Team: Moranimals
May 2, 2019
Nathan Carney, Francis Chval, Jamie Clark, Wyatt McCabe, Jaclyn Riddiford, Mark Rodriguez, Charlie Seaver, Zach Wenzler

Introduction:

Riding a bicycle with one's child is a special experience for a parent, allowing them to share a great milestone in their child's life. Our design team strived to give this opportunity to our client, Dr. Thomas Moran, who has recently become a father and is looking forward to riding our human powered vehicle with his daughter soon. Dr. Moran was born with spastic diplegic cerebral palsy, making him unable to ride a traditional bicycle. Our team was tasked with designing a vehicle that is adapted Dr. Moran's body and abilities. By working directly with Dr. Moran, we analyzed his abilities and began to conceptualize a human powered vehicle that he would be able to use.

Importance & Impacts:

<u>(Client/User) Dr. Moran:</u> Our human powered vehicle has the most direct impact on our client Dr. Moran. The vehicle will enable him to bike with his family, and specifically his daughter. In addition to this, the arm crank propulsion system will help Dr. Moran maintain a strong upper body. He will be able to use the bike to travel around his neighborhood. Dr. Moran will get to experience the thrill of riding a bike and feel good while getting a good workout. Most importantly, this customized vehicle will allow him to ride alongside his daughter.

<u>Environment:</u> Our design does not produce, contain, or use any harmful chemicals. The bike is propelled by applying force through the front arm bar crank. This design is a more eco-friendly alternative to a car for short distance trips.

<u>Dr. Moran's family:</u> With his chosen design, Dr. Moran will be spending lots of family time on bike rides. Dr. Moran is very physically active. With his new customized bike, he will likely encourage his family to ride more as well. Family bike rides might become routine for them.

<u>JMU Engineering department:</u> The work of this design project represents the entire JMU sophomore engineering class in the department. The final results of the sophomore classes hard work strengthen the image of the department and allows prospective students to see the variety of learning opportunities JMU Engineering provides.

<u>Engineering and bike staff:</u> Every professor involved in the sophomore design project has learned new information about the project this year. Working with Dr. Moran this year required course material taught to be client-centered. Because of this project, professors have learned more about Dr. Moran and how to tailor the lecture material.

<u>(Designers) Students involved:</u> The majority of sophomore design students came into ENGR 231 and ENGR 232 without knowing much about bikes. Throughout the past year, students involved

in the project have learned about advanced bike mechanics, subsystems, tools, and safety considerations. Additionally, students learned to adapt to unfamiliar group dynamics within teams of 4 in ENGR 231 and 7 to 8 in ENGR 232. A variety of engineering tools were introduced and used to make better decisions throughout the process.

Methods[1]:

The customer persona development was our first method used to gain an understanding of the scope of this project. The persona development can be broken into two parts, persona conception and persona gestation. Persona conception might include interviewing the client or watching a workout video to develop client data for the persona. Persona gestation is the process of developing and validating the persona. In our case, this was creating a large poster that included a picture, tagline, pain points and more about Dr. Moran and then presenting it to the class to gain a collective knowledge.

With a general idea of project at hand, each group created a list of 30 design objectives. These objectives were created by listening to the recorded statements collected from Dr. Moran during our persona development. Once this list was completed, the objectives were sorted into categories and ranked by importance. This was used as the base for what the design need to include so that it would meet Dr. Moran's needs.

Target specifications were created in order to narrow our solution space and give our concept designs more direction. These specifications contain qualitative and quantitative values for goals that are to be met by the design. In order to have accurate specifications, we met with Dr. Moran to get his opinion on ideas along with measurements and visual aids. By having these specifications, we could also measure our progress on the design and make adjustments accordingly.

For the benchmarking process, each member of the team conducted research on human powered vehicles and bicycles to compare these products with each other. These products were stripped down by function and these subsystems were compared to the others. This allowed the team to see the most desirable designs and what made those designs work well. The benchmarking process was important in deciding what subsystems to use in our design.

C-sketching is a type of brainstorming that was done with randomly formed groups within each class, where everyone started with a rough sketch of an idea that they had. After a few minutes, the paper was rotated to each member at the table so they could add to the idea or draw a different idea. This activity was a good method for combining design ideas since the time limit forced individuals to draw the first thing on their mind. In the brainstorming phase, it is important to not judge any ideas and remain creative. This activity broadened the design space by allowing ideas to be exchanged among different teams.

A morphological matrix is a grid-style structured brainstorming tool which allows designers to mix and match different solutions across subsystems. In this project, the matrix lists six major subsystems of the human powered vehicle: propulsion, braking, steering, seating, stability, and structure. Ten concepts were then brainstormed for each subsystem. The matrix allowed our team to compile all the concepts for each function into one chart. We could then select a concept from each function to create a potential solution.

In order to narrow down the vast array of solutions, each team used a pugh chart. A pugh chart compares each solution to a datum design using a -/0/+ scoring system. Each solution receives a score on a multitude of design criteria, then total points are tallied. The designs that receive the highest scores are considered the “best options” and a select number make it onto the next section of design decision making.

The next design decision making tool we used was a decision matrix. Design criteria is listed and given percentage values based on their importance. The relative importance of each criterion was determined by our interpretations of Dr. Moran’s statements. Dr. Moran’s top focus was on a safe design. Each of the possible solutions under each criterion was ranked on a scale of 1-5 (higher numbers mean the design is more likely to fulfill the criteria). The numerical value is multiplied by the corresponding weight percent. The values for each design idea are totalled at the bottom of the chart. The design solution with the highest value is the most optimal solution.

The redesign brief was completed at the beginning of the semester with our new design team and told a story of of our redesign process. The team came together and compared the work they had done during the first semester to decide on the best conceptual design. The decision of the best design was done through a voting process to ensure that each design had a fair chance of being chosen. We chose our final design based on the amount of detail, simplicity, and feasibility of the idea. The redesign brief included which conceptual design was chosen and an explanation of why this design was deemed the best.

Once the final design was chosen for the project, began to analyze the the functionality and feasibility of the design. The first step was to analyze the center of mass. This was done by breaking the frame into different sections, determining the density constant of the frame material, and roughly calculating the total mass. We also calculated the center of mass both with Dr. Moran on the Human Powered Vehicle and the vehicle alone.

Testing ideas through prototypes can be a great way to learn more about the design, proof of concepts are a great way to achieve this. These prototypes were designed to analyze subsystem interaction and determine the feasibility of the interacting subsystem components. Each subsystem group completed 3 proof of concepts, with each one building on the last, helping to finalize the design before fabrication. The prototypes were not made with the same materials and components as the final design, but they still had to provide an accurate representation of the final design subsystem.

With a more refined idea of the design prototype, we were able to start CAD modeling using Solidworks. Each person was responsible for making at least three parts of the human powered vehicle. These parts were shared and uploaded to a single assembly where the full construction was made using both CAD models from the internet, as well as, the parts that each team member designed.

Detailed engineering drawings were created in Solidworks. These included multi-angle projections of parts and systems along with dimensions of these parts so they could be fabricated correctly. These drawings had to be made to the exact measurements of the final design (which was also completed on SolidWorks) to ensure that all of the parts fit together properly and the systems were functional.

Using our SolidWorks CAD model and drawings, we made sure that each part was accounted for. We worked our way through all of the model, covering every subsystem and accounting for all machined parts. With this information, a subteam determined which parts had to be bought and which could be scrapped. With just $400 dollar budget, this was a tedious process.

After the final frame design was completed, the center of mass was determined using MatLab programming software**[2]**. This information was important for the safety of our design, since a low center of mass was desired for the vehicle stability and a lightweight design was desired for portability. The frame is a critical part of the design since any weak points in the frame could cause it to break. Any changes to the frame design would consequently affect other subsystems.

The prototype plan served as a calendar for the team and included tasks to be completed and the people responsible for them. Given the time constraints we had, this plan was an effective way to organize our time and ensure that the work was distributed evenly across the team. This plan helped to hold individuals accountable for their tasks.

With the alpha prototype complete, a testing plan was made to assess the functionality of human powered vehicle. The vehicle was tested for weight, tip angles, and turning radius among other tests. This was done to break our design refinement strategy into specific tasks.

Results & Justification:

While developing Dr. Moran's persona, we learned the general process of constructing a persona, but also how to tailor it to our client's intent and purpose. The main discovery from our persona is that Dr. Moran wants the same personal freedom that any other bike rider enjoys. He wants to enjoy time with his daughter as she grows and explores her surroundings on a bicycle.

Listing out and analyzing the design objectives shaped the goals and final deliverables of the project. Our design objectives were focused around Dr. Moran's abilities, limitations, and wants. This gave us an outline of basic design goals without identifying specific methods to prevent any premature solutions. Dr. Moran's abilities and preferences were crucial to identifying the strong points of the bicycle design, such as upper body propulsion. Dr. Moran demonstrated his physical limitations to aid us in designing a bike within his comfort zone and abilities. This included aspects of a low step frame and a forward leaning seat position. The design objectives also allowed us to rate the importance of each objective using a +/- ranking system.

The target specifications draw upon the design objectives and provide a way to tie broad objectives into specific goals for the ending result of the project. These goals include quantitative data with values and units that must be met during the testing portion of the design process. The testing and refinement phase is where we will understand clearly if we have met those goals with our design solutions.

When benchmarking our defined target specifications, we narrow down our ideas based on feasibility. This meant attaching numbers to the specifications with realistic goals in mind, but still being able to accomplish the basic design objectives for Dr. Moran. We benchmarked these target specifications with respect to physical solutions which already existed. Dr. Moran's input forces were used to perform force analysis on a standard bicycle, and we tested different types of components against each other both physically and analytically.using physical prototypes and analytical models A result of this included the use of disk brakes against traditional cantilever brakes due to their increased modularity with the frame and increased stopping power.

