2008 UC Basic Utility Vehicle

by

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2008 Basic Utility Vehicle

Suspension Design

By

Andrew K. Morison

ABSTRACT

In developing countries around the world, there is a need for cheap and reliable transportation. The Institution for Affordable Transportation held a contest on April 19, 2008 to see which engineering colleges can design the best Basic Utility Vehicle (BUV) for the least amount of money.

The University Of Cincinnati College Of Applied Science has a team of students that are participating in this contest. The design was broken down into four sections: the chassis by Marcus Knapp, the suspension by Andrew Morison, the drive train by Andrew Malatesta, and the electrical system and accessories by Josiah Brinkerhoff. Josiah Brinkerhoff will manage the BUV team. Surveys were created and sent to end users in Africa to find out what features are really needed on basic transportation.

The BUV is to be assembled in Africa, so they use truck frames that are already in Africa to reduce the number components that will need to be imported. Therefore, the key features that are most important to the end user of the BUV are the fabrication time, the number of parts, and the cost to manufacture. The BUV should be cheap to make and very rugged and reliable so that developing towns in Africa will be able to use it for many different purposes for a long time.

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PROBLEM STATEMENT AND BACKGROUND

The focus of this design is on third world countries needing cheap and reliable transportation sources. Yearly the Institute for Affordable Transportation (IAT) has a competition. This competition is to test college students to see who can design the best vehicle for the lowest cost. This vehicle must be able to carry at least a 1200-pound payload and can be used to transport people. In addition, the vehicle must be easily maintained and cheap to repair with parts readily available in the region.

The competition will take place on April 18th and 19th 2008 around Indianapolis, Indiana. Acculube and BAE Systems donated money will fund the vehicle, and the Basic Utility Vehicle (BUV) team will provide any additional funds.

This project will be broken down into four parts, each part delegated to one member of the group, which goes as follows:

- The Chassis - Marcus Knapp
- The Suspension - Andrew Morison
- The Drive Train - Andrew Malatesta
- The Electrical System and Accessories - Josiah Brinkerhoff.

The 2008 BUV team manager will be Josiah Brinkerhoff with Dr. Janak Dave as advisor.

The focus of this report is on the suspension of the BUV. The competition rules state that the rear suspension and brakes must be from a standard production pickup truck. The front end will be a motorcycle style, with a single front wheel. The majority of this design project will be to design and build the front suspension and steering of the BUV.

RESEARCH OF EXISTING DESIGNS

There are three major design groups for suspensions.

- The first design uses a linkage with a shock bolted to the front end; this allows the suspension to extend when the brakes are applied. This allows for a lot of suspension travel that is good for traversing rough terrain.

- The next set of designs use an A arm with a shock mounted to the main frame of the motorcycle; this keeps the suspension and steering forces separate to allow for better control while stopping.
- Lastly is the internal fork spring design; this is a very simple and self contained set up that can have a lot of suspension travel but is not cheap to produce. Each of these designs has its strengths and weakness for use in a third world country (see Appendix B).

LINKAGE DESIGNS

The linkage style designs are the Earls fork, The Rationally Advanced Design (RADD), and the trailing link front end. All of these designs keep the vehicle from pitching forward under heavy braking and provide a smooth ride with plenty of suspension travel.

The Earls fork front-end design has been employed since the 1950s when BMW used it for its production motorcycles. It has a shock on either side of the wheel that bolts onto the upper part of the front-end frame. The wheel is mounts to a link that pivots behind the wheel, which allows a lot of travel. This design allows for a very smooth ride and easy repairs should something break as seen in Figure (1).

Figure 1- Earls Fork On A BMW /2

Yamaha used the RADD design in 1993 on the GTS 1000 production motorcycle. It utilizes a single side front swing arm with a shock mount back to the frame of the motorcycle. The steering is accomplished by a telescopic shaft connected to a ball joint, which controls the mounts for the front wheel as seen in Figure (2).

Figure 2- RADD Design On A Yamaha GTS-1000

Many different companies on a wide variety of vehicles have used the trailing link front end. Indian, BMW, and Bajaj have all produced this style front end. This design suspends the wheel on a link with a pivot point forward of the wheel axle. The trailing link design has been made as a single sided or double sided design, see Figure (3).

Figure 3-Trailing Link Design On A Bajaj 3 Wheeler

A ARM DESIGNS

The two major designs that use A arms are produced by BMW. The Duolever (or Hossack) and the Telelever (or Saxon Motodd) designs have been around for years but they have never been used widely. Then BMW took the concepts and refined them. Both of these designs eliminate dive under braking which gives better control while braking hard.

The Telelever design was first used on all BMW motorcycles in the mid 90s and remains in production on many of their motorcycles. This design has a single A arm bolted to the motor case and a shock mount on the frame of the motorcycle and the A arm. The wheel is mounted to a pair of tubes that are connected to the A arm by a bearing, illustrated in Figure (4).

Figure 4-Telelever Design On A BMW R1200GS

The Duolever design is a newer design released on the 2003 K1200S model BMW. This design mounts a pair of A arms on the front of the frame. Both of these arms are attached to a mount for the front wheel. A shock connects to the front wheel mount and the frame of the motorcycle. This allows the wheel to travel straight up and down, rather than at an angle, as seen in Figure (5).

Figure 5-Duolever Design On A BMW K1200S

INTERNAL SPRING DESIGN

The last design is the most common for production motorcycles of all kinds. The telescopic front-end design is used by almost every motorcycle manufacture for all different purposes. This design has an outer and inner tube, which house a spring. Fluid is used to dampen the spring and aid in the travel of the outer tube over the inner tube. One of these is mounted on either side of the front wheel and bolted into a clamp, which is connected, to the front end of the motorcycle frame by tapered roller bearings. See Figure (6) for an example.

Figure 6-Internal Spring Design On A Honda XR650

SUMMARY OF RESEARCH

From all the research there are four designs that really stand out as being optimal for the BUV, they are the Earls fork, trailing link, Telelever, and Duolever. These are all fairly simple designs that give better handling under braking and also do not dive while braking. The Earls fork and trailing link are very similar designs that are simple to work on and do not require a high cost to build. The Telelever and Duolever designs are more complex and would be more costly to build but would give the BUV better handling and steering. The RADD is a very good design but the cast swing arm and all the bearings needed, will make this design very costly. The internal spring design would be very simple to install but would be costly and too complex to easily repair over in Africa.

END USER FEEDBACK

The results that were received back from the survey of twenty-two end users, told what would be the most important features of the BUV to them. As Table 1 shows in bold, the most important features to the end user concerning the suspension are the ease of maintenance and having a spare tire (see Appendix C). This means that the front suspension will have to be simple to work on and easily repairable. Also from the customer survey, the most common terrain the BUV will be dealing with is sand and gravel. This will affect the front wheel that will have to be chosen for the front suspension.

