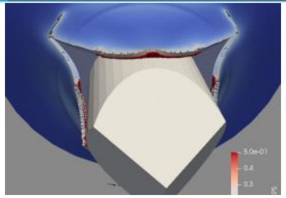
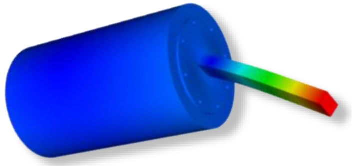
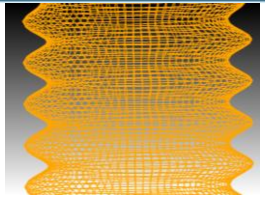
Quantitative Analysis of Pulse-Shape Modeling for Shock Tests

N-O-MAD Research Institute



THE UNIVERSITY OF NEW MEXICO

Prepared by: Abigail Smith, Zachary Boeringa, Adam Krzywosz

Mentors: Nancy Winfree, David Soine, Tyler Alvis, Adam Slavin

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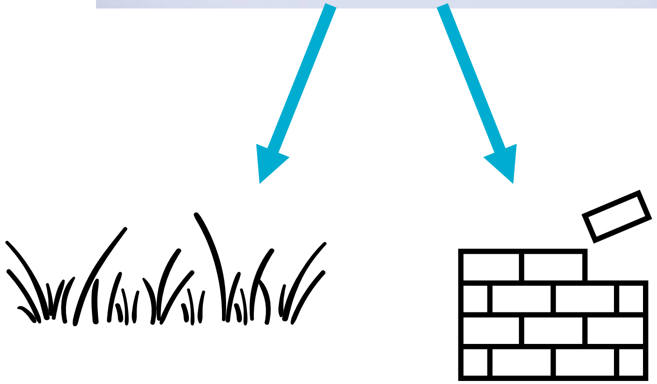
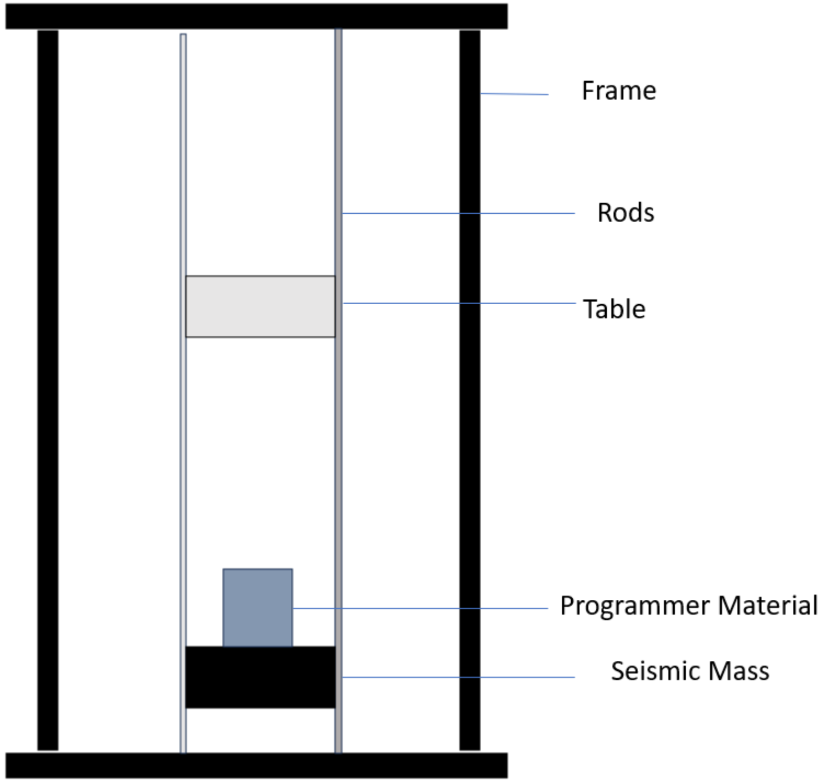
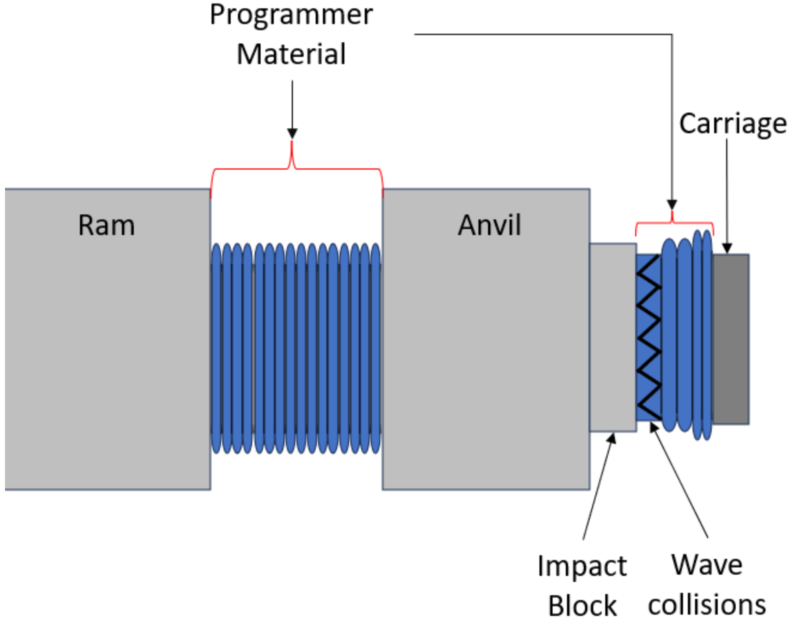
SAND2024-10184PE

