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Head Armor Pro

Team 101

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Design Review #5

Team Introduction

Saiabhinav Devulapalli
Biomedical Engineer

Anghea Dolisca
Biomedical Engineer

Connor Hollis
Mechanical Engineer

Riley Stroth
Mechanical Engineer

Maddie Valachovic
Biomedical Engineer

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Sponsor and Advisors

DEPARTMENT OF
CHEMICAL & BIOMEDICAL
ENGINEERING

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Project Supervisor
Dr. Stephen Arce

Project Coordinator
Dr. Shayne McConomy

Academic Advisor
Emily Thiel

Connor Hollis

Project Objective

The objective of this project is to design a device that will reduce the risk of concussions for athletes across all sports, with a specific focus on football players.

Background Overview

Connor Hollis

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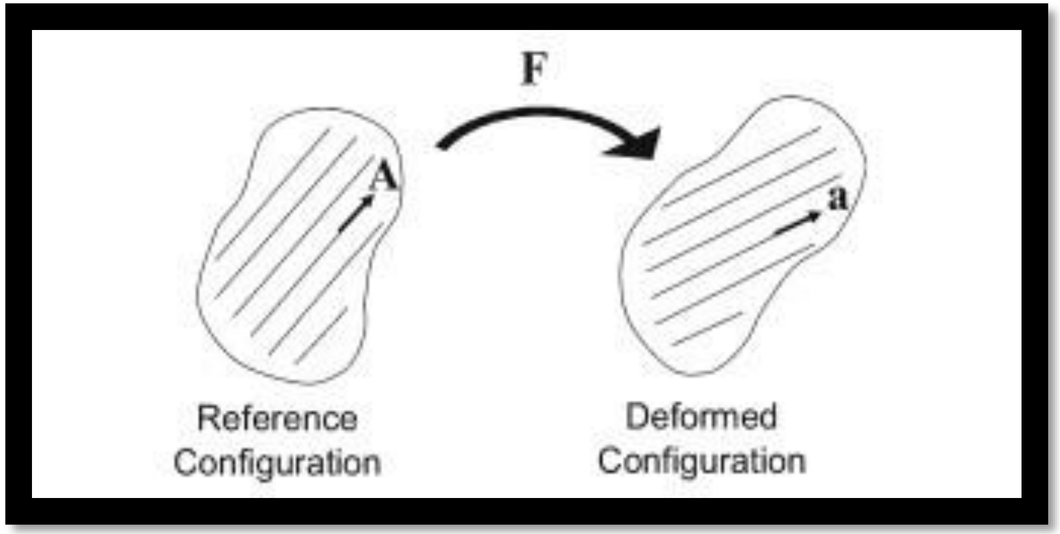
Connor Hollis

Stress-Strain vs. Cavitation

Stress-Strain Theory

- Forces deform brain cells.
- Disrupts biochemical process.



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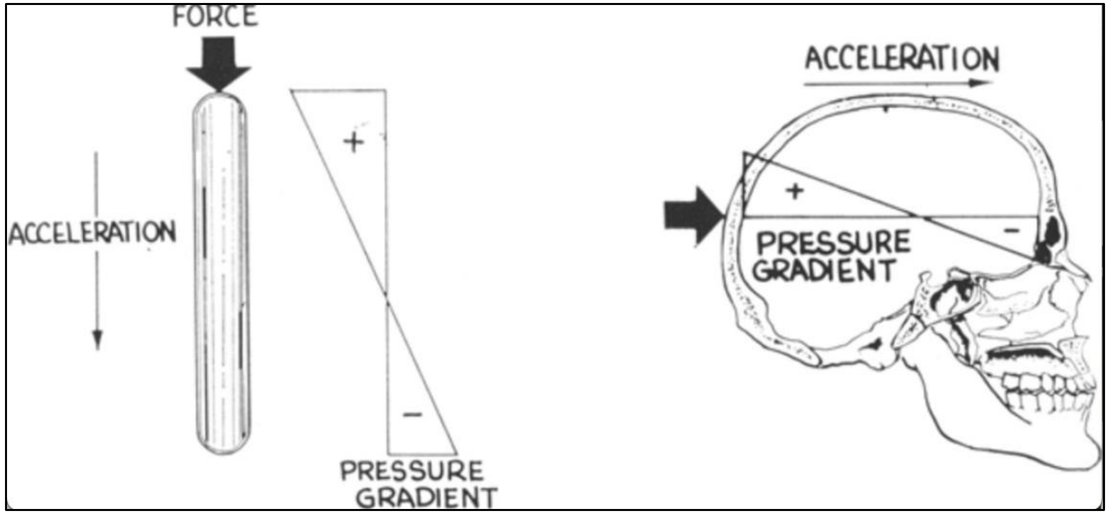
Stress-Strain vs. Cavitation

Cavitation Theory

- Tensile force > Tensile strength of liquid.
- Microscopic bubbles implode and release large amounts of energy.



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Stress-Strain vs. Cavitation

Stress-Strain Theory

+

Cavitation Theory

→

Deaccelerating the Brain

Connor Hollis

Design Goals and Targets

Deaccelerate the Brain by 5%

Weigh Less than 1.5 kg

Linear Acceleration Reduced by 25%

Withstand 1,000 Impacts

Reduce Rotational Force by 20%

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Design Goals and Targets

Deaccelerate the Brain by 5%

Linear Acceleration Reduced by 25%

- Head Injury Criteria predicts the likelihood of receiving a brain injury
- Concussions: HIC > 250

$$HIC = \{(t_2 - t_2)(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt)^{2.5}\}max$$

Weigh Less than 1.5 kg

Withstand 1,000 Impacts

Reduce Rotational Force by 20%

Design Goals and Targets

Deaccelerate the Brain by 5%

- Concussive Threshold: 70g to 120 g

$$F_R = Mass\ x\ 981\ m/s^2$$

Weigh Less than 1.5 kg

Linear Acceleration Reduced by 25%

Withstand 1,000 Impacts

Reduce Rotational Force by 20%

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Design Goals and Targets

Deaccelerate the Brain by 5%

Linear Acceleration Reduced by 25%

- Concussive Rotational Acceleration Threshold- 4500 to 6000 rad/s^2

$$a_r = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

Reduce Rotational Force by 20%

Weigh Less than 1.5 kg

Withstand 1,000 Impacts

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Connor Hollis

Design Goals and Targets

Deaccelerate the Brain by 5%

Weigh Less than 1.5 kg

Linear Acceleration Reduced by 25%

Withstand 1,000 Impacts

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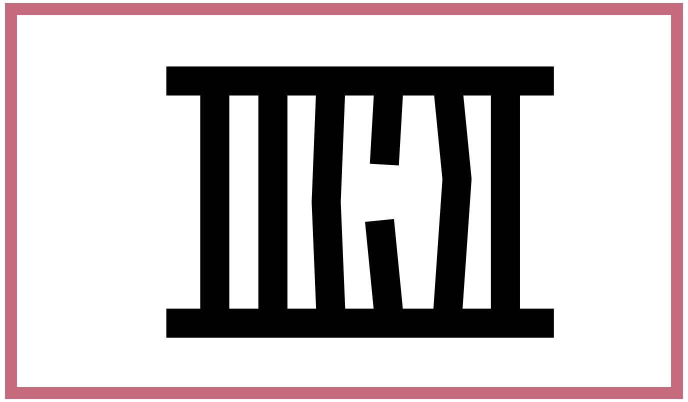
Connor Hollis