Table 1-Survey Results

Feature	**Importance**
Spare tire	**4.86**
Emergency road side repair kit	4.77
Ease of maintenance	**4.64**
Driver/Passenger seat belt	4.05
Auxiliary fuel can	4.05
Auxiliary lights	3.68
First aid kit	3.64
Shaded cargo bed	3.45
Ability to transport patients	3.27
Trailer hitch	3.18
Winch	3.14
Ability to transport fragile cargo	3.09
Fire extinguisher	3.09
Medical Devices	2.86
Cargo bed step ladder	2.73
Water pump attachment	2.68
Waterproof passenger/cargo	2.50
Bug shield passenger/cargo	2.32
Plow attachment	2.27

The design characteristics that have an effect on the suspension design are as follows with their relative importance: fabrication time 14.0%, number of parts 13.6%, cost to manufacture 12.5%, and weight 6.9% (see Appendix D). These engineering characteristics show that the design that has the least number of parts and is the easiest to manufacture and assemble would best meet the needs of the end user.

BUV SUSPENSION OBJECTIVES

The objectives of the BUV front end and suspension were as follows:

- A lock to lock steering distance of at least 100 degrees
- Eight inches of ground clearance
- Five inches of front suspension travel
- A load capacity of 2100 pounds
- A foot actuated rear brake and hand operated front brake
- Stopping ability of 50 feet on dry pavement from a speed of 20 miles an hour
- Ability to turn in a twenty foot diameter circle
- An emergency brake to keep the BUV in place

DESIGN

DESIGN ALTERNATIVES AND SELECTION

Out of the six different designs that were initially researched, three were sketched out for more in depth research. These three designs were the Earls Fork, Telelever, and Duolever. These sketches can be seen in Appendix H.

A weighted decision matrix was created to select the best design according to the results of the customer survey and the QFD. The most important factors to consider in a design were the fabrication time, number of components, cost to manufacture, and the weight. When all the designs were put into the weighted decision matrix and their ranking was multiplied by the relative weight of each factor, the design that came out on top was the Earls Fork. This meant that the Earls Fork design would best fulfill all the needs of the BUV end user. The weighted decision matrix can be seen in Appendix G.

The rear suspension mounts needed to be designed when the drive train design did not include the stock truck frame rear axle. Since the drive train transaxle rotated around the neutral idler shaft, while the leaf springs moved vertically in a linear motion, there needed to be an attachment between them that would allow them both to move, while not binding each other. Many designs were created but rejected for the high cost or complexity. The final design had fewer parts and low cost but would give the needed movement to both the drive train and the suspension.

DRAWINGS

Once the final design was selected, it could now be drawn up in detail in Solid Works design software. Solid Works will allow the design to drawn up in three dimensions, be load tested, and have the stress of the components analyzed as an overall system in a short amount of time. This initial stress analysis allowed any problem areas to be recognized and better analyzed before parts were ordered and building began. Detailed drawings of the overall design can be seen in Appendix I.

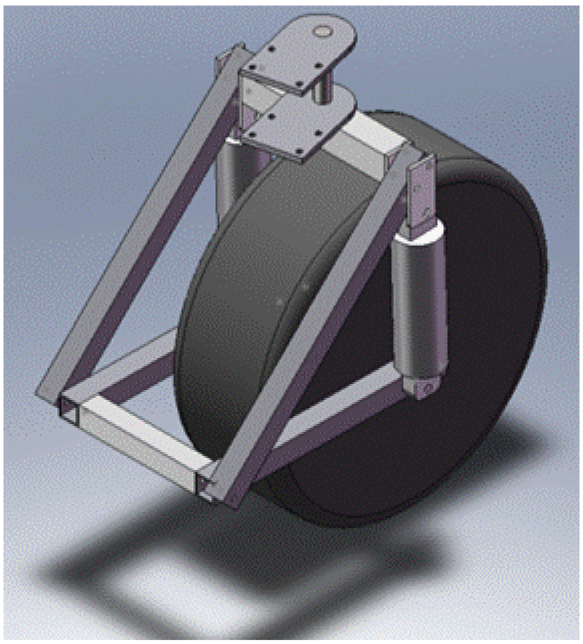

Figure 7- Front Suspension

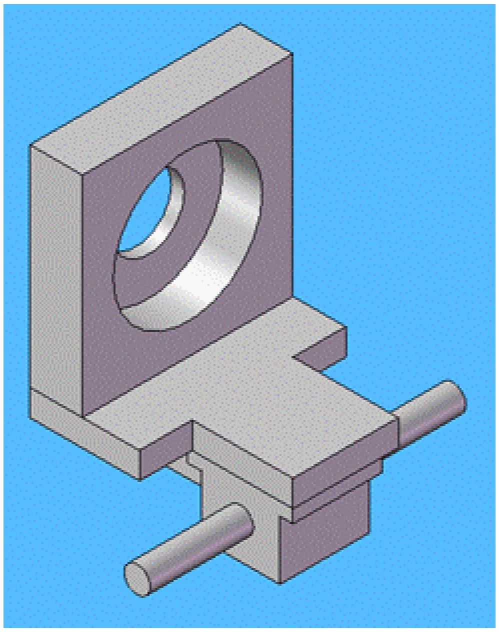

Figure 8-Rear Suspension Mount

LOADING CONDITIONS

The loading conditions for the front end were assumed to be a repeated load for the majority of the structure. The front axle will be the only part to see an impact load while the coil over shocks will take up the majority of that force before it gets to the rest of the structure. To analyze the front suspension, a worst-case scenario was thought up; it would be going down a 20-degree slope at 20 miles an hour while braking. This would transfer the maximum amount of weight to the front suspension and stressing it as much as possible. Assuming the BUV weights 3,000 pounds fully loaded (which is 500 pounds more than it should weight), so at any given time there will be about 1,000 pounds on the front suspension. When going down a 20-degree slope and additional 855 pounds will be sent to the front. The braking forces will transfer another 600 pounds onto the front suspension. This gives a worst-case scenario load of 2,455 pounds on the front end of the BUV.

For the rear suspension mounts, the worst-case scenario was going up a 20-degree slope while accelerating. This would transfer a lot of weight to the rear suspension and stress it to the maximum. Assuming the BUV weights 3,000 pounds fully loaded (which is 500 pounds more than it should weight), there will be about 2,000 pounds on the rear suspension. If one side of the suspension were to be on the down side of the hill, it could see up to 1,500 pounds. The acceleration of the BUV could transfer an additional 526 pounds while the slope of the hill would transfer 855 pounds onto the rear of the BUV. This loading condition would make the maximum load on the rear suspension 2,881 pounds.

DESIGN ANALYSIS

The initial stress analysis was done using Solid Works Cosmos. Once the parts were drawn up in three dimensions and then mated together where they will actually be attached, then the parts can have a material assigned to them, forces can be applied to certain points, and restrains can be applied where the front suspension is bolted to the frame of the BUV. Solid Works software will then analyze the structure and report the stresses and deformation that will occur when the force is applied.

