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### **MEMS 411: The Water Bike**

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# Washington University in St. Louis

## JAMES MCKELVEY SCHOOL OF ENGINEERING

### FL21 MEMS 411 Mechanical Engineering Design Project

#### WATER BIKE

The water bike provides lifeguards with an efficient way to travel to work and continue guarding on the same equipment. To transition from a road bike to a water bike, the following steps are taken: the front wheel is removed, and a wooden crossbar is attached to the fork. Two rear wooden bars are clamped to the chain stays, one on each side of the bike. And finally, a PVC rudder slides along the back of the front crossbar and aids in steering. Off of the wooden crossbar and the rear wooden bars are the four pontoons, one on each side in the front and back, attached with 3/8" steel threaded rods.

The water bike is large enough to provide stability to a lifeguard helping a swimmer, but also is small enough to fit within a lane in a pool. The interviewed lifeguards provided the following customer needs: the water bike must be lightweight, can support a passenger up to 200 lbs, does not tip over while in water, can tow a rescue, and can switch from road to water configuration. We set the following performance goals: bike can travel 200 meters in less than 4 minutes, bike can switch from road to water configuration in less than fifteen minutes, rider can dismount and remount the bike while in water.

After final prototype testing, it was determined that the water bike met 2 of the 3 performance goals. The switch from road to water took 12:39; our test rider was able to remount the bike in the water. The remaining goal of traveling 200 meters in less than 4 minutes was unable to be tested because once the rider began to pedal, weight shifted backwards, causing the bike to rotate backwards and sending the rider for a swim.

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# 1 Introduction

The goal of the project is to design and create a human powered water-bicycle capable of being ridden in lakes and pools. The product will be a kit that can be attached to pre-existing bicycles to make them rideable on smooth bodies of water. The customers for this bike are two lifeguards looking for a more efficient way to travel across large distances of water. For convenience, the final product should be able to attach to and detach from any road bicycle's fork and frame dropouts using common quick release skewers. The bike should be large enough to provide stability to a lifeguard helping a swimmer, but must also fit within the lanes of a pool.

## 2 Problem Understanding

### 2.1 Existing Devices

Multiple competing water/hydro bikes are already on the market. These bikes are all very similar in stature and operation, with slight differences. Three of the most popular water bikes have been highlighted below.

#### 2.1.1 Existing Device #1: Schiller Water Bikes



Figure 1: Schiller Water Bike

Link: <https://schillerbikes.com/shop/#S1-C>

Description: The Schiller Water Bike is the first competitor we are highlighting for a few reasons. This bike is on the cutting edge of hydrobikes, with a sleek design and a ergonomic user interface, it is no surprise the Schiller Water Bike is at the top of the market. This bike is outfitted with a flotation device on either side, measuring at 12'8". An attached propeller allows the bike to move, when powered by the cyclist. The Schiller Water Bikes pricing starts at approximately \$4000.

### 2.1.2 Existing Device #2: Hydrobike Explorer



Figure 2: Hydrobike Explorer

Link: <https://hydrobikes.com/products/explorer-1>

Description: The Hydrobike Explorer is another popular model. Priced more modestly than the Schiller Bike, the Explorer starts at \$2399. This bike has a similar construction with flotation devices on either side and user-powered propeller. However, this model is much wider and less sleek of a design than the Schiller bike. It deconstructs into multiple pieces for ease of transportation. The Explorer also can move at a max speed of up to 6 miles per hour!

### 2.1.3 Existing Device #3: Sea Cycle SOLO



Figure 3: Sea Cycle SOLO

Link: <https://www.sea-cycle.com/prices/>

Description: The last competitor to highlight is the Sea Cycle SOLO. The SOLO is priced in the middle of the previous two models, at \$3495. Similar to the previous bikes, it also has the dual flotation construction. It has a lower profile seat and has the option to add additional seats for more passengers. This unit appears to be the lowest quality of the three, despite the increased price.

## **2.2 Patents**

### **2.2.1 Water Bicycle (US1920391A)**

This patent outlines an invention where a normal bicycle frame is mounted on pontoons. The rear wheel is replaced with a paddle wheel for motility in water. A front pontoon can be fitted with a rudder for steering in the water. In total there are three pontoons organized similarly to tricycle wheels.

### **2.2.2 Water-Bicycle (US1034278A)**

This patent is for a bike that can be ridden on both land and water. On land the flotation devices fold up out of the way of the ground and the wheels. For water they can be folded back down under the wheels to work on water. The floats are made of metal drums. Two sit in the front and two in the back. Air can be added to these floats if needed because they are fitted with presta valves. The drive train is a paddle wheel connected to a belt that attaches to the wheel.

## **2.3 Codes & Standards**

### **2.3.1 Floating Leisure Articles for Use On and In the Water (ISO 25649)**

This International Standard outlines requirements for class E floating devices. Class E devices are for protected bathing zones, an area this bike would most likely remain in. Some of the requirements outlined are: residual buoyancy or rated load. The entire code is unavailable and we would need to purchase it.

### **2.3.2 Front Wheel Retention (ISO 4210-8)**

This standard enumerates how the front wheel of a bicycle needs a secondary method of retention when the skewer is open. This serves as a fail safe. The wheel shall not detach when a force of 100 N is applied radially outward for one minute.

## **2.4 User Needs**

The goal of the Water Bike is to provide lifeguards with the opportunity and ease of riding a regular road bike to work and being capable of transforming the road bike into a water bike. This eliminates the need for a canoe, kayak, or other flotation device while guarding.

### **2.4.1 Customer Interview**

Interviewees: Ariana Miles and Leandre Pestcoe

Location: Athletic Complex, Washington University in St. Louis, Danforth Campus

Date: September 10<sup>th</sup>, 2021

Setting: We met two WashU lifeguards before they were on duty and presented our idea. Both lifeguards provided ample feedback to a set of questions that we had prepared ahead of time. Being in the pool area helped formulate additional questions. The whole interview was conducted in the Athletic Complex pool area and took ~20 min.

Interview Notes:

*How stable does the bike need to be in the water and should the bike be able to handle choppy water?*

- It shouldn't take any effort to keep the bike upright while just sitting on it so that the guards are focused on the swimmers and not focused on their personal balance.
- Doesn't necessarily have to handle choppy waters like an ocean but if it could then the outreach of this product could be expanded.

*How easy does the swap between tires and float need to be? And ideally how long should it take? If tools are required is that okay?*

- Timing wise, it is dependent on the main use of this bike. If the guard's main goal is to ride to and from work, then a quick swap would be nice, but if the bike will be mostly left at work then it would be okay if the swap took longer.
- The necessary tools could be built into the bike for ease of access.

*In helping us choose the proper materials, will this bike be used in saltwater, freshwater, or chlorine?*

- Saltwater, freshwater

*Are there any size restrictions as to how wide/large the on-water contraption can be?*

- Yes, would be convenient if it could fit within a lane line.

*How heavy of a passenger does this need to be able to support?*

- 175-200 lbs

## 2.4.2 Interpreted User Needs

Table 1 below displays our interpreted user needs for the Water Bike. The order of the needs in the table is arbitrary, while the rankings of importance in the right-hand column are critical to our design steps discussed later in this report. For conciseness, Water Bike will be referenced as 'WB' in Table 1 below.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The WB is lightweight	4
2	The WB can support a passenger up to 200 lbs	4
3	The WB is 100% waterproof	5
4	The WB does not tip over easily while in water	4
5	The WB can tow a rescue	5
6	The WB can switch easily between tires and paddles	3
7	The WB is safe to ride to and from work	5
8	The WB comes equipped with any necessary tools for switch	3

Safety of the lifeguards and the guards' ability to complete a rescue are vital to the success of the Water Bike. Needs such as the Water Bike coming equipped with tools for the switch as well as the ease of the switch from land to water are pieces of the design that can be improved upon but are not crucial to safety.

## 2.5 Design Metrics

Table 2 below displays the target specifications of the Water Bike based on our customer needs.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1	Total weight not in water	lb	20	15
2	1	Total weight water bike	lb	<60	<30
3	2	Total weight of passenger to be supported	lb	> 150	< 200
4	3	Time materials last in/out of water	months	> 12	> 24
5	4	Number of tips allowed per shift	integer	1	0
6	5	Weight water bike can tow	lb	> 150	< 200
7	6	Time it takes to switch	minutes	< 20	< 10
8	7	Meets all safety regulations and standards	binary	Pass	Pass
9	8	All tools for switch are stored on/in bike	binary	Pass	Pass

## 2.6 Project Management

The Gantt chart in Figure 4 gives an overview of the project schedule.

