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MEMS 411: Rowing Force Plate

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FL21 MEMS 411 Mechanical Engineering Design Project

ROWING FORCE PLATE

The Rowing Force Plate is a device that is designed to measure a rower's force over time so that they can understand how hard they are rowing. Most rowing aids communicate the speed at which someone is rowing, which is variant on water speed, wind speed, and other inconsistent environmental and situational factors. Force, however, can be consistently measured and is a better indicator of effort a rower is exerting. Other products that measure force do exist, but use complex and expensive technology, unlike our design.
After brainstorming and analyzing multiple possible designs, we concluded to use four force sensors under the existing shoes in the boat would be the most feasible design. These force sensors would be connected to an Arduino (a microcontroller), which would then display data to a screen for the rower to read while rowing. This design was chosen over other concepts because of its high expected accuracy, low weight, and fairly easy integration with existing systems.
We set three performance goals of measuring force at time point, accurately measuring force, and making the device strong in tension for safety purposes. The initial prototype was able to measure force at time points and be strong in tension, but could not measure force accurately. This was due to electronic issues with old load cells measuring force and integrating with the circuit. With new load cells, we were able to meet our prototype performance goals, and were even able to successfully use the device in a real boat on the water.

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1 Introduction

The rowing force plate is a device that will aid rowers and their coaches in understanding rowing performance. Many devices on the market measure speed, which is very dependent on local conditions, such as wind speed, water speed, etc. However the measure of power output can be compared across different conditions, providing a valuable statistic.

The rowing force plate will be placed under the rower's foot plate, where all of their horizontal force is distributed to. With that information, the power will be calculated and displayed on a mini screen for instant feedback to the rowers, and stored for future analysis from coaches.

From research and interviewing the Washington University club rowing coach, there are some key considerations that this device must have. The device must be light (no more than 1 or 2 lbs per rower). Also, the device should permanently be in the boat, as moving foot plates is challenging and time consuming. Given the device's placement in a boat, it should be waterproof. Finally, instant feedback to the rowers through a small screen would be helpful, but coaches would not benefit from that as much and would be content with being able to access stored data.

2 Problem Understanding

2.1 Existing Devices

Currently several devices exist to achieve similar goal: to measure a rower's effort and produce quantitative feedback. By measuring force exertion at different boat components, existing devices quantify slightly different values and therefore deliver slightly different information about the rower's efforts.

2.1.1 Existing Device #1: Oarlock Sensor

Figure 1: Empower Oarlock (Source: NK Sports)

Link: https://nksports.com/empower-oarlock
Description: A standard rowing shell used in races includes a fastener at the pivot point where the oar connects to the boat. This fastener is called the pin, or oarlock. By adapting the oarlock

to include a force transducer and angle detector, this technology records and displays the effective work that the rower exerts with the oar. It collects data points 50 times per second and provides per-stroke parameters. It collects data for five key elements of each stroke: catch angle, slip, peak force, peak force location, wash and finish angle. Data is displayed through wireless connection to other NK products, allowing for real time performance analysis. It is waterproof and is powered by AA batteries. This design differs from our proposed design; the Empower Oarlock only conveys information about the effective work output while our proposed design conveys information about the work the rower is putting into the oar system. The discrepancy between these quantities could provide insight into rower efficiency.

2.1.2 Existing Device #2: smartOar

Figure 2: smartOar (Source: smartoar.com)

Link: https://www.smartoar.com/
Description: By attaching a strain gauge to the shaft midway between the blade and the collar, and connecting this to an electronic mount, the smartOar measures force exerted by the oar. The electronic sensor component records the force exerted by the oar throughout the stroke to create a force curve for each rower in the boat. This information is wirelessly delivered to a tablet, which displays the force curves in real time.

2.1.3 Existing Device #3: Foot Stretcher Force Sensor

Figure 3: Foot Stretcher Force Sensor (Source: BioRow)

Link: http://biorow.com/products/biorow_sensors/stretcher_force2
Description: The foot stretcher is the angled plate secured to the base of the shell. Each rower's shoes are secured to this plate. By attaching three special load cell at the three points of contact between the plate and the shell, the sensors will measure the overall horizontal propulsive force exerted by the rower. Through these three sensors (two on either side of the top edge, one on the bottom edge), the product can also detect side to side imbalance of force exertion. The product is lightweight (0.63lb per foot stretcher) and measures a wide range of forces (-900N to +2400N). However, this mechanism does not contribute real time information, but rather serves as a diagnostic tool for later use.

2.2 Patents

2.2.1 Rowing force and rowing performance monitoring device (US10016158B2)

This patent outlines the basic principles of the oarlock force sensor. It specifies that this product is attached to the oarlock without any modification to other elements of the shell, only requiring some mechanical contact between the oar and the oarlock. This oarlock sensor device is said to wirelessly transmit measurements to some smart device in a format that is easily interpreted, either in real time or for later diagnostic use.

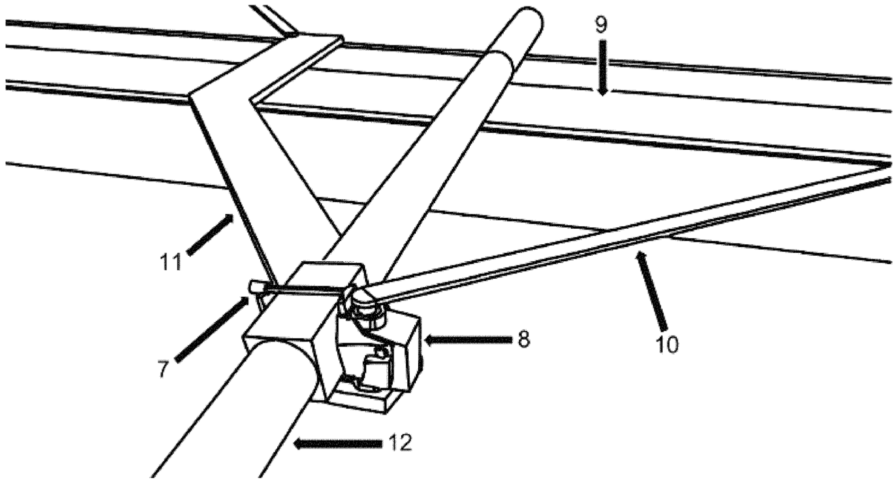


Figure 4: Patent Images for force sensor oarlock

2.2.2 Force sensing oar (US8192242B2)

This patent outlines a product that determines the force exerted by an oar using a deflection sensor and temperature sensor. A processor connected to both sensors receives this information and converts it to a force and displays this force on some connected device. The whole system is powered by some electric power source.

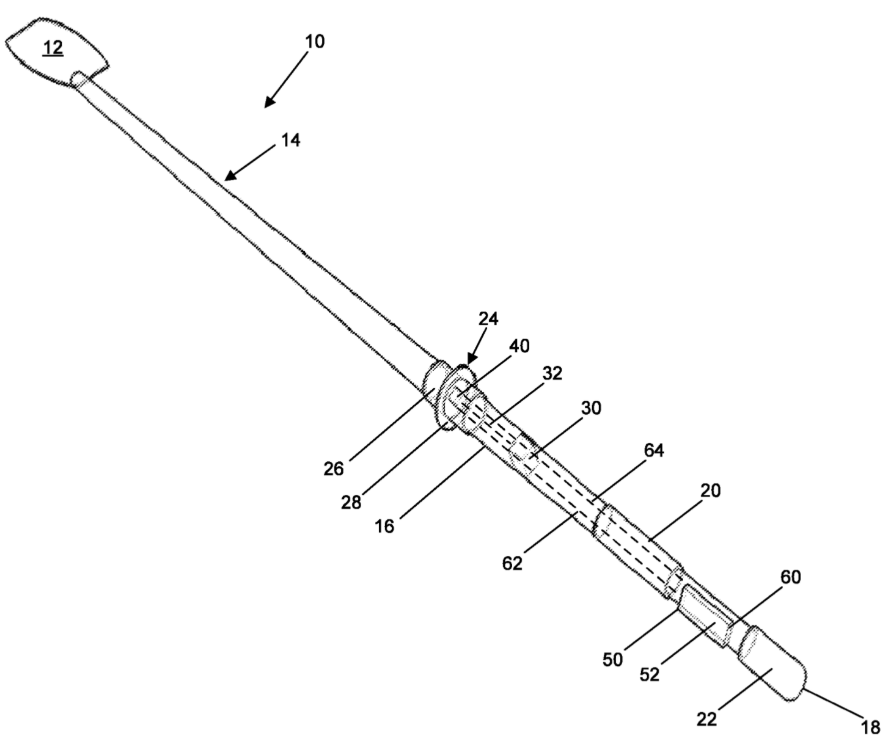


Figure 5: Patent Images force sensing oar

2.3 Codes & Standards

2.3.1 Rowing Competition- Electronic Communication (Rules of Rowing: 11-210 Outside Assistance)

The Rules of Rowing state that rowers cannot receive any instructions, advice, or directions via electronic communication. When designing this device, it is crucial to ensure that it does not or could not be perceived to be illegally helping the rowers during a race, as breaking the rule results in exclusion from the race. [1].

2.3.2 Rowing Competition- Minimum Boat Weight (Rules of Rowing: Procedure: Weighing of Boats)

All boats at a rowing race must meet a minimum boat weight. This must be regulated because lighter boats are faster. The rules state that electronic wiring must be counted in the boat's weight, while removable electronic devices, such as personal screens, are not included in the minimum weighing. This is important to understand how the device will impact a team's official and effective weight when rowing at a competition. [1].

2.4 User Needs

In our case the user is Washington University's rowing coach Andrew Black. He will hopefully be able to provide us with useful insight as to the coaches more technical understanding of boat speed.

2.4.1 Customer Interview

Interviewee: Andrew Black
Location: Zoom
Date: September 8^{th}, 2021
Setting: We explained the concept a little bit more and discussed existing technology and potentially useful improvements on the already existing products. We took notes and recorded the meeting to refer back to later. The interview lasted about a half an hour the design group was together while Andrew was in his office talking to us via zoom.
Interview Notes:

What are the main physical constraints of the system?

- Where feet attach to boat is adjustable so it cannot constrain that adjustment
- Must fit in the space under the foot stretcher.
- Must be powered (batteries, rechargeable, siphon power from stroke coach)

What metrics would you ideally want displayed?

- Shows average watts/stroke
- Want to see how much power force being applied; force time

Approximately how heavy could this mechanism be, at a maximum, potentially as a percentage of boat weight?

- Whole boat (8) is min 210 lb. Don't want to add more than a pound or two for each person.
- Every 10 lb you add to an 8, slows boat down by 1.6 sec over 2000 m race
- Replace other item, so could gain some flexibility there

How would you like metrics displayed (Just for the rowers, Rowers and coach/cox, recorded for later analysis)?

- Record data to analyze later on
- Display numbers in real time to the rowers and send to the coach

Do you envision this mechanism being removed after each use or left in the boat for longer periods of time?

- Measuring instrument itself could stay in, but monitor could be removed each time
- Shoes are bolted into the boat. Removing shoes is a pain but doable if necessary

How do you envision this mechanism ideally working?