Introduction: Mechanical Shock Testing

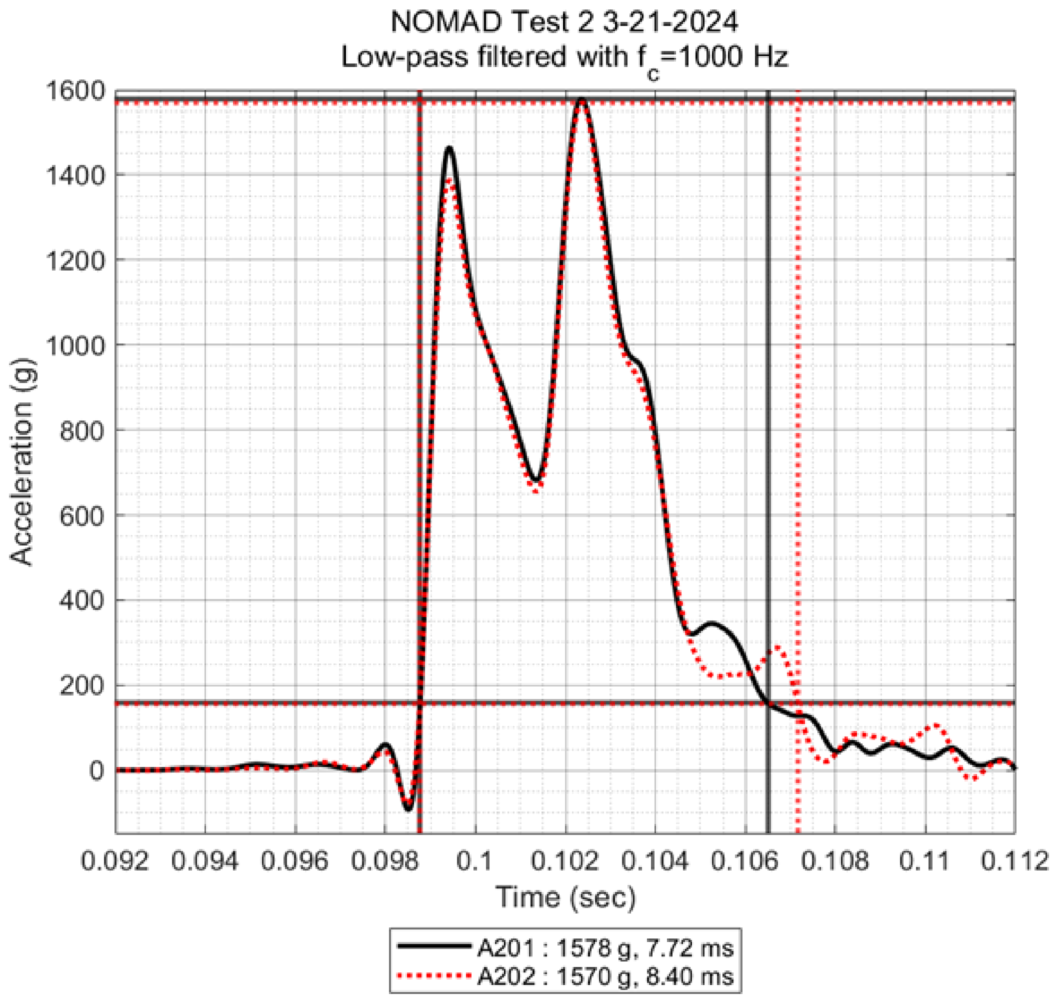
[1]

