Department of
Biomedical Engineering
UNIVERSITY OF WISCONSIN–MADISON

Asymmetrical Force Sensor for Rowing Biomechanics

BME 400

Clients: Dr. Jill Thein-Nissenbaum, Ms. Tricia De Souza, and Sarah Navin

Advisor: Dr. David Appleyard

Colin Fessenden, Simerjot Kaur, Neha Kulkarni, Allicia Moeller, Emily Wadzinski

Overview

- Problem Statement
- Background Research
- Competing Designs
- Product Design Specifications
- Preliminary Designs
- Design Matrix
- Conclusion and Future Work
- Acknowledgements
- References

Figure 1. UW-Madison rowing team. [1]

The Clients

Figure 2.

Tricia De Souza

UW Athletic Trainer

[2]

Figure 3.

Jill Thein-Nissenbaum

UW Athletics Physical Therapist

[3]

Figure 4.

Sarah Navin

PT Student

Former UW Crew

[4]

Department of Biomedical Engineering
UNIVERSITY OF WISCONSIN-MADISON

Problem Statement

- Rowing athletes, particularly women, are susceptible to lower back or hip injuries
  - Asymmetric weight distributions on each leg while rowing
- Current methods
  - Visual analysis from coaches and PT staff
  - Fully qualitative data looking for potential injury risks
- Sensor system to collect biomechanical data from rowers' lower extremities
  - Capture force output during time of use in the ergometer
- User-friendly interface
  - Assess lower extremity asymmetry
  - Improve both performance and safeguarding against injuries

Background

Figure 5. Rowing Phases. [5]

Figure 6. Ergometer [6]

- When rowing, most force is exerted by the leg [7]
- Most of the year is spent on indoor training and using the ergometer
- Majority of rowers face injuries while using the ergometer rather in the boat

Competing Designs

- BioRow 2D Stretcher [8]
  - Load cells utilize strain gauges
  - Senses horizontal and vertical force components
  - Two load cells per foot
  - Too expensive, no interactive display
- Bertec Force Plate [9]
  - Load cells on each corner
  - Collects forces in all three directions
  - Designed for gait, balance, and performance analysis
  - Too large and expensive

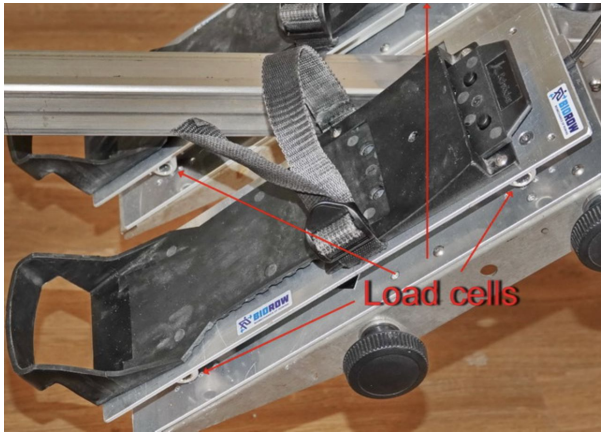


Figure 7. BioRow 2D Stretcher. [7]

Figure 8. Bertec Force Plate. [8]

Product Design Specifications

Force Sensor/Footplate

- Compatible with RowErg
- Margin of error < 5% [10]
- Adjustable to foot size
- No technique impedance

Display/User Interface

- 24 Hz frame rate [11]
- Mounted at 1.1 m height
- Clear indication of asymmetry

Figure 9. Foot stretcher on Concept2 RowErg.