- Invisible. Feed into already existing technology? Like stroke coaches. Get wifi enabled one so that it transmits info wirelessly
- Place where measuring force must be thin. Tuck away- able

Do you have any current technology that achieves the same goals? If so, how do they work? What are their pros/cons?

- Generally measure force at the pin at the ore lock. That measures effective force, rather than the actual work that you're putting in (that's what ours would measure). Would be interesting to measure difference (can help "diagnose inefficiencies")
- Oar lock sensor roughly $400. Would wirelessly send info to phone
- Stroke coach can display other metrics that are potential useful

Are there any rules that may prohibit this from being used in a race?

- Nothing that prevents you adding. Rules restrict electronic communication between boat someone outside of boat.

As a potential customer, what would you be willing to spend on this product?

- Whatever people are willing to spend on oar lock. $300-500 per station

2.4.2 Interpreted User Needs

Table 1: Interpreted user needs

Question	Customer Statement	Interpreted Need	Imp.
Metrics Displayed	How hard someone rows, time	Power display, s/m	5
Weight	No more than 10 lbs total "No harm adding a couple pounds per person"	Individually ¡ 1.25lbs	4
Are there rules that limit this in rowing?	Cannot send info in real time to a coach during a race (but can in a practice)	May or may not send info to coach depending on final design	3
How adjustable must it be/how removable	Need the shoes in every day without removing them	Design needs to be removable without affecting shoes or needs to stay in almost all the time	3
Power capacity	One full practice (if it can be easily removed partially for charging)	Removable power source	5
Display mechanism	Ideally would use a wifi enabled stroke coach to send to the coach	Need a method to display (probably a stroke coach) that can transmit info	4

2.5 Design Metrics

The foot stretcher force plate needs to be unobtrusive to rowing, accurate, lightweight, waterproof, and have a reasonable battery life.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	4	Total weight	lb	2	1
2	2	Total volume	in^3	< 200	< 50
3	5	Accuracy & Consistancy	% deviation in 10 tests	$< 5\%$	$< 1\%$
4	5	Distance it moves foot's heel vs typical design	in	< 2	$< .5$
5	3	Battery Life	hours	> 2	> 6
6	4	Refresh rate	per stroke	every 3	each stroke
7	5	Waterproofing IP58 IEC Ingress Protection Ratings	binary	Pass	Pass

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

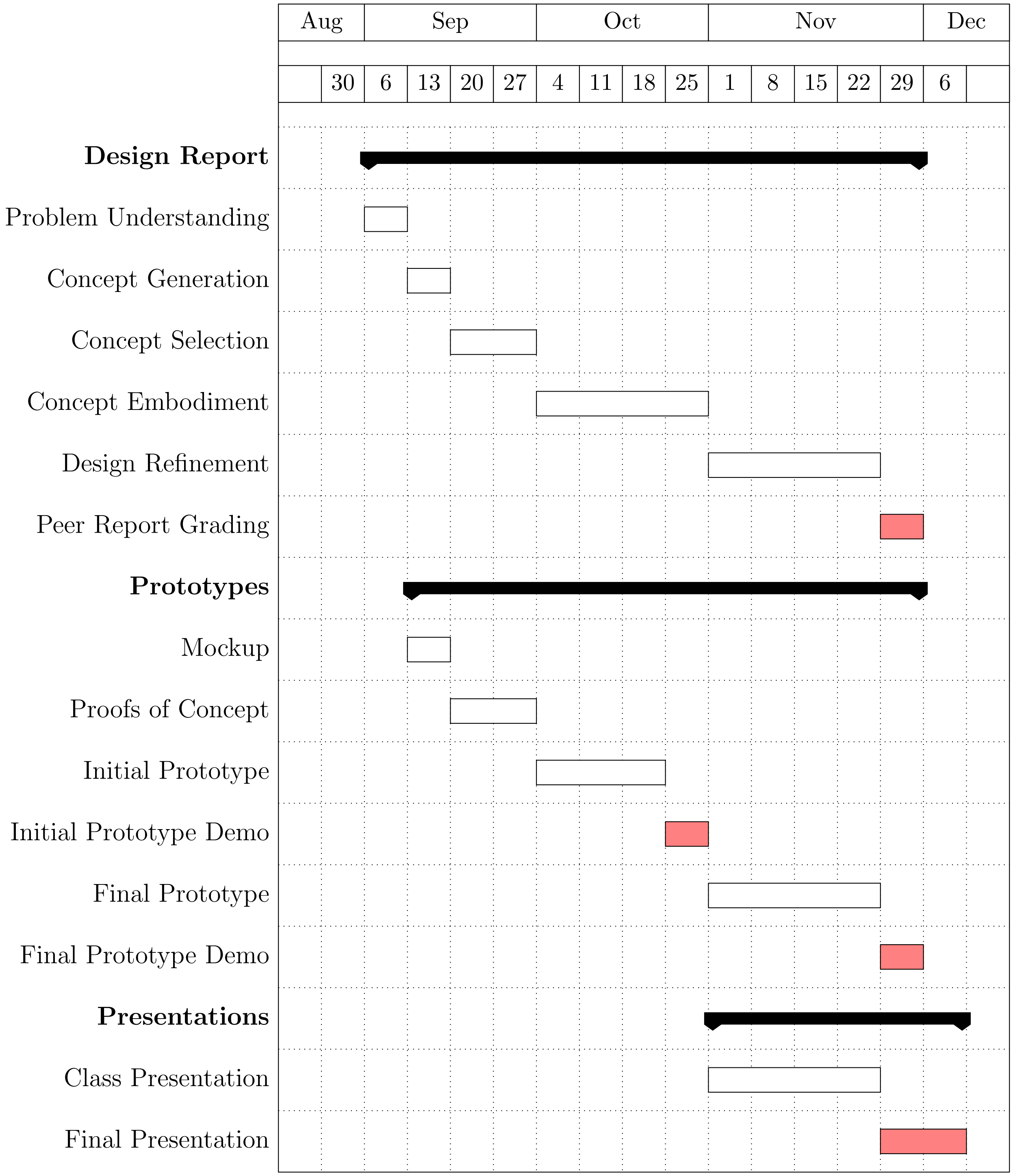


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

Figure 7: A ladder acting as a pulley for the 15 lb. weight

Figure 8: The rower in the catch position

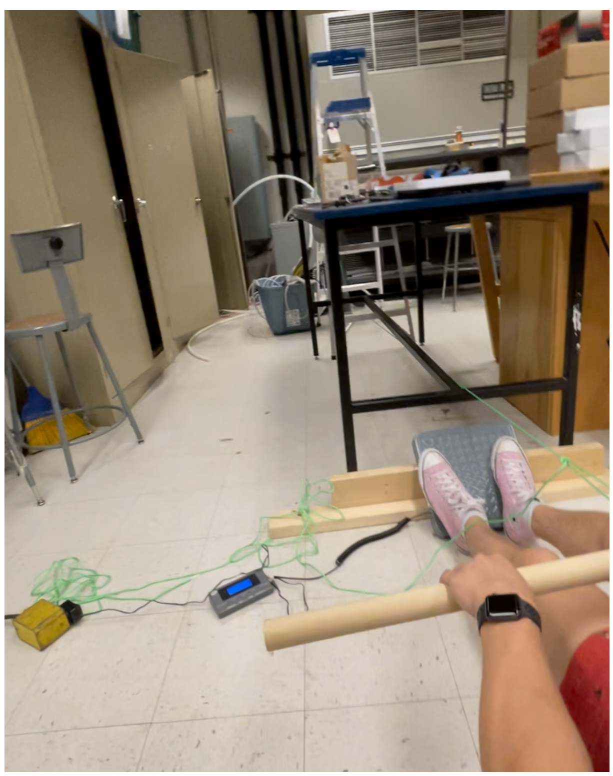


Figure 9: The rower in the finish position

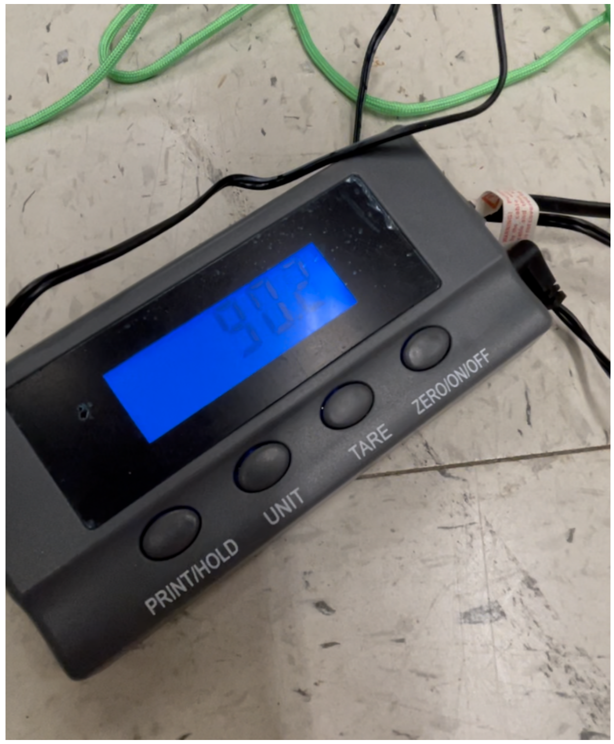


Figure 10: The scale showing a maximum force of 90.2 lbs

Through making this prototype, we learned more about how this device should be implemented and how we can test it in the future. First, the building of this mockup provided a better understanding of how our testing apparatus will work. Being able to have an easily accessible test bed will help us easily try out new designs and different setups. Second, we realized that the rower's force does not go to zero in between strokes, as they are always connected to the foot stretcher. This is crucial to know so that we can brainstorm a way out how parse the data in a way that separates each stroke. We also learned how nuanced the system can be, and while a testing apparatus is very important for quickly testing ideas, we will need to test this device on boats (likely multiple times) before reaching a fully-working solution.

3.2 Functional Decomposition

In order to construct overall design concepts, we broke the final design goal into multiple subfunctions. These subfunctions are outlined in the function tree below.