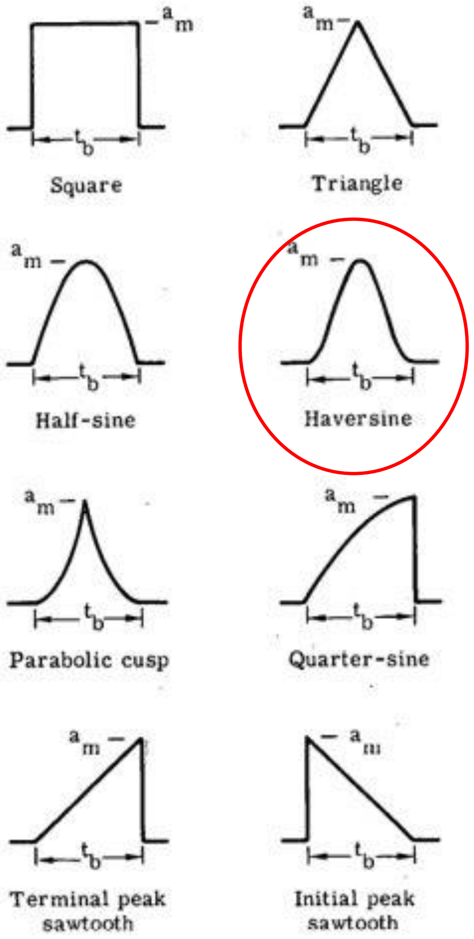




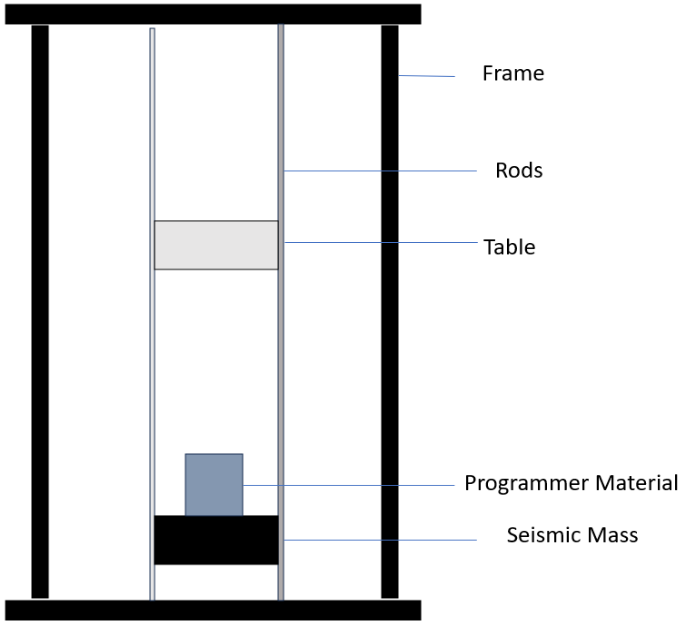


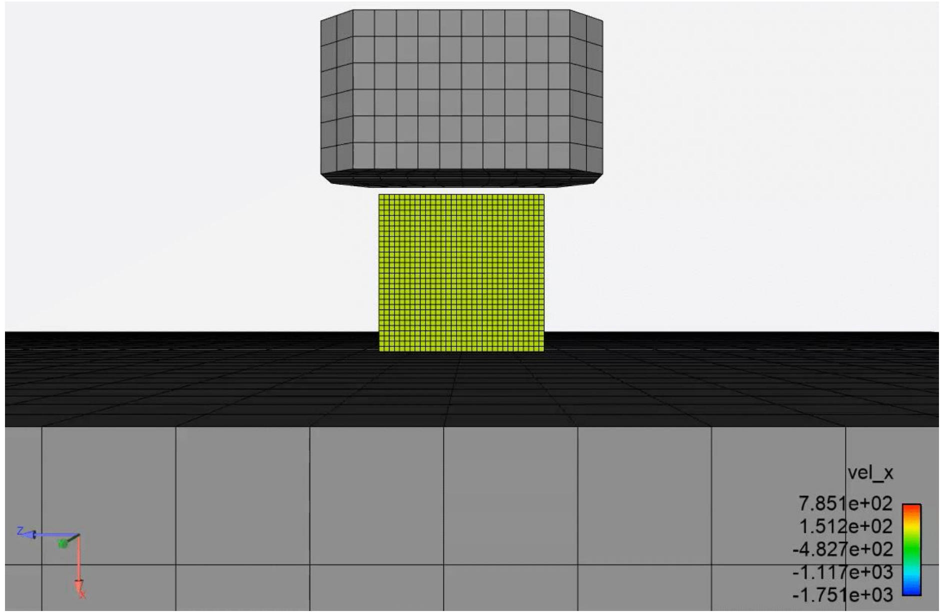
Introduction: Pulse Shapes

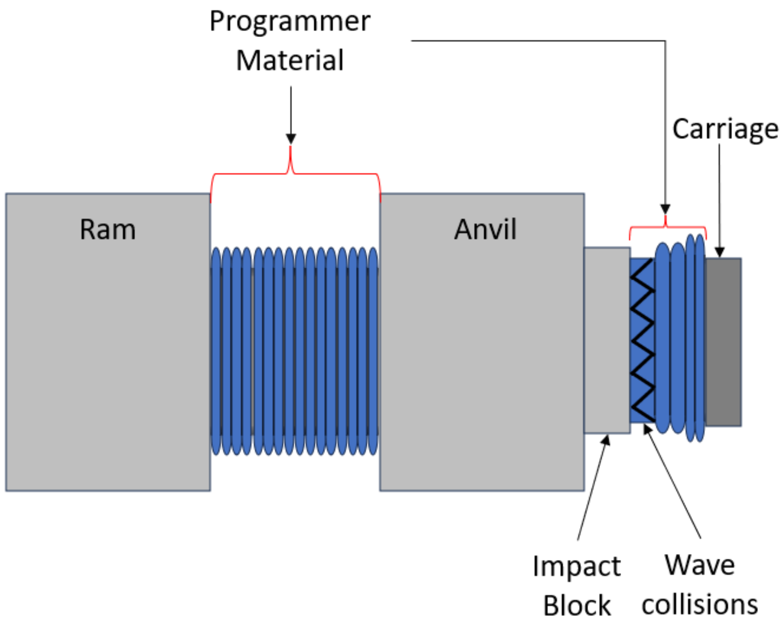


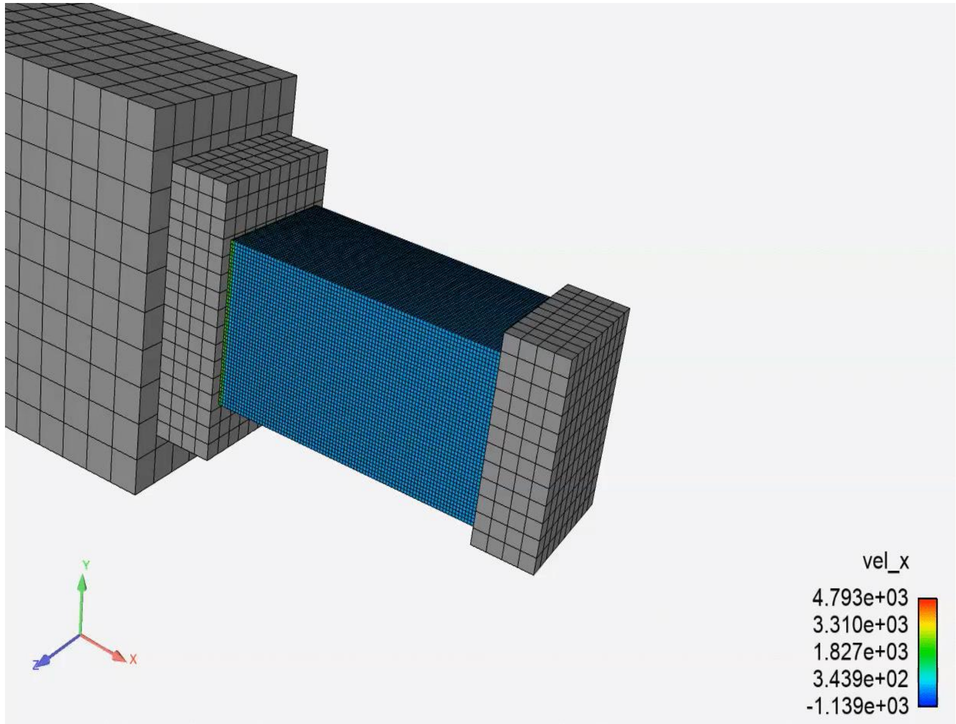


Common Pulse Shapes [2]


Frame
Rods
Table
Programmer Material
Seismic Mass


vel_x
7.851e+02
1.512e+02
-4.827e+02
-1.117e+03
-1.751e+03


Programmer Material
Carriage
Ram
Anvil
Impact Block
Wave collisions


vel_x
