LS-DYNA Simulation Validation & HIC Reduction

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Goal of Design Challenge

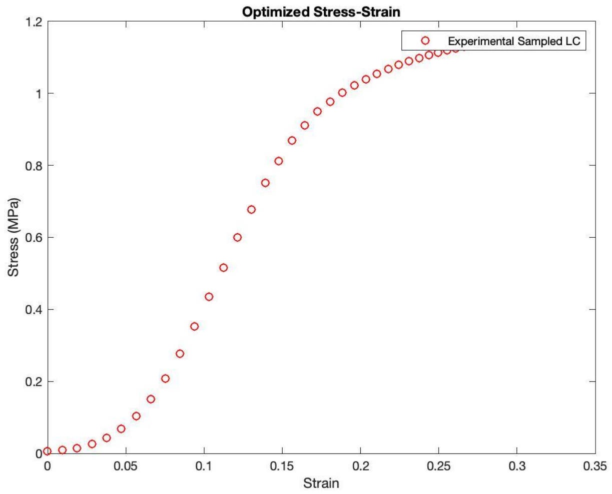
- Design Improved Foam Pad to Better Protect from Head Collision Injuries Compared to Existing Dytherm Foam
- Model Protective Foam Material in Collision Given Loading Curve Data and Altering Damping Factor
- Adjusting Loading Curve Data and Damping Factor to Lower HIC of Material

Purpose of Design Challenge

- Understand how Changing the Loading Curve and Damping Factors Affect the HIC for a Material
- Develop Proficiency in Modeling a Material's Physical Properties given Experimental (Loading Curve) Data in LS-DYNA
- Understand Relevance in Design Processes with Respect to Future Neck Testing

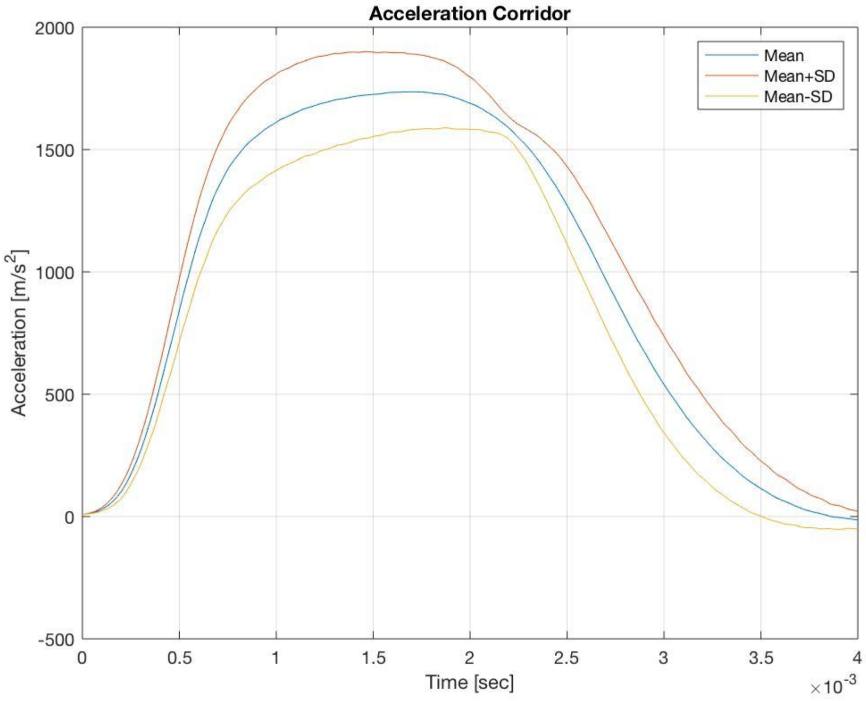
Dytherm Stress-Strain Curve

- Averaged 3 Experimental Trials
  - 3 m/s
  - 0.5 in Thick Foam
- Smoothed Data with 20 Point Mean Windows
- Saved every 5th Point
  - From Start to Peak Stress [Loading Phase]



Acceleration Corridor

- Compared to Experimental Data
  - Dytherm 3 m/s (n=3)
- Average ± 1 Standard Deviation



