ABSTRACT
A team of students incorporating various majors including mechanical engineering from Brigham Young University-Idaho designed and manufactured a prototype of an off-road recreation buggy. Design efforts focused on reducing weight from last year, improving aesthetic appeal, beginning with the end in mind, increasing suspension travel, and maneuverability. The prototype meets SAE competition criteria and provides the future manufacturer with a proven product that is worth selling. All systems outlined in the report explain the purpose for chosen designs, specific design objectives, and also improvements over last year’s vehicle.

INTRODUCTION
Starting June of 2010, a group of Brigham Young University-Idaho students from the mechanical engineering department began designing an improved model of an off-road buggy to compete in the Baja SAE Collegiate Design Series. Collaborative efforts combined resources, student talent, and experience from across university departments to build BYU-Idaho’s best baja buggy to date. Prototype building began in late January 2011. The following article outlines the engineering and design process that was used in developing each system of the vehicle. It also addresses other special concerns relating to other aspects of the design process such as: improvements over last year’s prototype, manufacturing processes, and team limitations and strengths. Note: in all “Design Objectives” sections, however not mentioned, SAE specifications were first considered before all listed

Major Design Goals for 2009
- Reduce weight from last year
- Increase suspension travel
- Increase maneuverability
- Improve aesthetic appeal
- Improve drive train

FRAME SHAPE – When designing the frame the primary goal was to keep the driver safe in the event of an accident. The shape of the frame maintains a safe distance between the driver and the environment in whatever position the car lies after an accident. The frame was also designed to be aesthetically pleasing. This year the frame was built with complimentary angles and flowing members. The belly pan under the driver was boat sided to improve side clearance and decrease area to become high centered on.
MATERIAL CHOICE AND FABRICATION–The tubing chosen was 1"ODx.120"Wallx.76"ID and 1.25"ODx.065" Wallx1.12"ID DOM for the primary tubing and 1"ODx.065"Wallx.87"ID and 1"ODx.049"Wallx.9"ID DOM. This steel was chosen because of the low cost and ease of welding and bending compared to chromoly. The body panels will be made of aluminum sheet. The belly pan will be made of steel sheet for its durability. MIG welding was chosen to manufacture this year’s vehicle due to the material choice; and because it is faster and easier than TIG welding and provides sufficient strength. All bends were done using a hydraulic bender.

SUSPENSION

Design Objectives
- Maximize maneuverability
- Clearance over obstacles
- Increase suspension travel
- Shift on-the-fly sway-bar disengage/engage mechanism.

The main objective of the suspension system is to maintain control of the buggy while steering or traversing rough terrain. This year’s vehicle will have independent suspension front and rear. Having each tire independently suspended allows for greater overall clearance and better high speed stability over rough terrain.

SUSPENSION DESIGN – The front suspension system was designed with unequal length A-arms. The rear suspension will incorporate a hybrid trailing arm suspension. There was special design attention given to the front A-arms to ensure minimal camber change as the suspension was either fully extended or compressed. The minimal allowed camber change maintains the wheel alignment perpendicular to the ground taking into account body roll of the vehicle in cornering situations. This was done by offsetting the top A-arm from the bottom to create a calculated radius on which the A-arms pivot maintaining proper alignment when traveling up or down over terrain. The front suspension arms are also raised in the front to allow some horizontal component of suspension travel. This horizontal movement increases the effectiveness of the front suspension as the wheels are allowed to move rearward as they deflect up. This motion minimizes the impulse peak force from obstacles by allowing more time for the impulse to be absorbed. Suspension travel in the front will be approximately 12°.

The rear suspension will incorporate a hybrid trailing arm design. This will be used to achieve the rear suspension travel of 14". This will help keep the buggy from bucking in high speed washboard and whoop sections that were noticed in the previous year’s buggy, which had limited rear travel.

SWAY-BAR DESIGN–The rear suspension incorporates a shift on the fly sway bar design. This allows for the buggy to have maximum articulation in tough terrain, but then reduces body roll in high speed maneuvering. In some instances it can be adjusted for over steer to achieve higher maneuverability in tight situations. The sway bar can be engaged or disengaged from the drivers controls. This allows the driver to be stable through high speed sections with the sway bar engaged. When approaching an obstacle the driver may remain in the vehicle while disengaging the sway-bar to achieve maximum traction over the obstacle. Once over the obstacle the driver can re-engage the sway-bar and continue driving. This allows for more drive time, safer control of the buggy, and keeps the driver from having to decide between running a sway-bar or not.

Suspension Arm Construction – The front A-Arms were completely redesigned. Previous year’s front A-Arms were Polaris Predator or copies of Polaris Predator’s front suspension arms. 1"ODx.095"Wallx.81"ID DOM tubing was used for the lower A-Arms and 1"ODx.065"Wallx.87"ID DOM was used for the upper A-Arms. Each side is identical in geometry to reduce part numbers and allow for less spares required. ½" rod ends were used on the inboard side and 5/8" rod ends were used on the out board side.

Shocks – The front suspension will incorporate Fox Racing Shox Float Rs, while the rear suspension will incorporate Fox 2.0 Air Shocks. The use of air shocks allows for easier tuning than a typical coil over and comes with a significant weight reduction. The Float Rs also have a rebound adjustment for fine tuning to terrain and driver needs.

