ME 424 - Final Capstone Report

Kinetic Sculpture Team
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Executive Summary

The ME 424 Kinetic Sculpture team designed and built a vehicle to compete in the 2025 Baltimore Kinetic Sculpture race, hosted by the American Visionary Art Museum (AVAM) on May 3rd. The team created a functional, durable, and visually engaging kinetic sculpture capable of navigating the challenging multi-terrain course of the race, which includes urban streets, water crossings, sand, and mud. This design was constrained by a budget of $2000, the size of a U-Haul trailer, and the race theme of “Play.”

The design criteria established by the team, after discussion with the client Dr Santillan, fit under 6 categories - safety, durability & performance, budget, transportability, race rules, aesthetics and team fitness.

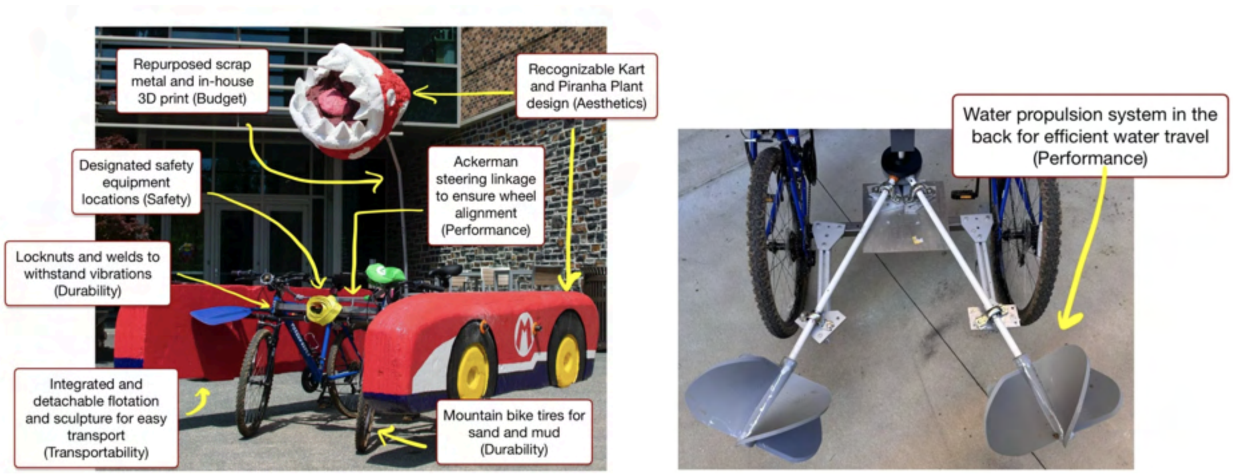


Figure 1: Final Design Solution

The team’s final design solution satisfies all design criteria established by the team within these categories. The kinetic sculpture is known informally as “Rainbow Road Rage” as a nod to the selected Mario Kart theme. It is composed of two mountain bikes rigidly connected together and bounded by foam flotations. The handlebars used for steering are linked with an Ackerman mechanism and the bikes have additional propulsive support in the water with a double propeller hand-crank system in the rear of the vehicle. There are two Mario Kart themed pontoons on either side of the sculpture and a piranha plant head dangling over top. Figure 1 above describes the sculpture’s components and their relationship to the team’s design criteria in further detail.

This human-powered sculpture design optimizes structural integrity, buoyancy, and maneuverability, addressing the core challenge of creating a sculpture that successfully withstands diverse terrain while embodying the spirit of creativity.

Background

The client for this project is Dr. Santillan, the Associate Director of Undergraduate Studies and Associate Professor of Practice in the Duke MEMS Department. The design team will be the users of the solution. On the day of the race, members of the design team will serve as either the pilots or pit crew to guide the sculpture down the race course. Each sculpture is required to have at least one pilot, and each pilot must have the support of their pit crew member. The team decided on two pilots in favor of compact sizing, weight balance, and easy synchronization.

The Baltimore Kinetic Sculpture Race, hosted by the AVAM, is a unique engineering and artistic competition. Teams must navigate a 15-mile course across diverse terrains – including city streets, mud, sand, and water – using only human-powered sculptures. Vehicles must also meet stringent safety and construction requirements, be transportable across long distances, and fit within specified dimensional limits. Importantly, each team's creation must embody creativity, durability, and functionality while adhering to a tight budget of $2,000.

The importance of solving this design challenge extends beyond the race itself. Success in the project teaches critical lessons in real-world engineering constraints, teamwork, budget management, prototyping under imperfect conditions, and rapid problem-solving. Broader impacts include fostering engineering education, promoting artistic innovation in public spaces, encouraging sustainable transportation concepts, and strengthening Duke University's representation.

Existing solutions from past races fall into several archetypes – most notably the "bike and pontoon" models, wagons, and advanced "ACE Award" vehicles. While these approaches provide useful inspiration, each has significant drawbacks. Bike-pontoon hybrids are often simple and mobile but tend to fail in deep mud and can appear structurally crude. Wagons can handle flat sections and water crossings but also struggle with traction in mud and sand. ACE vehicles, which must complete the race without external pushing or pulling, demonstrate the highest engineering sophistication but are complex, heavy, and often challenging to construct within budget and time constraints.

Each year's theme (this year's theme is "Play") also influences design decisions, meaning that no single solution can be reused wholesale from previous years. Additionally, because every team has different access to materials, skills, and support, designs must be tailored to fit the specific context and capabilities of each group.

In this landscape of challenges and opportunities, the ME 424 team aims to develop a novel, creative, and reliable solution that pushes both their technical and creative abilities, while also ensuring the safety of participants and the success of the sculpture across all terrains.

Client Needs and Design Criteria

After consulting with the client, the team identified a series of project goals that guided the generation of specific design criteria. Each client goal was translated into measurable performance targets, with clear justifications grounded in either the Baltimore Kinetic Sculpture Race requirements or practical engineering considerations. These criteria were then classified into primary or secondary based on their impact on safety, functionality, eligibility, and competitiveness. The design criteria and performance goals are summarized Table 1 in the Appendix.

I. Safety

Safety was established as the top priority, given the sculpture's direct interaction with human riders and spectators. To meet Baltimore Kinetic Sculpture Race rules and ensure participant safety, the sculpture must be equipped with essential gear: helmets, a 25-foot tow rope, a 12" x 12" life preserver, 1 quart of water per pilot, a first aid kit, a cell phone, a paddle/oar, a horn, and a tow ring. Additionally, the sculpture must pass a pre-race safety inspection and allow emergency evacuation of all riders within 15 seconds, minimizing risk of injuries such as drowning.

Performance Criteria & Justification:

- Primary
    - Safety equipment is always present
        - Required by race rules
    - Emergency evacuation in <15 seconds
        - The 15-second evacuation standard aligns with human drowning times (~40 seconds) to ensure a large margin of safety.
    - Pass the safety inspection before operation
        - Required by race

II. Durability and Performance

The sculpture's ability to navigate diverse terrains is vital for successful race completion. The sculpture should be able to be driven/floated for the length of the course, withstanding different terrains. Performance criteria reflect the specific challenges outlined by the Baltimore Kinetic Sculpture Race course. For all the criteria, the sculpture must be able to accomplish these tasks repeatedly during testing without functional damage.

Performance Criteria & Justification:

- Primary

    - Travel 15 miles continuously on land
    - Navigate >80 feet of water
    - Traverse >50 yards of mud & sand continuously
    - Climb a 60-foot incline
        - Terrain-specific goals match course sections
    - Carry >500 lbs (pilots and equipment)
        - Weight limits include riders and miscellaneous gear (see Appendix Figure B.1).

III. Budget

The total vehicle design cost must be tracked throughout the project to remain within the $2,000 budget, which covers design and construction but excludes travel expenses. This constraint encourages critical evaluation of design choices, prioritization of essential components, and innovative solutions to maximize performance while minimizing costs. It reflects real-world engineering challenges, where budget adherence is as vital as technical success.

Target Values & Performance Criteria:

- Primary
    - Total cost ≤ $2,000 (excludes travel costs).
        - Budget limit established by ME424 faculty to encourage resource-efficient, innovative design.

IV. Transportability

The kinetic sculpture will be constructed in Durham, NC, and will need to be transported to Baltimore, MD, to participate in the race on May 3, 2025. It takes approximately 5 hours to travel from Durham to Baltimore (assuming average traffic and weather conditions). This means that the sculpture must be able to withstand 5 hours of highway conditions, such as large jostling motions or smaller vibrations, without major damage. Additionally, it must be able to fit inside the U-Haul, either assembled or disassembled. The U-Haul trailer with the largest storage space has dimensions of 6' x 12' x 5' [1]. It would be preferred if the sculpture did not exceed these dimensions so that it does not need to be dismantled for transport, but this is a secondary criteria and may not be met. If the sculpture does need to be disassembled for transportation purposes, the team must be able to reassemble it in 90 minutes or less to ensure it can be put together in time for the start of the race (9:30 AM).

Performance Criteria & Justification:

- Primary
    - Withstands 5 hours of highway transport without damage
        - Reflects average travel time and conditions to baltimore

- Fits into a 6' x 12' x 5' U-Haul either assembled or disassembled
    - U-Haul dimensions align with the most feasible transport option, balancing size and budget constraints
- Reassemble in <90 minutes if disassembly is required
    - Ensures sufficient time to prepare the sculpture for the 9:30 AM start

V. Race Rules

The Baltimore Kinetic Sculpture race sets forth two types of rules for the race. Some are mandatory and teams cannot participate if they are not followed, while others simply incur race time penalties if they are broken. The team must follow the required rules, but can sacrifice race time penalties if needed. The following rules are necessary and need to be met for the team to participate in the race. As a result, they are the primary design criteria:

1. **Sculpture Size:** The sculpture may not be greater than 8 feet wide, 13 feet tall, and 35 feet long.
2. **Follow the Law & Officials:** Sculptures and pilots must follow all law enforcement instructions throughout the race. Additionally, teams may not harass race officials.
3. **No Pulling/Pushing:** Outside of designated zones, sculptures may not be pushed or pulled by anyone except for designated pit crew members and pilots.
4. **License Plate:** The sculpture must have an identifiable license plate that is visible at all times.
5. **Passing Vehicles:** The pilots must pull over and allow faster sculptures to pass if they honk.
6. **Stay the Course:** Sculptures must stay on the race course the entire time, and may only take official race shortcuts.
7. **Alcohol:** Pilots, barnacle, and pit crew may not have alcoholic beverages throughout the duration of the race.
8. **Maryland Rules:** Kinetic sculptures should follow the rules of the road in the state of Maryland.

The remaining guidelines should be followed to maximize the team's potential to place well in the race, but do not need to be followed to participate. As a result, they become secondary design criteria:

1. **Equipment:** Special terrain equipment should be on board throughout the entire race.
2. **Starting:** Pit crew and spectators should not push or pull the sculpture at the start of the race.
3. **Coast Guard Limits:** During the water portion of the race, sculptures should not drift out of the boundaries set by the U.S. Coast Guard,
4. **Drafting:** Sculptures may not draft other vehicles on land or in water.
5. **Pilot Changes:** In order to be eligible for certain awards, pilots should stay consistent throughout the duration of the race.

6. **Pilot Wetness:** Pilots should be no more than 8% wet throughout the race.

Performance Criteria & Justification:

- Primary
    - Follow laws and official instructions.
        - Mandatory rules ensure eligibility for the race.
- Secondary
    - Follows official guidelines
        - Secondary guidelines optimize performance and position the team for awards while allowing flexibility if required.

VI. Team Fitness

Before the race, all team members must demonstrate their ability to travel 15 miles to ensure readiness for the event. Pilots are required to complete this distance on a bike with additional loading to simulate race conditions, while pit crew members may complete it by biking or on foot, reflecting their flexible roles. This preparation ensures the team is physically equipped for the race's demands. By establishing this benchmark, the team ensures that all members are adequately prepared for the challenges ahead. This criterion is secondary, as there is allowance for personnel to be switched during the race, but a time penalty will be incurred.

Performance Criteria & Justification:

- Secondary
    - All members demonstrate the ability to travel 15 miles (pilots on bike and loaded; pit crew flexible).
        - Aligns with race requirements and ensures the team is conditioned.

VII. Aesthetics

A strong aesthetic helps the sculpture stand out and clearly conveys the theme "Play," which is valued in the competition for its emphasis on creativity. Recognizable and well-coordinated designs, along with matching costumes, provide an edge by resonating with the audience. Themes that are broadly understood and visually cohesive in color and style enhance this impact. While aesthetics are important for audience engagement, they are secondary criteria, as they do not affect functionality or race eligibility. A survey of at least 30 people will be conducted to ensure the design aligns with the theme before the race.

Target Values & Performance Criteria:

- Secondary
    - Sculpture design and costumes recognizable by >50% of surveyed.

- Recognizable and engaging aesthetics enhance audience engagement and scoring in creativity categories, but does not directly impact functionality.

Function Analysis and Journey Map

After discussions with the client and researching previous designs, the team identified the key functions of a successful design. The team grouped these functions into 5 main functions groups with sub-functions as follows:

1. Transport Sculpture
    a. Disassemble Sculpture, Load into Uhaul, Transport in Uhaul, Reassemble Sculpture
2. Locomote Sculpture
    a. Start Race, Generate motion, cross sand, cross mud, cross water, traverse streets, climb hill
3. Control Movement
    a. Receive Pilot input, change direction, maintain stability, turn sculpture, provide braking, control speed
4. Be Safe
    a. Prevent failure, support load, float sculpture, enable ingress & egress, hold safety equipment
5. Be Aesthetically Appealing
    a. Wear costumes, look fun!
6. Dispose of Sculpture
    a. Disassemble sculpture, Recycle materials, dispose materials

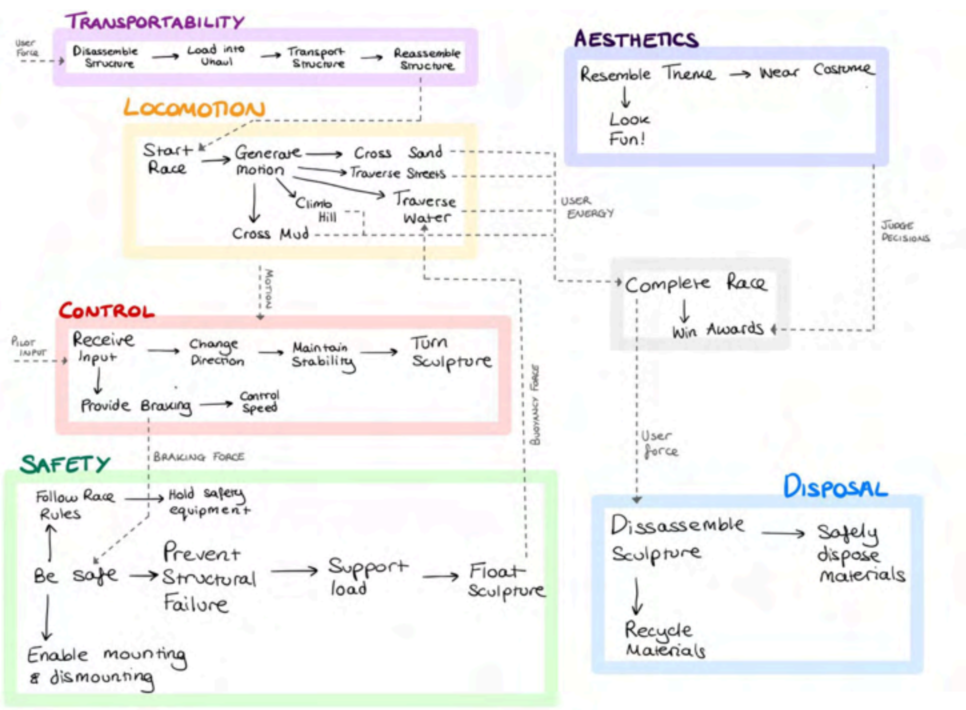


Figure 2: Function Structure

The function analysis provided a complete breakdown of all the necessary actions the kinetic sculpture system and team must achieve, without committing to any specific physical designs. By first organizing broad client needs into clear modules, the team ensured that every phase of the sculpture's lifecycle, from transport to race to post-race handling, was systematically addressed.

For example, the team recognized that traversing land could not be treated as a single environment. Instead, the team separated it into crossing sand, crossing mud, traversing streets, and climbing hills, acknowledging that each surface would pose different mechanical and stability challenges. This forced us to think about drivetrains, traction, and gearing early in the design phase rather than treating all land travel the same way.

Similarly, by creating a standalone Be Safe module, safety considerations like preventing failure, supporting loads, floating on water, enabling ingress and egress, and holding safety equipment were incorporated into the system architecture from the beginning, rather than as afterthoughts. This helped ensure that flotation and structure were tightly integrated with pilot protection and ease of use.

Overall, having a complete function structure allowed us to systematically brainstorm design ideas for each subsystem and understand how they would need to connect and interact. It helped ensure that no major race requirements — from transportation logistics to water crossing to rider safety — were overlooked in the early stages of ideation.

Actor	Kinetic Sculpture Team											
Scenario	The team is participating in the Baltimore Kinetic Sculpture Race 2025 and are expected to complete the race.											
Journey Phases	Travel		Starting Line		Race and Obstacle Course					End of Race		
Actions	Loading the vehicle onto the UHaul and packing supplies	Travelling from Duke University to Baltimore	Reassembly of the kinetic sculpture before the race starts.	Safety inspection of the vehicle by the race officials.	Driving the first section of the race course. Including a number of turns, a steep incline, and a 240 degree roundabout.	Entering/ exiting/and traversing the bay.	Driving through the sand section of the race.	Traversing through the mud section.	Driving the final section of the race course.	Crossing the finish line!	Award Ceremony	Disposing o Sculpture
Feelings and Needs	Excited about the journey ahead, but also frustrated if needing to disassemble the vehicle for transport.	Stressful since driving a large UHaul is difficult and coordinating a team of seven members and all necessary supplies could be hectic .	Anxious during reassembly and ensuring the sculpture looked as good as it did at Duke.	A little nervous about any penalties from lost or forgotten safety items, but overall excited for the race to start.	Excited about the race and going through the streets of Baltimore.	Need a fast and seamless transition between land and water without getting too wet. High bouyancy is needed in the water and good contact with the land during the transition.	Nervous that the vehicle may weigh too much and sink into the sand. Wider wheels are a must, so that they can stay on top of the terrain.	Tired after going through two different obstacles with higher resistance than the road. Confident that we can get through the final major obstacle of the race.Similar needs to sand section.	Excited to have almost completed the race! Hoping that everything stays together after all of the obstacles we have gone through.	Proud about finishing the race! Looking forward to getting some rest and attending awards later.	Excited about the outcome of the race and awards received.	Sad to dispose of th project. Will need to com prepared wit a plan regarding what material to dispose o or return to Duke.
Outcomes	Potential stress from taking apart the sculpture to fit into the vehicle.	Stress from driving and navigating traffic	Potential stress from quickly putting together the sculpture for the race.	Potential time penalties as a result of not being properly prepared for the safety inspection.	Issues may arise regarding joints, wheels, or any component that is critical to travel.	Potential loss of balance in the water or sinking as a result of being too heavy/dense	Team fatigue from multiple difficult obstacles			Accomplishment since completing the race was the major design function	Possibly an award for the team and Duke MEMS department	Sculpture is disposed of..
Opportunities	Creating a modular design that can be taken apart easily without compromising the integrity of the design	Allowing plenty of time for traffic and any other unexpected issues that may arise.	Creating a modular design that can be put together easily without compromising the integrity of the design	Ensuring all aspects of the safety inspection are tested well in advance before the race.	Making sure all joints are properly joined, welded, etc. so that they do not come apart during the race. Reinforcing the joints in whatever way possible.	Having multiple flotation points to allow for balance and ensuring the sculpture stays above water	Having wheels that allow for faster and more efficient travel through sand and mud		The ability to use the original road way wheels after having gone through mud and sand without any hinderance. Possibly would involve cleaning	Very functional brakes to allow a smooth stop at the end of the race	Including optional aspects that make the team's sculpture eligible for certain awards (ACE award, etc).	Using recycle materials to minimize the effects the sculpture ha on the environment

Figure 3: Journey Map

Seen in the journey map above, there are many areas in the race that can cause stress or fatigue to both the pilots and the pit crew. The points of stress can range from packing the sculpture well before the race starts to ensuring the team makes it through the sand and mud obstacles. These stresses helped reveal the opportunities where the performance of the sculpture can be improved, and the stress for the users could be lessened. For packing the sculpture, the team focused on a modular design, allowing for quick deconstruction and reconstruction. This alleviated two stressful touchpoints in the journey. Similarly, the selection of mountain bike tires allowed one set of wheels to fit multiple terrains, allowing for less time to be wasted in transition.

Most of the opportunities are focused on “losses”; however, there are three critical opportunities for gains highlighted in the journey map. First off, the team’s opportunity to design for certain optional criteria may allow them to win awards. These awards will not only be fulfilling to achieve but will look good for the Duke MEMS program. Second, the team designed using recycled materials wherever possible. This will allow for easy deconstruction as the parts will be manageable in size but also allow them to be disposed of more easily as there are fewer non-recyclable parts. Finally, the team prioritized safety above everything. By making choices with safety always in mind - brakes, lifevest, etc, the vehicle is designed to cross the finish line with all riders in one piece.

To mitigate or eliminate the identified losses, the team focused on a couple different opportunities. First, they created a design that allows for easy disassembly and reassembly without compromising the structural integrity of the sculpture. This will reduce stress during the transport and setup. This will help the team easily get the sculpture to the race without fear of damage while in route, and easy setup upon arrival. Second, adding flotation points significantly enhanced its reliability during the water and obstacle sections. Properly secured joints and additional buoyancy will prevent structural failures and ensure a seamless transition between land and water, reducing the risk of sinking or imbalance in the bay.

Ideation and Design Selection

Overview of the Idea Generation Process

The team initiated the ideation phase with individual brainstorming, assigning each member responsibility over one of seven key subsystems: chassis, sand travel, mud travel, water travel, roadway travel, safety, and aesthetics. This approach ensured comprehensive exploration across all major functional requirements of the Baltimore Kinetic Sculpture Race and alignment with the project's design criteria.

After this individual phase, the team reconvened to consolidate overlapping or similar ideas, grouping them into clearly defined functional clusters. Each member led the discussion for their assigned subsystem, standardizing the level of resolution across all ideas. This consolidation process ensured that concepts were comparable and avoided redundancy.

The clustered ideas were compiled into a visual slideshow, with each slide presenting one functional group of solutions and supported by images or sketches for clarity. This structured presentation format enabled team members to reflect on all proposed ideas in a consistent manner, which became especially important for the next phase of asynchronous evaluation.

A complete list of ideated and clustered solutions is included below.

- **Chassis** (custom metal frame, retrofitted vehicle, connected bikes + buoys, bamboo raft, monocoque)
- **Wheel Style**(ATV tires, beach tires, tank treads, bike wheels, water tricycle, airless tires, wagon wheel)
- **Tread Style** (normal bike, mountain bike, sand, spiked/studded)
- **Drive Layouts** (rear-wheel drive, front-wheel drive, 4 wheel drive)
- **Flotation** (foam, bamboo, inflatables, kayak/boat)
- **Water Propulsion** (oars, paddle blades, paddle boat style)
- **Braking Systems** (coaster brakes, handlebar brakes, anchor)
- **Number of Wheels** (1, 3, 4)

- **Drivetrain** (Modified bike, axle + differential)

Although the **Mario Kart theme** was selected in the prior semester, aesthetic implementation ideas were deferred until a primary vehicle structure was defined to ensure maximum compatibility and flexibility.

Down-Selection Methods and Justification

To refine the wide array of ideas into a cohesive working concept, the team employed two complementary evaluation methods: **Dot Voting** and **Borda Count Voting**.

- **Dot Voting** allowed team members to quickly highlight standout concepts in each functional category. This method was particularly useful due to scheduling challenges that prevented all members from being present simultaneously.
- **Borda Count Voting** introduced a more structured process. Each team member ranked all options within each cluster (with a score of 1 for their top choice, 2 for second, and so on). These scores were then summed across the team, and the lowest total score indicated the highest-ranked concept. Results were recorded in **Appendix Table A.2**.

While neither method used formal weighting of design criteria, members evaluated options through the lens of internally established priorities based on **race-critical design criteria**:

1. **Land traversal** – the most extensive and demanding part of the race.
2. **Water flotation and maneuverability** – necessary for eligibility and safety.
3. **Mud and sand performance** – important but lower priority due to shorter terrain segments.

These priorities reflect direct alignment with the client's goals and the specific terrain layout of the Baltimore Kinetic Sculpture Race.

Evaluation Outcomes and Integration into Final Concept

These selections were not just popular choices—they aligned closely with the project's primary design criteria: safety, durability, performance, and transportability.

- The **custom metal frame** allowed control over dimensions for transport and structural reinforcement for safety.
- **Thicker wheels with mountain bike tread** handled all terrains without modification, maximizing performance and minimizing risk.
- The **four-wheel layout** improved stability and control, directly supporting safety and durability.

- **Rear-wheel drive** and **handlebar brakes** were chosen for traction and responsive control across challenging conditions.
- **Foam flotation** and **oars** offered simple, stable water navigation without compromising land travel.

The evaluation methods—Dot and Borda Voting—enabled efficient down-selection based on team insight and informal weighting. While not explicitly quantitative, they reflected internal priorities, especially land traversal and transportability, and helped identify solutions that best met client goals.

Design and Design Components

The kinetic sculpture's final design consists of two bikes, rigidly connected by three square steel tubes. Two EPS foam pontoons on either side of the sculpture are supported by steel tubing and decorated to look like a classic Mario Kart. The handlebars of each bike are connected using an Ackermann steering linkage. A decorative foam piranha plant is supported over the center of the sculpture by an aluminium tube. Two propellers extend off the back of the structure, driven by a hand crank located between the two drivers.

Major design subsections are shown in Figure 4 below. Additionally, conventional bicycle frame terminology will be used to refer to each section of the design. An annotated image of bike frame nomenclature can be found in the appendix.

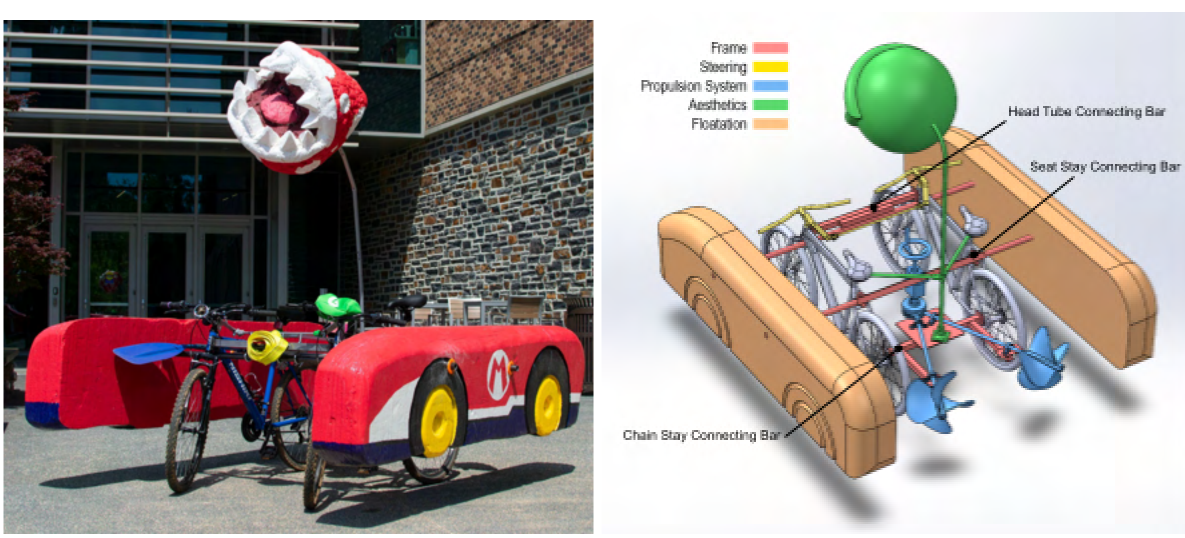


Figure 4: Photo and CAD Diagram of Final Design

I. Frame

The frame consists of three bars that rigidly join the two bikes, highlighted in Figures 5 and 6. The head tube connecting bar attaches at the front of the two bikes and also supports the front flotation support pipe. The seat stay connecting bar sits just behind and under the pilots, providing additional support to the water propulsion systems crankshaft and the rear flotation support pipes. Finally, the chain stay connecting bar is located toward the back and bottom of the bikes, providing support structure for the water propulsion system.

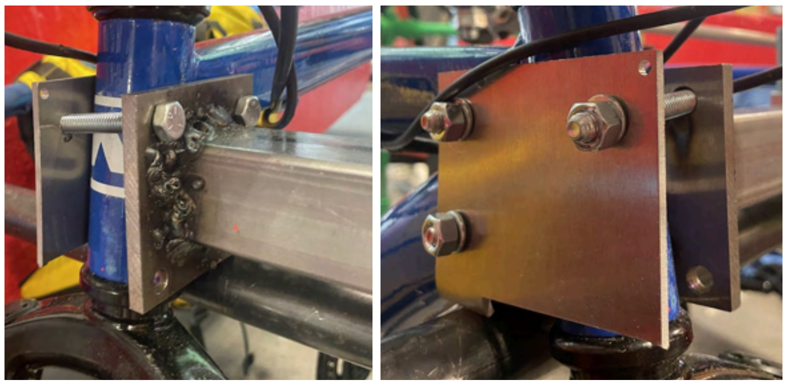


Figure 5: Head Tube Connecting Bar Attachment to Frame

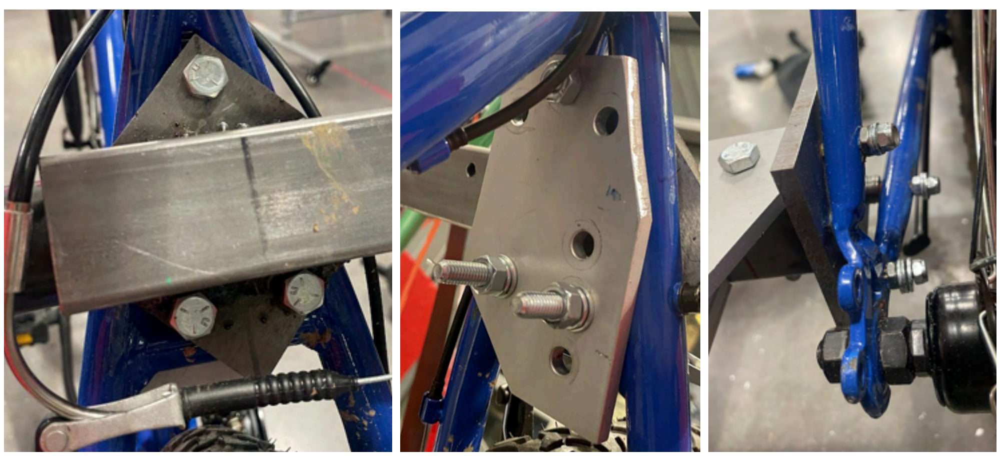


Figure 6: Seat Stay Connecting Bar Attachment and Chain Stay Connecting Bar Attachment

Each bar was fabricated by welding steel plates to steel rectangular tubes. Justification for the welding comes from the need for a more rigid and stronger attachment between the bikes, allowing for the frame to last the duration of the race. In addition, the number of attachments and their locations came from a consideration of what can provide a secure attachment and what is needed to maintain shape during use. A bolted attachment is used to connect the bars to the bikes. Two plates with matching hole patterns are bolted around a section of the frame and held in place by the friction due to clamping. This limits shear stress on the thin walls of the bike frame. While further welding may be beneficial, bolts are present due to limitations in the welding process at Duke University. In the bolted attachments, 5/16” hex head screws are used whenever possible and secured with lock nuts. On the chain stay connecting bar, M5 bolts and locknuts are used for their size and ability to connect to the existing bike frames. For all bolted connections, appropriately sized washers are used when needed to provide a better connection to the bar and lock nuts.

II. Steering

The kinetic sculpture’s steering assembly is based on Ackermann steering geometry used in most 4-wheeled vehicles [2].The two turning wheels are linked with a *tie rod* of a specific length (for more specifics, refer to the engineering analysis section on steering). The tie rod was constructed from a length of ½” aluminum tube with a wall thickness of 1/16”. The tie rod adapter rigidly links the tie rod to the ball-joint rod end by clamping over a nut that threads onto the rod end and pinning the tie rod using a bolt (see section view below). ⅜” fine-thread ball-joint rod ends were used to handle misalignment between tie rod arms, ensuring that the tie rod only handles tensile and compressive loading. The ball-joint rod ends also have opposing shank thread direction, allowing the tie rod to act as a *turnbuckle*. As the tie rod is rotated, both rod ends are (un)screwed uniformly, decreasing (increasing) the distance between the two rod ends. This allows for easy and precise adjustment of the steering geometry; the ideal tie rod length would not have to be arduously calculated, rather found experimentally. A nut and washer located on the rod end shank can be tightened against the tie rod adapter, locking the rotation (and thus the length) of the tie rod linkage.

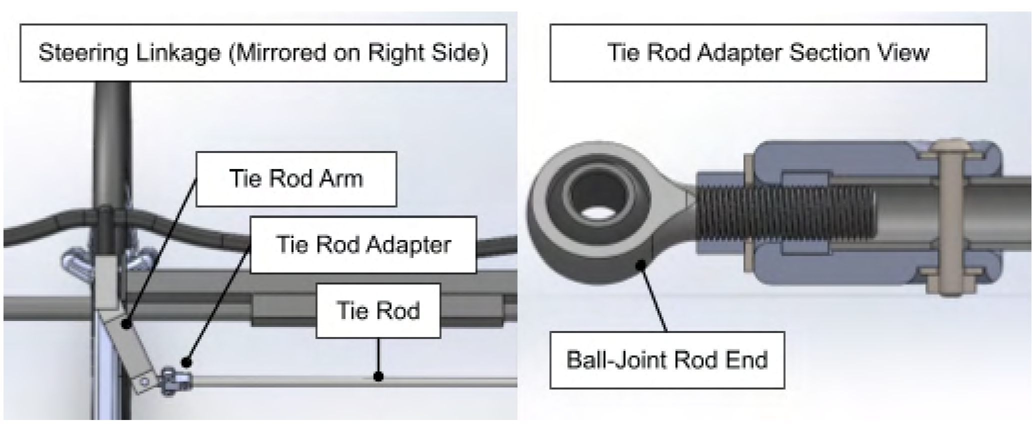


Figure 7: CAD of Steering Linkage

The tie rod arms translate this force to the handlebars, linking them with minimal flexure while still allowing for stable turning. The tie rod arm is composed of two pieces - one 3” length of 1.5” square aluminum angle and one bent 1.5” x 6” aluminum bar stock. A chamfer is cut out of the bar stock to prevent interference with the rod end. These are connected by 3 bolts. The aluminum angle has a ⅞" hole for the stem cap to be placed in with the stem binder bolt compressing everything together. For steering forces to be effectively transmitted, the binder bolt is not enough to constrain the tie rod arm to the bike stem. One face of the aluminum angle is pressed into the stem (obscured by the stem and shown as a dashed line in the figure below) and a hose clamp is tightened around both stem and arm, rigidly linking the two.

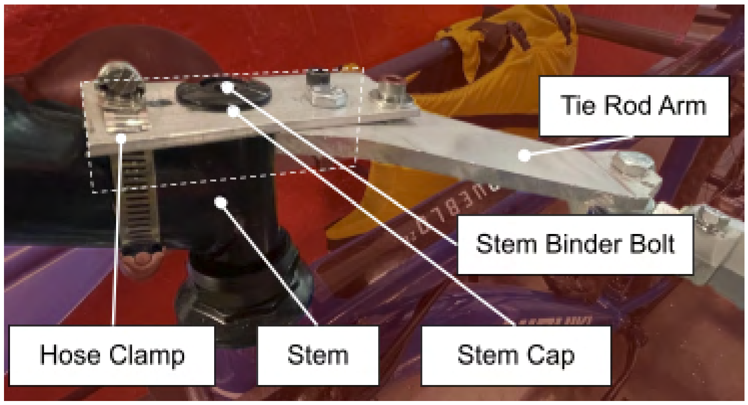


Figure 8: Steering Linkage

This steering linkage was designed to attach to the preexisting handlebars as easily as possible for several reasons. Pilot comfort is crucial over an 8-hour race and the existing bike handlebars ensure a comfortable and familiar riding position. The brakes and gear shifters are also located on the handlebars; this would be challenging to reposition if a custom handlebar was made. Additionally, the handlebars and stem are designed to sustain continuous usage that one might expect on a mountain bike. Any modifications, destructive (drilling) or otherwise (welding), could potentially create failure points.

III. Propulsion System

The propulsion system consists of four distinct subsystems: the dual propellers, 5:1 bevel gear system, the hand crank, and the shaft supports surrounding the system. When engaged, the user turns the hand crank which will engage the lower bevel gear through the central shaft. The bevel gear will rotate pinions attached to the propellers, producing a thrust force while in the water.

The propellers were designed using the thrust force calculations from Report 4. In these calculations, it was determined that a thrust force of 86.55 N is needed to overcome the drag forces and maintain a constant speed while in the water. Using this information, identical propellers were designed in SolidWorks and analysed for the amount of thrust force produced. From this analysis, properties such as the number of blades, the dimensions, and the shape of the blades were decided. In fabrication, the propellers were 3D printed in four pieces due to size constraints of the print bed, and pins and holes were added to properly connect and align the individual parts. The individual propeller parts are attached to each other and the supporting shaft through a marine weld adhesive.