Design Goals and Targets

Deaccelerate the Brain by 5%

Linear Acceleration Reduced by 25%



Reduce Rotational Force by 20%

Weigh Less than 1.5 kg

Withstand 1,000 Impacts

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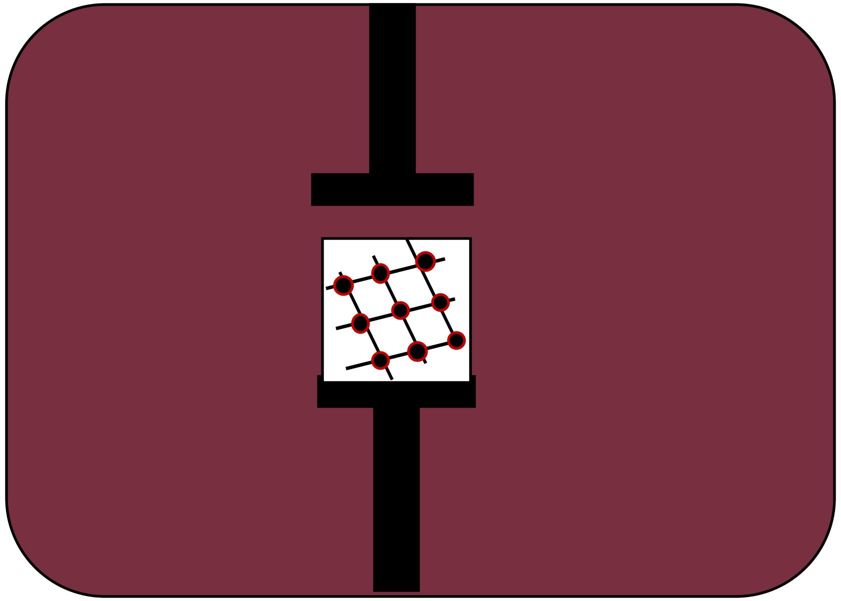
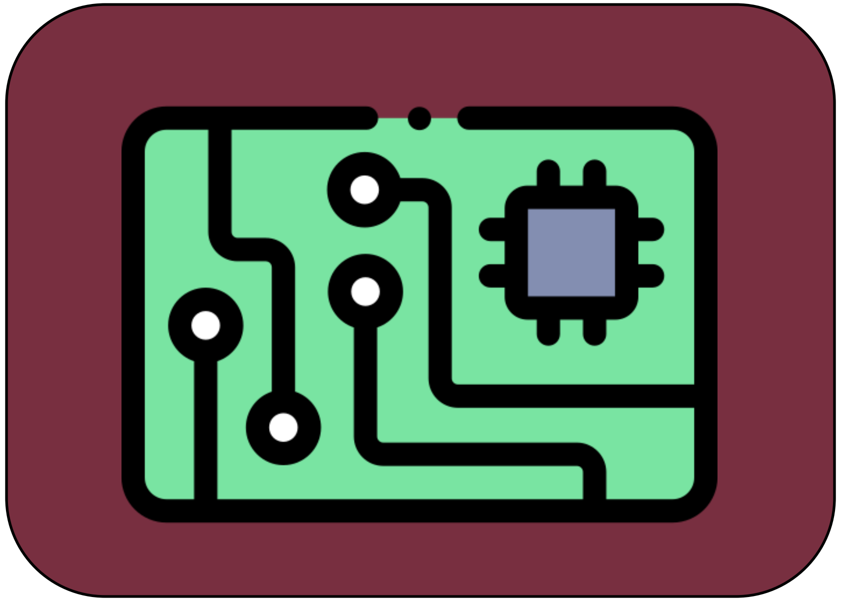
Proposed Solution





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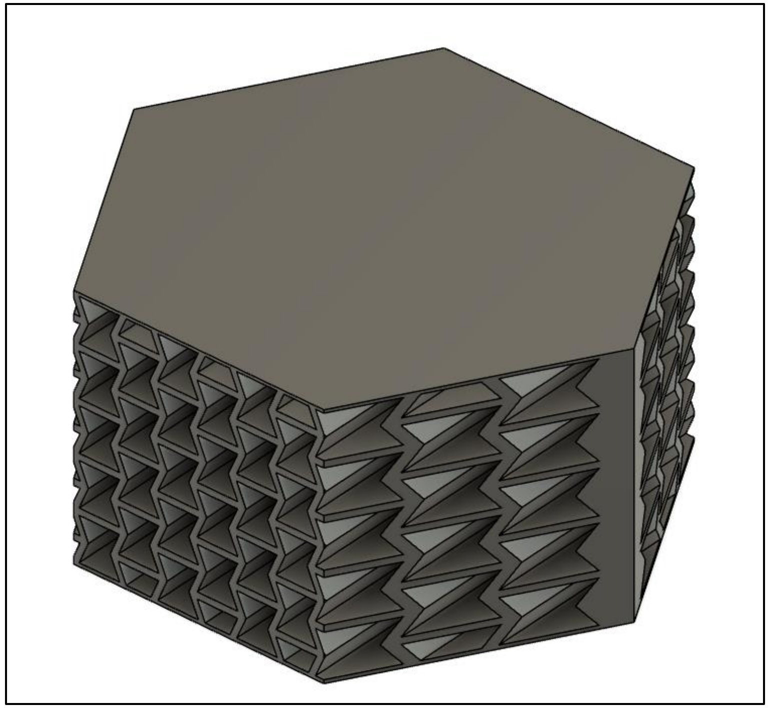
Current Auxetic Foam Design

- Honeycomb hourglass structure
  - 3D printing with stereolithography (SLA) technology
  - Flexible 80A resin
  - Light weight profile
- Hexagonal auxetic foam structure
  - Negative Poisson's ratio
  - Enabling lateral expansion during impact deformation



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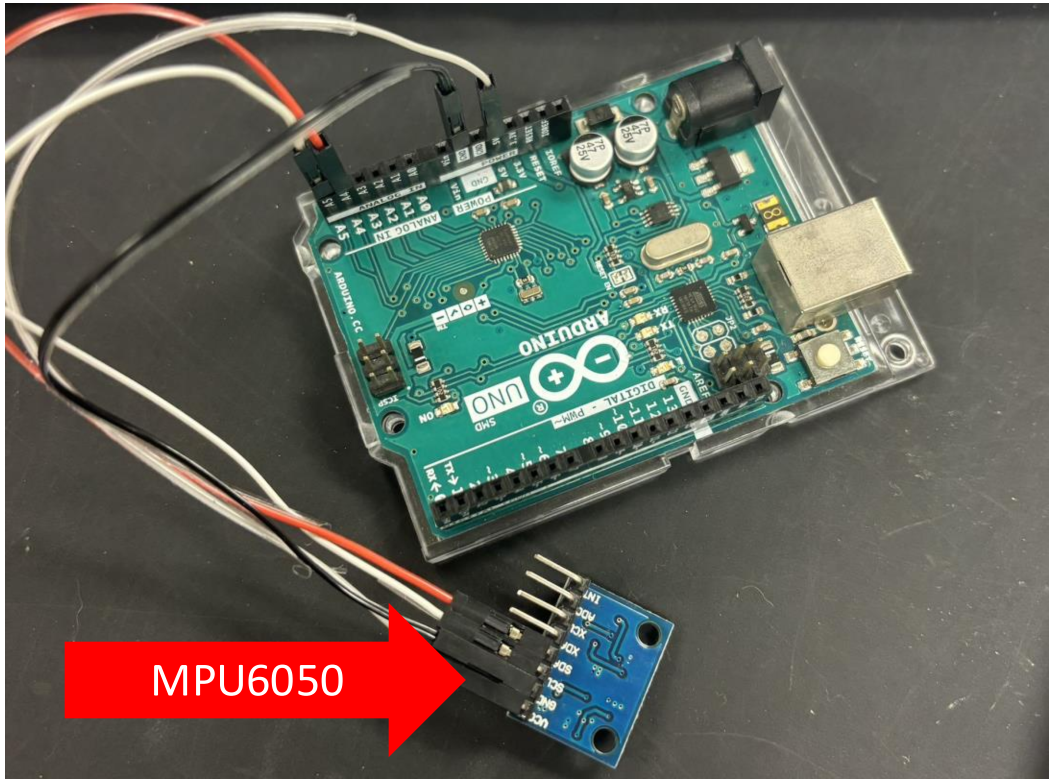
Impact Monitoring Sensor