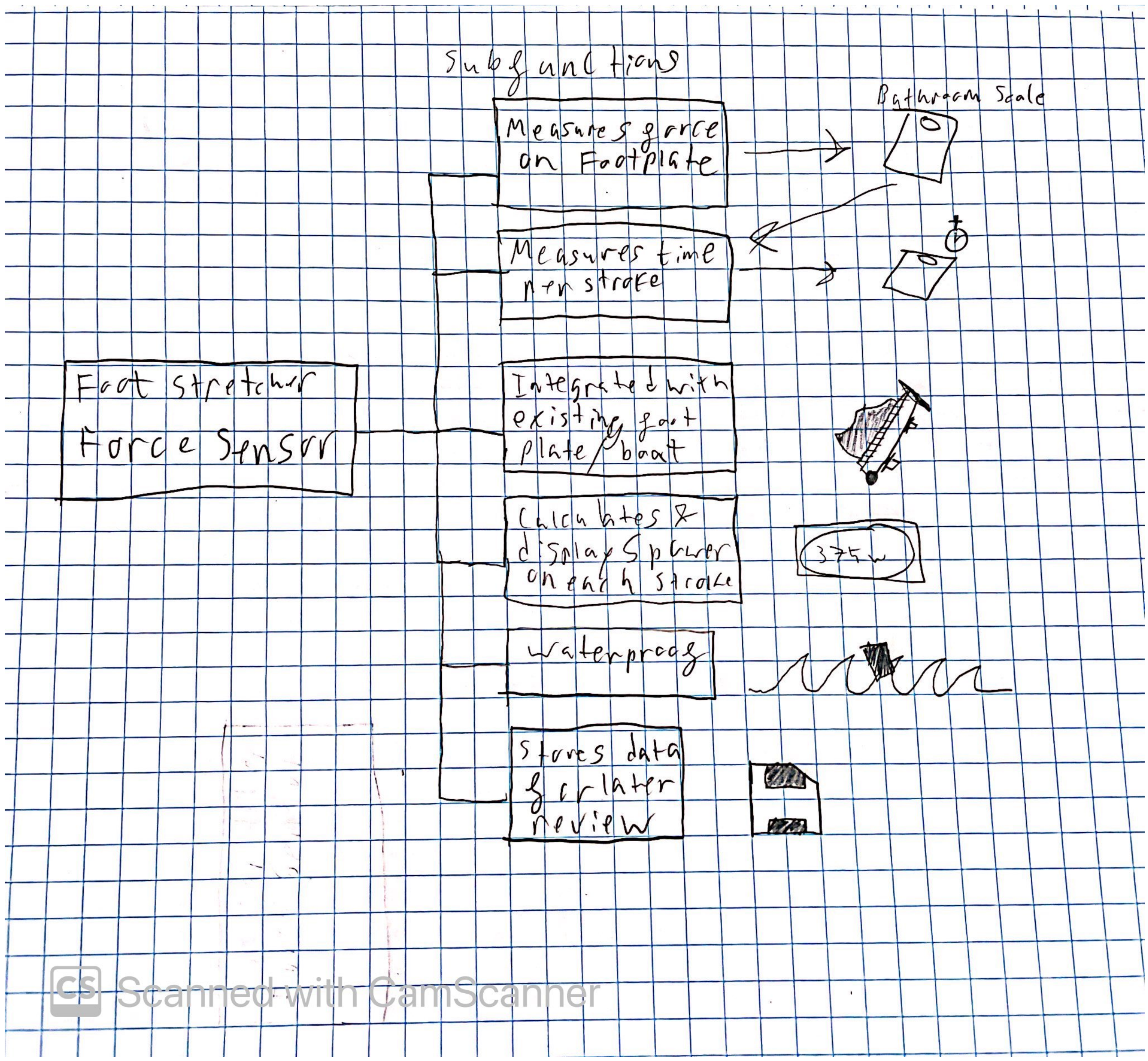


Figure 11: Function tree for Rowing force plate

3.3 Morphological Chart

Each subfunction shown in the function tree can be achieved using various different elements. The morphological chart below shows a few design alternatives for each subfunction.

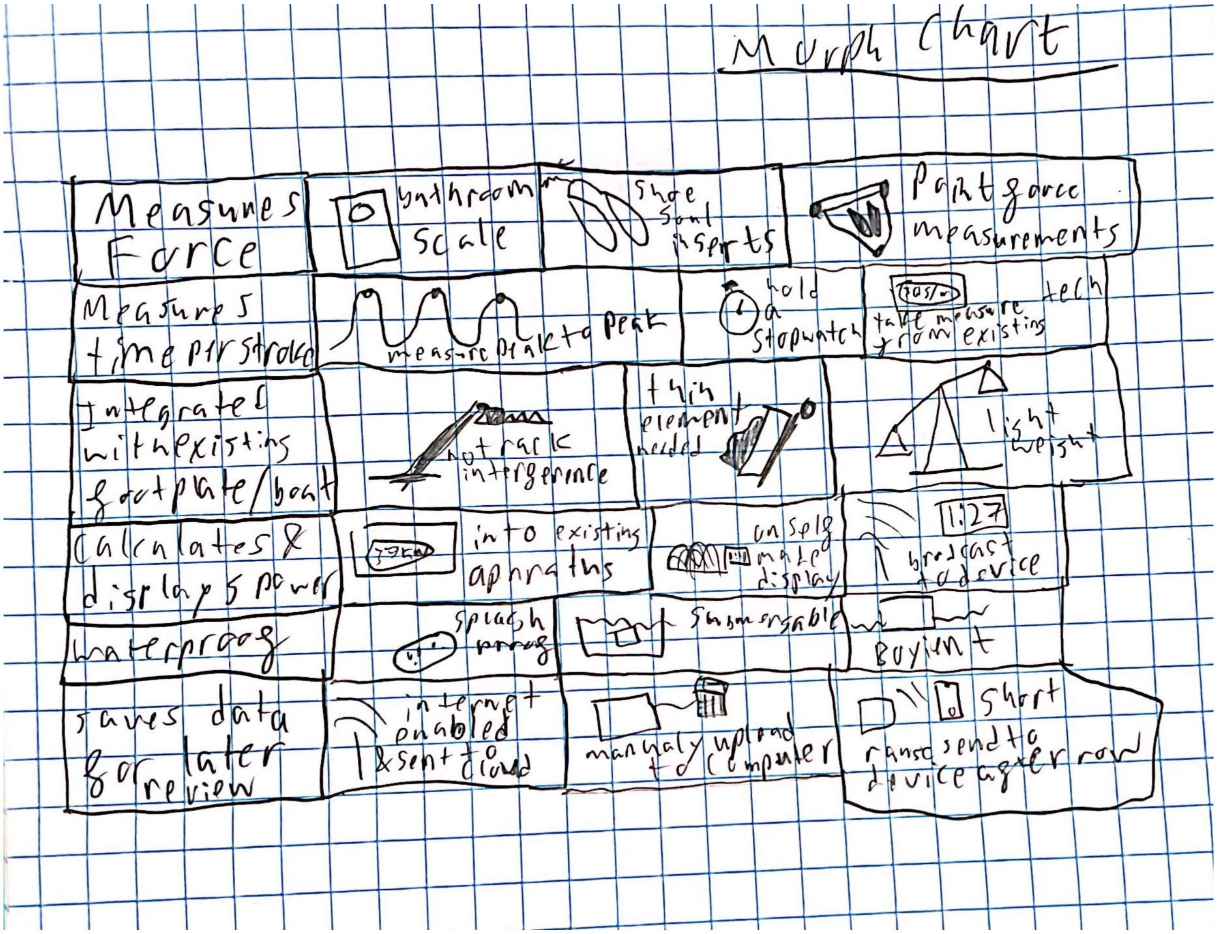


Figure 12: Morphological Chart for Rowing Force Plate

3.4 Alternative Design Concepts

3.4.1 Integrated System

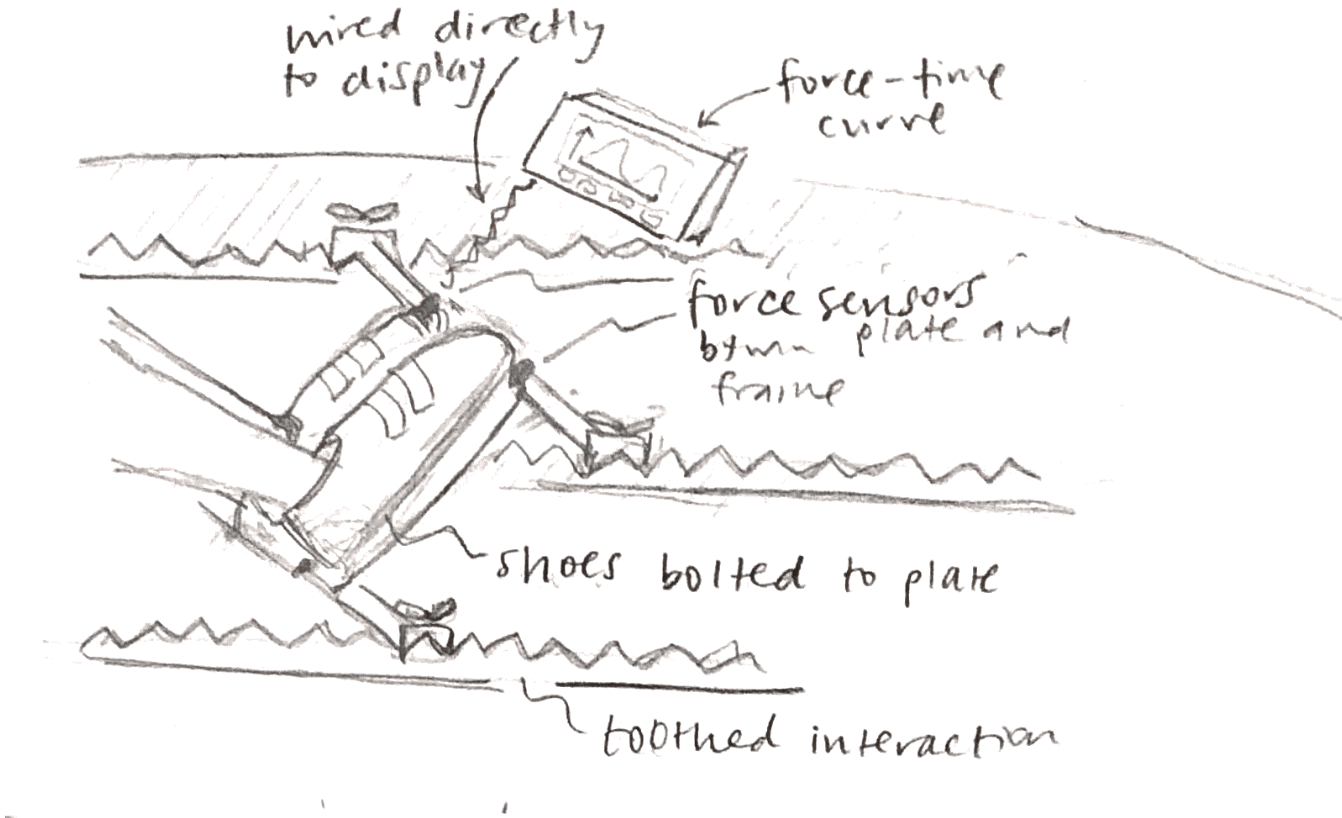


Figure 13: Sketches of Integrated System concept

Description: The three force sensors located at the connection between foot plate and plate frame will sense force applied by the rower. The shoes are bolted into the frame and the frame fits into the adjustable toothed tracks already present in the shell. This data is wired to an electronic device, which uses the known plate angle to calculate horizontal force and display a force vs. time curve in real time. The information is stored in this display and can be downloaded after the row to further analyze and coach the rower.