Figure 10. Concept2 RowErg. [12]

Design Components

- Two force-sensing footplates over foot stretchers
  - 3 designs
- Visual feedback
- Instrumentation

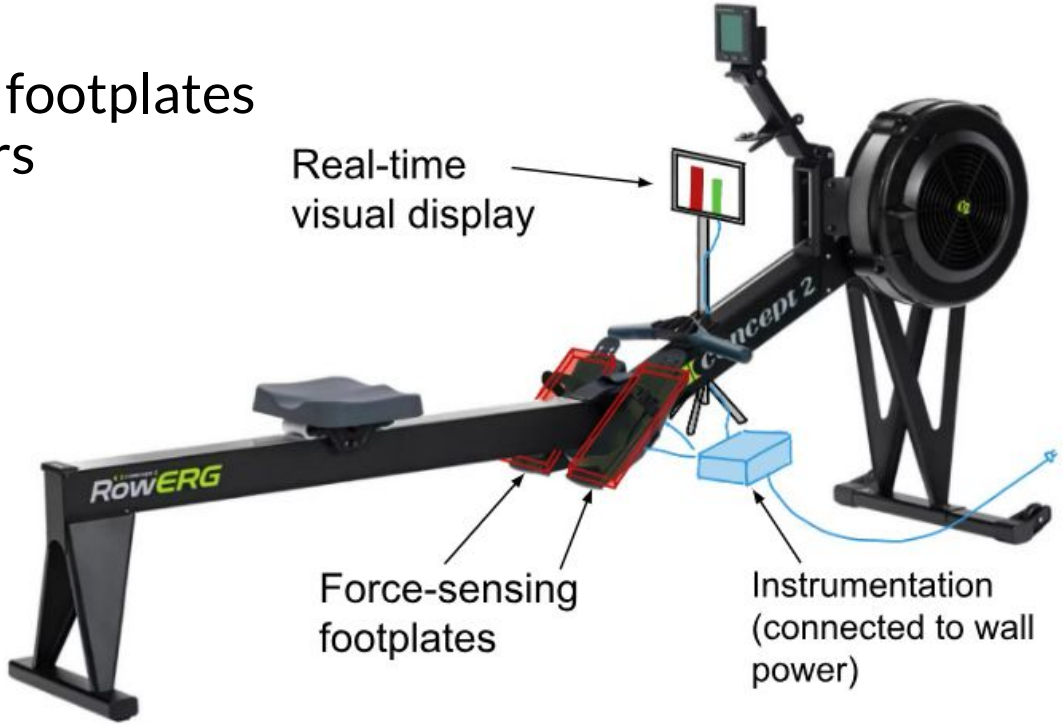


Figure 11. Sketch of Comprehensive Design with Concept 2 RowErg. [12]

Footplate Design 1: Stationary Force Plate

- 4 single-axis load cells
- Two parallel aluminum plates

- Strength:
  - Few parts
- Weakness:
  - Does not account for off-axis loading

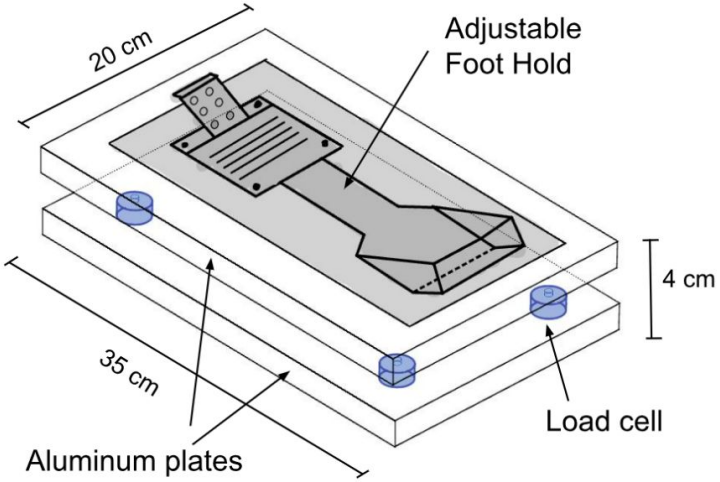


Figure 12. Sketch of Stationary Force Plate Design.