- Alerts coaches and trainers to high-impact events, for immediate injury assessments
- Understanding linear and rotational impacts
- <u>Concussive Thresholds:</u>
  - Linear Acceleration- 70 to 120 g
  - Rotational Acceleration- 4500 to 6000 rad/s^2



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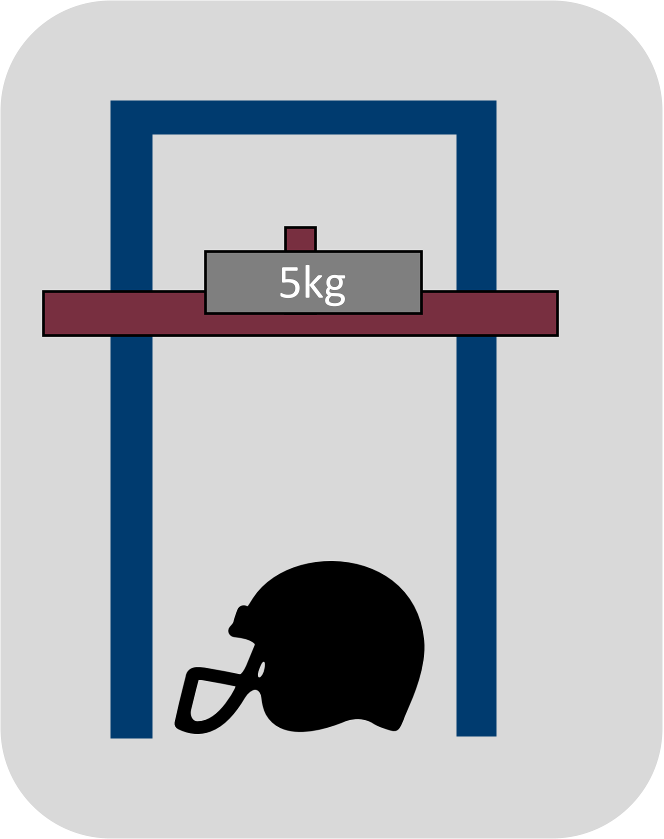
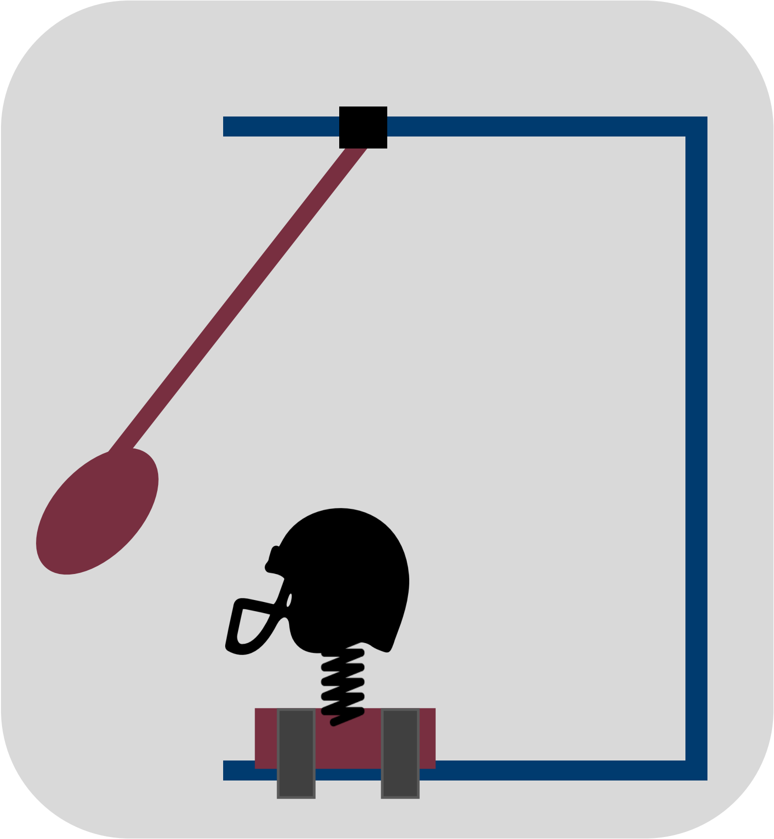
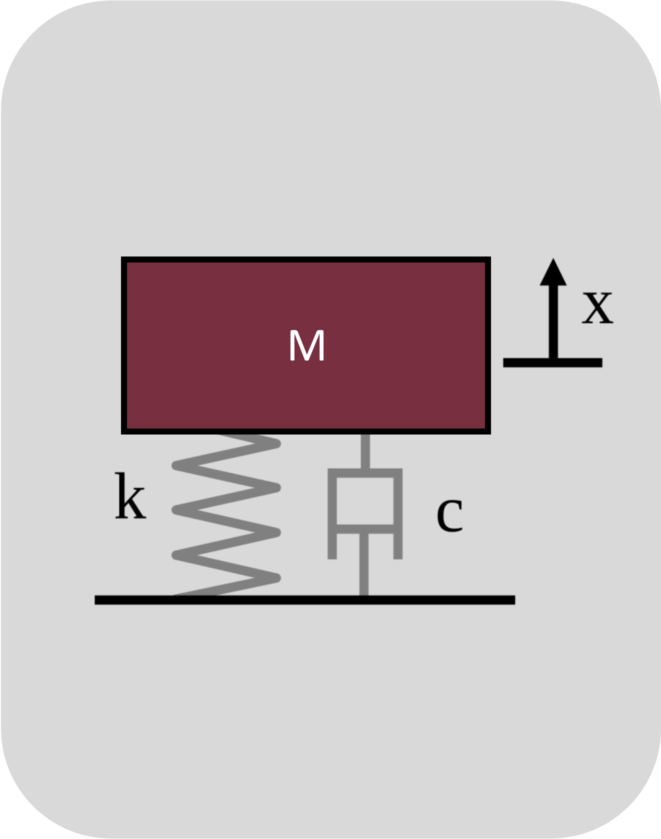
Riley Stroth