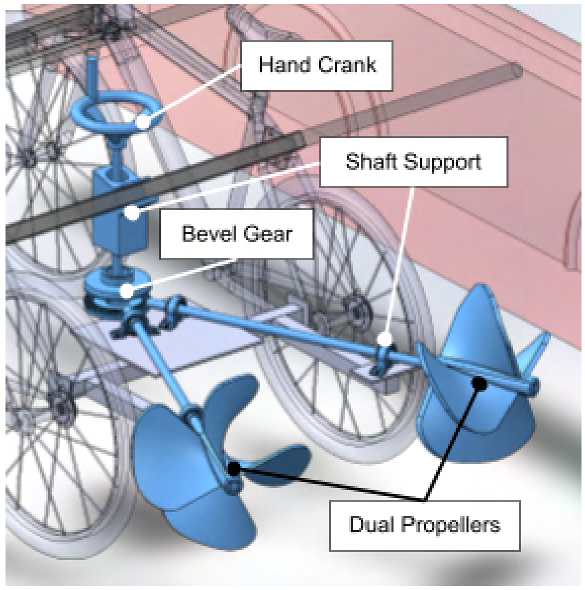


Figure 9: CAD Diagram of Propulsion System

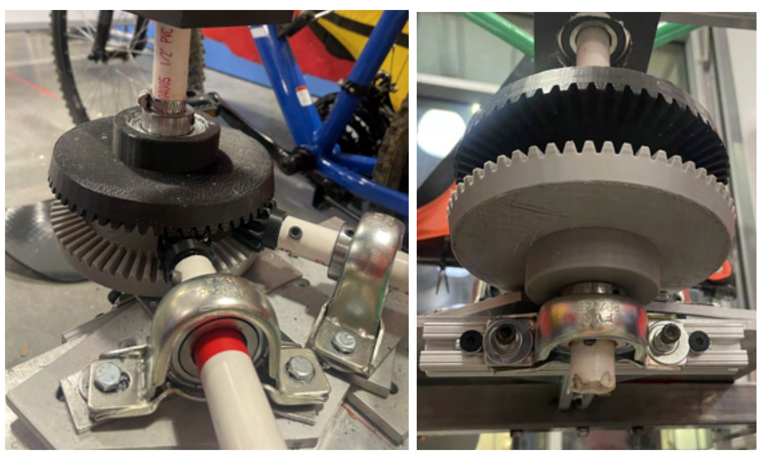


Figure 10: Bevel Gear Assembly

The gear system contains two two bevel gears and two pinions to transfer the rotational force from the crank to the propellers, resulting in forward thrust. A gear ratio of 5:1 was selected so that the pilots did not need to rotate the crank as fast in order to reach the necessary propeller angular velocity. The bevel gears were developed using pre-existing gears from McMaster-Carr, but were updated to allow for better fits with the design solution. The upper bevel gear is press fit to a ⅞” inner diameter bearing above the pinions to keep them in line and prevent skipping. This does not apply to the lower bevel gear that is press fit to the shaft itself. Attachment to the shaft itself for both gears is additionally supported by a marine weld adhesive. The pinions of the gear system connect to the supporting shafts of the propellers through a sliding fit with a pin. Justification for this sliding fit is to allow for quick replacements of the pinion if needed during the race or testing. During fabrication, the bevel gears and pinions were 3D printed to allow for custom fits to the rest of the system.

The hand crank was designed as a wheel with a handle for easy use and to fit the design theme around Mario Kart. Fillets were added to the design to mitigate stress concentrations and safety when turning the crank. Through testing, it was decided that the wheel was preferred over the handle because of the pilot's ability to grasp it. In fabrication, the wheel is 3D printed in one piece and is limited by the size of the printers. The wheel is reinforced with carbon fiber to increase the rotational load it can take during use. In attachment to the rest of the system, it is pinned and bolted to the shaft connected to the lower bevel gear.

Finally, the propulsion support structure includes a 3D printed hand crank shaft support mounted to the seat stay connecting bar and an aluminum frame that is attached to the chain stay connecting bar. The PVC shafts were supported and attached to bearings that allowed for their rotation while in use. Pillow blocks were used on the propeller shafts and were leveled for their height using smaller pieces of metal. For the hand crank shaft, the shaft was kept in line by a custom 3D attachment that behaved similar to the pillow blocks in that it allowed for constant aligned rotation while maintaining the shafts location. For both the pillow block and the attachment, they are both bolted using ¼" bolts and locknuts to the overall sculpture.

Figure 11: Hand Crank Shaft Support Block and Aluminum Support Frame

IV. Floatation

In the ideation selection process, the method for flotation was selected to be foam pontoons mounted on either side of the sculpture. This was for a multitude of reasons - easy to mount/work with, sculptable for aesthetics, and most importantly, very buoyant.

The foam pontoons are made of EPS foam due to the low weight-to-buoyancy ratio and are carved and painted to be on theme. The design of the foam pontoons will be discussed further in the Aesthetics section. The pontoons were coated in Flex Seal liquid to ensure that they are waterproofed and allow for multiple water tests before race day without degradation of the pontoons. To mount the pontoons on the vehicle, two holes were made on each pontoon for the steel pipes to slide into. To avoid water entering the pontoons through this hole and excessive wear, PVC pipes were inserted and sealed into place using FlexSeal. The floats were held in place by ¼-20 bolts placed into holes drilled into the float support pipes on either side. A 3D printed washer was placed between the bolts and the pontoons to minimize wear and distribute the force over a greater area.

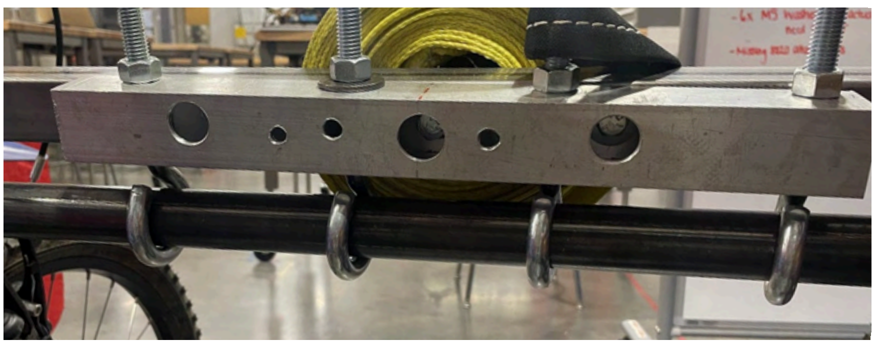


Figure 12: Front Float Support Pipe Mounting

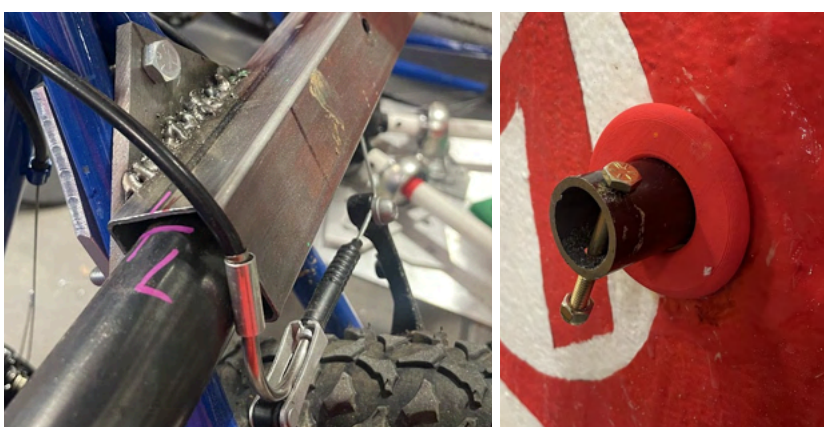


Figure 13: Rear Float Support Pipe Mounting and Float Washers

The floats are mounted to the front and rear float support pipes made from 1” schedule 40 pipe (OD 1.344”). The front pipe is held in place by four large eye hooks screwed into a length of aluminum stock bolted to the head tube connecting bar. These are tightened to prevent the tube from sliding back and forth. The rear support tube is split into two equal lengths that fit snugly into the seat stay connecting bar. A bolt runs through the pipe and bar on either side, keeping it from sliding out.

V. Aesthetics

As this competition is also a sculptural contest, aesthetics played a large role in the design process. The final sculpture features two Mario Kart themed pontoons constructed out of EPS foam on either side, with a Piranha Plant dangling over the pilots. The team incorporated the pontoons into the sculpture’s aesthetics to ensure that the final kinetic sculpture had a seamless image. In addition, both the pontoons and Piranha Plant are easily detachable for transportation, driving several functional design choices to keep the structure lightweight and easy to transport.

The goal was for the design to be easily recognizable to a wide audience. This was achieved through the signature Mario Kart design, the logo on the side of the foam pontoons, and the prominent Piranha Plant that hangs over the pilots’ heads. This combination makes the sculpture not only functional but also visually exciting and identifiable.

Material selection was crucial for this section of the project. EPS foam was chosen for the pontoons due to its high buoyancy-to-weight ratio and ease of sculpting. Selecting adhesives, primers, paints, and sealants that were safe for EPS was a significant challenge, as EPS is highly susceptible to chemical degradation. The EPS was coated in Mod Podge to prime it, then acrylic paint for the design and finally Flex Seal Liquid Clear to waterproof it. To provide structural support for the pontoons, a PVC inner tube was inserted into a cavity in the foam, allowing for repeated insertion and removal of the metal bar without wear. Sealing around the connection point ensured that no water could penetrate the foam.

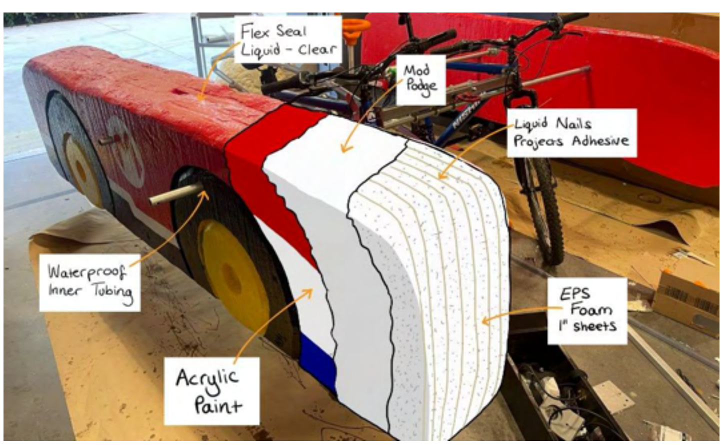


Figure 14: Pontoon Construction

The Piranha plant sculpture was created using chicken wire, spray foam, and bent aluminium tubing to support the head, combining both art and engineering in a seamless design. The Aluminium tube and piranha plant head was attached to the bike with custom 3D printed parts anchoring the stem to the bottom steel bar connection and the back of the bike tubes.

Figure 15: Piranha Plant Support Structure Assembly

In summary, the aesthetic design of the sculpture integrates playful, recognizable elements with practical engineering considerations. The focus on ease of transport, durability, and material safety ensures that the sculpture is not only eye-catching but also race-ready. The combination of art and engineering in this project results in a design that is both visually striking and structurally sound.

VI. Safety Features

Safety was very important for the vehicle. The safety plan is outlined and detailed below in the user's manual in Appendix C. The location of the safety equipment is outlined in the following table. Necessary safety equipment was decided based on the rules and regulations of the Baltimore Kinetic Sculpture Race.

Table 1: Safety Equipment

Item	**Location**
Warning Triangle	Mounted on back bar with velcro
Life Preservers	Hanging on back bar with its own clips
Brakes	Pre-mounted on bikes
Tow Ring	On the front bar
Tow Rope	On tow ring
Drinking Water	Water bottle holders, front bar
Paddle	Strapped across bars with bungee cords
Horn	On front handlebars
First Aid kit	Plastic bag in top tube pouch
Cell Phone	In fanny bag pocket
Helmet	On head at all times

Engineering Analysis

I. Frame Structural Analysis

The main frame of the vehicle is composed of two bicycles with steel bars connecting them. There are three of these bars, each welded to small steel plates and bolted onto or around the bike frame. To keep the bikes aligned, the plates are attached in the same location on both bikes, holding them parallel to each other. The bars connect the bikes on the head tubes, seat stays, and chain stays. The orientation of the bars, bolt hole and weld placements, and location of attachment on the bicycles can be seen in Figures 16 and 17 below.

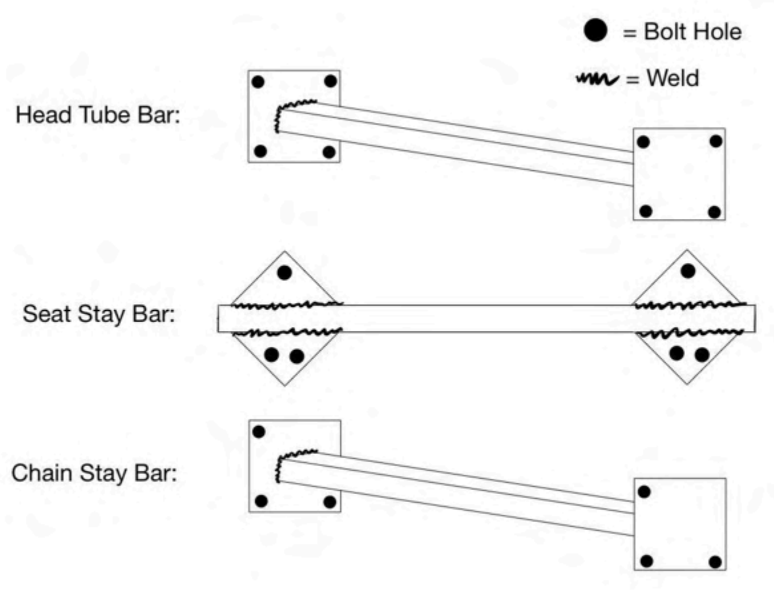


Figure 16: Diagram of Welded Steel Tube Attachments

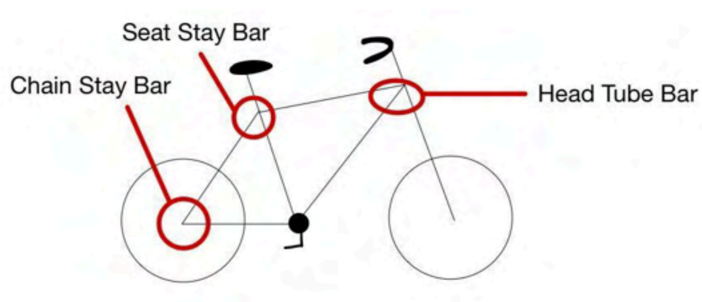


Figure 17: Diagram of Location of Steel Tubes

The team's first choice for the bars was a square tube with a 1.5" outer width and 0.065" thickness, since it is a reasonable size and price (Appendix Figure H.2). Similar logic led to the team selecting 3"x3"x0.25" steel plates (Appendix Figure H.1). The Nishiki Pueblo line of mountain bikes has a 300 lb weight limit, including the bicycles themselves [3]. The estimated weight with the two riders, bikes, and metal framing will be approximately 400 lbs [4]. This is under the combined weight limit of the two bikes and leaves room for the sculpture and flotation mechanisms to add weight.

From here, the team estimated that the loads on the bars between the bikes would primarily come from the two riders working in opposite directions, whether that be one of them moving faster or one of them leaning away from the other to turn. Another possibility is one rider encountering a pothole and jolting down. This is illustrated in Figure 18.

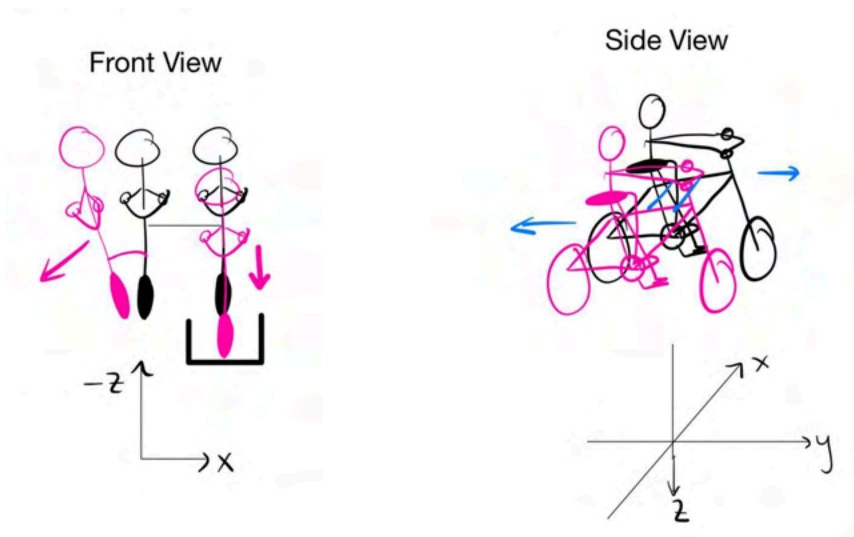


Figure 18. Bikes in Opposing Motions

Based on this, some calculations were done to estimate the load from these motions. First, it was estimated that the maximum turn angle of a bicycle is 35°. This angle estimate is based on research saying that the maximum turn angle is 45° only in pristine conditions as far as tire pressure, weight, balance, smooth road, etc [5]. Since the riders in this situation will not be in ideal conditions in Baltimore, the maximum turn angle was estimated to be 35°. Since the z-direction will be supported by the bike tires and normal force of the ground, the team need only be concerned with the potential x-direction force caused by the riders leaning into their turn. If the rider is estimated as 150 lb, this yields approximately a 382 N force in the x-direction.

Additionally, the shear force created by the two bikes possibly going in opposite y-directions was estimated from the average acceleration of a biker on a flat surface as 0.231 m/s^2 [6]. Multiplying this by the estimated weight in kilograms (~100 kg) of one rider's half of the sculpture, gives an estimated force of 23.1 N. Only half the sculpture weight is used since the other half of the sculpture weight, primarily composed of the second rider, will be following the second rider's motions. Overall, this means that if one rider were to pedal forward at an average pace while the other remained still, the pedaling rider could be pulling their end of the welded bar forward with a force of 23.1 N.

Finally, throughout testing the team noticed that the most jarring force between the two bikes occurred when one bike hit a bump or dip in the road while the other did not. Since Baltimore roadways may not be completely smooth, it is important to account for this in the analysis. To calculate the force this has on the bicycles and their connections, the team assumes only about half of the weight of the sculpture (~100 kg) is could be pulled into a pothole by gravity (9.81 m/s^2), yielding a 981 N downward (negative z-direction) force on the rider and their side of the bar.

All of these forces were considered and entered into a SolidWorks Finite Element Analysis (FEA) test to calculate the von Mises stresses present. The test was performed on a simplified model of each of the bars. The material used for all parts in the model is SolidWorks' "Alloy Steel". In each model, the bolts of one side are fixed as if one rider is staying still (stuck, braking, or otherwise), while the other rider is accelerating forward, hitting a pothole, and leaning as if they were turning on a normal bicycle. This is an absolute worst case scenario for both riders, implementing maximum stresses on each bar. Results for each bar, zoomed in at the most prominent stress concentrations, can be seen in the images below. Zoomed out views of each model with a von Mises and displacement heat map can be viewed in Appendix Figures I.1-I.3.

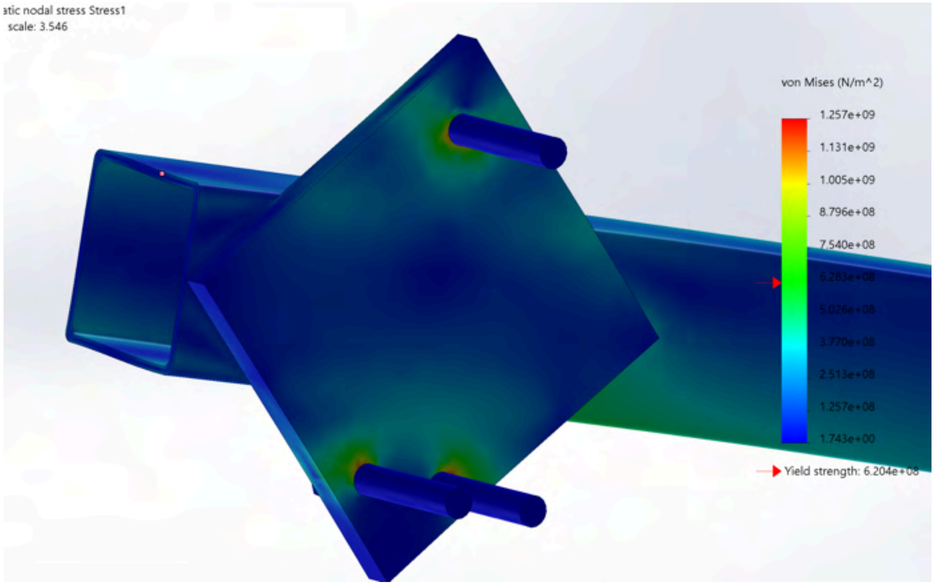


Figure 19: Seat Stay Bar von Mises Maximum Stresses

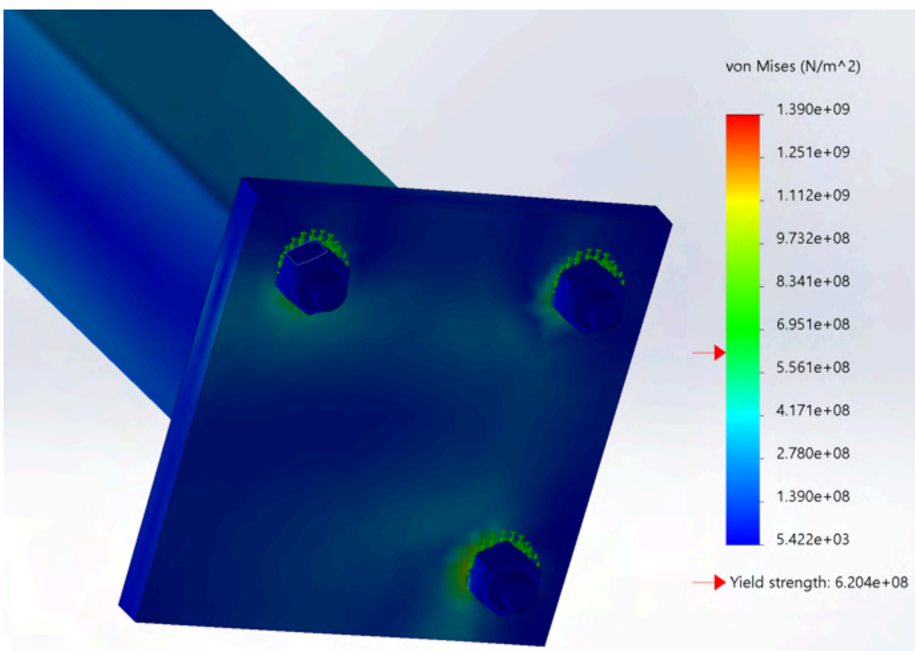


Figure 20: Chain Stay Bar von Mises Maximum Stress

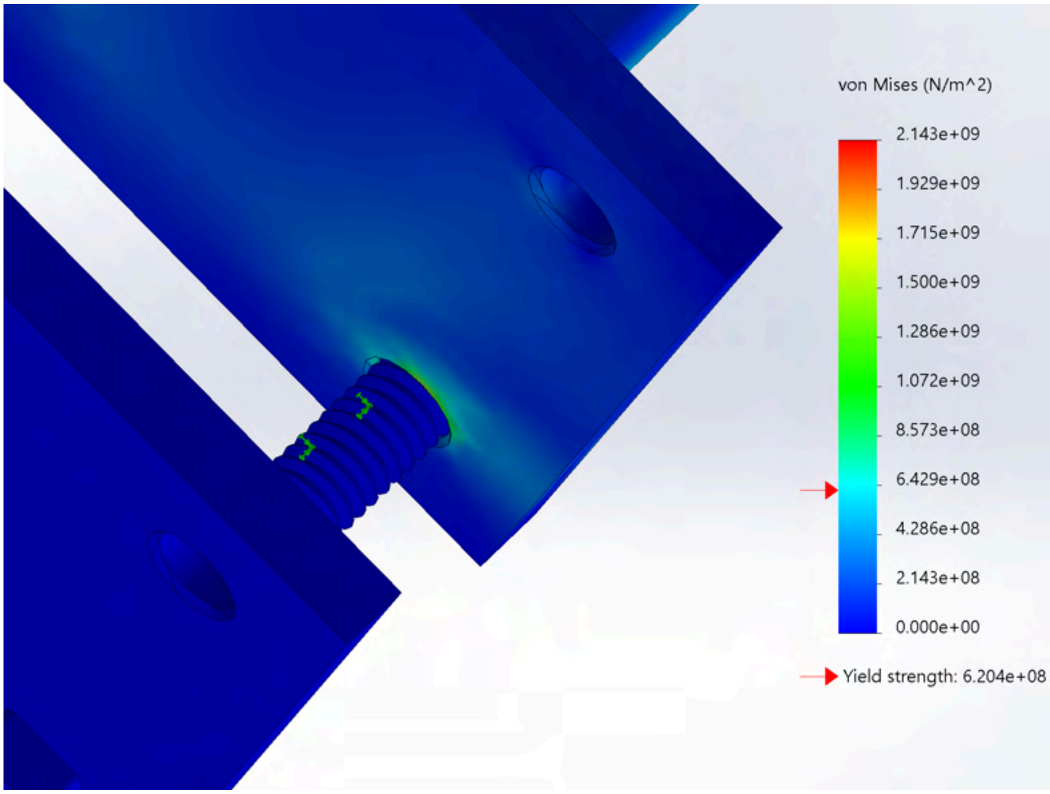


Figure 21: Head Tube Bar von Mises Maximum Stress

One can see that if the absolute worst case scenario were to occur, there are small areas around the bolt holes in each plate where stress could exceed the yield strength of the material. This in turn can be used to calculate the factor of safety using the following equation:

$$\sigma' = \frac{S_y}{n}$$

The low carbon steel plates and bars used have a yield strength of 36,000 PSI. This means each bar, in a worst case scenario, has a factor of safety less than one in this extreme scenario. However, without the pothole assumption, the total von Mises stresses stay below the yield strength of the material for all bars. According to the Maryland Department of Transportation, potholes must be two feet before they will repair them [7]. Since the bike tires are specified as 26” in diameter, this means the tire cannot fully enter the average unrepaired pothole in Baltimore, and the difference in the z-direction between the two bicycles will be negligible. The von Mises stresses for this assumption are shown below, with full view von Mises and displacement heat maps located in Appendix Figures I.5-I.7.

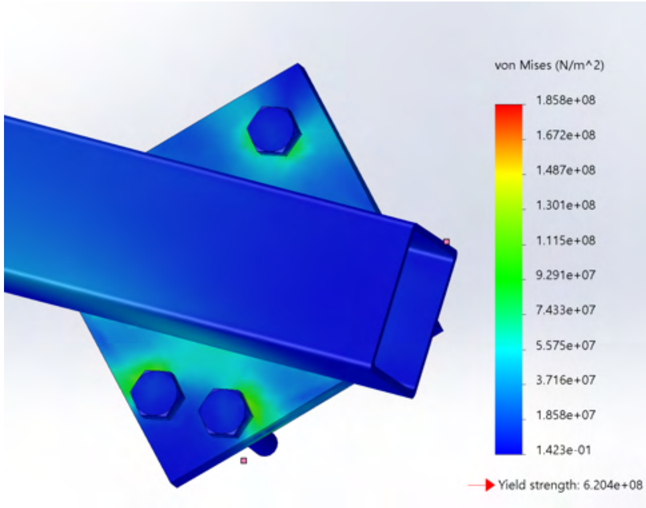


Figure 22: Seat Stay Bar von Mises Maximum Stress without Pothole

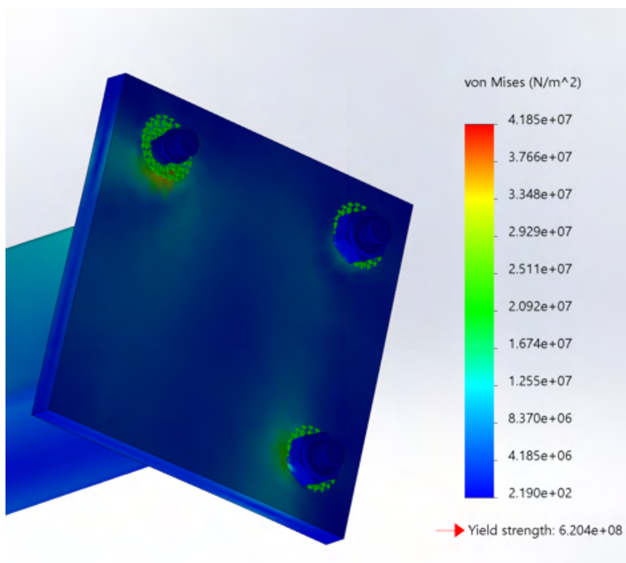


Figure 23: Chain Stay Bar von Mises Maximum Stress without Pothole

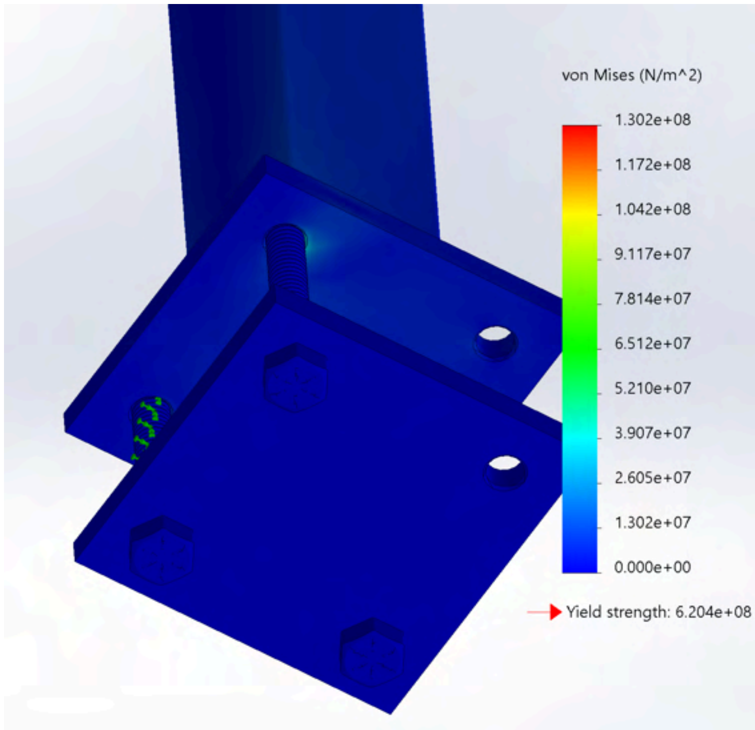


Figure 24: Head Tube Bar von Mises Maximum Stress without Pothole

Using these von Mises stresses, the following factors of safety are calculated:

Table 2: Frame von Mises Stresses and Factors of Safety

Bar Location	**Maximum von Mises Stress (PSI)**	**Factor of Safety**
Seat Stay	26,948.01	1.34
Chain Stay	6,069.83	5.93
Head Tube	18,883.91	1.91

The team also attempted to do fatigue analysis on the part but discovered that the loads applied are below the minimum S-N curve value for steel. This result was confirmed using the SolidWorks S-N curve for Alloy Steel, seen below in Figure 25.

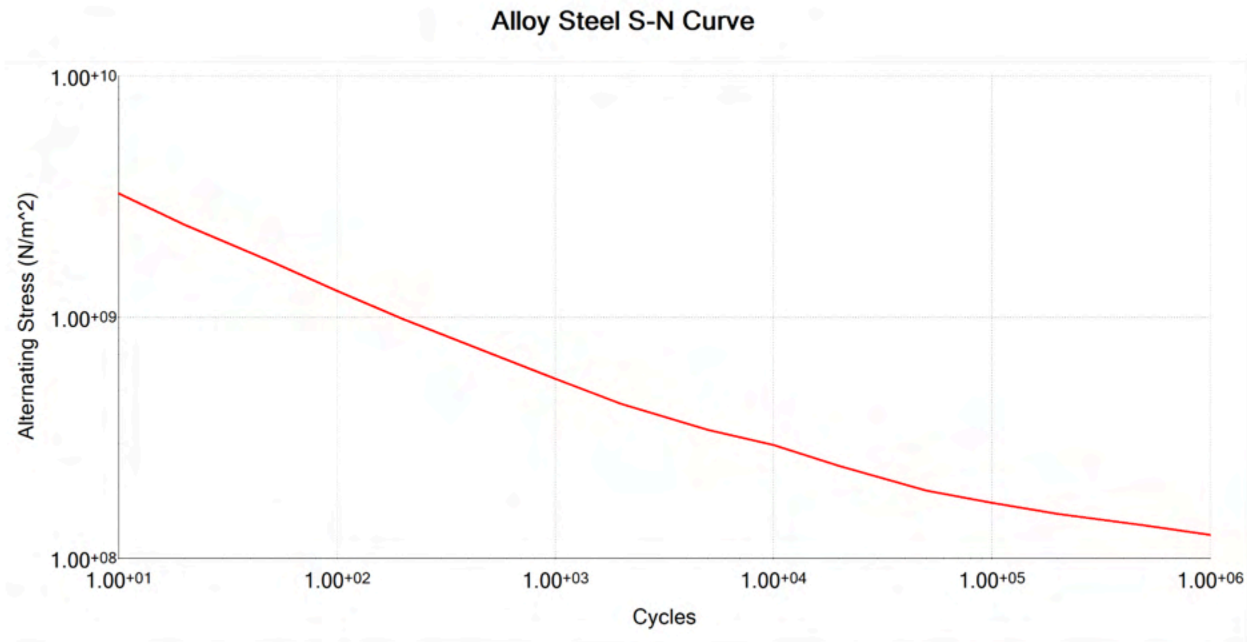


Figure 25. Alloy Steel S-N Curve

The minimum stress on this curve is approximately 125 MPa, and our von Mises stresses will alternate between 0 and a maximum of 186 MPa (26,948 PSI). Alternating stresses are calculated by calculating the difference between the minimum and maximum stress and dividing by two.

$$\sigma_a = \frac{\Delta\sigma}{2} = \frac{\sigma_{max} - \sigma_{min}}{2}$$

This yields a maximum alternating stress of 93 MPa, which is well below the S-N curve. This means that despite the repeated loads our riders will be applying to the bicycles and extended frame, pieces should not fail from fatigue.

Although this frame connection has proved robust in testing, the team would recommend additional measures be taken in future years to guarantee no yielding due to potential one sided drops such as potholes, etc.

II. Steering System Analysis

Wheel alignment while steering is critical for smooth vehicle operation, especially with a four-wheel vehicle. For four wheels to roll smoothly in a turn, each axle must point to a common point - the center of the turning circle. With two fixed wheels at the rear, the front two have to turn at different angles to accommodate this - this is most often done with Ackermann steering geometry composed of two front steering arms connected to a tie rod [8]. This trapezoidal linkage causes the inside wheel to turn at a steeper angle than the outside wheel. With a properly tuned tie rod length, every wheel axle goes through the same point, minimizing tire scrubbing, where one or more tires slide against the ground laterally.

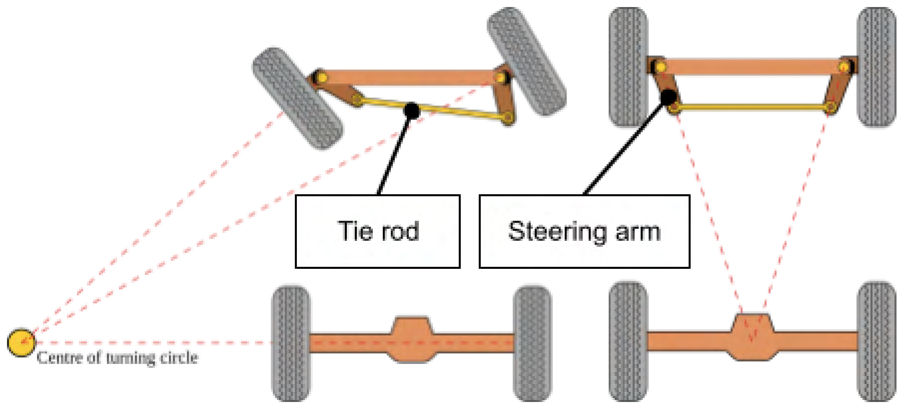


Figure 26 - Ackermann Steering Linkage

The figure above shows an idealized Ackermann steering configuration; the optimal tie rod length and steering arm angle can be found by tracing a line from the steering axes to the center of the rear axle. In reality, the bikes have a positive caster angle, meaning that the front wheels turning axis is tilted back. This makes a bicycle more stable at speed but means that these idealized calculations won't necessarily give the correct tie rod length. Paired with the irregular geometry of the bicycles, this presents a significant modeling challenge. For the kinetic sculpture, the idealized steering geometry was used to estimate an initial tie rod length that could then be fine tuned using the turnbuckle system highlighted in the steering design section. With a wheelbase of 41 inches and a width of approximately 30 inches, the angle from the front pivot point to the center of the rear axle is $\tan^{-1}\left(\frac{30''/2}{41}\right) = 20.5$ deg. Assuming a steering arm length of 6 inches, the tie rod connecting the two steering arms should be 30" - 2x6"sin(20.5) = 25.75". The 6" steering arm length was found by modeling the geometry in Solidworks - any shorter and it severely limits the turning radius, any longer and it hits the pilots' knees.

The final steering design was analyzed to ensure that it would not fail. A maximum expected load was determined to correctly spec each component. Since the frame linking the bikes is very rigid, it is assumed that the steering linkage will not have to bear any load caused by the pilots' pedalling. Additionally, since these loads are hard to approximate, the force required for another component in the steering assembly to break will be used as an approximation for maximum load. Of every component in the original bicycle steering assembly, the wheel is most likely to fail, especially under lateral loading (these could result from attempting to turn the wheel while stuck in the mud). Using an online wheel simulator with known size and approximate material properties for the bike wheels, the lateral force required to buckle the wheel is roughly 95lbs [9]. Assuming this acts as a point load at the maximum radius (the radius of the wheel is 13”) from the steering axis, the torque acting in the stem is 1235 in-lbs.

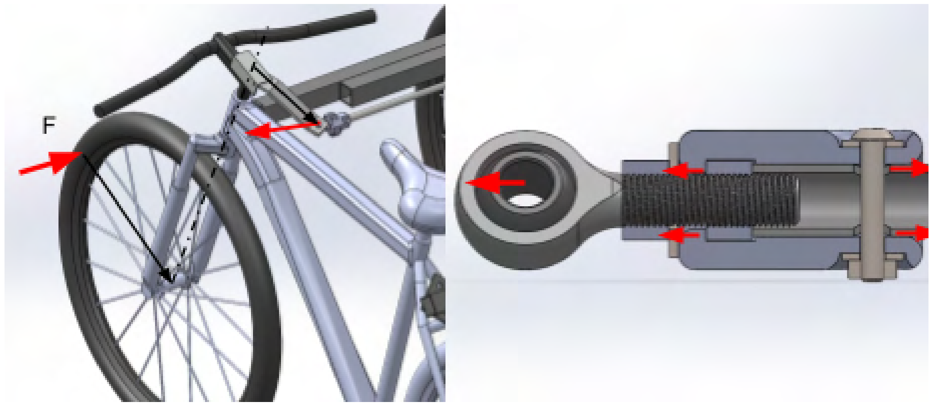


Figure 27: Steering Loading

At a radius of 6 inches from the stem, the rod end would experience 205 lbs of force (1235 in lbs / 6 in). A ¼-28 ball joint rod end has a radial load capacity of 2800 lbs, making it highly unlikely that it will fail. Since the tie rod will be under only tension and compression, the shear stress between the #8 bolt and the tie rod in the tie rod adapter can be quickly calculated. Using the bearing stress formula $\sigma = F/td$ where F is the load, t is the tube thickness, and d is diameter, the bearing stress is roughly 19.5 ksi. This is well below the yield strength of both the aluminum rod and #8 bolt. The 3D-printed tie rod adapter and hose clamp used to hold the steering arm in place were both separately verified to hold up to 200 lbs by standing on it. Finally, to verify the strength of the steering arm, a piece of 1” aluminum welded onto the handlebar stem was simulated in Solidworks using FEA. These simulations were performed on an earlier design iteration that included several holes in case the steering arm length wanted to be changed. As shown in the simulation below (Figure 28), under 200 lbs of force at the outermost hole (r = 6in), the L beam has a maximum von Mises stress well below yield (F.O.S ~ 2).To conclude, in a worst case loading scenario, the wheel is most likely fail before any other component in the steering assembly, not requiring further improvement.