Concept sketches represent our design objectives with visual solutions. This step was critical in the design process since we compared these concept sketches in the morphological matrix. With each member of the group participating in this phase, we were able to draw from the various abilities and ideas of everyone without coming to any premature design solutions.

The morphological matrix was key to the final design in which we were able to pool together the aspects of different concept sketches. This conglomeration of various solutions allowed us to step back and broaden the design space. In this process, we focused on each unique combination individual solutions without questioning budget constraints and feasibility.

The pugh chart is a systematic way to analyze all of the results of the morphological matrix and find the strong points of each design. Identifying these strong points across different designs helped us create new iterations better aligned with design objectives and specifications. This was something we decided on as a team, where all of our opinions about the results of the morphological matrix were taken into consideration. Due to the nature of the morphological matrix, this helped us bring the solutions back into reality and discuss their feasibility as an entire system.

At the end of ENGR 231, each group came to a final consensus on the chosen design based on the decision matrix. Initially in ENGR 231, we learned which conceptual design met our criteria the best based on design objectives and target specifications. In ENGR 232 however, each team brought a new design with them. We used the decision matrix to weigh the most detailed final concepts from each ENGR 231 team according to how well it met each criteria objective. The results were that the team decided on Francis' team design since he got the highest score from the matrix.

To develop the redesign brief, our newly formed team met to reflect on our ENGR 231 design journey. Our project ideas as a group were unified under the new ideas and background that each member brought. Our new ENGR 232 team came to a consensus about on our new team objectives were, target specs, and final design we were going with.

With the chosen material for the frame of our human powered vehicle, we needed to determine if the material and design would meet our target specification of our bike weighing under 80 pounds. With MatLab, we calculated the overall weight of the frame to be just under 30 pounds, which left us plenty of wiggle room. We determined the center of mass with respect to the weight and position of Dr. Moran. Our center of mass was low to the ground, which provides more stability to Dr. Moran. As subsystems were integrated into and around the frame, we re-calculated the mass and center of mass of the human powered vehicle. Mass increased to about fifty-five pounds, but the center of mass stayed relatively the same.

From the proof of concepts (POCs), each subteam learned new ways to make each subsystem more feasible with each iteration. For the first proof of concept, each subsystem team verified that their theory for their design of their component was practical for Dr. Moran and feasible in creating. As the second and third proofs of concept were created, each subsystem was simplified into creating a more feasible design.The full-scale POC iterations of each subsystem reduced the compatibility issues that would occur with integrating subsystems. Showing our POC iterations to Dr. Moran, we were able to get his feedback that led us to significantly simplify our steering subsystem.

The Solidworks model aided in mapping the spatial layout of the human powered vehicle. A virtual model was created with all of the correct dimensions and components that were decided on through the previous design methods. It was easy to adjust the CAD model as we made slight design modifications throughout the process. The final model was created from scale models of the components found on public CAD databases.

The engineering drawings of the custom parts allowed us to 3D print the parts in order to test their tolerances and interactions with other subsystems. A critical 3D component was the set of spacers used in the hand propulsion bar to adapt the pedal axle outer diameter to the aluminum tubing inner diameter. In this process, we also created engineering drawings for the frame subsystem to specify the location of welds and the dimensions of the tubing to be cut.

A bill of materials was made to compile a list of purchasable components for the physical prototypes. The bill of materials was very rough at first and did not include columns for person responsible or materials cost for machining. Once this was redone for the second iteration, there was much more detail throughout the entire process and the bill of materials was linked back to the original CAD model with an exploded view of the subsystems/components.

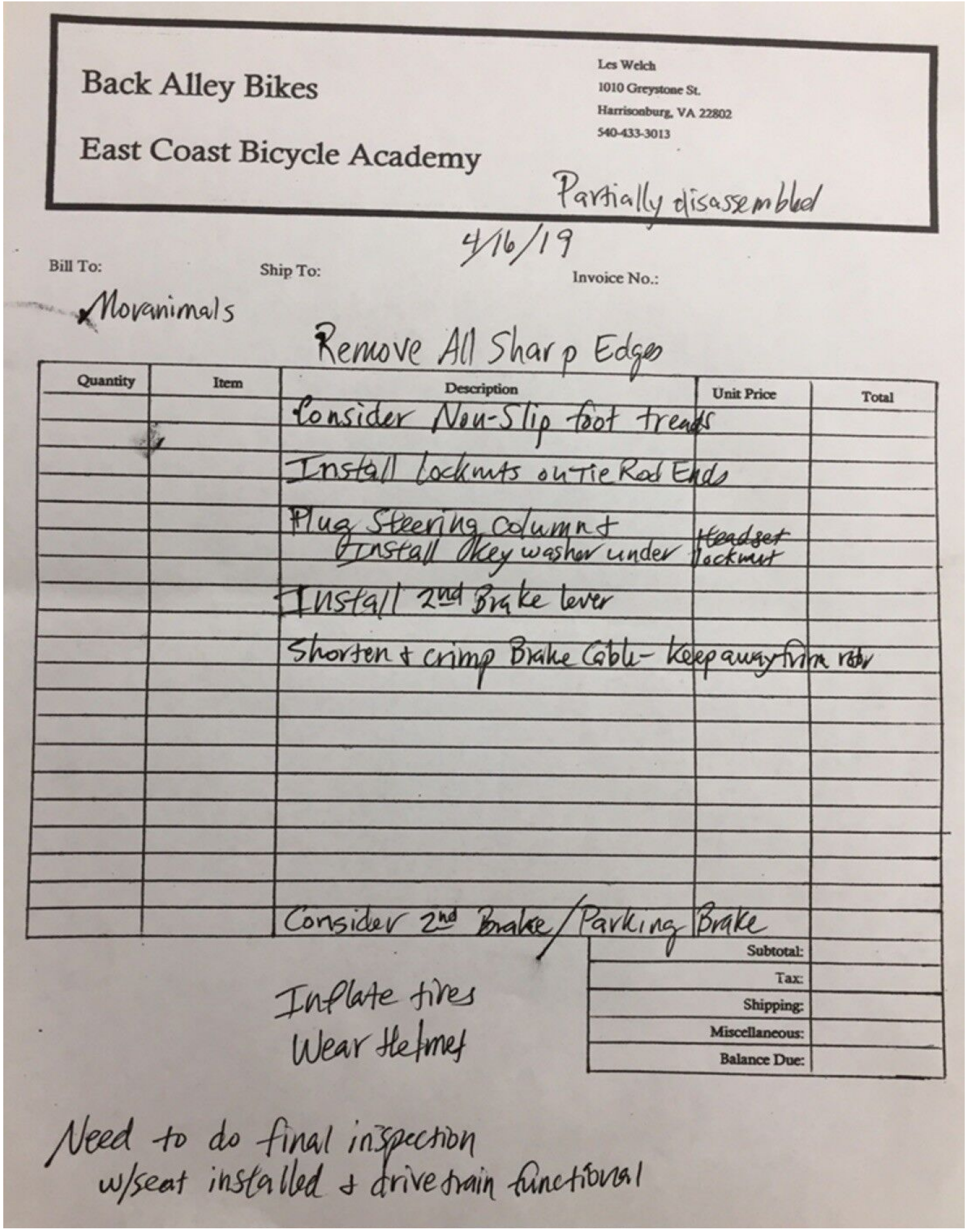
In the vehicle frame analysis, we discovered which forces were acting on junctions of separate tubing coming together. Key results from this included adding a second adjacent tube leading to the front wheel to keep the rigidity within the tubing specifications. This is seen with all modern bicycle frame designs, where there is always one section supporting the top (top tube) and one section supporting the bottom (down tube). We did not account for the force of the chain tension on the drive side arm and this showed once we fully welded and fully assembled the frame. When there was significant force exerted on the chain, the arm would bend in the direction of the tension. This was alleviated through adding a longer section of truss supporting the lower joint with the bottom frame rails.

The prototype plan proved to be a crucial guiding force in pushing us to complete our goals on time. As we went through the physical prototype process, it was evident that we would need more time for certain goals to be accomplished. The plan forced us to get everything done within the constraints that we put on ourselves. It was very useful to have done this prior to the prototype development because it allowed us to make unbiased decisions for the allocation of time.

The final step in improving the design of our vehicle was to test and adjust everything and anything that is functional on the bike. Within each subsystem, we tested the reliability of the propulsion system by applying extensive force to the crank arm, making the system run as fast as possible. To test the bike, we conducted a steering analysis to ensure that the client is able to turn the bike no matter how fast or slow he's travelling. We adjusted the foot mount after the steering test in order for the client to be more comfortable while riding. The same goes for the brake check in terms of how it would hold up with respect to speed. We also weighed the bike to make sure the specifications suit Dr. Moran's needs. We determined that the final weight of our vehicle was 55lbs, about 31% less than our target weight of 80lbs.

Design Decisions:

When all subsystems were being solidified from the engineering drawings and Solidworks models**[3]**, major decisions involving materials used and design execution were discussed throughout the team. Either the fabricator, the safety officer, and/or leader decided on the final course of action. We had to finish the human powered vehicle by a deadline, analyze our resources (i.e. Fabrication Lab hours, Dr. Moran's available hours), and identify the extra expenses (i.e. buying more material for the HPV out the team's pocket) that may influence our design. These factors influenced the beta prototype with one extra important factor that decides whether Dr. Moran will be safe within our design, the safety check (image below). These decisions were mostly discussed amongst the team. The safety factor of the HPV was set by Les Welch to make sure our design is safe for Dr. Moran to use once reached to the beta prototype by reviewing all possible places for possible error and injury to the client.