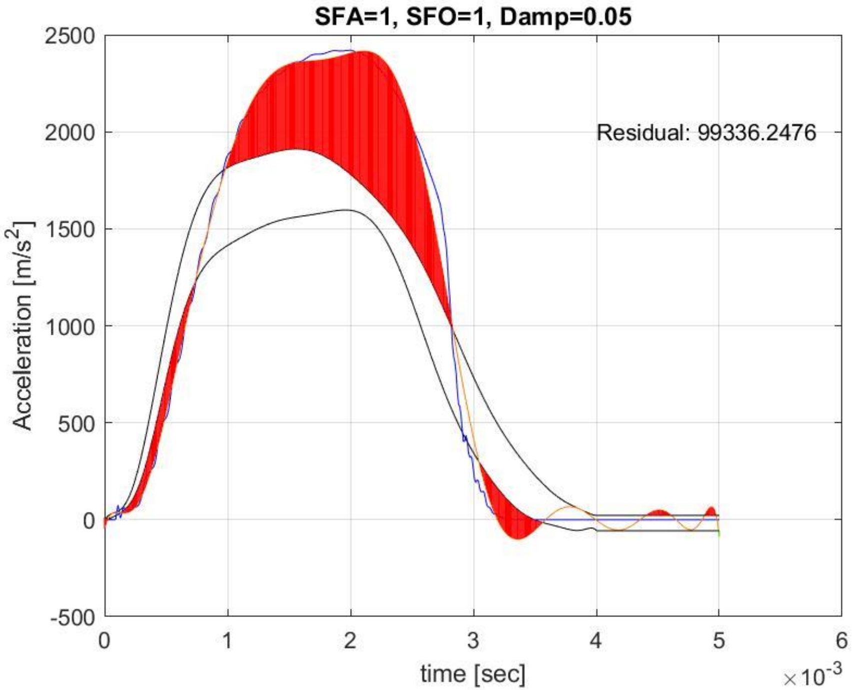
Assessing Data with Corridor

- Difference Between Corridor Bounds and Compared Simulated Acceleration Data
- Polynomial Fit → Linear Spacing
  - 100 points within 1 ms
- Weighting/Scaling Option

Performance Metric: Lowest Residual

Strengths: Linearly Spaced, Intuitive, Weighting

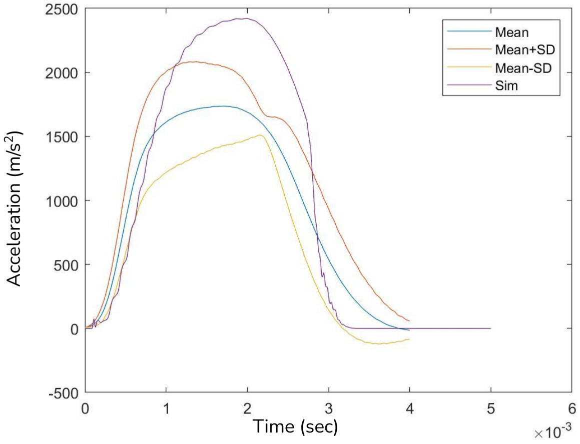
Weaknesses: Bad fits, Meaning of Residual



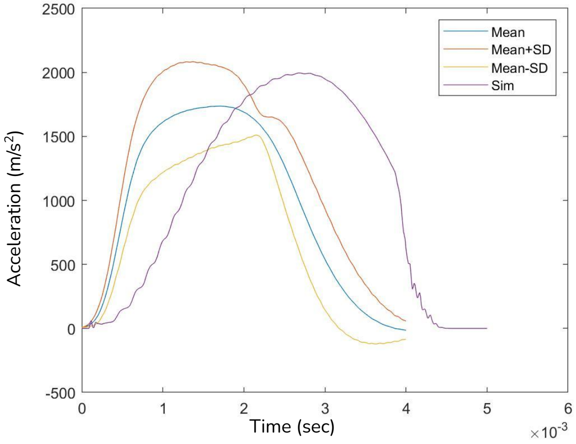
Simulated Acceleration

- SFA, SFO, and Damping were Adjusted to Fit the Simulated Acceleration within the Acceleration Corridor
    - SFA Scales the Loading Curve in the x-Direction
    - SFO Scales the loading Curve in the y-Direction
    - Damping is Characteristic of Material Stiffness and Ability to Absorb Energy.