3.4.2 The Manual Option

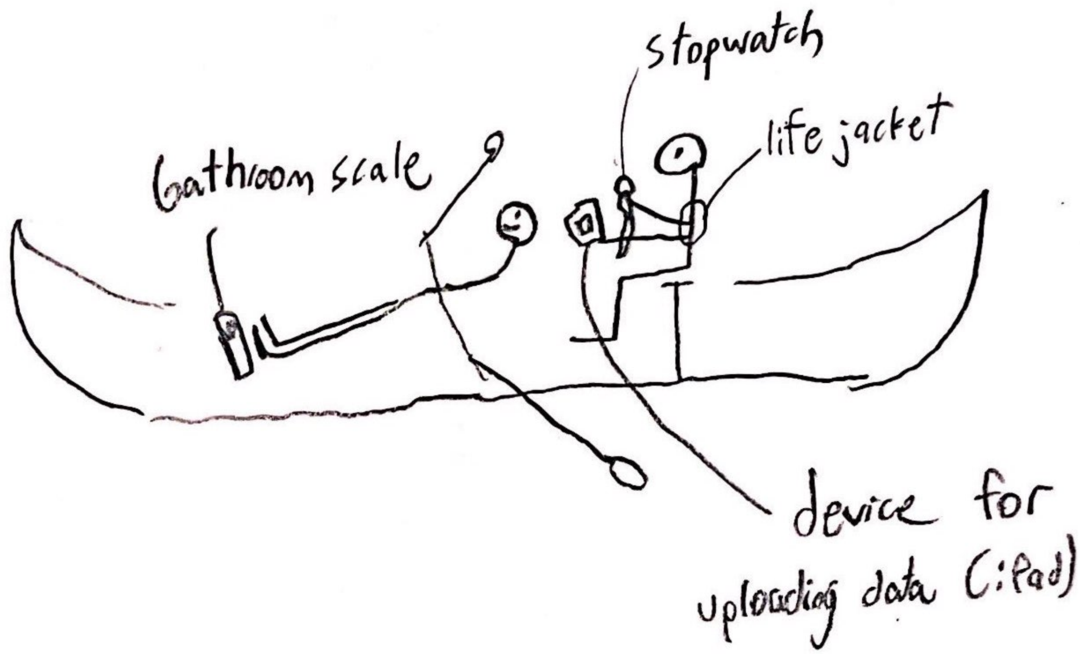


Figure 14: Sketches of the Manual Option concept

Solutions from morph chart:

1. Bathroom scale
2. Stopwatch
3. Broadcast to device
4. No track intereference
5. Buoyant
6. Manually uploaded to computer

Description: This concept is the least automated and requires the most work from the user or an additional human. A person records the force from the bathroom scale and also records the time elapsed for each stroke. They will upload this to an application that will compute the power and other statistics. Assuming the person is wearing a life jacket, they will be buoyant.

3.4.3 Shoe Focused Design

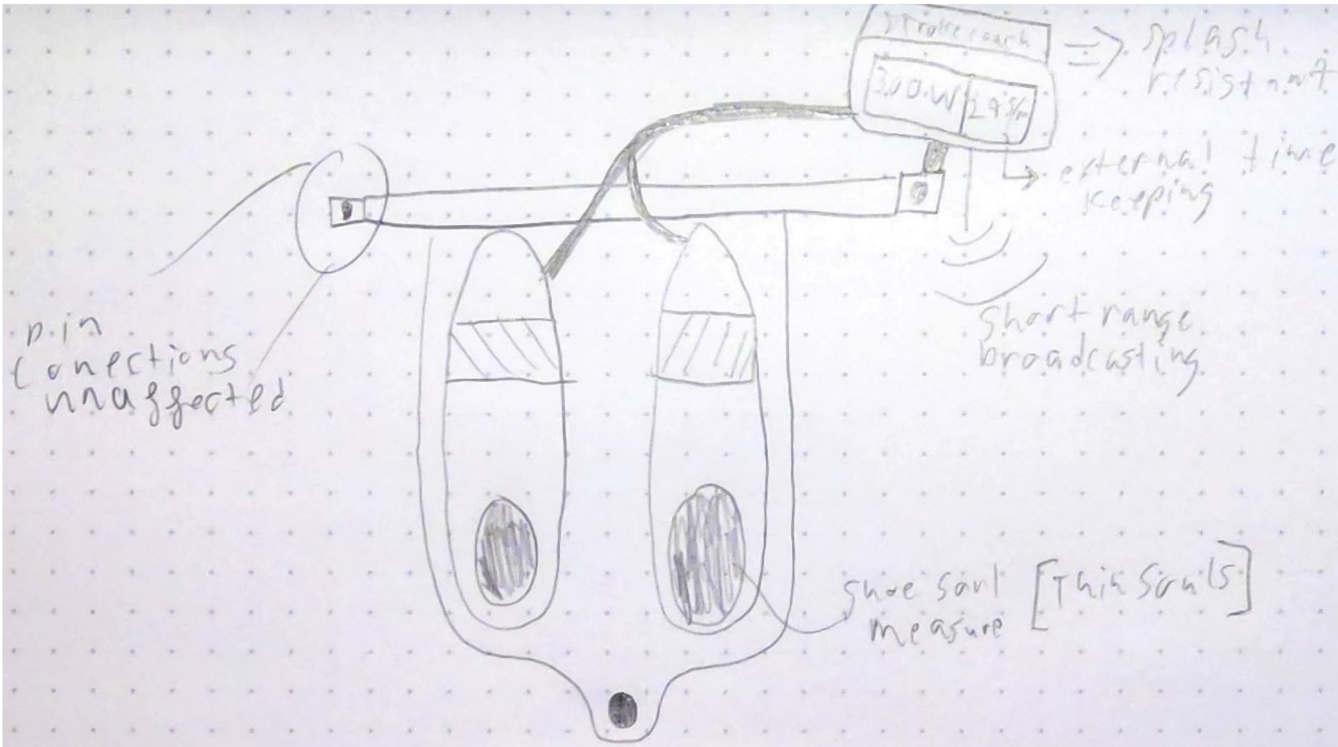


Figure 15: Sketches of the Manual Option concept

Solutions from morph chart:

1. Shoe Soul Inserts
2. External measurement
3. Thin souls for small displacement
4. Displays on existing equipment
5. Splash Proof
6. Short range broadcasting

Description: This concept is all about using and replacing already existing equipment with minimal additions to the boat. The shoe soul force sensors ideally would replace the souls in a typical foot stretcher and hopefully not be much thicker. The stroke coach connection would also minimize external technology required.

4 Concept Selection

4.1 Selection Criteria

Table for determining the relative values of each critical aspect of the design is shown below in table 16.

	Lightweight	Waterproof	Long battery life	Integrates with existing system	Accurate power measurements		Row Total	Weight Value	Weight (%)
Lightweight	**1.00**	0.33	5.00	0.33	0.14		6.81	0.13	12.58
Waterproof	3.00	**1.00**	7.00	3.00	1.00		15.00	0.28	27.71
Long battery life	0.20	0.14	**1.00**	0.20	0.11		1.65	0.03	3.06
Integrates with existing system	3.00	0.33	5.00	**1.00**	0.33		9.67	0.18	17.86
Accurate power measurments	7.00	1.00	9.00	3.00	**1.00**		21.00	0.39	38.80
						Column Total:	**54.13**	**1.00**	**100.00**

Figure 16: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

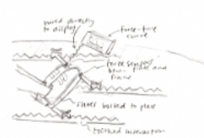
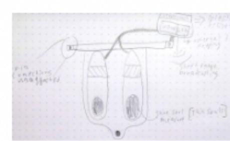
Alternative Design Concepts		**Integrated System**		**Manual Option**		**Shoe-Focused Design**	
							
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Lightweight	12.58	4	0.50	1	0.13	5	0.63
Waterproof	27.71	3	0.83	4	1.11	4	1.11
Long battery life	3.06	3	0.09	4	0.12	4	0.12
Integrates with existing system	17.86	4	0.71	2	0.36	4	0.71
Accurate power measurments	38.80	5	1.94	2	0.78	3	1.16
	Total score	**4.080**		**2.490**		**3.738**	
	Rank	**1**		**3**		**2**	

Figure 17: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

Each system focused mostly on methods of force measurement. This is the most important aspect of our design and needs to be strongly considered. The design with the most accurate power measurement won unsurprisingly. After that waterproofing is an essential component of the design and all of our concepts had it in mind to some degree. Integration with existing system refers to the electronics fitting in the empty space of the boat and not affecting the rower's foot placement or angle. Lightweight is obviously important for racing and is therefore an important characteristic. Long battery life is relatively unimportant since charging the device between uses would be easy and it would only need to be able to run for about 2 hours at a time.

4.4 Engineering Models/Relationships

4.4.1 Model 1

$$\frac{dV}{V} = -\left(\frac{1}{6}\right)\frac{dW}{W}$$

dV = change in velocity
V = original velocity
dW = change in boat weight
W = original boat weight

Figure 18: Model 1: How weight of a rowing boat affects velocity.

This equation shows how weight affects speed in rowing [2]. Given that our device will be in rowing boats in both practice and possible races, it's important to understand how the implementation of our device will affect the speed of the boat. With the change in speed, the change in time with a given race distance can also be found. This will inform us by helping us accurately quantify the time penalty for each added part of our device.

4.4.2 Model 2: Force Curve

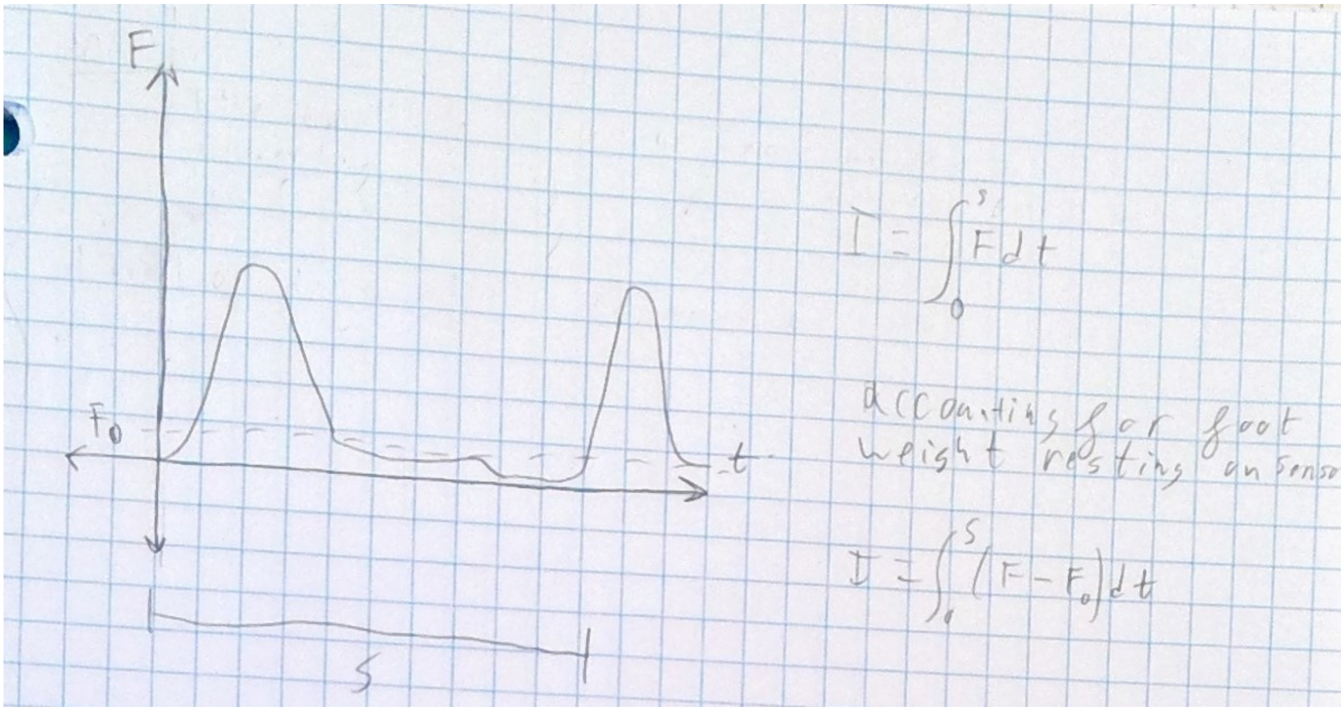


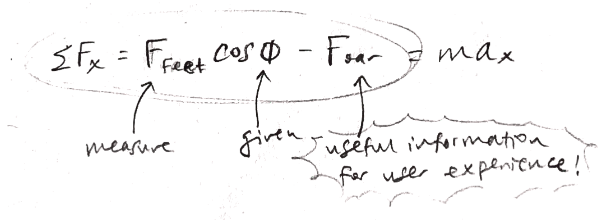
Figure 19: Force curve of the rowing stroke taken by this model

Figure 19 shows the theoretical force we expect to see on this device. The magnitude of the force curve will be driven by many conditions including wind, water flow, weight of the boat, and actual force output. The general shape hopefully will be preserved at many conditions which will make it possible for us to find F_0. A similar curve can be seen in ref. [3].