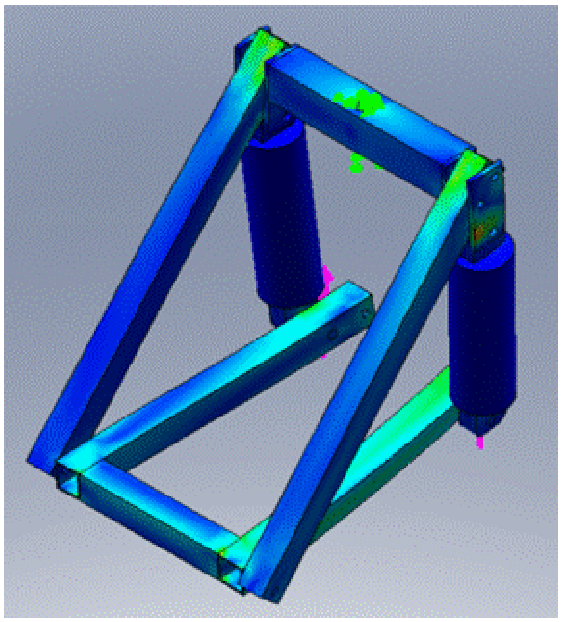

Figure 9-Front Suspension FEA

The front suspension was put under 5,000 pounds of force to see which parts would have the highest stress and would need more calculations and analysis. Parts that need more stress calculation were the front axle, shock mount bolts, shock mount plates, top cross bar, stem bolt, frame mount plates, and the rear suspension mount. Most of these parts fell into a few different types of stress: shear, bending, or buckling. Each one of these parts was analyzed to find the exact amount of stress that it would undergo. To see the FEA stress results see Appendix J and to see all the calculations go to Appendix K.

FACTORS OF SAFETY

Since all of the loading of the BUV will be a repeated load, if not an impact load, the factor of safety needs to be at least four and up to 12 depending on the stress it will see, for some parts, like the front axle, will need a factor of safety of at least 12. Once the stress was calculated then the actual factor of safety could be calculated to ensure that it would be adequate and that the part would not fail under load. To see the factors of safety see the calculations in Appendix K.

COMPONENT SELECTION

The main component that was used for the entire BUV design was 1-1/2 inch square 0.120 wall steel tubing. By using this tubing throughout the entire BUV, the overall costs would be reduced and there would be more extra tubing available if it was needed. Additionally this tubing was chosen since it would allow holes to be drilled through it without fear of creating a stress concentration point.

A front wheel from a Honda ATC 200, a three-wheeled ATV, was chosen as the front wheel for the BUV. From the end user survey, it is known that the BUV will be going through sand and gravel. The Honda ATC 200 front wheel is very wide and has a large amount of tire mounted on a small rim. This will keep the BUV from digging the front tire into the ground and keep the rim from getting bent in case the BUV were to hit something. Another benefit of the ATC front tire is that there is a mount for a small front brake. This will give extra braking force and allow better control over stopping the BUV.

Progressive Suspension coil-over shocks were chosen to be used on the front suspension because of its simple design. These coil-over shocks are very simple and easy to work on and fix. The springs are progressively wound, which means that the spring tension increases as the spring is compressed. This allows the shock to act as if it has a greater amount of travel than it actually does. In addition, the spring can be removed and replaced in a matter of minutes, once the shock is removed from the BUV. On the bottom of the shock, there is a collar that adjusts the preload of the spring and that will allow the ride to be slightly adjusted.

On the rear suspension for the half shaft support bearings, a tapered roller bearing was chosen since it would be able to cope with the radial and thrust loads that the BUV will put on it. Another benefit of a tapered roller bearing is that it was more cost effective than any other type of bearing for the force it was able to withstand.

BILL OF MATERIALS

The bill of materials was kept up to date throughout the entire build of the BUV. This allowed the BUV team to keep a close eye on the total cost of the BUV. In addition, by standardizing parts the BUV team kept the number of items needed for the build to a minimum and reduced the costs.

FABRICATION AND ASSEMBLY

The fabrication of the BUV was done mostly at the machine shop in the laboratory building of the College of Applied Science campus. Additional help in the assembly of the chassis was received from Brad Scehpar, who did all the welding for us. The entire assembly was done by Josiah Brinkerhoff, Andrew Malatesta, Marcus Knapp, and Andrew Morison. Ideas and assistance for the entire assembly process was gained from Professor Dave Conrad.

TESTING AND PROOF OF DESIGN

TESTING METHODS

Prior to the IAT competition, testing was done on the BUV by driving around the local roads and steep hills. This allowed critical problems to be identified and fixed without creating irreparable damage to the BUV.

The IAT competition would test the BUV in a wide variety of terrain such as mud pits, dirt moguls, a long distance endurance run, and an obstacle course with many different challenges. During all these events, the BUV will carry 500 pounds of sand.

TESTING RESULTS/PROOF OF DESIGN

From the IAT competition, the front suspension was tested to the limits. The endurance run showed some weaknesses in the structure of the lower linkage. For the most part, the front suspension performed as it was designed to. The coil over shocks, which were not manufactured by a well-known company, failed after the endurance run. The shock rod holding the spring in place broke, however the BUV could be safely driven off the path. A set of replacement coil over shocks was installed later that night, but the weight of the BUV with only one shock for support, had twisted the lower linkage and had ovaled out some of the bronze bushings. This extra play in the bushings allowed excessive flex into the lower linkage and the BUV team deemed it unsafe to compete in the rest of the IAT competition.

The standards set in the fall quarter, by the proof of design had all been met except for one. There was not time to special order a brake line so a front brake could be installed. The BUV did meet the criteria for the proof of design, which entailed the following:

- A lock to lock steering distance of 100 degrees

- More than eight inches of ground clearance
- Two inches of front suspension travel
- A load capacity of 1200 pounds
- The ability to stop in 50 feet on dry pavement from a speed of 20 miles an hour
- The ability to turn around in a twenty foot diameter circle
- An emergency brake to keep the BUV in place

PROJECT MANAGEMENT

BUDGET

The initial budget was made with a general design concept in mind. The final budget for the sub assemblies of the BUV is as follows:

- Suspension $970.56
- Drive Train $1,354.55
- Chassis $691.49
- Cargo Bed $549.45

The total budget for the BUV came out to be $3,566.05 (see Appendix E). The BUV suspension was $350 under budget. Once the suspension built with more rigidity, it will meet the initial budget. A breakdown of the parts purchased and the amount spent can be seen in Appendix L.

SCHEDULE

The entire BUV team (see Appendix E) created the schedule. It sets reasonable dates for all the parts of this design project and allows the team to keep track of the overall project progress. The schedule also helps the team to finish all the different parts of the project at the same time and bring the total design and build together easier. The important dates for this part of the design are listed below in Table 2. The dates that were met on time in Table 3are green, the red indicates dates that were missed by a few days of their required date.