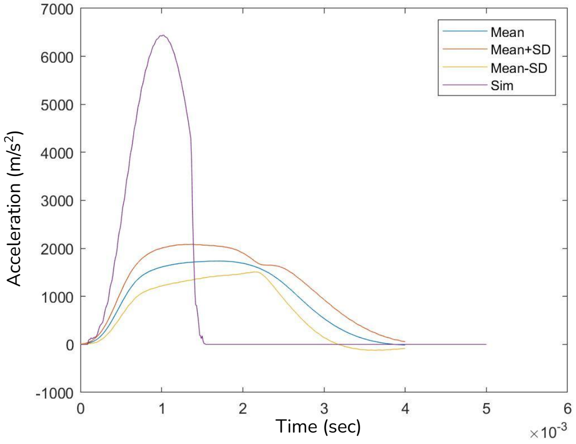
SFA = 1; SFO = 1; Damp = 0.05



SFA = 2; SFO = 1; Damp = 0.05



SFA = 1; SFO = 5; Damp = 0.05



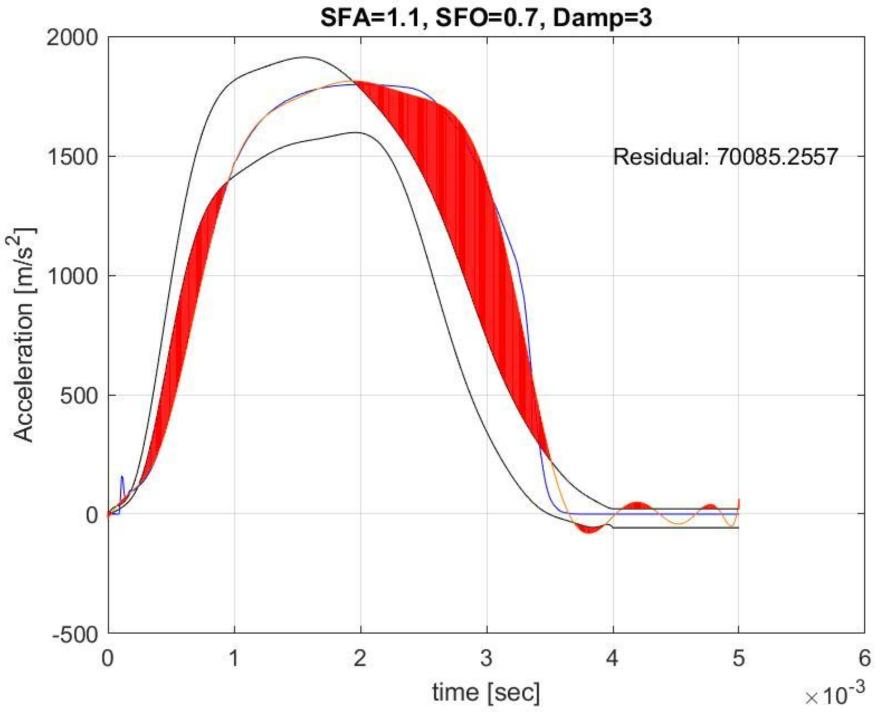
Comparison between Simulated Acceleration and Acceleration Corridor

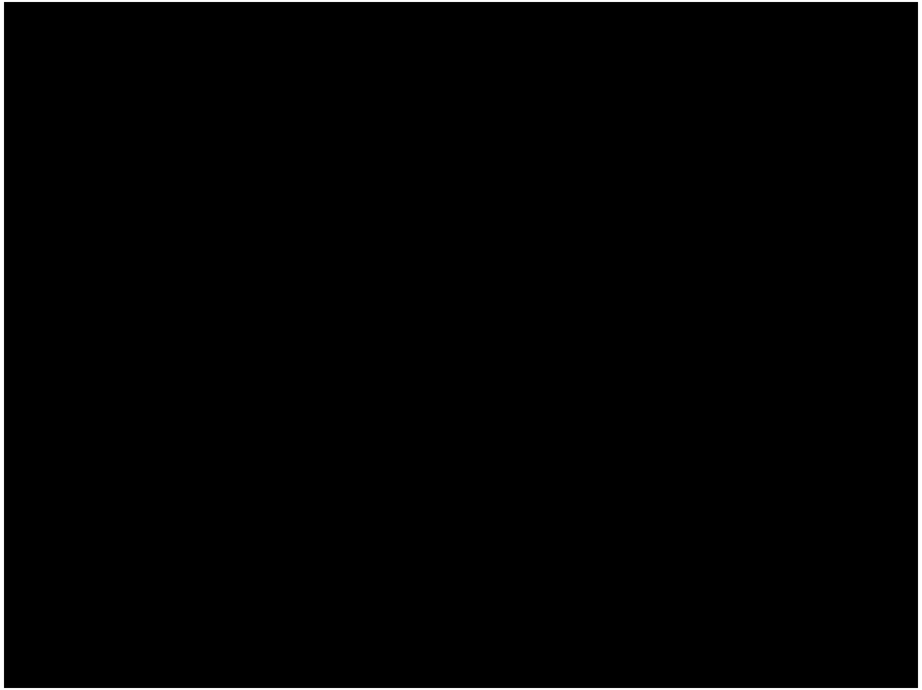
Table 1: Residuals between acceleration corridor and simulation acceleration

