University of Alaska Anchorage Seawolf Motorsports Design Report

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ABSTRACT

The 2015 Seawolf Motorsports Baja SAE vehicle has five primary subsystems: the frame, drivetrain, front suspension and steering, rear suspension, and the control systems comprised of the brakes and throttle. These subsystems are optimized and integrated such that they complement one another without exceeding the limitations of any one system during anticipated race conditions at the Washougal Motocross Track. Overall, the vehicle design was shaped under the guidance of three primary goals: reliability, durability and most importantly safety.

INTRODUCTION

The design of the 2015 Seawolf Motorsports Baja SAE off-road vehicle was developed through the analysis of each subsystem in relation to the three principal goals set by the design team: reliability, durability and most importantly safety. The car's five primary subsystems consist of the frame, drivetrain, front suspension and steering, rear suspension, and the control systems comprised of the brakes and throttle. These subsystems combine to complement and support one another without surpassing the limitations of any one subsystem during anticipated race conditions at the Washougal Motocross Track.

Careful consideration was taken to increase the strength to weight ratio of materials used, reduce the production cost, ensure the reliability and longevity of the vehicle, and guarantee the ease of operation and maintenance of the vehicle.

METHODS

The design team validated system designs for strength and durability, and qualities such as machinability, weight and cost effectiveness. The team considered material, geometry and overall ergonomics to optimize components and maximize the performance of the vehicle. The use of finite element analysis (FEA) was an integral part of identifying potential system failures such that a design could be improved upon and perfected. For design analysis, the team utilized the finite element analysis capabilities of SolidWorks.

FRAME

The frame (Figure 1) is the primary structure of the Baja vehicle because it is the groundwork into which all other subsystems are integrated. Thus, several key design consideration were taken into account.

DESIGN CONSIDERATIONS

The weight was a primary concern, as minimizing the weight of the frame without compromising the structural integrity is critical. Thus, all non-essential members were eliminated and the trailing arm design was chosen in order to allow a slimmer more streamline rear frame geometry. The material 4130 carbon steel (Chromoly) was selected for frame construction for its high strength to weight ratio. Additionally, this material was chosen based on its bending strength, bending stiffness, carbon content, yield strength, machinability, and cost.

Ergonomics were another factor considered during design. The frame was designed to accommodate a 5-foot and 6-foot tall driver, providing the head, shoulder and leg clearances necessary for the larger driver, while maintaining the safety equipment positioning required for the smaller driver. A five-point harness was affixed to the roll cage, which was constructed from the strongest Chromoly tubing specified for the project, to optimize its reliability.

As the host of all subsystems, members were added to the frame for mounting components of the vehicle such as the shocks, brake and gas pedals, the shifter, the steering rack, and the motor as the frame design progressed. Collaboration with the suspension design team enabled members to be installed for supporting suspension loads and improving the suspension stroke and strength. Furthermore, the frame was designed to allow easy access to the power transfer system. The engine and transmission mounts position and orient these components not only such that they are easy to place and remove for maintenance, but also such that they contribute to a lower center of gravity for the entire vehicle. In addition, the mounts allow the positions of these components to be adjusted slightly should the need arise.

DESIGN VALIDATION

To validate the integrity of the frame, the design team used the finite element analysis (FEA) package in SolidWorks. The use of physical test results validated the FEA results by comparing the deflection of the frame from a previous prototype and the deflection tabulated in SolidWorks Simulation. The difference between the experimental and computer generated deformation was found to be about three percent. Thus, the design team deemed it reasonable to simulate potential impact scenarios in SolidWorks by applying forces calculated to recreate various impacts to locations on the car corresponding to the type of impact. The following is a list of impacts the team considered:

- Frontal collision
- Rear collision
- Lateral collision
- Nose dive
- Overhead roll
- Lateral roll
- Suspension deficit

At the highest stress points, frame members were found to withstand impacts of greater than 2,000 lbf without fracturing, and although deformation of members was inevitable during certain impact scenarios, at no time was the deformation great enough to endanger the driver.