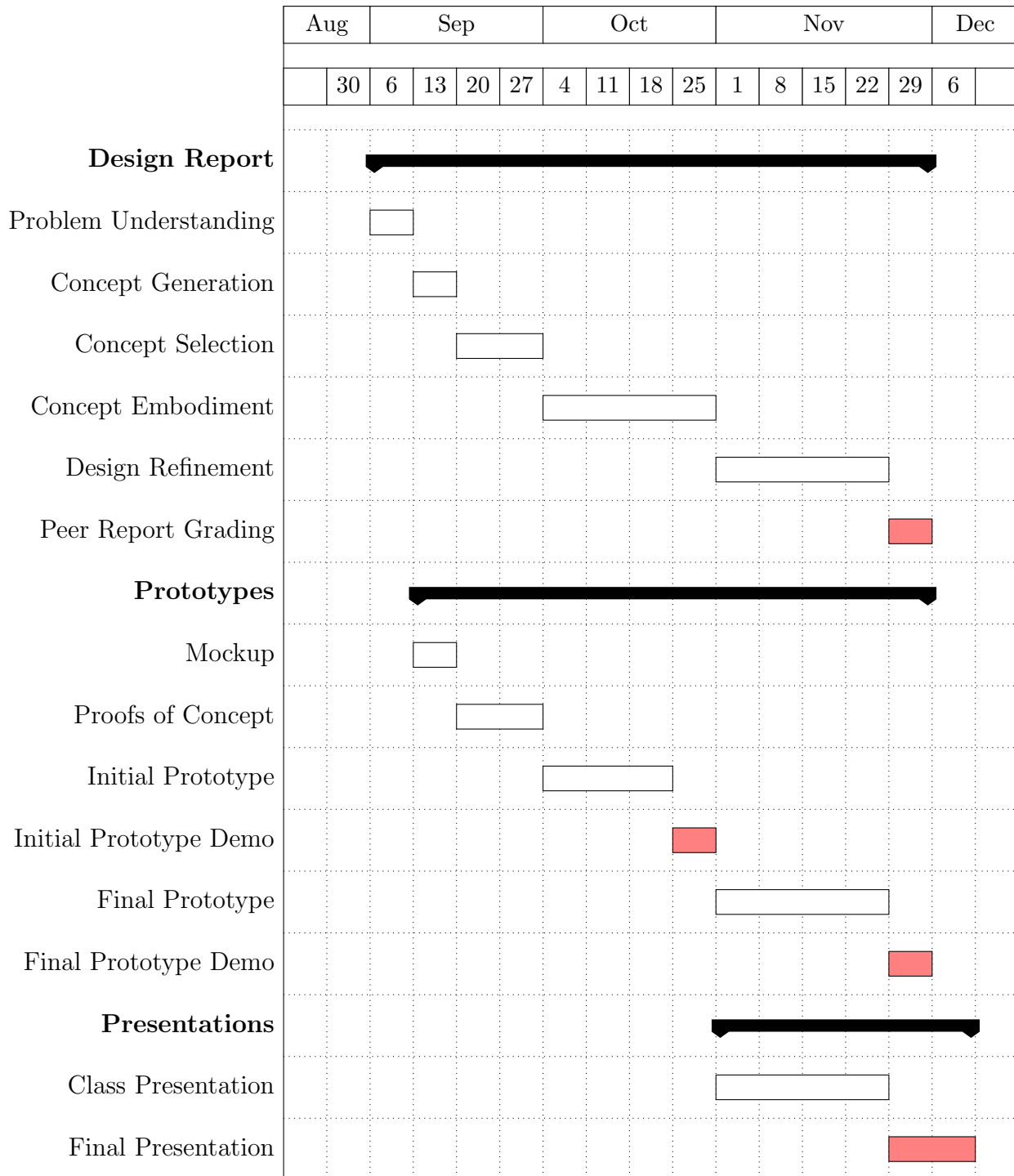


Figure 4: Gantt chart for design project

## 3 Concept Generation

### 3.1 Mockup Prototype

#### 3.1.1 Paddle Wheel

Figure 5 below displays the first part of our mockup prototype, the paddle wheel.



Figure 5: Top and Side Views of Paddle Wheel Mockup

While formulating ideas for our prototype, we initially thought of adding smaller paddles to the existing larger-sized bike tires. However, during the mockup stage, we acquired smaller bike tires which sparked the idea of altering our design to use these smaller tires, allowing for larger paddles. This design time helped us think about what materials we will be using for the actual paddles, and we concluded that a 3D-printed plastic would endure the various elements necessary for our customers.



### 3.1.2 Method of Flotation

Figure 6 below displays the second part of our mockup prototype, the flotation mockup.



Figure 6: The flotation mechanism and rudder.

The flotation mechanism consists of two pontoons supported by axles that will fit in the bike forks. The front of the mechanism has a rudder that can be used for steering. Building this mockup was helpful as it got us to think through how the steering mechanism will work. We concluded that in subsequent generations, the two axles should be independent of each other, resulting in 4 pontoons instead of two. This allows for steering to be controlled by the bike's handlebars.



### 3.2 Functional Decomposition

The following function tree breaks down the goals of the water bike. The bike must be able to carry a rider up to 200 lbs, tow guarding equipment, move effectively and remain upright while in water, aid lifeguards in completing a rescue, and switch easily from road to water. The images on the rightmost side of the function tree display the initial idea for how to make the subfunction a reality.

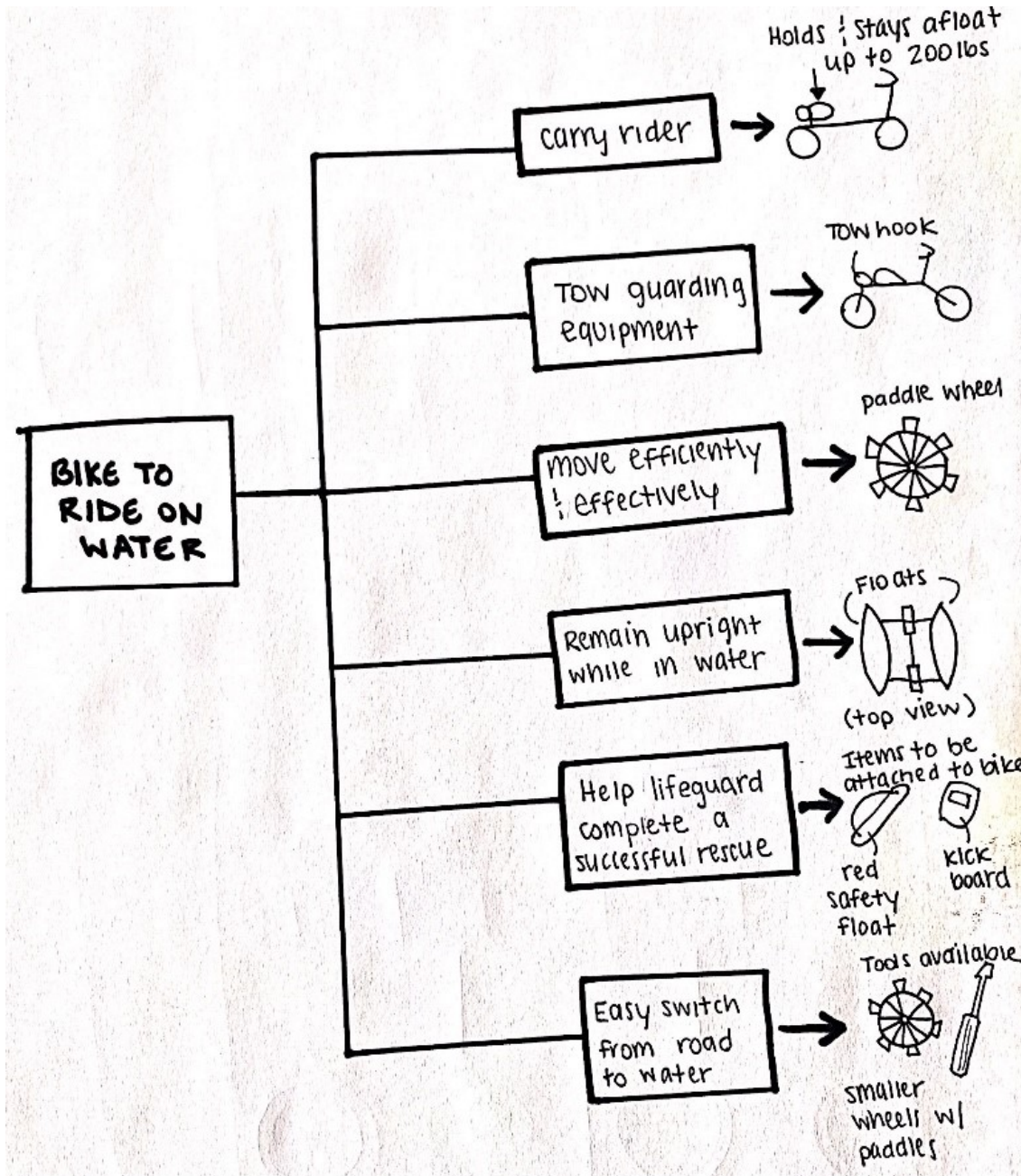


Figure 7: Function tree for Water Bike, hand-drawn and scanned

### 3.3 Morphological Chart

The following morphological chart depicts multiple solutions for each of the design requirements outlined in Figure 7. Each drawing represents a possible design characteristic that will satisfy a single design requirement. Design concepts will make use of each of these different attributes to create possible final designs.

