, more manufacturable, and stronger than the default 1018 steel option. All tubing is 0.65" wall thickness, allowing for more predictable welding on the frame.

DRIVETRAIN

As specified by the 2016 rules, the drivetrain was designed around the Briggs & Stratton Model 20 engine, with a maximum rated RPM of 3800. This specification, along with a desired top speed of 40 miles per hour, target vehicle weight, and the size of the tires and wheels used, led the drivetrain team to design an overall gear ratio with a range of 5.7:1 to 39.8:1. One notable feature on the drivetrain is the combined motor and gearbox mounting.

Motor Mount - The drivetrain mount is a multiple component structure composed of ¼" 6061 aluminum sidewalls with 4130 steel screw bosses connecting the pieces together as seen in Figure 2. The mount is designed such that the motor can be shifted fore and aft via a slotted motor mount, and is locked into place via the motor tensioner.

Continuously Variable Transmission - The intermediate drive was narrowed down to a chain drive and a continuously-variable transmission (CVT). The required gear ratio combined with packaging constraints eliminated the chain drive option, leaving the CVT as the most viable design. Additionally, the use of a CVT implies that manual shifting is not necessary. Several makes of CVT were considered, including options from Gaged, Polar, Comet, Polaris and CVTech. The CVTech was chosen primarily due to packaging constraints given that it mates directly to the Model 20 engine.

Gearbox - The gearbox used is a Dana/Spicer H12 FNR live axle model. This series of gearbox was chosen for its simplistic design and ease of implementation. The live axle version was purchased based on its availability and low cost. A custom spool replaces the differential that comes with the H12 gearbox. While the spool does provide for better traction on off-road surfaces, the decision to use a spool to lock the final drive was driven by the need to solve an interference issue between the CVT and left side rear brake rotor. By locking the rear end, one brake rotor could be used only on the right side of the vehicle while still adhering to rule B.11.3. A custom gear adapter serves as the connection between the spool and the final gear that came with the H12.

Half Shafts - Each half shaft consists of three parts, a Polaris Sportsman 500 outer rzeppa joint, Dodge Neon inner tripod joint, and a custom center shaft. The shafts serve to transmit torque from the spool to the rear hubs while allowing for suspension travel.

SUSPENSION

Although Macpherson struts, trailing arms, and a live axle were considered, eventually an independent double wishbone suspension system was decided upon due to its proven success in Baja competitions and the team's better familiarity with the system, as well as the total control afforded over wheel movement and critical suspension geometry characteristics. The suspension system allows for complete front and rear camber and toe adjustment in the front and rear of the vehicle.

A-Arms - All of the A Arms are constructed from 4130 steel tubing. The designs for front & rear, upper & lower arms passed through many revisions and loading scenarios before a final configuration was achieved. A minimum safety factor of 3 was chosen, allowing for errors in load determination or changes in vehicle configuration, as well as the unknown terrain conditions.

Shocks - The shock absorbers are top level FOX Racing air shocks. These shocks were chosen for their high & low speed bump and rebound damping adjustment. The shocks also feature a large range of spring rates. A large portion of the project budget was allocated towards the shocks after suspension performance was deemed paramount among subsystems.

Uprights – Upright design on the vehicle was primarily motivated by packaging constraints, modularity, and good design practice with regard to ball joints. In the front suspension, uprights can be swapped from left to right, meaning a single spare can replace either component in the event of a catastrophic failure. All ball joints on the uprights are mounted in double shear in an orientation which allows for full manipulation of toe and camber.

Finite Element Analysis - Nearly all suspension components on vehicle #65 rely heavily on analysis completed primarily using Solidworks FEA. In acknowledgement of the tendency for FEA to provide useless or false results, a myriad of loading conditions and hand calculations were used to verify component performance under varying stresses and strains. Complex combined loading scenarios were designed to challenge component performance under the most strenuous conditions. While results have not proven completely accurate, the process has still driven important iterations in critical vehicle components. Examples of the FEA calculations used in development can be seen in the Appendix.

STEERING

Design of the steering system is based on a rack and pinion mechanism. Other options included a five-linkage system, hydraulic steering, and an automated electrical system. The rack and pinion option was chosen for its simplicity, ease of packaging in the vehicle’s toebox, and proven success in past Baja applications.