DRIVETRAIN

The drivetrain was designed based upon set specifications, experimentation, and research. The subsystem consists chiefly of the transmission, transaxle, and gear box. The primary goals of the design team were to increase the maximum speed of the vehicle to 35 mph, reduce the vehicle's weight and lower the center of gravity, and to optimize gearing such that maximum torque and power are generated.

TRANSMISSION AND TRANSAXLE

A continuously variable transmission (CVT) was chosen for this vehicle based on its ability to provide power at a variety of speeds, allowing it to transmit proficient torque to maximize speed. A CVT is also advantageous due to its comparably low weight, the minimal maintenance it requires, and the simplicity it affords the vehicle's operator by eliminating manual gear shifting. Based on the supplied 10hp Briggs and Stratton engine, the CVTech continuously variable transmission was chosen in conjunction with the Schafer Gear Works Spicer H-12 FNR transaxle to compose the powertrain.

In order to evaluate the drivetrain performance more effectively, a system was developed to experimentally analyze engine and wheel RPM with respect to time. To determine wheel RPM, a photoelectric sensory system utilizing a sensor and emitter through the rear brake rotor was designed and implemented. As the rotor spun, holes in the disc allowed intermittent pulses to pass through from emitter to detector. Using the known number of holes per rotation and total time, wheel RPM was back calculated. To determine engine RPM, a wire was wrapped around the spark plug ignition wire such that, through induction, a revolution of the engine could be monitored. Both signals were routed back to a data acquisition device connected to a computer where they were processed using LabView and MATLAB. Multiple experiments were conducted on a previous vehicle prototype that modeled various vehicle conditions such as low tire pressure and fully bottomed out suspension. The results allowed the design team to determine the maximum vehicle speed, as well as create a baseline with which to compare future vehicles.

The experimentation also allowed the team to analyze the shift out times of the CVT and provided data upon which to refer during gearing calculations. It was determined that the CVT was not shifting out fully, meaning that the vehicle was not reaching its optimal gear reduction. To reach the 35 mph goal, gear reduction calculations were done backwards. Knowing the goal was 35 mph and that when working properly the output of the CVT is 0.43:1, generating approximately 8372 RPM from an engine governed to 3600 RPM, the design team calculated that a reduction of 16.15:1 was desirable.

GEARBOX

Multiple gearboxes were analyzed in order to meet the 16.15:1 reduction criteria between the CVT and wheels. A Comet gearbox tuned for 16hp engine outputs was considered, but due to the RPM multiplying output of the CVT in overdrive, the Comet's 4000 RPM limit was too low. Previous designs utilized a Polaris Razor UTV transaxle which was determined to be excessive for the application, but the Polaris gearbox required a final chain reduction in order to meet the desired ratio. Therefore, the Spicer H-12 FNR transaxle was chosen. The stock transaxle supplies a reduction of 13.25:1, which theoretically allows the vehicle to reach 42 mph. This puts operation within the chosen power curve, while simplifying the drivetrain configuration and allowing the center of gravity to be lowered.

FRONT SUSPENSION AND STEERING

The front suspension and steering (Figure 2) need to be optimized for the ideal driving experience. The A-arm type front suspension of the previous vehicle prototypes was chosen, as it proved functional. The overall goal was to improve the suspension geometry in terms of maneuverability without sacrificing durability.

GEOMETRY

The major weakness identified in previous prototype designs was excessive bump steer. This put added stress on the tie rods and ultimately led to failure. To minimize bump steer, the motion of the suspension was closely examined in SolidWorks by manually running the suspension through its full travel. Thus, bump steer was almost completely eliminated by keeping the tie rods and A-arms parallel and of similar length.

To improve maneuverability, the main area of concern is the steering geometry. When a vehicle makes a turn, the two front tires must follow different radii [1]. As a result, incorporating Ackerman steering geometry was vital. The larger turning angle on the inside tire allows for an overall smaller turning radius and the faster cornering speeds. This geometry also improves traction and reduces stress on steering components by limiting the need for the tires to skid as the vehicle negotiates tight corners. To achieve this, the Polaris knuckles were rotated 180 degrees and moved to opposite sides of the vehicle from the previous prototype design. This allowed the axes intersecting the steering arms and kingpins to intersect at the center of the rear axle. This had the added benefit of moving the steering rack to the front of the vehicle, out of the way of the driver’s feet.