4.4.3 Model 3: Free Body Diagram

Figure 20: Free body diagrams of relevant forces.

Figure 20 includes two free body diagrams: the isolated foot stretcher and the isolated rower. Isolating these two main components allows us to determine the force between the two and the broader significance of this force in relation to the rowing process. Assuming the boat only moves in the horizontal direction and the rower only applies a horizontal force to the oar, we will apply Newton's law in the horizontal direction to relate the force detected to the effective work the rower is applying to propel the boat forward, as shown in the equation below:



5 Concept Embodiment

5.1 Initial Embodiment

The following drawings depict the initial prototype for the Rowing Force Plate system. Placeholder shoes and circuitry are used to demonstrate how the overall system fits together. The metal foot plate, load cells, and plastic housings are all modeled to exact dimensions. In final assembly, the system will be held together using bolts that constrain motion in one direction (outwards) but not the other (inwards) to allow load cell compression and accurate force readings.

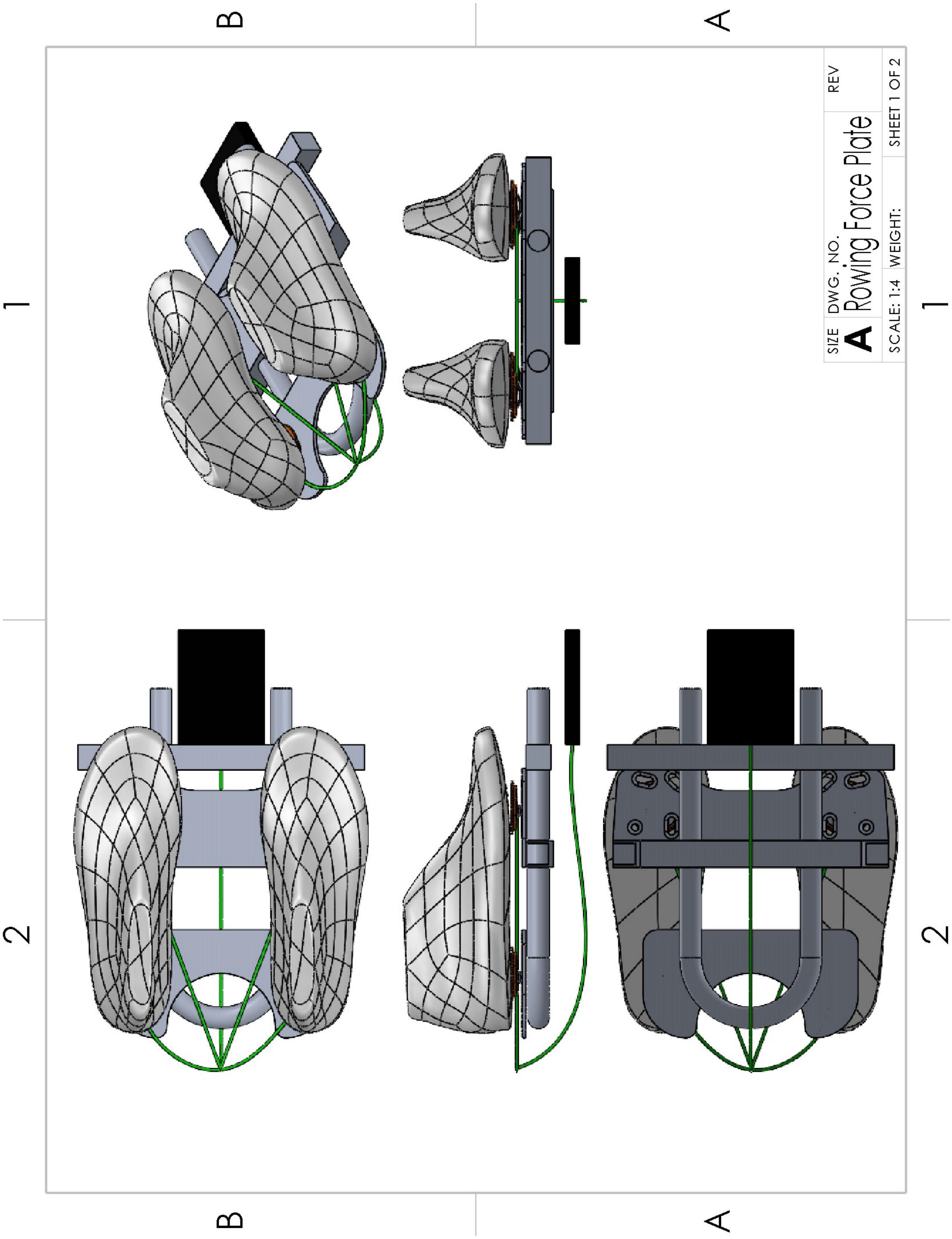


Figure 21: Assembled projected views with overall dimensions

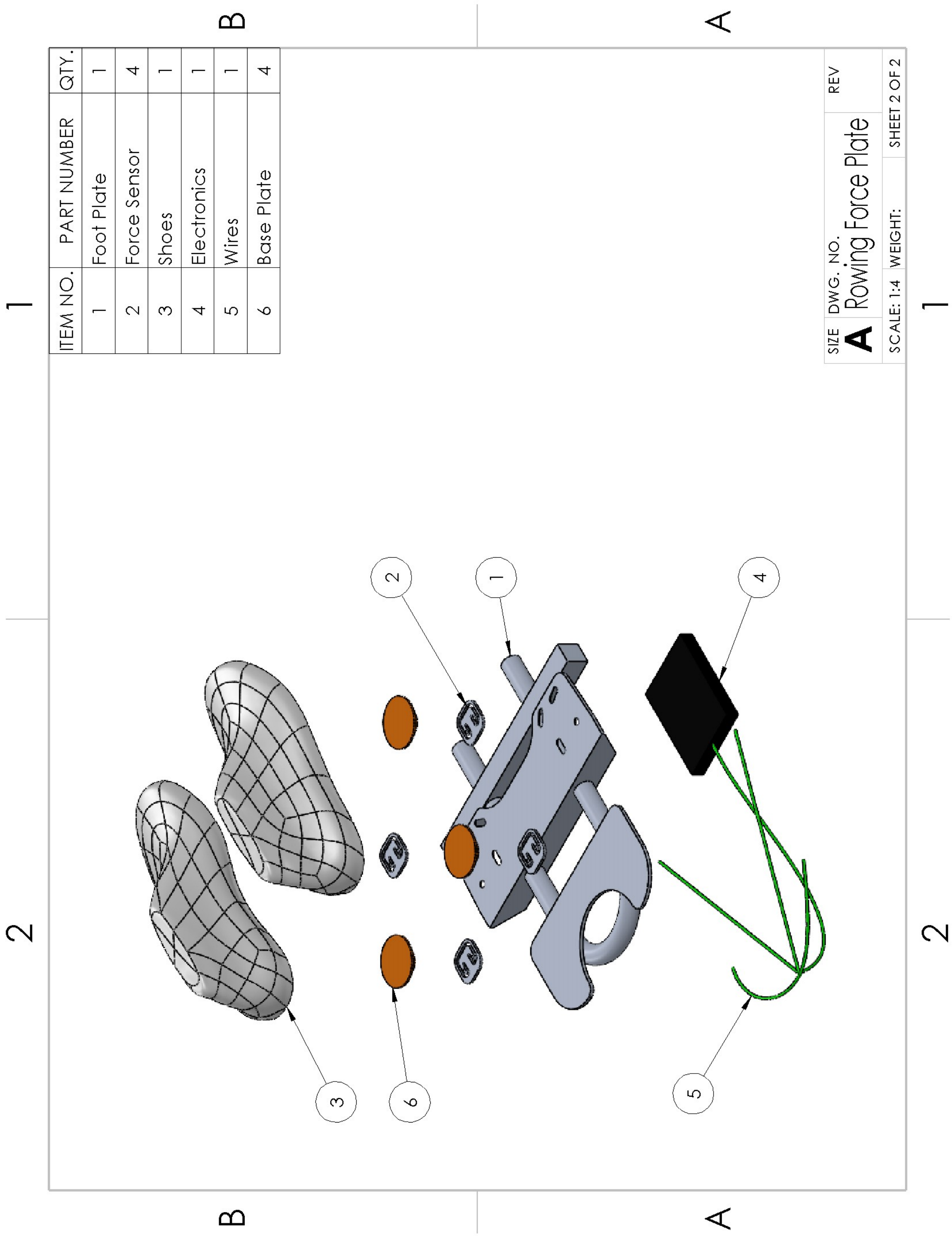


Figure 22: Assembled isometric view with bill of materials (BOM)

We had three prototype performance goals. The first is to have our prototype measure force at time points. The second is to measure force accurately within 5%, which will be tested by standing on it. And finally, the device should hold 40 lbs. in tension, as tensile forces happen when stopping the boat, and ideally, this device will not hinder any safety mechanisms.

5.2 Proofs-of-Concept

Our first proof-of-concept design involved a system of weights, pulleys, and a rolling platform in order to test the ergonomics and feasibility of any prototype. This design allowed a team member to test realistic motions of rowing for the given prototype and interpret its effectiveness. From this proof-of-concept, we noticed that the prototype needs to be able to hold force in tension as well as compression. We also noticed that having four discrete load cells as the only points of contact between the shoes and platform gave for an uncomfortable and uneven rowing technique, inhibiting natural performance. We adapted load censor housings to have larger contact area and therefore feel more comfortable when in use.