Back Alley Bikes

East Coast Bicycle Academy

Les Welch
1010 Greystone St.
Harrisonburg, VA 22802
540-433-3013

Partially disassembled

4/16/19

Bill To: Moranimals

Ship To:

Invoice No.:

Remove All Sharp Edges

Quantity	Item	Description	Unit Price	Total
		Consider Non-Slip foot treads		
		Install locknuts on Tie Rod Ends		
		Plug Steering column + Install Okey washer under	Headset locknut	
		Install 2nd Brake lever		
		Shorten + crimp Brake Cable – Keep away from rotor		
		Consider 2nd Brake/Parking Brake		

Subtotal:	
Tax:	
Shipping:	
Miscellaneous:	
Balance Due:	

Inflate tires
Wear Helmet

Need to do final inspection w/seat installed + drivetrain functional

Our results within our process of making our final design were very influential towards our design decisions because we were able to see what would work and what wouldn't work through each step of the process. Thinking broadly in the beginning was beneficial in the concept generation phase, testing POC ideas for feasibility narrowed down our options on our final design options. We were able to focus our plan and adjust it without jumping around trying to see whether other broader ideas would work. When we were able to view our results from the various testing, from POC to alpha prototypes, we were able to justify the feasibility of our ideas to improve our design all the way up to the beta prototype stage.

Our final design decision as a team consists of a design adapted Dr. Moran, allowing him to comfortably ride our vehicle. We want this human powered vehicle to allow Dr. Moran to ride beside his daughter on their adventures. Our ultimate goal may be more than just a the HPV itself, it helping a person in fulfilling their dreams.

Reflection:

Accountability Report:

	Team Members								**Sum**
Tasks	**Zach**	**Charlie**	**Francis**	**Jaclyn**	**Jamie**	**Mark**	**Nathan**	**Wyatt**	100%
Project Redesign Brief	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	100%
Code of Conduct	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	100%
Determining Vehicle Weight and Locating COM	**5**	**30**	**5**	**5**	**5**	**35**	**10**	**5**	100%
CAD Model for HPV	**2**	**2**	**85**	**2**	**2**	**2**	**2**	**3**	100%
BOM and Cost Estimation	**0**	**0**	**80**	**0**	**0**	**0**	**20**	**0**	100%
Engineering Drawings for HPV	**20**	**0**	**15**	**0**	**0**	**0**	**5**	**60**	100%
Static Analysis	**5**	**5**	**5**	**5**	**5**	**40**	**5**	**5**	100%
BOM Final	**0**	**0**	**75**	**0**	**0**	**0**	**25**	**0**	100%
Exploded	**0**	**0**	**85**	**0**	**0**	**0**	**15**	**0**	100%

View Linked to BOM									
Prototype development Plan	**5**	**20**	**5**	**20**	**20**	**15**	**5**	**5**	100%
Prototype Testing Plan	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	**12.5**	100%
Alpha Prototype	**9.2**	**9.2**	**25**	**9.2**	**9.2**	**20**	**9.2**	**9.2**	100%
Alpha Prototype Testing	**5**	**21.25**	**21.25**	**5**	**21.25**	**21.25**	**0**	**5**	100%
Beta Prototype	**12**	**8**	**30**	**7**	**7**	**15**	**15**	**4**	100%

Zach Wenzler's Signature
Zach Wenzler 05/01/2019

Charlie Seaver's Signature
Charlie Seaver 05/01/2019

Francis Chval's Signature
Francis Chval 05/01/2019

Jaclyn Riddiford's Signature
Jaclyn Riddiford 05/01/2019

Jamie Clark's Signature
Jamie Clark 05/01/2019

Mark Rodriguez's Signature
Mark Rodriguez 05/01/2019

Nathan Carney's Signature
Nathan Carney 05/01/2019

Wyatt McCabe's Signature
Wyatt McCabe 05/01/2019

Future Work:

For component improvement, the brake lever needs to be relocated and a cane holder should be attached. In order to verify that our design is reliable for our client, a top priority would be an increased focus of extensive design testing. We were tasked with coming up with testing criteria and had to modify our design to pass the tests. Our tests did not include Dr. Moran operating the vehicle. Therefore, our testing has not been done to the fullest yet. Future iterations to our design can be made from structural failure analysis. Having the expense of testing structural components to failure would be beneficial to analyze. If Dr. Moran choses our design as the final, then the bike design will be improved to include sturdier newer components over the summer.

References:

[1]: Methods conducted by team
[2]: 'MatLab' Center of Mass calculated by Mark Rodriguez
[3]: Final Solidworks Model constructed by Francis Chval and Jamie Clark
[4]: Steering POC 1-3 constructed by Jaclyn Riddiford, Nathan Carney, Wyatt Mccabe
[5]: Bill of Materials created by Francis Chval and Nathan Carney
[6]: Safety Check Validations 1-2 done by Zach Wenzler and Francis Chval

Appendices:

Objectives Chart

	Objective Description	Ranking
1	Maneuverability/Ease of Operation 2	++++0 =4
2	Accessibility/Ease of Access 3	++000 = 2
3	Portability (can it fit in garage) 6	--0-+=-2
4	Stability 4	00++0= 2
5	Maintenance/Durability 5	-0-0+ = 0
6	Weight 7	000-- = -2
7	Maximizes Safety 1	+++++=5
8	Storage (space on HPV) 9	-----= -5
9	Cost/Feasibility 8	0--0- = -3

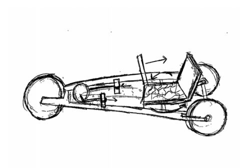
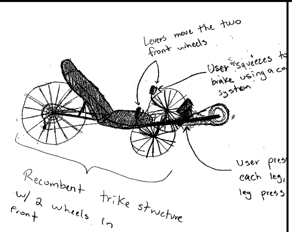
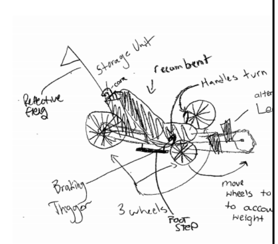
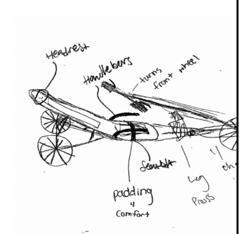
Prototype Plan

Due	Deliverables	Materials and Fabrication	Responsible Persons
Week of 3/25/2019	Functional Frame	Frame System - Cut up old bikes and ordered tubing - Tubes ordered to size - Bend all the tubes to correct angles - Weld frame members together Seating System - Finalize seating design and order additional materials	John Wild (Professional) Fab Lab TA to weld Francis Mark
Week of 4/01/2019	Functional Seating System	Seating System - Bend sheet metal - Cut holes for bolts - Cut tube for support - Weld metal and tube support together then on frame - Bolt on seat	Jamie Mark
	Functional Stability System	Stability System - Pick up delivered wheels - Attach the wheels to the assembly	Francis Nathan Jamie
	Functional Braking System Begin Propulsion System	Braking System - Machine brake mount - Install brake wire Propulsion System - Fabricate elbow	Machine Shop TA Francis Charlie Zach Mark

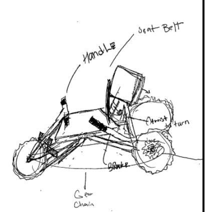
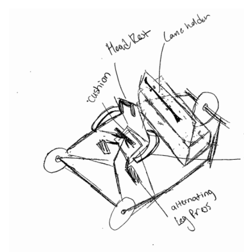
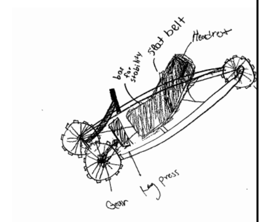
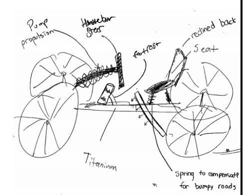
Week of 4/08/2019 **Alpha Deliverable**	Functional Propulsion System	<u>Propulsion System</u> - Attach handlebar, elbows, gears and chain, and then chainguard	Charlie Zach Mark Jaclyn
	Functional Steering System	<u>Steering System</u> - Weld wings onto the fork - Attach ball joints - Weld rods together - Attach pedals	Nathan Wyatt Jaclyn Francis

Week of 4/29/2019 Beta Deliverable: Final completion of subsystems with additional material and fine adjustments for spacing made by feedback.