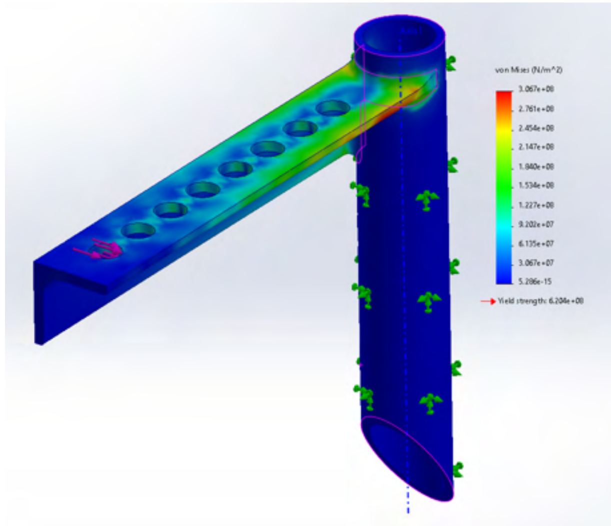


Figure 28: FEA of Steering Linkage

III. Weight and Rider Effort Analysis

When riding a bike on flat terrain, the primary forces affected by added mass are rolling resistance and acceleration force. Rolling resistance is the friction between the tires and the ground, which depends on the total weight of the rider and bike.

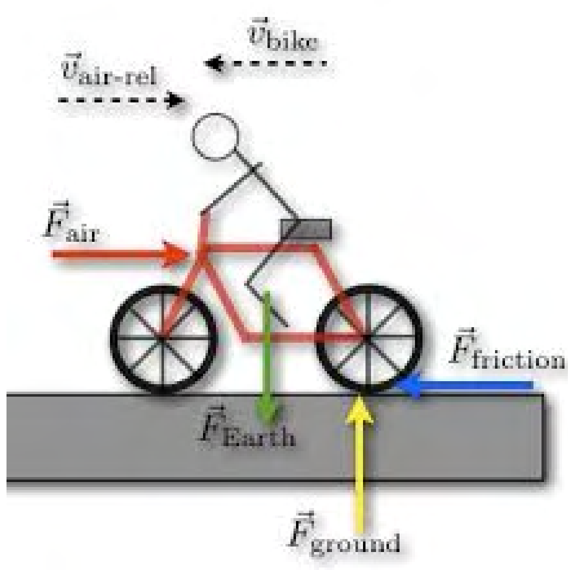


Figure 29. Free Body Diagram of a Bicycle

Acceleration force is the effort needed to increase speed, which is directly proportional to mass. While aerodynamic drag also affects cycling effort, it remains unchanged by weight unless the rider's posture changes due to the added load. The power required to maintain speed increases as the resisting forces grow, making it harder to sustain a ride over long distances. Rolling resistance is calculated using the formula, $F_r = C_r mg$, where C_r is the rolling resistance coefficient (typically between 0.002 and 0.008 for road bikes), m is the total mass in kilograms, and g is gravity (9.81 m/s²). Increasing the total weight from, say 500 lbs (226 kg) - the current total mass of the vehicle including riders - to 600 lbs (272 kg) - a possible mass if more supports/items were added- results in a 20% increase in rolling resistance, as shown by the ratio:

$$\frac{m_2}{m_1} = \frac{272}{226} = 1.20$$

Similarly, the force required to accelerate at the same rate also increases proportionally according to Newton's Second Law, $F = ma$. Since mass is increasing, the acceleration force must also increase by 20% to achieve the same speed-up as before. The power required to maintain a constant velocity is given by $P = F_r v$, which means that a 20% increase in rolling resistance translates directly to 20% more power needed to keep moving at a steady pace.

The impact on the rider depends on their cycling style. On flat roads, a heavier bike will be noticeably harder to start and accelerate, requiring more energy output. Once moving, the extra rolling resistance makes long rides more tiring. However, on a downhill slope, the additional mass could be beneficial by increasing momentum. In stop-and-go situations, like frequent stops due to avoiding collisions with other vehicles/pit crew members, the added weight will result in significantly higher energy expenditure due to frequent accelerations.

Increasing the total mass from 500 lbs to 600 lbs makes cycling 20% harder in terms of rolling resistance and acceleration force. This added difficulty requires more power from the rider, especially when starting, climbing, or maintaining speed over long distances. To reduce effort, the team could optimize tire pressure, use smoother tires to lower C_r – however, the best method would be to minimize weight where possible.

IV. Water Propulsion Analysis

Although the team is required to have oars on board, they decided to add an additional source of water propulsion to enhance the efficiency of the kinetic sculpture. Ultimately the team decided on propellers due to their common usage in boats and efficiency. Boats (or kinetic sculptures!) can be modeled as straight and level movement through the water, which means the force pushing the sculpture forward (thrust) is balanced by the force resisting its motion through water (hydrodynamic drag). Under this model, the team approximated the sculpture as a boat, needing some acceleration to begin motion once the pilots entered the water. Calculating the drag needed to overcome by the thrust of the propellers is a first step to understanding how much additional thrust can contribute to acceleration.

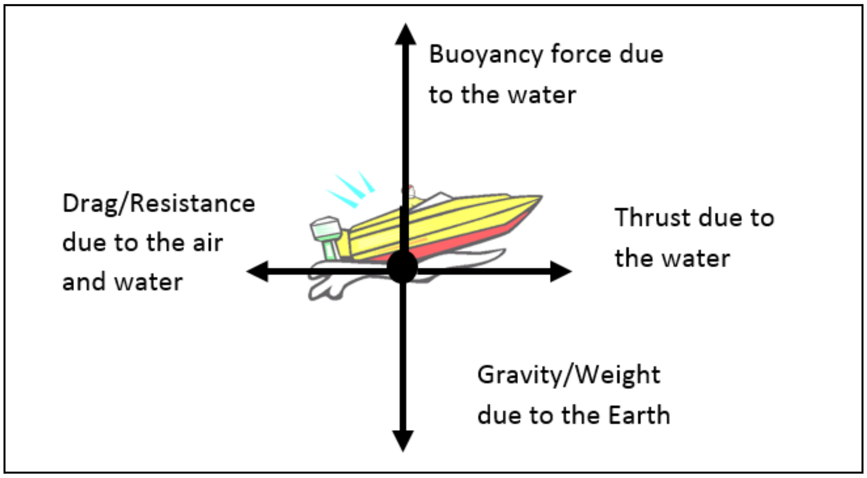


Figure 30. Free Body Diagram of Boat Model

The first calculation done was the hydrodynamic drag force, which can be found using the equation, $F_d = \frac{1}{2} c_d A \rho v^2$. The sculpture's velocity v was set at 3 mph (1.341 m/s), which is the average speed of a recreational kayaker [10]. Because the water section of the race takes place in the Baltimore Inner Harbor, the water density ρ was assumed to be 1004 kg/m^3 based on the salinity of the Atlantic Ocean in May [11]. Another approximation is the coefficient of drag c_d, which is highly dependent on Reynolds number and shape of the object. In order to determine a suitable drag coefficient, the sculpture is simplified into two bullet-shaped pontoons, the bicycles, and the rectangular prism bar connecting the two bicycles that will be submerged underwater. All other cross-sections were determined to be negligible by the team. The waterline is assumed to be covering 18" of the total height of the pontoons, based on water testing experience. This determines the cross-sectional area of the pontoons and bicycles underwater.

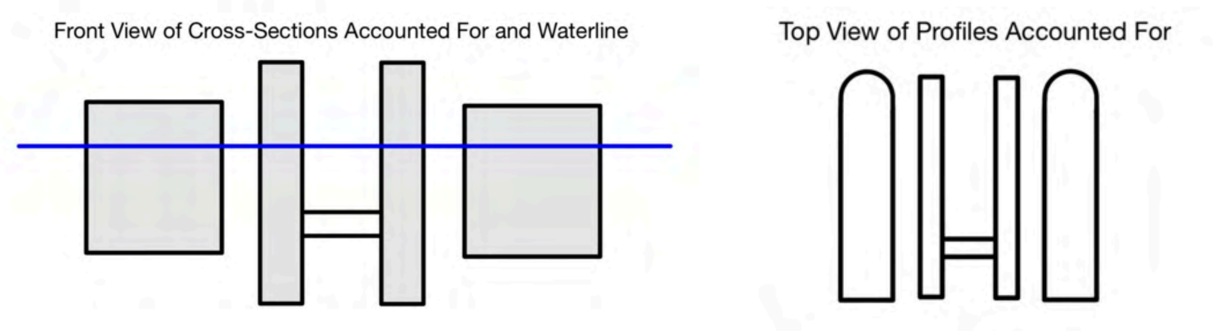


Figure 31: Top and Front View of Profiles Accounted for in Drag Calculations

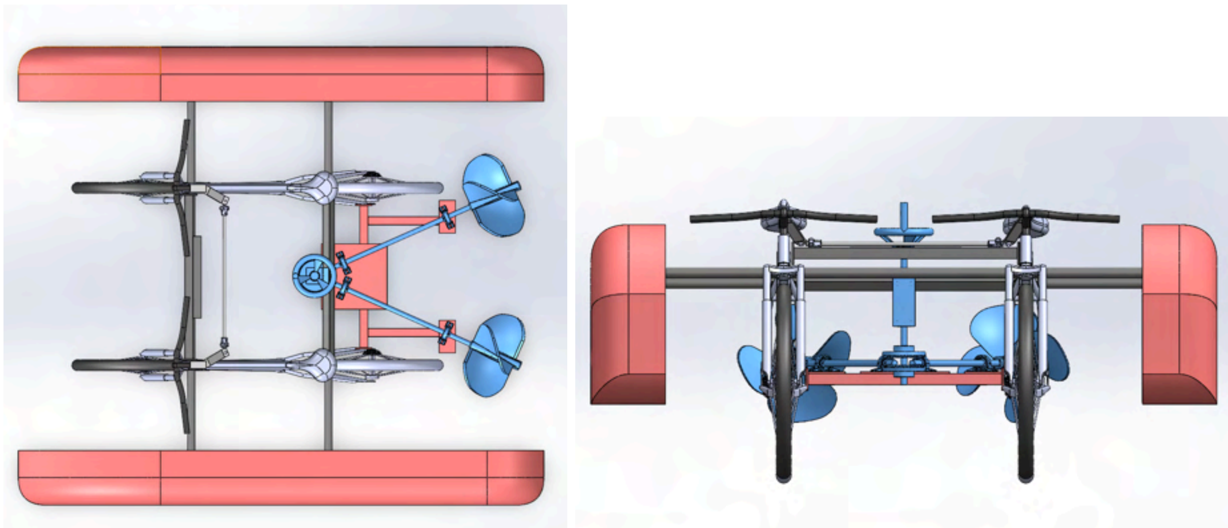


Figure 32: Top and Front View of CAD Model of Bike Structure

A summary of the coefficients of drag, cross-sectional areas, and calculated drag force can be seen below.

Table 3: Drag Calculation Coefficients and Areas

Cross-Section/Part	**Coefficient of Drag** [12,13]	**Cross-Sectional Area Underwater (m^2)**	**Drag Force (N)**
Pontoon	0.295	0.116	30.89
Bicycle	0.9	0.026	18.69
Horizontal Bar	2.1	0.023	49.29

Since there are two bicycles and two pontoons, this yields a total drag force of 148.45 N. This means the propellers need to generate over 148.45 N of thrust to overcome this drag force, and the excess thrust will determine the acceleration using Newton's second law.

From here, the team experimented with variations in the angle of the blades, number of blades, number of propellers, and blade length and height to determine the best propeller for this situation. A SolidWorks Computational Fluid Dynamics analysis was run on a model of the propellers to quickly make changes and test for maximum thrust. In this model, it was assumed that the propellers were functioning in water, and rotating at 15.708 rad/s. This number is calculated based on the average hand crank speed of 30 rpm and a maximum possible gear ratio of 5:1 [14]. This gear ratio was as large as the team was willing to go due to concerns about fit and consistency with the gears.

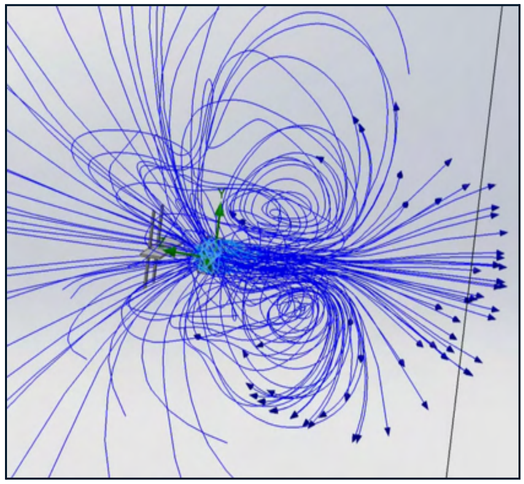


Figure 33: Screenshot of CFD Flow Simulation

The team's precise manufacturing methods for this task were limited to 3D printing, and so when it was determined that the propellers would need to be larger than the Bambu 3D printer beds available, the blade number was decided to be four in order to make the propellers smoothly separated into parts without difficult connections.

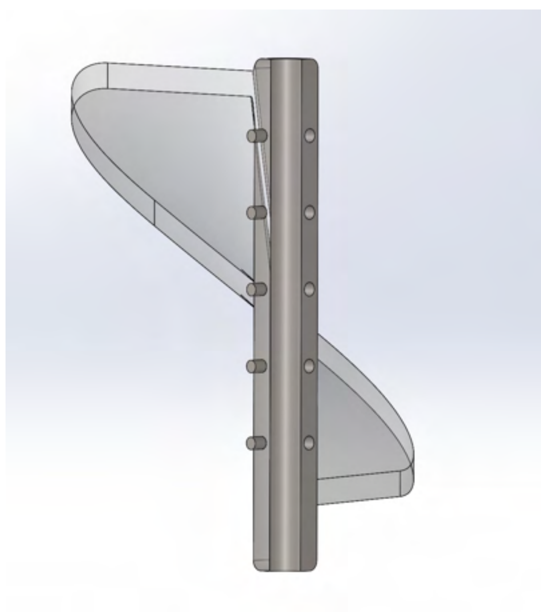


Figure 34: View of the Propeller Slice as 3D Printed

Finally, the size of the blades was fine tuned until significant additional thrust was provided by the propeller combination. Two propellers were deemed necessary to prevent the size of the blades from again becoming too large for the 3D printers, at which point they would likely start becoming too large to be mounted appropriately on the vehicle. This is because the propellers need to be mounted low enough to be under the vehicle's water line, while also above the roadway while the vehicle travels on land.

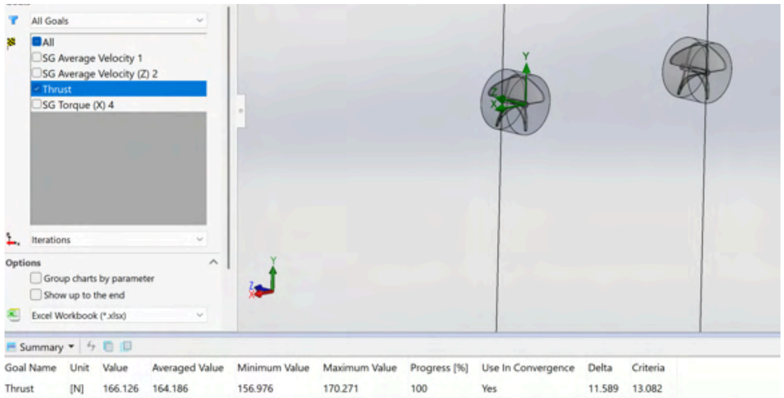


Figure 35: Final CFD Calculations

The final configuration's CFD calculations yielded a thrust of 166.126 N. By subtracting the force needed to overcome the drag force of the structure, this leaves 17.676 N to accelerate the vehicle from zero velocity. Using F = ma and the estimated sculpture mass of 225 kg, this yields an acceleration of 0.079 m/s^2. Using the definition of acceleration, change in velocity over change in time, the team can estimate that a change from zero velocity to 1.341 m/s will take approximately 17 seconds. This means that the pilots should crank the propellers at 30 rpm for approximately 17 seconds before their motion begins. Full calculations are shown in Appendix I.

V. Floatation/Buoyancy Analysis

For an object to be buoyant, the mass of the object needs to be less than that of the amount of water it displaces.

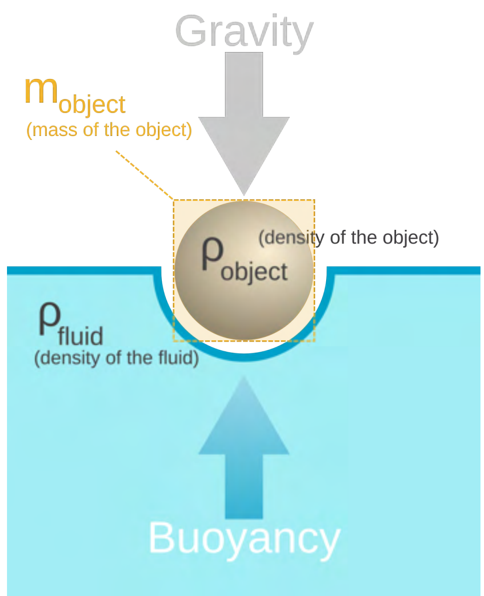


Figure 36. Buoyancy Diagram

To determine the amount of foam needed, the following equation was used:

FoS * (Total Weight of Sculpture + Weight of Foam) = Density of Water * Volume of Foam

This equation had a major assumption that the weight was evenly distributed throughout the sculpture. The first step in this calculation is to determine the total mass of the sculpture, which was found to be 499.31 lbs (Appendix Figure B.1). Once the total mass was estimated, the sizing of the flotation pontoons could be found. At a bare minimum the volume of pontoons had to displace the same weight of the sculpture which was found to be around 8 cubic feet. To avoid any issues with floatation, a large factor of safety was added - the final volume of the pontoons was 26 cubic feet - or two 8' by 2' by 10" blocks. This was to avoid any issues with adding additional parts or issues with freeboarding, or the phenomena of the water level getting too close to the top of a boat. Further calculations can be seen in the Appendix I.3.

In the final design, a total of 26.67 cubic feet of foam was used to construct the pontoons on the sculpture. This is well over the value needed to meet the criteria, leading to a new factor of safety of 3.2 after taking into account the new total weight of the sculpture. With this factor of safety, the team can say with high certainty that the kinetic sculpture will be able to float safely on the water with little concern of sinking.

VI. 8% Wet Calculation

One of the race rules is that the pilots stay less than 8% wet while going into the water section, or have a penalty.

The average surface area of a human body can be estimated using the Du Bois formula which is commonly used in medicine and physiology for calculating body surface area (BSA). The formula is:

$$BSA = 0.007184 \times Height\ (cm)^{0.725} \times Weight\ (kg)^{0.425}$$

Using this equation, Graham's body surface area is $2.1m^2$ and Matthew's is $1.85m^2$.

With a total sculpture weight of 500 lbs and two pontoons providing 26.67 ft^3 of flotation, only about 8.01 ft^3 of foam needs to be submerged to stay afloat. This corresponds to approximately 30.03% of the pontoon volume, or about 7.2 inches of the 2-foot pontoon height submerged.

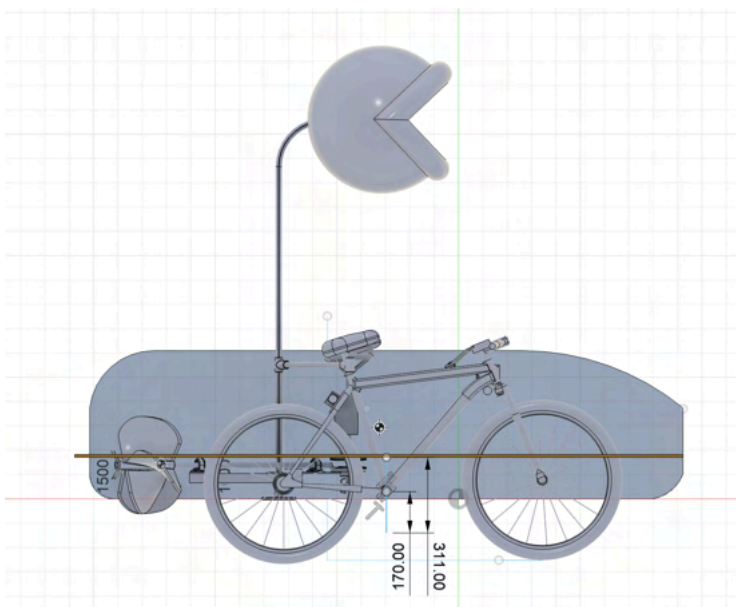


Figure 37: Sculpture with Theoretical Water Level (orange line)

With the pilots' feet placed on the pedals, rotated so that one foot is fully downward, the water level would reach approximately 311 mm (1.02 feet) up the pilots' legs, aligning with mid-shin for both riders.

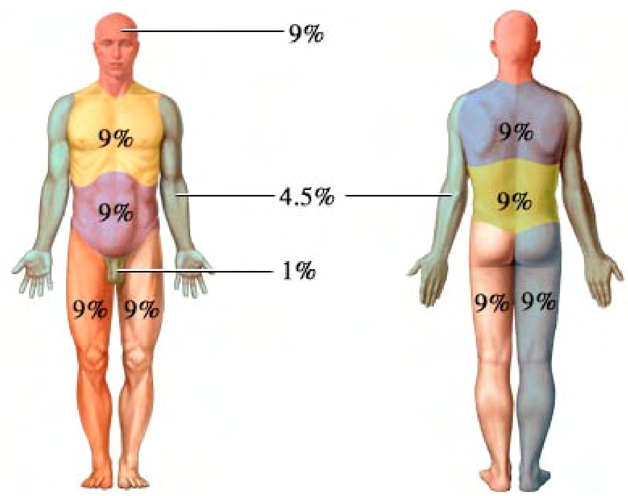


Figure 38: Wallace Rule of Nine for Body Surface Area [15]

According to the Wallace Rule of Nines:

- One full leg (hip to toes) covers approximately 18% of total BSA.
- The knee down accounts for approximately 9%.
- Mid-shin down accounts for approximately 4.5% per leg.

Thus, both legs mid-shin down would represent about 9% of total body surface area.

Although this calculated wetness slightly exceeds the 8% limit, it assumes the pilots are actively pedaling, allowing both legs to be submerged. If the pilots remain stationary with their feet on the pedals without rotating, only one leg would be lowered, resulting in approximately 4.5% wetness. Additionally, during the water crossing, the pilots will not need to pedal and can lift their legs completely out of the water to stay completely dry.

Finally, testing showed that the pontoons were less submerged than predicted, meaning even less of the riders' bodies would be exposed to water.

Based on both theoretical calculations and real-world testing, the team is confident the sculpture will meet the ACE wetness requirement without issue.

VII. FEA of Piranha Plant

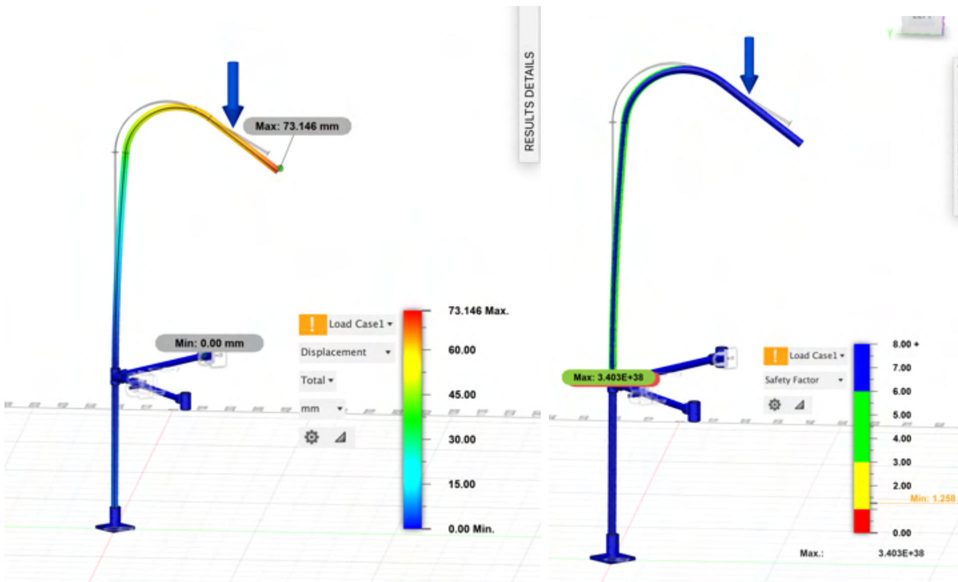


Figure 39. FEA Analysis of the Stem Assembly (Left - Displacement, Right - FoS)

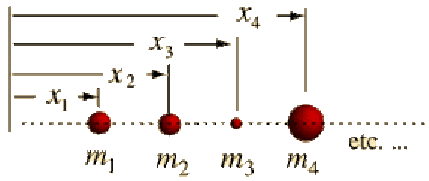
To evaluate whether the Piranha Plant stem could support the weight of the head, the team conducted FEA on the bent aluminum tube as well as its attachment points to the bike frame. A conservative load of 20 kg was applied – greater than the actual weight of the Piranha head – to account for potential dynamic forces and safety margins. The analysis predicted a maximum tip displacement of 73.1 mm and a minimum factor of safety of 1.258. Given the load assumptions and the structural role, these results were deemed acceptable for race conditions.

VIII. Center of Mass & Stability on Incline

To simplify the center of mass (CoM) calculation for the sculpture a few key assumptions were made:

- The sculpture's weight is **symmetrically distributed** across the z-axis (i.e., both pontoons, bikes, propellers, and riders approximately balance each other) therefore the center of mass will be on the xy plane.
- Sculptural components are approximated as **point masses** located at their geometric centers.
- The rider is assumed to be in a **static, upright seated position**, representing a "worst-case" for tipping risk, as it raises the center of mass.

To compute the center of mass, the equation for multiple point masses (shown in Figure 40) was used, with the reference point defined at the ground level at the very front of the sculpture (labeled point **X** in Figure 41). Once the distances and masses of all critical elements (sculpture components and riders) were measured, the center of mass was calculated. The results are summarized in Appendix Table I.1.



$$x_{cm} = \frac{\sum_{i=1}^{N} m_i x_i}{M}$$

Figure 40: Center of Mass equation

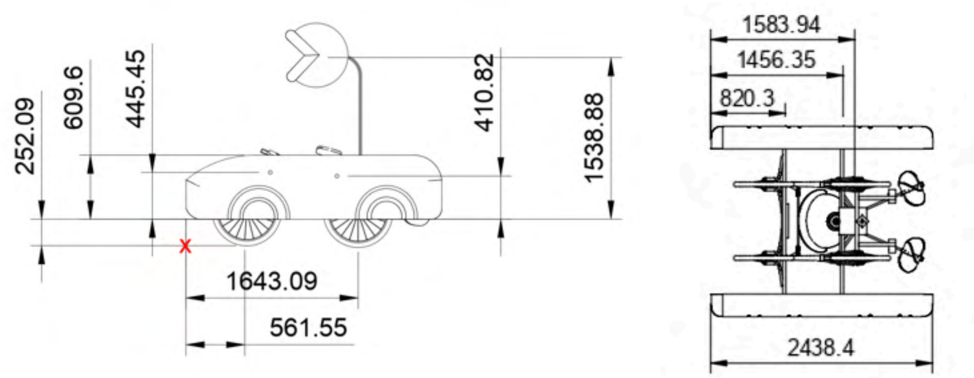


Figure 41: Dimensions for the Center of Mass Calculation

Using the calculated center of mass, the maximum allowable incline and decline angles were determined through basic trigonometry (Figure 42).

The results are:

- **Maximum uphill incline**: **18.94°**
- **Maximum downhill decline**: **36.31°**

The steepest section of the race course occurs at the Canton Waterfront boat ramp, which has a 15% grade, equivalent to approximately 8.58°. This slope is well within the sculpture's maximum safe incline and decline limits. While Battery Avenue presents another notable slope during the race, it is less steep than the boat ramp and therefore does not pose a stability risk.

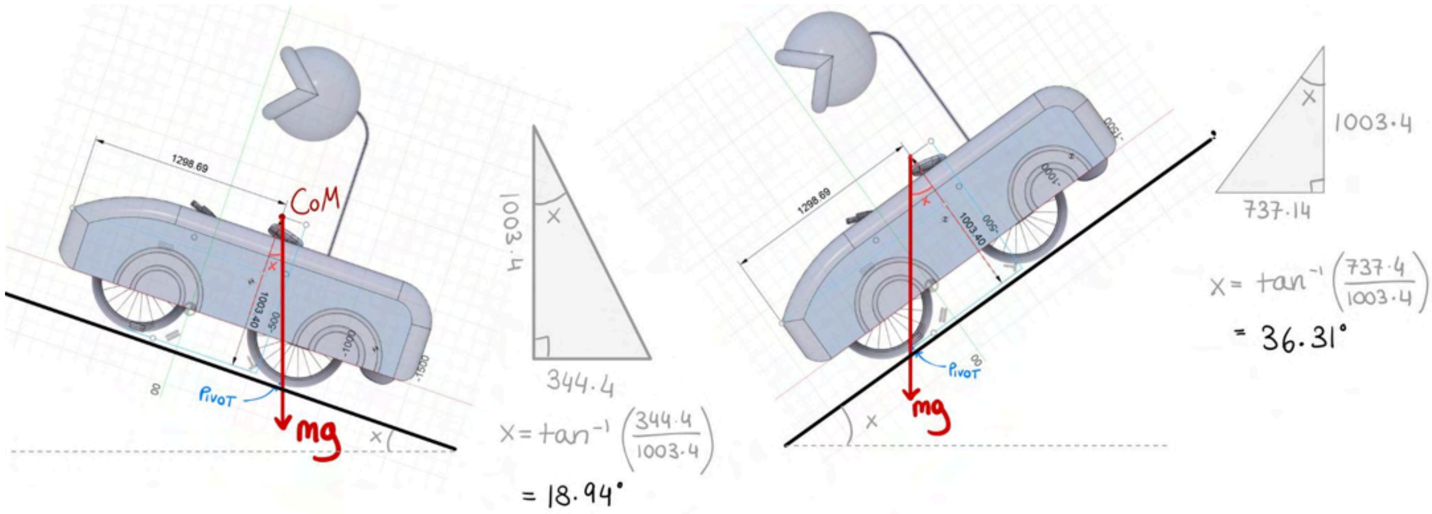


Figure 42: Maximum angle of incline and decline calculation.

Testing

Testing was a critical component of the sculpture's development process, conducted throughout ideation, fabrication, and system integration. Each round of testing addressed specific design criteria, validated assumptions from earlier analysis, and informed iterative improvements to the vehicle's structural integrity, performance, and safety.

1. Early Rideability and Frame Prototyping

The first round of functional testing aimed to evaluate the viability of connecting two bicycles into a single stable chassis. The team initially used T-stock aluminum tubing to join the bike frames and manually rode the early prototype.

- **Purpose:** Assess the feasibility of dual-bike control and lateral stability
- **Relation to Design Criteria:** Transportability, Safety, Terrain Traversal
- **Result:** The system was technically rideable, but the aluminum connections flexed under lateral loads and proved too weak under the dynamic weight of two riders. This led to an early design revision.

2. Iterative Frame Testing and Structural Feedback

As the chassis evolved into a welded steel three-bar system, the team repeatedly tested the sculpture by riding it under increasing loads and various terrain conditions.

- **Purpose:** Validate rider comfort, turning radius without steering linkage, and structural response
- **Relation to Design Criteria:** Durability, Terrain Performance
- **Result:** Feedback from team riders helped refine the steering geometry and wheel alignment. Also alerted the team to a need for lock nuts and tighter connections on the back bottom bar.

3. Steering Linkage Evaluation

The **Ackermann steering linkage** was prototyped and tested iteratively, first with cheap, lightweight materials and later with aluminum rods.

- **Purpose:** Validate turning behavior and identify structural weak points
- **Relation to Design Criteria:** Maneuverability, Safety
- **Result:** Multiple linkage geometries were evaluated. A key performance requirement was smooth turning on various terrains. The steering arms and rod ends were tested under rider-induced lateral loads.

4. Propulsion System Testing

The team explored several water propulsion options, starting with a water-wheel style system powered by rear wheel rotation and later switching to propellers.

- **Purpose:** Enable water mobility without compromising land performance
- **Relation to Design Criteria:** Performance
- **Result:** Initial water-wheel concepts provided insufficient thrust. Propeller systems provided more thrust, however a lot of torque was necessary for the rotation while in water. This led to a larger wheel to reduce the necessary input torque. Water locomotion can also be achieved with handheld paddle**s**, which provide reliable control with minimal mechanical complexity.

5. Adhesive and EPS Compatibility Testing

To construct reliable pontoons from expanded polystyrene (EPS) foam, the team tested multiple adhesives, primers, and paints on foam samples.

- **Purpose:** Prevent foam degradation and delamination during race
- **Relation to Design Criteria:** Durability, Floatation
- **Result:** Some adhesives marked “foam-safe” or “low-VOC” online caused degradation of the foam. Rigorous testing led to the selection of a paint (Acrylic), primer (Mod Podge), sealant (Flex Seal Liquid) and adhesive (Liquid Nails Projects) combo that preserved foam integrity.

6. Terrain Testing (Water, Sand, Mud, Road)

With the fully assembled sculpture, the team conducted field tests in every relevant terrain.

- **Water (Test 1):**
  - **Goal:** Confirm flotation and structural integrity
  - **Result:** Vehicle floated successfully without riders, but aluminum crossbars bent under pilot weight. Switched to steel tubing.
- **Water (Test 2):**
  - **Goal:** Verify flotation with riders and propulsion effectiveness
  - **Result:** Sculpture remained afloat with both pilots. Paddling allowed steady movement. Propellers failed due to excessive torque requirements.
- **Sand & Mud:**
  - **Goal:** Confirm traction and progress through loose terrain
  - **Result:** Sculpture advanced slowly using a ratchet-and-clank propulsion system. Movement was consistent, though slower than on land. No structural issues.
- **Road:**
  - **Goal:** Assess full rideability, handling, and stopping power
  - **Result:** Performance exceeded expectations. The sculpture rode smoothly at speed, braking and turning safely with no instability.
- **Emergency Egress:**
  - **Goal:** Meet design criterion of exiting in <15 seconds
  - **Result:** All riders successfully evacuated in under 15 seconds in water and on land, satisfying the key safety requirement.

Testing led to several key improvements:
- Replacing aluminum tubing with steel based on bending under rider weight
- Refining the steering linkage geometry and materials for smoother turning
- Increase diameter of hand crank and reduce distance from bevel gear to bearing
- Selecting effective adhesives and coatings for EPS pontoons
- Validating road-worthiness and meeting all terrain-specific performance goals
- Confirming egress time under 15 seconds to meet safety compliance

Design Implications and Moral Vision

The team's kinetic sculpture for the 2025 Baltimore Kinetic Sculpture Race was designed with a strong focus on societal, environmental, and ethical considerations. The team made intentional decisions to make sure the design would have a positive impact on the community while also completing the vision of the project. Throughout the design process, the team kept in mind the values of the Baltimore Kinetic Sculpture Race, the American Visionary Art Museum (AVAM), and the local community.

Environmental sustainability was a core consideration in both the design and material selection. The team used materials that were durable yet non-toxic, making sure that if parts of the sculpture broke or were discarded, they would not harm the environment. Steel, PVC, and foam were selected for their durability and ease of recycling. However, PVC and foam pose disposal challenges, as they are not easily recyclable. The team plans to donate any unused materials to local schools or non-profits to extend their life cycle. While transportation emissions associated with moving the sculpture to Baltimore remain a challenge, the team plans to mitigate this impact through efficient logistics and potentially offsetting emissions.

A qualitative life cycle analysis reveals that material production, especially steel and PVC, has the highest environmental impact due to the energy-intensive processes involved. While recycling reduces some of the environmental footprint, the disposal of PVC and foam remains a concern, as these materials contribute to landfill waste. The transportation emissions, while significant, are somewhat mitigated by efficient planning. Overall, the project's design aims to balance functionality, creativity, and sustainability, reducing its impact where possible while ensuring the sculpture is functional for the race.

Regarding the societal context, the project was created for an art museum that values creativity and freedom of expression. AVAM encourages individuality and artistic exploration, and the design of the sculpture aims to reflect those values. The sculpture was intended to be a platform for creativity, showing how engineering and art can work together in fun and meaningful ways. Ethically, the design and execution were approached with respect for all people and cultures. The team chose a Mario Kart theme, which is culturally significant and widely recognized across various demographics. Given the global popularity of the Mario Kart franchise, particular care was taken to ensure that the design would be perceived positively and respectfully by the public. Steps were taken to avoid any designs or representations that could be offensive or harmful, reflecting a commitment to inclusivity and respect.

As the project was short-term, the primary focus was on cutting costs without compromising functionality. The team repurposed parts from past projects and used donated materials to keep expenses low. Metal recycling companies were utilized to find reliable, affordable materials. The goal was to strike a balance between affordability and durability, as choosing lower-quality materials could lead to structural failures during the race, creating safety concerns and wasting resources. Transportation costs were also an important factor, including the fuel costs, vehicle space, and logistics involved in moving the completed sculpture to Baltimore. The team had to factor in how they would travel to the race and how to manage the transportation of the sculpture effectively. After the race, proper disposal or recycling was considered to avoid wasting materials and money.

A successful solution to this design problem could inspire future projects that emphasize sustainability and creativity, especially combining art and engineering. However, challenges such as transportation emissions and the disposal of non-recyclable materials remain. These issues were mitigated by repurposing materials, planning for recycling, and exploring potential carbon offset strategies. The team also focused on creating a design that would be engaging, safe, and respectful to the diverse audience of the race.