Footplate Design 2: Membrane-Bound Force Plate

- Single-axis load cells
- Outer and inner aluminum plates separated by gap
- Fabric membrane

- Strengths:
  - Accounts for off-axis loading
- Weaknesses:
  - Difficult fabrication
  - Cost

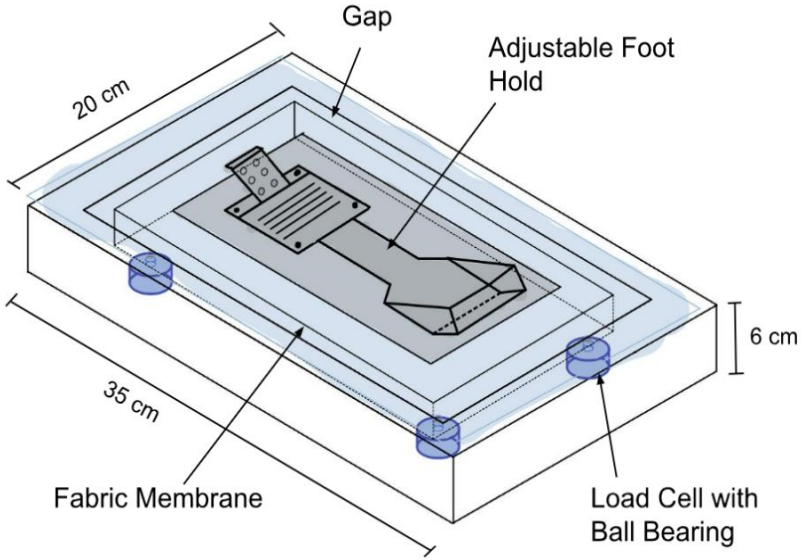


Figure 13. Sketch of Membrane-Bound Force Plate Design.

Footplate Design 3: Bearing-Guided Force Plate

- Single-axis load cells
- Outer and inner aluminum plates separated by bearings

- Strengths:
  - Accounts for off-axis loading
- Weaknesses:
  - Difficult fabrication
  - Cost
  - Bearings will wear down

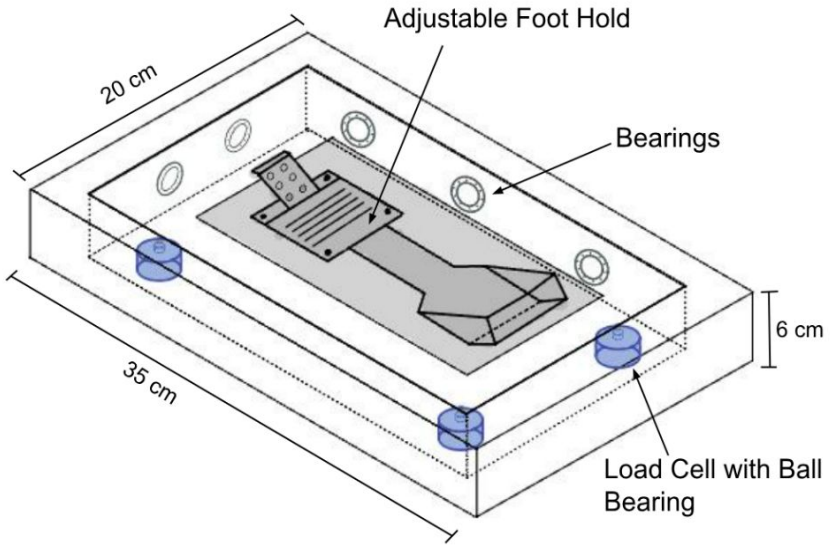
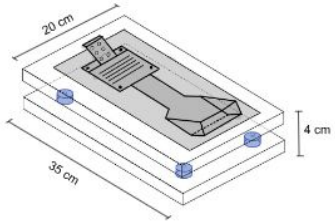
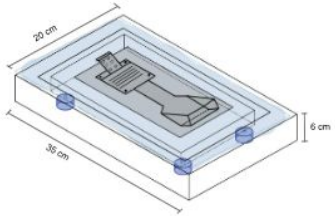
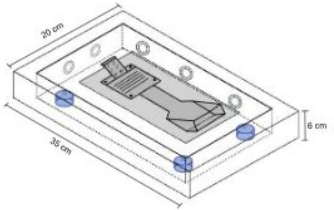


Figure 14. Sketch of Bearing-Guided Force Plate Design.