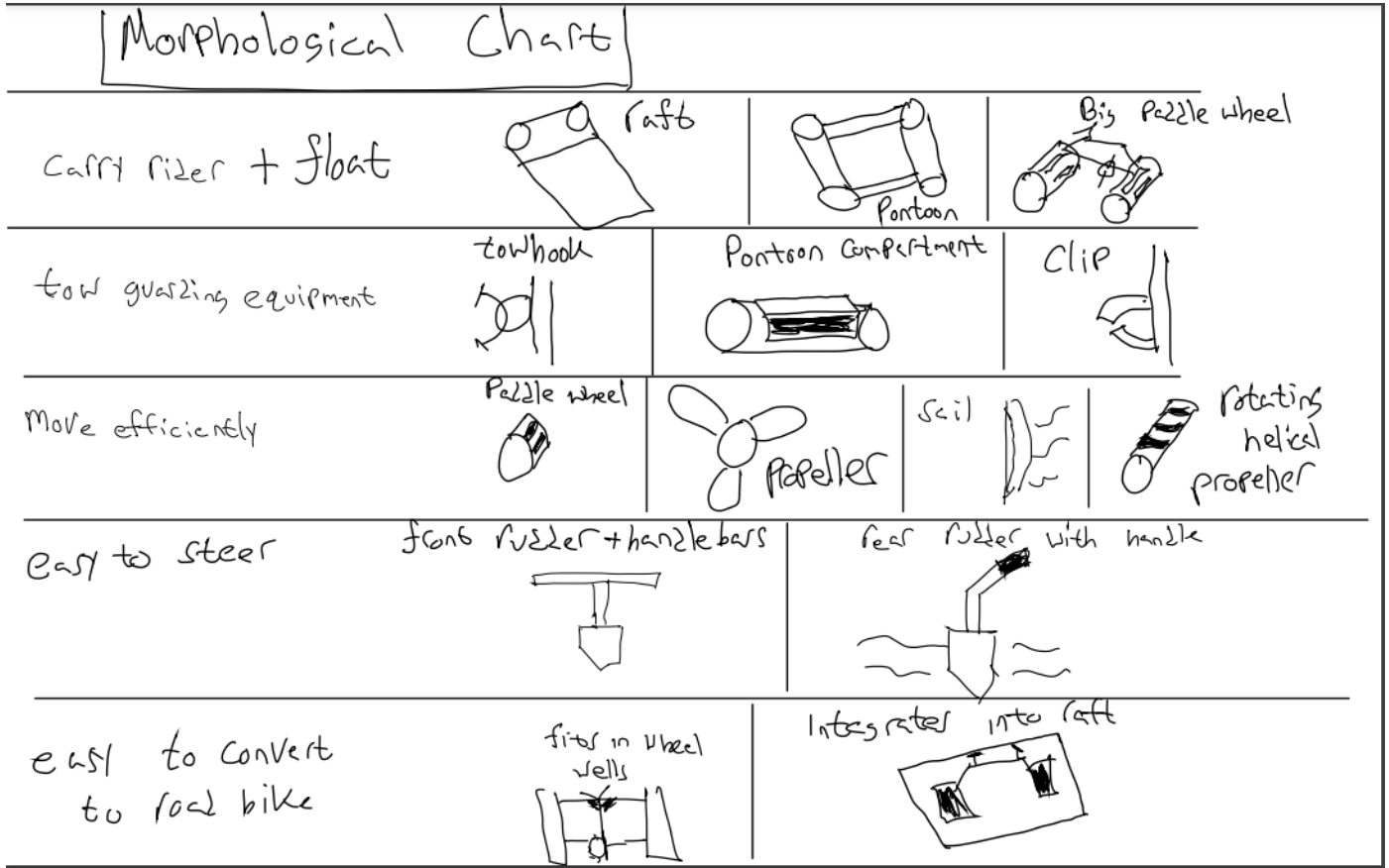


Figure 8: Morphological Chart for Water Bike

## 3.4 Alternative Design Concepts

### 3.4.1 Wide Tires

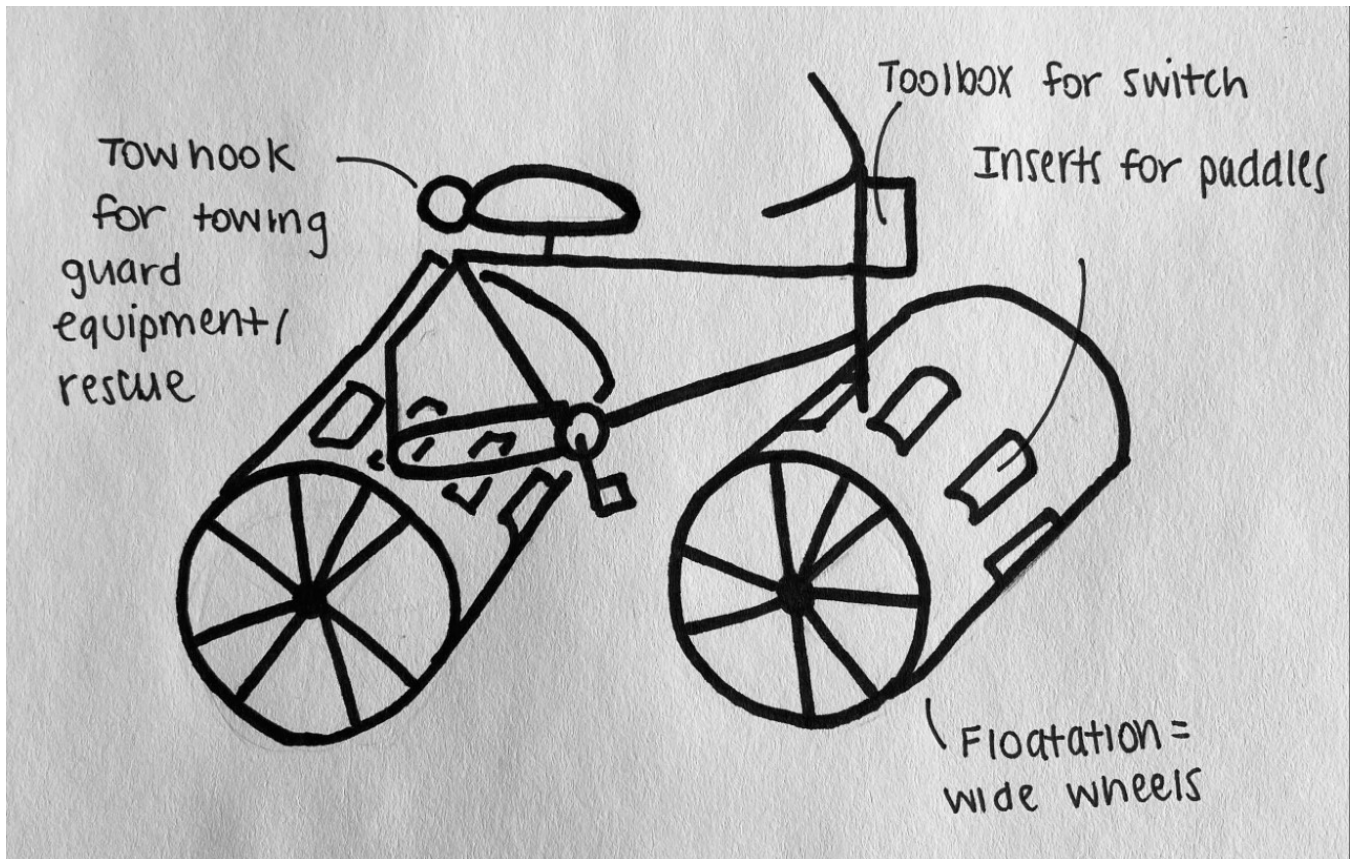


Figure 9: Sketches of Wide Tire Water Bike Concept

#### Solutions from morph chart:

1. Tow hook
2. Wide wheels for flotation
3. Inserts for paddles
4. Toolbox for ease of switch

Description: The lifeguard can actively pedal while on duty and not worry about tipping over into the water because of the stability that the wide wheels provide. The large inserts on the wide wheels allow for wider, shorter paddles to easily attach. The tow hook allows for all guard equipment to be easily carried behind the water bike and is strong enough to endure the tow of a rescue. The toolbox under the handlebars can hold any necessary tools to perform the switch from road bike to water bike.