Table 2-Schedule

2008 BUV SUSPENSION SCHEDULE Andrew K. Morison

DATE (begins every Monday)	1/28 - 2/03	2/04 - 2/10	2/11 - 2/17	2/18 - 2/24	2/25 - 3/03	3/03 - 3/09	3/10 - 3/16	3/17 - 3/23	3/24 - 3/30	3/31 - 4/06	4/07 - 4/13	4/14 - 4/20	4/21 - 4/27	4/28 - 5/04	5/05 - 5/11	5/12 - 5/18	5/19 - 5/25	5/26 - 6/01	6/02 - 6/08
TASK																			
Component Fabrication							16												
BUV Assembly									30										
ASME Conference Presentation									27										
Test BUV										31									
BUV Modification											12								
Final BUV Test												16							
BUV Competition Final Report												17							
BUV Competition												18							
Final Design Report Revision																13			
CAS Tech Expo																	22		
Oral Final Presentation																		27	
Final Report Due																			6

Table 3-Dates

Scheduled Task	Proposed	Actual
Choose Best Concept	12/9/2007	12/22/2007
BUV Preliminary Design	12/9 - 1/13	1/10/2007
Design Freeze	1/13/2008	1/14/2008
Order Components	1/28/2008	1/28/2008
Component Fabrication	1/28 - 3/16	3/21/2008
BUV Assembly	3/17 - 3/30	4/7/2008
Preliminary Test	3/31/2008	4/7/2008
Final BUV Test	4/07 - 4/17	4/14/2008
BUV Competition	4/18/2008	4/18/2008
CAS Tech Expo	5/22/2008	5/22/2008
Final Report Due	6/06/2008	6/09/2008

CONCLUSION/RECOMMENDATIONS

The 2008 University of Cincinnati BUV Team finished fifth out of six teams in the IAT competition. After finishing the endurance run, the BUV drove off the course and one of the shocks had broken. By the time the shock was changed out, the bronze bushings had be warped and allowed a dangerous amount of flex into the lower linkage.

There are a few main things that could have been changed to improve the front suspension design. The square crossbars should have been round tube to increase torsional rigidity. In addition, the bolts attaching the lower linkage to the diagonal square tubing should go all the way through the lower linkage to prevent the lower linkage from twisting. Critical parts, such as the coil over shocks, should be name brand parts. Even if this costs more in the final BOM, the better quality parts will provide far better service than the less costly alternative.

However, the biggest recommendation from what has been experienced from this design is more testing time was needed. The majority of problems could have found and fixed if there had been four weeks of testing. The increased testing time would allow enough time to thoroughly test the entire BUV and correct all problems that appeared. This would ensure that the BUV would perform its best at the IAT competition.

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APPENDIX A: IAT BUV SPECIFICATIONS

Capstone Design Project
BUV School Bus for Africa www.driveBUV.org
Basic Utility Vehicles for Developing CountriesInstitute for Affordable Transportation (IAT)

Challenge: Design a 3-wheel vehicle based on the rear clip of a *small* pick-up truck. Design a school bus attachment which connects to the rolling chassis. The bus is intended to serve school children and orphanages in Africa. In addition to low cost, design emphasis is on the steering and front suspension. Design for small scale assembly operations in Africa. Volume is one vehicle per day. Minimize factory investment.



Photo is for reference only…these vehicles do not meet this design specification

System Description: *Front Unit* – includes front wheel, steering mechanism, front frame, driver's seat & controls, engine, transmission, PTO

Rear Clip – the rear end (i.e. the axle, suspension, wheels, frame, brakes, etc) of a Chevy S-10, GMC S-15, Nissan, or Toyota pickup cut near the cab/bed interface. Excludes the sheet metal pickup bed.
Driveable Chassis – a front unit attached to a rear clip. Ready to drive. Various bodies can be attached to the driveable chassis.

School Bus Body / Cargo Bed – a body that attaches to the driveable chassis that is multi-purpose, and can carry both cargo as well as children is a safe manner.

Specifications – Driveable Chassis

Cost:	Not to exceed $1300 for kit (all non-truck parts). Does not include final assembly, freight, duties.
Engine / Fuel:	10 hp motor
Transmission:	Not specified. No automotive transmissions.
Seating:	Room for 9 children. Seating surface must provide a 5-7" drop for legs.
Reverse:	Provide a powered reverse (not human powered) Electric reverse is permissible.

Noise Level:	Within OSHA standards for driver, and for children.
Front Seat(s):	Motorcycle seating arrangement
Payload:	1200 lbs (includes driver). Do not count the cargo bed as part of the payload.
Top Speed:	20 mph on grass (governed)
Front Suspension:	Type not specified. Min 2” wheel travel. Do NOT use a motorcycle front suspension**.**
Throttle:	Mount on steering mechanism. No foot throttle.
Rear Brakes:	Use existing truck brakes with hydraulic activation via foot pedal.
Parking Brake:	Use existing truck emergency brake operable from drivers seat. Activation method not specified
Length:	<12.5 ft long overall
Ground Clearance:	> 10.5” except at differential, leaf springs, or lower shock mounts
PTO Pulley:	Disengage driveline. Power items on board or off-board vehicle.
Color theme:	School bus yellow
Children Safety	Allow safe egress/ingress. Provide grab handles, rounded edges, padding, belts, sun/rain protection
Safety Equipment:	Horn, kill switch, tow hooks (fore/aft), on-board fire extinguisher, passenger handles/ropes, **“**anti-roll” protection (shoulder height roll-bar helps stop vehicle rotation at ¼ roll and helps shield driver from cargo), 1 headlight, 2 tail-lights, 2 brake lights, two light reflectors per side, fenders.

Performance Requirements:
- Capable of climbing 20% slope (fully loaded)
- Fording Ability: 15 inches of water
- Brake(s) will lock during an emergency stop (on pavement, fully loaded)
- 5 minute conversion (or less) for 2 people to convert from bus mode to cargo mode.

Design Objectives:
- Minimize total lifetime cost of ownership
- Utilize off-the-shelf components or recycled components where possible to minimize cost.
- Minimize the number of part numbers, and the part count to simplify purchasing, logistics, service, etc.
- Require only two people to assemble vehicle. Utilize Design For Assembly (DFA) methods
- Utilize simple, durable, low maintenance design
- Minimize center of gravity to increase stability
- Minimize number of common tools required to service / repair vehicle
- Minimize machining, welding, and fixtures for African assembly to reduce investment/skill required
- Emphasize safety in all aspects of design. Protect driver and passengers from moving parts
- Emphasize reliability and ease of service
- Gender friendly

Other Data that Judges will collect

(related to the performance and objectives)

	Number of “off-the-shelf” parts (not including fasteners)
	Number of fabricated or custom parts
	Number of fasteners used.
	Total Number of Parts
	% of fabricated parts to Total Number of Parts
	The number of different Part Numbers (i.e. 4 screws of the same type count as 1 part number),
	Number of Special Tools or fixtures used in fabrication or assembly
	Area of cargo bed (inside dimensions)
	Distance from ground to bottom of engine (inches)
	Estimated man-hours of assembly time of front kit
	Inches of weld on prototype
	Noise level (decibels). Measured at drivers head (R and L side) at full throttle. Drive by measurement at 10 ft.
	Time to convert from school mode to cargo mode
	Ability to power other devices
	Canopy
	Weight of front unit (detached from rear)

	Total weight of vehicle
	Corrosion Prevention Methods used
	Multi-purpose Service Tool. If you have designed one for your vehicle (not required), please show the judges.
	Estimate Production Cost (fully assembled)

Costing Information:
For engines, use $26 per horsepower OEM cost (i.e. 10 hp engine is $260)
For the truck rear clip – use $150 (no matter the actual cost)
For purchased parts, use 50% of retail price, for fabricated parts & painting, use industry quotes (based on monthly orders of 100 units/mo.)
Volume assumption for sourcing parts: 300 BUVs per year (roughly 1 BUV per day)
Use $1/hour labor rate. Use new equipment retail pricing on investment.