In conclusion, the design of this kinetic sculpture reflects a commitment to ethical, environmental, and societal responsibility. By addressing these key factors, the project contributes to the success of the Baltimore Kinetic Sculpture Race while remaining mindful of its broader impact.

Recommendations and Conclusions

Throughout the development and testing of the kinetic sculpture, several areas for future improvement were identified. These enhancements could improve both performance in the race and the overall quality of the project experience.

1. More Extensive Sculptural Design

While the sculpture successfully met the functional and thematic goals of the project, many of the most memorable entries in the Baltimore Kinetic Sculpture Race – such as *TikTok the Croc* and *Fifi the Poodle* – featured much grander and more elaborate designs. With additional time, budget, and a more secure transportation method to Baltimore, the team could have expanded the sculpture to a larger, more striking form. A larger, more visually commanding sculpture would have improved audience engagement and potentially made the team more competitive for creativity awards.

2. Fully Integrated Structural Design

Due to concurrent design and fabrication, the final vehicle consisted of multiple partially independent substructures (frame, flotation, propulsion, aesthetics) built in sequence rather than as a single, unified system. This piecemeal approach led to design inefficiencies—for example, having a floatation support bar intersect through a welded frame instead of extending a single piece, or bolting on an aluminium plate to a steel support bar to hold the propellers. While the modularity aided transportation and assembly, a fully integrated design would reduce unnecessary weight, improve structural efficiency, and simplify assembly. Early comprehensive integration of frame, floatation, propulsion, and sculpture systems is a key target for future designs.

3. Self-Sufficient Water Exit System

Currently, the sculpture requires manual cranking of the front wheels to exit the water ramp when the rear wheels are suspended. Future improvements could include a built-in cranking mechanism, such as:

- A dedicated hand crank attached to the front wheels.
- A quickly detachable flotation element at the rear to sink the back wheels into contact with the ramp.

These improvements would make water exits faster, safer, and more self-reliant, aligning better with the performance and efficiency goals set during design.

4. Combining Pedaling with Water Propulsion

The hand-cranked propeller system ultimately required too much torque to operate efficiently. A key improvement would be integrating water propulsion with the primary pedaling system, enabling riders to power both land wheels and water propellers simultaneously. This would dramatically increase available torque to the propellers and allow smoother, continuous movement through water without relying entirely on upper-body effort. A drivetrain redirection system or gear engagement system could accomplish this in future iterations.

For mass production, the sculpture would need to shift from custom welded assemblies to modular, standardized components. Prefabricated tubing with bracketed connections would replace hand-welded frames, and off-the-shelf marine parts would be used for propulsion. The design would also need to allow for faster assembly and adjustable seating for different riders. For aesthetics, the current process of hand-gluing, priming, sealing, carving, and painting foam sheets would need to be replaced with pre-molded or prefabricated decorative shells to greatly reduce labor and improve consistency.

Throughout the two semesters working on the kinetic sculpture, the team learned the importance of starting physical prototyping early, especially finalizing the structural frame quickly, as many subsystems depended on it. Building and iterating sooner would have improved integration and reduced the number of last-minute workarounds. Physical testing proved invaluable, as real-world results often differed from initial analysis predictions, particularly regarding material strength and rider interaction forces. Communication between subteams was critical; working in parallel without a full-system integration plan led to inefficiencies that could have been avoided with better coordination. Beyond technical skills like welding, fabrication, FEA, and buoyancy calculations, the project also taught us how to adapt quickly, solve unexpected problems creatively, and manage the complexity of a real-world engineering project under time and resource constraints.

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Appendix

Appendix A: Supplementary Tables

Table A.1. Summary Kinetic Sculpture Goals and Criteria

Goals	Primary or Secondary	Criteria
Safety - The vehicle must be safe for the pilots, pitcrew, and audience	Primary	Safety equipment is always present in kinetic sculpture
	Primary	Pilots and barnacles need to be able to safely exit the vehicle in 15 seconds or less.
	Primary	Pass safety inspection before any time driving the vehicle.
Durability & Performance - Vehicle should be able to be driven/float for the length of the course withstanding different terrains.	Primary	Sculpture must be able to travel on land for at least 15 miles in one total stretch.
	Primary	Sculpture must be able to travel in water for >80-feet.
	Primary	Sculpture must be able to travel continuously through mud for >50-yards.
	Primary	Sculpture must be able to travel continuously up an incline for >60-feet.
	Primary	Sculpture must be able to travel continuously through sand >50-yards.
	Primary	The Kinetic Sculpture must be able to hold and travel with an additional load of >500 lbs.
Budget - The cost of the kinetic sculpture design should be within the ME 424 budget	Primary	The total cost of the vehicle design should be tracked throughout the project and not exceed $2,000. This does not count travel costs for the race.
Transportability - The vehicle must be transported from Duke University to Baltimore, MD	Primary	Vehicle can sustain five hours of vibrations, jostling in an enclosed space and not sustain damage.
	Primary	The sculpture can be arranged to fit in a U-Haul (6' x 12' x 5') either assembled or disassembled.
	Primary	Vehicle should need less than 90 minutes to reassemble if

		disassembly is necessary.
	Secondary	The sculpture can fit in the U-Haul (6' x 12' x 5') without being disassembled.
Race Rules - Vehicle and team should adhere to the Baltimore Kinetic Sculpture race rules	Primary	Vehicle must fulfill all requirements by the Baltimore Kinetic Sculpture Race[1]
	Secondary	Vehicle is in accordance with the guidelines set by the Kinetic Sculpture Race
Aesthetics - Visually appealing (and on theme) sculpture for the team and audience	Secondary	Both sculpture design and team costuming must fit a common theme (Play) and be recognizable by >50% of those surveyed at Duke
Team Fitness - All members of the team are able to successfully travel the length of the race	Secondary	Prior to the date of the race, all members are able to travel a distance of 15 miles. For the pilots, it must be by bike with an additional load to mimic the load on the sculpture. For members of the pit crew, this can be on bike or on foot.

Table A.2: Summary of Dot and Borda Count Voting Results

Cluster	**Sub-Cluster**	**Borda Voting Results (Note: lower is better)**	**Dot Voting Points (Note: higher is better)**
Chassis	Monocoque	22 points	0
	Retrofit existing ATV/Paddle Boat	17 points	3
	Connected Bikes + Buoys	22 points	0
	Bamboo Raft	26 points	0

[1] "Baltimore Kinetic Sculpture Race: Official Kinetic Sculpture Race Rules." *Kineticbaltimore.com*, 2024, kineticbaltimore.com/KSR/Rules.asp. Accessed 5 Dec. 2024.

	Custom Metal Frame	**15 points**	**4**
Number of Wheels	1	19 points	0
	3	14 points	0
	4	**9 points**	**7**
Wheel Style	Bike Wheel	16 points	1
	Water Tricycle Wheel	30 points	0
	Large Wagon Wheel	26 points	0
	ATV Wheel	**13 points**	**6**
	Beach Balloon Wheel	39 points	0
	Tank Style	41 points	0
	Airless Tires	28 points	0
Tread Style	Normal Bike	17 points	0
	Mountain	**10 points**	**6**
	Sand	16 points	1
	Spiked/Studded	27 points	0
Brakes	Coaster Brakes	13 points	1
	Handlebar Braking	**10 points**	**6**
	Anchor	19 points	0
Water Propulsion	**Oars**	**11 points**	**4**
	Paddle Boat Style	16 points	1
	Blades on existing wheels	15 points	2
Floatation	Bamboo	18 points	1
	Inflatables	17 points	1

	Foam	**15 points**	**5**
	Kayak/Boat Attachment	21 points	0
Drive + Steering Layout	Trike RWD	20 points	1
	Trike FWD	22 points	0
	Quad RWD	**11 points**	**4**
	Quad FWD	14 points	2
	4 Wheel Drive, Pivot	23 points	0
Drivetrain	Modified Bike Drivetrain	**7 points**	**7**
	Car Axle + Differential	12 points	0

Appendix B: Supplementary Figures

Item	Mass
Rider #1	81.65
Rider #2	65.77
Bikes	31.75
Metal Framing	8.09
Steel Pipes	9.19
Aesthetics	30.00
Total (kg)	226.44
Total (lbs)	499.31

Figure B.1: Load Calculation

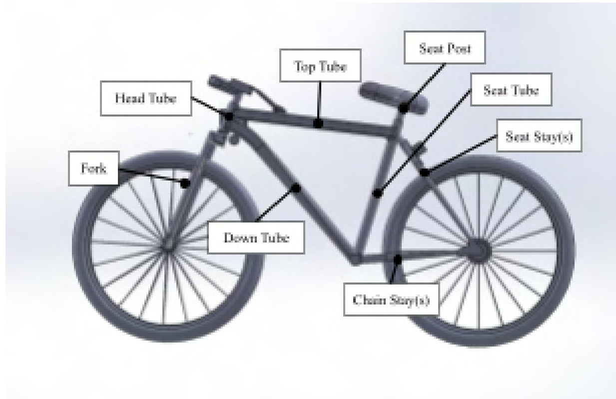


Figure B.2 - Annotated Bike Frame

Appendix C: User Manual

- Riders must be **5'7" or taller** to operate the sculpture safely.

Riding on Land

1. **Mounting**
   - Approach the bike from the **pontoon side** or from the back (avoiding the propellers).
   - Raise your leg over the pontoon or the back bar and then mount a bike as normal.
2. **Operation**
   - The handlebar linkage synchronizes steering between both riders.
   - **Communication and coordination** are essential while pedaling together.
   - Ride the sculpture like a **regular tandem bicycle** when on land.
3. **Dismounting**
   - Dismount a bike as normal and either step over the pontoons or the back bar avoiding the propellers.

Transitioning into Water

1. **Approach**
   - Pedal slowly and maintain balance as you approach the water.
   - Continue until the pontoons **fully engage** with the surface.
2. **In-Water Operation**
   - Pedal gently and steer using the handlebars.
   - Turn the **crank wheel** to engage the propellers for propulsion.
   - If the crank wheel does not engage, **use the paddles** to move through the water.

Exiting the Water

1. **Ramp Exit**
    - Pedal toward the boat ramp and bring the vehicle **as far up the ramp** as possible.
    - Grab the **front wheel** and roll the sculpture forward until the **back wheel contacts the ground**.
2. **Ascending the Ramp**
    - Shift into the **lowest gear** available.
    - Pedal forcefully to climb the hill.

Navigating Sand and Mud

- **Do not panic** if the sculpture begins to sink or stall.
- Communicate and **coordinate pedaling** with your teammate.
- Attempt a **full 180-degree pedal turn** at the same time.
- If needed, **use the ratchet-and-clank technique**:
    - Push the pedal **down** firmly.
    - **Ratchet back up** (rotate backward ~90 degrees).
    - Push down again, repeating as necessary to move forward.

Safety Protocol

- **Lifejackets**: Strapped to the side of the sculpture for emergency use.
- **Oars/Paddles**: Mounted for water maneuvering if propellers fail.
- **First Aid Kit**: Stored **under the right bike seat**.
- **Horn**: Located **on the right handlebar** for signaling.
- **Emergency Dismount**: In any emergency, dismount by stepping off on the pontoon side as described in the “Mounting” instructions above.

Maintenance Checklist

- **Foam Repair**:
    - If pontoons are **chipped** or **battered**, spot-treat damaged areas with **waterproof paint** and **liquid Flex Seal** as needed.
- **Structural Inspection**:
    - **Check all bolts and nuts** for tightness before each use.
    - Retighten any loose hardware.
- **Gear Maintenance**:
    - **Apply grease** to all gears and moving parts periodically to maintain smooth operation.
- **Chain Tension**:
    - Check that the bike chains are **tight but not overstrained**. Adjust if necessary to prevent slippage.

Appendix D: Fabrication Instructions

Pontoons

- Begin by cutting ten 8' x 4' x 1" EPS foam sheets vertically in half, creating twenty 8' x 2' x 1" sheets.
- Stack and glue two sets of ten sheets together using Liquid Nails Projects Adhesive (approximately one tube per sheet) to form two 8' x 2' x 10" blocks.
- Carve the blocks into the desired pontoon shape, rounding the sides and cutting out spaces for the wheels.
- Prime the carved pontoons with two coats of Mod Podge. Allow approximately 12 hours for drying between coats.
- After priming, paint the pontoons with at least two coats of 100% acrylic paint (important: do not use paints with solvents, as they will dissolve the foam). Allow 12 hours for the paint to fully cure.
- Using a sharp-edged tube sized to match the steel support rods, core out holes at the required mounting locations.
- Insert 10" long sections of PVC pipe into each hole, securing them in place with Great Stuff Big Gap Filler spray foam.
- Once the spray foam is fully cured, lightly scuff the painted surfaces with fine-grit sandpaper to create micro-abrasions.
- Apply an even coat of Flex Seal Liquid Clear over the entire surface, paying particular attention to sealing around the PVC pipe inserts. (Note: Flex Seal spray cannot be used, as it will dissolve EPS foam.)

Piranha Plant

- Shape the general form of the Piranha Plant head by molding chicken wire into a 3D "Pac-Man" style sphere, leaving a cutout for the mouth.
- Cover the chicken wire with plastic wrap, then coat with spray foam.
- Once the spray foam is no longer tacky, cover with another layer of plastic wrap, pressing it into the final desired shape, and allow it to fully cure.
- Repeat this process separately to form the lips and the interior mouth lining.
- After the foam has set, sand as necessary to refine the shape.
- Carve ten teeth from 2" thick EPS foam sheets and attach them to the mouth using spray foam adhesive.
- Prime the entire structure with Mod Podge and apply two coats of 100% acrylic paint.
- Finish by sealing the entire head with Flex Seal Liquid Clear to weatherproof it.
- Before completing the interior of the mouth, insert a 3D-printed aluminum tube mount into the head and secure it with screws and additional spray foam.
- Bend a 1" diameter, 8' long aluminum tube into a candy cane shape, ensuring the last 15 inches of the bent portion are straight.

- Insert the straight section into the mounting hole in the head and secure with a bolt. Spray paint the tube green to resemble a plant stem.
- 3D print the necessary attachment pieces: two adapters for the bike seat tube, one connection between the aluminum stem and the bike seats, and one connection from the aluminum tube to the base.
- Mark and drill the bolt holes in both the aluminum tube and the bike frame as needed.
- Mount the base to the bike structure, then use two 14” long, 1” diameter green acrylic tubes to connect the aluminum stem to the bike seat adapters.
- Secure all connections with bolts to finalize assembly.

<u>Frame</u>

- Collect materials: two Nishiki Mountain 26” wheel bicycles, ten 5/16”-18 2.5” hex head screws, two 5/16”-18 1.5” hex head screw, six 5/16” washer, twelve 5/16”-18 lock nuts, two M5 - 18 hex nuts, four M5X0.8-30 partially threaded socket head screw, two M5X0.8-40 partially threaded socket head screw, thirty-two M5 Washers, six M5X0.8 lock nuts, six M5x0.8 hex nuts, six 3”x3”x0.25” low carbon steel plates, three 36” square steel bars (OD - 1.5”, wall thickness - 0.065”).
- Head Tube Bar:
    - Hold one of the steel plates up to where the head tube meets the top tube of one bicycle. Mark where two 5/16” holes can be drilled such that two bolts can go across the front of the head tube (not through the bike). Mark a third hole where a 5/16” hole can be drilled through the steel plate as well as the center of the head tube. Drill these holes through the plate and bike frame.
    - Drill holes in three other steel plates to make another plate for this bike and two identical ones for the other bike.
    - Metal Inert Gas (MIG) weld two plates with holes drilled to the end of the steel tube. Be especially careful to orient the plates correctly so that they can be bolted into the bike frame, and that the bar is centered in the same spot on both plates so the bikes can be correctly aligned.
    - Attach the bar first with the steel plate and pre-drilled holes in the bike frame with three 5/16”-18 2.5” hex head screws and 5/16”-18 lock nuts. One of the other steel plates should be on the outer part of the bike frame to connect the hex head screws going across the head tube.
    - Then carefully align the other plate against the second bike, using a level to ensure the bar and steel plates are keeping the bicycles perpendicular to the ground. Clamp this in place and drill 5/16” holes through the bike frame using the plate as a guide. Repeat the bolting process above.
- Seat Stay Bar:
    - Hold one of the steel plates up to where the fork in the seat stay is under the bicycle seat. Mark where three 5/16” holes can be drilled such that there is one at

the top at the start of the fork, and another two at the bottom with at least 2” of space between the top hole and the bottom two. Drill these holes through the plate.
  - Drill holes in three other steel plates to make another plate for this bike and two identical ones for the other bike.
  - Metal Inert Gas (MIG) weld two plates with holes drilled to the steel tube, with the center of the plate 2” in from the end of the 36” tube. Be especially careful to orient the plates correctly so that they can be bolted into the bike frame, and that the bar is centered in the same spot on both plates so the bikes can be correctly aligned.
  - Attach one plate with two 5/16”-18 2.5” hex head screws, one 5/16”-18 1.5” hex head screw, and six 5/16”-18 lock nuts. The hex head screws should be tightened to clamp the plates over this fork in the seat stay.
  - Then carefully align the other plate against the second bike, using a level to ensure the bar and steel plates are keeping the bicycles perpendicular to the ground. Repeat the bolting process above on the other bicycle.
- Chain Stay Bar:
  - Hold one of the steel plates up to the crux of the seat and chain stay. Mark three locations where an M5 hole can be drilled through the tubing of the bicycle without breaking the bike structure tubing completely. This is especially important here since the bike tubing is so thin.
  - Drill through these spots on the bicycle frame and create corresponding holes on the steel plate. Create identical holes in a second steel plate. Be careful to drill straight through the bar.
  - Cut one of the 36” steel tubes to 26.25”. MIG weld the two plates with holes drilled to the end of the steel tube. Be especially careful to orient the plates correctly so that they can be bolted into the bike frame, and that the bar is centered in the same spot on both plates so the bikes can be correctly aligned.
  - Attach the bar first with the steel plate and pre-drilled holes in the bike frame with two M5X0.8-30 partially threaded socket head screws and one M5X0.8-40 partially threaded socket head screw on the top hole since it is furthest from the bar when held perpendicular to the ground/parallel to the wheel. Add washers in any empty spaces between the plate and bike frame tubing before adding an M5X0.8 lock nut.
  - Then carefully align the other plate against the second bike, using a level to ensure the bar and steel plates are keeping the bicycles perpendicular to the ground. Clamp this in place and drill M5 holes through the bike frame using the plate as a guide. Repeat the bolting process above.

<u>Propulsion System</u>

- Collect materials: two M5x0.8-30 partially threaded socket head screws, two M5x0.8 hex nuts, twenty nine 1/4"-20 1.5" hex head screws, twenty nine 1/4"-20 lock nuts, six 7/8" ID pillow blocks, one 7/8" ID ball bearing, one 1-1/2" x 3' long T-slotted framing rail, one 1" x 1' long T-slotted framing rail, one 12" x 12" x 1/4" aluminum slab, two 3" x 3" x ¼" aluminum plates, and two 1/2" x 10' PVC pipe.
- Steering shaft:
  - Press fit the bearings into both sides of the back attachment piece as well as the top bearing.
  - Attach the back attachment piece to the center of the seat stay bar. Drill a 1/4" hole through the existing hole in the 3D printed piece, and through the steel bar. Insert the 1/4"-20 2.5" hex head screw and lock nut on the opposite side.
  - Cut one PVC pipe to 18". Slide the PVC pipe into place through the bearings. Pin it at the bottom using the shaft pins. Drill a 1/4" hole through the bottom gear 3D printed piece and the PVC shaft to perfectly align the holes, and insert a 1/4"-20 2.5" hex head screw. Place a lock nut on the other side. Insert two extra pinions into the gear grooves on opposite sides of the gear, and press the gear with a bearing down on top of them for a tight fit and leveled gears. Tighten the shaft pins on this bearing. Remove the pinions.
  - Finally, install the steering wheel on the top of the shaft, and insert a 1/4"-20 2.5" bolt with a lock nut on the end.
- Frame to support the propeller shafts:
  - Cut the 3' long T-slotted rail into two equal parts of 16" in length. Each of these rails will be mounted perpendicularly to the chain stay bar. The remaining 4 inches will not be needed. C-clamp these rails in place as far apart as they can be (should be essentially the total length of the chain stay bar). Grab the two identical aluminum plates and align the front-facing edges with the edge of the steel bar. For each aluminum plate, drill two ¼" holes through the plate and steel beneath it. A third hole should be drilled as the point of a triangle, and this hole should go through the plate and the T-slot. There should be a total of 6 hex head screws bolted through these holes (3 on each side) and secured with lock nuts on the bottom.
  - Cut the 1' long T-slotted rail in half. These two pieces will be attached in a T-shape, with the bottom of the T connected to the steel chain stay bar perpendicularly (in the same plane as the T-slots). Angle brackets will need to be bolted with 8020 fastener hardware to hold the right angles of the T. Bolt one of the pillow blocks in the same plane so that the bearing is horizontal and can fit the end of the vertical PVC shaft inside. This allows for the pipe to rotate while the aluminum frame remains static.

- Find the horizontal centerline of the 12" x 12" x 1/4" aluminum slab and mark it with a writing utensil. Match this line with the centerline of the chain stay tube's top surface. This plate will rest on top of 8020 T-slots to prevent rotation. Drill two 1/4" holes along the vertical centerline, one through the bottom of the T, and the other through the steel.

- Propeller blades on shafts:
  - Cut the 10' PVC pipe into two 5' lengths. Attach four propeller blade parts around one end of each of the two 5' pipes, putting JB Marine Weld in between each blade part to ensure the pins stay together well. Drill an M5 hole on the opposite end of each PVC pipe, 0.25" away from the end. Drill a matching hole into the 3D printed pinion. Later, these will be attached with M5 socket head screws, after the shaft is placed through the support bearings.
- Supports for propellers:
  - Grab four of the ball bearings. Unscrew each of the ball bearing screws. Run the two propeller shafts each through two ball bearings. Now it's time to attach the pinions at the end of each PVC pipe and secure them with M5 socket head screws. Place these identical shafts at 30° angles from the vertical and rest the pinions in between the teeth of the sandwich gears. Take the two ball bearings closest to the pinions and angle them so that the bearing is perpendicular to the PVC. Tighten these ball bearing screws with an ⅛" allen key and mark the holes of the bearing. Drill through these holes to place more ¼" bolts through the aluminum slab and secure the location of the bearings. Check if the bearings are level, and if not, add spaces as needed.
  - Find the intersection point of the last 3 inches of the 1.5" T-slots with the angled propeller shafts. Similar to the previous step, the bearing holes need to be marked and drilled. Use the two 3" x 3" x ¼" aluminum plates as spaces between the bearings and the T-slots and drill through all material. Secure all bolts with lock nuts.

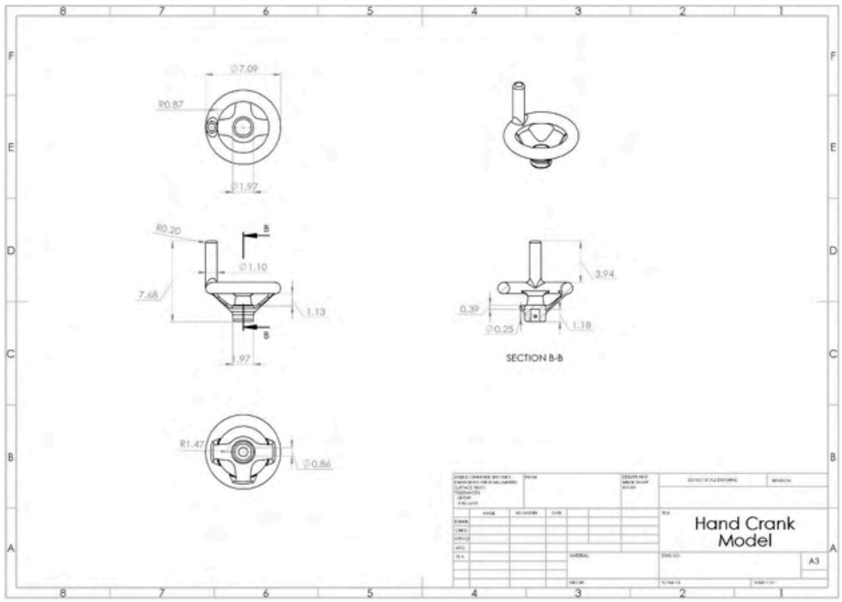
<u>Steering Assembly</u>

- Collect materials (see BOM - Steering)
- Tie rod + Adapter Assembly:
  - Cut ½" aluminum tube to 25.75", drilling two .136" through holes .75" from either end
  - Arrange one half of tie rod adapter on either side of tube, lining up the through holes and place a right-hand-thread ⅜"-24 hex nut into the hexagonal relief on the right side and a left-hand thread nut into the left side.
  - Place the other half of the adapter over and fasten the two together with #8-1" socket head bolts, including washers on either side and lock nuts. Ensure tightness.

- Thread a nut and washer on each ball-joint rod end and thread them into their correct adapter.

- Tie Rod Arm x2 (mirrored)
  - Cut 1.5” aluminum angle to 3.15”, drilling a ⅞” hole along the centerline, 1” from the end. Cut to 10mm wide slots at either tip of the “L”.
  - Take a 6” length of 1.5”x.25” aluminum bar and create a 20deg bend 1” in from either end. The two ends should be parallel. Drill a ⅜” hole along the centerline ½” from the lower end and three .316” holes at the other end. Cut a 45deg chamfer at the end with the ⅜” hole.
  - Clamp the two pieces together at a 20 degree angle, with the aluminum bar on the inner face of the aluminum angle. Mark the three hole locations and drill out the aluminum angle at those locations, fastening the two with #8 bolts, washers, and locknuts.
  - Loosen the stem binder bolt and cap using a 6mm allen key and line up the bike stem with the ⅞” hole in the aluminum angle. Place the cap into the hole and tighten the hole assembly, ensuring the wheel is aligned with the stem and the downward face of the angle is pressed into the stem.
  - Chain two 8mm hose clamps into one another and string them around the bottom of the stem and around the aluminum angle, going through the two slots. Tighten.
- With a ⅜” bolt, fasten the ball joint end rod onto the underside of the tie rod arms on either end, securing with washers and locknuts.
- Turn the Tie Rod in either direction to adjust the steering toe. When the two wheels are pointing in the same direction, tighten the nuts on the rod end shanks against the rod end adapter, securing the assembly.

Appendix E: Engineering Part and Assembly Drawings



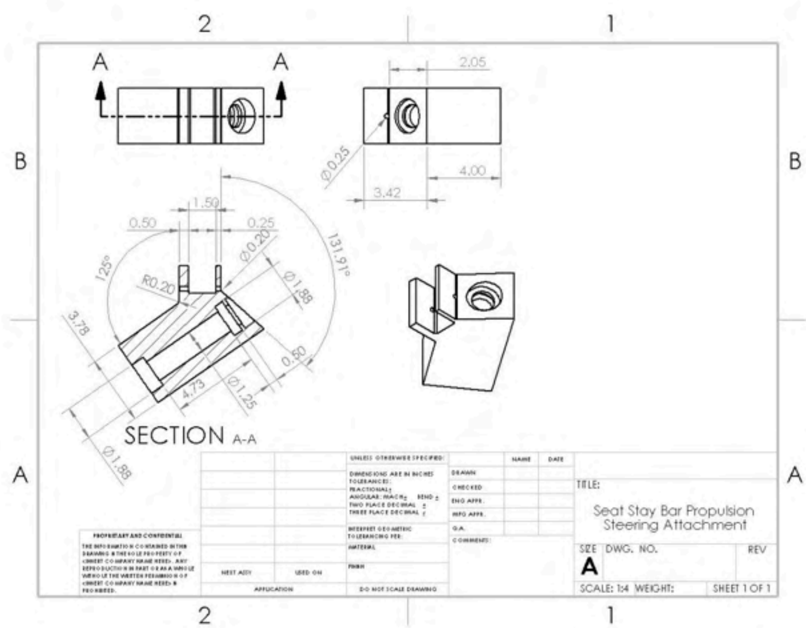


Figure E.1: Hand Crank Attachment Drawings

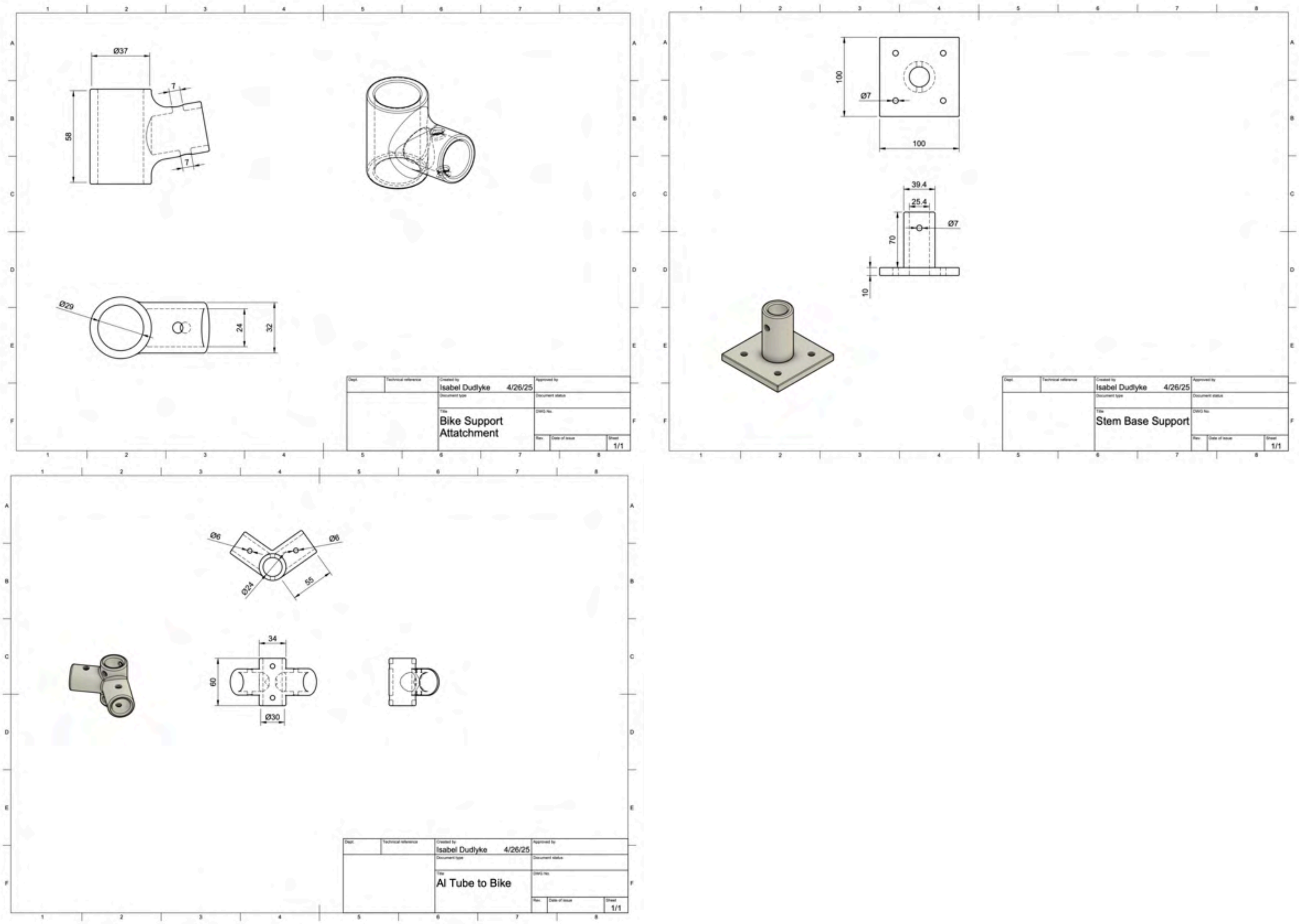


Figure E.2: Piranha Plant Stem Drawings

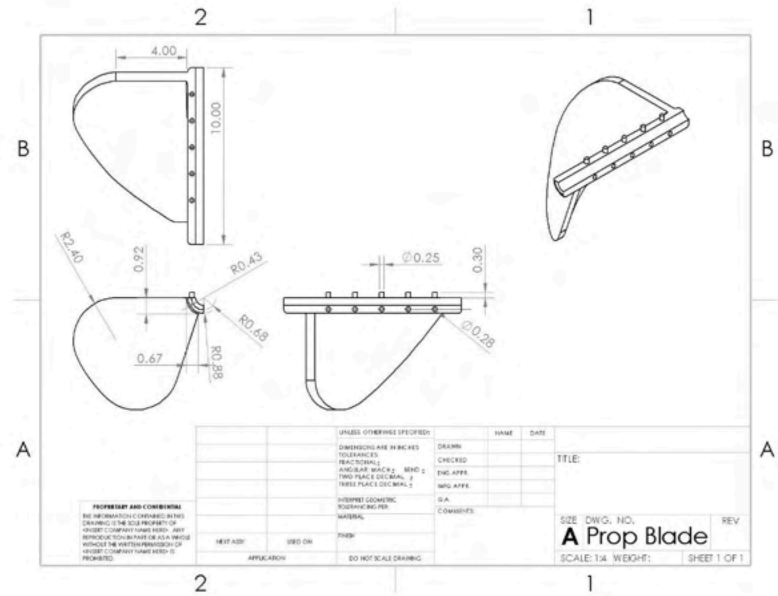


Figure E.3: Propeller Blade Drawing

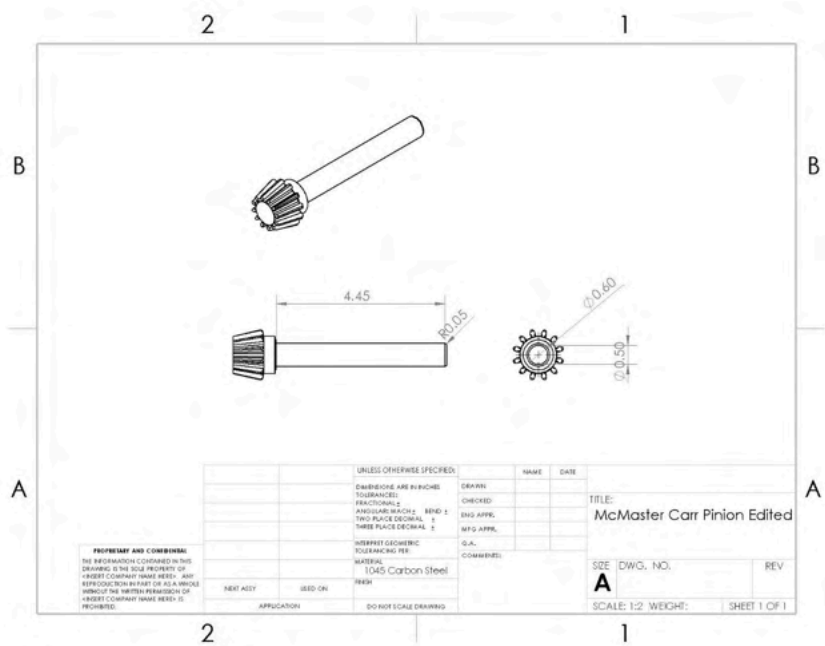


Figure E. 4: Edited Pinion Measurements Drawing

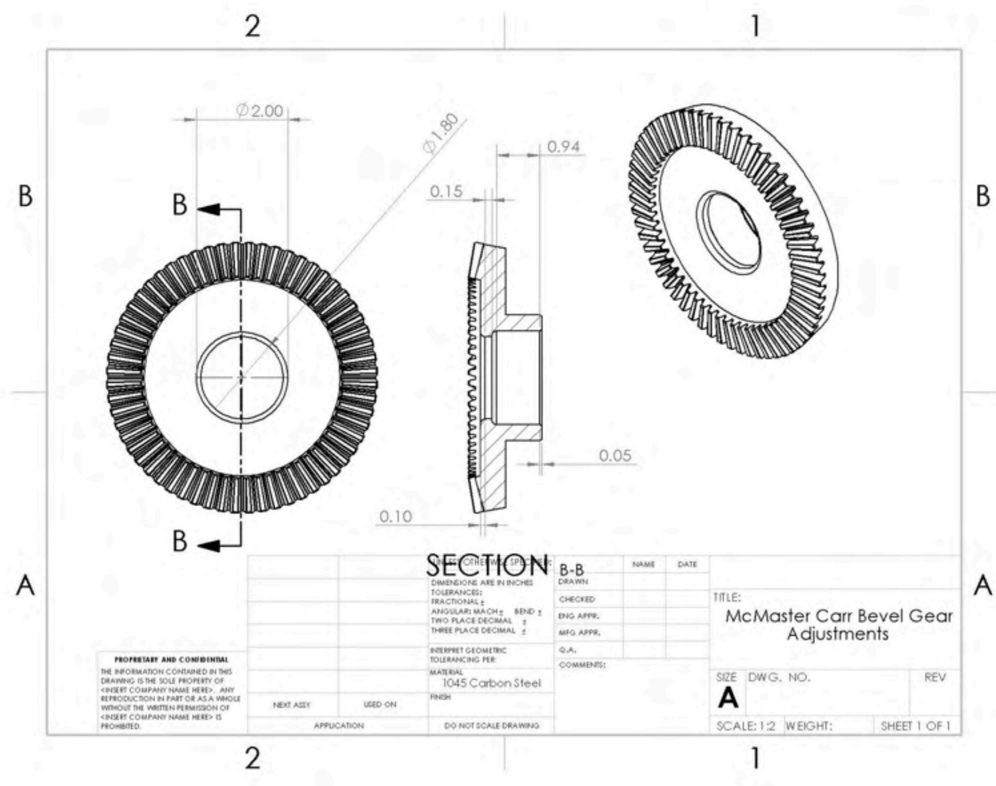


Figure E.5: Edited Gear Measurements Drawing (For Gear With Bearing)