Our second proof-of-concept design was to use the load cells of a bathroom scale wired to an Arduino Uno to try out in different locations in our foot stretcher frame. With this, we were able to determine the most practical position and location to put each load cell within the system. This proof-of-concept was flawed because the Arduino Uno was malfunctioning and the load cells were not providing readable information; instead of providing quantitative feedback of force applied to the load cells, the system provided feedback when the wires were jostled. While this was not the desired information, it encouraged us to protect internal wiring from movement that may inhibit accurate readings or product longevity moving forward.

5.3 Design Changes

The initial prototype generally follows the initial design concept with a few simplifications. The selected concept is shown in Fig. 23.

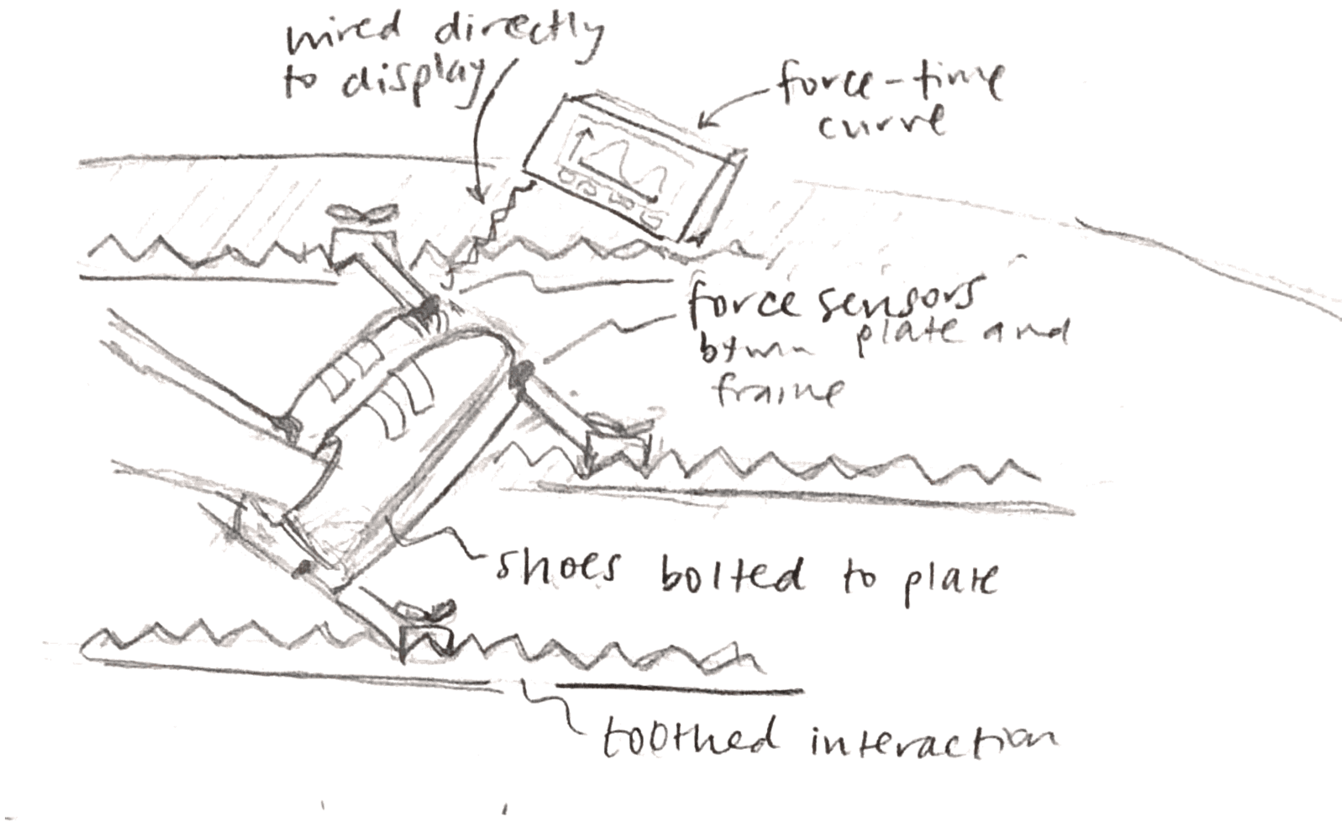


Figure 23: Sketches of Integrated System concept

Our initial prototype has the same ideas of force sensors in between the shoes and the plate, with shoes bolted to the plate, and force being recorded by a microcontroller. Where our prototype differs from this concept is that the prototype does not have a screen. This is due to time constraints and focusing on increasing force-measuring accuracy for the final prototype, but the final prototype is anticipated to have a screen.

The initial concept did not have a well thought out way to house the force sensors, and this was a design challenge we had to face when designing our prototype. We want the housing for the force sensor to be as thin as possible to minimize interference with the current foot security mechanisms. It also needed to ensure that all forces on one side are exclusively exerted onto the outer ring of the load cell and all forces on the other side are exclusively exerted onto the middle bump on the load cell, all the while remaining secured between the shoes and the foot stretcher. We want the housing for the force sensors to be as small as possible because we also want to minimize the weight of the housing, as added weight decreases boat speed, as shown below in Fig. 27.

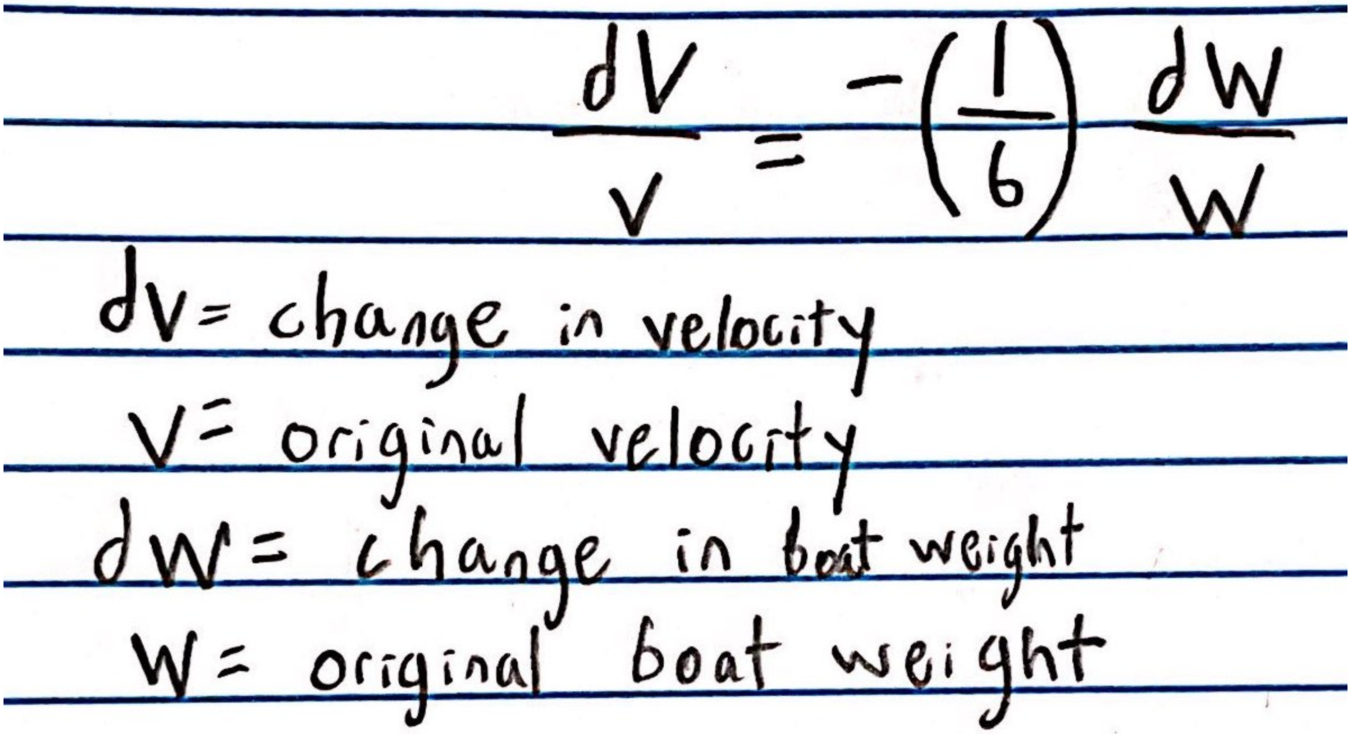


Figure 24: Model 1: How weight of a rowing boat affects velocity [2] .

Because the housings for each of the four force sensors need to be as thin and as light as possible, we determined that 3D printing these parts would be the best option. 3D printing allows for rapid prototyping, thin and complex geometry, lightweight plastic composition. As long as the print is strong enough to undergo repetitive force from the rower's feet, which we expect it to be, it should be a good solution. An initial housing that we printed can be seen in Fig. 25.

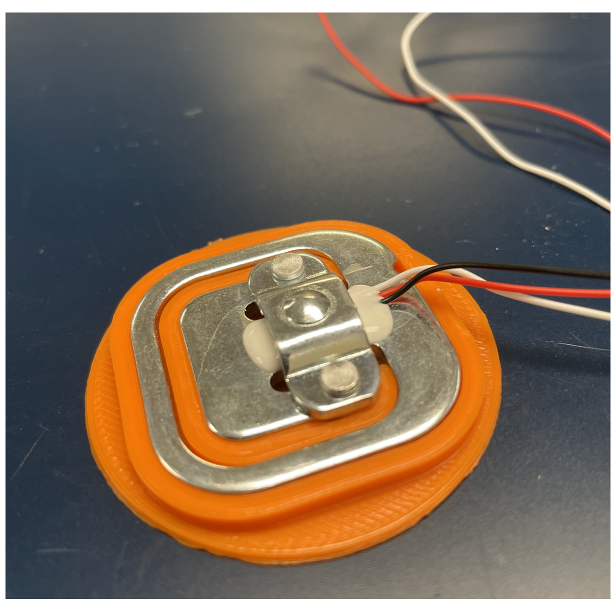


Figure 25: Free body diagrams of relevant forces.

With the initial prototype, we recorded the normal force on the sensor. For the final prototype, we will need to take into account the angle of the foot plate to calculate an accurate horizontal force output from the rower. This analysis is dependent on the angle in which it fits into the boat and can be seen in the figure and equation below.