Driver response was an important consideration when researching rack and pinion options. Team drivers requested full turn control within a single steering wheel rotation for operation with wrist restraints over the four-hour endurance race. The rack and pinion chosen boasts a 12:1 ‘fast’ steer ratio. This ratio allows the driver to reach maximum turn angle in both directions without having to lift their hands from the wheel.

BODY

A firewall, skid plate, and body panels were designed to protect both the vehicle and driver from hazards. It is required that the cockpit is completely separated from both the ground and the engine compartment. Thin, 6061-Aluminum sheets were chosen for their superior weight savings, manufacturability, and cost.

Skid Plates - Designed to protect the vital components of the car, driver, engine, etc., from damage and debris, 1/8” thick, 6061-Aluminum sheet is bolted to tabs welded to the floor of the frame.

Firewall - Provides a barrier between the driver and machinery immediately behind them. The Aluminum sheet used is 1/16” thick, as it does not take direct collisions like the skid plate. Due to the constrained placement of the firewall, it was cut into multiple sections, each of which is small enough to slide into place without interfering with existing frame members. It lies on the engine-side of the rear roll hoop, allowing the seat belts to wrap around the frame without passing through the firewall.

Body Panels - Made from 1/16” thin Aluminum, these sheets are meant to shield the driver and equipment from mud and light debris. Panels do not extend beyond the lower half of the vehicle, affording improved visual awareness for the driver when approaching challenges like the rock crawl.

BRAKES

This system features two independent hydraulic circuits for the front and rear brakes which are tuned to allow lock up on all four wheels with the application of a balance bar.

Master Cylinders – Directly transfer the force of the pedal to pressurize the hydraulic braking circuit. Two single-chamber cylinders were chosen which abide by SAE redundancy requirements.

Calipers - The Wilwood PS1 caliper with a 1.12-inch piston bore was chosen for the final design. This caliper is capable of producing more than the requisite force on the rotors, while still remaining small enough for packaging.

Rotors - The front rotors are from a Yamaha Banshee 300 due to their compatibility with the front hubs, master cylinders, and caliper design. The rear brake rotor was designated as an inboard rotor.

Pedal - The brake pedal was designed as a second class lever, where the load is placed between the fulcrum and the applied force. The subsystem was assembled using waterjet components and affords a wide range of ergonomic flexibility in driver input. The vehicle's toebox also features a heel bar rest designed with the same intent.

SEATING

A Kirkey racing seat with a foam and leather cover was chosen for its ease of implementation, proven success in a variety of racing environments, and ergonomics. Cut from Aluminum, the seat is lightweight and easy to modify for mounting and safety belts. The orientation of the seat back is set to 21° to allow for an improved driver experience during long endurance stints and to accommodate a wide range of driver heights in a comfortable position.

CONCLUSION

Development oriented towards a vehicle capable of completing a four-hour endurance challenge has culminated in the design and fabrication of a truly durable off-roader. Testing of vehicle #65 has already yielded successes in acceleration, braking, steering, rollover, obstacle management, and hill climb scenarios.

Unique designs like modular uprights and fully independent, adjustable suspension highlight a sturdy, dependable vehicle. The University of Colorado at Boulder Mechanical Engineering Department has developed a vehicle worthy of the Baja SAE California competition and a standing in the commercial all-terrain market.