Other important design considerations in the steering system of an off-road vehicle are the caster angle and camber angle, which were used to improve handling. A caster angle of 10 degrees was chosen to increase stability without decreasing responsiveness and to greatly improve the ability of the front tires to automatically return to center without driver input. This caster angle also increases the mechanical trail of the front tires by 1.75 inches. The caster angle leads to a negative camber angle of five degrees when the tires are fully turned. This results in nine percent more force being directed through the vertical plane of the tire rather than horizontally across the tread surface. The ball joints on the A-arms permit adjusting camber angle after assembly.

SIMULATION

Once the necessary geometry was established, the components were modeled using SolidWorks. Because of the complexities of three-dimensional connections in the final assembly, a second simplified model (Figure 3) was created to study the kinematics of the system. Through this examination of the kinematics of the vehicle, the suspension and steering system moves through its full range of motion without affecting fundamental relationships.

Every major component was then analyzed using finite element analysis (FEA). The FEA results were validated experimentally by comparing the displacements of the upper A-arm from a previous prototype to the theoretical displacements calculated in a SolidWorks. The average percent error was calculated to be about eight percent, validating the results from the numerical analysis.

REAR SUSPENSION

The rear suspension of the vehicle is based on an independent drive system. The independent suspension allows the right and left suspension systems to operate separately. This improves both the driver comfort and maneuverability of the vehicle over obstacles and uneven terrain.

Due to ease of manufacture and the effectiveness of its geometry, a trailing arm (Figure 2) was decided upon for the rear suspension. Along with the trailing arm, an adjustable control arm was implemented to properly tune the camber of the rear wheel for better traction. As a result of the geometry, Fox Float 3 adjustable air shocks are mounted to achieve maximum suspension travel. The design also provides sufficient clearance for the transmission and engine for ease of maintenance.

To compensate for the high forces experienced by the trailing arms while going over obstacles, 4130 carbon steel tubing with an outside diameter of one inch and a wall thickness of 0.065 inches was used to construct the arms. In addition, vertical supports of 4130 steel were added to strengthen the arm near the bearing carrier mount and in the middle section where the shock tabs connect. The added support bar decreases bending at the mid-section of the trailing arm and provides a stronger member. The bottom member of the trailing arm was extended closer to the frame of the car for added strength between the shock tab and frame of the vehicle.

CONTROL SYSTEMS

The control systems of the car consist of the brakes, throttle and shifter.

HYDRAULIC BRAKE SYSTEM

The weight supported by each tire is not equal. As a result of this incongruity, the brakes were designed to handle a 67% to 33% front-to-rear braking force distribution to accommodate dynamic weight transfer. In addition, all four tires must lock up when the brake pedal is actuated [2]. The hydraulic brakes are actuated by using a mechanical advantage called a pedal ratio, which multiplies the force applied to the brake pedal in order to pressurize the brake system lines more effectively. Thus, it was essential that the design team choose an appropriate pedal ratio that maximized the brake efficacy, while minimizing operator effort. Thus, the pedal ratio of 6 was chosen.

The brake system relies on seven-inch diameter disc brakes. The discs are mounted at each front tire, and on the rear axle for the rear tire pair. The single rear disk provides sufficient braking, while reducing the weight of the vehicle by eliminating the second disk and caliper set. The calipers attached to each disc have two pistons, both one inch in diameter. The brake pads are a critical component of the caliper assembly; the chosen calipers require standard semi-metallic brake pads. The Brembo

PS12E Master Cylinders with a piston bore size of 0.512 inches are used.

The force that needs to be applied to the pedal is about 76 lbf, which is distributed between both hydraulic circuits to lock up all four tires effectively. Yet as described, the force required for each circuit is different. To compensate, the design team chose to use a balance bar in the design.

PEDALS

The force required to actuate the brake pedal is not the force that the pedals are designed to withstand. To accommodate the maximum amount of force that a driver could potentially exert on the pedal, the pedal was designed to withstand 300 lbf of foot force and solid models of the pedal assembly were made in order to perform finite element analysis (FEA) and test the design under loading. Performing this analysis identified the maximum stress state of the pedal assembly and the material of the pedal assembly was determined. The pedals are made from 4130 carbon steel. The main pedal lever arm, and the brackets used to weld the assembly to the frame are also made out of 4130 carbon steel, and the hinge pins and the locking pins are made from 1020 steel.

