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Head Armor Pro

Team 101

Design Review #2

Team Introduction

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Objective

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

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The Problem:
What is a concussion?

A dive into Stress-Strain Theory, Cavitation Theory for Traumatic Brain Injury (TBI) and its relationship to Head Injury Criterion (HIC)

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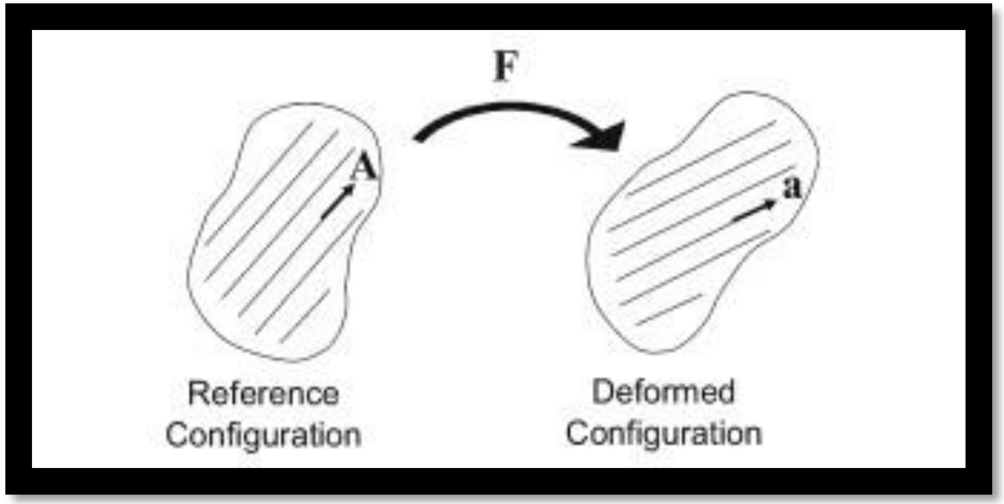
Stress-Strain Theory

- Sudden inertial loads to the head cause injury
- Mild TBI, damage occurs at cellular and subcellular level
- Neural axons are stretched inelastically (~18%), disrupting normal biochemical processes in the cells
- This leads to impairment of the neurons cell and even death



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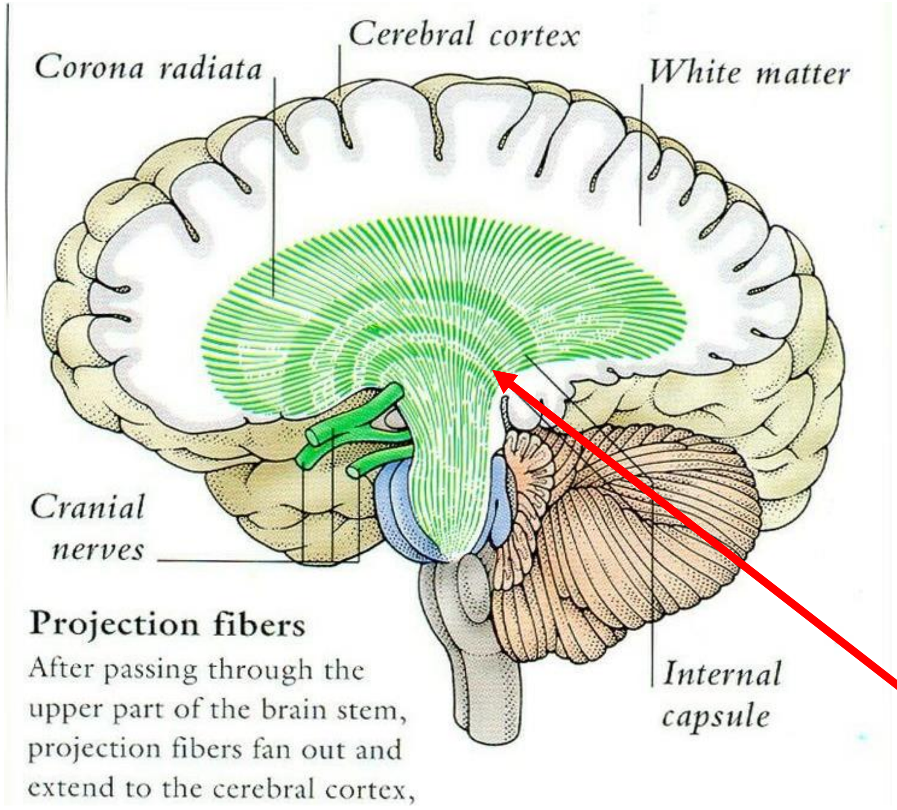
Stress-Strain Theory cont.