SFA	SFO	Damping	Residual
1	1	0.05	99336.2476
2	1	0.05	270081.7472
1.5	1	0.5	161634.7629
0.5	1	2	219408.7736
1.2	0.75	3	92639.6908
1.1	0.7	3	70085.2557

Best Simulation

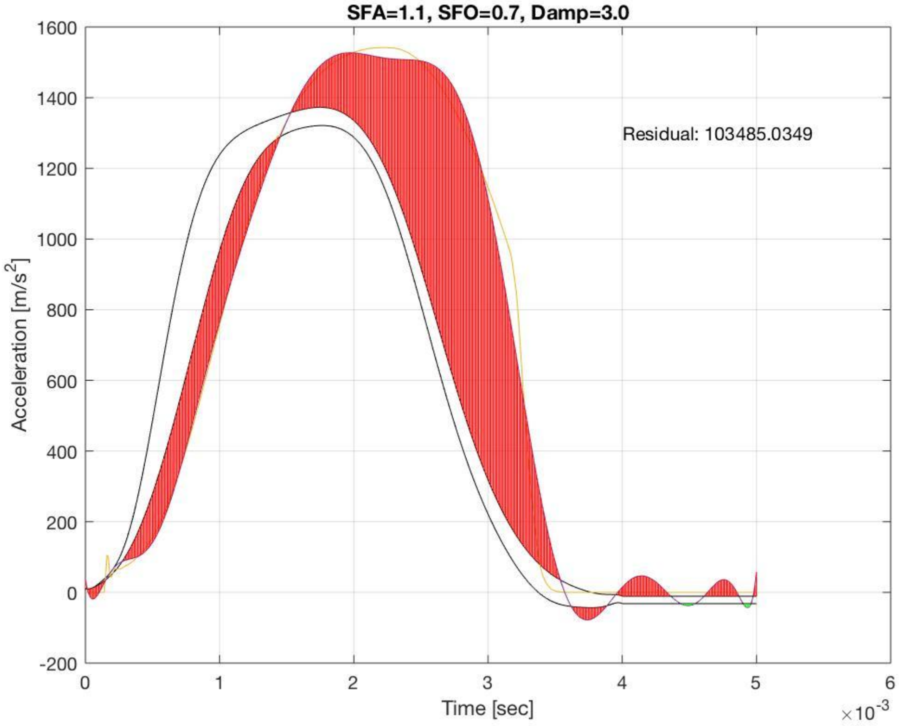
SFA = 1.1; SFO = 0.70; Damp = 3



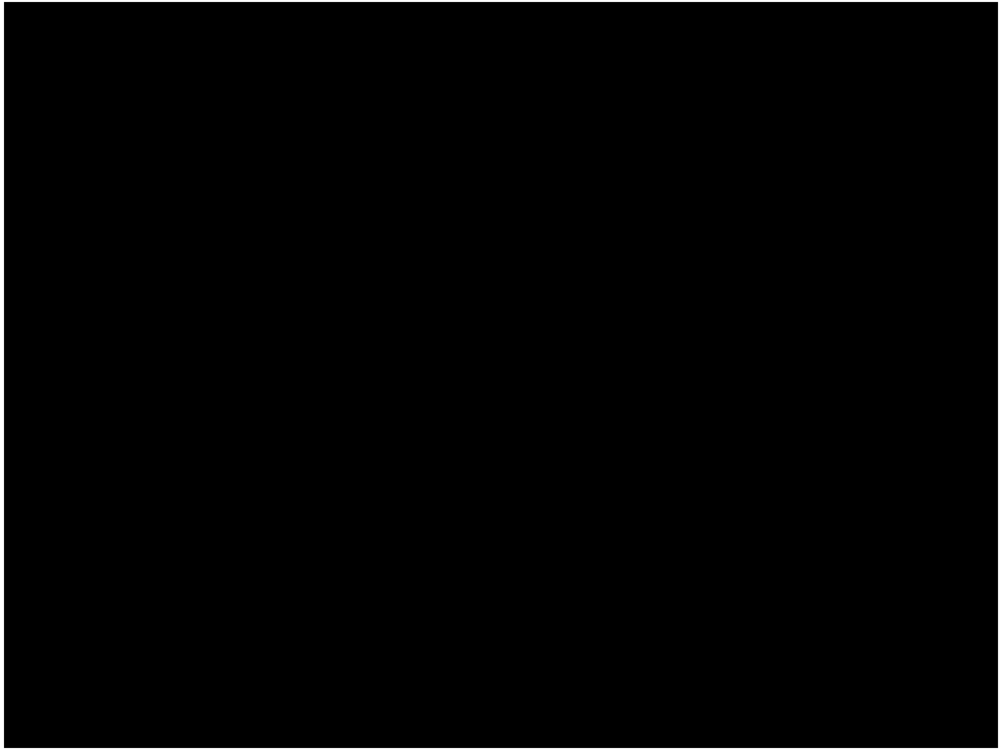


Model Verification

- Used Previously Described Methods, but Compared to the 2 m/s Data Instead of 3 m/s
- Larger Residual Values than the 3 m/s Impact