Adjustability of the pedals was a primary goal in the design. Leg length differs and affects performance if not taken into account. To compensate and create a more ergonomic design, the pedals were designed with a forward and a rear position. The adjustability of the pedals is accomplished by changing the hole on which the pedal hinges. Since the gas pedal incorporates a throttle linkage to create a large throttle cable pull for a small pedal movement, there is a linkage set for each gas pedal position that compensates for the changes in throttle movement as a result of adjusting the gas pedal position. Additionally, mechanical stops attached to the frame prevent the throttle cable from overextending and breaking. For further ease of use, both the gas and the brake pedals were designed with a spring return so that they naturally return to a neutral position after removing the foot from the pedal.

GEAR SHIFTER

The car shifts between two active gears, forward and reverse, with a neutral position in between. The gear shifter includes an internal locking mechanism that prevents the shifter from inadvertently changing position while driving. The mechanism is internal to prevent the mechanism from being clogged with dirt or mud, which would make operating the gear shifter much more difficult for the driver. Thus, ease of use was a primary design consideration for the shifter.

The shifter was designed to withstand a force of 40 lbf for both push and pull; this amount of force, however, will only be a concern when the shifter assembly is in the locked position. The shifter is mostly made out of 6061 aluminum. To accommodate for the stress needed to withstand the large internal loads as a result of the relatively thin locking pin being subjected to the design force of 40 lbf, the locking pin sections of the assembly are made of 1020 carbon steel.

CONCLUSION

The goal of this project was to fully model, design and build an off-road vehicle, while complying with the SAE Baja rules and requirements. The design process provided many challenges that were solved by team work and the utilization of engineering methods. The team designed a rugged off-road vehicle able to handle long trips through rough terrain.

ACKNOWLEDGMENTS

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REFERENCES

[1] Millekin, W. F. “Race car vehicle dynamics.” 1st Edition. Warrendale, PA Society of Automotive Engineers, Inc. 1995. Print.

[2] SAE International. “2015 Collegiate Design Series: Baja SAE Rules.” 2015. Print.

Figure 1. Frame.

Figure 2. Front suspension and steering.

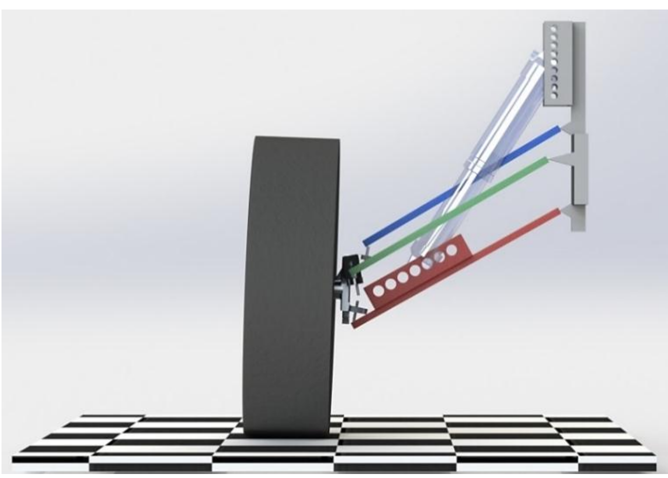


Figure 3. Simplified suspension model.

Figure 4. Trailing arm.