Engineering Report

Follow your class requirements. Additionally, IAT wants a costed Bill of Material (BOM) with part number, source, weight info and a cost breakdown by system (powertrain, front frame, rear-clip, etc) in the report (include system weight as well). Also include a summary of the assembly process, equipment required, assembly time, and micro-factory costs. Determine labor content per unit, equipment investment required, factory layout for 4000 sq ft, and staffing for a 1 unit per day micro-factory. Predict which three parts are most likely to fail first.

Common Errors to Avoid:
Heavy and over-designed vehicles: a good target is 1000 lbs to perform well at the competition
Inappropriate Gearing: ensure that you have at least a 50:1 reduction in your powertrain in low gear
Inappropriate Tires: car tires and tires over 30” in diameter generally do not perform well in the competition.
Center of gravity: please minimize!
No sharp burrs on any surface.
Do not forget to design against mud, sand, water intrusion. If necessary, use debris guards to prevent service issues and protect vehicle.

Contact: will.austin@drivebuv.org 317-213-1088

Competition BUVs donated to IAT will be sent to humanitarian organizations in developing countries (assuming the vehicle is safe).

APPENDIX B: RESEARCH

The closest similar senior design project is by Daniel Lingrosso in 2006.

The rear end suspension is to be the standard rear end off of a production pickup truck. This means it will have a solid axle, leaf spring suspension, and drum brakes.

<table>
<tr>
<td>Earls Forks

I interviewed Len Kerkhoff, owner of Autobahn Craftwerks a vintage motorcycle shop in Northside, about Earls forks since there are no production vehicles using this set up. He is a big fan of Earls forks, preferring them on older bikes for a more comfortable ride while being much easier to maintain. “On older, less powerful BMWs, Earls forks are fantastic. They can do everything you want.”

<www.autobahn-craftwerks.com>
Len Kerkhoff proprietor
4111 Spring Grove Ave.
Cincinnati, OH 45223
513-591-2629
Interviewed on 20 September 2007</td>
<td>• Front end rises under braking
• Simple to produce
• Easy to fix and repair
• Shocks can be adjustable
• Very rugged</td>
</tr>
</table>

Appendix B2

RADD Front End

The Rationally Advanced Design (RADD) is very similar to the suspension used on many cars. It is simply a swing arm mounted on the front of the motorcycle to control the front suspension. While a series of spindles and ball joints are used to control the steering of the front wheel.

arc.losrios.edu/~mccleld/gts_blue.html 27 September 2007

- Doesn’t dive under braking
- Would have to be custom made
- Very stable at all times

Appendix B3

Appendix B4

Appendix B4

Trailing Link Front End  This is a very simple design that has the wheel axle in front of the pivot point and shock. Also, the front wheel is bolted onto the front end, without an axle, which makes maintenance much easier. www.bajajusa.com/Bajaj%203%20 Wheelers.htm 27 September 2007 Bajaj 3 wheelers bajajusa.com	• Doesn't Dive under braking • Not much suspension travel

Telescopic Front End  This type of front end is widely used by every motorcycle manufacturer. A fork tube holds a spring and damper, which are resting in oil. The forks can be adjusted for any type of use or performance. http://powersports.honda.com/motorcycles/off-road/model.asp?ModelName=XR650L&ModelYear=2008&ModelId=XR650L8 27 September 2007 XR650L Honda.com	• Lots of suspension travel • Dives under braking • Lightweight • Simple to install

Hossack Fior (Duolever) Front End

This is a very elegant set up that separates the steering forces from the suspension forces. There are a set of parallel A arms that connect to the front end to handle suspension while a folding linkage controls the steering. While the suspension goes over potholes the geometry of the front end never changes.

www.bmwmotorcycles.com/bikes/bike.jsp?b=k1200s 26 September 2007
K1200S bmwmotorcycles.com

- Doesn't dive under braking
- Front end geometry never changes
- Lots of parts would increase production cost
- Not a lot of suspension travel

Saxon Motodd (Telelever) Front End  The Saxon-Motodd has an additional swing arm that mounts to the frame and supports the spring. This causes the trail and rake to increase during braking instead of decreasing as with traditional telescopic forks. www.bmwmotorcycles.com/bikes/bike.jsp?b=r1200gs 26 September 2007 R1200GS bmwmotorcycles.com	• Can offer lots of suspension travel • Doesn't dive under braking • Very rugged

APPENDIX C: SURVEY

Basic Utility Vehicle

Product Improvement Survey

A group of students in the MET department is attempting to improve the design and usefulness of the basic utility vehicle. Please take a few minutes to fill out the customer survey and return it to the student marketer.

What terrain is primarily in the area of travel? (Circle at most 2 please)

Mud   Swamp Rocky   Gravel   Sand

What power source is primarily available? (Circle one)

Gasoline engine   Diesel engine   Electric motor

Please list the common types of lumber available.

____

____

____

Please indicate the level of importance you attach to the following aspects of a basic utility vehicle.

(1 = low importance   5 = high importance)

Auxiliary Lights	1	2	3	4	5
Medical Devices	1	2	3	4	5
Water Pump Attachment	1	2	3	4	5
Plow Attachment	1	2	3	4	5
Auxiliary fuel can	1	2	3	4	5
Shaded cargo bed	1	2	3	4	5
Emergency road side repair kit	1	2	3	4	5
Spare tire	1	2	3	4	5
Trailer hitch	1	2	3	4	5

Winch	1	2	3	4	5
Driver/passenger seat belt	1	2	3	4	5
Fire Extinguisher	1	2	3	4	5
First Aid Kit	1	2	3	4	5
Cargo Bed Step Ladder	1	2	3	4	5
Ability to transport fragile cargo	1	2	3	4	5
Ability to transport patients	1	2	3	4	5
Ease of Maintenance	1	2	3	4	5
Waterproof Passenger/Cargo	1	2	3	4	5
Bug Shield Passenger/Cargo	1	2	3	4	5

Please elaborate on any other suggestions.

____

____

____

Thank you for participating in this important basic utility vehicle evaluation survey. Your input is important and greatly appreciated.