    - Smaller Standard Deviations
    - Still Lower than Majority of Iterations when Exploring SFA, SFO, and Damping
- Predictive Ability



Model Verification Simulation



Lowering HIC Purpose

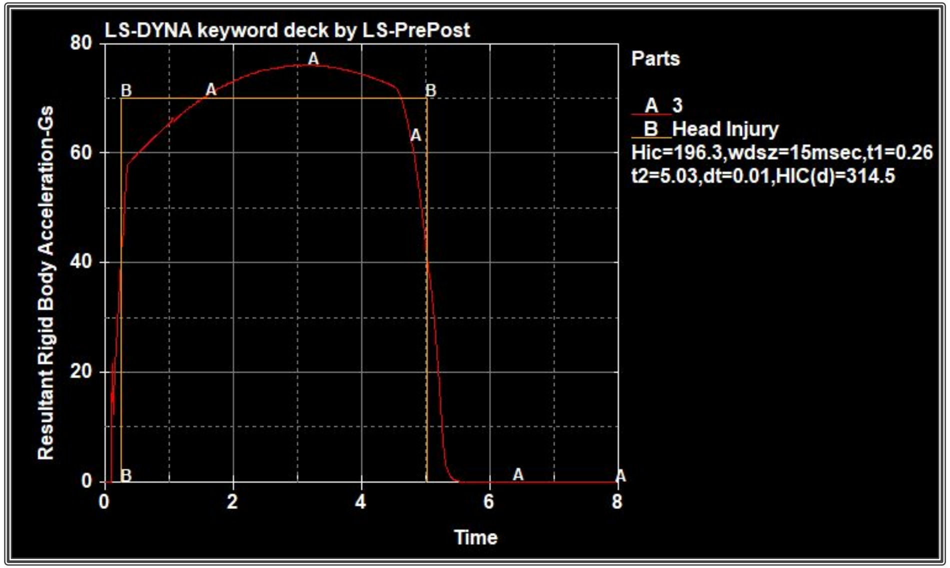
- Paramount Focus is to Maximize Protection of the Brain and Skull

- Helmets Aim to Reduce HIC
    - Acceleration Attenuation
    - Energy Absorption
    - Load Distribution