Material Testing







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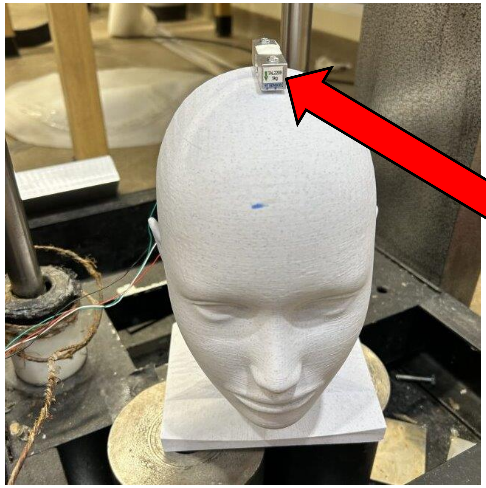
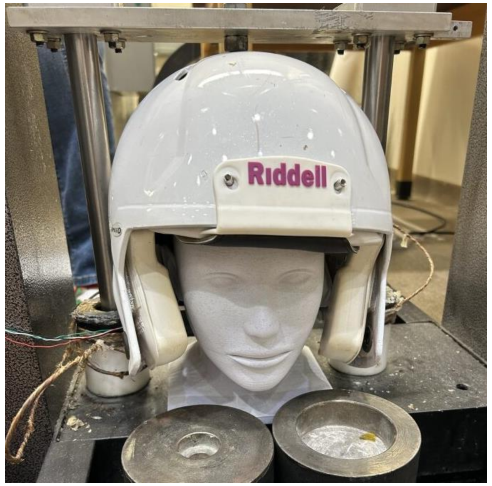
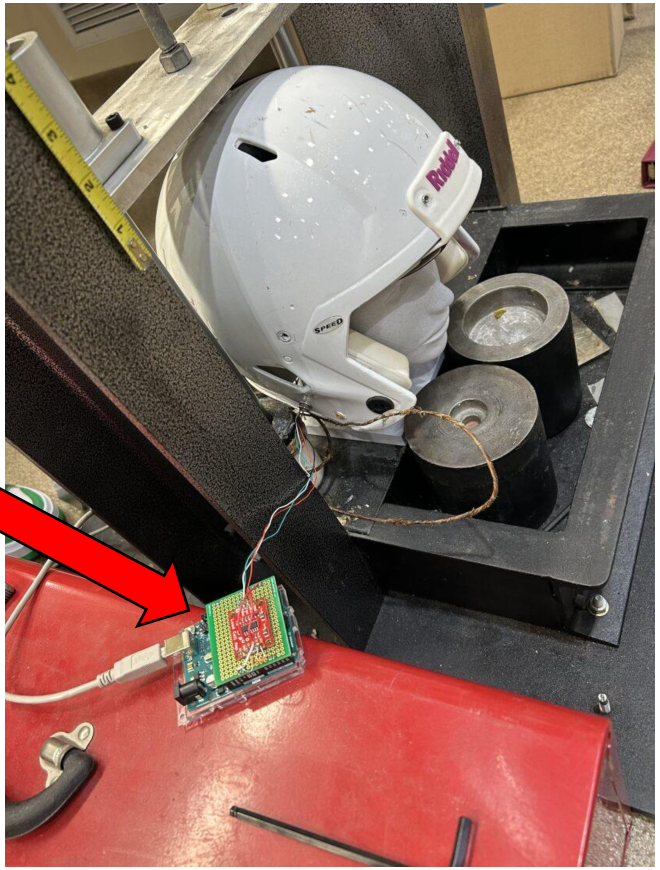
Drop Test – Failures and Successes



Load Cell



Arduino
& Circuit



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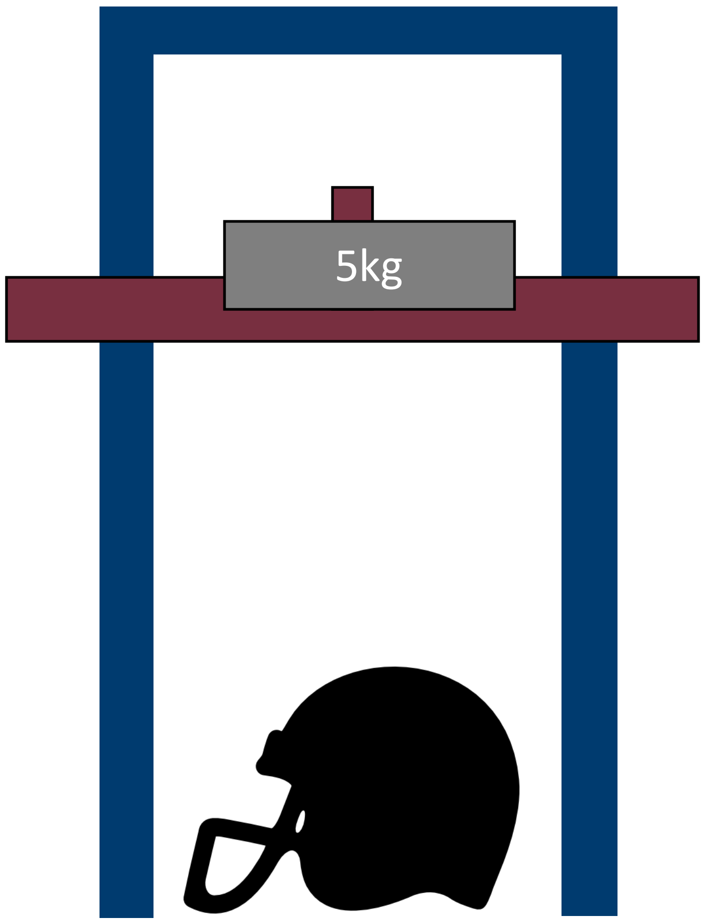
Drop Test – Failures and Successes



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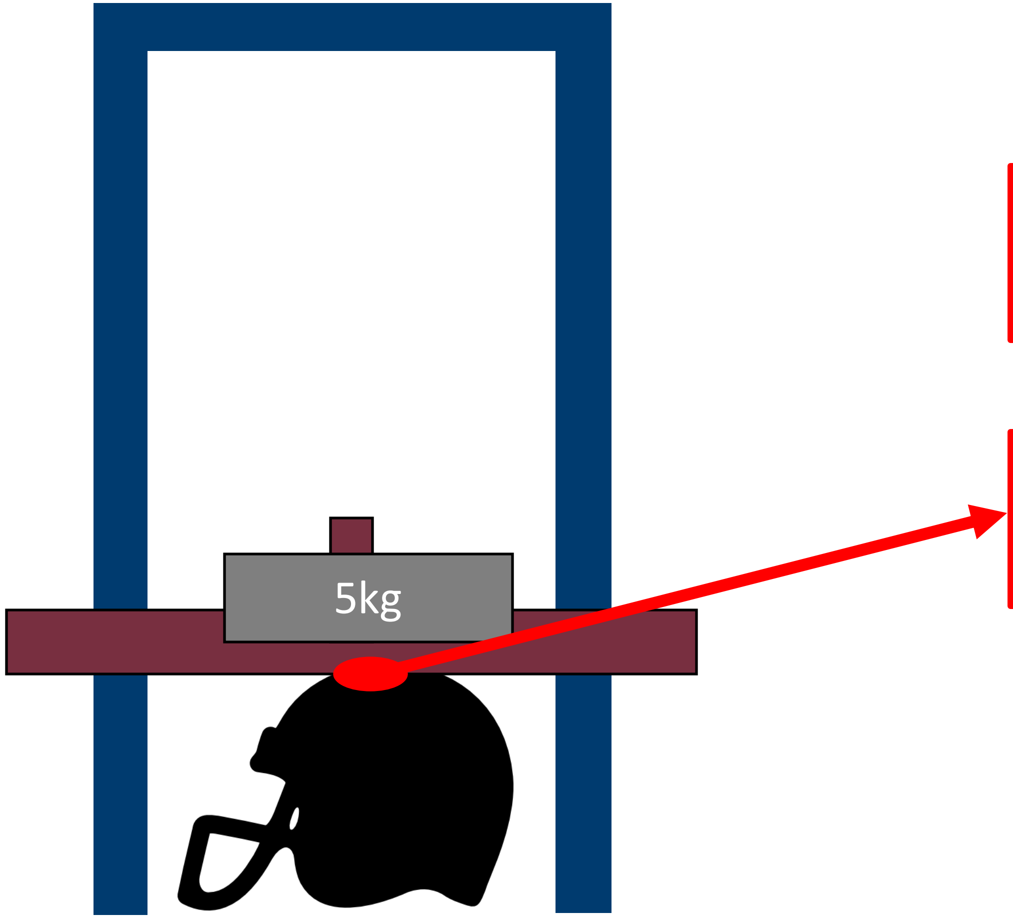
Drop Test – Failures and Successes