- Different areas of the brain's white matter are affected differently depending on neural fiber orientation
  - Brain is very heterogeneous
- Example: Corpus Callosum is anisotropic – can induce strains differently

Corpus Callosum

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Head Injury Criteria

- Helmet testing, automotive safety, and sports
- Quantifies potential head injury risk from impact
- Based on duration and severity of acceleration
- **Thresholds**:
  - HIC < 250: Low risk
  - HIC > 250: Increased risk of serious injury

$$HIC_{15} = max\left\{\left[\frac{1}{t_2 - t_1}\int_{t_a}^{t_2} a(t)dt\right]^{2.5} (t_2 - t_1)\right\}$$

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Head Injury Criterion relating to Stress-Strain Theory

- The threshold of 60g+ of linear acceleration
- Force distribution of the brain affects some areas more than others
- Neural orientation plays a factor

Table 6
Various local injury criteria based on pressure gradients, strains, stresses and strain rates.

Criterion	Threshold	Location of injury	Probability (%)	Application	Reference
Stress					
von Mises	6–11 kPa	Corpus callosum	50	Rat brain/car crash injuries	Shreiber et al. [127]
	8.4 kPa	Corpus callosum	50	Footballers (FEM)	Kleiven [77]
	>30 kPa	Brain neurological lesions	100	Motorcyclists/footballers	Willinger and Baumgartner
	>16 kPa	Brain neurological lesions	50	Motorcyclists/footballers (FEM)	[157]
Shear	8–16 kPa	Diffuse axonal injuries	100	Sheep brain	Anderson et al. [4]
	11–16.5 kPa	Diffuse axonal Injuries	100	Motorcycle Accidents	Claessens et al. [27]
	>10 kPa	Mild TBI	80	Footballers (FEM)	Zhang et al. [163]
Strain					
$\varepsilon\dot{\varepsilon}$	30/s	Gray matter	50	Multiple specimens	Viano and Lovsund [148]
$\varepsilon\dot{\varepsilon}$	10.1/s	Gray matter	50	Footballers (FEM)	Kleiven [77]
$\varepsilon, \dot{\varepsilon}$	$\varepsilon > 0.2$ $\dot{\varepsilon} > 10/s$	White matter	100	Tissue culture	Morrison et al. [95]
Shear strain	>0.24	Mild TBI	80	Footballers (FEM)	Zhang et al. [163]
Lagrangian principal strain	>0.21	Morphological injury	50	Guinea pigs	Bain and Meaney [8]
	>0.181	Electrophysiological impairment			
Cumulative strain	$\geqslant 0.55$	White matter	50	FEM	Takhounts et al. [138]
Intra Cranial Pressure (ICP)					
ICP	<173 kPa	Concussion	0	Animal/human cadavers	Ward et al. [155]
	>235 kPa		100	(FEM)	
	>90 kPa	Injury (coup side)	50	Footballers (FEM)	Zhang et al. [163]
	>–76 kPa	Injury (counter coup)			
Amount of explosives					
0.205 lb TNT (standoff distance 160 cm)	ICP > 235 kPa Shear stress > 16.5 kPa Principal strain > 0.22	Coup/counter coup side Brain stem	100	FEM	Chafi et al. [20]

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Cavitation Theory

- Introduced by Dr. David Smith – inventor of Q-Collar
    - The brain and spinal column can intake 30mL of fluid
- F = m x a
- "Tensile force exceeds the tensile strength of the fluid, the fluid will tear apart, producing temporary cavities."