### 3.4.2 Four Floats

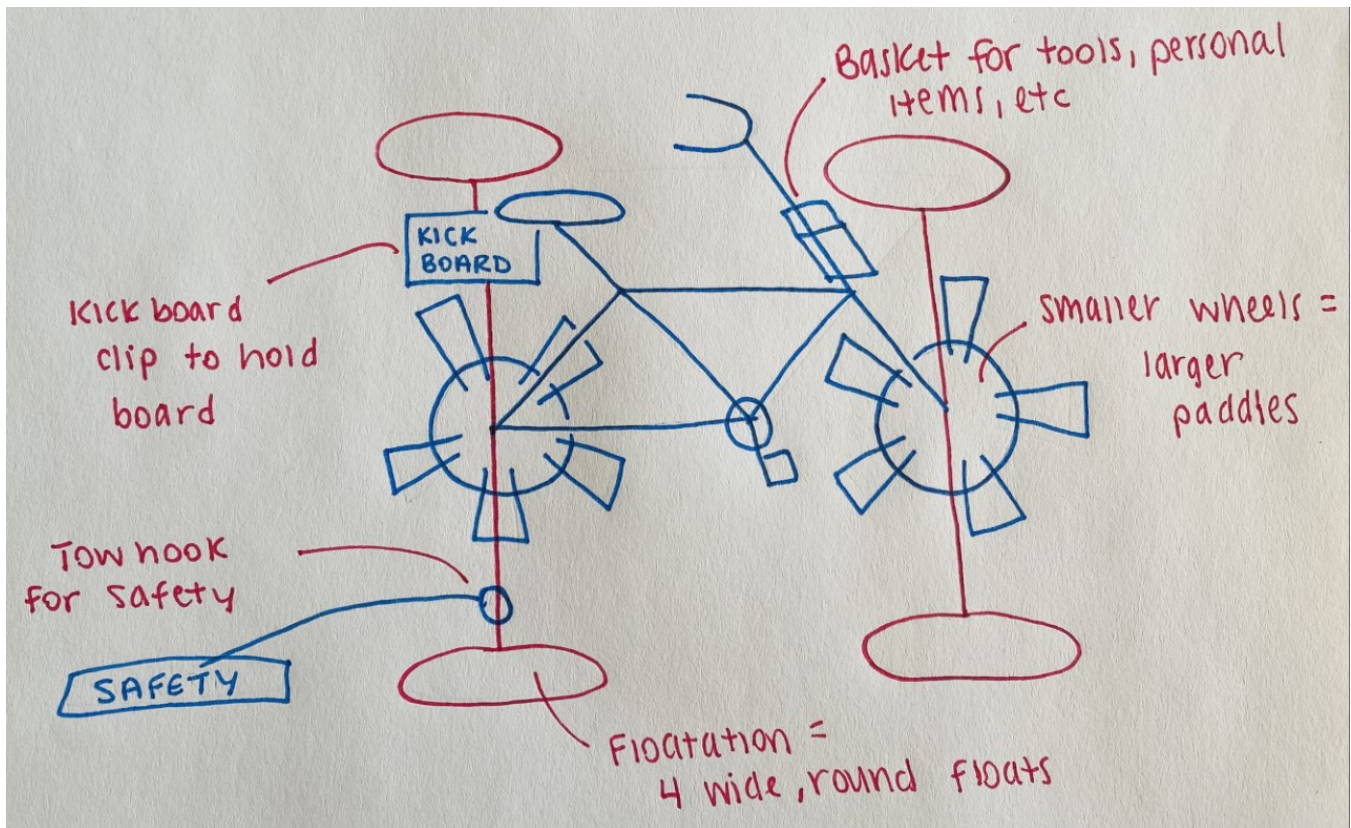


Figure 10: Sketches of Four Floats Water Bike Concept

Solutions from morph chart:

1. Tow hook
2. Smaller wheels with larger and fewer paddles
3. Clip for kick board
4. Basket for tools/personal items
5. Four wide, round floats for flotation
6. Balance from four floats prevents tipping

Description: The stability from the four floats gives the lifeguard on duty balance and prevents tipping. The smaller wheels allow for fewer, larger paddles. The tow hook and kick board clip hold safety items for the lifeguard to successfully complete a save and rescue. The basket can hold any tools necessary for the switch from road to water and is 100% waterproof for personal item storage as well.

### 3.4.3 The Pontoon

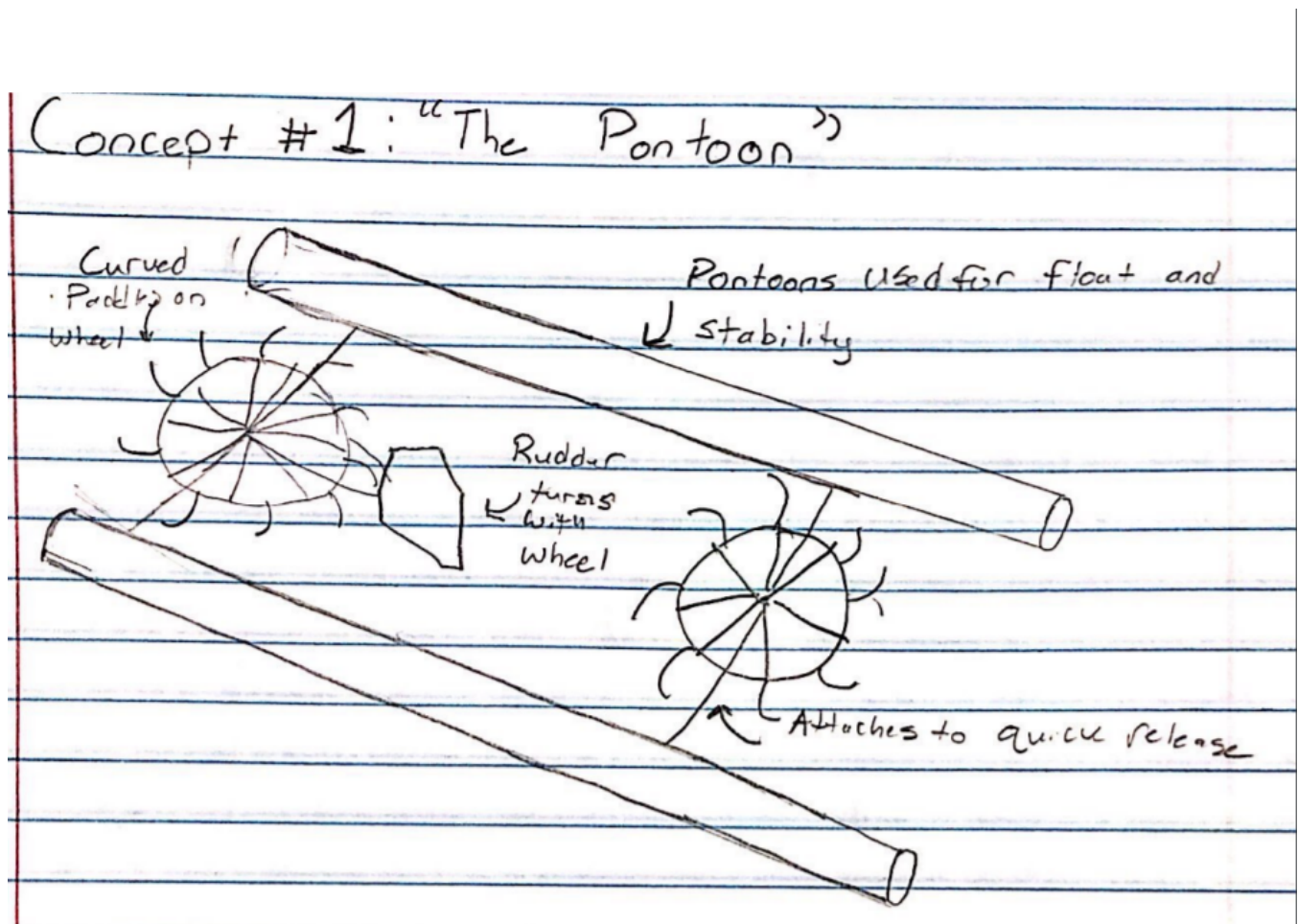


Figure 11: Sketches of Pontoon Bike Concept

#### Solutions from morph chart:

1. Rudder behind front wheel
2. Two pontoon arms
3. Curved paddles on wheel
4. Quick release axles

Description: The two connected pontoon arms give the vehicle buoyancy and stability on the water. A fin mounted behind the front wheel allows the lifeguard to turn the bike with the handlebars. Curved paddles attached to the rear wheel provide the most propulsion to the bike. Quick release axles allow the one piece frame to be removed from any road bike with ease.