Theoretical Value-
Force = Mass • Gravity • Height

Load Cell Reading-
Recorded Pound Force

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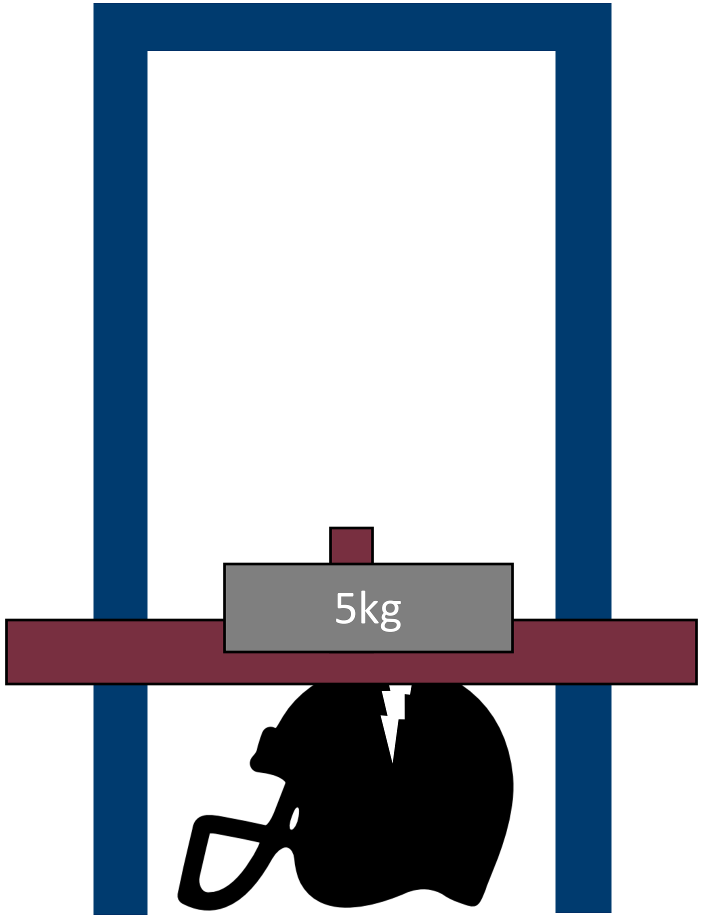
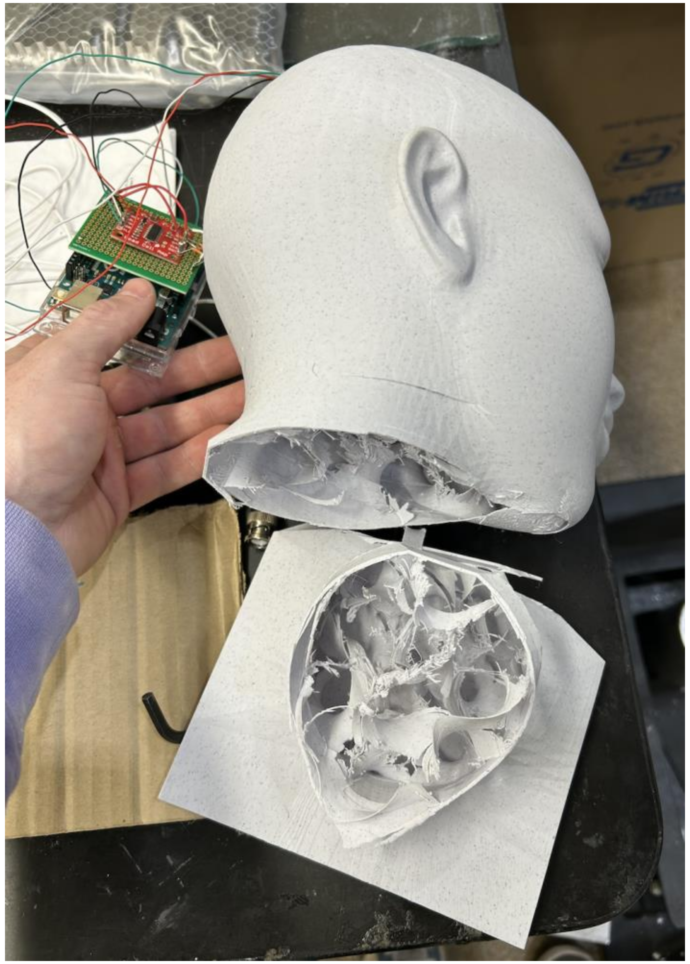
Drop Test – Failures and Successes





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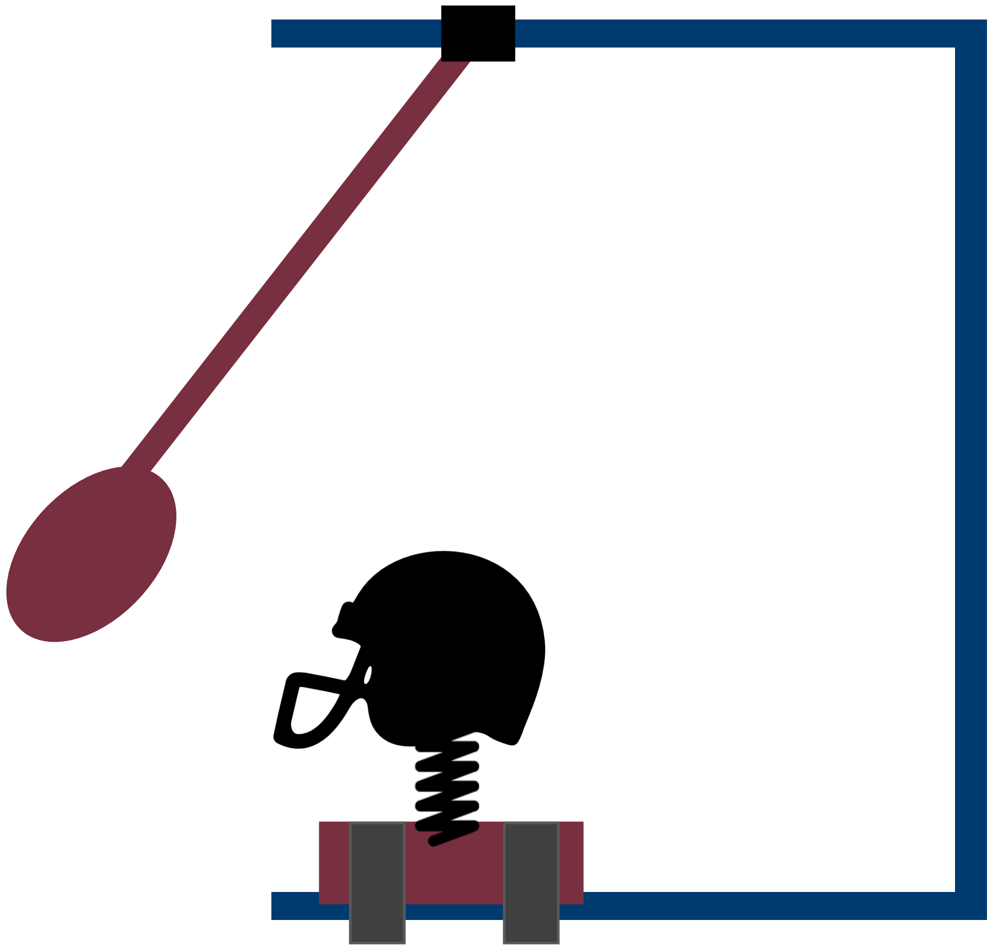
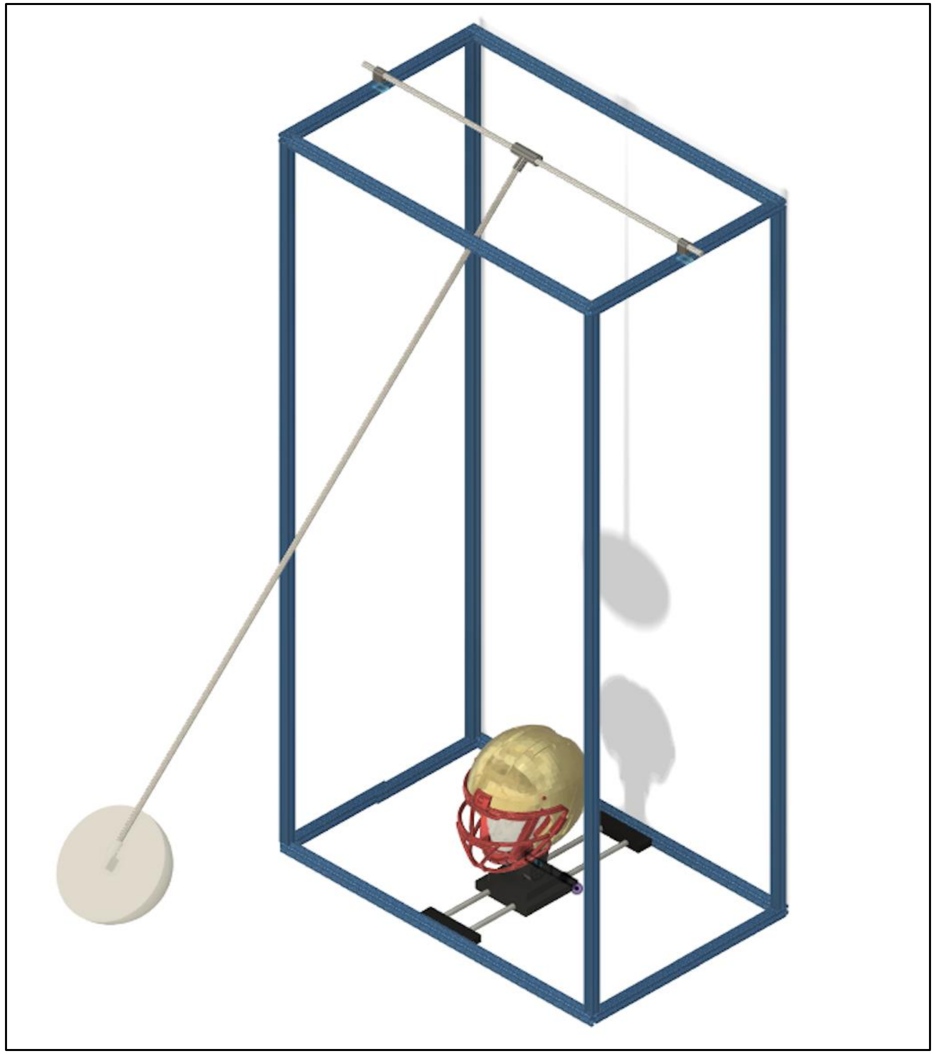
Pendulum Impact Test