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Cavitation Theory

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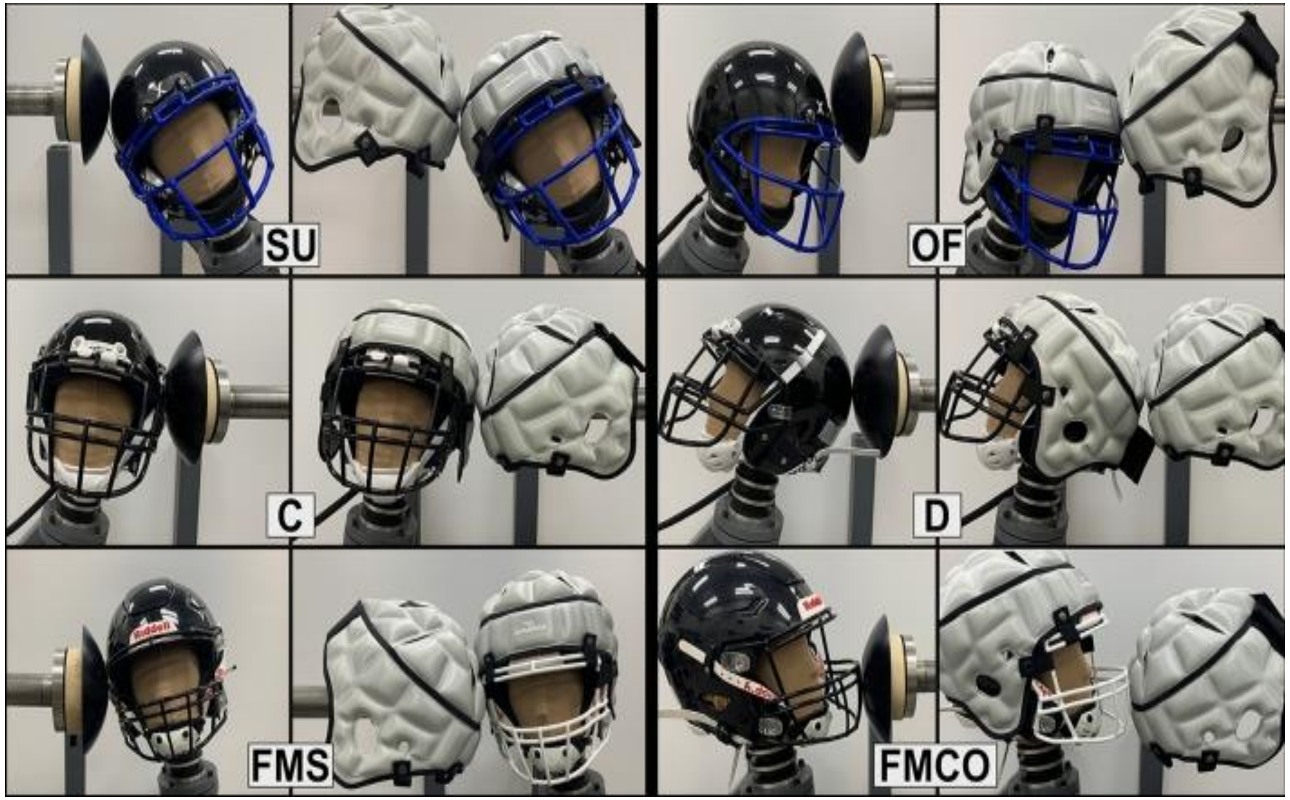
Is this phenomenon occurring inside of your head?