ACKNOWLEDGMENTS

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APPENDIX

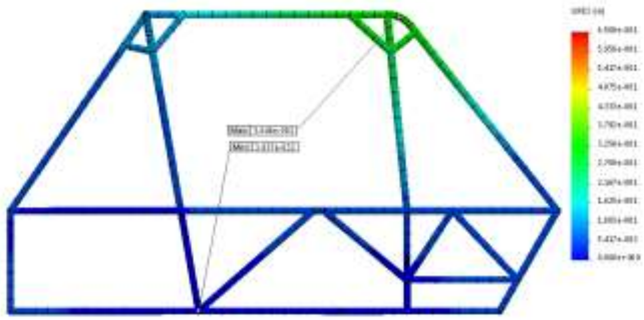

Figure 1: Frame FEA - Rollover Loading

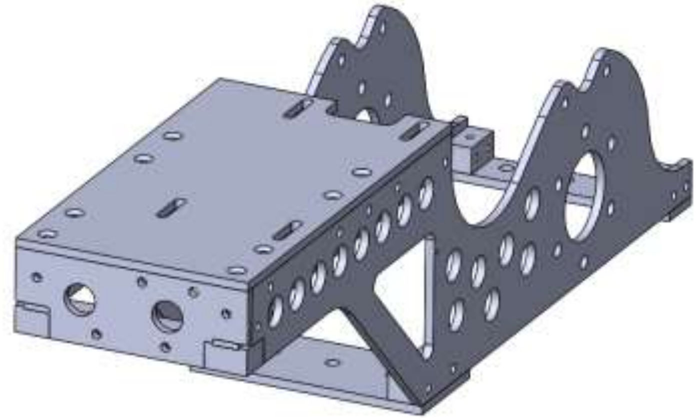

Figure 2: Drivetrain Mount

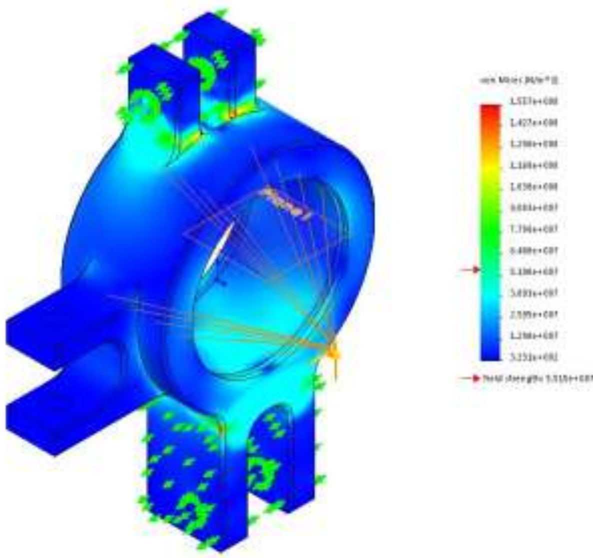

Figure 3: Suspension FEA - Rear Upright - Front Bump Loading

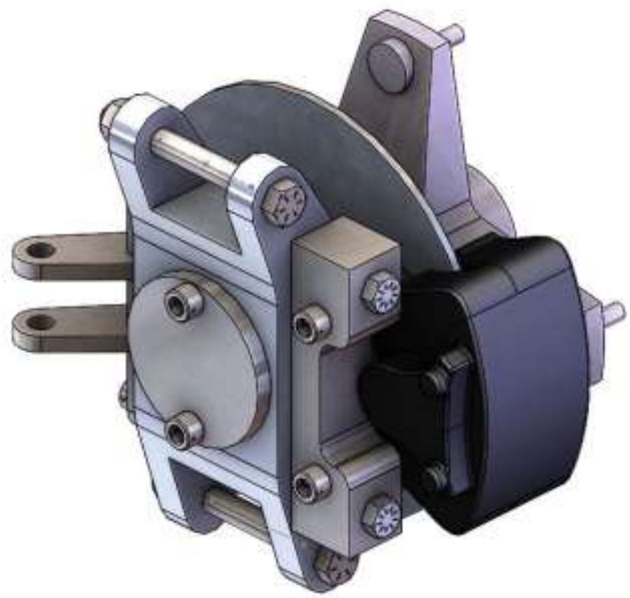

Figure 4: Modular & Symmetric Front Upright Assembly

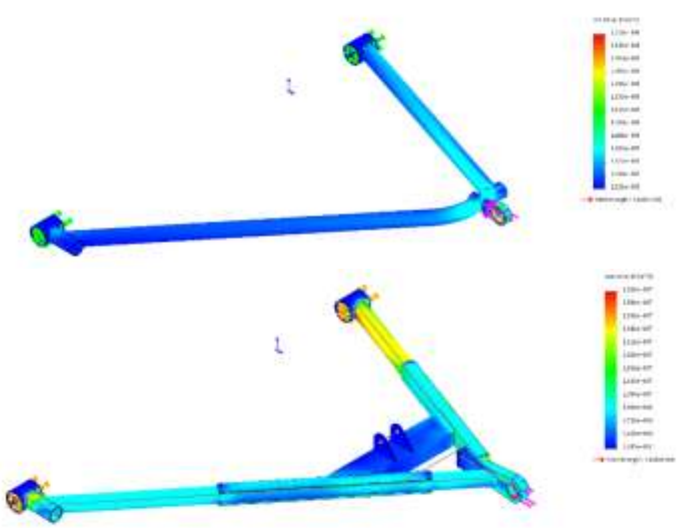

Figure 5: Suspension FEA- Rear A-Arms - Side Bump Loading

Figure 6: Rear Suspension Assembly with Full Toe & Camber Adjustment