CLEARANCE – The vehicle has an overall clearance of 12". The front approach and rear departure angle are greater than 90 degrees to allow better obstacle climbing ability and reduce hang-ups on departure. The break over angle is yet to be determined.
DRIVETRAIN

Design Objectives
- Easily serviceable
- Forward and reverse
- Optimize balance of low-end torque and top-end speed
- Lower weight and increased efficiency

The overall objective of the drive train is to transmit power from the engine to the wheels. One of the design team’s objectives was to ensure that each element of the drive train was easily accessible to work on if need be. Last year’s vehicle would take several hours to change a sprocket to adjust gear ratios. The balance of power distribution to allow for low-end torque and top end speed was also very important because of the limited 10 hp and 14.5 lb*ft of torque output from the Briggs & Stratton engine. All of the drive train components were positioned as low and forward as possible to ensure proper weight distribution. Several years ago the baja vehicle had a rear differential, however this year’s vehicle was designed to have a spooled rear axle to minimize weight and maximize traction. The entire drivetrain includes: the engine, a CVTech CVT, a Comet Forward-Neutral-Reverse gearbox, a multistage chain and sprocket reduction system, and independent rear drive shafts.

ENGINE – All engine specifications are set and cannot be changed; and engine speed is limited to 3800 rpm. With the limited power, minimizing weight is an important factor in vehicle performance. The vehicle’s frame design allows for easy access to the engine and also mounts it as forward as possible.

CVT – Part of the drive train is a CVTech brand Continuously Variable Transmission (CVT). The CVT was chosen due to reliability, ease of use, and maintenance. The transmission gear ratios range from 3.0:1 minimum to a 0.43:1 overdrive maximum. This gives a 6.97 ratio range. This is an increase over past years which will allow for more torque down low to achieve the same top end speed.

F-N-R GEARBOX – This year’s buggy was specifically designed a forward-neutral-reverse gearbox. With a significant weight savings over last year’s design and the ability to have reverse, the minimal weight added to the buggy is worth the additional benefits.

SPROCKET REDUCTION SYSTEM – The goal of this system is to lower the final gear ratio. The sprocket reduction system was designed to use off-the-shelf components. Size 428 chain and 4 interchangeable 428 aluminum sprockets were used. Aluminum sprockets were used in replacement of heavy steel industrial sprockets. This will increase drive train efficiency by reducing moments of inertia. The chain case is CNC’d from billet aluminum. Internally it houses the final reduction of the drive train. It also has mounted to it the rear brake caliper.

The ratios for the drive train at the axle shaft are 49.22:1 initial ratio and 7.055:1 final ratio. This is an improvement from the past buggy which only had 33.94 initial ratio and 5.335:1 final ratio. This will allow for greater acceleration, but lowers theoretical top speed which was never obtained because the previous gear ratio was geared too high.

DRIVE SHAFTS – The design is optimized by using driveshafts with universal joints on each end. Last year’s buggy had a u-joint on the inboard side and a CV joint on the outboard side. This combination was not ideal and it had noticeable driveline vibrations at low speeds. This was caused by the high and low speed of the u-joint turning without a matched u-joint clocked correctly to negate this effect.

BRAKING

Design Objectives
- Safely bring the vehicle to a stop
- Reduce unnecessary momentum

The design goal of the braking system is to stop the vehicle in the shortest distance possible. Disc brakes were used on each front wheel. The rear braking power comes from a single disc and caliper located on the chain case. By housing the brake outside instead of inside brake fade will be reduced because cool air will be allowed to pass over the rotor and caliper. Also, with ability to switch the transmission into neutral the brakes will not have to counteract the momentum of the engine when competing in the brake test. Another design feature of the braking system is dual master cylinders. One controls the front calipers and the other controls the rear. In case of failure of one master cylinder the other will have sufficient braking power to safely stop the vehicle.

STEERING

Design Objectives
- Minimize turning radius
- Maintain proper tire alignment

The steering system contains the steering wheel, steering column, rack and pinion, tie rods, knuckles, and ball joints. The steering wheel will be mounted with a
quick release mechanism to decrease exit time from the vehicle in case of an accident.

The steering system on last year's vehicle was loose and unresponsive at low speeds. This year's vehicle was designed with rack and pinion steering. One of the benefits of this type of steering is a lighter feel in the steering wheel due to a gear reduction. It also improves the feel of the road allowing the driver to rely more on feel than sight. The specific rack and pinion that will be installed in the car has one and three quarter turns from lock to lock.

STEERING GEOMETRY – The front suspension was designed to eliminate bump steer, which can have unwanted affects while negotiating tough terrain.

TIRE ALIGNMENT – The front alignment is adjusted by lengthening or shortening the tie rods. Each component (A-Arms, trailing arms, etc.) is fully adjustable to accommodate the driver’s needs.

MANUFACTURABILITY

Part of the purpose of this project is to determine the feasibility of manufacturing 4,000 of this year’s baja prototype. In order to accommodate future manufacturers, several factors were taken into account. The frame was designed using bent-tube construction. All welds were MIG welded to simplify the manufacturing process. Joints were fish-mouthed using a belt grinder with changeable dyes making grinding easier and providing a fast method to ensure a tight fit at the joints. And, all replaceable parts are easily purchased at any motorsports dealer.

CONCLUSION

Design and construction of this year’s prototype we hope to be successful. Budget limitations and time restraints have caused the BYU- Idaho team to be resourceful and innovative with regard to their design plans and prototype construction. It has been a good exercise to work within limited means to produce the best vehicle possible to compete in the Baja SAE Collegiate Design Series. Design goals will be met, resulting in a final product that will withstand the abuse of off-road conditions and be a formidable competitor in next year’s competition.

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REFERENCES


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DEFINITIONS, ACRONYMS, ABBREVIATIONS

BYU(Brigham Young University)
CNC(Computer Numerically Controlled)
CV(Constant Velocity)
CVT(Continuously Variable Transmission)
DOM(Drawn Over Mandrel)
ID(Inner Diameter)
MIG(Metal Inert Gas)
OD(Outer Diameter)
SAE(Society of Automotive Engineers)
TIG(Tungsten Inert Gas)