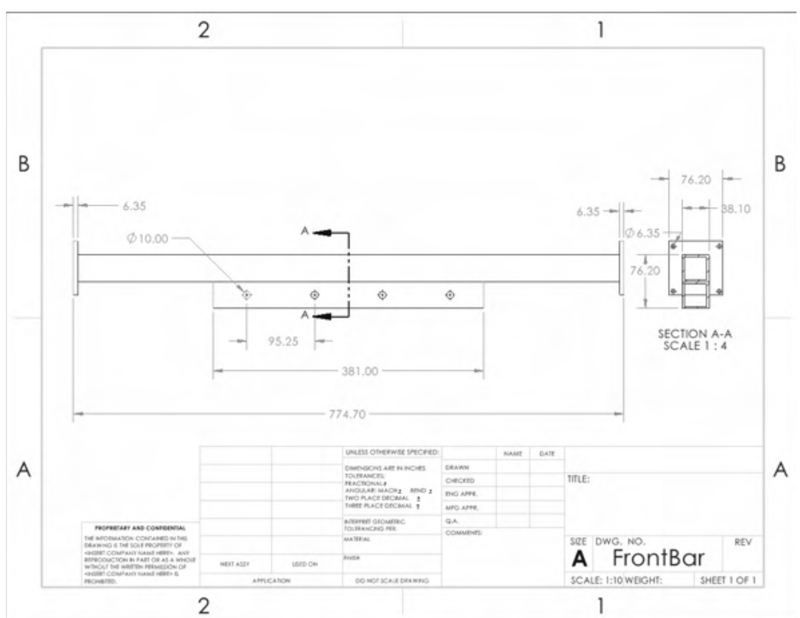


Figure E.6: Head Tube Connecting Bar

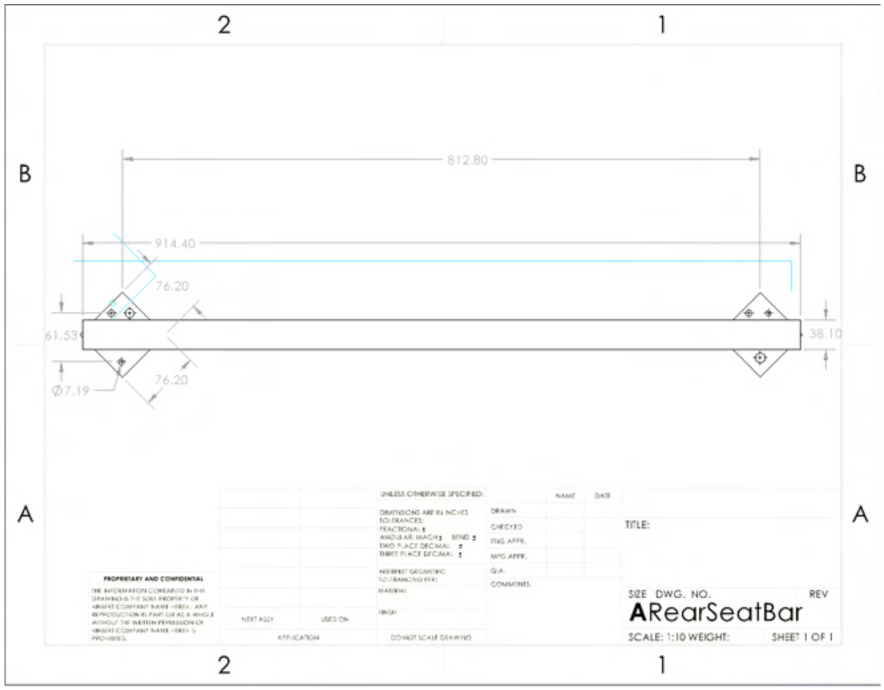


Figure E.7: Seat Stay Connecting Bar

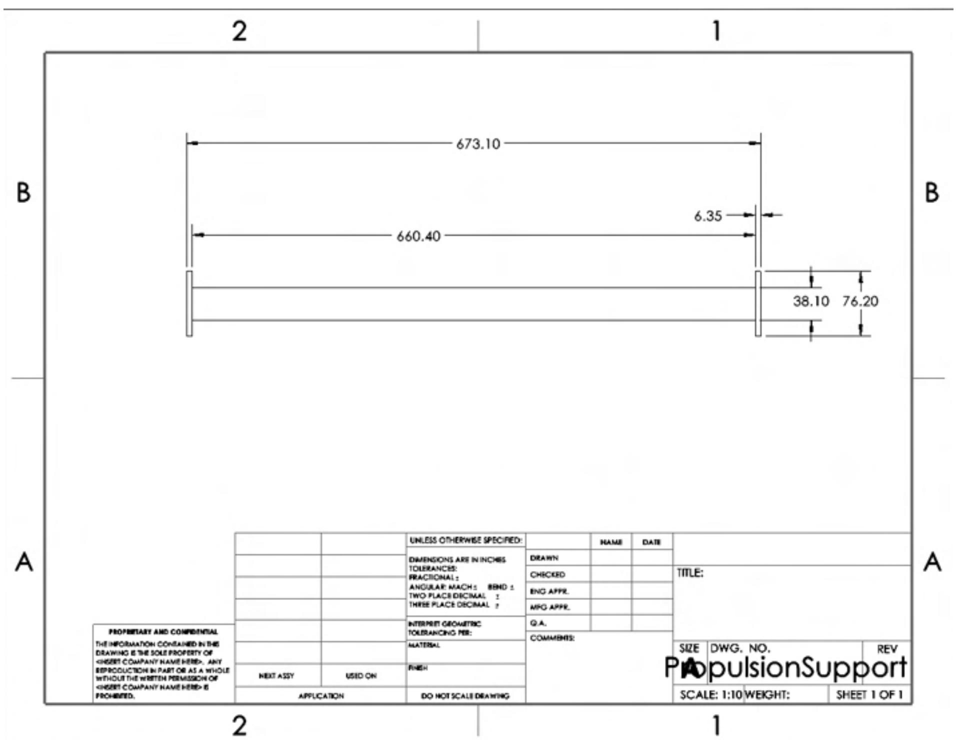


Figure E.8: Chain Stay Connecting Bar

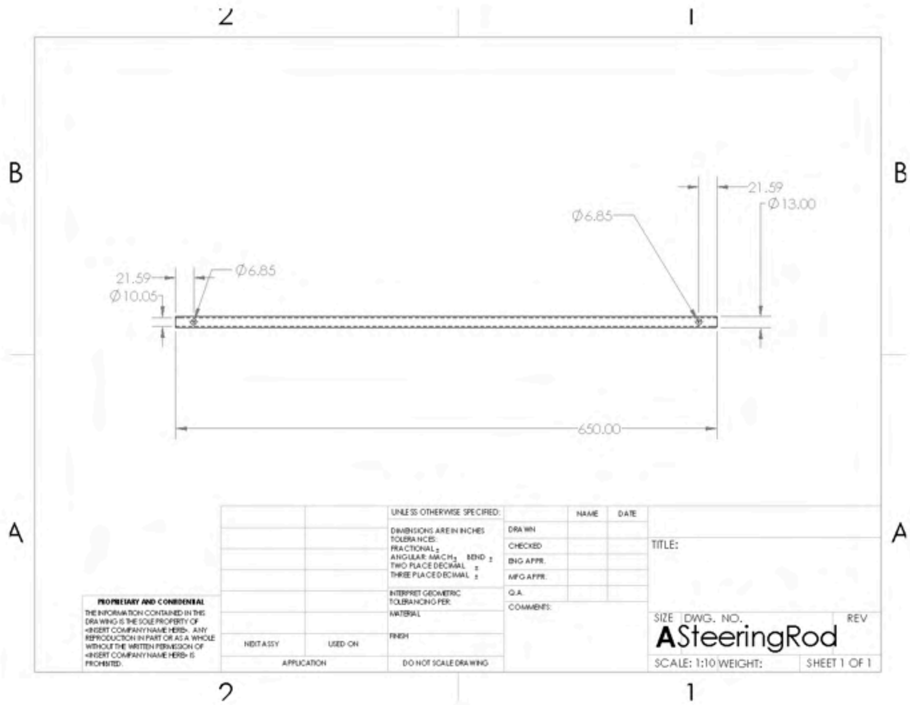


Figure E.9: Tie Rod

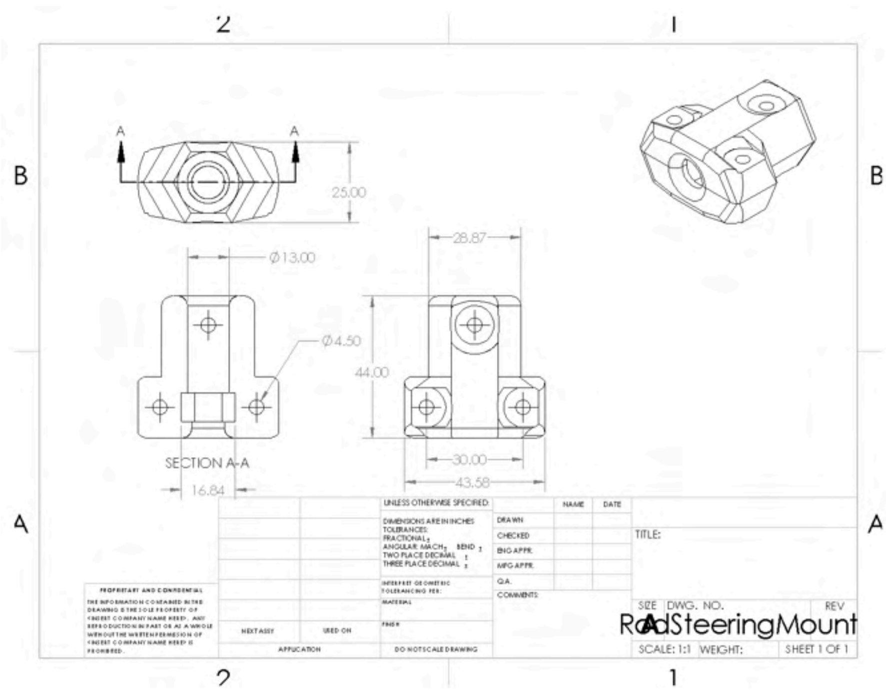


Figure E.12: Tie Rod Adapter

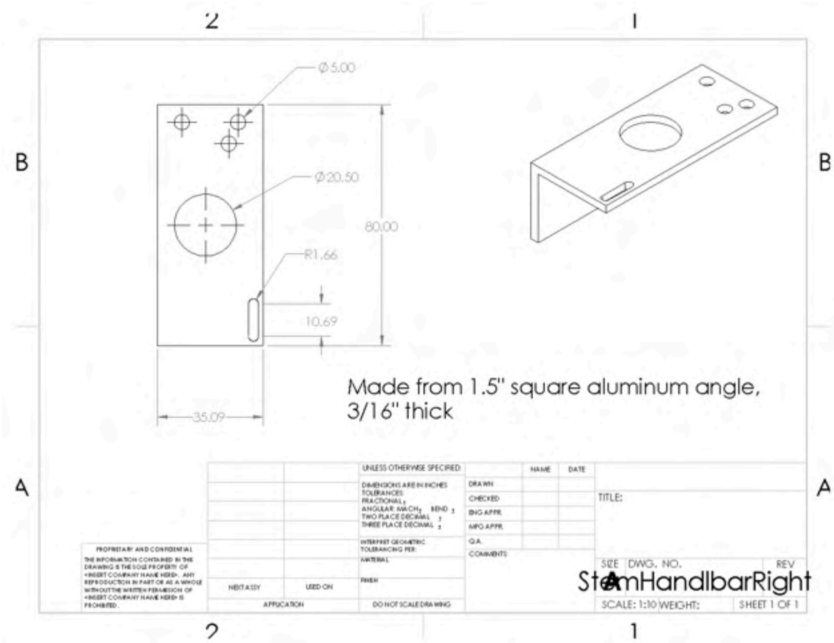


Figure E.13: Tie Rod Arm (Aluminum Angle)

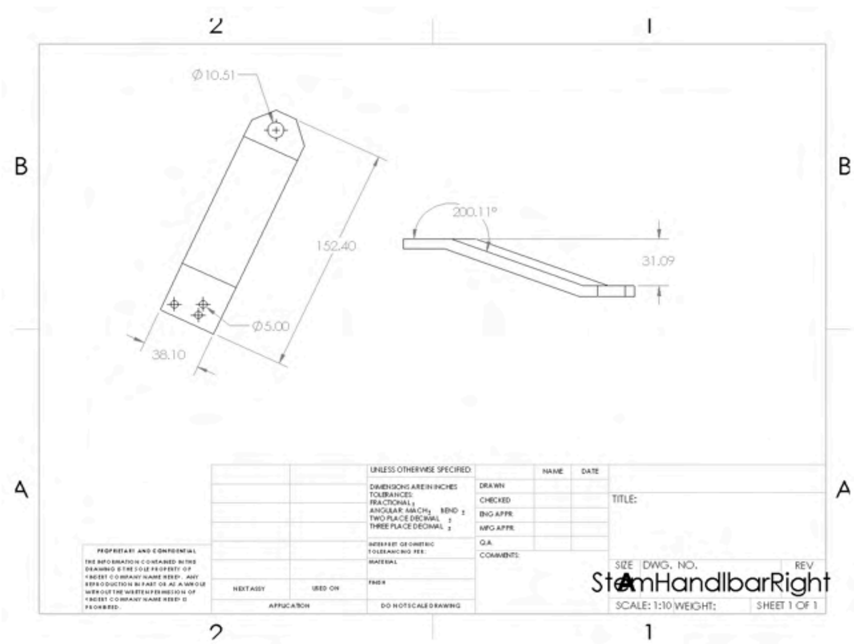


Figure E.14: Tie Rod Arm (Aluminum Bar)

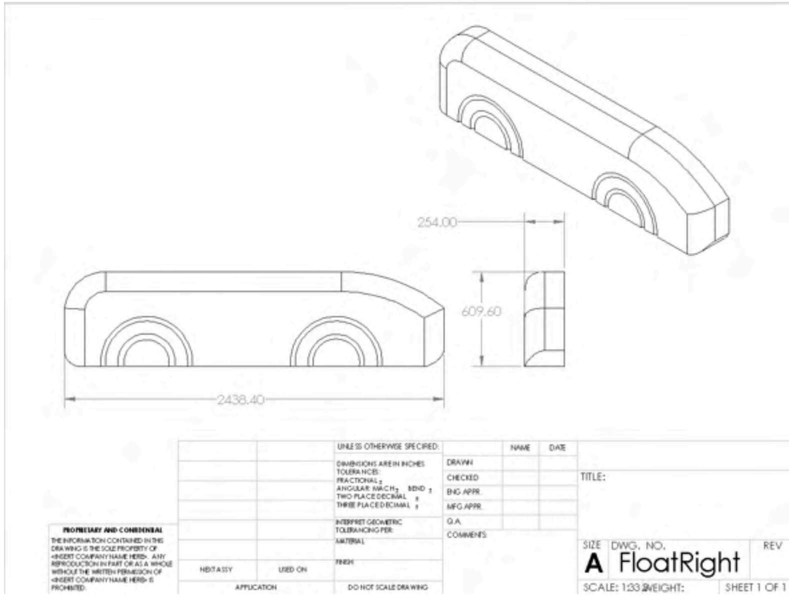


Figure E.15: Float

Appendix F: Bill Of Materials

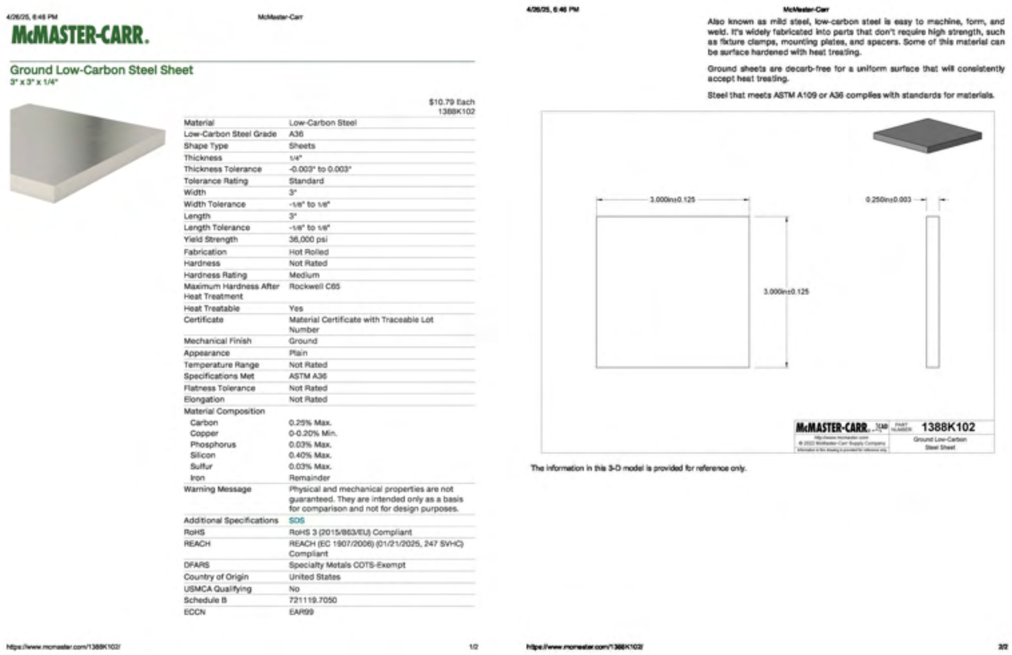
Item	Description	Material	Source	Quantity	Part #	Unit Price	Total Price
Subsystem 1: Frame							
Nishiki Mountain Bike	Mountain Bikes	Steel (Grade Unknown)	Dick's Sporting Goods	2		$269.00	$538.00
Low-Carbon Steel Sheet	Steel Plates (3"x3"x1/4")	1018 Low-Carbon Steel	McMaster-Carr	10	1388K102	$10.79	$107.90
Low-Carbon Steel Rectangular Tubes	Tubes (1.5"x1.5"x3', 0.065" wall thickness)	1018 Low-Carbon Steel	McMaster-Carr	3	6527K572	$16.91	$50.73
Hex Head Screw, 5/16"-18 Thread Size, 2-1/2" Long	Bar Weld Attachment	SAE Grade 8 Steel	Duke (Garage Lab)	10	92865A593	$0.43	$4.30
Hex Head Screw, 5/16"-18 Thread Size, 1-1/2" Long	Bar Weld Attachment	SAE Grade 8 Steel	Duke (Garage Lab)	2	92865A587	$0.26	$0.52
5/16" Washer	Bar Weld Attachment	18-8 Stainless Steel	Duke (Garage Lab)	6	92141A030	$0.08	$0.48
5/16"-18 Locknut	Bar Weld Attachment	Zinc-Plated Steel	Duke (Garage Lab)	12	90630A115	$0.21	$2.52
5/16"-18 Hex nut	Bar Weld Attachment	SAE Grade 8 Steel	Duke (Garage Lab)	2	95505A602	$0.10	$0.20
Socket Head Screw, M5x0.8-30, Partially Threaded	Bar Weld Attachment	Black-Oxide Alloy Steel	Duke (Garage Lab)	4	91290A254	$0.23	$0.92
M5 Washer	Bar Weld Attachment	18-8 Stainless Steel	Duke (Garage Lab)	32	93475A240	$0.04	$1.28
M5x0.8 Locknut	Bar Weld Attachment	Zinc-Plated Steel	Duke (Garage Lab)	6	94645A102	$0.17	$1.02
M5x0.8 Hex nut	Bar Weld Attachment	Zinc-Plated Steel	Duke (Garage Lab)	6	90591A260	$0.04	$0.24
Socket Head Screw, M5x0.8-40, Partially Threaded	Bar Weld Attachment	Black-Oxide Alloy Steel	Duke (Garage Lab)	2	91290A258	$0.32	$0.64
						Subtotal:	$708.75
Subsystem 2: Steering							
Ball Joint Rod End, 3/8"-24 RH Thread	Tie Rod End	Zinc Plated Steel	McMaster-Carr	2	60645K14	$6.60	$13.20
PLA Raw Material - Included in propulsion	Tie Rod End Adapter	PLA	Duke (Garage Lab)	1		$0.00	
Steel Left-Hand-Thread Hex Nut, 3/8"-24 Thread Size	Left-Hand-Thread Hex Nuts	Zinc Plated Steel	McMaster-Carr	2	90738A150	$0.38	$0.76
Steel Hex Nut, 3/8"-24 Thread Size	Right-Hand-Thread Hex Nuts	Zinc Plated Steel	McMaster-Carr	2	95462A515	$0.12	$0.24
Socket Head Screw, 8-32, 1" Long	Fastener	Zinc Plated Steel	Duke (Garage Lab)	12	91251A199	$0.22	$2.59
No. 8 Washer, .172" ID, 0.375" OD	Washer	Stainless Steel	Duke (Garage Lab)	24	92141A009	$0.02	$0.50
Nylon-Insert Locknut 8-32 Thread Size	Locknut	Zinc Plated Steel	Duke (Garage Lab)	12	90631A009	$0.05	$0.55
Worm-Drive Clamps 5/16" Band Width	Hose Clamp	Stainless Steel	Duke (Garage Lab)	4	5388K24	$1.32	$5.28
90 Deg 1/16" Thickness, 1.5" Outside Height	Tie Rod Arm- Aluminum Angle	6061 Aluminum	Duke (Garage Lab)	2	8982K7	$0.80	$1.60
6061 Aluminum Bar, 1/4" Thick x 1-1/2" Wide	Tie Rod Arm - Aluminum Bar	6061 Aluminum	Duke (Garage Lab)	2	8975K518	$1.64	$3.29
Aluminum Tube, 1/2" OD, 0.065" Wall Thickness	Tie Rod	6061 Aluminum	Duke (Garage Lab)	1	89965K26	$8.54	$8.54
						Subtotal:	$36.55
Subsystem 3: Propulsion							
PLA Raw Material (5kg)	3D Printed Parts	PLA	Duke (Garage Lab)	1	DCUS-PLA+2.0-BK-5KG	$59.99	$59.99
Socket Head Screw, M5x0.8-30, Partially Threaded	Propellers	Black-Oxide Alloy Steel	Duke (Garage Lab)	2	91290A254	$0.23	$0.46
M5x0.8 Hex nut	Propellers	Zinc-Plated Steel	Duke (Garage Lab)	2	90591A260	$0.04	$0.08
7/8" ID Pillow Blocks	Support	Steel	McMaster-Carr	6	5913K76	$15.51	$93.06
7/8" ID Ball Bearing	Support	Stainless Steel	Amazon	1	H20220603066	$8.99	$8.99
1-1/2" T-Slotted Framing Rail, 3' Length	Support	Aluminum	McMaster-Carr	1	47065T101	$34.40	$34.40
1" T-Slotted Framing Rail, 1' Length	Support	Aluminum	McMaster-Carr	1	47065T101	$8.67	$8.67
12" x 12" x 1/4" Aluminum Slab	Support	Aluminum	McMaster-Carr	1	8973K97	$39.55	$39.55
1/2" x 10' PVC Pipe	Connect Shafts	PVC	Home Depot	2	319692959	$4.96	$9.92
Hex Head Screw 1/4"-20 Thread Size, 1-1/2" Long	Various Attachments	SAE Grade 8 Steel	Duke (Garage Lab)	29	91268A160	$0.79	$22.91
1/4"-20 Lock Nut	Various Attachments	SAE Grade 8 Steel	Duke (Garage Lab)	29	90630A110	$0.18	$5.22
						Subtotal:	$283.25
Subsystem 4: Flotation & Aesthetics							
EPS Foam sheet 8 feet x 4 feet x 10 inches	For Pontoons	EPS Foam	Home Depot	10	202532854	$14.38	$143.80
Liquid Nails - Project	Foam Adhesive		Home Depot	18	100659439	$2.78	$50.04
Great Stuff - Big Gap Filler	Pirahna Head	polyurethane foam	Home Depot	5	202893739	$5.98	$29.90
Mod Podge	128 oz	PVA	Amazon	1	B0018N96CG	$44.49	$44.49
Acrylic Paint - Red	1 Gallon - Whiplash red	Acrylic	Home Depot	1	315215417	$31.98	$31.98
Acrylic Paint - Blue	1/2 gallon	Acrylic	Amazon	1	B0042SUQH8	$20.39	$20.39
Acrylic Paint - Yellow	16 oz	Acrylic	Amazon	1	B0018NBSTK	$4.97	$4.97
Acrylic Paint - White	1/2 gallon	Acrylic	Amazon	1	B0042SWSW4	$23.35	$23.35
Acrylic Paint - Black	1/2 gallon	Acrylic	Amazon	1	B0042SSY0E	$16.19	$16.19
Flex Seal Liquid - Clear	128 Fl oz	Rubber	Home Depot	1	310388023	$109.99	$109.99
Spray Paint - Green	For Stem		Home Depot	1	307246309	$5.98	$5.98
Aluminium Tube - 1" Diameter	Pirahna Plant Stem	Aluminium	Duke (Garage Lab)	1	204487850	$48.05	$48.05
3D Printed Support Parts - 213 g	For Pirhana Plant	PLA	Duke (CoLab)	1	DCUS-PLA+2.0-BK-5KG	$21.30	$21.30
1/4" -20 x 2-1/2" GR5 Hex Head Bolt	For Pirhana Plant	SAE Grade 8 Steel	Duke (Garage Lab)	8	92865A552	$0.32	$2.56
1/4" -20 x 2" GR5 Hex Head Bolt	For Pirhana Plant	SAE Grade 8 Steel	Duke (Garage Lab)	5	92865A549	$0.23	$1.15
1/4"-20 Lock Nut	For Pirhana Plant	SAE Grade 8 Steel	Duke (Garage Lab)	13	90630A110	$0.18	$2.34
1/4" -20 x 2" Hex Head Bolt	For flotation support	SAE Grade 8 Steel	Duke (Garage Lab)	10	91268A430	$1.09	$10.90
Eye bolts	For flotation support	Steel	Duke (Pod)	4	9489T39	$2.63	$10.52
Steel Tubes	For flotation support	Steel	J&D Recyling	2	N/A	$40.64	$81.28
						Subtotal:	$475.10
Subsystem 5: Safety Features							
Safety Triangle	Safety	Plastic	Amazon	1		$8.99	$8.99
Horn	Safety	Plastic	Amazon	1		$9.99	$9.99
Tow Rope	Safety	Nylon	Duke	1		$24.99	$24.99
Tow Ring	Safety	Metal	Duke	1		$9.99	$9.99
Paddles	Safety	Metal	Student's house	2		$9.99	$19.98
Life jacket	Safety	Foam	Student's house	2		$9.99	$19.98
First Aid kit	Safety	Cloth	Duke	1		$3.99	$3.99
						Subtotal:	$97.91
						Total Cost:	$1,601.56

Figure F.1: Bill of Materials

Appendix G: Prototype and Projected Production Costs

The prototype cost $1602. This project is not designed for scale so it can be estimated to cost the same amount if built again or attempted to be built in scale.

Appendix H: Specification Sheets



4/26/25, 6:46 PM McMaster-Carr

McMASTER-CARR.

Ground Low-Carbon Steel Sheet
3" x 3" x 1/4"

$10.79 Each
1388K102

Material	Low-Carbon Steel
Low-Carbon Steel Grade	A36
Shape Type	Sheets
Thickness	1/4"
Thickness Tolerance	-0.003" to 0.003"
Tolerance Rating	Standard
Width	3"
Width Tolerance	-1/8" to 1/8"
Length	3"
Length Tolerance	-1/8" to 1/8"
Yield Strength	36,000 psi
Fabrication	Hot Rolled
Hardness	Not Rated
Hardness Rating	Medium
Maximum Hardness After Heat Treatment	Rockwell C65
Heat Treatable	Yes
Certificate	Material Certificate with Traceable Lot Number
Mechanical Finish	Ground
Appearance	Plain
Temperature Range	Not Rated
Specifications Met	ASTM A36
Flatness Tolerance	Not Rated
Elongation	Not Rated
Material Composition	
Carbon	0.25% Max.
Copper	0-0.20% Min.
Phosphorus	0.03% Max.
Silicon	0.40% Max.
Sulfur	0.03% Max.
Iron	Remainder
Warning Message	Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes.
Additional Specifications	SDS
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/21/2025, 247 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	United States
USMCA Qualifying	No
Schedule B	721119.7050
ECCN	EAR99

https://www.mcmaster.com/1388K102/ 1/2

4/26/25, 6:46 PM McMaster-Carr

Also known as mild steel, low-carbon steel is easy to machine, form, and weld. It's widely fabricated into parts that don't require high strength, such as fixture clamps, mounting plates, and spacers. Some of this material can be surface hardened with heat treating.

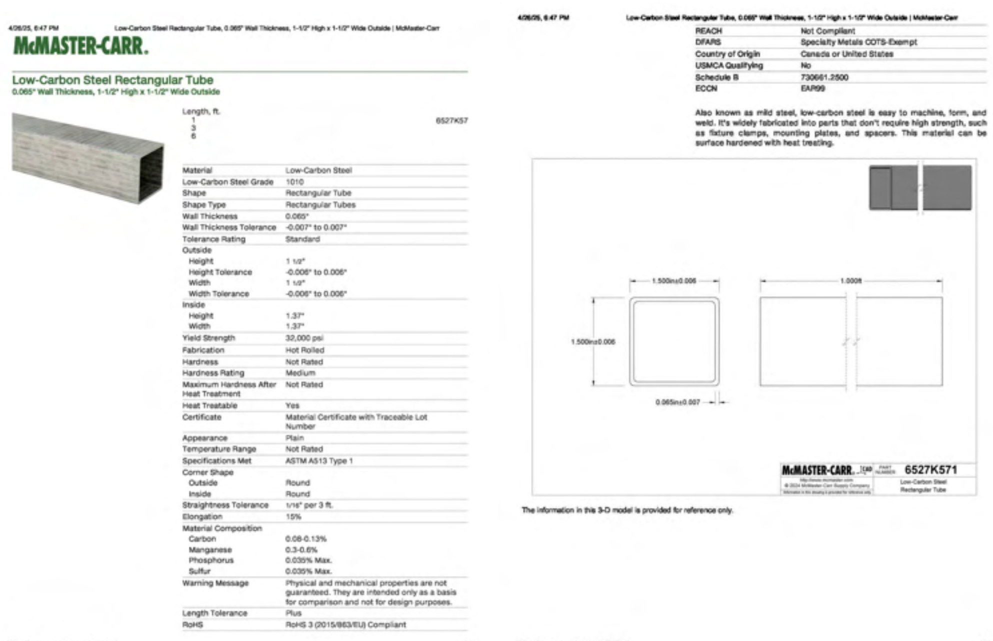
Ground sheets are decarb-free for a uniform surface that will consistently accept heat treating.

Steel that meets ASTM A109 or A36 complies with standards for materials.

The information in this 3-D model is provided for reference only.

https://www.mcmaster.com/1388K102/ 2/2

Figure H.1: Steel Plate Specification Sheet



4/26/25, 6:47 PM Low-Carbon Steel Rectangular Tube, 0.065" Wall Thickness, 1-1/2" High x 1-1/2" Wide Outside | McMaster-Carr

McMASTER-CARR.

Low-Carbon Steel Rectangular Tube
0.065" Wall Thickness, 1-1/2" High x 1-1/2" Wide Outside

Length, ft.
1
3
6

6527K57

Material	Low-Carbon Steel
Low-Carbon Steel Grade	1010
Shape	Rectangular Tube
Shape Type	Rectangular Tubes
Wall Thickness	0.065"
Wall Thickness Tolerance	-0.007" to 0.007"
Tolerance Rating	Standard
Outside	
Height	1 1/2"
Height Tolerance	-0.006" to 0.006"
Width	1 1/2"
Width Tolerance	-0.006" to 0.006"
Inside	
Height	1.37"
Width	1.37"
Yield Strength	32,000 psi
Fabrication	Hot Rolled
Hardness	Not Rated
Hardness Rating	Medium
Maximum Hardness After Heat Treatment	Not Rated
Heat Treatable	Yes
Certificate	Material Certificate with Traceable Lot Number
Appearance	Plain
Temperature Range	Not Rated
Specifications Met	ASTM A513 Type 1
Corner Shape	
Outside	Round
Inside	Round
Straightness Tolerance	1/16" per 3 ft.
Elongation	15%
Material Composition	
Carbon	0.08-0.13%
Manganese	0.3-0.6%
Phosphorus	0.035% Max.
Sulfur	0.035% Max.
Warning Message	Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes.
Length Tolerance	Plus
RoHS	RoHS 3 (2015/863/EU) Compliant

https://www.mcmaster.com/6527K57/ 1/2

4/26/25, 6:47 PM Low-Carbon Steel Rectangular Tube, 0.065" Wall Thickness, 1-1/2" High x 1-1/2" Wide Outside | McMaster-Carr

REACH	Not Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Canada or United States
USMCA Qualifying	No
Schedule B	730661.2500
ECCN	EAR99

Also known as mild steel, low-carbon steel is easy to machine, form, and weld. It's widely fabricated into parts that don't require high strength, such as fixture clamps, mounting plates, and spacers. This material can be surface hardened with heat treating.

The information in this 3-D model is provided for reference only.

https://www.mcmaster.com/6527K57/ 2/2

Figure H.2: Steel Tube Specification Sheet

4/27/25, 11:50 PM — Low-Profile Mounted Sealed Steel Ball Bearing, with Set Screw, for 7/8" Shaft Diameter | McMaster-Carr

McMASTER-CARR.

Low-Profile Mounted Sealed Steel Ball Bearing
with Set Screw, for 7/8" Shaft Diameter

$15.51 Each
5913K76

System of Measurement	Inch
Mounted Bearing Type	Base Mount
Bearing Type	Ball
For Load Direction	Radial
Housing Material	Steel
Bearing Material	Steel
Seal Type	Sealed
Inner Ring Type	Standard
Shaft Mount Type	Set Screw
Set Screw Thread Size	1/4"-28
Number of Set Screws Included	2
For Shaft Type	Round
For Shaft Diameter	7/8"
ID	0.875"
ID Tolerance	0" to 0.0007"
Center Height	1 1/8"
Overall	
Height	2 7/32"
Length	4 1/4"
Width	1 25/64"
Mounting	
Hole Center -to-Center	3 25/64"
Number of Holes	2
Fasteners Included	No
Radial Load Capacity, lbs.	
Dynamic	3,140
Static	1,760
Maximum Speed	5,100 rpm
Temperature Range	0° to 210° F
ABEC Rating	Not Rated
Alignment Style	Self Aligning
Misalignment Capability	3°
Lubrication	Lubricated
Lubricant	Grease with Lithium Thickener
Grease Fitting Included	No
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/27/2024, 241 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Peoples Republic of China
Schedule B	848320.0010
ECCN	1C999

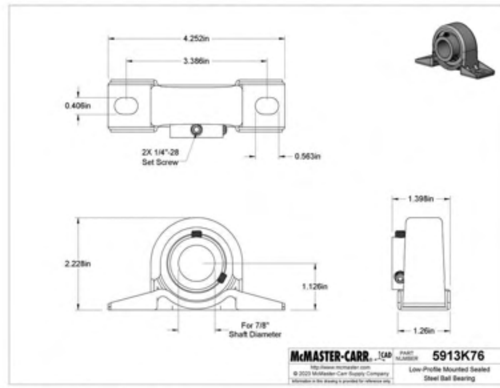
https://www.mcmaster.com/5913K76/ 1/2

4/27/25, 11:50 PM — Low-Profile Mounted Sealed Steel Ball Bearing, with Set Screw, for 7/8" Shaft Diameter | McMaster-Carr

Designed with a thin, compact housing, these bearings are good for space-constrained applications.

Bearings with steel housing are stronger than bearings with stainless steel and aluminum housings. They are self-aligning to compensate for shaft misalignment. Seals block out dust and contaminants.

Sealed bearings block out dust and other contaminants better than shielded bearings.



The information in this 3-D model is provided for reference only.

https://www.mcmaster.com/5913K76/ 2/2

Figure H.3: Pillow Block Specification Sheet

4/28/25, 3:57 PM — Metal Shaft-Mounted Bevel Pinion, 20mm Wd Face | McMaster-Carr

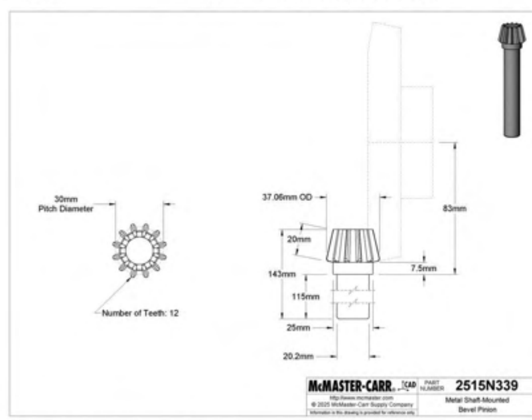
McMASTER-CARR.

Metal Shaft-Mounted Bevel Pinion, 20mm Wd Face

$83.09 Each
2515N339

Gear Type	Bevel
Component	Shaft-Mounted Gear
System of Measurement	Metric
Face Width	20 mm
Module	2.5
Pressure Angle	20°
Speed Ratio	5:1
Number of Teeth	12
Gear Pitch Diameter	30 mm
OD	37.1 mm
Overall Width	143 mm
Shaft	
Diameter	20.2 mm
Length	115 mm
Mounting Distance (B)	83 mm
Hub	
Diameter	25 mm
Width	8 mm
Material	Black-Oxide 1045 Carbon Steel
Teeth Heat Treatment	Hardened
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/14/2023, 235 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Japan
Schedule B	848340.9000
ECCN	EAR99

4/28/25, 3:57 PM — Metal Shaft-Mounted Bevel Pinion, 20mm Wd Face | McMaster-Carr



The information in this 3-D model is provided for reference only.

Figure H.4: Pinion Specification Sheet (Before Edits)

4/28/25, 3:58 PM Metal Bevel Gear, 20 mm Face Width, 2.5 Module, 5:1 Speed Ratio | McMaster-Carr

McMASTER-CARR.

Metal Bevel Gear
20 mm Face Width, 2.5 Module, 5:1 Speed Ratio

$201.07 Each
2515N355

Gear Type	Bevel
Component	Gear
System of Measurement	Metric
Bore Type	Round
Face Width	20 mm
Module	2.5
Pressure Angle	20°
Speed Ratio	5:1
Number of Teeth	60
Gear Pitch Diameter	150 mm
OD	150.5 mm
Overall Width	40 mm
For Shaft Diameter	20 mm
Mounting Distance (A)	50 mm
Hub	
Diameter	70 mm
Width	20 mm
Material	Black-Oxide 1045 Carbon Steel
Teeth Heat Treatment	Not Hardened
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/14/2023, 235 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Japan
Schedule B	848340.9000
ECCN	EAR99

A type of miter gear where one gear (sometimes called a pinion) is smaller than the other, bevel gears provide right-angle speed reduction at speed ratios ranging from 2:1 to 5:1. All are carbon steel for strength; they're compatible with plastic bevel gears. Teeth are not hardened so you can harden them to fit your application. Hardening a gear's teeth increases its wear resistance.