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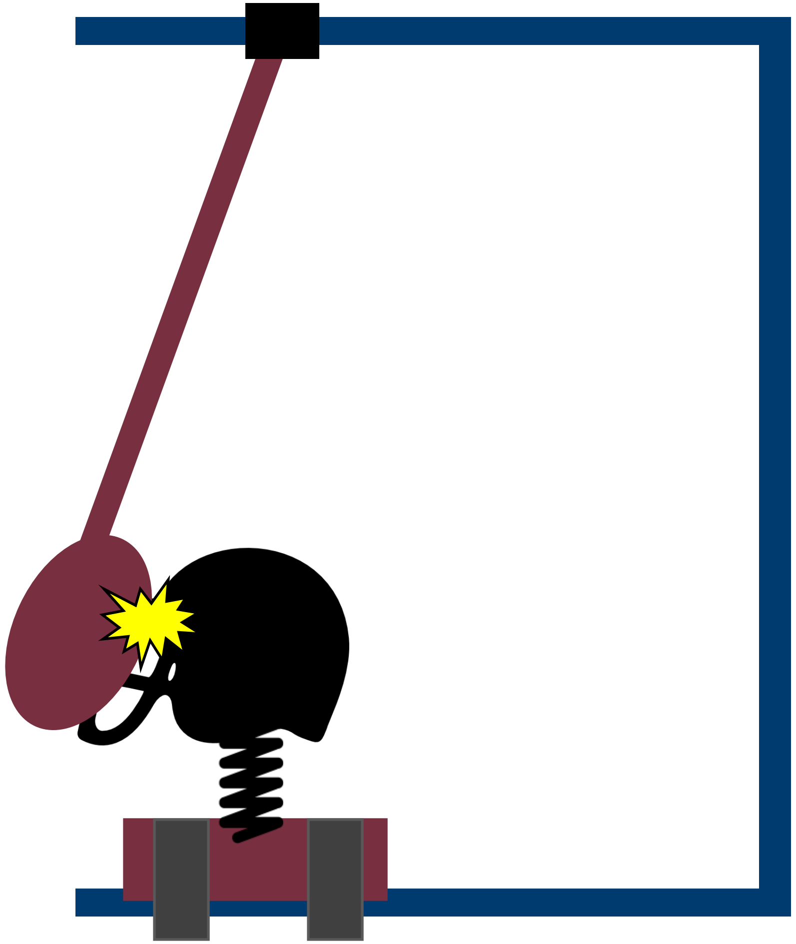
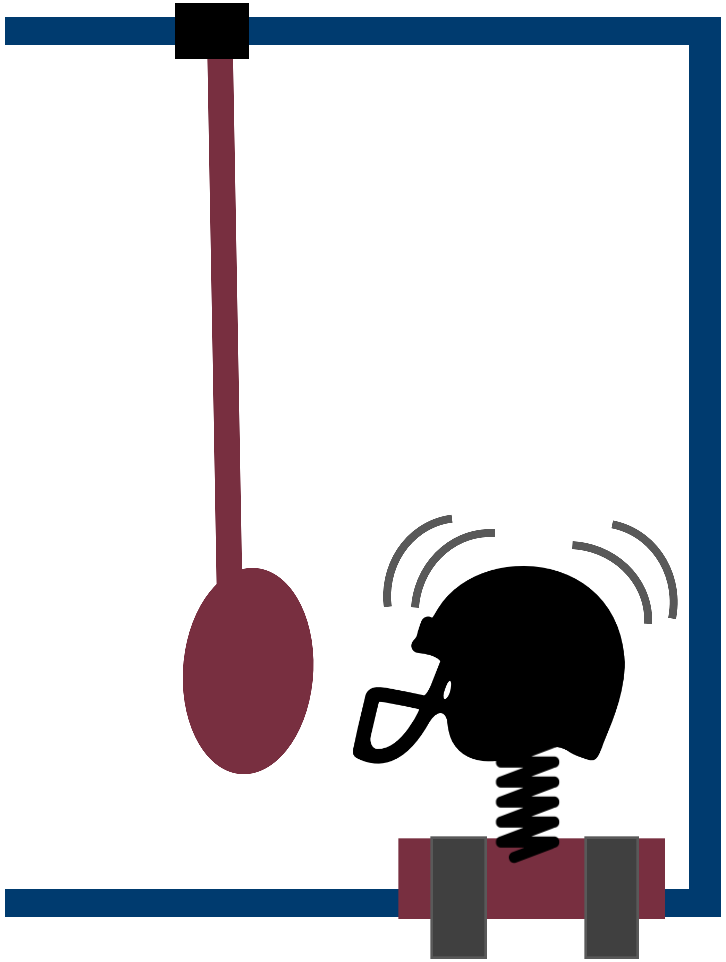
Pendulum Impact Test