Footplate Design Matrix

Table 1. Design Matrix for Force Plate Housing Designs.

		Stationary Force Plate 		**Membrane-Bound Force Plate** 		**Bearing-Guided Force Plate** 	
Criteria	**Weight**	Score (5 max)	Weighted Score	Score (5 max)	Weighted Score	Score (5 max)	Weighted Score
Reliability	25	2	10	4	20	5	25
Ergonomics	25	5	25	4	20	4	20
Cost	20	3	12	2	8	1	4
Ease of Fabrication	15	4	12	3	9	2	6
Ease of Maintenance	15	4	12	3	9	2	6
Sum	**100**	**Sum**	**71**	**Sum**	66	**Sum**	61

Final Design: Stationary Force Plate

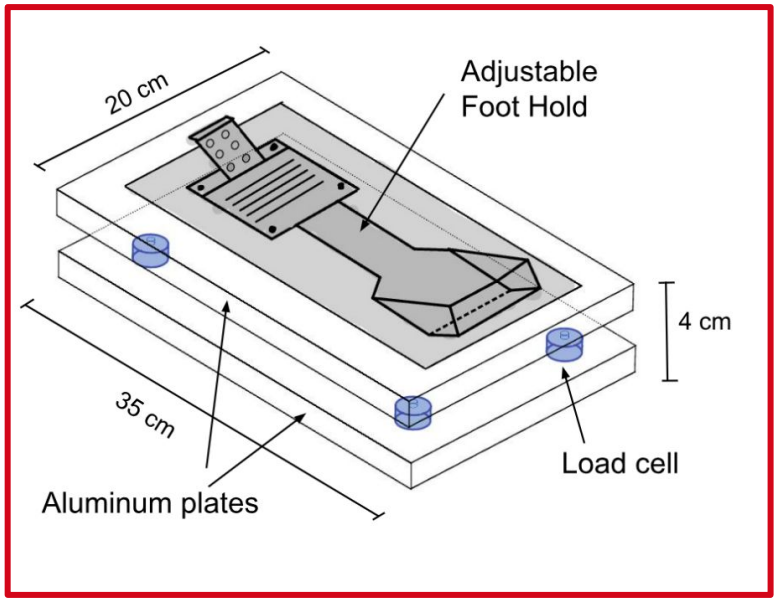


Figure 15. Sketch of final footplate design.

- Minimalistic
- Single-axis load cells
- Adjustable FlexFoot
- Connected to:
  - Raspberry Pi Microcontroller
  - Display
- Flexibility to iterate

GUI + Display

- GUI
  - Rowers/coaches choose preferred graphic
  - Absolute Force vs. Force Difference
  - Line Graph vs. Bar Graph
- Display
  - Laptop
  - Can be hooked up to TV/Tablet

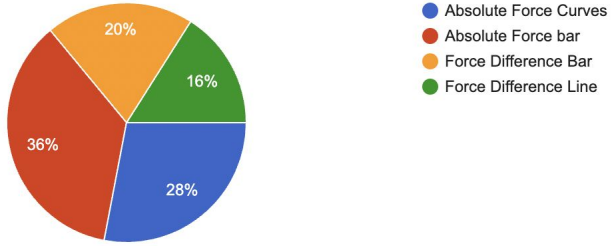
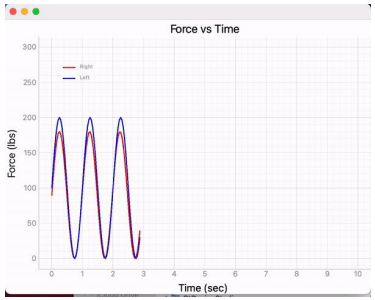
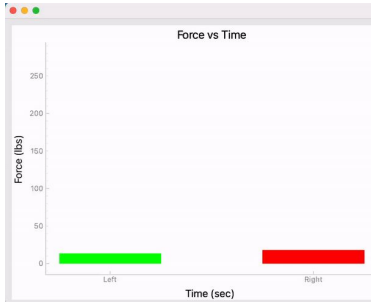


Figure 16. Pie chart of preferred GUIs based on survey response.