### 3.4.4 Utility Raft

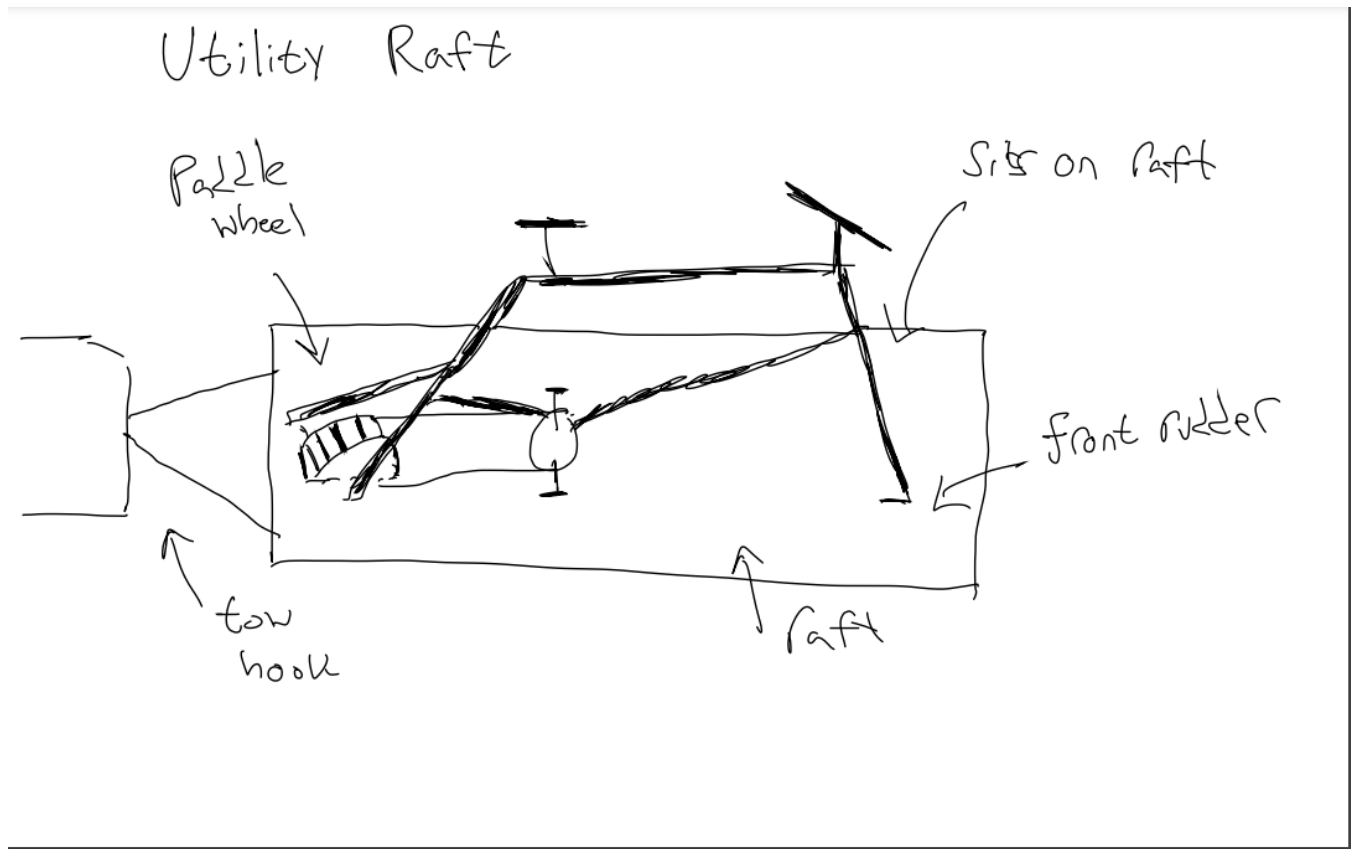


Figure 12: Sketches of Utility Raft Concept

#### Solutions from morph chart:

1. Rear paddle wheel
2. Tow hook
3. Front rudder below fork
4. Raft for flotation

Description: The integration with the raft gives the bike a very stable base. Steering is accomplished via a rudder attached to the handlebars that goes through a small cutout in the raft. In a similar cutout towards the rear of the raft, a paddle wheel can be rotated with the native pedals to power the raft. A passenger can be towed with a cable and hook at the rear of the raft.

# 4 Concept Selection

## 4.1 Selection Criteria

The image below displays a snapshot of our Analytic Hierarchy Process (AHP) which was used to determine scoring matrix weights. These weights were then used in the concept evaluation below.

	No Tipping	Easy Switch	Ability to Turn	Efficiency	Tow Capacity		Row Total	Weight Value	Weight (%)
No Tipping	1.00	7.00	3.00	7.00	1.00		19.00	0.39	39.23
Easy Switch	0.14	1.00	0.33	0.14	3.00		4.62	0.10	9.54
Ability to Turn	0.33	3.00	1.00	0.33	3.00		7.67	0.16	15.83
Efficiency	0.14	7.00	3.00	1.00	0.33		11.48	0.24	23.70
Tow Capacity	1.00	0.33	0.33	3.00	1.00		5.67	0.12	11.70
<b>Column Total:</b>							<b>48.43</b>	<b>1.00</b>	<b>100.00</b>

Figure 13: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

## 4.2 Concept Evaluation

Taking the matrix scores from above, we evaluated the four concepts generated from each team member. This ranking can be found in Figure 14 below.

Alternative Design Concepts *reference		Four Floats		Wide Tires		Utility Raft		The Pontoon *	
		Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
No tipping	39.23	5	1.96	1	0.39	1	0.39	3	1.18
Easy switch	9.54	3	0.29	3	0.29	5	0.48	3	0.29
Ability to turn	15.83	1	0.16	1	0.16	1	0.16	3	0.47
Efficiency	23.70	1	0.24	4	0.95	3	0.71	3	0.71
Tow capacity	11.70	3	0.35	4	0.47	5	0.59	3	0.35
<b>Total score</b>		<b>2.994</b>		<b>2.253</b>		<b>2.324</b>		<b>3.000</b>	
<b>Rank</b>		<b>2</b>		<b>4</b>		<b>3</b>		<b>1</b>	

Figure 14: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

### 4.3 Evaluation Results

Our reference concept was the Pontoon. The pontoon was the only concept idea that included a rudder behind the front wheel to aid in turning the water bike. Additionally, two pontoons helps create stability on water and prevents tipping. Curved paddles on the wheels will help cut through the water to be more efficient. This concept also provides an easy switch between road bike and water bike because the water wheels attach to the quick release. While this concept initially struck as the best overall design, a couple other concepts excelled in specific areas. The Four Floats provides greater maneuverability, as each axle can aid in turning, unlike the Pontoon floats. The Wide Tires design has the potential to be more efficient and have a greater tow capacity than the Pontoon depending on what size and shape paddles are added to the slots. The Utility Raft provided an easier switch and potentially greater tow capacity than the Pontoon, but its overall design idea is unlikely to stay upright in the water. While the Pontoon did not initially address tow capacity in its design, a tow hook for guarding equipment can easily be added to the final concept. Overall, the Pontoon provided the most feasible and best ideas for our water bike because it provides a rudder, has an easy switch, prevents tipping, is efficient, and can have a tow hook added to increase tow capacity; however, we will be using four floats instead of two in our final design to increase maneuverability of the water bike.

### 4.4 Engineering Models/Relationships

#### 1. Buoyancy Force

$$F_{buoyancy} = \rho g V$$

In the equation above,  $F$  is the buoyancy force defined in Newtons,  $\rho$  is the density of the fluid,  $g$  is the acceleration due to gravity and  $V$  is the volume of the buoyant object.

This model will help my team to decide how big we need to make our pontoons. We can find the required buoyancy force based on the weight of the rider and the bike and some factor of safety. The density of the water and the gravity are relatively constant. From this, we can calculate the required pontoon volume for sufficient floating.

#### 2. Drag Force

$$F_{drag} = 0.5 \rho v^2 c_{drag} A$$

In the above equation,  $F$  is the drag force on the bike,  $\rho$  is the density of the fluid,  $v$  is the velocity at which the bike travels,  $c$  is the drag coefficient, and  $A$  is the surface area the fluid is exposed to.

In the equation above, the drag force on the bike can be calculated. This model can help us determine what drag force we will experience, based on desired speed of the bike and the surface area of the pontoons that the fluid will encounter. We can optimize this system, minimizing the surface area of the pontoon, while maximizing traveling velocity.

#### 3. Pontoon Support Angle

$$\theta = \text{Tan}(\Delta h/L)$$



In the above equation,  $\theta$  is the angle of the support that extends from the fork of the bike,  $\Delta h$  is the added height necessary to keep the pedals from touching the water, and  $L$  horizontal length the pontoons will extend from either side of the fork.

In the equation above, the angle of the support of the pontoons can be calculated. This model can help us determine what angle must be used to keep the pedals out of the water, based on desired pontoon height and width.