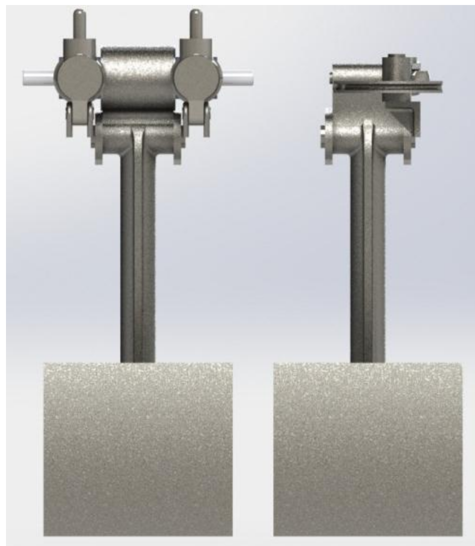
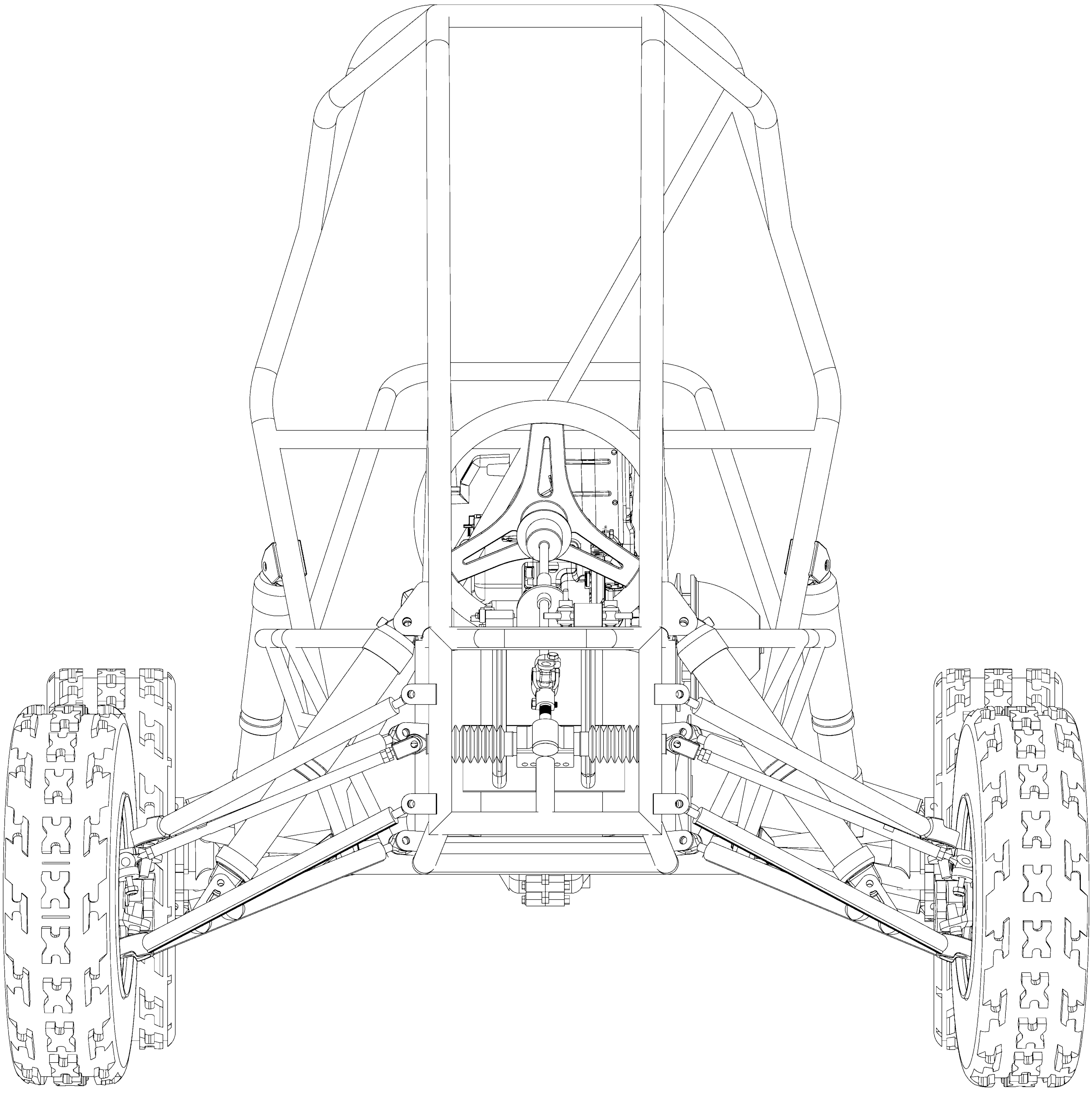