A study done on "Guardian Caps"



- Linear Impactor:
  - 3.5, 5.5, 7.4 (m/s)
  - 6 impact locations tested: 4 covered by padding, 2 on facemask
- HARM values (Head Acceleration Response Metric) reduced by an average of 25%, 18%, and 10% respective to the velocities

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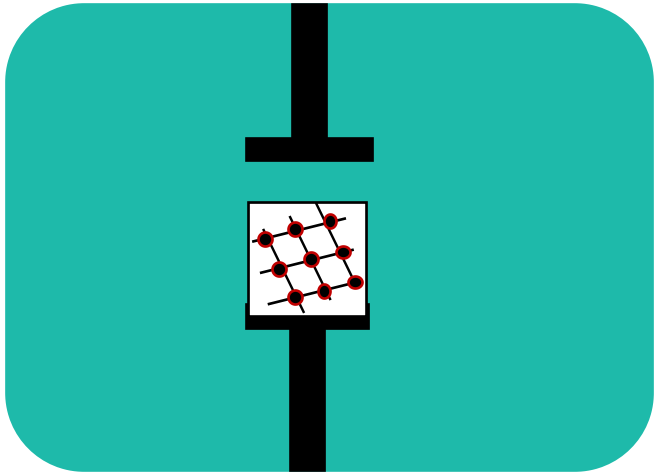
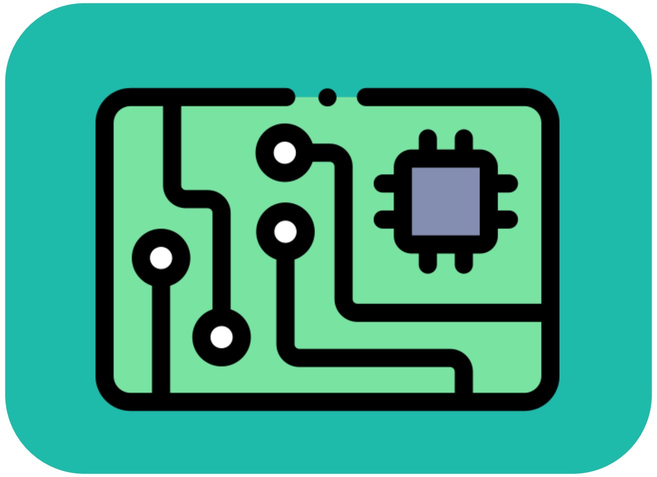
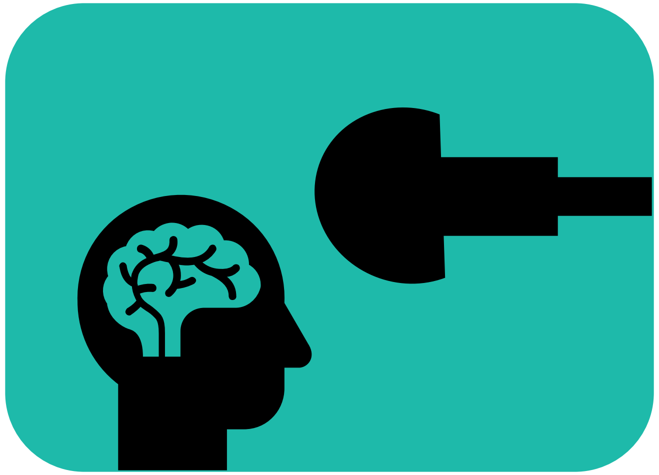
Approach to Solving the Problem