4.793e+03
3.310e+03
1.827e+03
3.439e+02
-1.139e+03
Y
Z
X

Introduction: Programmer Material Properties

- Programmer materials - shape the pulse of a wave, via
  - Increasing Duration
  - Decreasing Peak Acceleration

- F-1 and F-3 material deck was based on prior Hopkinson bar test data [6]
  - Linear Piecewise elastic model

Felt Grade	Tensile Strength [psi]	Density [lb/sq. yd]
F-1	500	16
F-3	400	16
F-5	400	12.24
F-11	200	8.48

[5]

F-5 Wool Felt [3]

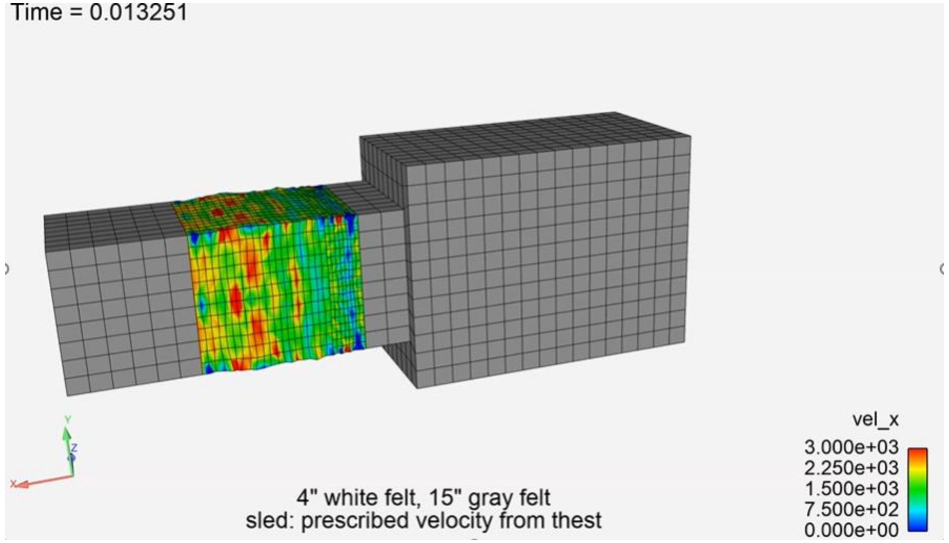
F-3 Wool Felt [4]

Prior ¼ Model Simulation

- Input velocity was applied to the anvil

- Velocity damping was applied to the felt
  - Less destruction of felt at high impact velocities
  - Large effect on wave pulse

- Order of mixed felt (F-1 and F-3)
  - With F1 in the back, and F-3 in the front, similar result from prescribed test velocity
  - When F1 was in front of the F3
    - Aberrations in the model during compression