Pendulum Impact Test



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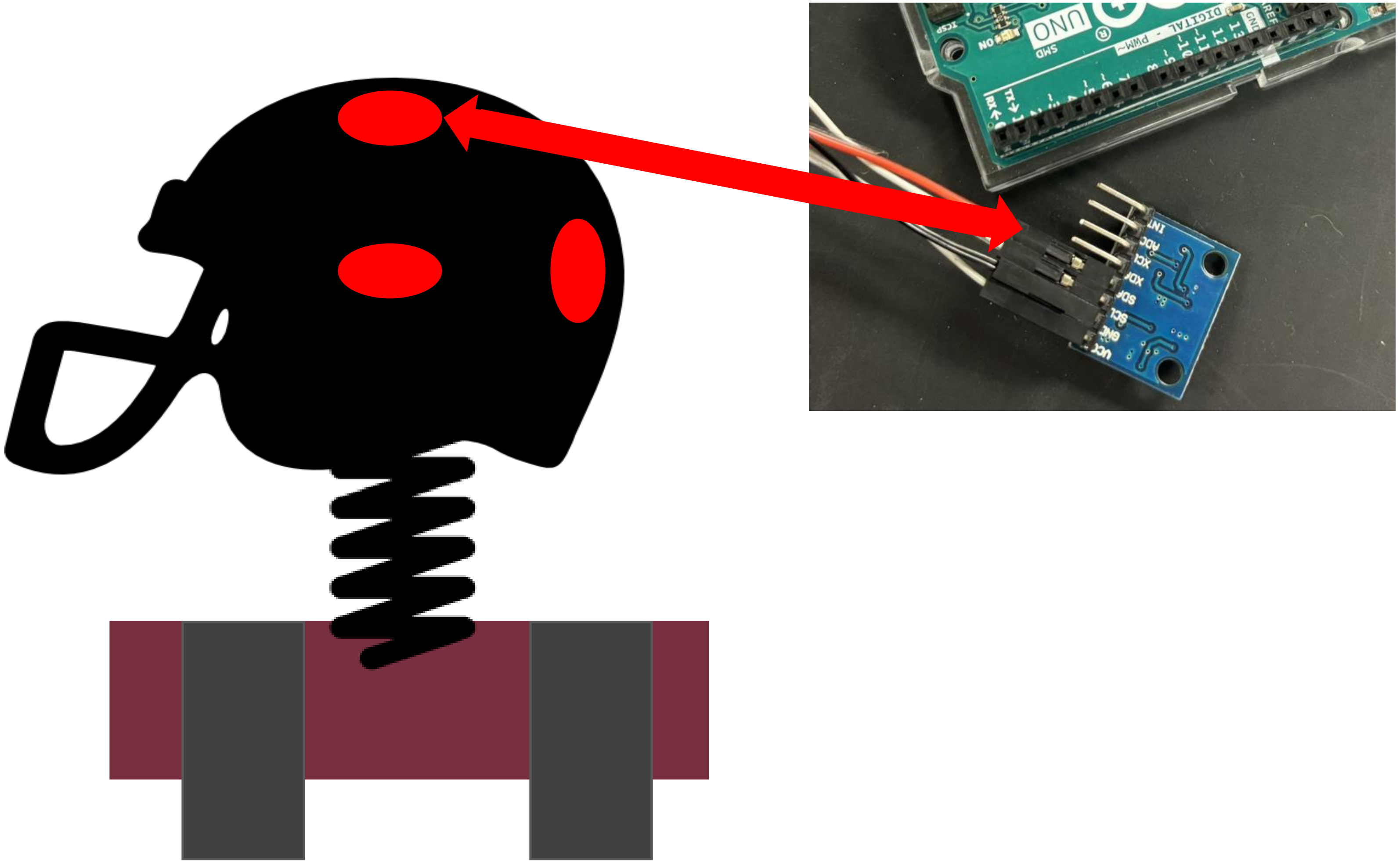
Pendulum Impact Test



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Material as a Spring

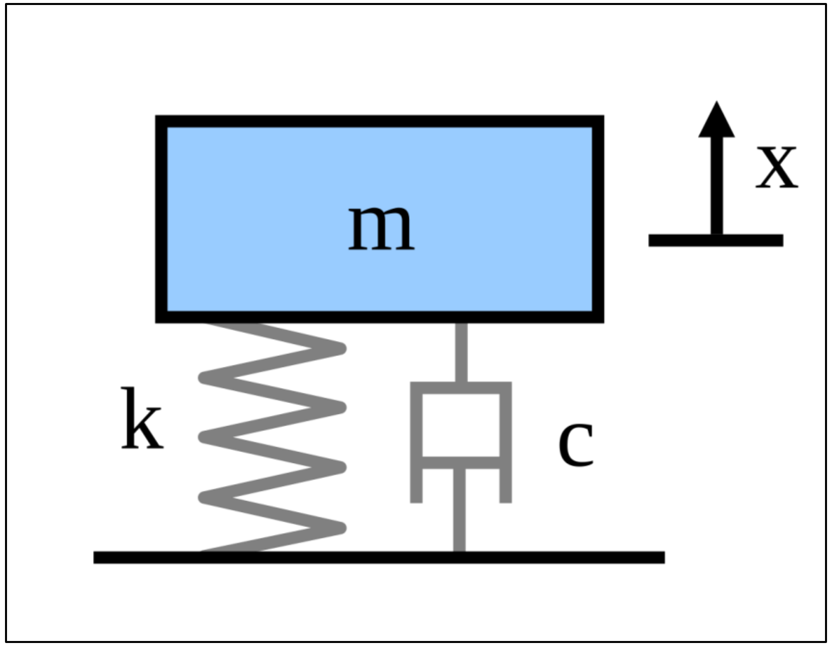
Stiffness (K) and Damping Coefficient (C)

Energy Absorbed :

$$U = \frac{1}{2}kx^2$$

Deformation Under Certain Frequencies

Theoretical Acceleration



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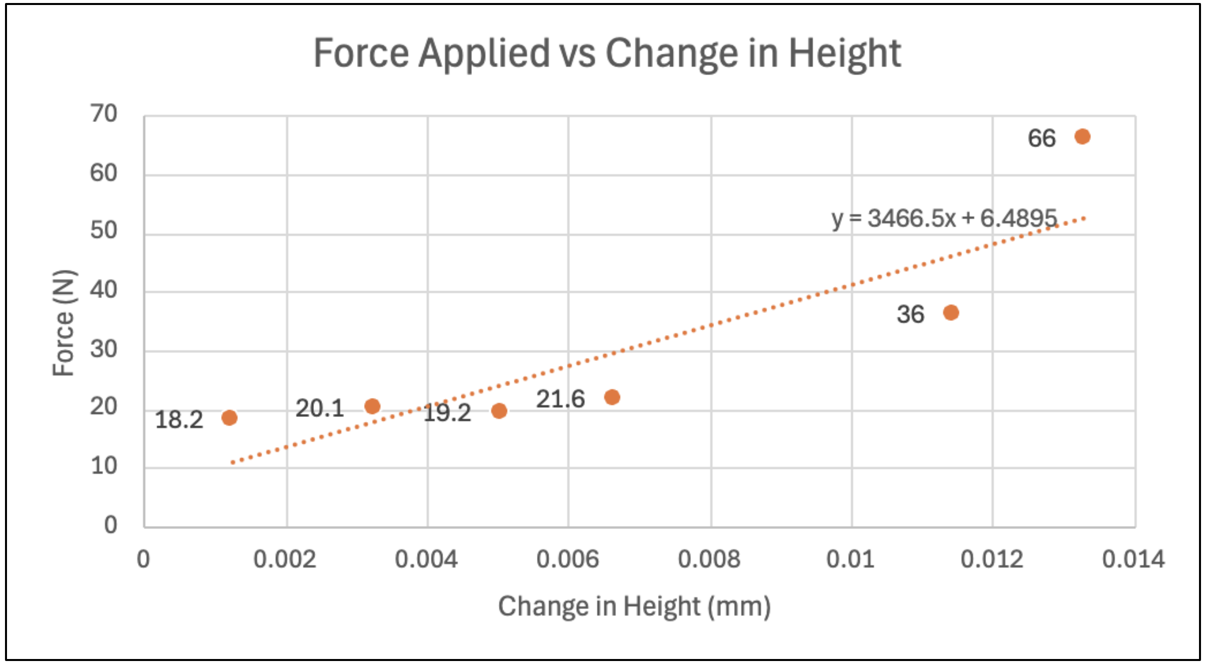
Material as a Spring