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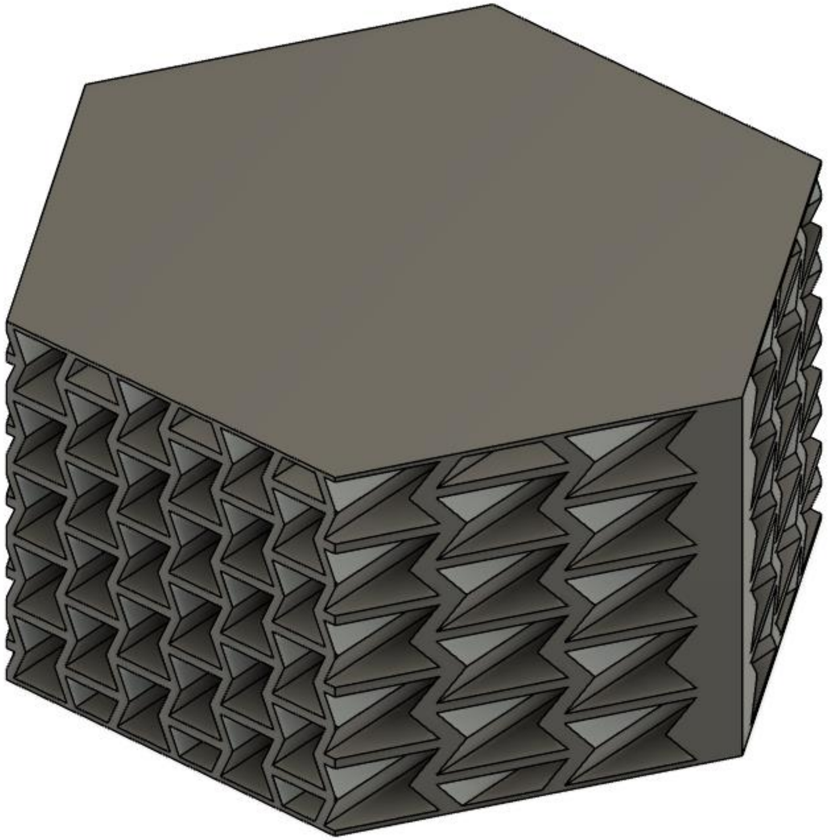
Auxetic Foam Design

- Auxetic Foam Characteristics-
  - Thicker when stretched
  - Compresses efficiently under force
  - **Negative Poisson's ratio-** expands perpendicular from pressure
- Hexagon with Hourglass Design
  - Flexible
  - Energy distribution
  - Resistant to shear force



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Foam Tensile Testing

- Testing-
  - Assess **durability, flexibility, and material integrity**
  - Evaluate ability to withstand impact, compression, and wear
- Expected Results-
  - Impact Absorption
  - Durability

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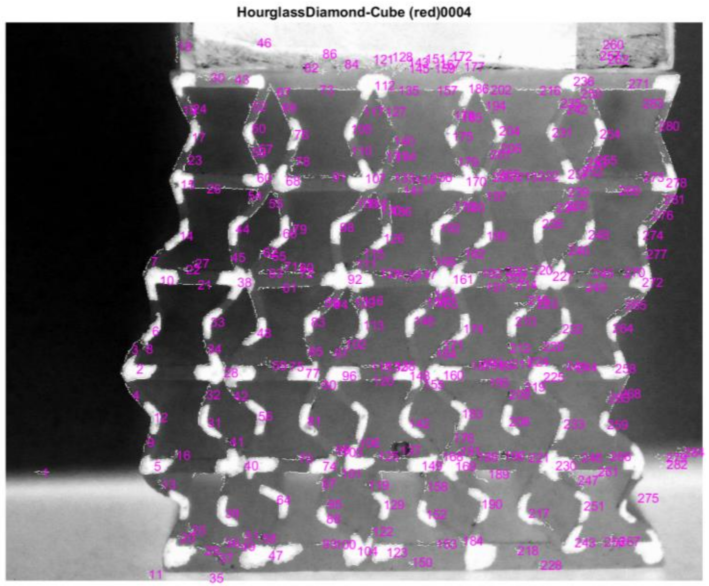
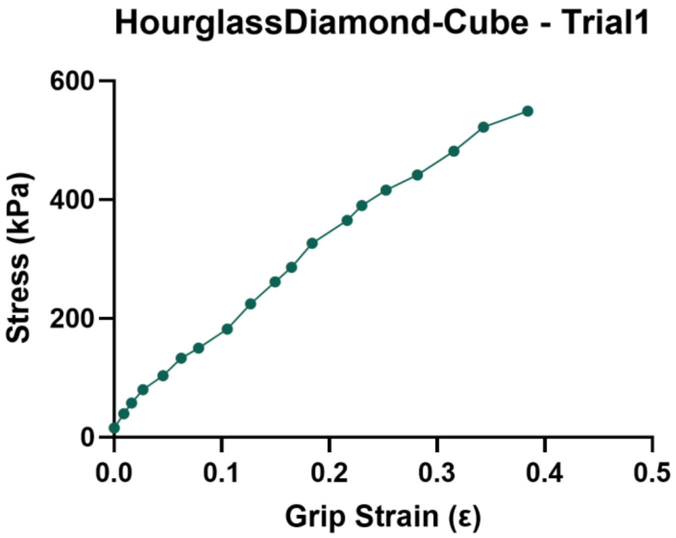
Results (So Far...)