## 5 Concept Embodiment



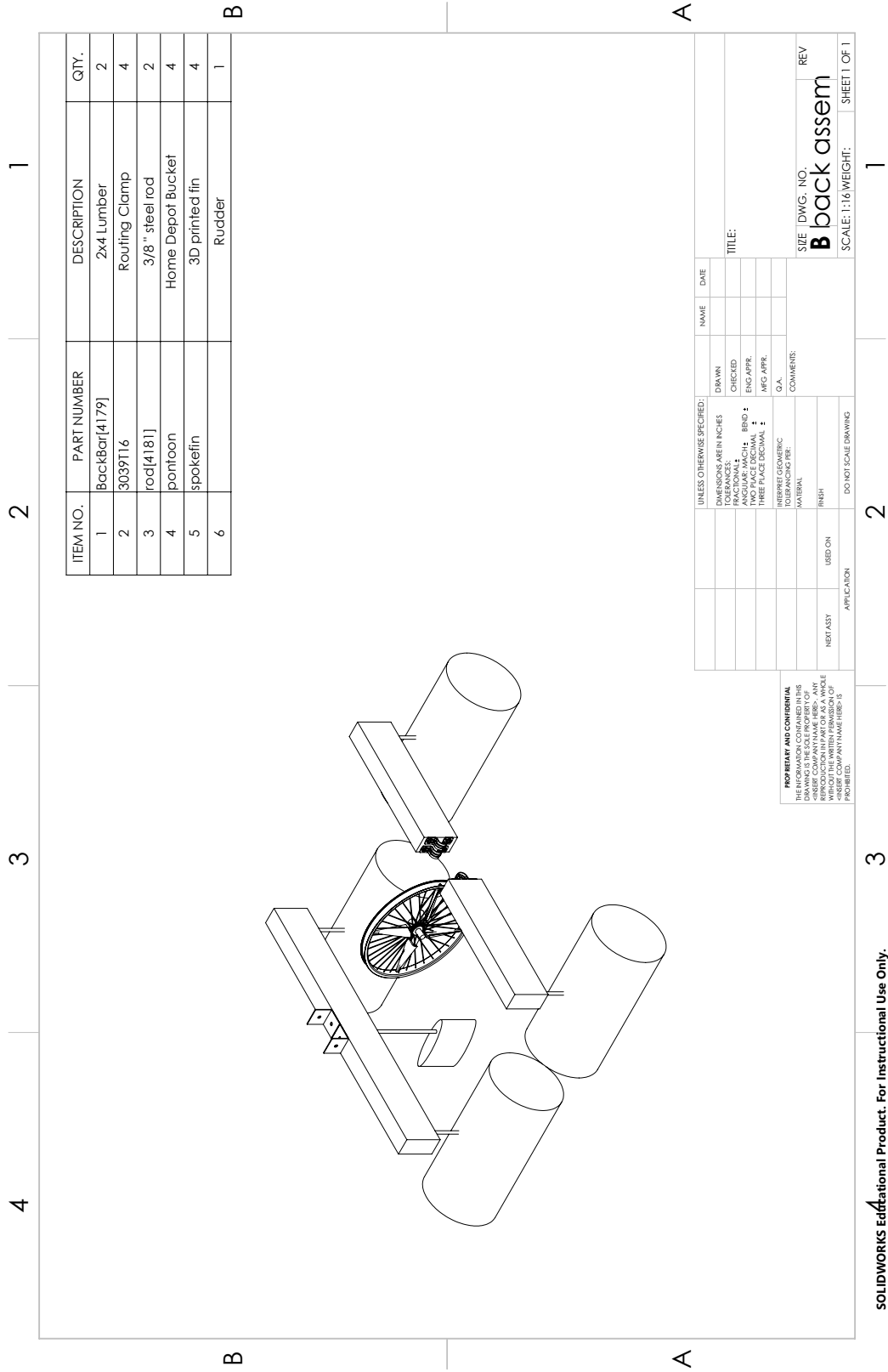


Figure 16: Assembled isometric view with bill of materials (BOM)

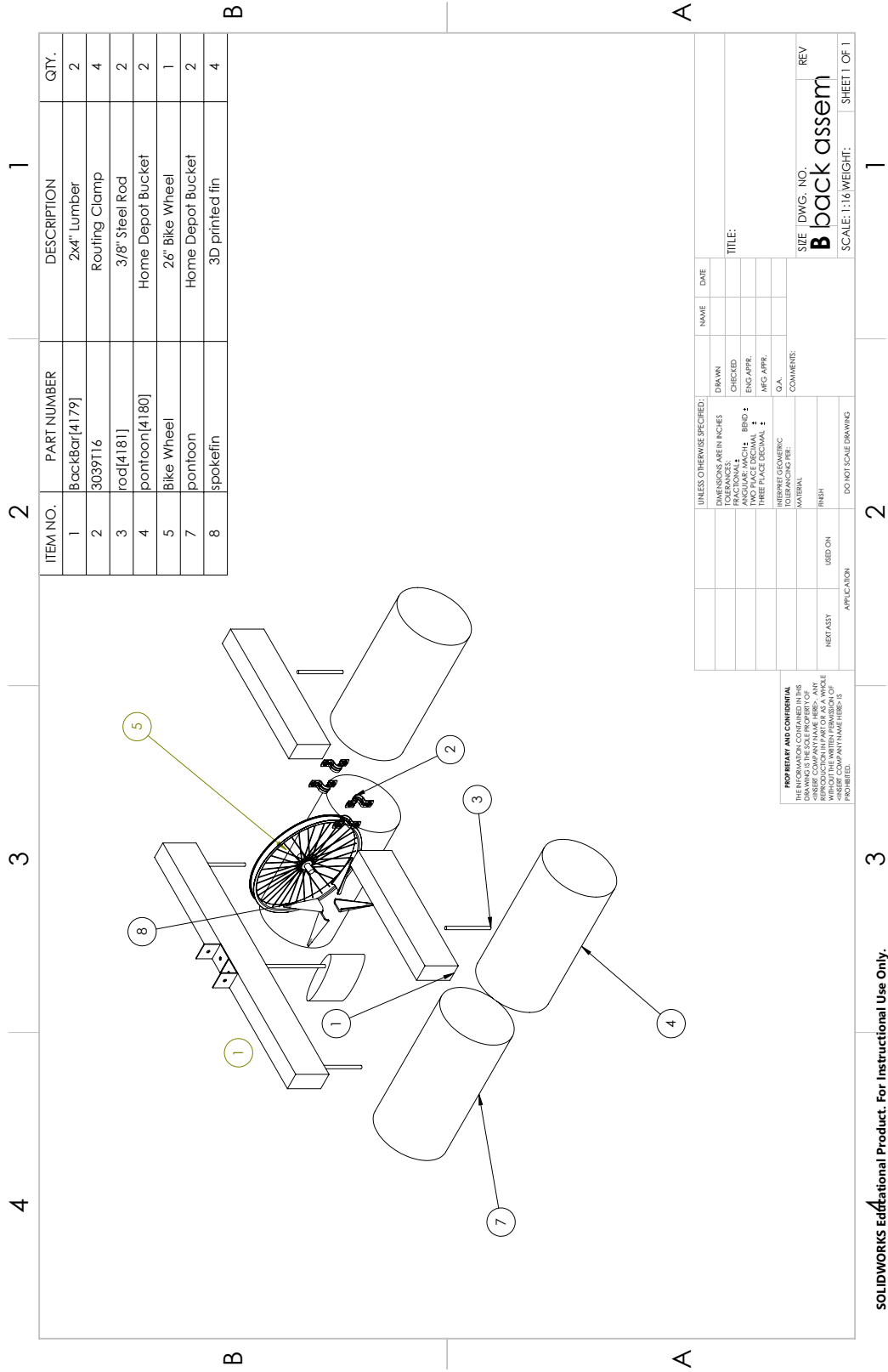


Figure 17: Exploded view with callout to BOM

### 5.1.2 Performance Goals

The following list encompasses our three main performance goals going into the initial prototype:

- Vehicle can travel 200 meters in less than 4 minutes.
- The vehicle can be switched from road configuration (standard bicycle) to water configuration in less than fifteen minutes.
- A rider can dismount and remount the bicycle while the vehicle is in the water.

## 5.2 Proofs-of-Concept

The Proof-of-Concept testing and prototypes influenced our design for the initial prototype. Initially, we imagined the paddles connecting to the outside of the bike wheel, but going into construction of our initial prototype, we realized that we did not have the clearance to do so. We altered our design to have the paddles connect to the spokes. Our method of flotation prototype inspired the pontoon design for flotation, which was carried into construction; however, we initially purchased flat body boards to use as our floats, but quickly realised that we miscalculated and would need to displace more water in order to stay afloat. Hence, the pontoon style float was used in our initial prototype. Finally, in construction, we moved to four floats instead of two for additional maneuverability of the bike.

## 5.3 Design Changes

Our initial prototype consisted of four pontoons; the front two pontoons were connected to the bicycle via a crossbar which also contained the rudder, while the back two pontoons were individually attached to the bike at the chainstay. An image of our initial prototype is shown below in [Figure 18](#).



Figure 18: Initial Prototype

As seen above, the initial prototype included the rudder design from the selected concept, The Pontoon, from Section 4. The Pontoon was designed with two floats, as opposed to four in the initial prototype. The four floats posed an issue for us in the initial prototype because there was no stability between the front and rear flotation, creating too many degrees of freedom about which the floats rotated. Another difference between the selected concept and the initial prototype was the inclusion of the quick release on the selected concept. The bike that we acquired for the initial prototype did not have the quick release option, which increased our transition time from road configuration to water configuration. Overall, the Pontoon and our initial prototype shared many similarities; however, the main differences from design to construction opened our eyes to design problems that we will be able to attack going into the final prototype configuration.

## 6 Design Refinement

### 6.1 Model-Based Design Decisions

#### 6.1.1 Buoyancy

The first step was to verify that the pontoons could support the weight of the entire system. Once this was verified, further calculations were done to estimate the depth that the pontoons would be submerged. This submersion depth was used to set the pontoon height in relation to the paddle wheel. This ensured that the paddles were fully submerged and providing maximum thrust.

The required buoyancy force was determined from the sum of the weight of the bike and rider. This was used with Archimedes' Principle to find the necessary pontoon volume. We assumed the

pontoons would be half submerged in the water to avoid too much drag, and confirmed that we did have enough buoyancy. Then, the true submersion depth was solved for.