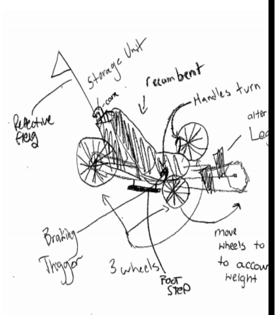
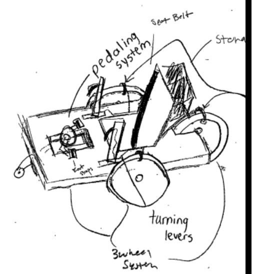
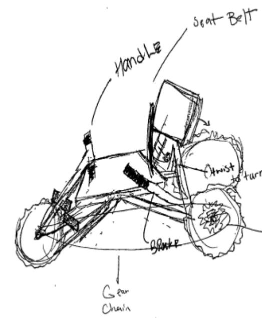
Pugh Chart

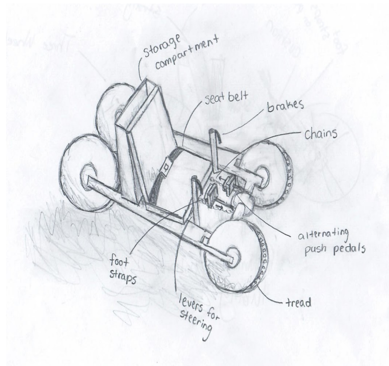
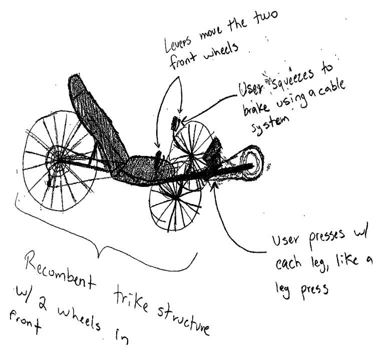
	Concepts			
Selection Criteria				
Stability of the user	0	+	+	+
Safety of the user	0	-	-	+
Durability of the vehicle	0	-	-	-
Propulsion Efficiency	0	0	0	-
Braking Ability	0	+	+	0
Balance of the vehicle	0	0	0	-
Steerability	0	+	+	-
Storage	0	-	+	-

Creativity of the vehicle	0	+	+	+
Intuitivity of the vehicle	0	0	0	+
SUM (+)	0	4	5	4
SUM (-)	0	-3	-2	-5
SUM	0	1	3	-1

Selection Criteria				
Stability of the user	0	+	0	+
Safety of the user	0	-	0	0
Durability of the vehicle	0	-	0	-
Propulsion Efficiency	0	-	-	-
Braking Ability	+	-	0	-
Balance of the vehicle	0	+	0	+
Steerability	+	-	0	0
Storage	-	+	-	-
Creativity of the vehicle	0	+	-	+
Intuitivity of the vehicle	+	0	+	+
SUM (+)	3	4	1	4
SUM (-)	-1	-5	-3	-4
SUM	2	-1	-2	0

Decision Matrix

		Concepts					
							
Criteria	***Weight***	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Stability of the user	15%	3	.45	2	.3	4	.6
Safety of the user	20%	3	.6	4	.8	4	.8
Durability of the vehicle	10%	2	.2	3	.4	3	.3
Propulsion Efficiency	10%	4	.4	3	.3	3	.3
Braking Ability	10%	3	.3	4	.4	2	.2
Balance of the vehicle	10%	3	.3	4	.4	4	.4
Steerability	10%	3	.3	2	.2	4	.4
Storage	5%	4	.2	4	.2	2	.1
Creativity of the vehicle	5%	3	.15	4	.2	3	.15
Intuitivity of the vehicle	5%	3	.15	2	.1	4	.2
Total	100%	31	3.05	32	3.3	33	3.45

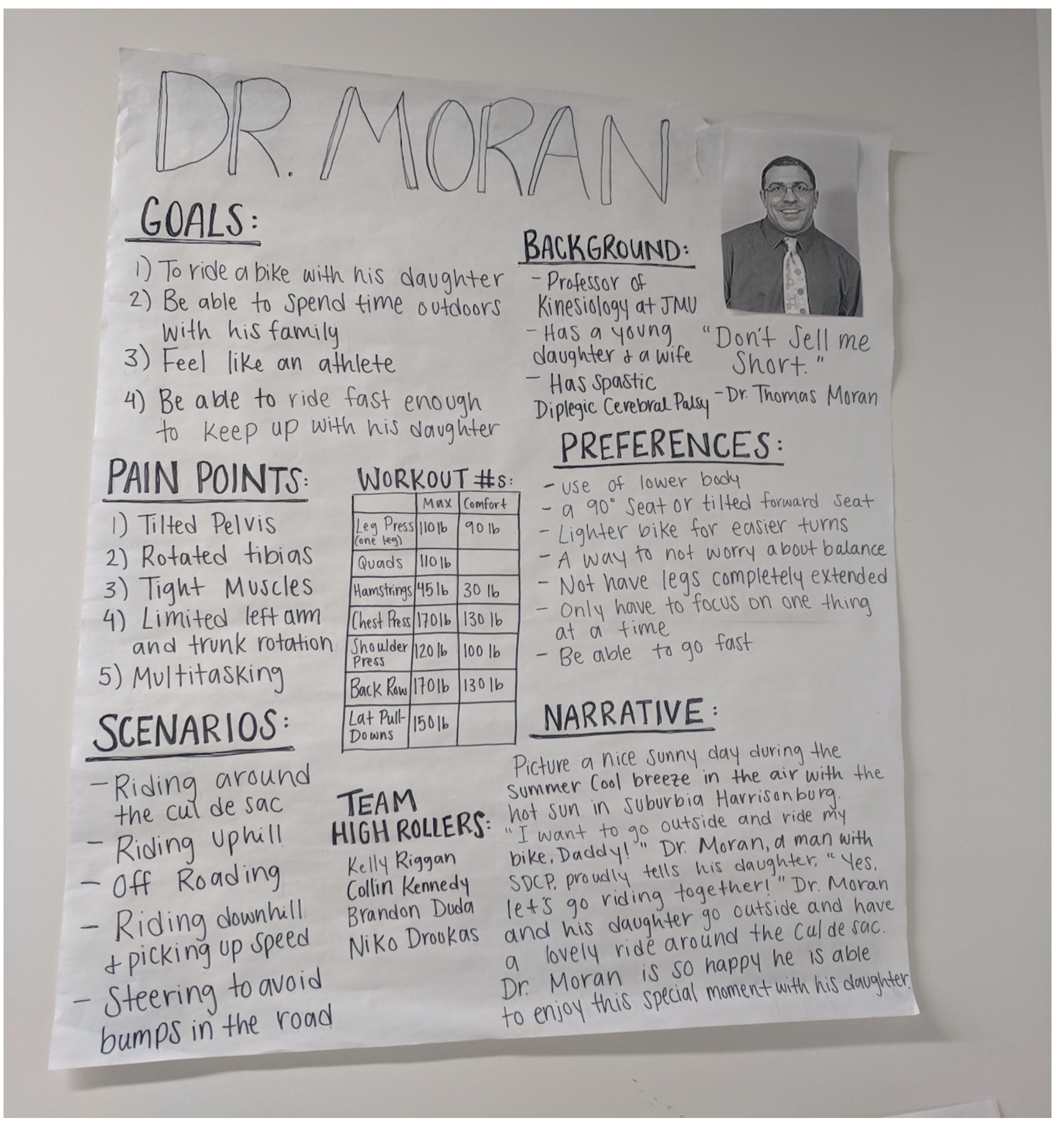
<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Concepts</td></tr>
<tr><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td>Criteria</td><td>Weight</td><td>Rating</td><td>Weighted Score</td><td>Rating</td><td>Weighted Score</td></tr>
<tr><td>Stability of the user</td><td>15%</td><td>5</td><td>.75</td><td>3</td><td>.45</td></tr>
<tr><td>Safety of the user</td><td>20%</td><td>5</td><td>1</td><td>2</td><td>.4</td></tr>
<tr><td>Durability of the vehicle</td><td>10%</td><td>4</td><td>.4</td><td>2</td><td>.2</td></tr>
<tr><td>Propulsion Efficiency</td><td>10%</td><td>4</td><td>.4</td><td>4</td><td>.4</td></tr>
<tr><td>Braking Ability</td><td>10%</td><td>4</td><td>.4</td><td>4</td><td>.4</td></tr>
<tr><td>Balance of the vehicle</td><td>10%</td><td>5</td><td>.5</td><td>3</td><td>.3</td></tr>
<tr><td>Steerability</td><td>10%</td><td>2</td><td>.2</td><td>3</td><td>.3</td></tr>
<tr><td>Storage</td><td>5%</td><td>5</td><td>.25</td><td>1</td><td>.05</td></tr>
<tr><td>Creativity of the vehicle</td><td>5%</td><td>3</td><td>.15</td><td>2</td><td>.1</td></tr>
<tr><td>Intuitivity of the vehicle</td><td>5%</td><td>3</td><td>.15</td><td>3</td><td>.15</td></tr>
<tr><td>Total</td><td>100%</td><td>40</td><td>4.2</td><td>27</td><td>2.75</td></tr>
</table>

Target Specifications

Design Objective Statement	Metric	Value with Unit
1. The client is able to reach handles and pedals	The distance of the user's arm at a comfortable but extended length	Right arm: 28.3 inches Left arm: 26.25 inches
2. Pedals are able to hold his feet in place	Size of his feet and turn out of his right foot when sitting	Shoe size: 7 25°
3. The product is designed around him and fits his measurements	Torso, inseam length, and height	Torso: 24.5 inches Inseam: 23.5 inches Height: 5 feet and three inches
4. The product does not overextend the client's muscles	Inseam length and the maximum distance of lifting the legs	Inseam: 23.5 inches Right leg lift: 8.25 inches Left leg lift: 8 inches
5. The product is able to support at least 150 pounds	The client's weight	Weight: 145 lbs
6. The product is comfortable for the client for at most an hour and a half	Height, the user's hip width and requested angle of the seat	Height: 5ft 3in Hip width: 11.94 inches Angle: 60° towards handles
7. The product can seat a person of at least 5 feet in height	The client's height	5 feet and 3 inches
8. The product is able to store various items	Height and weight of client's cane	Height: 2 feet Weight: 1-2 lbs
9. The product is at a seated incline that is most comfortable to the client	The angle of incline for back	Angle: 60° towards handles
10. The product is not heavy and easy to move around	Weight of bike, lifting strength of client	Max Shoulder Strength: 100 lbs Max Chest Strength: 130 lbs Weight of bike < 30 lbs

11. The client is able to mount and dismount the product independently	Client's height, inseam length, and comfortable distance lifting the legs	Height: 5' 3'' Inseam: 23.5 inches Right leg lift: 8.25 inches Left leg lift: 8 inches
12. The product is able to fit on the sidewalk	Width of a sidewalk	Average 48 inches
13. The client is able to get a good workout from product	The time he wants to improve his biking to	20 minutes
14. The product is able to support his back	Length of back	24.5 inches
15. The client is able to remove feet easily from pedals	Size and turn out of feet when sitting	Size: 7 Right foot: 25 degrees

Persona



Testing Plan

1. **Stability Test: Tilt test**
- Date: 4/10/2019
- Objectives: Determine the two maximum angles (back tilt and side tilt angle) required to tip the bike over. Tilt angle is determined from the horizontal.
- System/Subsystems/Components: COM + Frame
- Method (include testing cycles): Tilt test for 3 trials for each tilt types
- Methodology: Team members support the HPV from both sides. Tilt angle determined with an angle finder or using a protractor and plumbob. Dr. Moran's weight will be represented with weights attached to the seat.
- Criteria: Tilt angle is defined as the angle relative to the horizontal that the bike tips over.
  Back tilt angle less than 45 degrees: fail
  Back tilt angle greater than 45 degrees: pass
  Side tilt angle less than 35 degrees: fail
  Side tilt angle greater than 35 degrees: pass
- Expectation: Pass because of the HPVs low heighted center of mass.