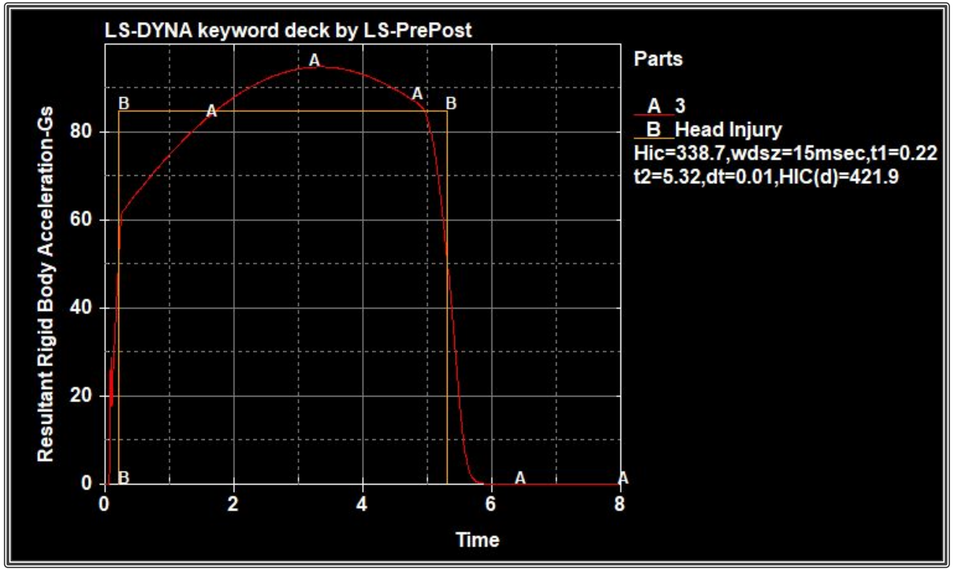
$$HIC = \left[\frac{\int_{t_1}^{t_2} a\,dt}{t_2 - t_1} \right]^{2.5} (t_2 - t_1)$$

Equation 1 - Head Injury Criterion (HIC)

Final Impact 3 m/s   HIC = 196.3



Final Impact 4 m/s



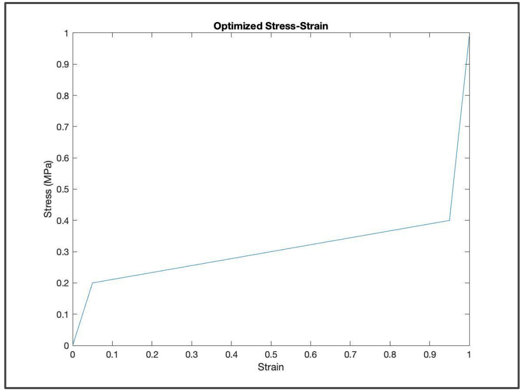
Optimized Loading Stress-Strain

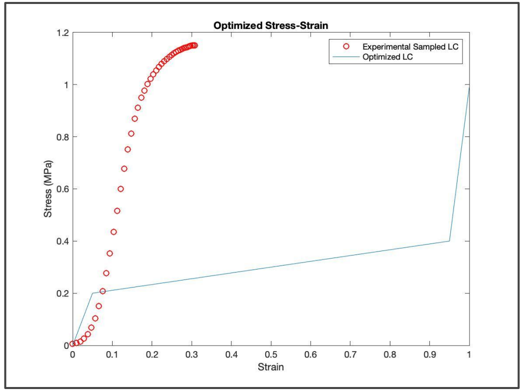
- 3 Primary Regions
  - 1. Initial Stiffness Facilitates Energy Dissipation
  - 2. Low Stiffness Reduces HIC
  - 3. High Stiffness Prevents Entirely Crushing Foam

- Strain [0.0, 0.05, 0.95, 1.0]
  Stress [0.0, 0.2, 0.4, 0.99]

- Decreased Stiffness -> Lower Acceleration -> Lower HIC

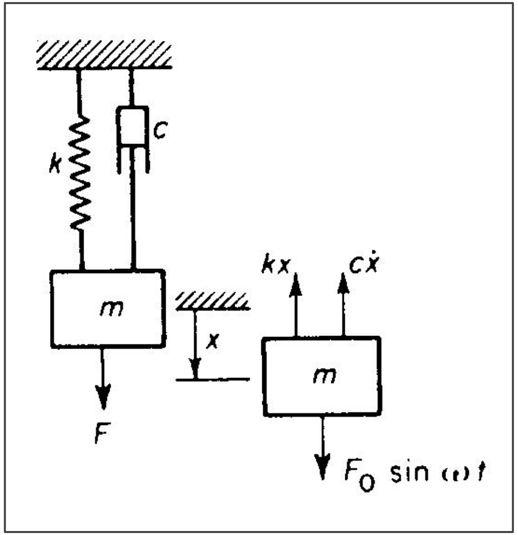
- SFA & SFO make Scaling Adjustments to the Load Curve
  - SFA & SFO = 1.0