-2008 UC CAS BUV Team – J. Brinkerhoff, M. Knapp, A. Malatesta, A. Morison

There are 22 completed surveys in the results listed below. These surveys are collected from Peace Corp Members in Africa thanks to the assistant of Ellen Brinkerhoff.

22 Survey Results for 2008 BUV

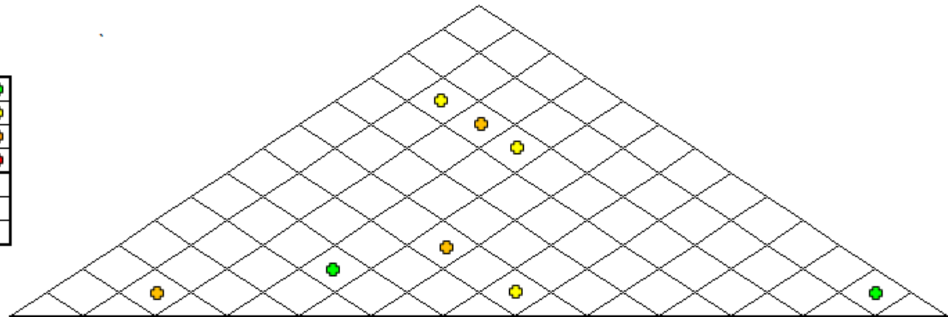
	AVERAGE	Frequency				
mud, gravel, swamp, rocky, sand	Rocky = 12; Mud = 6; Sand = 18; Gravel = 4					
Gasoline engine, diesel, electric motor	Gas = 17, Diesel = 4, Electric Motor = 1	1	2	3	4	5
lumber available	Little to none					
Auxiliary Lights	3.68	0	6	0	11	5
Medical Devices	2.86	4	4	7	5	2
Water Pump Attachment	2.68	4	6	7	3	2
Plow Attachment	2.27	9	5	3	3	2
Auxiliary fuel can	4.05	2	0	3	7	10
Shaded cargo bed	3.45	2	4	5	4	7
Emergency road side repair kit	4.77	0	0	2	1	19
Spare tire	4.86	0	0	0	3	19
Trailer hitch	3.18	2	4	6	8	2
Winch	3.14	0	6	8	7	1
Driver/passenger seat belt	4.05	2	1	3	4	12
Fire Extinguisher	3.09	2	6	6	4	4
First Aid Kit	3.64	1	2	7	6	6
Cargo Bed Step Ladder	2.73	6	5	4	3	4
Ability to transport fragile cargo	3.09	2	3	9	7	1
Ability to transport patients	3.27	1	6	4	8	3
Ease of Maintenance	4.64	0	0	2	4	16
Waterproof Passenger/Cargo	2.50	9	1	7	2	3
Bug Shield Passenger/Cargo	2.32	4	9	8	0	1

APPENDIX D: QFD

strong positive	(green)
positive	(yellow)
negative	(orange)
strong negative	(red)
strong	9
moderate	3
weak	1

IMPORTANT CHARACTERISTIC

LOW IMPORTANCE



		cost of manfuacture	power consumption	fuel efficienty	Stength of Material	Hours of Operation before Maintenance	Hours of Operation before failure	Fabrication Time	number of parts	ground clearance	Number of Auxillary Components	weight	area covered	time to covert cago bed	Cuustomer importance	Relative weight
		1	2	3	4	5	6	7	8	9	10	11	12	13	69.27	
Auxillary Lights	1		3						1		9				3.68	0.053
Medical Devices	2								1		3				2.86	0.041
Water Pump Attachment	3		1			1			1		3	1			2.68	0.039
Plow Attachment	4		3	3				9	3	1		3			2.27	0.033
Auxillary Fuel Can	5								1			1			4.05	0.058
Shaded Cargo Bed	6							3	1				9	3	3.45	0.050
Emergency Roadside Repair Kit	7								1						4.77	0.069
Spare Tire	8								1			1			4.86	0.070
Trailer Hitch	9				1			3		1		1			3.18	0.046
Winch	10		3					1				1			3.14	0.045
Driver/Passenger Seat Belt	11							1	1						4.05	0.058
Fire Extinguisher	12								1						3.09	0.045
First Aid Kit	13								1						3.64	0.053
Cargo Bed Step Ladder	14							1	1						2.73	0.039
Transport Fragile Cargo	15				1									3	3.09	0.045
Transport Patients	16				1									3	3.27	0.047
Ease of Maintenance	17						3								4.64	0.067
Waterproof passenger/cargo	18				1								1	3	2.50	0.036
Bug Shield Passenger/cargo	19								1						2.32	0.033
Cost to manufacture	20	9													5.00	0.072
Abs. important		0.650	0.432	0.098	0.174	0.039	0.201	0.725	0.707	0.079	0.718	0.357	0.484	0.533	5.20	1.000
Rel. importance		0.125	0.083	0.019	0.033	0.007	0.039	0.140	0.136	0.015	0.138	0.069	0.093	0.103	1.000	

APPENDIX E: BUDGET

2008 UC BUV Team

BUV Budget

J. Brinkerhoff, M. Knapp, A. Malatesta, and A. Morison

BUV Sub-Assemblies	**PRICE**
1. Drive Train Total	$1320
2. Front Unit/Suspension	$1320
3. Rear Clip/Chassis	$985
4. Cargo-Passenger Bed/Electrical	$915
TOTAL	**$4540**

Andrew Morison

2. Suspension Break Down

Steel Tubing	$200
Bushings	$6
Shocks	$300
Steering Head Bearings	$20
Steel Plate	$100
Handlebars	$20
Front Rim	$150
Front Tire	$70
Front Brakes	$100
Axle	$15
Bolts	$25
Seat	$30
Leaf Springs	$60
Additional Cost (20% of total)	$220
Suspension Subtotal	$1320

APPENDIX F: SCHEDULE

[redacted]

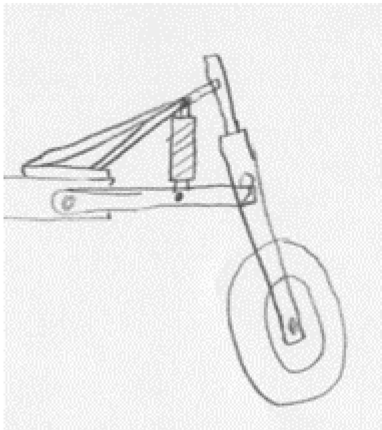
APPENDIX G: WEIGHTED DECISION MATRIX

	Fabrication Time	**Number of parts**	**Cost to Manufacture**	**Weight**	
Relative Weight	0.14	0.136	0.125	0.069	**Final Result**
Design	Relative scale				
Earls Fork	5	6	6	4	**25.42**
Telelever	3	4	4	5	18.09
Duolever	2	1	3	3	9.98
Trailing Link	4	5	5	6	**22.79**
RADD	1	2	1	1	6.06
Internal Spring	6	3	2	2	16.36