Future Work

- This semester:
  - Fabricate footplate
  - Implement GUI and data storage
    - Data visualization and extraction of clinical metrics

- Future semesters:
  - Reliability and repeatability testing
  - Clinical data acquisition on rowers
  - Identify risk factors, injury prevention techniques

Acknowledgements

- Dr. Jill Thein-Nissenbaum
- Ms. Tricia De Souza
- Ms. Sarah Navin
- Dr. David Appleyard
- Dr. Kreg Gruben
- UW Rowing Team Staff and Athletes

References

[1]"Badgers announce 2019-20 women's rowing roster," Wisconsin Badgers. Accessed: Oct. 05, 2023. [Online]. Available: https://uwbadgers.com/news/2019/9/20/badgers-announce-2019-20-womens-rowing-roster.aspx

[2] "Tricia De Souza | Men's Rowing Coach | Wisconsin Badgers." Accessed: Oct. 05, 2023. [Online]. Available: https://uwbadgers.com/sports/mens-rowing/roster/coaches/tricia-de-souza/731

[3] Walworth, "Jill Thein-Nissenbaum, PT, MPT, ATC, DSc, SCS Selected for National Athletic Trainers' Association Title IX Panel - UW Family Medicine," UW Family Medicine & Community Health. Accessed: Oct. 05, 2023. [Online]. Available: https://www.fammed.wisc.edu/jill-thein-nissenbaum-selected-for-national-athletic-trainers-association-title-ix-panel/

[4]"(17) Sarah Navin | LinkedIn." Accessed: Oct. 05, 2023. [Online]. Available: https://www.linkedin.com/in/sarah-navin-915862179/

[5]S, Arumugam, et al. "Rowing Injuries in Elite Athletes: A Review of Incidence with Risk Factors and the Role of Biomechanics in Its Management." Indian Journal of Orthopaedics, vol. 54, no. 3, Jan. 2020. pubmed.ncbi.nlm.nih.gov, https://doi.org/10.1007/s43465-020-00044-3

[6] "Black Concept 2 RowErg Rower - PM5 - Model D." Accessed: Oct. 04, 2024. [Online]. Available: https://www.roguefitness.com/black-concept-2-rowerg-rower-pm5-black

[7] S. Arumugam, P. Ayyadurai, S. Perumal, G. Janani, S. Dhillon, and K. A. Thiagarajan, "Rowing Injuries in Elite Athletes: A Review of Incidence with Risk Factors and the Role of Biomechanics in Its Management," *Indian J Orthop*, vol. 54, no. 3, pp. 246–255, Jan. 2020, doi: 10.1007/s43465-020-00044-3.

[8] "2D_Stretcher," Biorow. https://biorow.com/index.php?route=product/product&path=61_115&product_id=109 (accessed Sep. 21, 2023).

[9] "Force Plates," Bertec. https://www.bertec.com/products/force-plates (accessed Sep. 13, 2023).

[10] Q. Liu, Y. Dai, M. Li, B. Yao, Y. Xin and J. Zhang, "Real-time processing of force sensor signals based on LSTM-RNN," 2022 IEEE International Conference on Robotics and Biomimetics (ROBIO), Jinghong, China, 2022, pp. 167-171, doi: 10.1109/ROBIO55434.2022.10011703

[11] S. Allison, Y. Fujii, and L. M. Wilcox, "Effects of Motion Picture Frame Rate on Material and Texture Appearance," IEEE Transactions on Broadcasting, vol. 67, no. 2, pp. 360–371, Jun. 2021, doi: 10.1109/TBC.2020.3028276.

[12] "RowErg," Concept2. Accessed: Oct. 05, 2023. [Online]. Available: https://www.concept2.com/indoor-rowers/concept2-rowerg

Questions?