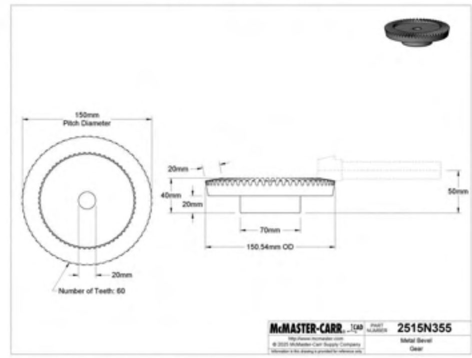
A complete set consists of a gear and pinion (sold separately). For a gear and pinion to mesh correctly, they must have the same pressure angle, pitch/module, and face width.

Shaft-mounted pinions come already securely fastened to a shaft.

Speed ratio is the ratio by which shaft speed is reduced when transferring motion from pinion to gear. To increase shaft speed, transfer motion from gear to pinion. Changing shaft speed also changes torque: as speed decreases, torque increases.

https://www.mcmaster.com/2515N355/ 1/2

4/28/25, 3:56 PM Metal Bevel Gear, 20 mm Face Width, 2.5 Module, 5:1 Speed Ratio | McMaster-Carr



The information in this 3-D model is provided for reference only.

https://www.mcmaster.com/2515N355/ 2/2

Figure H.5: Gear Specification Sheets (Before Edits)

IPEX
by aliaxis

10100 Rodney Street
Pineville NC 28134
1–800–463–9572

IPEX USA LLC
homeflexunderground@ipexamerica.com
homeflexunderground.com

Product Schedule 40 PVC Solid Wall Pressure Pipe

Project Information

Job Name: ______________________ Date Submitted: ______________________
Location: ______________________ Submitted by: ______________________
Engineer: ______________________ Approved by: ______________________
Contractor: ______________________ Manufacturer's Rep: ______________________

Application Information

For use in pressurized water systems requiring D1785 pipe and DWV applications requiring D2665 pipe and where maximum operating temperature will not exceed 140°F.

Technical Data

Materials

Polyvinyl Chloride 1120

Temperature Ratings

Max Operating Temperature: 140°F

Pressure Ratings

Ranges from 280 - 600 psi @ 73°F. Refer to table below.

Codes

Uniform Plumbing Code (UPC®)

Listings

IAPMO R&T: 13054 (1/2"-2" Pipe, ASTM D1785); 13055 (1-1/4"-2" Pipe, ASTM D2665); 13057 (NSF/ANSI/CAN 61)

Standards

ASTM D-1785-15; NSF/ANSI 14 & 61; ASTM D2665-20 (Applies to nominal pipe sizes ≥ 1.25". Pipe sizes marked with '*')

Dimensional Information

	Pipe Size	Part Number	Dimensions				PSI at 73°
			O.D. (in)	Nom. Pipe Size (in)	Min. Wall Thickness (in)	Weight (lbs)	
☐	1/2"×10'	022401	0.840	0.500	0.109	1.64	600
☐	1/2"×20'	022402	0.840	0.500	0.109	3.28	600
☐	3/4"×10'	022403	1.050	0.750	0.113	2.18	480
☐	3/4"×20'	022404	1.050	0.750	0.113	5.60	480
☐	1"×10'	022405	1.315	1.000	0.133	3.24	450
☐	-	-	-	-	-	-	-
☐	1-1/4"×10'*	022406	1.660	1.250	0.140	4.39	370
☐	1-1/4"×20'*	022407	1.660	1.250	0.140	8.78	370
☐	1-1/2"×10'*	149024	1.900	1.500	0.145	5.25	330
☐	1-1/2"×20'*	149027	1.900	1.500	0.145	5.50	330
☐	2"×10'*	022408	2.375	2.000	0.154	7.05	280
☐	2"×20'*	022409	2.375	2.000	0.154	14.10	280

NSF/ANSI/CAN 61
UPC®

2109/B

Figure H.6: PVC Pipe for Propellers Specification Sheet

MarineWeld™ Syringe - Part B

J-B Weld Company LLC

Version No: **4.6**
Safety Data Sheet according to OSHA HazCom Standard (2012) requirements

Issue Date: **12/07/2023**
Print Date: **12/07/2023**
S.GHS.USA.EN

SECTION 1 Identification

Product Identifier

Product name	MarineWeld™ Syringe - Part B
Synonyms	50172 MarineWeld™ Syringe Part B
Other means of identification	UFI:FGXF-64NM-V00E-8GF2

Recommended use of the chemical and restrictions on use

Relevant identified uses	Use according to manufacturer's directions.

Name, address, and telephone number of the chemical manufacturer, importer, or other responsible party

Registered company name	**J-B Weld Company LLC**
Address	400 CMH Road TX 75482 United States
Telephone	903-885-7696
Fax	Not Available
Website	WWW.JBWeld.com
Email	info@JBWeld.com

Emergency phone number

Association / Organisation	**InfoTrac**
Emergency telephone numbers	**Transportation Emergencies: 800-535-5053 or (24 hours)**
Other emergency telephone numbers	**Poison Control Centers: Medical Emergencies 800-222-1222 (24 hours)**

Figure H.7: JB Weld Identification for Chemical Specification Sheets

Specifications

FRAMESET:

Frame Sizes:	14 in., 16 in., 18 in., 20 in., 22 in.
Claimed Weight:	35.3 lbs.
Frame:	Durable steel frame, V-brake mount, kickstand mount
Fork:	Steel steertube and crown, travel 50mm, V brake mount
Suspension:	Front
Front travel:	50mm
Headset:	Steel, 1 in.

DRIVETRAIN:

Shifters:	Shimano Revo twist shift
Front Derailleur:	Sunrun/Power FD-10TT
Rear Derailleur:	Shimano 7s
Crankset:	Steel, 170mm, 42T, black chain guard
Chainrings:	KMC 7 speed
Bottom Bracket:	1.37 in.-24T, 68mm shell
Cassette/Cogs:	Power, 14-28T, 7S

BRAKES:

Brake Type:	Power V brake, 110mm arm
Brakeset:	Alloy linear pull

Chat

WHEELS:

Wheel Size:	26 in.
Rims:	Alloy, single wall, 32-hole, Schrader valve
Spokes:	Steel, 14G
Tires:	26 in. x 1.95 in.
Front Hub:	Steel, 32H, QR
Rear Hub:	Steel, 32H

COMPONENTS:

Handlebar:	Steel, 25.4mm
Handlebar Rise:	Rise 30mm, 25 degree
Handlebar Width:	620mm width
Stem:	Alloy/Steel
Grips:	PVC, 92mm, single density
Saddle:	Cionlli padded sport saddle
Seat Post:	Steel, adjustable
Seat Post Length:	28.6mm, 300mm length
Pedals:	Feimin 9/16 in. pedal & W/CPSC reflectors

Figure H.8: Nishiki Pueblo 1.1 26” Mountain Bike Specifications

TYPICAL PHYSICAL PROPERTIES OF R-TECH*

Property		R-TECH	Test Method
Nominal Density (pcf)		1.0	ASTM C303
R-value (Thermal Resistance) (hr-ft2-°F)/BTU			ASTM C518
(per inch)	@ 25° F	4.35	
	@ 40° F	4.17	
	@ 75° F	3.85	
Compressive Strength (psi, 10% deformation)		10	ASTM D1621
Flexural Strength (psi)		33	ASTM C203
Dimensional Stability (maximum %)		2%	ASTM D2126
Water Vapor Transmission (perms)		< 1.0	ASTM E96
Absorption (% vol.)		< 1.0	ASTM C272
Flame Spread		20	ASTM E84
Smoke Developed		150 - 300	ASTM E84

EFFECTIVE R-VALUE** (metallic-reflective facer and dead air space)

R-TECH Thickness	Design Temp.	Effective R-value (R-TECH MR + Air Space) ***
0.5"	40° F	4.90
	75° F	4.80
1.00"	40° F	7.00
	75° F	6.70
1.50"	40° F	9.10
	75° F	8.60
2.00"	40° F	11.10
	75° F	10.50
3.00"	40° F	15.40
	75° F	14.50

*Properties are based on data provided by resin manufacturers, independent test agencies and Henry.

**Effective R-value determined using R-TECH I. Higher density R-TECH products will provide higher R-value gains. The type of construction application and the depth of the air space will also impact the actual Effective R-value.

***Requires 0.75"- 3.50" dead air space and the R-TECH metallic-reflective facer towards the dead air space.

Figure H.9: Specification Sheet for EPS Foam Sheets

DUPONT

SAFETY DATA SHEET
DDP SPECIALTY ELECTRONIC MATERIALS US, INC.

Product name: GREAT STUFF™ Big Gap Filler Insulating Foam Sealant 12oz HC ES STW QP 192ct

Issue Date: 06/29/2020

Print Date: 07/23/2020

DDP SPECIALTY ELECTRONIC MATERIALS US, INC. encourages and expects you to read and understand the entire (M)SDS, as there is important information throughout the document. We expect you to follow the precautions identified in this document unless your use conditions would necessitate other appropriate methods or actions.

1. IDENTIFICATION

Product name: GREAT STUFF™ Big Gap Filler Insulating Foam Sealant 12oz HC ES STW QP 192ct

Recommended use of the chemical and restrictions on use
Identified uses: Polyurethane foam.

COMPANY IDENTIFICATION
DDP SPECIALTY ELECTRONIC MATERIALS US, INC.
400 ARCOLA ROAD
COLLEGEVILLE PA 19426-2914
UNITED STATES

Customer Information Number: 833-338-7668
SDSQuestion-NA@dupont.com

EMERGENCY TELEPHONE NUMBER
24-Hour Emergency Contact: 1-800-424-9300
Local Emergency Contact: 800-424-9300

2. HAZARDS IDENTIFICATION

Hazard classification
GHS classification in accordance with 29 CFR 1910.1200
Flammable aerosols - Category 2
Gases under pressure - Liquefied gas
Skin irritation - Category 2
Eye irritation - Category 2B
Respiratory sensitisation - Category 1
Skin sensitisation - Category 1
Effects on or via lactation
Specific target organ toxicity - single exposure - Category 3
Specific target organ toxicity - repeated exposure - Category 2 - Inhalation

Figure H.10: Great Stuff Big Gap Filler Specification Sheet

SAFETY DATA SHEET

1. Identification

Product identifier	**FLEX SEAL LIQUID BLACK**
Other means of identification	
Product code	LFSBLKR16; LFSBLKR32; LFSMAXBLK02; US855BLK32-4; US855BLK01-2
Recommended use	Sealant.
Recommended restrictions	None known.

Manufacturer/Importer/Supplier/Distributor information

Manufacturer/Supplier	Swift Response, LLC
Address	15499 SW 12th Street, Sunrise, FL 33326 FlexSeal™ is a Swift Response, LLC brand.
Website	www.flexsealproducts.com
Email	contact@flexsealproducts.com
Telephone number	1-833-411-3539 • 954-282-5400
Emergency Telephone Number	For Chemical Emergency, Spill, Leak, Fire, Exposure, or Incident: CHEMTREC within USA and Canada: 1-800-424-9300 CHEMTREC outside USA and Canada: +1 703-527-3887 (collect calls accepted)

2. Hazard(s) identification

Physical hazards	Flammable liquids	Category 4
Health hazards	Skin corrosion/irritation	Category 2
	Serious eye damage/eye irritation	Category 2
	Sensitization, skin	Category 1
	Specific target organ toxicity, repeated exposure (oral)	Category 2 (Blood, Cardiovascular system)
OSHA defined hazards	Not classified.	

Label elements

Signal word	Warning
Hazard statement	Combustible liquid. Causes skin irritation. May cause an allergic skin reaction. Causes serious eye irritation. May cause damage to organs (Blood, Cardiovascular system) through prolonged or repeated exposure by ingestion.
Precautionary statement	
Prevention	Keep away from flames and hot surfaces. - No smoking. Do not breathe mist/vapors. Wash thoroughly after handling. Contaminated work clothing must not be allowed out of the workplace. Wear protective gloves/protective clothing/eye protection/face protection.
Response	If on skin: Wash with plenty of water. If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Get medical advice/attention if you feel unwell. If skin irritation or rash occurs: Get medical advice/attention. If eye irritation persists: Get medical advice/attention. Take off contaminated clothing and wash it before reuse. In case of fire: Use foam, carbon dioxide, dry powder or water fog to extinguish.
Storage	Store in a well-ventilated place. Keep cool.
Disposal	Dispose of contents/container in accordance with local/regional/national/international regulations.

Version #: 02   Revision date: 23-February-2024   Issue date: 17-April-2023   SDS US
1 / 7

Figure H.11: Flex Seal Liquid Clear Spec Sheet

TECHNICAL DATA SHEET

BEHR PRO

e600 EXTERIOR SEMI-GLOSS PAINT

NO. PR670 WHITE BASE

PRODUCT INFORMATION

BEHR PRO™ e600 Exterior Semi-Gloss Paint is specifically designed to meet the demanding expectations of professional painters. Developed for optimal sprayability, this 100% acrylic formula provides excellent hiding power and a highly uniform, mildew resistant finish. BEHR PRO Semi-Gloss Paint is a durable, washable finish for exterior walls and trim. Not for use on floors.

COMPLIES WITH THE BELOW AS OF 3/1/16			
SCAQMD	YES	AIM	YES
CARB	YES	LEED v.3 (2009)†	YES
OTC	YES	MPI#	11
LADCO	YES		

†Please visit www.usgbc.org/LEED for additional details.

RECOMMENDED USES:

Ideal for both commercial and residential properties over properly prepared:

- Concrete, Concrete Tilt-Up
- Concrete Block/CMU
- Cement Board Siding
- Brick
- Stucco
- Wood
- Plywood
- Ferrous Metals
- Non-Ferrous Metals
- Vinyl Siding

PRODUCT SPECIFICATIONS:

Tint Bases/Max Tint Load:
No. 670 124 oz. / 6 oz.
No. 674 117 oz. / 13 oz.
No. 673 116 oz. / 14 oz.

Gloss: 35-45 @ 60°

Resin Type: 100% Acrylic

Weight per Gallon: 10.19 lbs.

% Solids by Volume: 32%

% Solids by Weight: 44%

VOC: <50 g/L

Flash Point: N/A

Viscosity: 95-105 KU

Recommended Film Thickness:
Wet: 6.4 mils; Dry: 2.0 mils @ 250 Sq. Ft./Gal.
Wet: 4.0 mils; Dry: 1.3 mils @ 400 Sq. Ft./Gal.

Coverage: 250-400 Sq. Ft./Gal., depending on the surface texture, porosity and application method. Does not include the loss of material from spraying. Film thickness depends on porosity and various substrate irregularities.

APPLICATION:

Brush: Nylon/polyester

Roller:
Smooth Surfaces: 3/8"-1/2" nap
Porous Surfaces: 1/2"-3/4" nap

Airless Spray: Fluid pressure of 1,500 - 2,200 psi

Tip: .015"- .021"

Filter: 60 mesh

Thinning: Not recommended. Product is formulated for use at package consistency only.

Dry Time: 77°F (25°C), 50% RH:
Longer dry time may be required in cooler temperatures and higher humidity.
To Touch: 2 hours
To Recoat: 4 hours
Full Cure: 14 days

SURFACE PREPARATION:

- All surfaces must be clean, free of dust, chalk, oil, grease, mold and mildew stains, loose and peeling paint, rust and all other foreign substances.
- Glossy surfaces must be 'scuff sanded' with an appropriate sandpaper and primed prior to coating.
- Allow new stucco, plaster and masonry to cure for 30 days before painting.

WARNING! If you scrape, sand or remove old paint, you may release lead dust. **LEAD IS TOXIC.** Contact the National Lead Information Center at 1-800-424-LEAD or visit www.epa.gov/lead.

RECOMMENDED PRIMER/SYSTEMS:

PROPERLY PREPARED NEW SURFACES:

Wood: Composition Panels/Siding, Fiber Board
- BEHR PREMIUM PLUS® Interior/Exterior Multi-Surface Primer & Sealer No. 436

Wood: Cedar, Redwood, Shakes & Shingles
- BEHR PREMIUM PLUS Interior/Exterior Multi-Surface Primer & Sealer No. 436

Tannin/Stainblocking:
- BEHR PREMIUM PLUS Interior/Exterior Multi-Surface Primer & Sealer No. 436

Masonry: Stucco, Cinder Block, Concrete Masonry Units (CMUs), Split Face Block
- BEHR PRO™ Block Filler Primer No. PR50
- BEHR PREMIUM PLUS Interior/Exterior Multi-Surface Primer & Sealer No. 436

Masonry: Cement Composition Panels/Siding, Exterior Insulation and Finish Systems (EIFS) or Synthetic Stucco
- BEHR PREMIUM PLUS Interior/Exterior Multi-Surface Primer & Sealer No. 436

Masonry with pH Levels up to 13.0:
- BEHR PREMIUM PLUS Interior/Exterior Multi-Surface Primer & Sealer No. 436

Ferrous & Non-Ferrous Metals:
- BEHR PREMIUM PLUS Interior/Exterior Multi-Surface Primer & Sealer No. 436

PREVIOUSLY PAINTED SURFACES:
- Use a full coat or spot prime with BEHR PREMIUM PLUS Interior/Exterior Multi-Surface Primer & Sealer No. 436

CLEAN UP:

- Clean all tools and equipment with clean water.
- For proper disposal of empty containers and unused product, contact your local household refuse collection service.
- To reduce waste, consult with your retailer or an online paint calculator to determine the correct amount of paint to purchase.

CAUTIONS/LIMITATIONS:

- Protect from freezing.
- IMPORTANT! Do not open can without reading instructions.
- For tint bases-do not use without the addition of colorant.

Revised 3/1/2016

Figure H.12: Acrylic Paint Spec Sheet

SAFETY DATA SHEET

Date of issue/Date of revision 7 July 2015
Version 4

Section 1. Identification

Product name	:	LN-704 PROJECTS AHE70424WH0
Product code	:	00409460
Other means of identification	:	Not available.
Product type	:	Liquid.

Relevant identified uses of the substance or mixture and uses advised against

Product use	:	Industrial applications.
Use of the substance/ mixture	:	Adhesive.
Uses advised against	:	Not applicable.

Supplier	:	PPG Industries, Inc. One PPG Place Pittsburgh, PA 15272
Emergency telephone number	:	(412) 434-4515 (U.S.) (514) 645-1320 (Canada) 01-800-00-21-400 (Mexico)
Technical Phone Number	:	1-800-441-9695 (8:00 am to 5:00 pm EST)

Section 2. Hazards identification

OSHA/HCS status	:	This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).
Classification of the substance or mixture	:	CARCINOGENICITY - Category 1A Percentage of the mixture consisting of ingredient(s) of unknown toxicity: 40.3%

GHS label elements

Hazard pictograms :

Signal word	:	Danger
Hazard statements	:	May cause cancer.

Precautionary statements

Figure H.13: Liquid Nails Projects Spec Sheet

Figure H.14: Safety Triangle Dimensions

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Figure H.15: Safety Horn Dimensions

McMASTER-CARR.

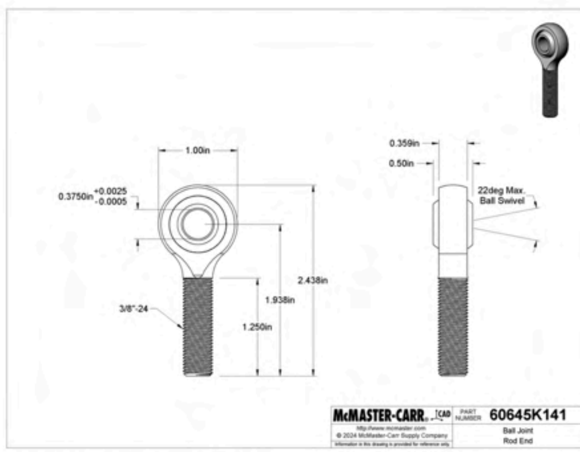
Ball Joint Rod End, 3/8"-24 Thread

Shank Thread Direction	$6.60 Each
Right Hand	60645K14
Left Hand	

Shank Thread Size	3/8"-24
ID	3/8"
ID Tolerance	-0.0005" to 0.0025"
Maximum Ball Swivel	22°
Overall Width	1"
Overall Thickness	1/2"
Shank Center Length	1 15/16"
Shank Thread Length	1 1/4"
Static Radial Load Capacity	6,300 lbs.
Material	Zinc-Plated Carbon Steel
Ball Material	Chrome-Plated Bearing Steel
Lubrication	Required
Relubrication	Required
Rod End Type	Ball Joint
Shank Threading	Fully Threaded
Shank Gender	Male
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/17/2023, 233 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Peoples Republic of China
Schedule B	848330.8055
ECCN	EAR99

Made of steel, these rod ends generally handle higher loads than stainless steel, aluminum, and nylon rod ends. They don't come lubricated, so you'll need to lubricate during installation and on an ongoing basis.

Zinc-plated steel rod ends provide moderate corrosion resistance.



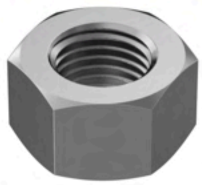
The information in this 3-D model is provided for reference only.

Figure H.16: Ball Joint Rod End Spec Sheet

McMASTER-CARR.

Medium-Strength Steel Hex Nut

Grade 5, Zinc-Plated, 3/8"-24 Thread Size



Delivers Wednesday

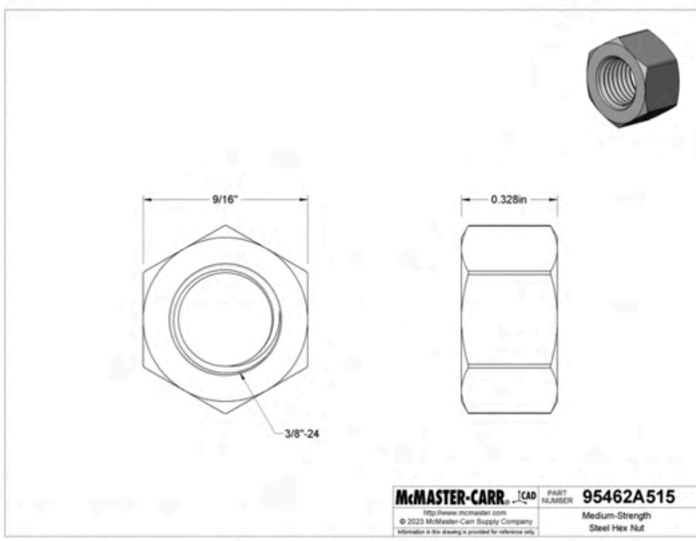
$12.00 per pack of 100
95462A515

Hex Nut Profile	Standard
Fastener Strength Rating	Medium
Material	Zinc-Plated Steel
Thread Size	3/8"-24
Width	9/16"
Height	21/64"
Fastener Strength Grade/Class	SAE Grade 5
Specifications Met	ASME B18.2.2
Drive Style	External Hex
Nut Type	Hex
System of Measurement	Inch
Thread Direction	Right Hand
Thread Fit	Unified Standard Class 2B
Thread Spacing	Fine
Thread Type	UNF
Country of Origin	China, South Korea, Taiwan
DFARS Compliance	Specialty Metals COTS-Exempt
Export Control Classification Number (ECCN)	EAR99
REACH Compliance	REACH (EC 1907/2006) (06/14/2023, 235 SVHC) Compliant
RoHS Compliance	RoHS 3 (2015/863/EU) Compliant
Schedule B Number	731816.0000
U.S.-Mexico-Canada Agreement (USMCA) Qualifying	No

The most commonly used hex nuts, these are suitable for fastening most machinery and equipment.

Medium-Strength Steel—These Grade 5 or Class 8 nuts are your go-to for fastening most machinery and equipment. To avoid stripped threads during installation, make sure your screw has a comparable strength rating.

Zinc-Plated Steel—A step up from plain steel, the zinc plating withstands occasional exposure to moisture.



The information in this 3-D model is provided for reference only.

Figure H.17: Right Hand Threaded Nut Spec Sheet

McMASTER-CARR.

Medium-Strength Steel Left-Hand-Thread Hex Nut

Medium-Strength, Zinc-Plated, 3/8"-24 Thread Size

Delivers Wednesday

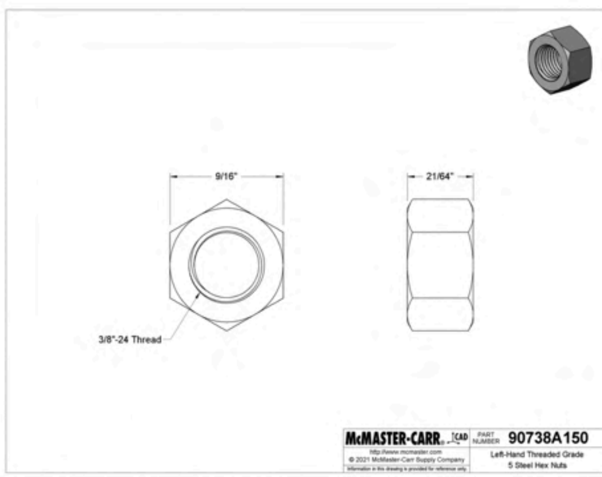
$9.53 per pack of 25
90738A150

Hex Nut Profile	Standard
Fastener Strength Rating	Medium
Material	Zinc-Plated Steel
Thread Size	3/8"-24
Width	9/16"
Height	21/64"
Fastener Strength Grade/Class	SAE Grade 5
Drive Style	External Hex
Nut Type	Hex
System of Measurement	Inch
Thread Direction	Left Hand
Thread Fit	Unified Standard Class 2B
Thread Spacing	Fine
Thread Type	UNF
Country of Origin	China, South Korea, Taiwan, Vietnam
DFARS Compliance	Specialty Metals COTS-Exempt
Export Control Classification Number (ECCN)	EAR99
REACH Compliance	REACH (EC 1907/2006) (06/14/2023, 235 SVHC) Compliant
RoHS Compliance	RoHS 3 (2015/863/EU) Compliant
Schedule B Number	731816.0000
U.S.–Mexico–Canada Agreement (USMCA) Qualifying	No

These nuts tighten when turned to the left. Use them with left-hand rods and screws to prevent counterclockwise-moving parts from loosening.

Medium-Strength Steel—These Grade 5 or Class 8 nuts are your go-to for fastening most machinery and equipment. To avoid stripped threads during installation, make sure your screw has a comparable strength rating.

Zinc-Plated Steel—A step up from plain steel, the zinc plating withstands occasional exposure to moisture.



The information in this 3-D model is provided for reference only.

Figure H.18: Left Hand Threaded Nut Spec Sheet

Appendix I: Detailed Analysis

Table I.1: Center of Mass Calculation

	Centre of Mass - x direction		Centre of Mass - Y direction	
	X coord (mm)	Mass (kg)	y coord (mm)	Mass (kg)
Foam pontoons	1174.2	15	474.815	15
Bikes	1140	31.75	552.09	31.75
Pirahna Stem	1555	1.098	1056.682	1.098
Pirahna Head	1230	15	1538.88	15
Pilot 1	1350	81.65	1152.09	81.65
Pilot 2	1350	65.77	1152.09	65.77
Front Steel Tube	820.3	2.7	697.54	2.7
Back steel tube	1456.35	2.7	662.91	2.7
Bottom steel tube	1583.94	2.69	377.09	2.69
Round Steel Tube Front	820.3	4.595	697.54	4.595
Round Steel Tube Back	1456.35	4.595	662.91	4.595
Propellors	2130	2	327.09	2
		229.548		229.548
	Centre of Mass X Coord	**1298.6885**	**Centre of Mass Y Coord**	**1003.4009**

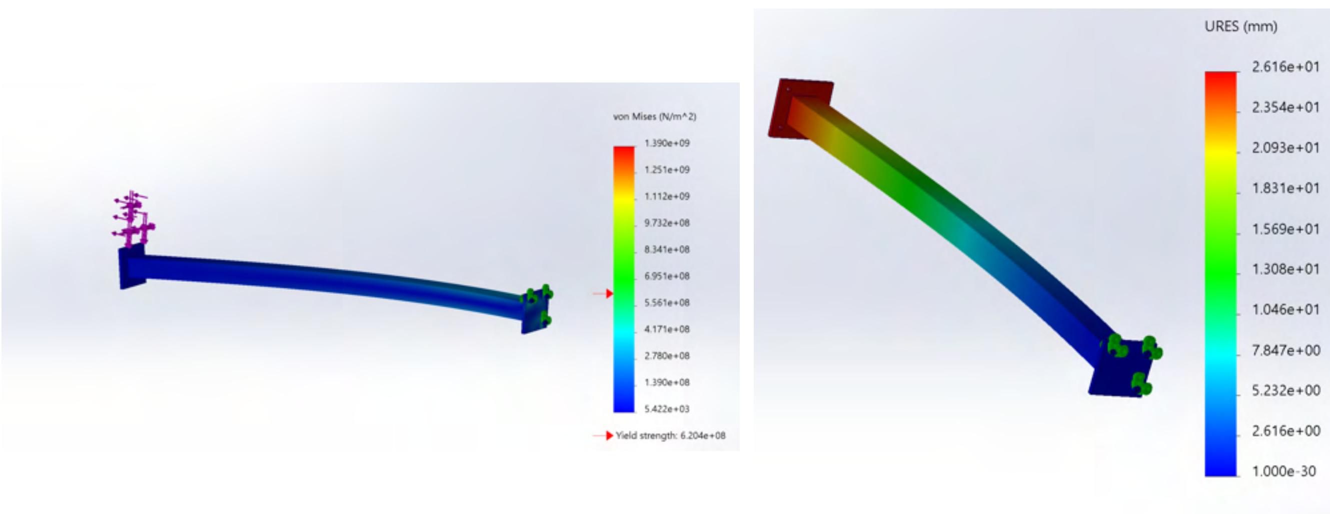
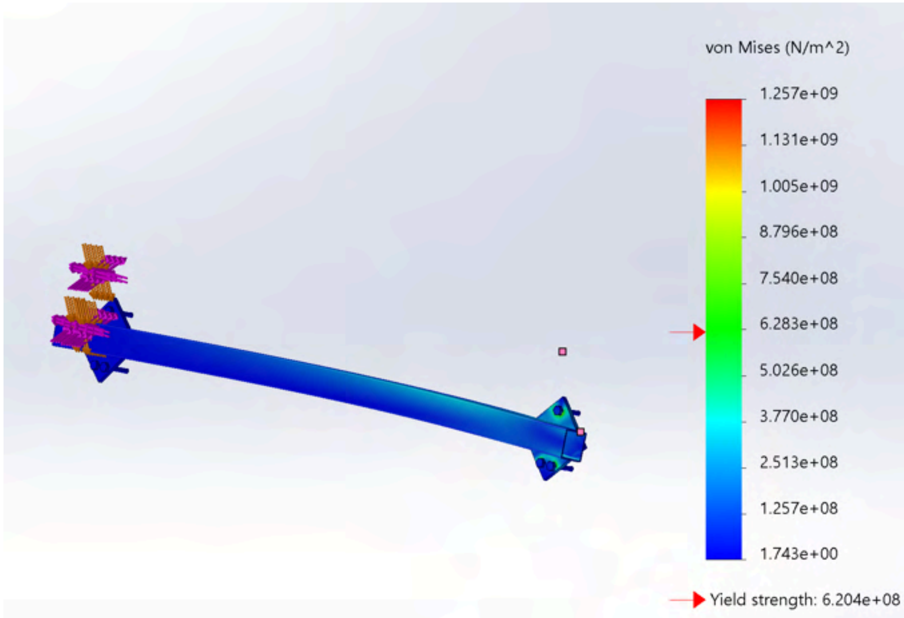