- Linear stress-strain relationship
  - Exponential curve is wanted
- Understanding of the foam's maximum stress threshold
- Current test - applies around 120 N





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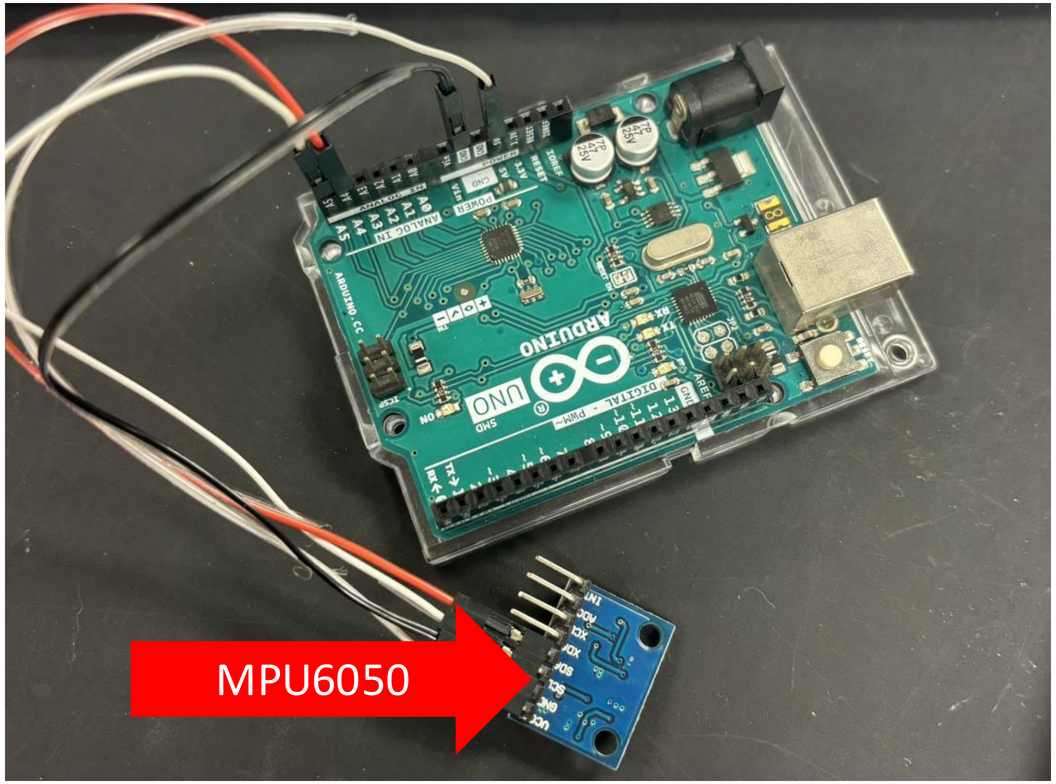
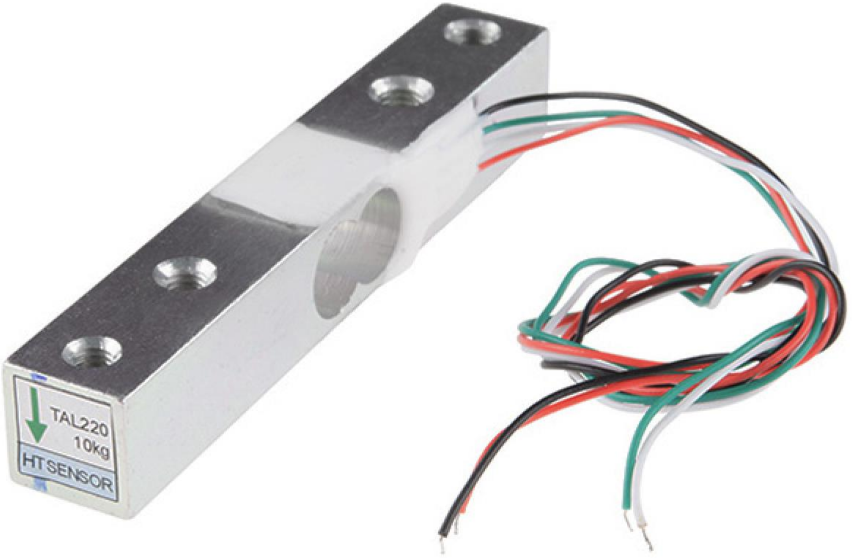
Key Components of the Circuit