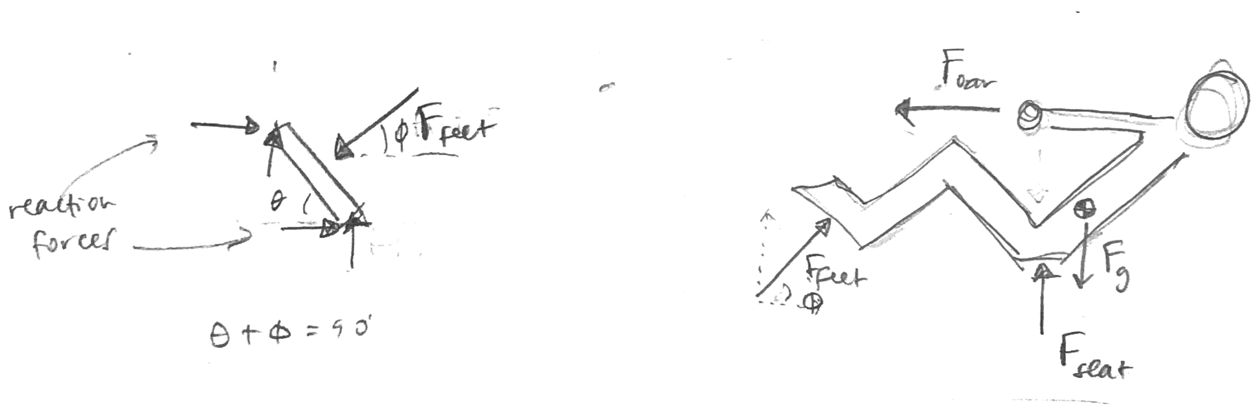
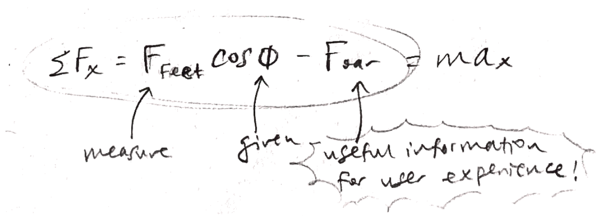


Figure 26: Free body diagrams of relevant forces.



6 Design Refinement

6.1 Model-Based Design Decisions

The calculations in Fig. 27 show that with the added weight from our device, we would add 0.053 seconds to a boat of 8 people in a 500 meter race. This is a very small amount of added time and is an acceptable value.

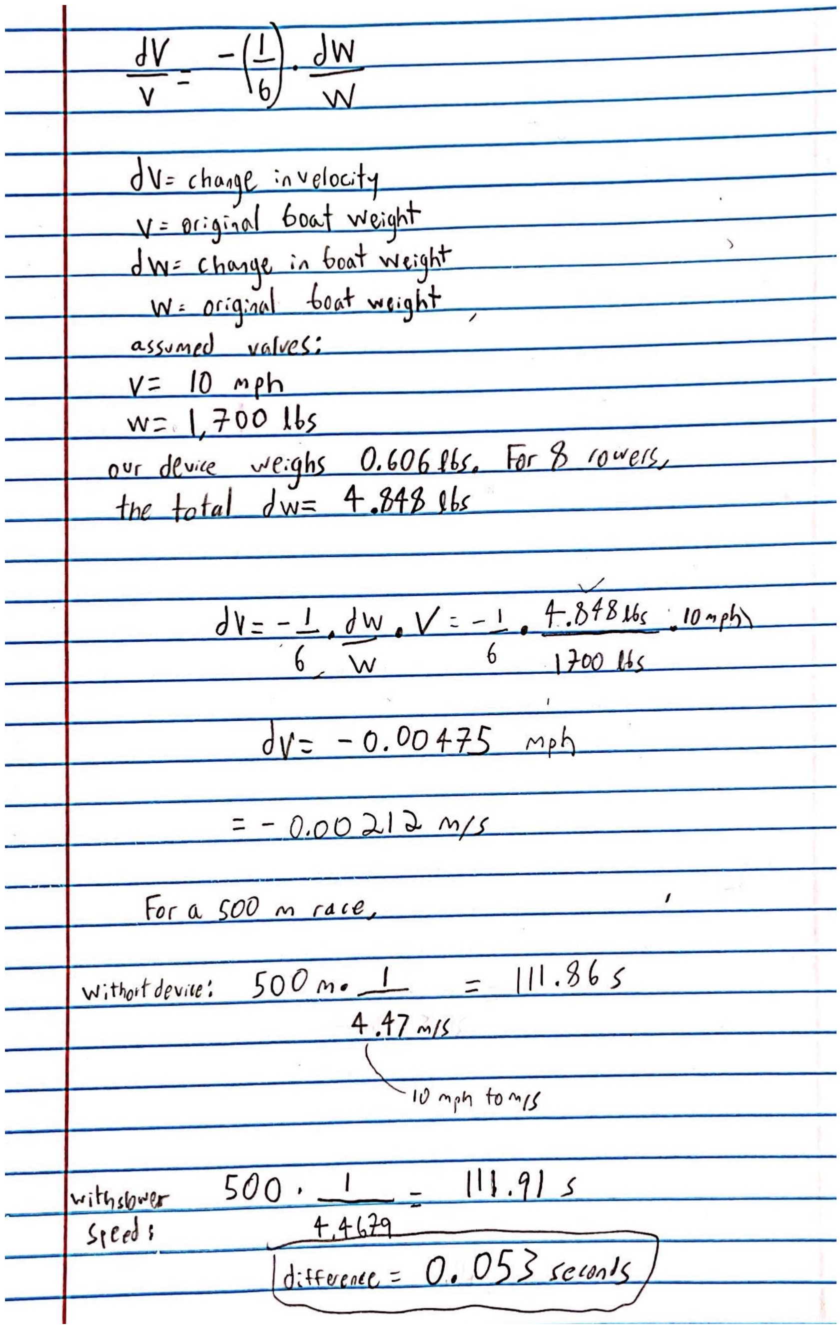


Figure 27: How weight of a rowing boat affects velocity [2] .

Because the housings for each of the four force sensors need to be as thin and as light as possible, we determined that 3D printing these parts would be the best option. 3D printing allows for rapid prototyping, thin and complex geometry, lightweight plastic composition. As long as the print is strong enough to undergo repetitive force from the rower's feet, which we expect it to be, it should be a good solution. An initial housing that we printed can be seen in Fig. 28.

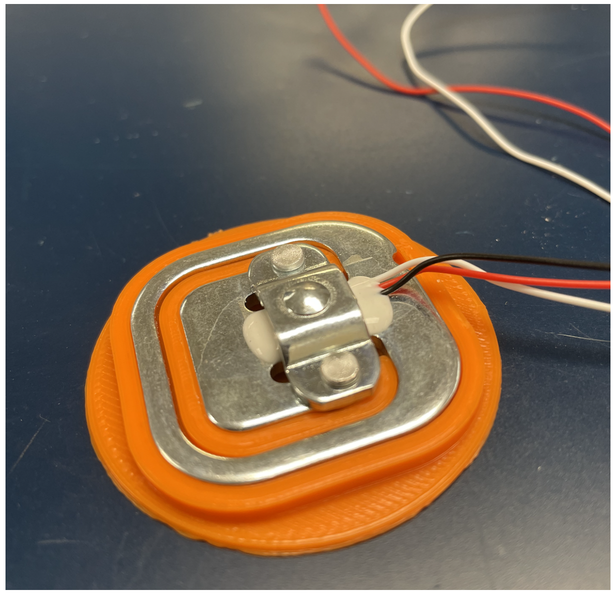


Figure 28: Picture of load cell housing.

The geometry of the housing was designed based on constraints of the load cell design; all forces from one direction needed be exerted onto the outer rim while all forces from the other direction needed to be exerted onto the middle fork. A section cut and force diagram, as shown in Fig. 29 and 30, were used to see the force path and ensure the forces were isolated to the appropriate regions.

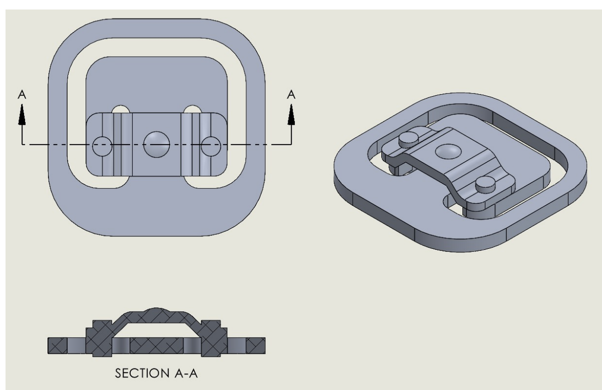


Figure 29: Isometric, top, and section cut views of load cell.

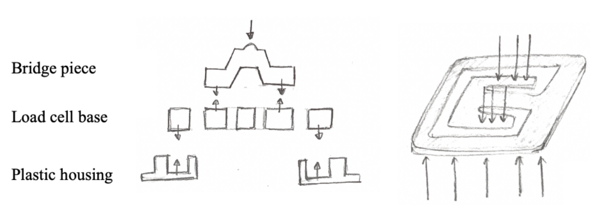


Figure 30: Force diagram of bridge, load cell, and plastic houses at section cut; isometric view of desired force distribution.

With the initial prototype, we recorded the normal force on the sensor. For the final prototype, we will need to take into account the angle of the foot plate to calculate an accurate horizontal force output from the rower. This analysis is dependent on the angle in which it fits into the boat and can be seen in Fig. 31 and equation below.

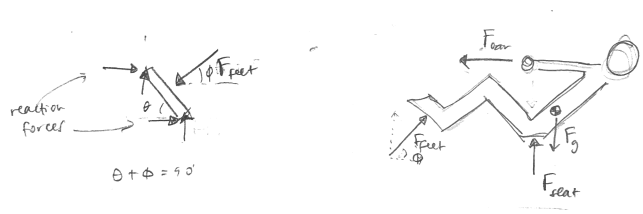


Figure 31: Free body diagrams of relevant forces.

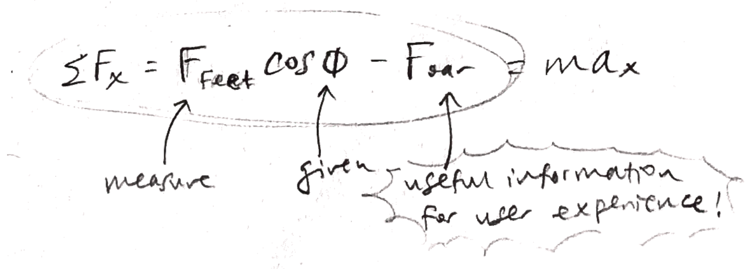


Figure 32 shows the theoretical force curve we expect to see on this device when used in the boat. The baseline force, denoted here as F_0, will be some nonzero value due to the weight of shoes and rower's resting legs. In the Arduino code, we can subtract this baseline force value to zero the load cells and measure an accurate force exertion reading. In next versions, the Arduino code will calculate impulse exerted by the rower in each stroke. To calculate impulse, we will use a Riemann sum to calculate the integral between consecutive local maximums.