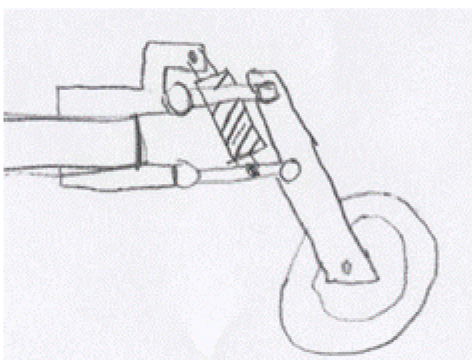
6 is the best   1 is the worst

APPENDIX H: INITIAL DESIGN SKETCHES

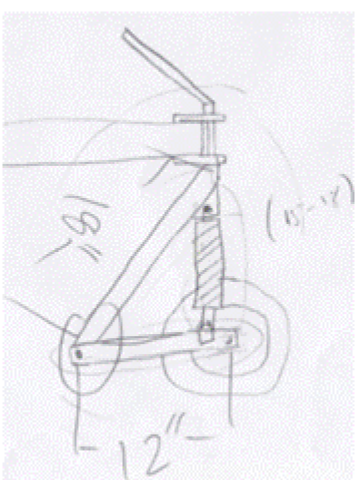
Telelever Design



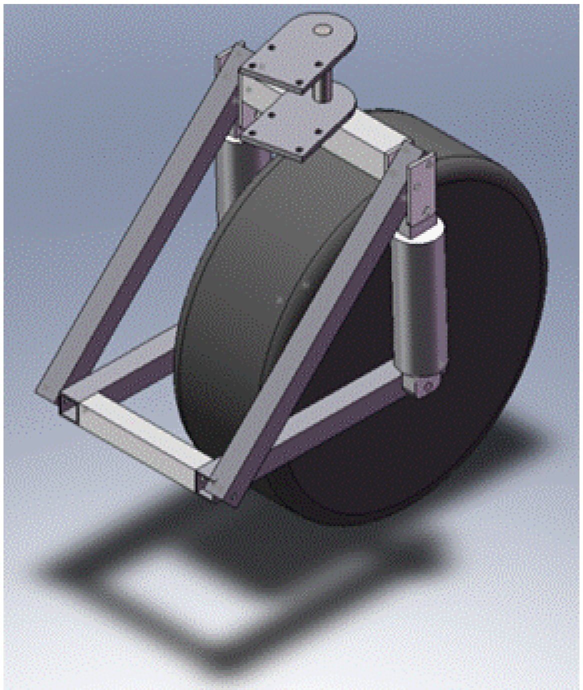
Duolever Design

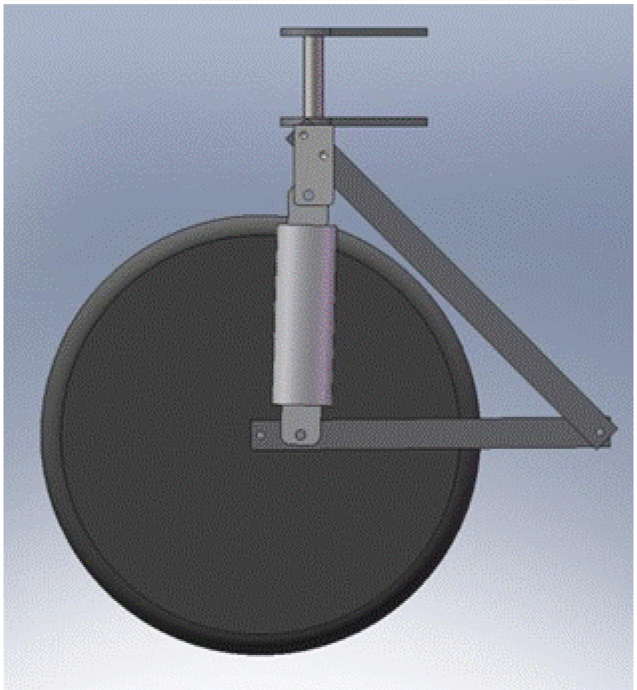


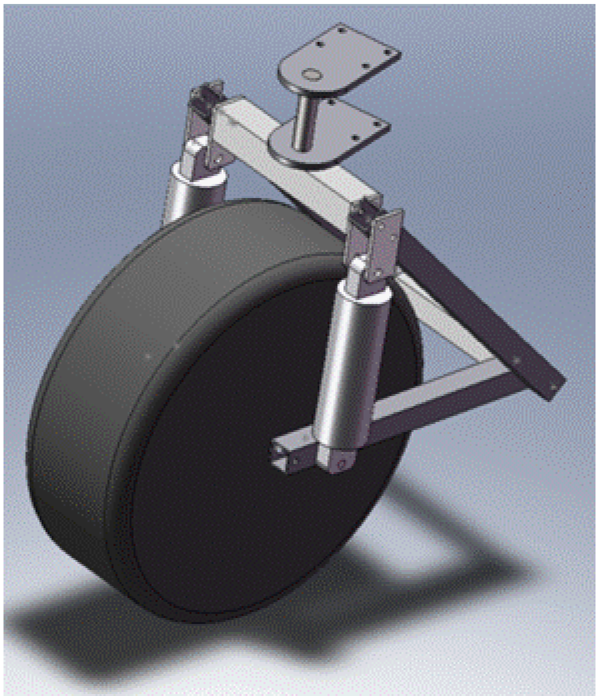
Earls Fork Design

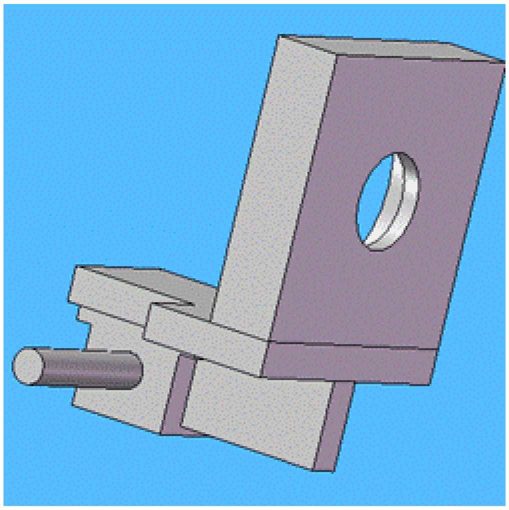


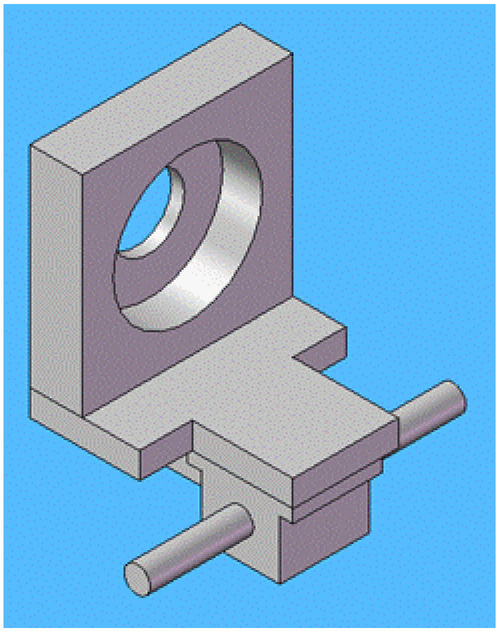
APPENDIX I: DETAILED DRAWINGS



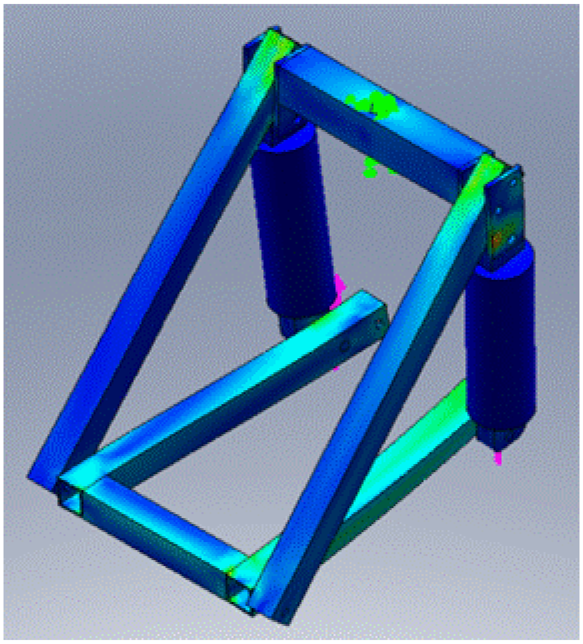


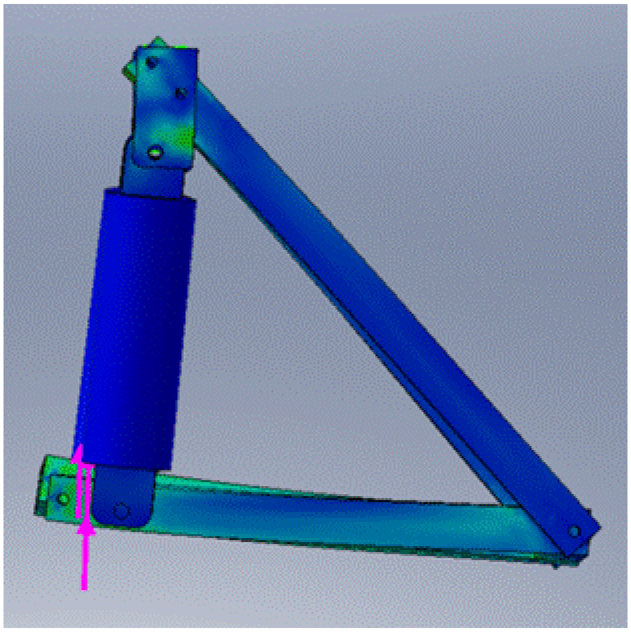






APPENDIX J: FINITE ELEMENT ANALYSIS





APPENDIX K: CALCULATIONS

[redacted]

[redacted]

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APPENDIX L: BILL OF MATERIALS

MANUFACTURED COMPONENTS

PART #	PART DESCRIPTION	MATERIAL	MATERIAL DESCRIPTION	PROTOTYPE COST / UNIT	QUANTITY	PROTOTYPE TOTAL	IAT Cost
BUV-SU-001	Front Suspension						
BUV-SU-010	Lower Linkage Tubing	1.5" Square Steel Tubing x .125" Wall	18" Length	$1.20	36	$ 43.20	$ 21.60
BUV-SU-020	Upper Linkage Tubing	1.5" Square Steel Tubing x .125" Wall	22" Length	$1.20	44	$ 52.80	$ 26.40
BUV-SU-030	Lower Cross Tubing	1.5" Square Steel Tubing x .125" Wall	9" Length	$1.20	9	$ 10.80	$ 5.40
BUV-SU-040	Top Cross Bar	2" Square Bar	11" Length	$28.76	1	$ 28.76	$ 14.38
BUV-SU-050	Upper Shock Mount Plate	4" x 2"	0.375" Thick	$2.50	4	$ 10.00	$ 5.00
BUV-SU-060	Frame Mount Plate	4" x 7"	0.375" Thick	$7.50	3	$ 22.50	$ 11.25
BUV-SU-002							
BUV-SU-070	Bearing Mount	4" x 4"	1" Thick	$15.18	2	$ 30.36	$ 15.18