Figure I.1: Chain Stay Bar von Mises and Displacement Heat Maps



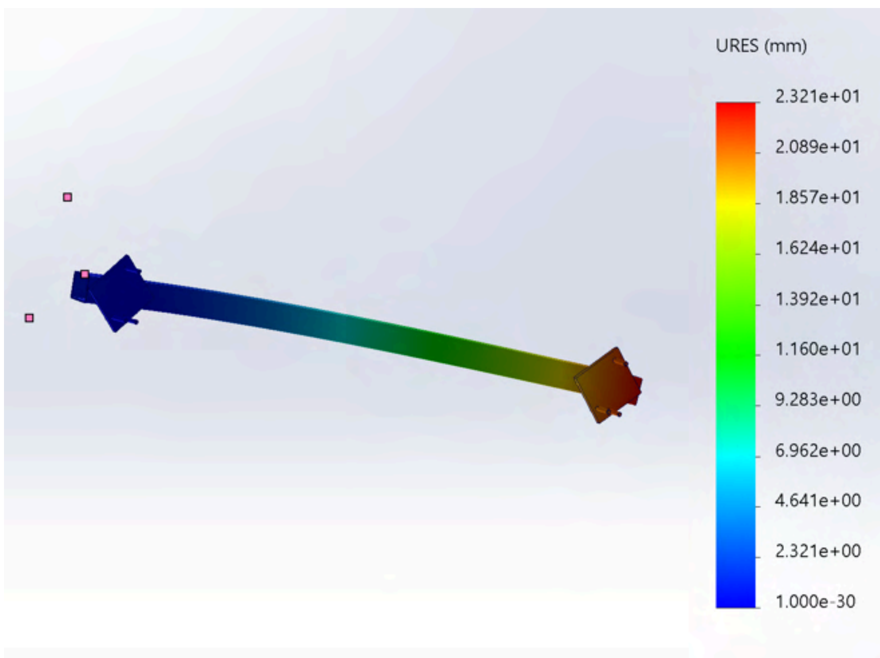


Figure I.2: Seat Stay Bar von Mises and Displacement Heat Maps

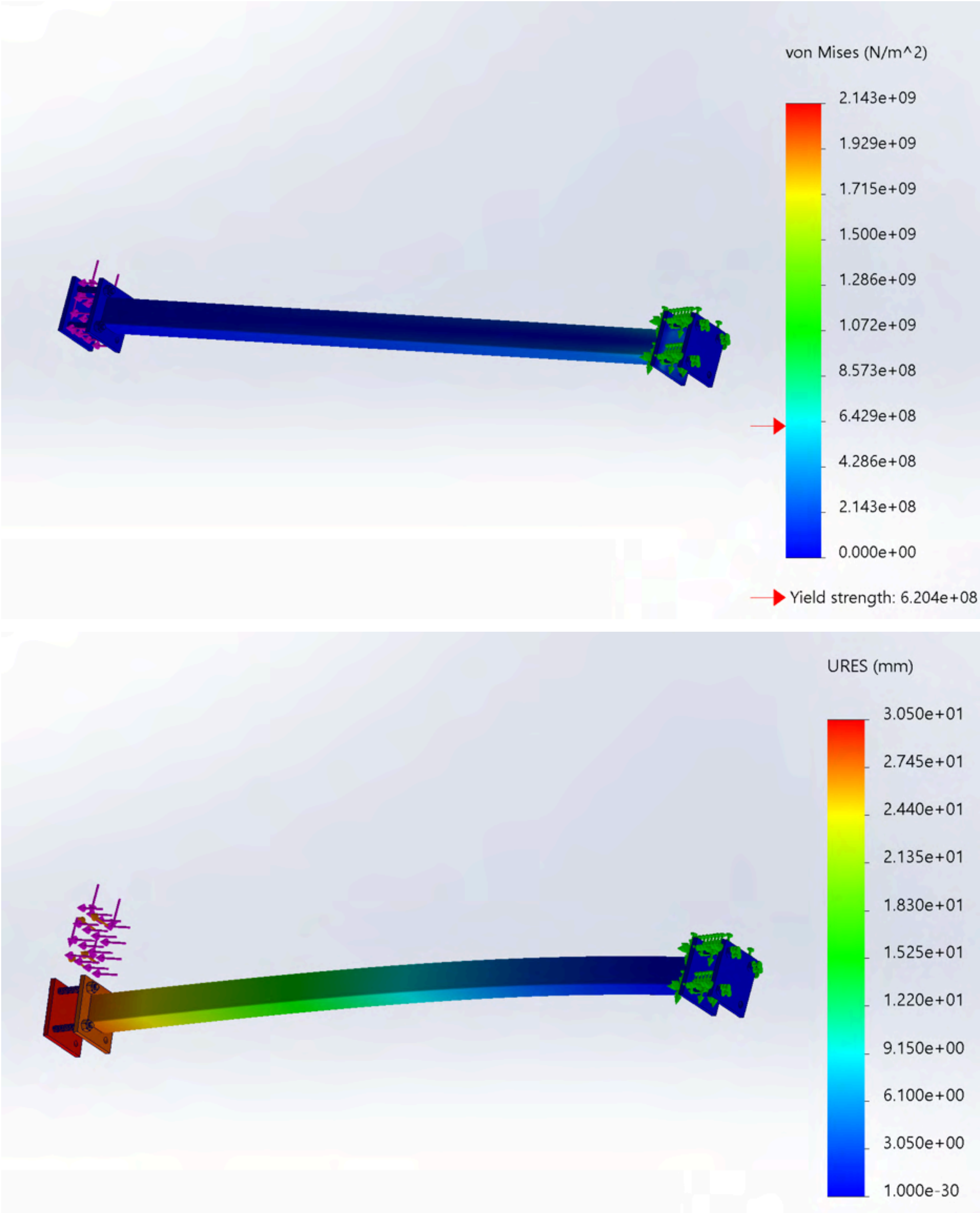


Figure I.3: Head Tube Bar von Mises and Displacement Heat Maps

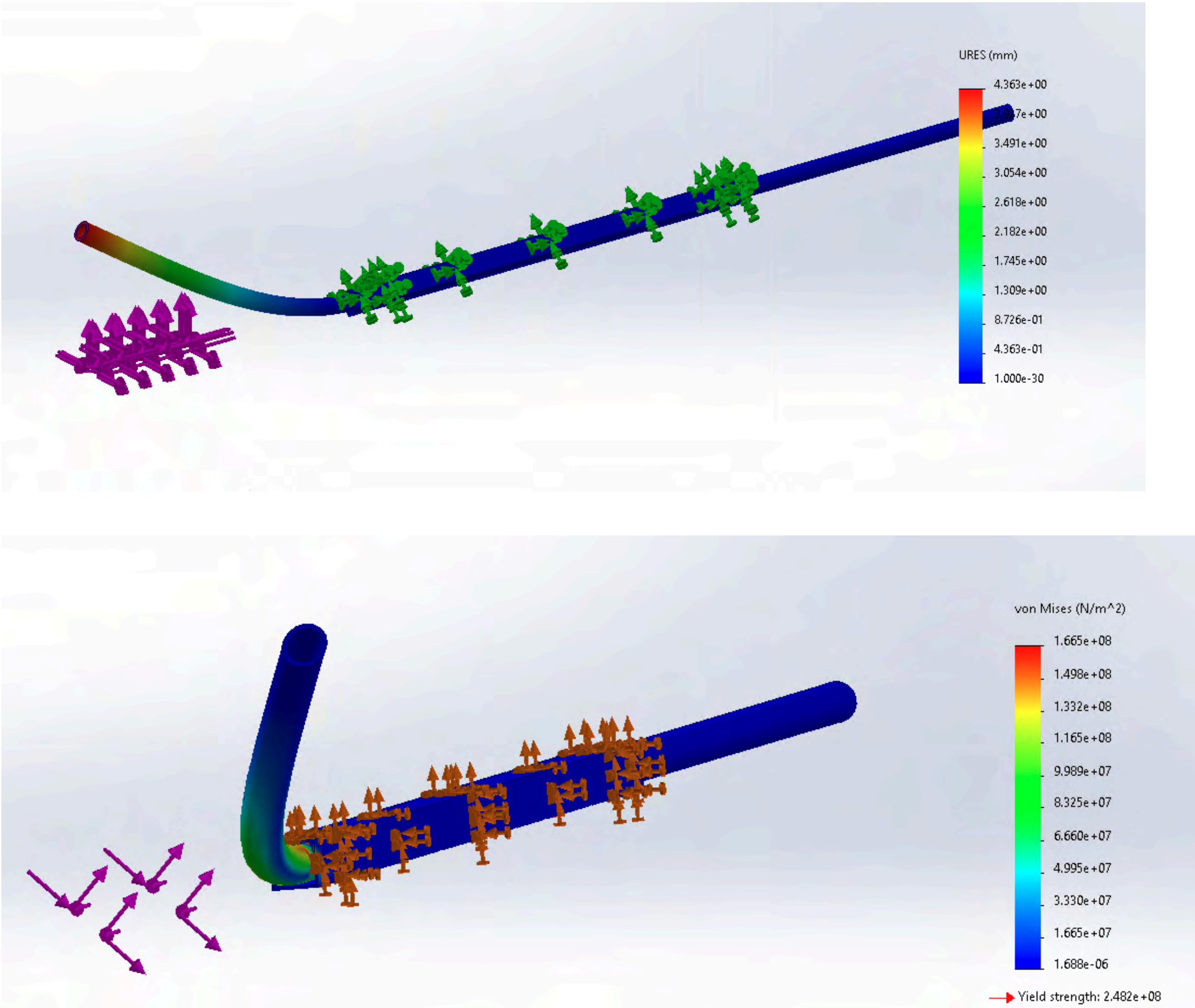


Figure I.4: Flotation bars with tip displacement and Von Mises

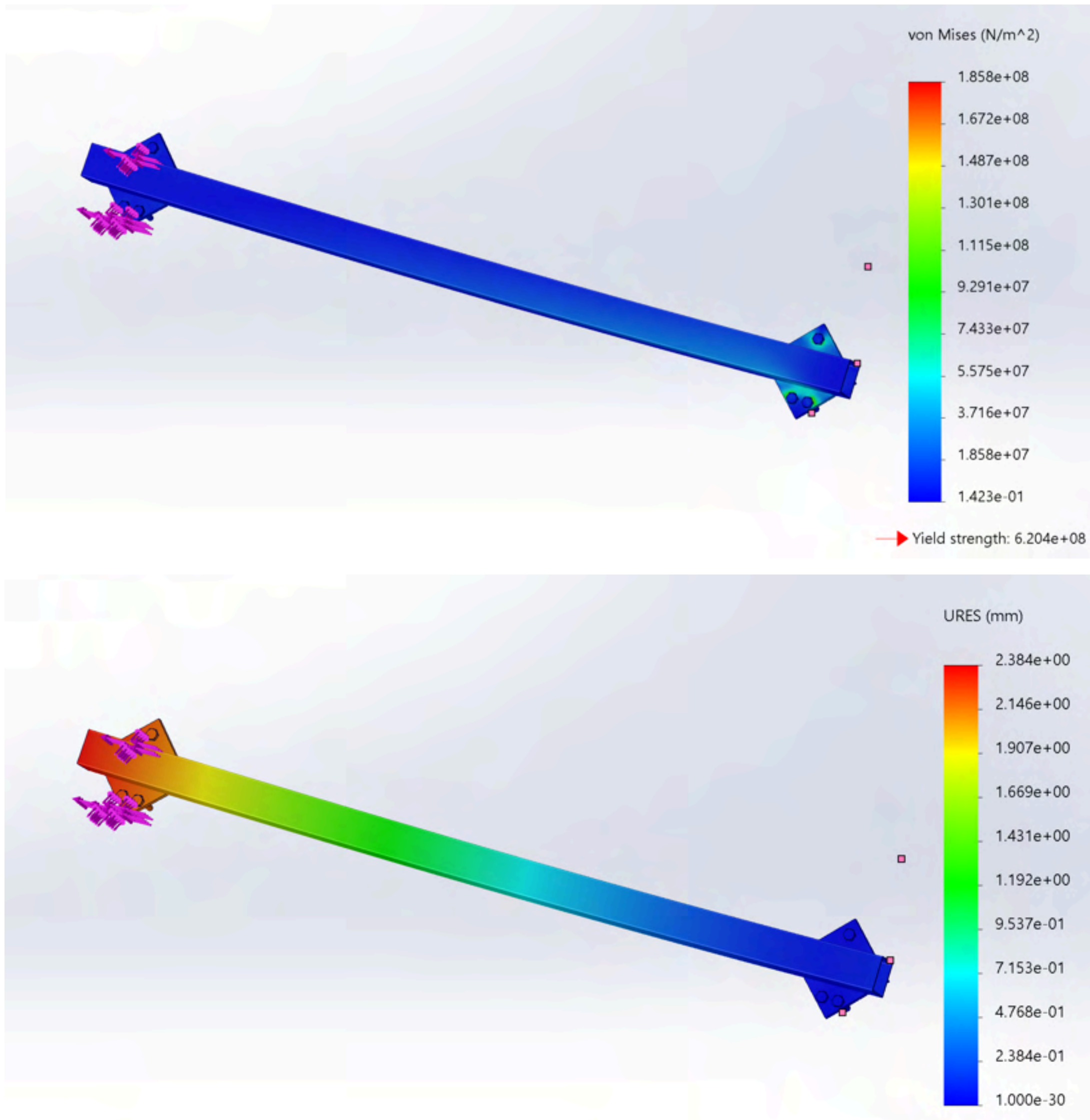


Figure I.5: Seat Stay Bar von Mises and Displacement Heat Maps without Pothole Assumption

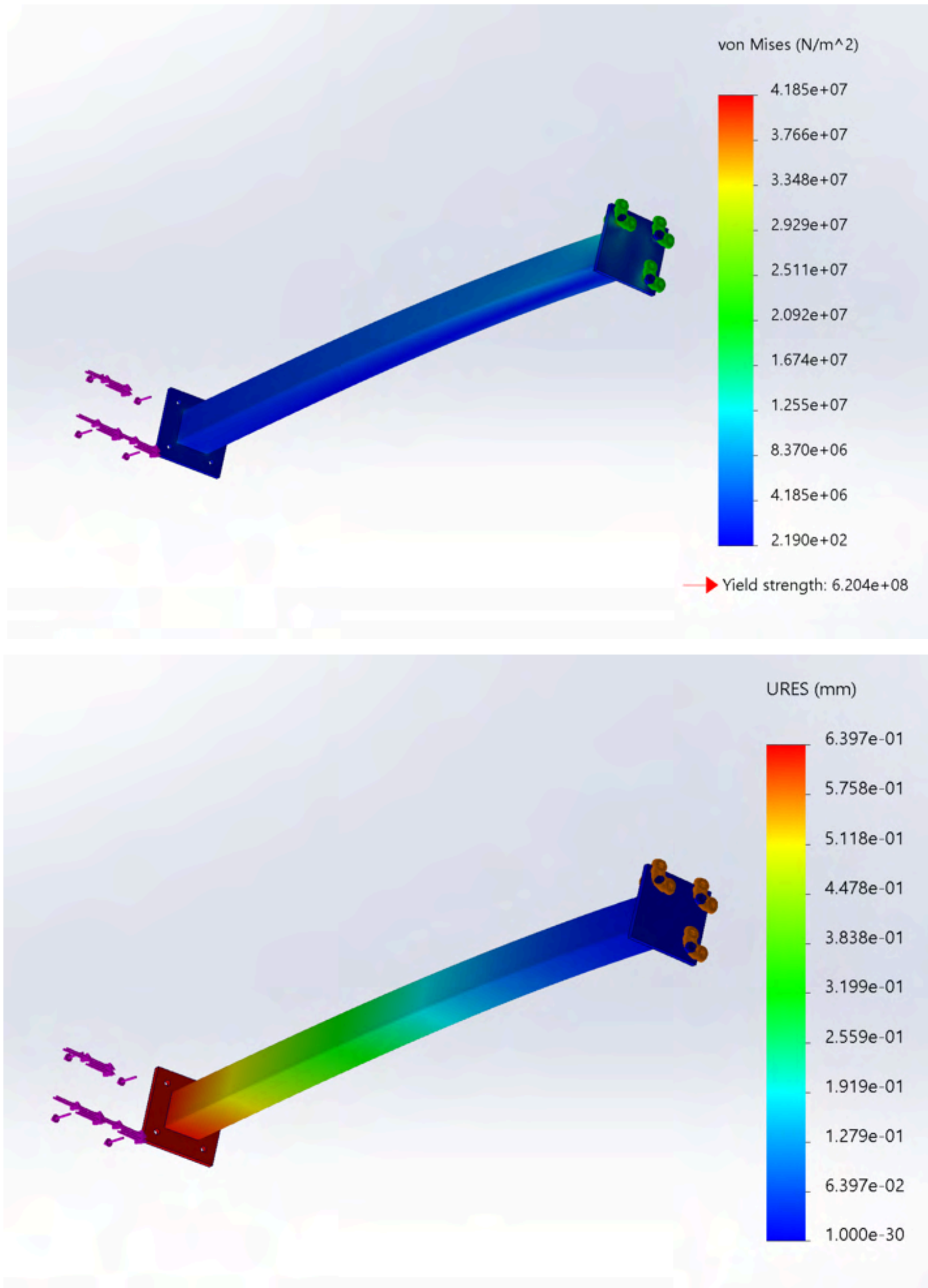


Figure I.6: Chain Stay Bar von Mises and Displacement Heat Maps without Pothole Assumption

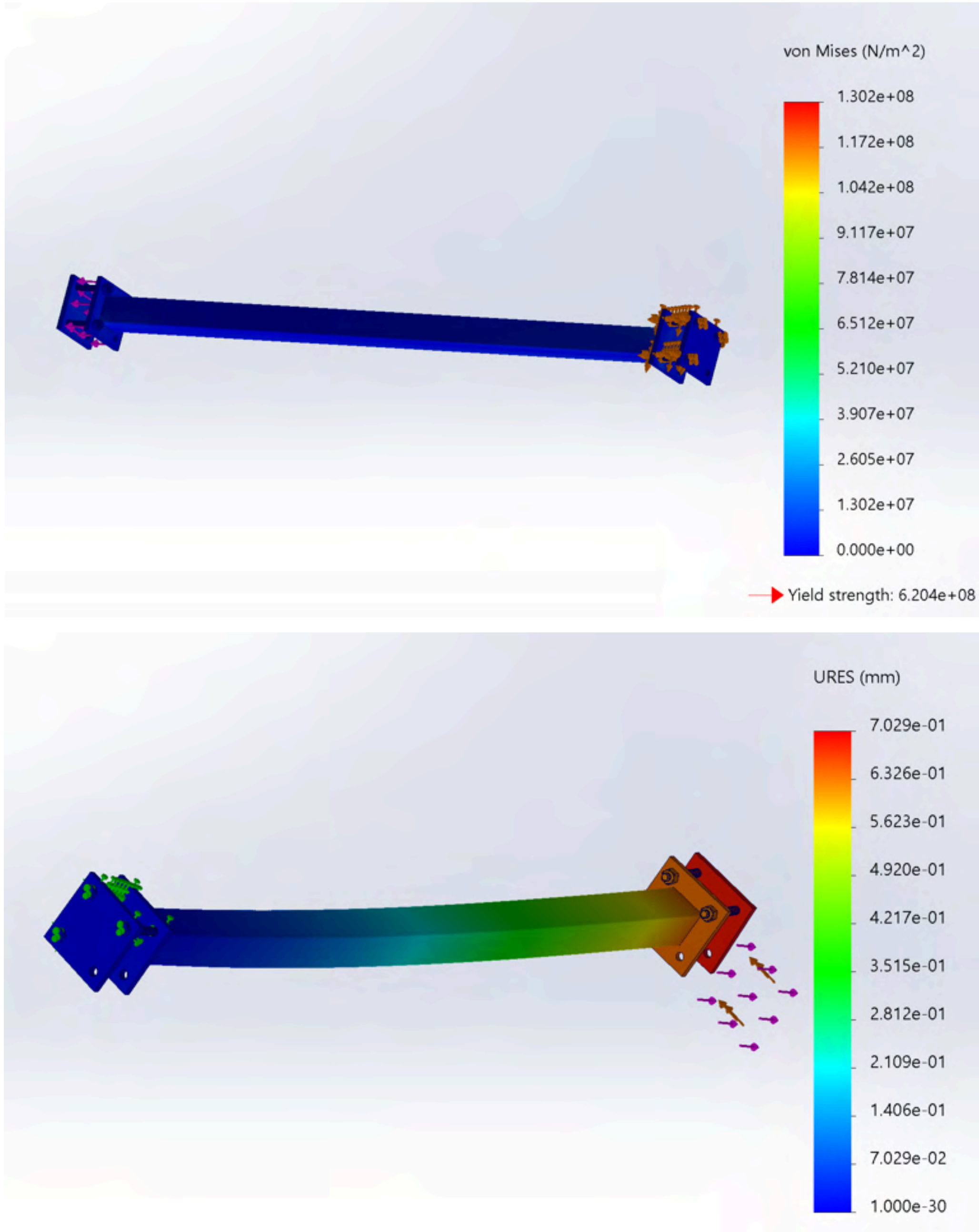


Figure I.7: Head Tube Bar von Mises and Displacement Heat Maps without Pothole Assumption

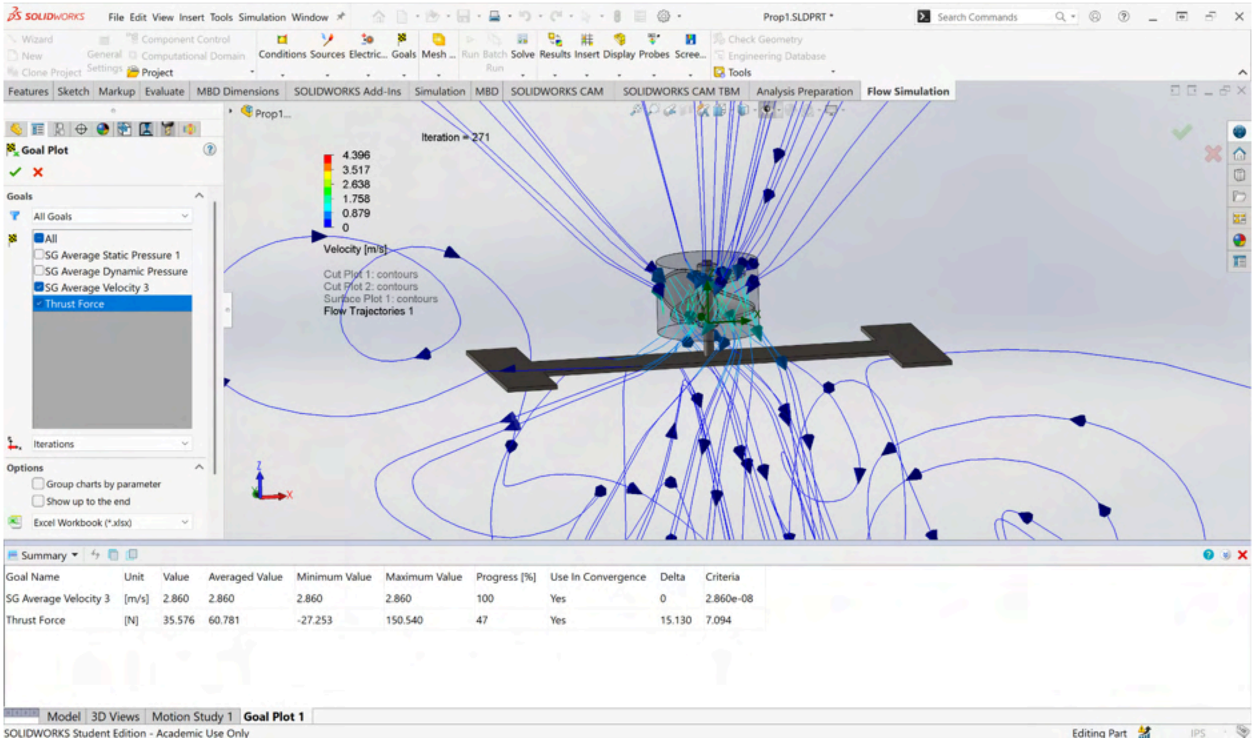


Figure I.8: 0.4 Revolution Spiral Propeller Blade Configuration

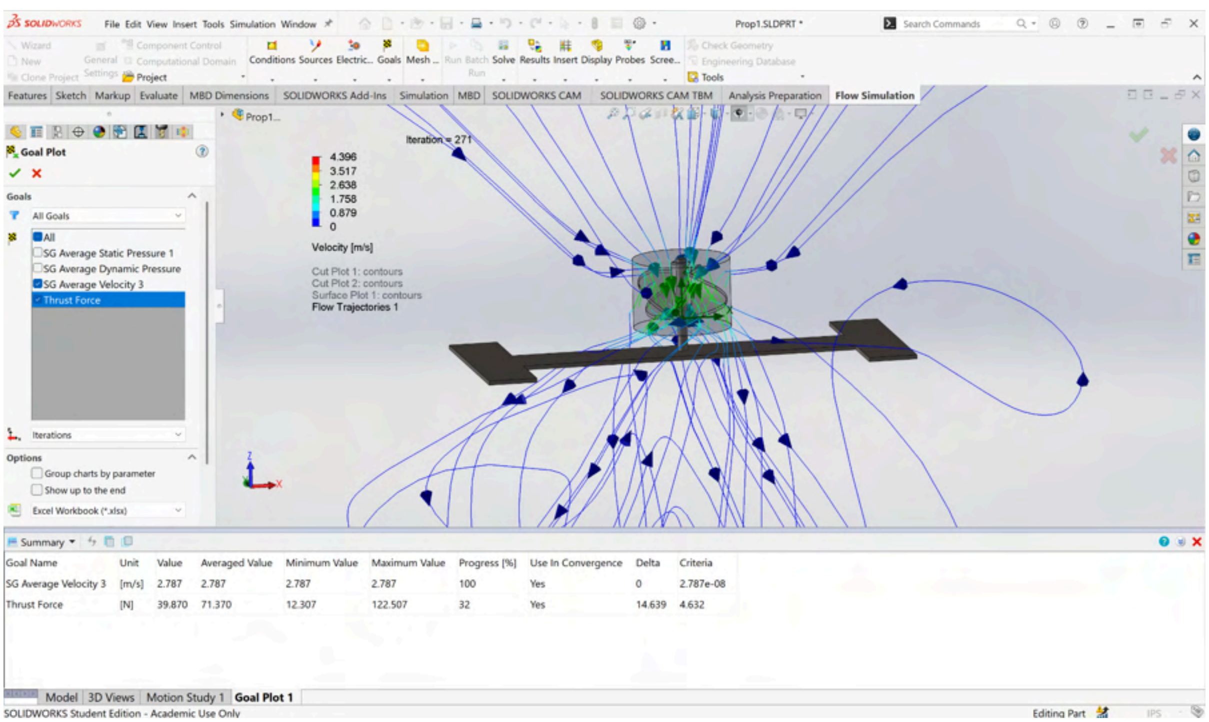


Figure I.9: 0.3 Revolution Spiral Propeller Blade Configuration

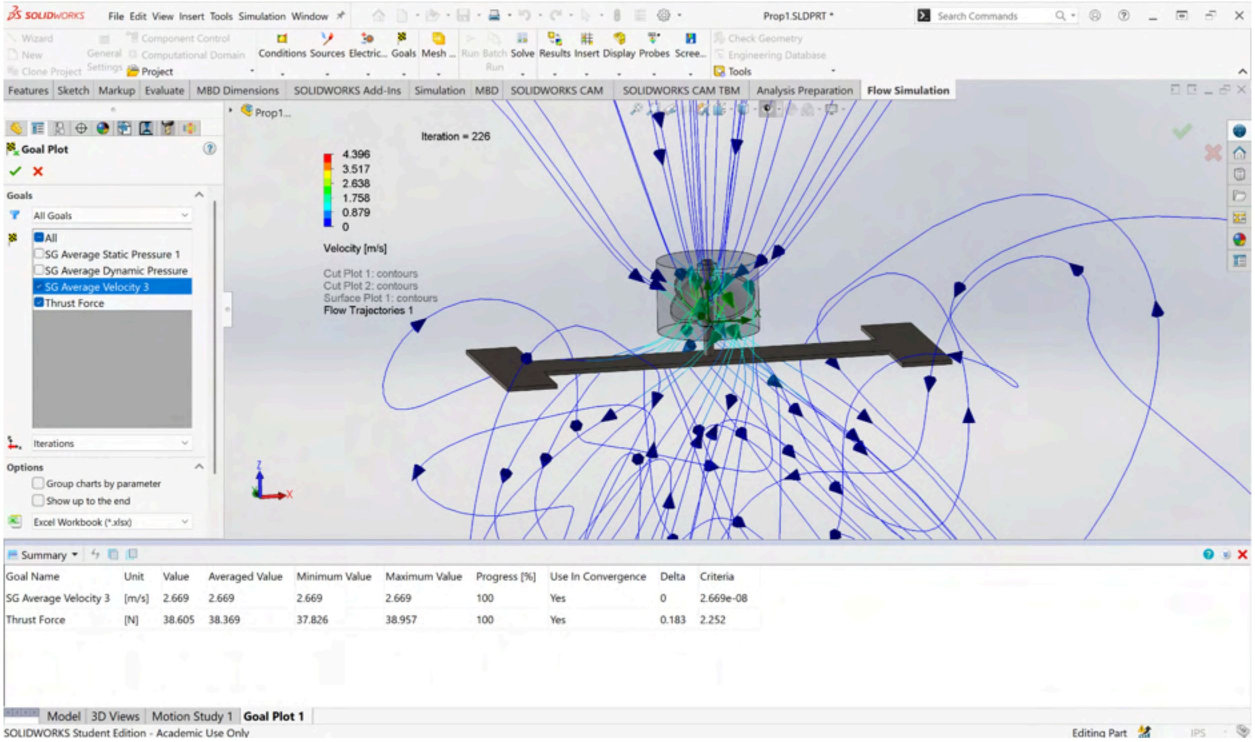


Figure I.10: 0.2 Revolution Spiral Propeller Blade Configuration

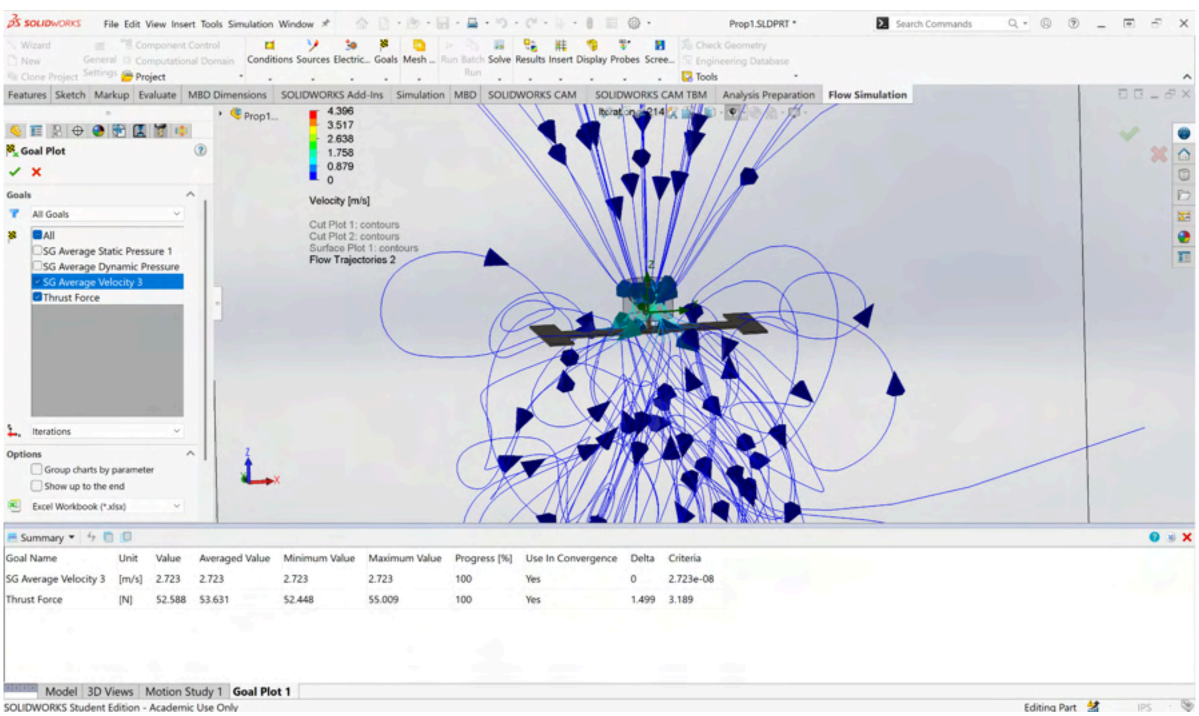


Figure I.11: Two Blade Propeller Configuration

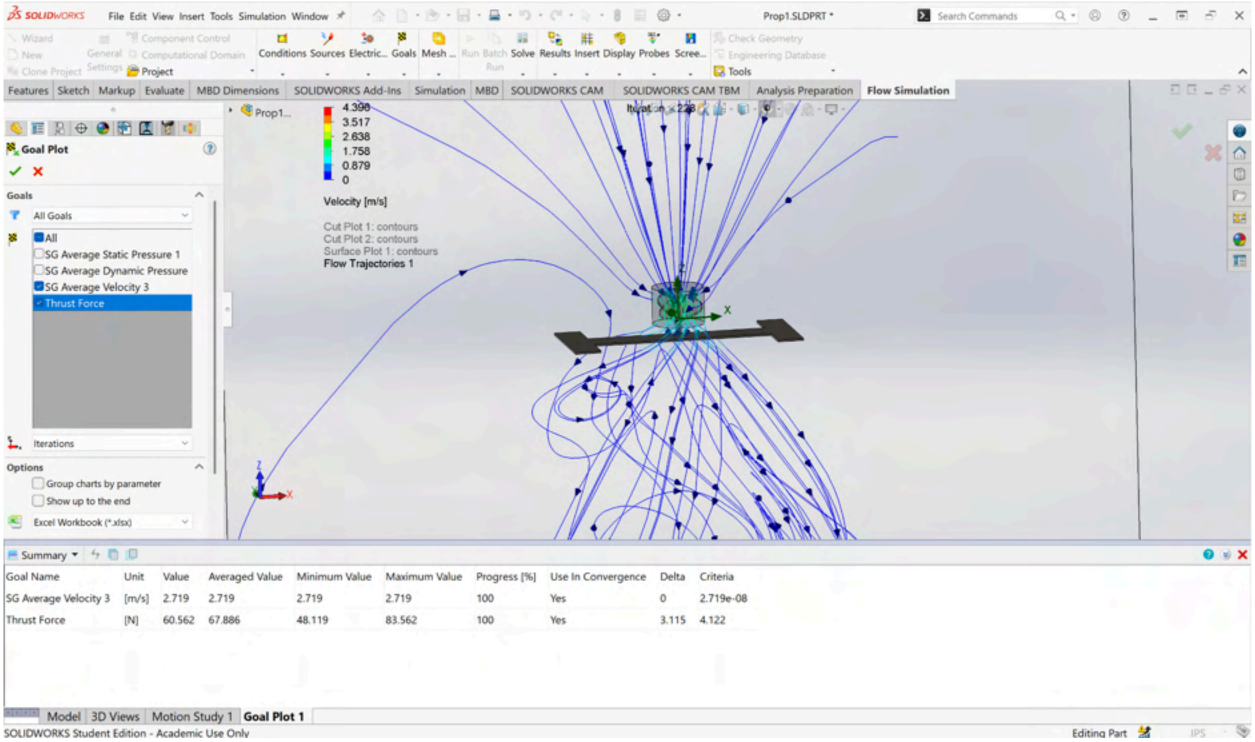


Figure I.12: Three Blade Propeller Configuration

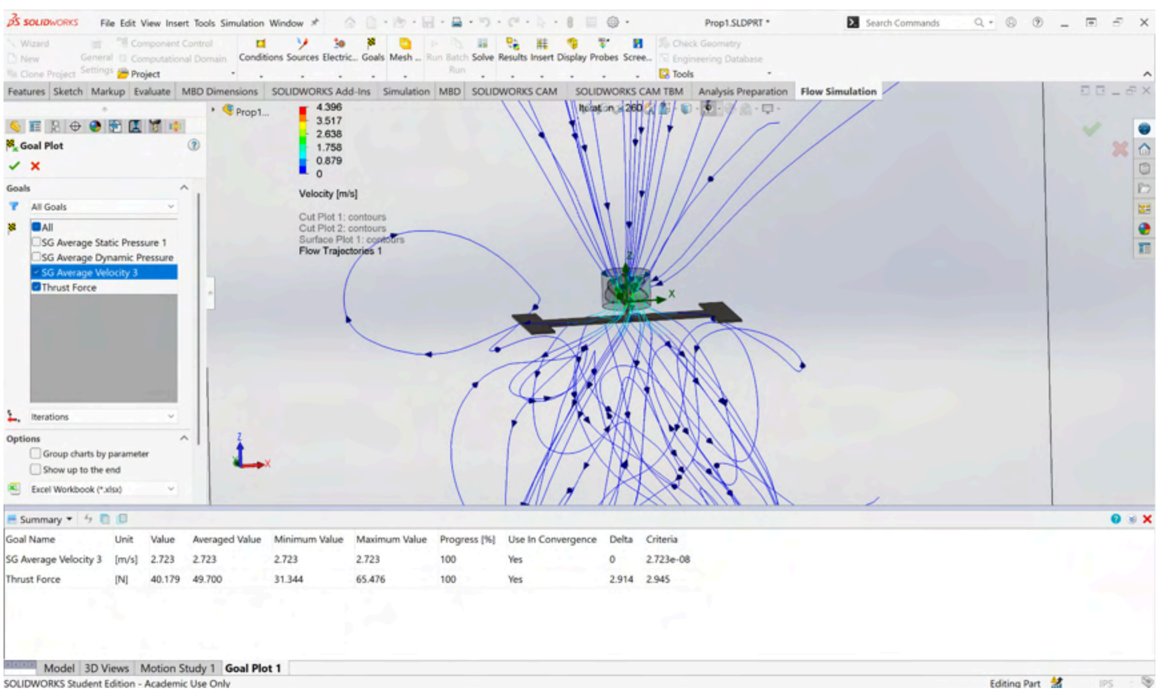


Figure I.8: Four Blade Propeller Configuration

Appendix I.1: Low Fidelity Paddlewheel Calculations and Prototyping

As of March 7, 2025:

The team is currently exploring a few different options for high-fidelity prototyping and the final product. Multiple ideas involve using the rotation of the bicycle wheels from human-powered pedaling to transmit torque to a water wheel. For example, one idea is to attach roller wheels behind the rear bicycle wheels via the existing steel frame, and the roller wheels would drive a shaft with two paddle wheels (see Figure 10). With an approximate angular velocity of 60 RPM in the water, the torque of the paddle wheels would need to be at least 26.4 N-m, which is dependent on the force between the bike wheels and roller wheels and the radius of the roller wheels.

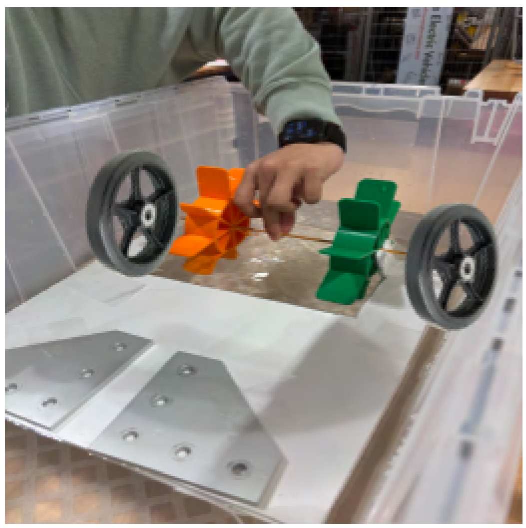


Figure I.1.1. Water Propulsion Low-Fidelity Prototype

Appendix I.2: Propeller Drag and Acceleration Calculations

$F_d = \frac{1}{2} C_d A \rho V^2$

Bar:

$F_d = \frac{1}{2}(2.1)(0.023\,m^2)(1004\,kg/m^3)(1.341\,m/s)^2$

$= 49.29\,N$

Bike:

$F_d = \frac{1}{2}(0.9)(0.026\,m^2)(1004\,kg/m^3)(1.341\,m/s)^2$

$= 18.69\,N$

Pontoon:

$F_d = \frac{1}{2}(0.295)(0.116\,m^2)(1004\,kg/m^3)(1.341\,m/s)^2$

$= 30.89\,N$

Total Drag Force:

$2F_{d,bike} + 2F_{d,pontoon} + F_{d,bar} = 148.45\,N$

$F = ma$

$F_{thrust} - F_{drag} = ma$

$F_{thrust} = 166.126\,N$

$F_{drag} = 148.45\,N$

$m = 225\,kg$

$\therefore\ a = 0.079\,m/s^2$

$a = \frac{V}{t}$ $\quad V = 1.341\,m/s$

$\therefore\ t = 17$ seconds

Appendix I.3 Floatation Calculations

Buoyancy Calculations	
Total Mass of Vehicle inc. pilots (kg)	226.44
Vol of Water to displace (cubic feet)	8.00
Factor of Safety (due to freeboarding)	1.50
Additonal Factor of Safety	1.10
Minimum Vol of Styrofoam (cubic feet)	**13.20**
Total Amount in Floats	*26.67*

Appendix J: Final Budget

Item	Cost	Vendor	Who Ordered?	Ordered?	Reimbursed?	Link
2 Bikes	$538.00	Dicks Sporting Goods	Izzy	☑	Yes	https://www.dickssporting
Steel Plates 3x3 (6x)	$64.74	McMaster Carr	Chloe via Pat	☑	Not Ap...	https://www.mcmaster.c
Steel Square Tubes (3x)	$50.73	McMaster Carr	Chloe via Pat	☑	Not Ap...	https://www.mcmaster.c
Tax for Steel	$10.53	McMaster Carr	Chloe via Pat	☑	Not Ap...	
Shipping Fees	$24.91	McMaster Carr	Chloe via Pat	☑	Not Ap...	
Foam and Deco Stuff	$179.45	Home Depot	Izzy via Pat	☑	Not Ap...	
Glue	$63.90	Home Depot	Izzy	☑	Not Yet	
Spray Foam	$23.92	Home Depot	Izzy	☑	Not Yet	
Steering Hardware	$34.73	McMaster	Graham	☑	Not Ap...	
Prop Bearings	$8.99	Amazon	Chloe	☑	Not Yet	
Prop Bearings	$22.00	Amazon	Eliana	☑	Not Yet	
Primer, and other paint colors	$117.70	Home Depot	Izzy	☑	Not Yet	
Home Depot - Sealant, Red, Brushes	$214.80	Home Depot	Izzy	☑	Not Yet	
Steel Pipes	$40.64	J and D Recyles	Mattthew	☑	Not Yet	
Extra Flex Seal and Spray Foam	44.03	Home Depot	Izzy	☑	Not Yet	
12" x 12" Warning Triangle	$8.79	Amazon	Matthew via Pat	☑	Not Ap...	
Horn	$9.97	Amazon	Matthew via Pat			
SUBTOTAL	$1,457.83					

Appendix K: Design Documentation

- Notes from Team Meeting with Dr. Santillan (10/21)
  - Travel is not part of our budget to build the device
  - How can we move it?
  - Last year 12 ft 3 inches by 6 ft 4 inches by 5 ft 5 inches
  - Door opening is 5 ft 4 in by 5 ft 1 in
  - Built to be disassembled
  - Who from last year?
  - Rebecca (Graham's roommate)
  - Clara McMillian
  - Matthew is a part of the Durham bike co-op
  - Duke Police - reclaimed bikes?
  - Creativity and engineering in parallel
  - Go through rule book and pull the important ones in
  - Should be functionable by the time AirBnb needs to be canceled (two weeks ahead)
  - Where to test in water?
  - Tested in pool on west
  - Well into brainstorming this semester, maybe some minimal prototyping
  - Presentation at the end of semester
  - Brainstorm themes and mechanical design, how the bulk of it will work

- Notes from Team Meeting (10/28)

Theme → “play”

The event challenges teams to design, construct, and *power* a sculpture that travels 15 miles on land (including muddy and sandy terrain) and through harbor water. Because this event is hosted by AVAM, artistic creativity and aesthetics are encouraged in each design.

1) Sculptures must be entirely human-powered. No pulling, pushing, paddling, or other propulsive method is allowed except by Official Pit Crew and Pilots.
2) Each sculpture must be no more than 8 feet wide, 13 feet tall, and 35 feet long while on land.
3) Entries and themes should be appropriate for spectators of all ages.
4) No motors, batteries, chemicals, or stored energy (for the use of propulsion) can be part of the sculpture.
5) Each sculpture must carry at all times:
    a. 1 comforting item of psychological luxury referred to as the “Homemade Sock Creature” (HSC). Homemade Sock Creature must be made in a home [or dorm], from a not-too- recently-worn sock from the home, and resemble a creature homemade from a sock.
    b. 12”x12” approved warning triangle
    c. Coast guard approved life preserver
    d. Operable and functioning brakes
    e. Affixed tow ring
    f. 25 feet of tow rope
    g. Drinking water (1 qt per pilot)
    h. Paddle or oar
    i. Horn
    j. First aid kit
    k. Cell phone
    l. Helmet (one per pilot)
    m. At least one pilot and one pit crew member per pilot
    n. All equipment to be used during travel
6) Each sculpture must pass an official safety inspection and every team must have an emergency exit plan.