- Stiffness of 3466.5 N/m
- Treated the material as a linear spring
- Not considering damping



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Material as a Spring

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Material as a Spring

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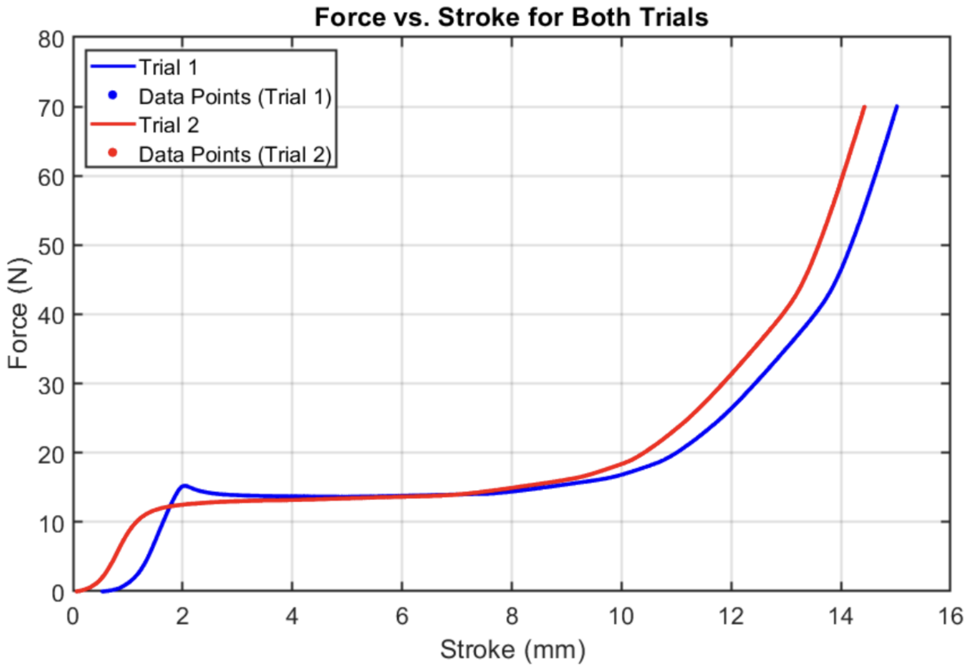

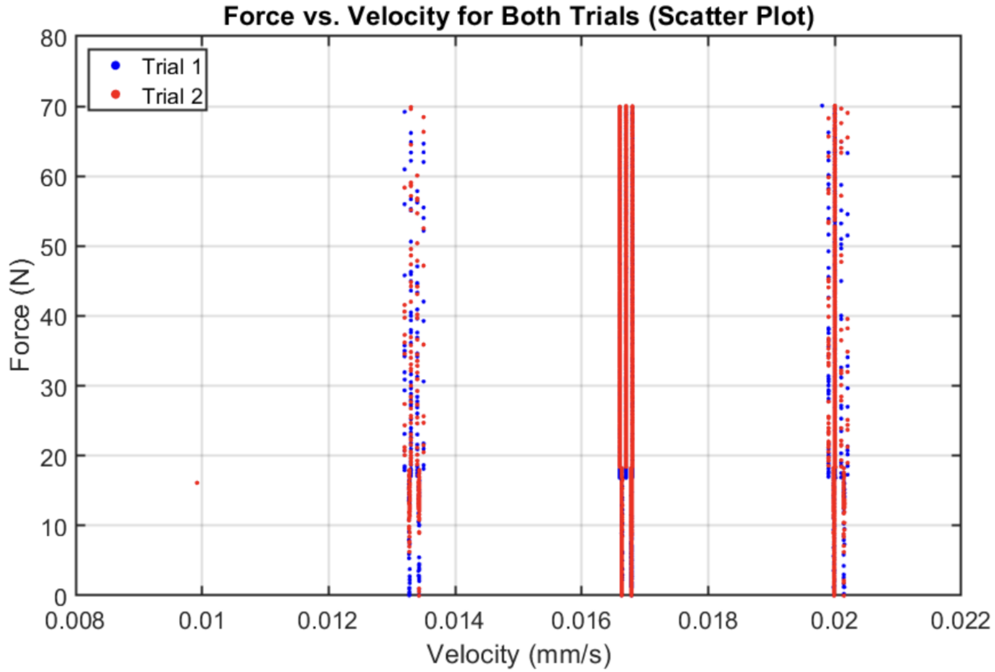

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Material as a Spring

- Kelvin Voigt Model
  - Viscoelastic material
  - Spring and Damper in Parallel

Based on Compression Instron Test:

	Spring Constant (K)	Damping Coefficient (C)
Trial 1	1087.4 N/m	319 x 10^5 N•s/m
Trail 2	251.9 N/m	109 x 10^5 N•s/m

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Future Work

Phase 1:
- Continue Compression Test
- Assure Linear Thresholds are Reached
- Evaluate Material Properties

Phase 2:
- Wireless Accelerometer
- Test with Pendulum Impactor
- Sizing and Implementing Material

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References

Gross, A. G. (1958). A new theory on the dynamics of brain concussion and Brain Injury. *Journal of Neurosurgery*, *15*(5), 548–561. https://doi.org/10.3171/jns.1958.15.5.0548

Wright, R. M., & Ramesh, K. T. (2011). An axonal strain injury criterion for traumatic brain injury. *Biomechanics and Modeling in Mechanobiology*, *11*(1–2), 245–260. https://doi.org/10.1007/s10237-011-0307-1

Östh, J., Bohman, K., & Jakobsson, L. (2022). Head injury criteria assessment using head kinematics from crash tests and accident reconstructions. *Traffic Injury Prevention*, *24*(1), 56–61. https://doi.org/10.1080/15389588.2022.2143238

Deck, C., & Willinger, R. (2008). Improved head injury criteria based on head fe model. *International Journal of Crashworthiness*, *13*(6), 667–678. https://doi.org/10.1080/13588260802411523

Kulkarni, S. G., Gao, X.-L., Horner, S. E., Zheng, J. Q., & David, N. V. (2013). Ballistic helmets – their design, materials, and performance against Traumatic Brain Injury. *Composite Structures*, *101*, 313–331. https://doi.org/10.1016/j.compstruct.2013.02.014

Corona radiata: Radiata, white matter, brain anatomy. Pinterest. (2020, February 11). https://in.pinterest.com/pin/614459942896848304/

Cavitation gifs. WiffleGif. (n.d.). https://wifflegif.com/tags/386612-cavitation-gifs?page=0

Cecchi, N. J., Callan, A. A., Watson, L. P., Liu, Y., Zhan, X., Vegesna, R. V., Pang, C., Le Flao, E., Grant, G. A., Zeineh, M. M., & Camarillo, D. B. (2024, October). *Padded helmet shell covers in American Football: A comprehensive laboratory evaluation with preliminary on-field findings*. Annals of biomedical engineering. https://pmc.ncbi.nlm.nih.gov/articles/PMC10013271/#Sec2

O'Connor, K. L., Rowson, S., Duma, S. M., & Broglio, S. P. (2017, March). *Head-impact-measurement devices: A systematic review*. Journal of athletic training. https://pmc.ncbi.nlm.nih.gov/articles/PMC5384819/

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