## Buoyancy Calculations

Required buoyancy force

$$W = W_{\text{bike}} + W_{\text{rider}} \quad W_{\text{bike}} = 45 \text{ lbs}$$

$$W_{\text{rider}} = 170 \text{ lbs}$$

$$\underline{W = 215 \text{ lbs} = 957 \text{ N} = F_B}$$



Necessary pontoon volume

Archimedes' Principle —  $F_B = \rho g V$

$$V = \frac{F_B}{\rho g}$$

$\rho_{\text{water}} = 997 \text{ kg/m}^3$

$g = 9.8 \text{ m/s}^2$

$$\underline{V = \frac{957}{997(9.8)} = 0.0979 \text{ m}^3 = 5974.2 \text{ in}^3}$$

Available pontoon volume (assuming  $\frac{1}{2}$  of the pontoon is submerged in the water)

$$V = \frac{1}{2} (\pi r^2 L) \times 8 \text{ buckets} \quad r = 6 \text{ in}$$

$$\underline{V = 4 (\pi (6)^2 (14.5)) = 6559.6 \text{ in}^3} \quad L = 14.5 \text{ in}$$

$V_{\text{available}} > V_{\text{required}} \quad \checkmark \text{ it will float!}$

## Pontoon submersion depth

$$V = 8 \text{ buckets} \cdot A L$$

$$V = \frac{8}{2} (\theta - \sin \theta) r^2 L$$

$$V_{\text{required}} = 5974.2 \text{ in}^3$$

$$r = 6 \text{ in}$$

$$L = 14.5 \text{ in}$$

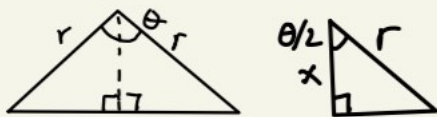
$$\frac{V}{4r^2 L} = \theta - \sin \theta$$

$$\frac{5974.2}{4(6^2)(14.5)} = \theta - \sin \theta$$

$$2.86 = \theta - \sin \theta$$

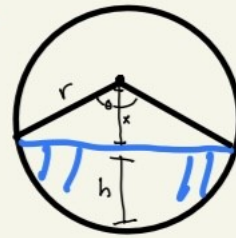
graphing intersection

$$\theta = 3 \text{ rads}$$



$$x = r \cos(\theta/2) = 6 \cos(1.5)$$

$$x = .424 \text{ in}$$



Area of submerged

$$A = \frac{1}{2} (\theta - \sin \theta) r^2$$

$$h = r - x$$

$$h = 6 - .424$$

$$h = 2.544 \text{ in}$$

submerged

Figure 19: Buoyancy Calculations

### 6.1.2 System Weight Distribution

As seen in the above section, it was found that the pontoons could support the weight of the system. However, the weight is most likely not evenly distributed across the front and the back pontoons. The system was modeled as a rigid beam with point forces for the rider and bike weights. The opposing forces were placed at the ends of the beam representing the seat and the handlebars. It was assumed that there was no variation in weight from the right and left sides of the bike.

Simple force and moment balances were performed to find the true force that would be exerted



on the supporting rear/front pontoons. The rider was assumed to have a center of mass relatively near the seat. The bike was assumed to be balanced evenly.

Ultimately, it was found that each rear pontoon would need to sustain 75 lbs of force. It was confirmed that the pontoon has sufficient volume to sustain this force.

**System Weight Distribution**

$x$  is the location of the rider's center of mass

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Assumptions:

- rider's C.O.M is near the seat  
 $\Rightarrow x = \frac{1}{4}L$
- Bike is evenly balanced  
 $\Rightarrow \text{Bike com} = \frac{1}{2}L$

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$\sum F_x = 0$   
 $\sum F_y = F_s + F_B - W_{\text{rider}} - W_{\text{bike}} = 0 \Rightarrow F_s = W_{\text{rider}} + W_{\text{bike}} - F_B$  ①  
 $\sum M_s = -xW_{\text{rider}} - \frac{1}{2}W_{\text{bike}} + LF_B = 0$   
 $LF_B = xW_{\text{rider}} + \frac{1}{2}W_{\text{bike}}$   
 $F_B = \frac{x}{L}W_{\text{rider}} + \frac{1}{2}W_{\text{bike}}$  ②  
 $L = 29.25 \text{ in} \quad x = \frac{1}{4}L = 7.313 \text{ in}$

$W_{\text{rider}} = 170 \text{ lbs}$   
 $W_{\text{bike}} = 45 \text{ lbs}$

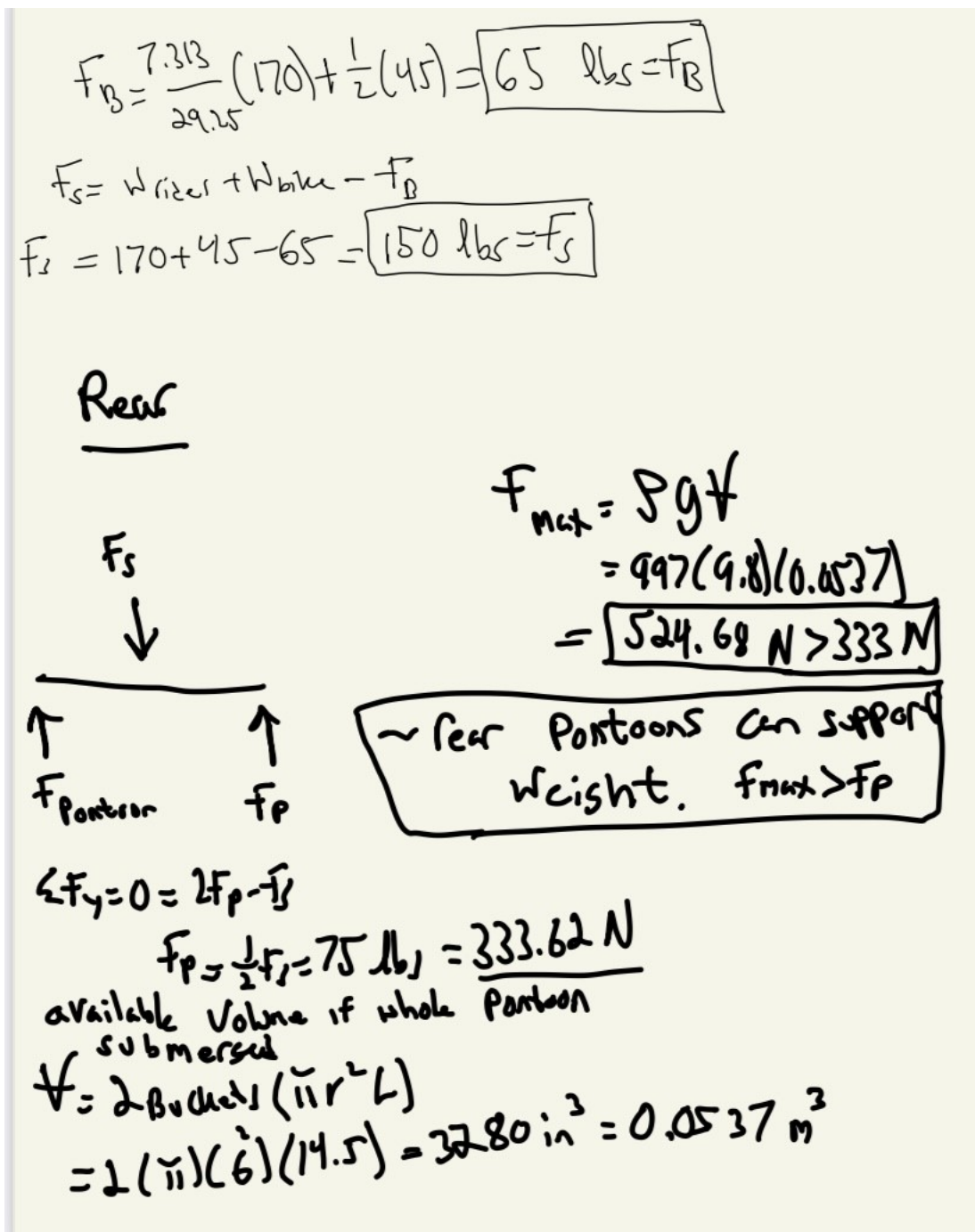


Figure 20: System Weight Distribution Calculations

After testing, we found that the system was stable until the rider started paddling. When this happened, the rear floats began to sink. This can be explained by this model. When the rider begins to ride, his center of mass shifts towards the seat, increasing the force on the rear pontoons and exceeding the maximum force that they can support.

### 6.1.3 Rear Triangle

Although the pontoons were able to provide a large enough buoyant force to keep the bike and the rider afloat, the c brackets used to connect the rear pontoon arms to the chain stays of the bike were not tight enough to hold the pontoons in place. The normal force of the water on the pontoons when a rider's weight is applied to the system creates a moment about the c bracket that was greater than the friction force between the bracket and the bike, causing the pontoon arms to rotate upwards.

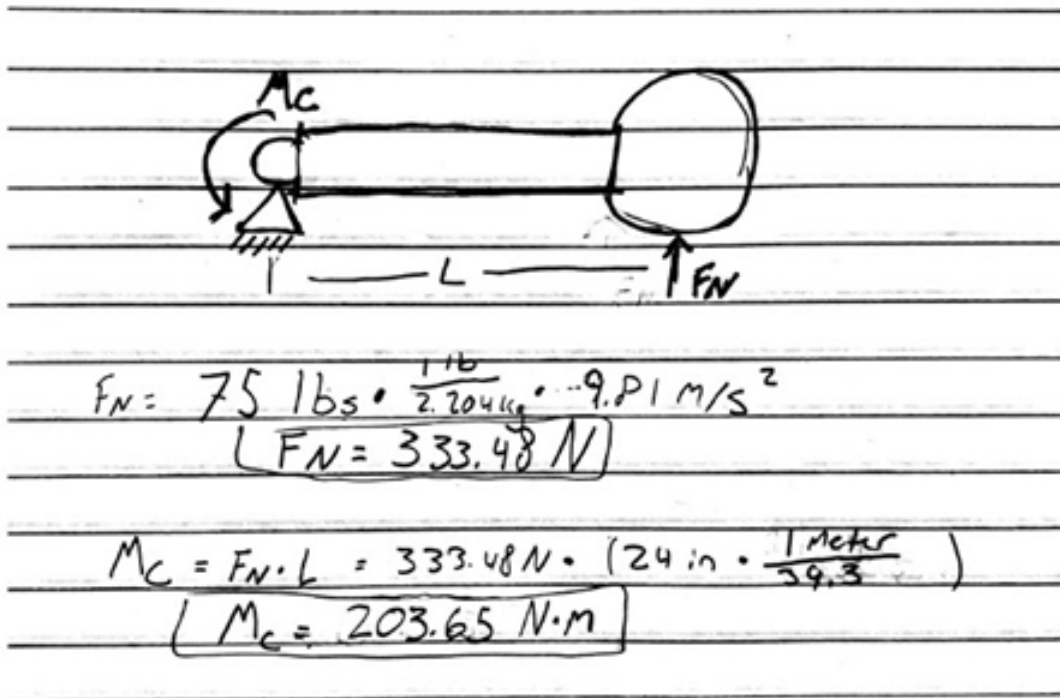


Figure 21: Moment about C Bracket on Chain Stay

To prevent the rotation of the pontoon arms, a triangular support was attached to each of the rear pontoons and connected above the rear tire. A triangle is the most effective shape because when force is applied to a triangle every side prevents the distortion of the opposing angle, making the shape much sturdier. This differs from a square because the connections can be bent without interfering with the members between the connection points.