Sculpture Ideas:

- Toys
    - Legos*
    - Pokemon
    - Action figures

    - Barbie
    - Slinky Dog
    - Little Tikes Cars*
    - Raggedy Anne
- Sports
    - Basketball/baseball/football
- Beach day
- State Fair
- Video games/arcade
    - Pacman
    - Wii
    - Mariokart*
- Board games
    - Monopoly
    - Clue
    - Catan
    - Candyland
    - Jenga
    - Casino
- Dog Park
- Kids playroom/Toy Story
    - Everyone dressed up as their own toy
- Music (Press Play)
- Playbill
- Instruments
    - Xylophone/keyboard
- Playground*
    - With Slide
- Train*
- Tricycle
- Paddle boat

Questions to Answer:

- How many pilots do we want?
    - Will Professor Santillan be on pit crew?
    - Could other classmates come to be a part of the pit crew?
- How to propel on land
- How to propel in water

Official Rules Restated:

1. Sculptures must be entirely human-powered. No pulling, pushing, paddling, or other propulsive method is allowed except by Official Pit Crew and Pilots.
2. Each sculpture must be no more than 8 feet wide, 13 feet tall, and 35 feet long while on land.
    a. U-Haul size requirement? How to travel?
3. Entries and themes should be appropriate for spectators of all ages.
4. No motors, batteries, chemicals, or stored energy (for the use of propulsion) can be part of the sculpture.
5. Each sculpture must carry at all times:
    a. 1 comforting item of psychological luxury referred to as the “Homemade Sock Creature” (HSC). Homemade Sock Creature must be made in a home [or dorm], from a not-too- recently-worn sock from the home, and resemble a creature homemade from a sock (penalty one hour).
    b. Warning triangle
    c. 12”x12” approved warning triangle
    d. Coast Guard approved life preservers
    e. Operable and functioning brakes
    f. Affixed tow ring
    g. 25 feet of tow rope

   h. Drinking water (1 qt per pilot)
   i. Paddle or oar
   j. Horn
   k. First aid kit (band-aids and antibacterial wipes)
   l. Cell phone
   m. Helmet (one per pilot)
   n. At least one pilot and one pit crew member per pilot
   o. All equipment to be used during travel
   p. Special terrain equipment
   q. Kinetic License Plate (visible)
6. Can have:
   a. 1 human barnacle (passenger)
   b. Up to 3 pilots (based on our size)
7. Each sculpture must pass an official safety inspection and every team must have an emergency exit plan.
8. To win awards, have to stay on board the whole time (no pilot rotation)
9. No projectiles/dangerous objects.
10. Pilots can only be 8% wet (cannot get wet)

- Notes from Team Meeting with Dr. Santillan (10/29)

● The website has a description of every sculpture and how they faired in the race online.
● We may need a bike rack if we want to bring bikes with us (or we can rent scooters, etc)
● Mario kart?!

- Notes from Team Meeting (11/4)

Ideas:

● Team instagram
● Walkie talkies
● Speaker for race day
● Everyone pick one best idea to put in a Google Form:
    ○ Eliana: retweet on the Mario Kart car
    ○ Chloe: Mario Kart (tricycle or Toad stroller)
    ○ Diego: Playbill
    ○ Izzy: Little Tikes Car, Mario Kart, fire breathing dragon ??? Wicked???
    ○ Caroline: Mario Kart
    ○ Graham:
    ○ Matthew:
● Talk to Steven Hayes - Sculpture Prof at Duke
    ○ Especially about materials for sculptures and what would hold up best

Favorites from other projects:

● Paddle mechanisms attached to pedaling mechanisms
● Large wheels and pontoons
● Floating mechanism on larger wheels
● Be able to onboard floating mechanisms when you're not in the water
● Mud hand crank mechanism?? - dual torque system
● Figure out optimal type of tire for traction through mud (think EGR 121)
● Tripod wheels seem really successful overall
● General base designs should be gotten first
● Should come prepared for bribery

Lessons learned from other projects:

● Trailer idea seems bad
● Small/thin tires fail most of the time

- ## Notes from Team Meeting with Dr. Santillan (11/5)

Notes:

- They play an anthem when you go into the water
- Barnacle can be a mario kart flag guy?!
- If there are three bikes, do they have to be connected?
- Tripod wheels style is more successful - be worried about alignment
- Did the Duke team test last year in the mud?
    - Maybe? But not really
    - Test in volleyball courts for sand
- Storing in Garage Lab during the project
- Bribing is real - team did it last year
- Judges dress in actual gowns and wigs

To-Do:

- Set up meeting with team from last year
- Talk to Steven Hayes (especially about materials)
- Look into and test water proofing material
- Three different carts attached (armada vibes??)

- ## Notes from Team Meeting (11/19)

- worked on the Design Criteria Memo
- discussed using a ski-like system to get through the mud and sand portions of the race

- ## Notes from Team Meeting with Jared (TA) (11/20)

- Izzy and Matthew explaining our overall project and showing past projects
- Feedback on design criteria assignment
    - Move reasoning for criteria to paragraph form
    - Keep table to condense everything else
    - Make paragraphs with all info, and table should just be a summary of the info, nothing in table should be new
- For presentation in two weeks
    - Use ChatGPT to generate ideas
    - Our participation is helping the greater goal of competition(engineering education, promoting Duke engineering?, representing Duke, practicing engineering skills, building a portfolio, a project to be proud of, community oriented?, race registration fee and what it benefits , AVAM museum supporting and what it benefits ?

- In production, use as much pre existing materials as possible, not necessarily a whole bike but the parts (machine as few parts as possible)

- Notes from Team Meeting with Dr. Santillan (11/21)
- Nasher contact from Dr. Payne, meet with them about sculpture and kinematic sculptures
- Stephen Hayes, MFA in Sculpture
- No page limit on report, 10 min limit on presentation

- Notes from Brainstorming Verb Nouns (1/9)
- Verb Noun Functions
    - move people
    - convert energy
    - float float (float weight?)
    - carry sock puppet
    - maintain theme
    - withstand loads
    - be safe? survive human kind?
    - win awards
    - contain bodies
    - transport sculpture
    - fits in UHaul
    - traverse terrain

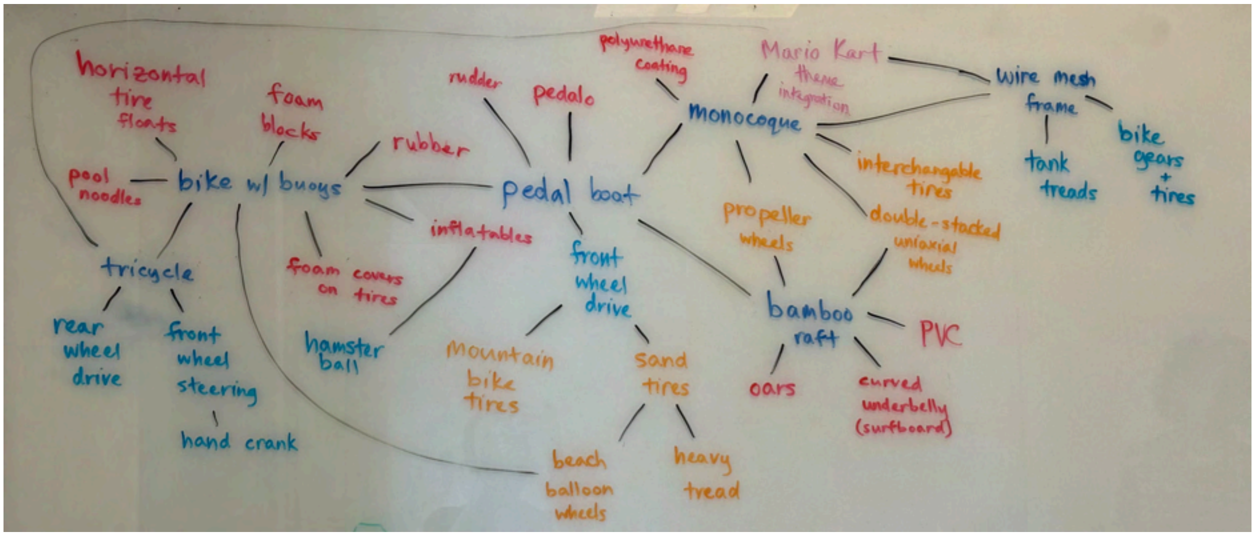
- Notes from Team Meeting with Dr. Santillan (1/13)
- Set meeting time outside 3:05 pm time
- Confirmed that we can just do the function tree
- Prepare questions for Nasher contact
- Use goals and any feedback from last report
- Dr. S homework:
    - What to do about transport
        - Get a driver and fly?
        - Rent vans?
            - Brittney Blazicek
- It is a one-way transport trip
- Final Exams:
    - Diego (5/2, 7 PM) and Caroline (5/3, 7 PM)

- Edit journey map based on Dr. Santillan's comments AND the new journey map definition from assignment
- Kind of aimed at getting ace, but there is a chance it's not feasible
- Meet with last year's team?
- Downgrading to a two-seater cart
- Brainstorming - everyone should sketch the car and then come together and talk about what the car looks like and then combine
- Weekly once a week with Dr. Santillan

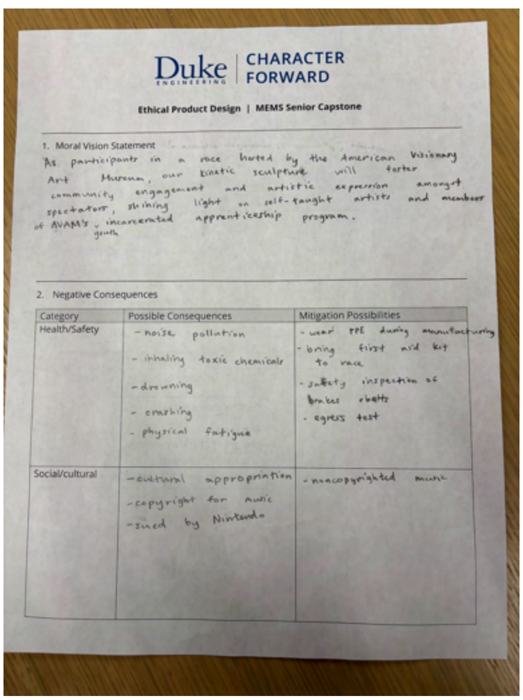
- Notes from Team Meeting with Dr. Santillan (1/20)

- Do brakes have to be brakes? Or can we just peddle backwards style brakes?
- Email to ask about this
- tom@kineticbaltimore.com
-
- Are the lists in the report actually lists or should things be put into paragraph format?
- Client needs should be expanded upon
- Don't need to write functions
-
- How are the function modules different from the function tree?
- Function tree - shows relationship between
- Need a function structure - copy machine structure (input and output and hoe they're related to each other < from there can determine modules and subcomponents < groupings of functions that make sense
- Group by input and output or another type of grouping that makes sense
-
- We need to think about a name for the sculpture
- Bush league - new league where you don't have to enter the water? Lol
- We need a team song as well
- Dr. Santillan will register together with us as a team
- Concept selection is part of next report

- Notes from Team Meeting (1/26)



- Character Forward Class Notes (1/27)



Duke ENGINEERING | CHARACTER FORWARD

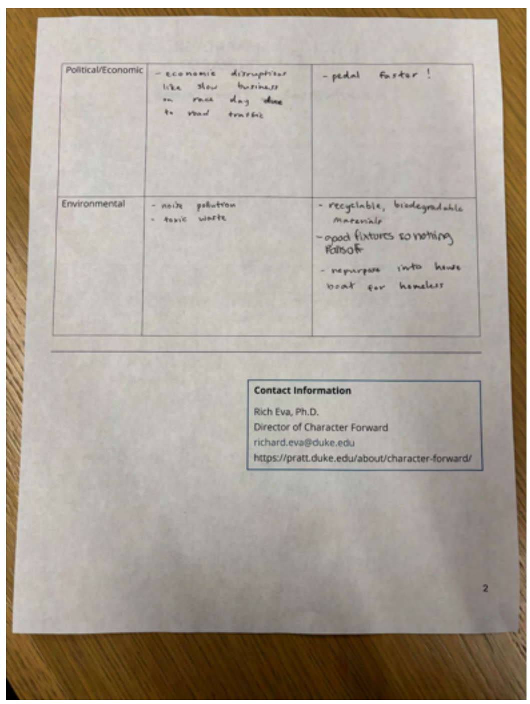
Ethical Product Design | MEMS Senior Capstone

1. Moral Vision Statement

As participants in a race hosted by the American Visionary Art Museum, our kinetic sculpture will foster community engagement and artistic expression amongst spectators, shining light on self-taught artists and members of AVAM's incarcerated youth apprenticeship program.

2. Negative Consequences

Category	Possible Consequences	Mitigation Possibilities
Health/Safety	- noise pollution - inhaling toxic chemicals - drowning - crashing - physical fatigue	- wear PPE during manufacturing - bring first aid kit to race - safety inspection of brakes + bolts - egress test
Social/cultural	- cultural appropriation - copyright for music - sued by Nintendo	- noncopyrighted music



Political/Economic	- economic disruptions like slow business on race day due to road traffic	- pedal faster !
Environmental	- noise pollution - toxic waste	- recyclable, biodegradable materials - good fixtures so nothing falls off - repurpose into house boat for homeless

Contact Information
Rich Eva, Ph.D.
Director of Character Forward
richard.eva@duke.edu
https://pratt.duke.edu/about/character-forward/

2

- Notes from Team Meeting with Dr. Santillan (2/10)

- meeting as a team to try a lego prototype out
- split into sub teams strategy, goal is to maybe develop solidworks by next Santillan meeting

- Notes from Team Meeting with Dr. Santillan (2/17)
- worried about us being behind
- look at elevation on Google maps of the hill
- start prototyping with a purpose

- Notes from Team Meeting with Clara (2/18)
- Welding makes a big difference - didn't get put back the same when they traveled to Baltimore
- When they reassembled it wasn't aligned properly
- Race starts with the hill which is really rough
- They started by recreating in-between bike structure to bike
- Floats didn't fit inflated on so they had to add them after
- Email Wilson about using the pool? Scout out doorway width
    - Follow up about who to ask about the pool in Wilson from Clara
- They didn't have any formal sand testing, beach volleyball court?
- Acquire bikes, etc. for the pit crew
- Warehouse in baltimore for storage the night before
- They got in and out of the water by lifting it in and out because the flotation devices were too large to be able to bike with them on
- Hill full of dog shit?

- Notes from Team Meeting with Dr. Santillan (2/24)
- Presented current prototype
- Email Santillan about talking to ME 321 grad TA about SolidWorks and simulation
- Wants us to start on aesthetics and flotation ASAP

- Notes from Team Meeting with Dr. Franzoni (3/3)
- Wants us to start working on the art prototyping ASAP
- Idea of flipping the roof upside down to be the raft? Fits with Chloe's lock-in idea
- Propellor VS paddle wheel ideas:
    - Propellers online
- Come up with team name
- Polystyrene

- Notes from Team Meeting with Dr. Santillan (3/24)
- Izzy - stuff glued and carved by end of the week

- Duke pond drained?
- Email Cliff about using the Wilson gym even though it says off limits
- Is Matthew’s attachment plan gonna be 8% wet proof?
- Finalize submission form by tonight

- Notes from Team Meeting with Dr. Santillan (3/31)

- Can we take the foam off if needed for the mud and sand portions of the race?
- Can we make two sets of holes, one for the water and one for the sand?
- Can we add a rudder for steering?
- Can we add something to the wheels in the front to make them into rudders?
- Need to add a tow hook
- Need more JB Weld maybe?
- Finalize safety plan, tow ring etc.
- Find new time for sand testing
- Class on monday????
- Graham steering wheel done next week
- Talk to Evan about the paint studio

- Notes from Team Meeting with Dr. Santillan (4/7)

- Isn’t carbon fiber supposed to not go in water?
- What needs to be around the piranha head? Cardboard box?
- Timing for steering? By next week
- Bring water to wash off bikes on Wednesday
- Bring bathing suits
- Document a lot
- Enter through the back and go through towerview/BZ
- Install tow ring before wednesday !!
- Go pro??

- Notes from Team Meeting with Dr. Santillan (4/14)

- Need to figure out ramp/water testing ASAP - plan for traction in the back
- Where can we help in the race? Dropping the back float?
- Falls Lake testing this weekend - decide ASAP
- Write Santillan about the water testing and truck
- Talk about when to leave on Friday
- 7 AM leave time for at least one
- Everyone coming back to Durham, early on Sunday

- Decide on the Baltimore Orioles game, Friday night?

Appendix L: Trello Screenshots

Kinetic Sculpture · Board · Table · Filters · +2 · Share

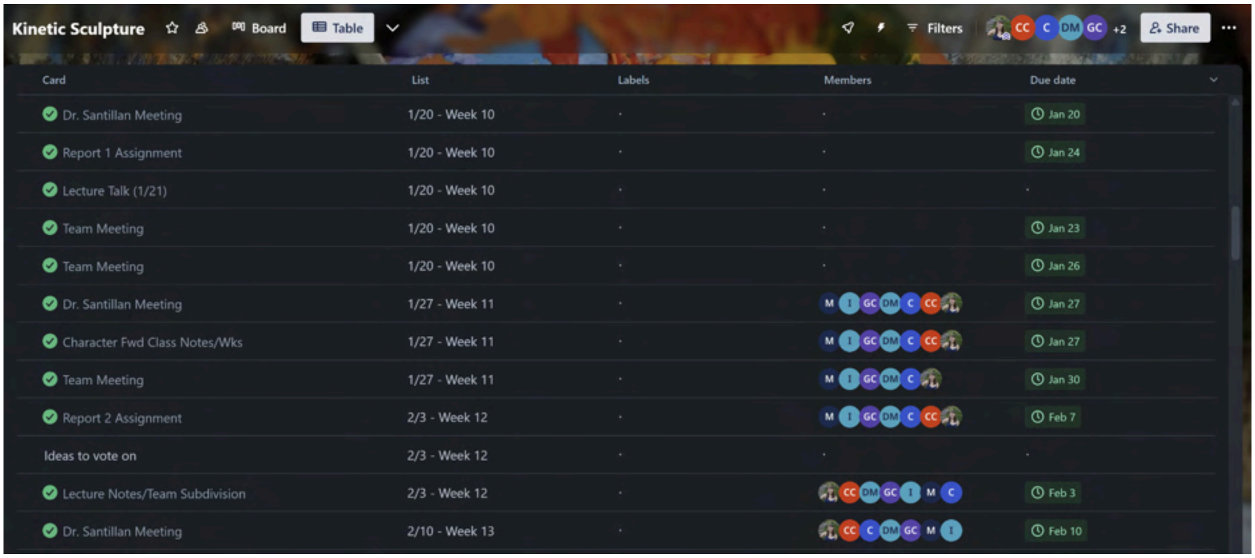
Card	List	Labels	Members	Due date
Meeting With Dr. Santillan	10/21 - Week 1	·	DM M CC I GC C	Oct 21, 2024
Team Meeting	10/28 - Week 2	·	CC I GC DM C	Oct 28, 2024
Meeting With Dr. Santillan	10/28 - Week 2	·	CC I GC DM C	Oct 29, 2024
Team Inspiration Slides	11/4 - Week 3	·	I DM C CC	Nov 4, 2024
Team Meeting	11/4 - Week 3	·	DM I CC C	Nov 4, 2024
Meeting With Dr. Santillan	11/4 - Week 3	·	C DM GC I CC	Nov 5, 2024
Problem Summary Report	11/4 - Week 3	·	CC C GC DM I	Nov 8, 2024
Journey Mapping Class Activity	11/11 - Week 4	·		Nov 14, 2024
Class Discussion	11/18 - Week 5	·	I C DM CC	Nov 18, 2024
Team Meeting	11/18 - Week 5	·	I GC DM C CC	Nov 19, 2024
Meeting with Jared (TA)	11/18 - Week 5	·	I GC C CC	Nov 20, 2024
Meeting with Dr. Santillan	11/18 - Week 5	·	I GC DM C CC	Nov 21, 2024

Figure L.1: Trello Tasks (10/21-11/21)

Kinetic Sculpture · Board · Table · Filters · +2 · Share

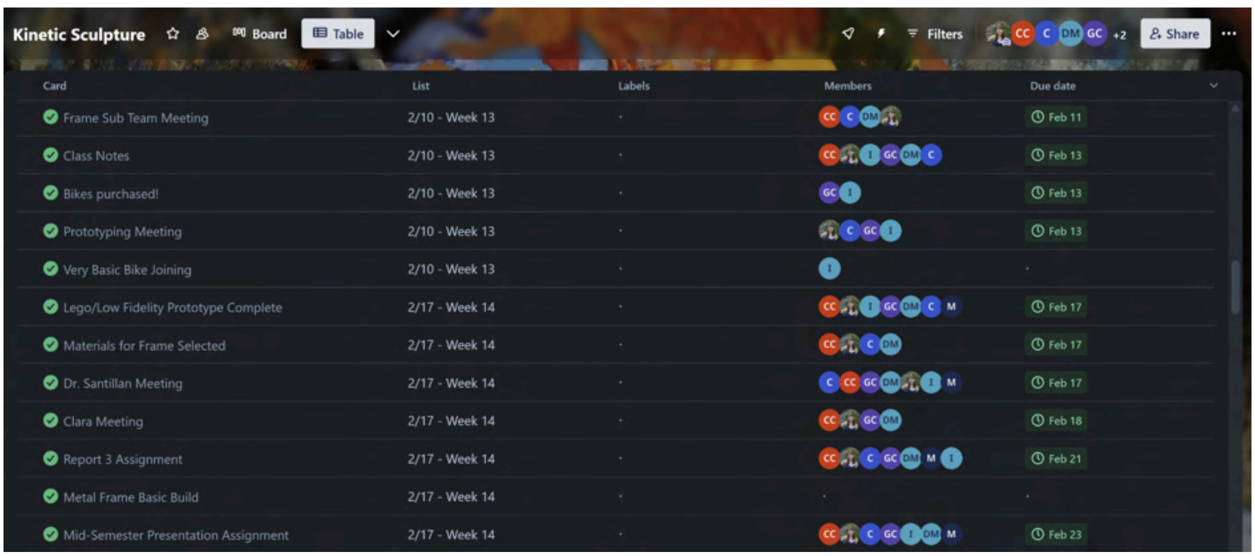
Card	List	Labels	Members	Due date
Design Criteria Report	11/18 - Week 5	·	I GC DM C CC	Nov 22, 2024
Thanksgiving!	11/25 - Week 6	·	·	·
End-of-Semester Presentation	12/2 - Week 7 (LWOC)	·	I GC DM C CC	Dec 2, 2024
Team Practice	12/2 - Week 7 (LWOC)	·	I GC DM C CC	Dec 2, 2024
Presentation Time Slot	12/2 - Week 7 (LWOC)	·	I GC DM C CC	Dec 2, 2024
End-of-Semester Report	12/2 - Week 7 (LWOC)	·	I GC DM C CC	Dec 6, 2024
Lecture 1 - Functions	1/6 - Week 8 (FDOC)	·	M I GC DM C CC	Jan 8
Brainstorming (Report 1)	1/6 - Week 8 (FDOC)	·	M I GC DM C CC	Jan 9
Team Meeting	1/13 - Week 9	·	M I GC DM C CC	Jan 13
Dr. Santillan Meeting	1/13 - Week 9	·	·	Jan 13
Contact Julia McHugh (Nasher)	1/13 - Week 9	·	·	Jan 18
Team Meeting	1/13 - Week 9	·	M I GC DM C CC	Jan 19

Figure L.2: Trello Tasks (11/22-1/19)



Card	List	Labels	Members	Due date
Dr. Santillan Meeting	1/20 - Week 10	·	·	Jan 20
Report 1 Assignment	1/20 - Week 10	·	·	Jan 24
Lecture Talk (1/21)	1/20 - Week 10	·	·	·
Team Meeting	1/20 - Week 10	·	·	Jan 23
Team Meeting	1/20 - Week 10	·	·	Jan 26
Dr. Santillan Meeting	1/27 - Week 11	·	M I GC DM C CC	Jan 27
Character Fwd Class Notes/Wks	1/27 - Week 11	·	M I GC DM C CC	Jan 27
Team Meeting	1/27 - Week 11	·	M I GC DM C	Jan 30
Report 2 Assignment	2/3 - Week 12	·	M I GC DM C CC	Feb 7
Ideas to vote on	2/3 - Week 12	·	·	·
Lecture Notes/Team Subdivision	2/3 - Week 12	·	CC DM GC I M C	Feb 3
Dr. Santillan Meeting	2/10 - Week 13	·	CC C DM GC M I	Feb 10

Figure L.3: Trello Tasks (1/20-2/10)

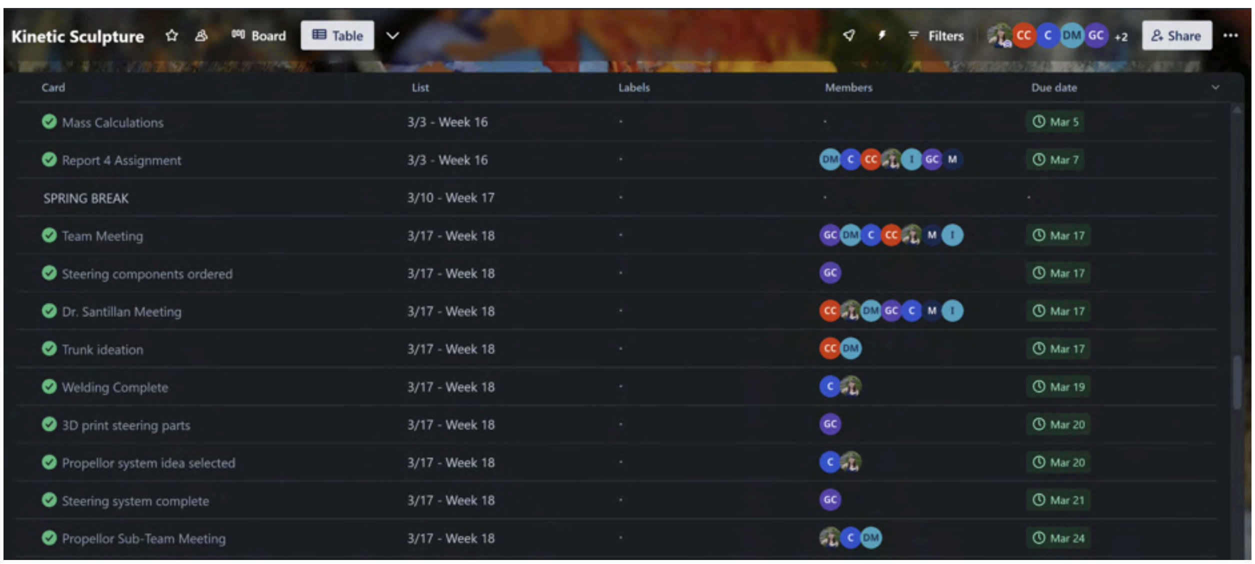


Card	List	Labels	Members	Due date
Frame Sub Team Meeting	2/10 - Week 13	·	CC C DM	Feb 11
Class Notes	2/10 - Week 13	·	CC I GC DM C	Feb 13
Bikes purchased!	2/10 - Week 13	·	GC I	Feb 13
Prototyping Meeting	2/10 - Week 13	·	C GC I	Feb 13
Very Basic Bike Joining	2/10 - Week 13	·	I	·
Lego/Low Fidelity Prototype Complete	2/17 - Week 14	·	CC I GC DM C M	Feb 17
Materials for Frame Selected	2/17 - Week 14	·	CC C DM	Feb 17
Dr. Santillan Meeting	2/17 - Week 14	·	C CC GC DM I M	Feb 17
Clara Meeting	2/17 - Week 14	·	CC GC DM	Feb 18
Report 3 Assignment	2/17 - Week 14	·	CC C GC DM M I	Feb 21
Metal Frame Basic Build	2/17 - Week 14	·	·	·
Mid-Semester Presentation Assignment	2/17 - Week 14	·	CC C GC I DM M	Feb 23

Figure L.4: Trello Tasks (2/11-2/23)

Card	List	Labels	Members	Due date
Team Meeting	2/17 - Week 14	·	C GC I M	Feb 23
SolidWorks for Frame Complete	2/17 - Week 14	·	CC C DM	Feb 23
Dr. Santillan Meeting	2/24 - Week 15	·	C CC DM M I GC	Feb 24
Pat Consult	2/24 - Week 15	·	DM C	Feb 24
SolidWorks FEA Progress	2/24 - Week 15	·	DM C	Feb 25
Presentation Practice	2/24 - Week 15	·	CC GC I DM M C	Feb 25
Contact Stephen Hayes (Sculpture)	2/24 - Week 15	·		Feb 26
Mid-Semester Presentation	2/24 - Week 15	·	CC C GC I M	Feb 27
Welding!	2/24 - Week 15	·	C	Feb 28
Team Meeting	2/24 - Week 15	·	CC DM	Mar 2
Dr. Franzoni Meeting	3/3 - Week 16	·	C DM GC M	Mar 3
Professor Hayes Consultation	3/3 - Week 16	·	I	Mar 5

Figure L.5: Trello Tasks (2/23-3/5)



Card	List	Labels	Members	Due date
Mass Calculations	3/3 - Week 16	·	·	Mar 5
Report 4 Assignment	3/3 - Week 16	·	DM C CC I GC M	Mar 7
SPRING BREAK	3/10 - Week 17	·	·	·
Team Meeting	3/17 - Week 18	·	GC DM C CC M I	Mar 17
Steering components ordered	3/17 - Week 18	·	GC	Mar 17
Dr. Santillan Meeting	3/17 - Week 18	·	CC DM GC C M I	Mar 17
Trunk ideation	3/17 - Week 18	·	CC DM	Mar 17
Welding Complete	3/17 - Week 18	·	C	Mar 19
3D print steering parts	3/17 - Week 18	·	GC	Mar 20
Propellor system idea selected	3/17 - Week 18	·	C	Mar 20
Steering system complete	3/17 - Week 18	·	GC	Mar 21
Propellor Sub-Team Meeting	3/17 - Week 18	·	C DM	Mar 24

Figure L.6: Trello Tasks (3/5-3/24)

Kinetic Sculpture | Board | Table | Filters | Share

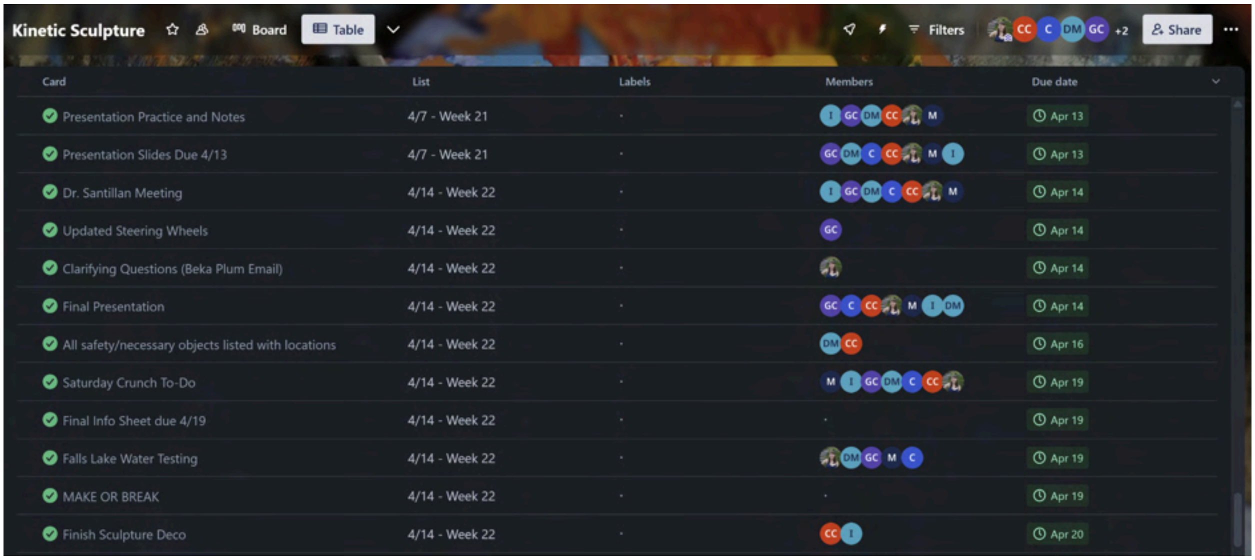
Card	List	Labels	Members	Due date
Dr. Santillan Meeting	3/24 - Week 19	·	DM C CC M I GC	Mar 24
Foam attachment idea complete	3/24 - Week 19	·	I M	Mar 24
Water testing plan confirmed and booked	3/24 - Week 19	·	M	Mar 24
Sand testing plan confirmed and booked	3/24 - Week 19	·	DM	Mar 24
Mud testing plan confirmed and booked	3/24 - Week 19	·	GC	Mar 24
Propellor prototype complete	3/24 - Week 19	·	C DM	Mar 27
Sand/mud addition prototype finalized	3/24 - Week 19	·	GC	Mar 27
Dr. Santillan Meeting	3/31 - Week 20	·	DM C CC M I GC	Mar 31
Final foam attachments installed	3/31 - Week 20	·	M I	Mar 31
Sculpture Basic Carving Done	3/31 - Week 20	·	CC I	Mar 31
Painting Studio/Painting Plan	3/31 - Week 20	·	I	Mar 31
Email facilities abt BZ sand court	3/31 - Week 20	·	DM	Apr 1

Figure L.7: Trello Tasks (3/24-4/1)

Kinetic Sculpture | Board | Table | Filters | Share

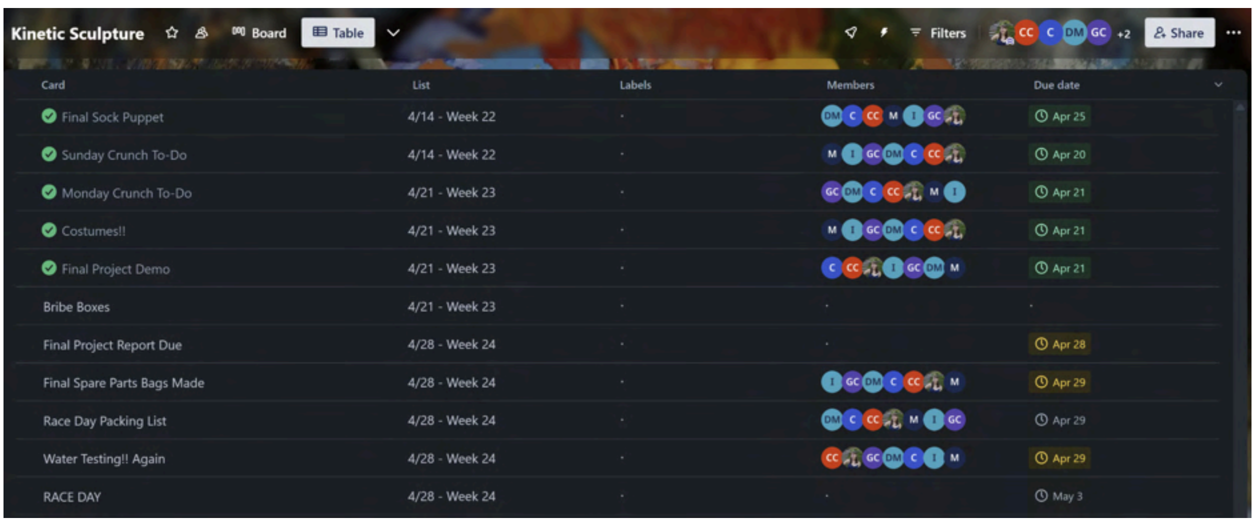
Card	List	Labels	Members	Due date
Sand/mud additions finalized	3/31 - Week 20	·	GC	Apr 1
Dimensions	3/31 - Week 20	·	·	Apr 3
Sand/mud testing at Gross Hall	3/31 - Week 20	·	CC C DM I GC M	Apr 6
Dr. Santillan Meeting	4/7 - Week 21	·	C I GC DM M	Apr 7
Sand testing complete	4/7 - Week 21	·	GC	Apr 7
Safety Plan Complete	4/7 - Week 21	·	M DM	Apr 7
Steering Wheels Installed	4/7 - Week 21	·	GC	Apr 7
Water proofing complete	4/7 - Week 21	·	I CC	Apr 8
Final propellor complete/installed	4/7 - Week 21	·	C DM	Apr 8
Wilson Water Test	4/7 - Week 21	·	CC C DM GC M	Apr 9
Rough Draft Slides Complete	4/7 - Week 21	·	C CC I GC DM M	Apr 11
Mud testing complete	4/7 - Week 21	·	DM GC M	Apr 13

Figure L.8: Trello Tasks (4/1-4/13)



Card	List	Labels	Members	Due date
Presentation Practice and Notes	4/7 - Week 21	·	I GC DM CC M	Apr 13
Presentation Slides Due 4/13	4/7 - Week 21	·	GC DM C CC M I	Apr 13
Dr. Santillan Meeting	4/14 - Week 22	·	I GC DM C CC M	Apr 14
Updated Steering Wheels	4/14 - Week 22	·	GC	Apr 14
Clarifying Questions (Beka Plum Email)	4/14 - Week 22	·		Apr 14
Final Presentation	4/14 - Week 22	·	GC C CC M I DM	Apr 14
All safety/necessary objects listed with locations	4/14 - Week 22	·	DM CC	Apr 16
Saturday Crunch To-Do	4/14 - Week 22	·	M I GC DM C CC	Apr 19
Final Info Sheet due 4/19	4/14 - Week 22	·	·	Apr 19
Falls Lake Water Testing	4/14 - Week 22	·	DM GC M C	Apr 19
MAKE OR BREAK	4/14 - Week 22	·	·	Apr 19
Finish Sculpture Deco	4/14 - Week 22	·	CC I	Apr 20

Figure L.9: Trello Tasks (4/13-4/20)



Card	List	Labels	Members	Due date
Final Sock Puppet	4/14 - Week 22	·	DM C CC M I GC	Apr 25
Sunday Crunch To-Do	4/14 - Week 22	·	M I GC DM C CC	Apr 20
Monday Crunch To-Do	4/21 - Week 23	·	GC DM C CC M I	Apr 21
Costumes!!	4/21 - Week 23	·	M I GC DM C CC	Apr 21
Final Project Demo	4/21 - Week 23	·	C CC I GC DM M	Apr 21
Bribe Boxes	4/21 - Week 23	·	·	·
Final Project Report Due	4/28 - Week 24	·	·	Apr 28
Final Spare Parts Bags Made	4/28 - Week 24	·	I GC DM C CC M	Apr 29
Race Day Packing List	4/28 - Week 24	·	DM C CC M I GC	Apr 29
Water Testing!! Again	4/28 - Week 24	·	CC GC DM C I M	Apr 29
RACE DAY	4/28 - Week 24	·	·	May 3

Figure L.10: Trello Tasks (4/13-5/3)