2. **Propulsion Test:**
- Date: 4/10/2019
- Objectives: Determine the maximum of force that can be applied to the crank without it failing under pressure.
- System/Subsystems/Components: Crank arms, crank bar, elbows, gears/chain
- Method (include testing cycles): Crank test for three trials of 15 seconds each
- Methodology: Team members crank propulsion system as fast as possible for 15 seconds.
- Criteria: Noticeable damage or impairment to the propulsion system: Fail
  No noticeable damage or impairment to the propulsion system: Pass
- Expectation: Pass. Materials used in propulsion system is trusted.

3. **Steering Test:**
- Date: 4/12/2019
- Objectives: Determine the feasibility of steering and how much force/effort the client has to put in to turn the front wheel (x) degrees
- System/Subsystems/Components: Foot steering
- Method (include testing cycles): Steer test for three trials

- Methodology: Dr. Moran sits in HPV and turn the wheels to both maximum sides using the foot steering system.
- Criteria: If Dr. Moran is comfortable with the steering: Pass
  If Dr. Moran is uncomfortable or unable to steer: Fail
- Expectation: Fail. Steering has been a complication during the design phase.

4. Structural Rigidity
- Date: 4/05/2019
- Objectives: Determine how much weight the bike frame can support without deformation.
- System/Subsystems/Components: Frame + Wheels
- Method (include testing cycles): Updated Frame analysis
- Methodology: Conduct frame analysis using knowledge from statics and dynamics. Add forces that are exerted from Dr. Moran and possible luggage to determine the internal forces of the pipes.
- Criteria: If found internal forces are greater than the steels capacity: Fail
  If the found internal forces are less than the steels capacity: Pass
- Expectation: Pass. From the previous frame analysis the the internal forces were lower than the steels maximum force it can bear.

5. Turning Radius:
- Date: 4/10/2019
- Objectives: Determine how wide the wheels will be able to turn
- System/Subsystems/Components: Wheels and steering system
- Method (include testing cycles): Turning test for 3 trials
- Methodology: Turn the wheel to the maximum left and right and calculate turning radius using angles.
- Criteria: Turning radius greater than 20 feet: Fail
  Turning radius less than 20 feet: Pass
- Expectation: Pass. Standard bikes have a turning radius much less than 20 feet.

6. Visibility:
- Date: 4/12/2019
- Objectives: Determine whether the client will be able to see clearly while riding the bike.
- System/Subsystems/Components: Frame, crank elbows
- Method (include testing cycles): As many cycles Dr Moran needs
- Methodology: Dr. Moran to sit all the way back and move head left and right.
- Criteria: If components are blocking vision: Fail
  If components are not blocking vision: Pass

- Expectation: Pass. Unless the propulsion system will be too tall.

7. **Braking Reliability:**

- Date: 4/15/2019
- Objectives: Determine the responsiveness and performance of the brakes.
- System/Subsystems/Components: Wheels, hand brake, braking system
- Method (include testing cycles): 5 heavy braking cycles of 4 sets of different speeds.
- Methodology: The time of when the brake is engaged to when the HPV stops is recorded.
- Criteria: At 5mph: If time is greater than 1 second: Fail
  If time is less than 1 second: Pass
  At 10 mph: If time is greater than 1.5 seconds: Fail
  If time is less than 1.5 seconds: Pass
  At 15 mph: If time is greater than 2 seconds: Fail
  If time is less than 2 seconds: Pass
  At 20 mph: If time is greater than 2.5 seconds: Fail
  If time is less than 2.5 seconds: Pass
- Expectations: Pass. New brakes were bought.

8. **Braking Distance:**

- Date: 4/15/2019
- Objectives: Determine the braking distance for the HPV at a variety of speeds.
- System/Subsystems/Components: Wheels, hand brake, braking system
- Method (include testing cycles): 5 heavy braking cycles of 4 sets of different speeds.
- Methodology: Engaging the brake system at various velocities and measuring the distance from when the brakes are engaged to when the HPV comes to a complete stop. Speed will be measured with a velocity radar gun or app.
- Criteria:At 5mph: If distance is greater than 1 meter: Fail
  If distance is less than 1 meter: Pass
  At 10 mph: If distance is greater than 1.2 meters: Fail
  If distance is less than 1.2 meters: Pass
  At 15 mph: If distance is greater than 1.5 meters: Fail
  If distance is less than 1.5 meters: Pass
  At 20 mph: If distance is greater than 1.8 meters: Fail
  If distance is less than 1.8 meters: Pass
- Expectation: Pass.

9. **Drivetrain Reliability:**

- Date: 4/12/2019
- Objectives: Determine the reliability of the drivetrain after number times

- System/Subsystems/Components: Propulsion, Chains, Gears
- Method (include testing cycles): 50 shifts up and 50 shifts down
- Methodology: Shifting the gears 50 times up and down while riding at different speeds.
- Criteria: 50 successful shifts up and down: Pass
  1 failed shift: Fail
- Expectation: Fail. Failed shifts are common issues in bikes.

10. Comfortability:

- Date: 4/15/2019
- Objectives: Determine how natural the client feels while riding the HPV.
- System/Subsystems/Components: Seat, steering
- Method (include testing cycles): As many cycles Dr Moran needs
- Methodology: Dr. Moran to sit in the HPV and operate the HPV.
- Criteria: Dr. Moran complains on comfortability: Fail
  Dr. Moran is comfortable: Pass
- Expectation: Fail. There are always minor or major adjustments that may create the driving experience more comfortable.

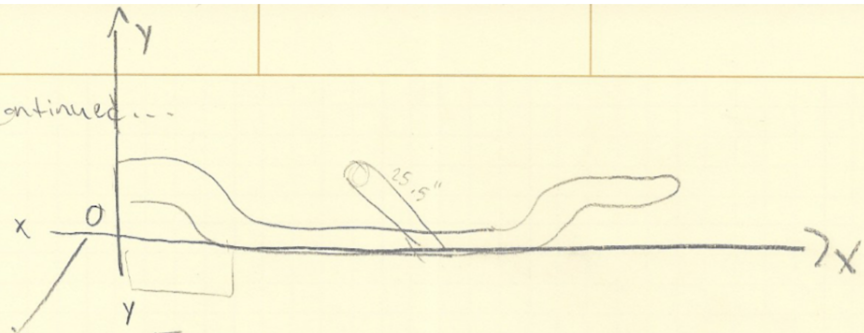
Steering POC 1.[4]

Steering POC 2.

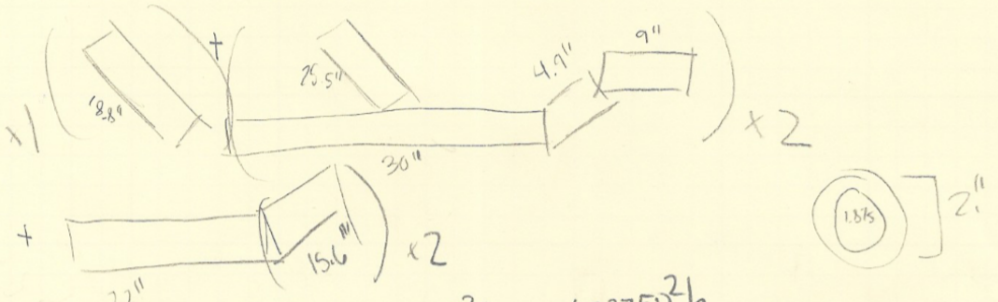
Steering POC 3.

Center of Mass Calculations

Continued...



Find Volume of each part.