BUV-SU-080	Rear Wheel Spacers	5-/12" Dia. Aluminum	7" Long	$56.33	2	$ 112.66	$ 56.33
			MANUFACTURED COMPONENTS TOTAL COST:			$ 311.08	$ 155.54

PURCHASED COMPONENTS

PART #	PART DESCRIPTION	MANUFACTURER MODEL #	MANUFACTURER	PROTOTYPE COST / UNIT	QUANTITY	PROTOTYPE TOTAL	IAT Cost
	Front Suspension						
91257A969	1" Dia. X 6" Length Grade 8 Bolt		McMaster Carr	$6.49	1	$ 6.49	$ 3.25
93839A852	1" Dia x 8 Threads/Inch Lock Nut		McMaster Carr	$2.04	3	$ 6.12	$ 3.06
91286A216	3/8" Dia x 3" Length Grade 8 Bolt		McMaster Carr	$0.57	10	$ 5.70	$ 2.85
93839A031	3/8" Dia x 16 Threads/Inch Nut		McMaster Carr	$0.15	4	$ 0.60	$ 0.30
91257A725	1/2" Dia x 3-1/4" Length Grade 8 Bolt		McMaster Carr	$0.88	4	$ 3.52	$ 1.76
93839A823	1/2" Dia x 13 Threads/Inch Nut		McMaster Carr	$0.35	4	$ 1.40	$ 0.70
5909K36	Needle Roller Thrust Bearing		McMaster Carr	$2.60	2	$ 5.20	$ 2.60
5909K49	Thrust Bearing Washers		McMaster Carr	$0.95	4	$ 3.80	$ 1.90
6338K415	Bushing, Lower Linkage		McMaster Carr	$0.70	2	$ 1.40	$ 0.70
6391K285	Bushing, Steering Stem		McMaster Carr	$3.93	1	$ 3.93	$ 1.97
	Front Wheel		Honda	$400.00	1	$ 400.00	$ 200.00
	Coil Over shocks		Progressive Suspension	$140.00	1	$ 140.00	$ 70.00
	Rear Suspension						
6677K62	Tapered Roller Bearing		McMaster Carr	$28.60	2	$ 57.20	$ 28.60
6072K213	Tie Rod End		McMaster Carr	$6.03	4	$ 24.12	$ 12.06

MANUFACTURED COMPONENTS TOTAL COST:	$ 659.48	$ 329.74

TOTAL SUSPENSION COST:	**$ 970.56**	**$ 485.28**