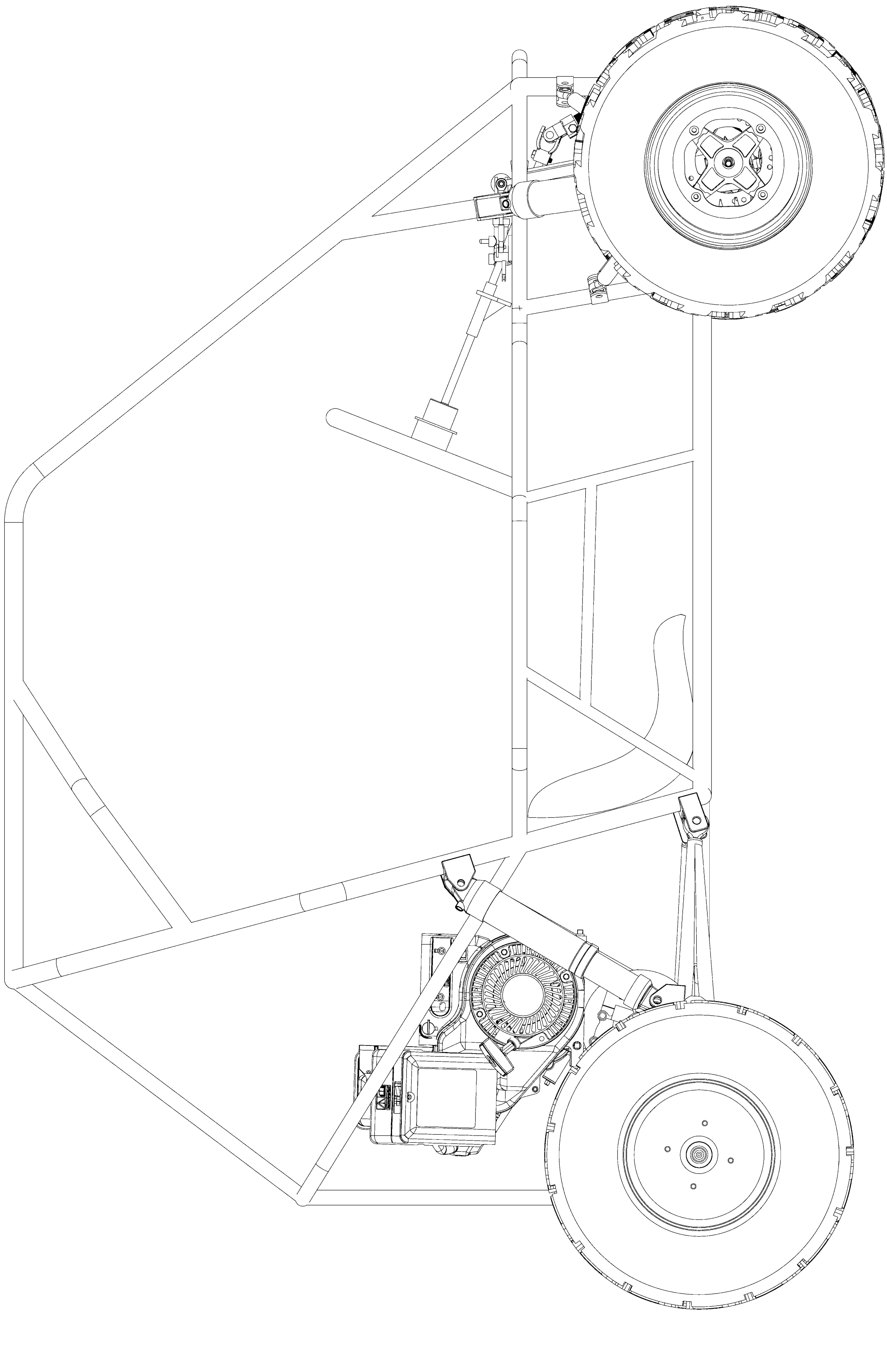
Figure 5. Pedal assembly.

Figure 6. Side (left) and front (right) views of the shifter assembly.

Front View



Side View



Top View