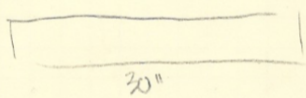
$$V = \pi (1\text{in})^2 h - \pi (.9375\text{in})^2 h$$

First piece:

$V = \pi (1\text{in})^2 (18.8\text{in}) - \pi (.9375\text{in})^2 (18.8\text{in}) = 7.1484\,\text{in}^3$

$\text{mass} = 7.1484\,\text{in}^3 \times (0.284\,\text{lb}/\text{in}^3) = 2.0301\,\text{lb}$

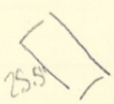
2nd piece:



$V = \pi (1\text{in})^2 (30\text{in}) - \pi (.9375\text{in})^2 (30\text{in}) = 11.407\,\text{in}^3$

$\times 2 = 22.814\,\text{in}^3 \quad \text{mass} = 22.814\,\text{in}^3 \times .284\,\text{lb}/\text{in}^3 = 6.479\,\text{lb}$

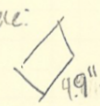
3rd piece:



$V = \pi (1\text{in})^2 (25.5\,\text{in}) - \pi (.9375\text{in})^2 (25.5\text{in}) = 9.696\,\text{in}^3$

$\times 2 = 19.392\,\text{in}^3 \quad \text{mass} = 19.392\,\text{in}^3 \times 0.284\,\text{lb}/\text{in}^3 = 5.507\,\text{lb}$

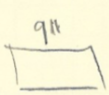
4th piece:



$V = \pi (1\text{in})^2 (4.9\text{in}) - \pi (.9375\text{in})^2 (4.9) = 1.863\,\text{in}^3$

$\times 2 = 3.726\,\text{in}^3 \quad \text{mass} = 3.726\,\text{in}^3 \times 0.284\,\text{lb}/\text{in}^3 = 1.058\,\text{lb}$

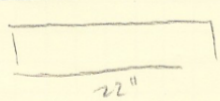
5th piece:



$V = \pi (1\text{in})^2 (9\text{in}) - \pi (.9375\text{in})^2 (9\text{in}) = 3.422\,\text{in}^3 \quad \times 2 = 6.844\,\text{in}^3$

$\text{mass} = 6.844\,\text{in}^3 \times .284\,\text{lb}/\text{in}^3 = 1.944\,\text{lb}$

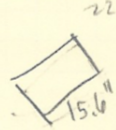
6th piece:



$V = \pi (1\text{in})^2 (22\,\text{in}) - \pi (.9375\text{in})^2 (22\text{in}) = 8.365\,\text{in}^3$

$\text{mass} = 8.365\,\text{in}^3 \times .284\,\text{lb}/\text{in}^3 = 2.3757\,\text{lb}$

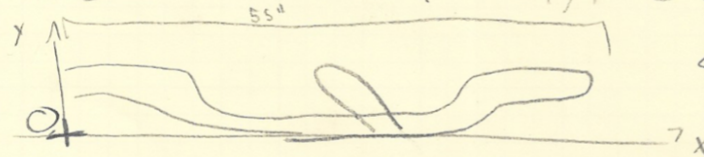
7th piece:



$V = \pi (1\text{in})^2 (15.6\,\text{in}) - \pi (.9375\text{in})^2 (15.6\text{in}) = 5.9317\,\text{in}^3$

$\times 2 = 11.863\,\text{in}^3 \quad \text{mass} = 11.863\,\text{in}^3 \times .284\,\text{lb}/\text{in}^3 = 3.369\,\text{lb}$

Find center of mass in x, y, and z directions



origin at O

$m_1 = (V_1(.284\,lb/in^3))$

Using the equation: $X_m = \dfrac{m_1x_1 + m_2x_2 + m_3x_3 \ldots}{m_1 + m_2 + m_3 \ldots}$

X-direction

$$X_m = \frac{(2.030\,lb)(6.65in) + (6.479\,lb)(28.3in) + (5.507\,lb)(32.3in) + (1.058\,lb)(44.8in) + (1.944\,lb)(50.8in) + (2.375\,lb)(24.3in) + (3.369\,lb)(48.6in)}{(2.030\,lb) + (6.479\,lb) + (5.507\,lb) + (1.058\,lb) + (1.944\,lb) + (2.375\,lb) + (3.369\,lb)}$$

$X_m = 30.33in$

Y-direction

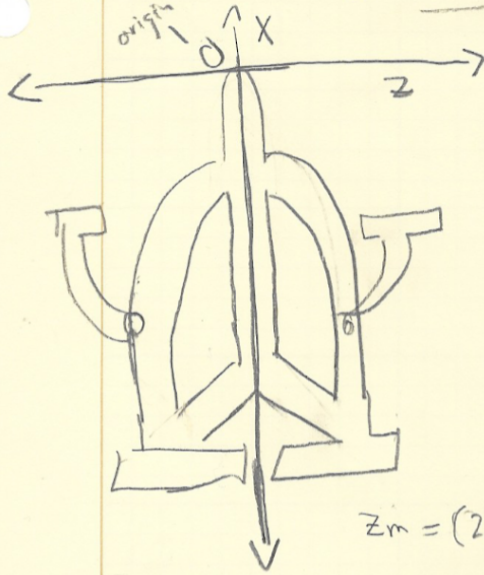
$$Y_m = \frac{m_1y_1 + m_2y_2 + m_3y_3 \ldots}{m_1 + m_2 + m_3 \ldots}$$

$m_1 = (V_1(.284\,lb/in^3))$

$$Y_m = \frac{(2.030\,lb)(6.65in) + (6.479\,lb)(1in) + (5.507\,lb)(11in) + (1.058\,lb)(1.5in) + (1.944\,lb)(4in) + (2.3757)(1in) + (3.369\,lb)(1in)}{(2.030\,lb) + (6.479\,lb) + (5.507\,lb) + (1.058\,lb) + (1.944\,lb) + (2.375\,lb) + (3.369\,lb)}$$

$Y_m = 4.203in$

Z-direction $Z_m = \dfrac{m_1 z_1 + m_2 z_2 + m_3 z_3 \ldots}{m_1 + m_2 + m_3 \ldots}$

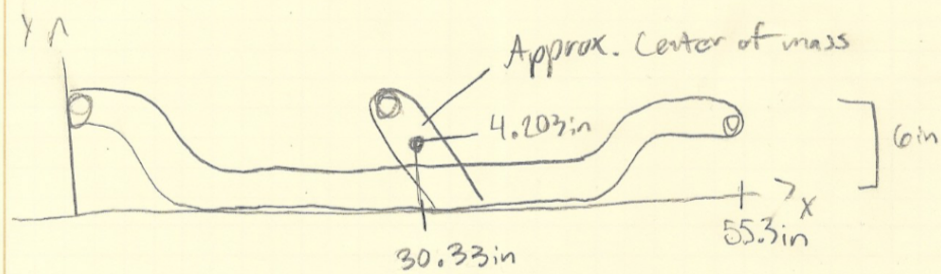


$$Z_m = \frac{(2.030\,lb)(0\,in) + (6.479\,lb)(0\,in) \ldots}{(2.030\,lb) + (6.479\,lb) \ldots} = 0$$

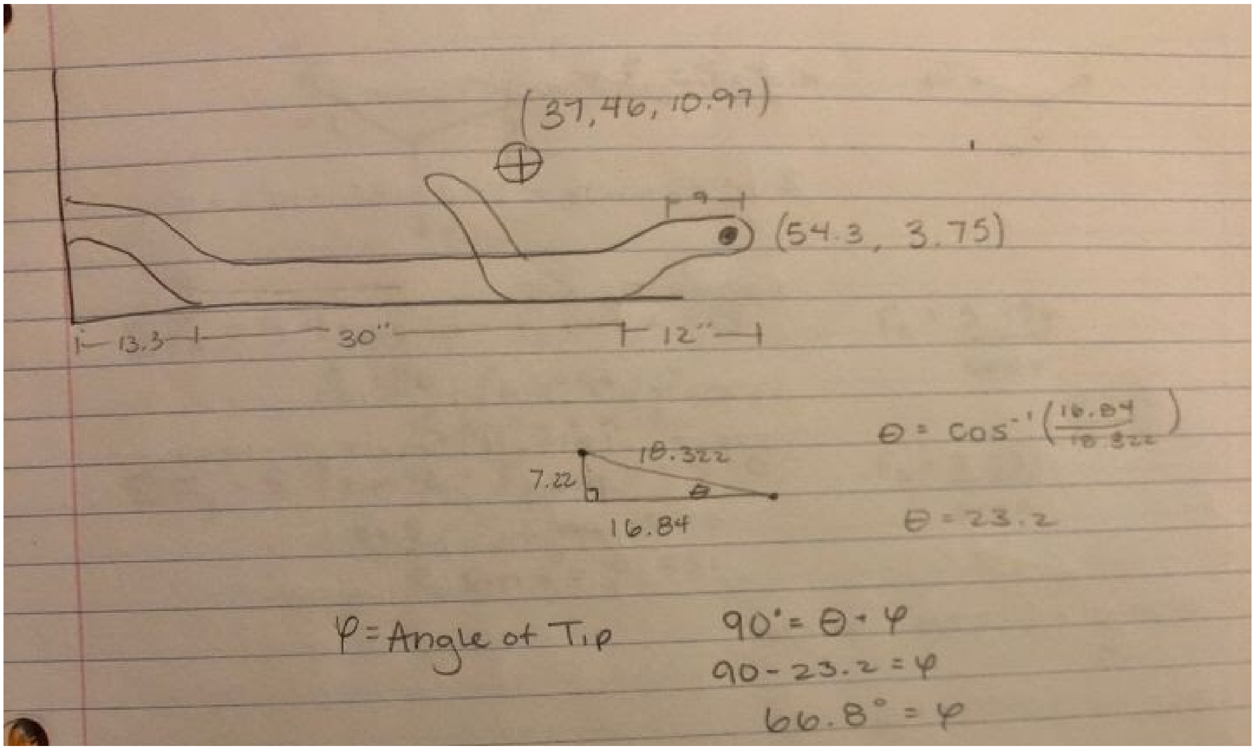
Since it is symmetrical along the Z axis is $Z_m = 0$