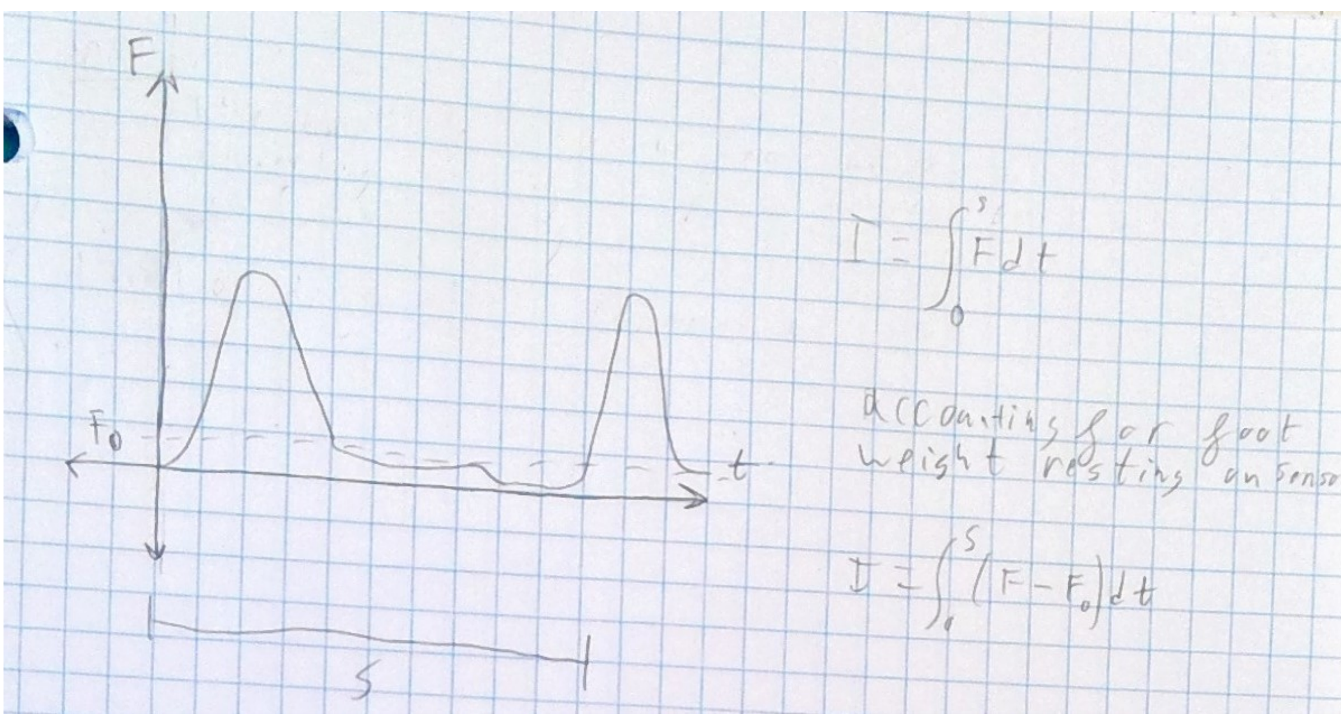


Figure 32: Force curve of the rowing stroke taken by this model

6.2 Design for Safety

Five risks were identified, along with their severity, probability, and mitigating steps.

6.2.1 Risk #1: Electrocution

Description: The electric wires get wet and electrocute the user. This would happen if there was water touching the rower and touching the electrical device without proper insulation and waterproofing of the electronics.

Severity: Catastrophic. Getting unexpectedly shocked when rowing would be dangerous to the rower and could inhibit their control of the boat, which increases the danger.

Probability: Occasional. Rowing boats get very wet and this device has many wires and electrical components, so there's a chance this hazard happens if the right steps aren't taken.

Mitigating Steps: Make sure the device is waterproof, especially where current flows. We will likely use epoxy, silicone, or clear nail polish to waterproof the circuit boards and have some cover over the electronics to make sure they are concealed from any water.

6.2.2 Risk #2: Inhibits Safety Mechanisms

Description: The device stops the user from safely being able to disconnect their feet in the event of a capsize. This would happen if the device was made to attach to the foot plate, but not designed to detach in the case of an emergency.

Severity: Catastrophic. Quickly being able to detach your feet from the boat is a crucial safety mechanism and is essential during capsizing. Not being able to detach quickly could lead to drowning.

Probability: Occasional. Given that our device is directly under and in between parts of the footplate, there is a good chance that it will affect how the safety mechanism works.

Mitigating Steps: Avoid connecting the device to existing safety features when possible. Also, test the device to make sure it's compliant and able to safely handle expected loads and is able to detach when needed.

6.2.3 Risk #3: Fire

Description: The device or battery catches fire because of its electric nature. This would happen if we drew too much power or the circuit was incorrectly made.

Severity: Catastrophic. Fire in a boat could hurt the rower or permanently damage the very expensive boat.

Probability: Seldom. We are not using high amounts of power to make this device, so it is unlikely that it's able to create a fire.

Mitigating Steps: Make sure the electrical components are working within their operating limits. Also check the breadboard to make sure everything is hooked up correctly and safely.

6.2.4 Risk #4: Heaviness Sinks Boat

Description: The device is so heavy that it sinks the boat. The added weight of the devices would have to be large enough sink the boat.

Severity: Catastrophic. Sinking boats are dangerous for the rowers and potentially expensive to recover them.

Probability: Unlikely. Almost all of the components in the device are lightweight (wires, small screens, etc.).

Mitigating Steps: Make sure the device is a reasonable weight (less than 3 lbs).

6.2.5 Risk #5: Reflection Blinding

Description: The screen reflects sun into the rower's eyes and temporarily blinds them, causing a hazard in the water. This could happen if the screen is reflective and the sun is at an angle that it would be directed onto the rower's eyes.

Severity: Critical. Having the sun reflected into the rower's eyes could make them temporarily lose vision, which could pose a hazard in a moving boat.

Probability: Occasional. This would only happen under specific conditions and we currently have a small screen, so the risk is lowered.

Mitigating Steps: Make sure the screen does not create glares. Use a cover or screen protector if necessary.

Severity of risk		Probability that something will go wrong				
	Category	**Frequent** Likely to occur immediately or in a short period of time; expected to occur frequently	**Likely** Quite likely to occur in time	**Occasional** May occur in time	**Seldom** Not likely to occur but possible	**Unlikely** Unlikely to occur
	Catastrophic			Electrocutiion Inhibits safety mechanisms	Fire	Heaviness sinks boat
	Critical			Reflection blinding		
	Marginal					
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial					

Figure 33: Risk assessment matrix.

According to the heat map, the two biggest risks are electrocution and inhibiting safety mechanisms. Therefore, mitigating these risks is the highest priority. This will be done by safely covering up the electronics from any water and properly integrating the device with existing safety mechanisms. The next priority risk is reflection blinding, which can easily be mitigated with a screen cover. The next priority risk is fire, which will seldom occur, and will be mitigated by properly setting up the circuit. And finally, the least priority risk is the device being so heavy that it sinks the boat, which is very unlikely to happen.

6.3 Design for Manufacturing

The number of parts in the current design is 13 not including wires, 38 with wires, and the number of threaded fasteners is 8.

Theoretically Necessary Components (TNC):

- Screen: The screen must be separate, as it needs to be a certain material to be able to display numbers and letters.
- 4 load cells: The load cells must be separate as they are precise devices which measure force applied though deflection.
- 3D printed load cell covers: These covers are stationary with respect to the moving load cells, so they must be separate.
- Arduino: The Arduino is made out of specific materials that allows it to make computations and send data to the screen.

6.4 Design for Usability

Having a vision impairment could possibly affect the usability of this device. The whole objective of the device is to display live statistics on a screen in front of the rower, and certain vision impairments could hinder that. Using screens with certain colors would help people with color blindness, while larger text would help people with presbyopia.

Having a hearing impairment would have no affect on the usability of this device. The device makes no noise and does not require any hearing. The only thing that could possibly get in the way is that in order to use this device safely, you must also be able to row safely, so the rower would need ways to safely and effectively receive relevant information from the coxswain.

Having a physical impairment could possibly lead to some usability issues. The device was designed for two feet to press on force sensors. If a person is missing part or all of their legs and use a modified rowing boat, our device would likely not be able to be used without adjusting its location. Any other physical impairments where the person has two legs and feet should not be an issue.

Our device is meant to be fairly easy to use, so a control impairment should not get in the way. Possibly setting it up could pose some challenges, but if the user has done it before, it shouldn't pose any challenges. Ultimately, if someone is truly impaired (e.g. intoxicated), they probably should not be rowing a boat regardless.

7 Final Prototype

7.1 Overview

The final prototype was able to successfully complete all three prototype performance goals set. The final prototype was able to measure force at time points and store it, measure force within 5 percent accuracy, and could hold 40 lbs in tension. In addition, the device was successfully waterproofed and tested in a real rowing situation, as shown in Fig. ??.

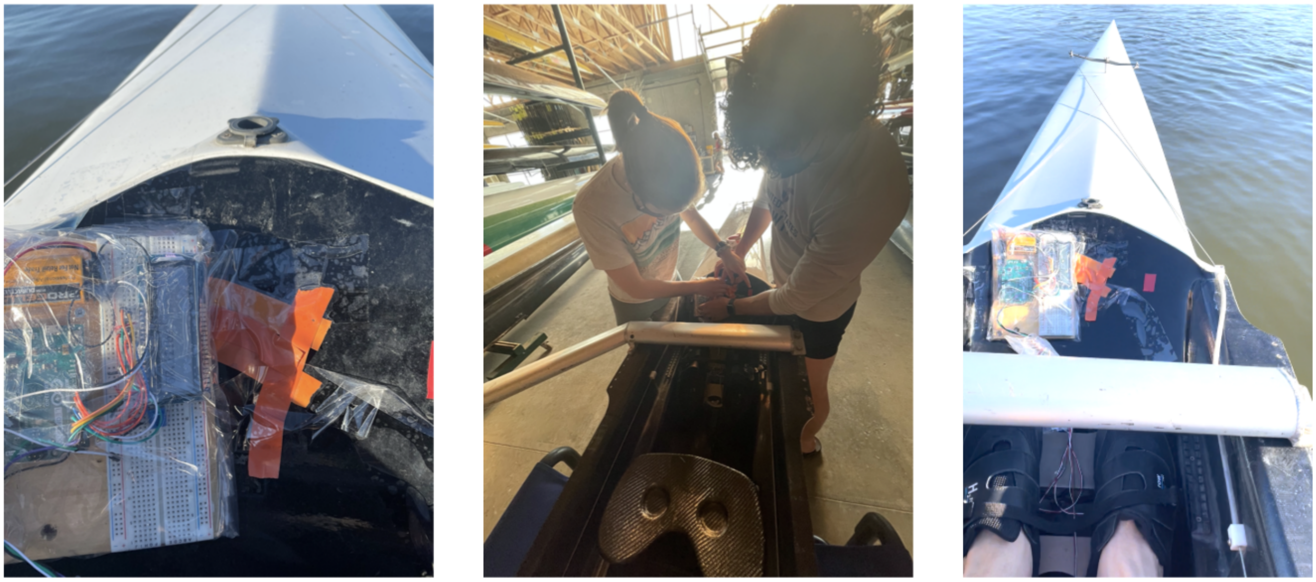


Figure 34: The final prototype being used in a boat.

The final prototype built off of the strong foundation of the initial prototype, such as load cell placement, circuit wiring, and Arduino code. To improve the initial prototype, we bought new load cells. These worked much better than our original, re-purposed load cells. Additionally, we iterated through various designs of the load cell housing units until they effectively held the load cells in place while still allowing for accurate force readings. Once the load cells were working, we could calibrate the code to ensure accurate force measurements. Finally, we bought and incorporated an LCD display from Adafruit that would display the average force readings over regular intervals. To test the device, we waterproofed all electrical components with clear nail polish, ziploc bags, and packing tape, and took it out on a boat to test it for real-world use.

7.2 Documentation

Bibliography

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[3] Rowing in Motion. *Understanding Force Curves and Boat Acceleration*. URL: https://www.rowinginmotion.com/understanding-force-curves-and-boat-acceleration/.