Product Design Specifications: Force Plates for Rowing Biomechanics

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BME 300/200, Section 303

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Function:

Force sensors have been widely used in sports biomechanics to measure load distribution and center of pressure for the purpose of correcting form and mitigating injuries. However, getting this real time data is often difficult to obtain in non clinical settings and may be very expensive to implement. Rowing is a rigorous sport that can lead to numerous lower extremity injuries due to asymmetries in load distribution when not following proper technique. Additionally, this asymmetry is impossible to quantify visually and can only be considered from stationary rowing simulation machines that disparately underestimate the mechanical power required against water currents [1]. Current methods of analyzing lower extremities from rowing include isolated studies that measure degree of leaning towards one side but not force loading. Our design aims to provide more accurate data by integrating a force sensor system in the rowboat to transduce real time data that rowers can view while on the water. The application of our design will allow athletes and coaches to gain greater insight into performance enhancement and injury prevention.

Client Requirements:

- The design must be compatible and inclusive with all weight classifications of rowboats (50kg to 90kg +) and foot sizes [2].
- The device must be strong enough to withstand the force exerted by rowers during the drive phase of the stroke [3].
- The device must accurately measure the load in each leg and translate the data to an interface that provides real-time data viewing while rowing.
- The device must be able to operate in wet conditions and humid environments.
- The client desires an easily integrated force measuring system that should operate without requiring change in rowing technique.
- The device should be fairly lightweight so as to not affect the weight of the rowboat.

Design Requirements:

1. Physical and Operational Characteristics:

a. Performance Requirements:

- The product must track the degree to which rowers are exerting symmetric force through their entire lower extremity, to track any asymmetry present.
- The product should provide real time data during a rower's row time so they can monitor any fluctuations as they occur.

- The product should be able to store data and display it through a visual interface so coaches and rowers can see the data in real time and analyze it later.
- The product should be able to display a force vs time graph at the end of a row as well as show the force during the catch to drive phase.
- The product should be waterproof.

b. Safety:

- This product should not disrupt the motion of the rower or the ergometer as a stroke is completed.
- This product should not cause any electrical shocks to the rower's and have minimal large cords in close proximity to the rower. The device needs to be plugged into an outlet with standard voltage of 120 V [4].
- This product should be able to be cleaned between uses with alcohol-based solution or soap and water. Bleach and/or hydrogen peroxide should be avoided [5].
- This product should not have any sharp edges.

c. Accuracy and Reliability:

- The device should be easy to replace if any of the components fail.
- The product should give data with high accuracy with a margin of error at 5% [6].

d. Life in Service:

- A typical rowing career for an Olympic rower tends to end near a rower's late 20s or early 30s. From college to this time, the device would have to be in service for about 10-12 years [7].

e. Shelf Life:

- The product will have a shelf life of around 50,000 hours to be able to be used for multiple college careers. This will allow for an array of results and different data to see its full effectiveness.
- The design should not necessarily have any features that wear away with time.

f. Operating Environment:

- The client would like to have the device at least inside on an ergometer. This would consist of room temperature conditions. These conditions are around 20-22° C and low humidity
- The client would like the force plates to be inside of their boats, which travel through the water. This would be a wet environment, could be cold or hot in temperature, and can withstand natural

conditions such as rain. The plates would have to be waterproof and functional in fluctuating temperatures. The outdoor rowing season takes place from April to around October, where it becomes too cold to row outside. The average conditions in Madison during this time are the following [8]:

- Temperature Range: 8.3° C to 22.2° F
- Humidity: 62% - 73%
- Rain Levels: 2.9 cm - 5.44 cm

g. Ergonomics:

- The design will easily allow users to view real time data and get feedback while they are rowing.
- The plates will not add any unnatural feeling for the rowers, and therefore they will not have to change their technique in order to use them.

h. Size:

- The client has expressed a main interest in placing such a device in practice ergometers as well as practice rowing tanks.
- After determining the brand of ergs used by the client both for conditioning and in tanks to be Concept2, it is noted that the width of the machine is 60.96 cm [9] so the device should fit within those constraints.

i. Weight:

- On their own, the Concept2 RowErg® weighs between 25.9 and 30.8 kg [8]. The device should be able to withstand this weight.
- The device will need to be lightweight enough so that users have no trouble rowing with the same technique and efficiency.

k. Materials:

- Current force sensors are typically constructed of silicone rubber elastomer with magnetic powders or particles used in calculations [10].
- Additionally, they are often cased in pure silicone or a similar material to maintain their shape, then adhered to thin aluminum plates as is “standard in force plate fabrication” [10].
    - The team will try to hold to these industry standards, using these materials as guidelines.
- Finally, the client has mentioned that some level of waterproofing will be a necessity for the product, given the likelihood of water exposure or possible immersion. Past experiments with

sensors indicate that a possible method is laser direct writing, in which a barrier is created using a 405 nm laser [11].

l. Aesthetics, Appearance, and Finish:

- At this moment, without an idea of specific materials that will be purchased, measurements for target placement of the device, and other necessary parameters, it is difficult to say exactly what the desired finish will be. Given that current practice ergometers used by the client are finished using a powder coat, and the devices' legs are made of both aluminum and steel, these materials can be kept in mind when considering aesthetics [9].
- Overall, the team aims to produce a product that seamlessly fits into a rowing boat or ergometer, prioritizes comfortable foot placement for rowers, and does not interrupt users' technique with any added bulkiness.

2. Product Characteristics:

a. Quantity:

- The client would like there to be at least 8 force sensor systems, in order to have one per person in a shell for 8 sweep rowers [12]. The sensors should be easily transferable between the shells and the rowing tanks, which hold a capacity of 24 rowers (12 per tank) [13]. With increased supplies and funding, the quantity of sensors may be considerably increased to eventually have one sensor for every rower, in which the University of Wisconsin's crew team currently has around 205 athletes.

b. Target Product Cost:

- The budget for this design project is between $100-$500 . The budget may be increased with approval from the UW Athletic Department.
- The competing designs listed in part 3d of the PDS have costs significantly greater than our budget. BioRow's 2D Flat stretcher force plate costs over $2000. Small-sized multi axis load cells can range from $300-$500 [14]. In order to make a product within our target, load cells are more cost efficient.

3. Miscellaneous:

a. Standards and Specifications :

- The device must not interfere with the construction of the Concept2 RowErg® such that it fails to comply with the ASTM Standard Specifications for Fitness Equipment (ASTM F2276 − 23) [15].
    - Specifies that edges should be free of burrs and sharp edges, and corners should be chamfered
    - Specifies that the ergometer should withstand 1560 on/off cycles
    - Specifies that the footplate should be slippage-resistant
    - Specifies that the ergometer should be able to withstand 136 kg or the maximum user weight, whichever is greater
- The device must also comply with the ASTM Standard Specification for Universal Design of Fitness Equipment for Inclusive Use by Persons with Functional Limitations and Impairments (ASTM 3021-17), such that rowers with functional limitations and impairments can use the device [16].
    - Specifies that color contrast on any visual display must be greater than or equal to 70%
    - Specifies that font size should be at least 10 mm
    - Specifies that the display should continue to display visual feedback at least 5 seconds after exercise has stopped.

b. Customer:

- The target customer for our product is the Physical Therapist and Athletic Training Staff for the University of Wisconsin Rowing Team.
- Because the product will be used by physical therapists and athletic trainers as they work with athletes, visualizing the magnitude of force asymmetry is extremely important for athlete understanding and adaptation; hence, the device should have an easily interpretable interface that is updated with real-time data from the athlete as they perform rowing strokes.
- The device should also be compatible with the Concept2 RowErg®, which is the ergometer used by the University of Wisconsin Rowing Team.
    - The footrests should remain adjustable, and the wheels and upright storage capabilities should be unimpeded [8].

c. Patient-Related Concerns:.

- The device should not interfere with proper rowing technique or injure the athlete in any way.

- The device should not interfere with the ergometer or boat such that they begin to degrade or malfunction.
- The device should be accompanied by a data storage drive or other technology that allows for patient performance data to be stored confidentially, in compliance with HIPAA [17].

d. Competition:

- Bertec® produces portable force plates for gait, balance, and performance analysis [18].
    - The load cells contained inside utilize strain gauges and transducers to measure forces and moments in the x, y, and z directions
    - The portable force plates have a sampling frequency of 1000 Hz.
    - The portable force plates have loading capacities of 4440, 8880, or 17760 N.
- Biorow produces a 2D force sensor that uses four load cells fixed to a plate, and the plate is screwed between the foot straps of the ergometer and the foot stretchers [19].
    - The load cells can measure from -800 to +3200 N.

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