$$\boxed{Z_m = 0\,in}$$

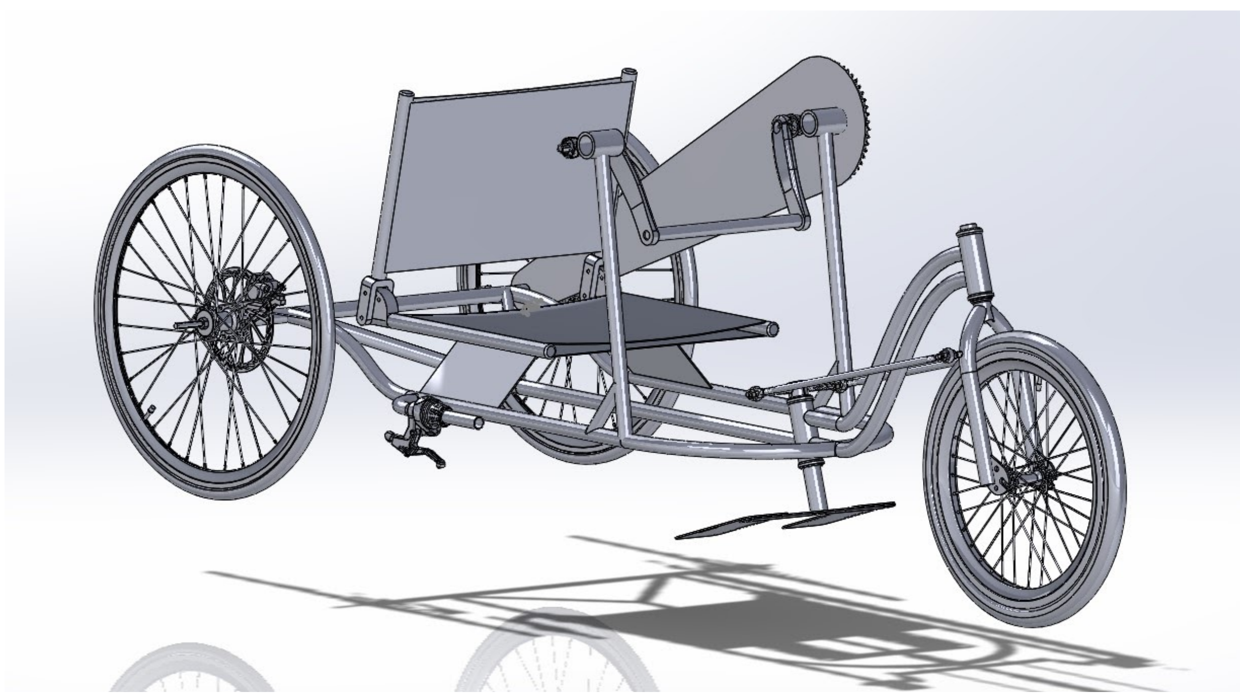
Center of mass = (30.33in, 4.203in, 0in)



Tipping Angle Calculations



CAD Model



Bill of Materials[5]

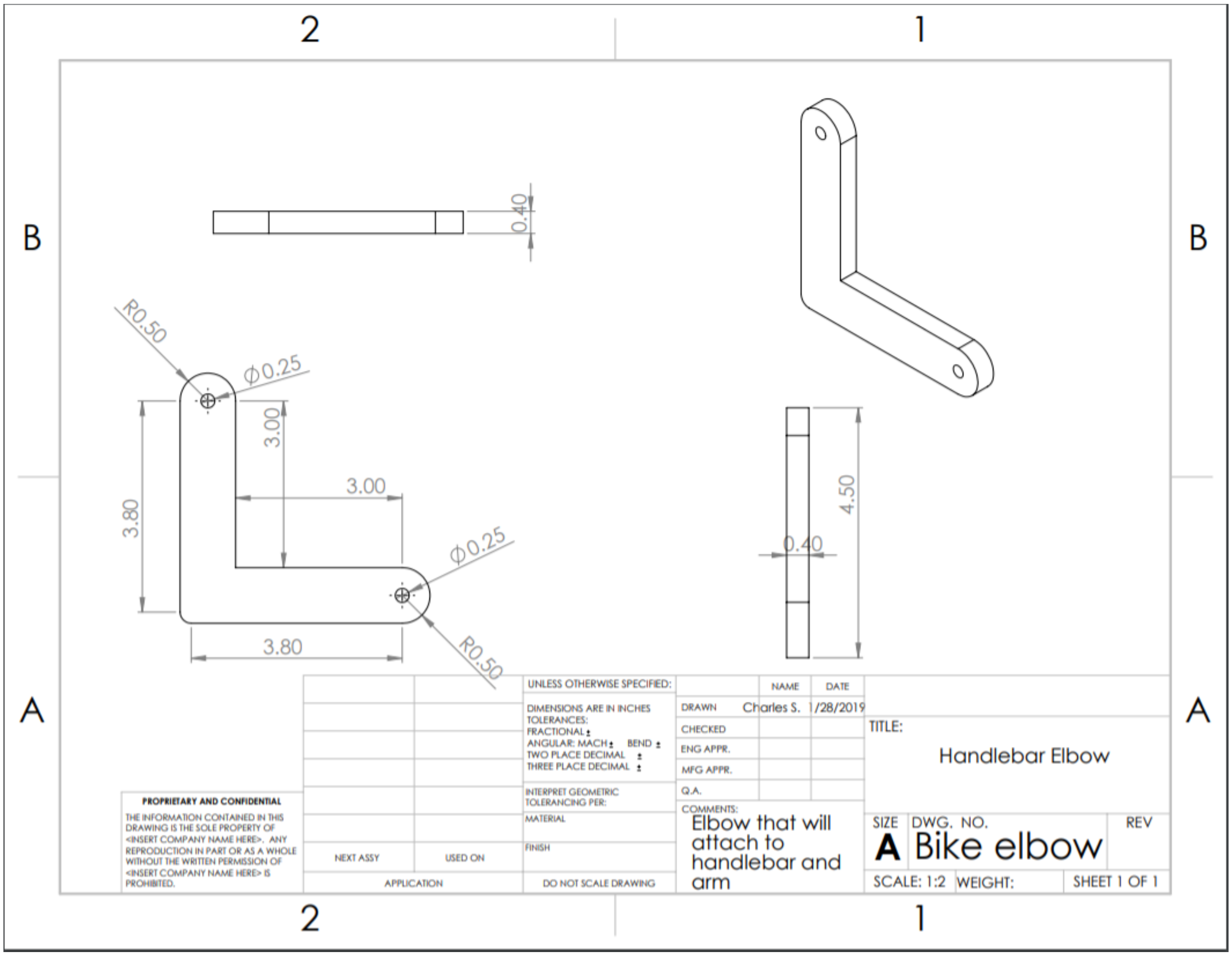
Purchased Materials									
BOM Part Numbe	Mfg. Part Numbe	Quantity	Description	Source	Person Responsib	Unit Cost	Tax/Shipping	Total Cost	Obtained
D1	70805-26	1	26" Sun Ringle Wheelset	bicyclewheelwarehouse.c	Scott Padgett	$139.99	$0.00	$139.99	
D2		2	26" Tire & Tube	PARTS BIN	Francis Chval	$0.00		$0.00	
S1		1	20" BMX Fork	PARTS BIN	Francis Chval	$0.00		$0.00	
D4		1	20" Tire & Tude	PARTS BIN	Francis Chval	$0.00		$0.00	
S2		2	11/8" Headset	PARTS BIN	Francis Chval	$0.00		$0.00	
F1	89955K636	2	1" OD 4130 6ft Tubing	mcmaster.com	Scott Padgett	$50.52	$0.00	$101.04	
F3		2	Scrap Steel Sheet	MACHINE SHOP BIN	Francis Chval	$0.00		$0.00	
D3		1	20" Front Wheel	PARTS BIN	Francis Chval	$0.00		$0.00	
S3	6072K64	4	Oil Embedded Ball Joint	mcmaster.com	Scott Padgett	$6.23	$0.00	$24.92	
S4	6516K64	2	Female 3/8" Threaded Ro	mcmaster.com	Scott Padgett	$18.93	$0.00	$37.86	
F2	1078N13	1	M10 Threaded Rod	mcmaster.com	Scott Padgett	$12.00	$0.00	$12.00	
D13	9056K72	1	7/8" Aluminum Tubing	mcmaster.com	Scott Padgett	$17.12	$0.00	$17.12	
D14		2	Left Pedal	PARTS BIN	Francis Chval	$0.00		$0.00	
D5	BB407A02	2	Shimano 68mm BB	jensonusa.com	Scott Padgett	$8.99	$0.00	$17.98	
F5		4	10mm Lock Nut	PARTS BIN	Francis Chval	$0.00		$0.00	
D12		2	8 Speed Chain	PARTS BIN	Francis Chval	$0.00		$0.00	
D6		1	4 Bolt Right Crankarm	PARTS BIN	Francis Chval	$0.00		$0.00	
D7	CR191Z00	2	SR Suntour Left Crankarm	jensonusa.com	Scott Padgett	$15.00	$0.00	$30.00	
D8		1	8 Speed Derailleur	PARTS BIN	Francis Chval	$0.00		$0.00	
D9		1	8 Speed Shifter	PARTS BIN	Francis Chval	$0.00		$0.00	
B1	sku376873	1	Clarks Disk Brake & Rotor	chainreactioncycles.com	Scott Padgett	$39.09	$0.00	$39.09	
D10		1	8 Speed Cassette	PARTS BIN	Francis Chval	$0.00		$0.00	
F4		2	68mm BB Shell	SCRAP BIKE	Francis Chval	$0.00		$0.00	
S5		2	11/8" Steering Tube	SCRAP BIKE	Francis Chval	$0.00		$0.00	
B2		1	Brake Lever	SCRAP BIKE	Francis Chval	$0.00		$0.00	
B4		6	M5 Screws	PARTS BIN	Francis Chval	$0.00		$0.00	
D17		1	Shifter Cable & Housing	PARTS BIN	Francis Chval	$0.00		$0.00	
B5		1	Brake Cable & Housing	PARTS BIN	Francis Chval	$0.00		$0.00	
S8	9433K99	2	Extension Spring w/ Hooks	mcmaster.com	Scott Padgett	$9.29	$0.00	$9.29	