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Circuit Thresholds

HIC > 250

Acceleration Magnitude
> 800 m/s^2

Resultant Load Force
> Mass x 981 m/s^2

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Our Approach – Impact Drop Testing

Experiment in HPMI Lab:

- Measure 4 locations of model head
- Measure 4 different heights from drop test
- Record acceleration inside helmet for foam vs. control
    - o Reduce accelerations by > 5%

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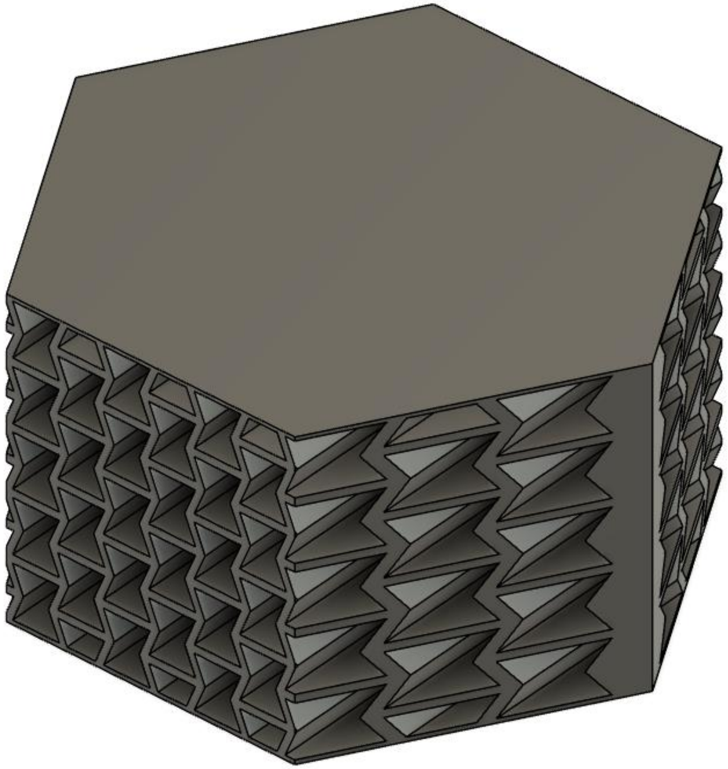
Future Work

Combine code

Wireless and compact circuit design

Complete experiments, record results, improve the design



Questions?

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