Damping

- Consider Foam Represented by Spring and Dashpot -> Damping Dissipates Energy
- Final damp = 3.0
- Damping Facilitates Energy Dissipation
    - Dependent on Velocity of Impactor
    - Results in Less Rebound Force on Impactor



Takeaways

- Decreased Stiffness and Greater Damping Lower HIC
  - Both Constrained by Foam Thickness
  - Ideal Helmet Foam would Maximize Thickness to Support less Stiff Foams

- Inability to Specify Unloading Curve Required Load Curve Adjustments to Replicate Data

- Adjusting SFA & SFO Scaled the Stress-Strain Curve and Altered Material Factors such as Stiffness

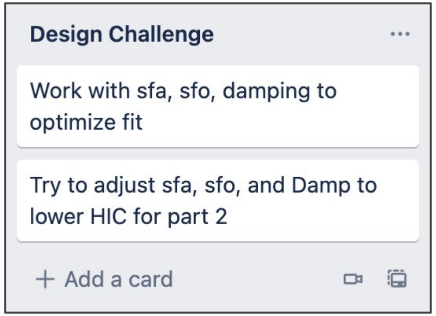
Review of Slack & Trello Implementation

Slack

- Clear Communication about Teammate Availability and Progress
- Method for Rapid File Sharing
- Room to Improve use of Threads to Organize Discussions
- Successful use of Reacts

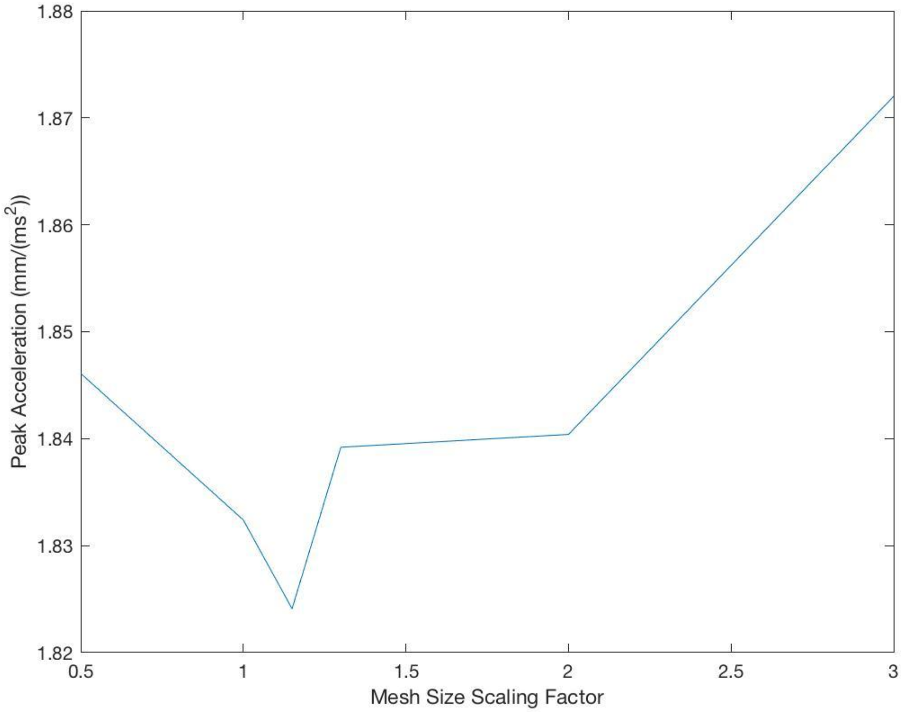
Trello

- Clear Initial Objectives Listed & Removed upon Completion
- Room to Expand use by specifying Team Member Name within each Card



Convergence Study

- Used several scaling factors to observe the impact of changing element size
    - **Larger scaling factors mean increased element size (less refined mesh)**
- As scale factor **increased**, peak acceleration also **increased**
    - Difference of 0.04 mm/(ms^2) between smallest and largest scale factor (sf = 1 and 3)
- Interesting drop around a scale factor of 1.15, but appears to be consistent around 1.84 mm/(ms^2) between a scale factor of 0.5 and 2



Convergence Study

- Saw significant changes in simulation run times when modifying scaling factor
- As the scale factor **increased**, the run time **decreased**
  - Lower element density
  - Much larger differences in run time as the mesh becomes more refined