Machined Materials									
Part Number		Quantity	Description	Source	Person Responsib	Labor Cost	Material Cost	Total Cost	Obtained
B3		1	Disk Mount	MACHINE SHOP	Mark Rodriguez			$0.00	
D15		1	Derailleur Mount	MACHINE SHOP	Mark Rodriguez			$0.00	
F6		2	Seat Bottom Hinge	MACHINE SHOP	Mark Rodriguez			$0.00	
F7		2	Seat Top Hinge	MACHINE SHOP	Mark Rodriguez			$0.00	
S6		2	Steering Pad	MACHINE SHOP	Mark Rodriguez			$0.00	
F8		2	Seat Fabric	PARTS BIN	Franics Chval				
D16		1	Drive Rod Bearing Housing	MACHINE SHOP	Mark Rodriguez			$0.00	

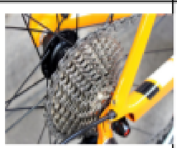
Labor Costs						
Team Member	Estimated Hours Worked		Pay Rate / Hou	FICA Taxes	Benefits	Total Cost
Francis Chval	50			7.65%	15.00%	$0.00
Mark Rodriguez	50			7.65%	15.00%	$0.00
Jaclyn Riddiford	35			7.65%	15.00%	$0.00
Charlie Seaver	35			7.65%	15.00%	$0.00
Jamie Clark	35			7.65%	15.00%	$0.00
Nathan Carney	35			7.65%	15.00%	$0.00
Wyatt McCabe	35			7.65%	15.00%	$0.00
Zach Wenzler	35			7.65%	15.00%	$0.00

Material Cost:	$429.29
Labor Costs	$0.00
Indirect Costs	$0.00
Total Costs	$429.29

Engineering Drawing



Benchmarking/Teardown

Component Name	Picture	How it works	Function	Integration and interaction with other components	Tool to remove/replace
Pedals		The rider places its feet on the pedals and then pushes one then the other steadily to move the bicycle forward.	To hold riders feet and turn the crank arms.	The pedals are connected to the crank arms. When pushed on the pedals the crank arms turn and then moves the gears.	Pedal Wrench
Chain		The chain is connected and moves along the gears and then turns the wheel.	Transmit power from the gears to the rear sprocket.	The chain is connected to the gears and the rear wheel.	Chain Tool
Gears		Rider chooses desire gear from gear lever. Then it switches gear while riding. The gears teeth are connected to the chain which turns the chain that is connected to the wheel.	Different bicycles have different amounts and sizes of gears. Each gear needs a certain force to push from the pedals which allows the rider to choose the right gear for their situation.	The gears are turned by the crank arms. Then the gear interacts with the chain by moving it along with itself.	Chain Whip
Crank Arms		The crank arms turn from the pedals. Then the crank arms turn the gears.	To hold the pedals in place and transmit power from the pedals to the gears.	The crank arms interact with the pedals and the gears of the bicycle.	Crank extractor body and bolt & Crank arm socket wrench & Cassette lockring tool

Gear Shifters	 	The lever is pulled, which moves the cables to help change gears on a bicycle.	The function is to easily change gears on a bicycle.	Sits on the handlebars of bicycle and interacts with the cables and gears.	Allen Wrench
Wheel		The wheel turns from the power from the chain. It is round so it can easily rotate on the ground allowing the bicycle to move.	The function of the wheel is to rotate on the ground to move the bicycle.	The wheel interacts with the chain. The front wheel is connected to the fork and the rear wheel is connected to the frame of the bicycle.	Wrench
Handlebars		When the handlebars are turned, it turns the fork which then turns the front wheel.	The function of the handlebars is to allow the rider to place their hands on them and turn them in the direction the riders wishes.	The handlebars is connected to the stem then its connected to the fork. It also holds the gear shifter.	Allen wrench or Y wrench
Stem		The stem connects the handlebars to the fork of the bicycle.	Allows the interaction between the handlebars and the fork to happen.	Connected to the handlebars and the fork.	Allen Wrench or Y wrench

Fork		The fork rotates because of the handlebars which then rotates the front wheel.	The forks function is to hold and turn the front wheel.	The fork is connected to stem and the front wheel. It also has bearings below the stem to reduce friction when rotating.	Allen wrench or Y wrench
Bearings		The lubricated balls in the bearing move along the ring with low friction.	The function of the bearings is to reduce friction when turning the front wheel.	The bearings sit along the top of the fork and the top of the frame of the bike next to the stem.	No tool

Safety Check (Design Validation)[6]

Back Alley Bikes

East Coast Bicycle Academy

Les Welch
1010 Greystone St.
Harrisonburg, VA 22802
540-433-3013

Partially disassembled

4/16/19

Bill To: Ship To: Invoice No.:

Moranimals

Remove All Sharp Edges

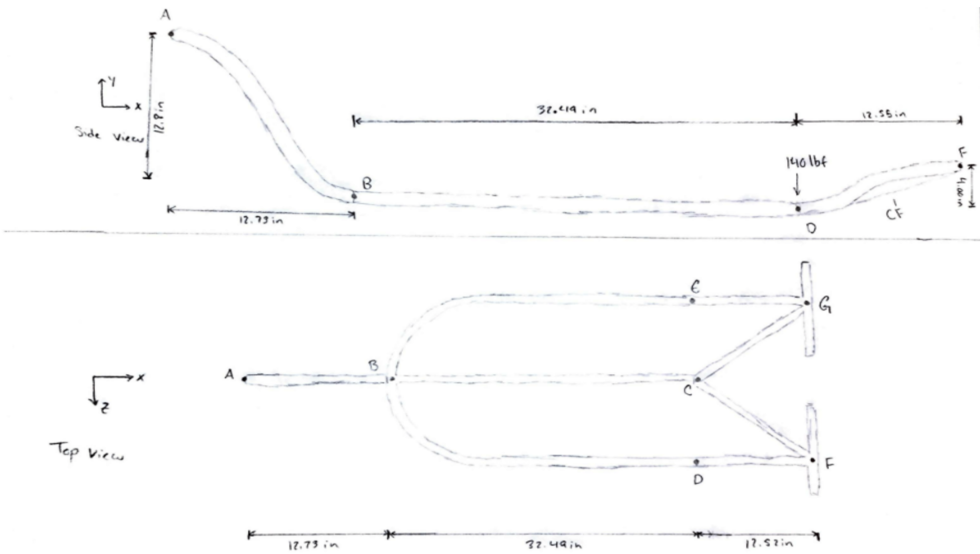
Quantity	Item	Description	Unit Price	Total
		Consider Non-Slip foot treads		
		Install locknuts on Tie Rod Ends		
		Plug Steering column +	Headset	
		+ Install Okey washer under	locknut	
		Install 2nd Brake lever		
		Shorten + crimp Brake Cable - Keep away from rotor		
		Consider 2nd Brake / Parking Brake		

Subtotal:	
Tax:	
Shipping:	
Miscellaneous:	
Balance Due:	

Inflate tires
Wear Helmet

Need to do final inspection
w/seat installed + drivetrain functional

Frame Analysis



ENGR 232 | Frame Analysis Calculations | Team Meranmais 1/1

Equations Used

1. $\Sigma F_x = A_x + BC = 0$
2. $\Sigma F_y = A_y + B_y = 0$
3. $\Sigma M_A = (12.73\,in)B_y + (12.8\,in)BC = 0$
4. $\Sigma F_x = -AB + CF\cos(72.3) = 0$
5. $\Sigma F_y = B_y + CF\sin(72.3) = 0$
6. $\Sigma M_B = (32.49\,in)CF\sin(72.3) = (32.49\,in)(140\,lbf)$
7. $\Sigma F_x = -AB + DF\cos(72.3) = 0$
8. $\Sigma M_B = (32.49\,in)D_y + (32.49\,in)DF\sin(72.3) = 0$
9. $\Sigma F_x = -BC + F_x = 0$
10. $\Sigma F_y = F_y = 140\,lbf$
11. $\Sigma F_x = F_x - BD = 0$

* Based on assumptions from Frame Symmetry:

$CF = CG$ $\quad F_x = G_x$
$DF = EG$ $\quad F_y = G_y$
$D_y = E_y$ $\quad BD = BE$

Solutions (lbf)

$A_x = -139.234$
$A_y = 139.234$
$BC = 139.234$
$B_y = -140.000$
$AB = 44.680$
$CF = 146.957$
$DF = 146.958$
$D_y = -140.001$
$F_x = -139.234$
$F_y = 140$
$BD = -139.234$

Calculations

10. $F_y = 140\,lbf$

6. $CF = (32.49\,in(140\,lbf))/(32.49\,in(\sin(72.3)))$
$CF = 146.957\,lbf$

4. $AB = 146.957\,lbf(\cos(72.3))$
$AB = 44.680\,lbf$

5. $B_y = -(146.957\,lbf(\sin(72.3)))$
$B_y = -140.000\,lbf$

3. $BC = -(12.73\,in(-140.000\,lbf))/12.8\,in$
$BC = 139.234\,lbf$

1. $A_x = -139.234\,lbf$

7. $DF = 44.680\,lbf/\cos(72.3)$
$DF = 146.958\,lbf$

8. $D_y = -(32.49\,in(146.958\,lbf)\sin(72.3))/32.49\,in$
$D_y = -140.001\,lbf$

9. $F_x = -139.234\,lbf$

11. $BD = -139.234\,lbf$

2. $A_y = 139.234\,lbf$