## 6.2 Design for Safety

The following risks are potential hazards while operating the water bike. Steps to mitigate these risks are explained below.

### 6.2.1 Risk #1: Tipping

**Description:** Bike tips over in water with or without rider.

**Severity:** Critical - If the bike were to tip over, the prototype would be deemed unsuccessful; therefore, this is a critical risk and must be avoided.

**Probability:** Unlikely - As long as the water bike is constructed properly, it will be balanced on four floats, remaining upright.

**Mitigating Steps:** Connecting the four floats with a U-frame of zinc rods reduced the degrees of freedom on the water bike design significantly. This provides the bike with more stability and will reduce the possibility of tipping over.

### 6.2.2 Risk #2: Turning Ability

**Description:** Bike does not turn easily in water.

**Severity:** Marginal - If the bike does not turn easily in the water, it is not critical because it is not our main priority in design. However, ideally the bike will have great maneuverability in order to minimize the time it takes to reach a swimmer.

**Probability:** Seldom - Ideally our bike will be able to turn easily in the water and this risk will be mitigated.

**Mitigating Steps:** To mitigate this risk, we would ideally be able to move the rudder farther back in design.

### 6.2.3 Risk #3: Failure to Tow Rescue

**Description:** Bike cannot tow the rescued swimmer in question.

**Severity:** Catastrophic - If the water bike fails to tow a rescue, the bike is not worthy of being marketed to life guards. Therefore, this risk is one of two catastrophic risks.

**Probability:** Seldom - Per final calculations, this risk is seldom to occur because based on a theoretical model, our bike will be able to tow a rescue.

**Mitigating Steps:** To mitigate this risk, additional flotation should be supplied to support the extra mass of towing a rescue. Extra flotation can be provided by adding more buckets to the U-frame.

### 6.2.4 Risk #4: Mobility in Water

**Description:** Bike does not move in the water efficiently.

**Severity:** Critical - If the bike does not move efficiently in the water, the bike should not be marketed towards life guards. A goal of the design is to move faster than the average swimmer, making this risk critical to success.

**Probability:** Unlikely - This risk is unlikely because of our paddle design on the rear wheel. The paddles designed will maximize efficiency.

**Mitigating Steps:** To mitigate this risk, the paddles must be small enough to be efficient in the water, but large enough to move enough water to create power. Additionally, the paddles must clear the bike frame while still maximizing the amount of water moved.

### 6.2.5 Risk #5: Sufficient Flotation

**Description:** Bike does not support the rider and guard tools.

**Severity:** Catastrophic - If the bike does not support the rider and guard tools, the bike is deemed unsuccessful.

**Probability:** Unlikely - This risk is unlikely because our final calculations prove the bike to float. However, there is still a chance of the bike sinking, and we will finalize design after initial testing.

**Mitigating Steps:** To mitigate this risk, we can increase the levels of flotation and buoyancy by adding buckets to the U-frame design. Adding buckets to the design will provide more stability to the bike as well.

Figure 22 below prioritizes these five risks.

		Probability that something will go wrong				
		Frequent Likely to occur immediately or in a short period of time; expected to occur frequently	Likely Quite likely to occur in time	Occasional May occur in time	Seldom Not likely to occur but possible	Unlikely Unlikely to occur
Severity of risk	Catastrophic				Failure to Tow Rescue	Sufficient Flotation
	Critical				Tipping	Mobility in Water
	Marginal		Turning Capability			
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial					

Figure 22: Heat Map of Risks

As seen above in the heat map of prioritizing risks for the water bike, Risk 3, Failure to Tow Rescue, is the highest priority to mitigate. The next highest priority risks are Risks 1, 2 and 5. These risks are the following: sufficient flotation, tipping, and turning ability. The lowest priority risk to mitigate is mobility in water, Risk 4. After analyzing this heat map, we decided to focus our risk mitigation on flotation ability because this focus will increase buoyancy, providing more support to tow a rescued swimmer. While mobility in the water is important to the success of the

water bike, our main focus will be supporting the mass of the rider, weight of guarding tools, and mass of the rescued swimmer being towed.

### 6.3 Design for Manufacturing

At the current stage of the bike's development, there are approximately 10 unique components in our assembly: the bike frame, pontoons, pontoon rods, front crossbar, rear crossbars, paddle wheels, rudder/steering mechanism, triangular support bar, crossbar support rods. There is also around 44 threaded fasteners in the current design. Out of the unique components there are a handful that can be considered Theoretical Necessary Components (TNCs). These include, but are not limited to: the bike frame, pontoons, front and rear crossbars, paddle wheels, and rudder/steering mechanism. The first component, the bike frame, is certainly necessary. The frame comes from a standard bike and is the framework off of which the rest of the waterbike is assembled. The pontoons are the next necessary component. The pontoons are used to provide the buoyancy force necessary to float the rider and bike, furthermore, they also provide stability for the rider on water. The paddle wheels are necessary, as they provide the propulsion of the bike through the water. To meet the performance goals, the bike needs to travel a certain amount of distance over a certain time span. These paddle wheels will be responsible for accomplishing this. Lastly, the steering mechanism/rudder is necessary for a lifeguard to maneuver this bike. In order to reach their victims, they will need to steer the bike. Hence, this is a vital part of the assembly. Hypothetically, the support system can be reduced to get closer to the minimum number of components in a few ways. Primarily, if the support rods between the back and front crossbars were sturdier, there would be no need for the rear triangular support bar. Additionally, if the fasteners for the rear crossbars were stronger, there would be no need to connect the front and rear crossbars. However, these goals have proven hard to meet. So, in order to limit rotation about the bike frame, the support bars have been used to create a stable, sturdy bike.

### 6.4 Design for Usability

**Vision Impairment:** Vision impairment would not influence the usability of the water bike. However, given that the customer of choice for the water bike is a lifeguard, vision impairment may come into play for the job position. Color blindness or presbyopia may influence one's ability to perform the duties of a lifeguard, but they would not influence one's ability to ride the water bike.

**Hearing Impairment:** Hearing impairment would probably not influence the ability of one to use the water bike because one could easily make their way around on water without hearing. The only difficulty with a hearing impairment would again be related to the lifeguard position and not related to the usability of the water bike.

**Physical Impairment:** Physical impairments such as arthritis, muscle weakness, or limb immobilization would influence the usability of the water bike because operating the water bike requires physical exertion. Mitigating this physical exertion would limit the effectiveness and mobility of the water bike; however, larger radii on the pedals would require less force from the rider, thus increasing the number of customers with physical impairments that could use the water bike. Additionally, in a future design of the water bike, there could be an option for an arm bike instead of a traditional upright leg-powered bike, to be more inclusive in design.

**Control Impairment:** Control impairments such as distraction, excessive fatigue, intoxication, or medication side effects could affect the usability of the water bike and the alertness of the lifeguard on duty. To ride the water bike, balance will be necessary, just like a regular bike, and

control impairments may affect this. To mitigate this factor, the water bike could be modified to have additional flotation and stability provided; however, this would likely come at the cost of efficiency of the water bike because additional drag would be enforced upon the bike.

## **7 Final Prototype**

### **7.1 Overview**

After final prototype testing, it was determined that the water bike met 2 of the 3 performance goals. The switch from road to water configuration took 12 minutes and 39 seconds, and our test rider was able to dismount and remount the bike in the water. The remaining goal of traveling 200 meters in less than 4 minutes was unable to be tested because once the rider began to pedal, the rider's weight shifted backwards on the bike frame, causing the bike to rotate backwards and sending the rider for a swim. Moving forward, we would amend this issue by one of two methods. First, we could shift the four existing pontoons backwards in the design to provide more support when the rider begins to pedal. Second, we could build a U-frame around the rear tire and install an additional horizontal pontoon behind the bike to provide that additional necessary flotation for when the rider begins to pedal and shifts weight backwards.



## 7.2 Documentation



Figure 23: Water bike afloat





Figure 24: Water bike beginning to rotate backwards due to insufficient buoyancy in the rear pontoons



Figure 25: Water bike beginning to rotate backwards