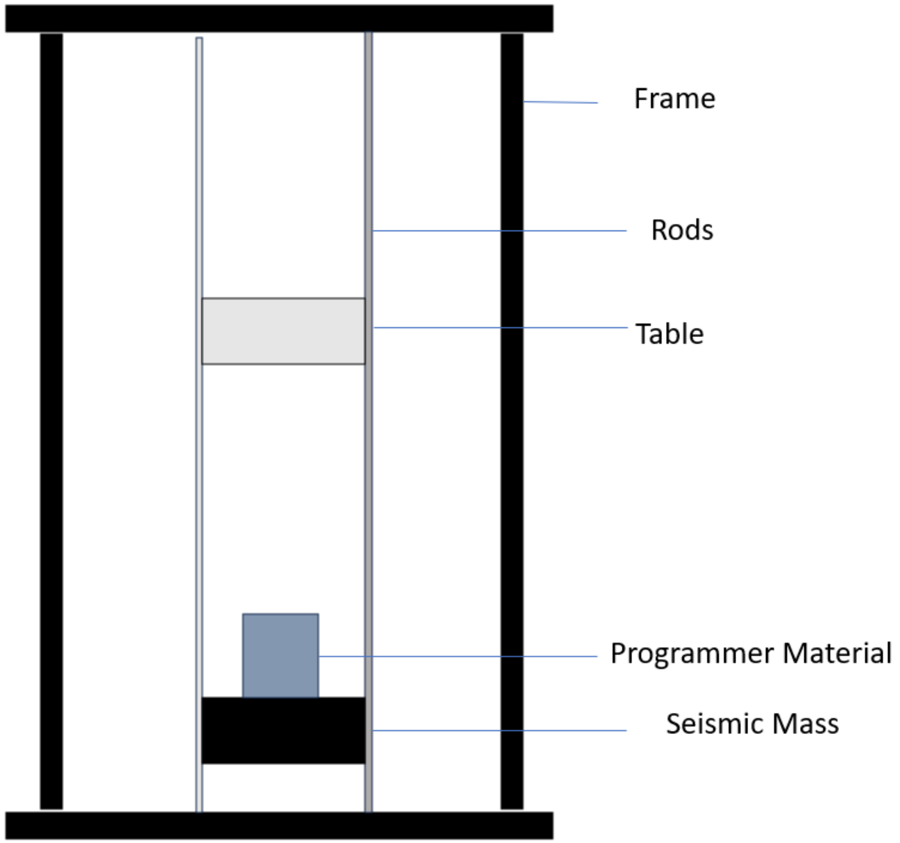


Inherited Simulation [7]

Method – Low G Acceleration Drop Shock Setup

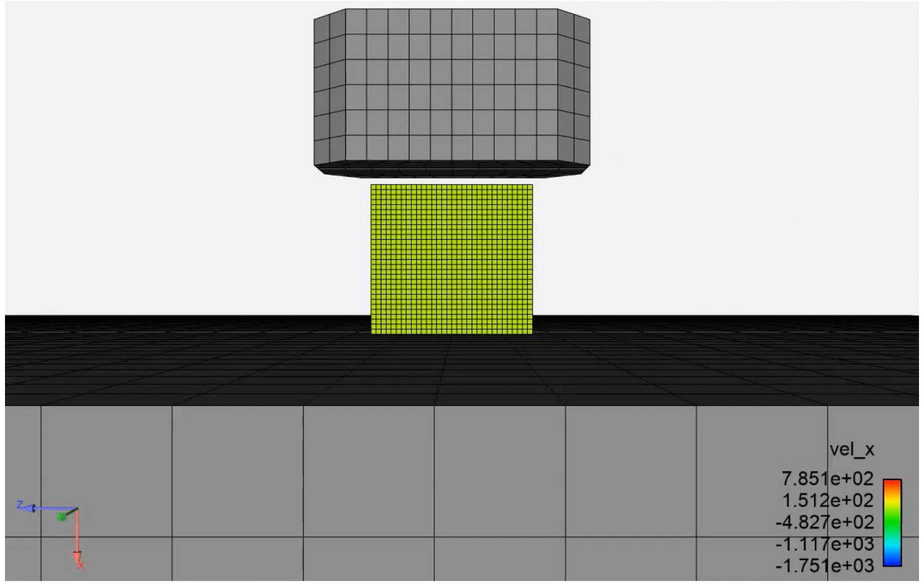
- Drop Shock Testing
  - Table drop height: 184 [in]
  - Impact Velocity Goal: 62 [ft/s]
  - Max output from tests: 1457 G

- Factors
  - Stack Height
  - Surface Area
  - Programmer Material



Method-Drop Shock Parametric Studies

- Experimental Tests
  - Four Felt Materials
  - Two Stack Heights (3" and 6")
  - Three Cross-Sectional Areas
  - Four Densities
- Simulation Tests
  - Two Felt Materials
  - Two Stack Heights (3" and 6")
  - Three Cross-Sectional Areas



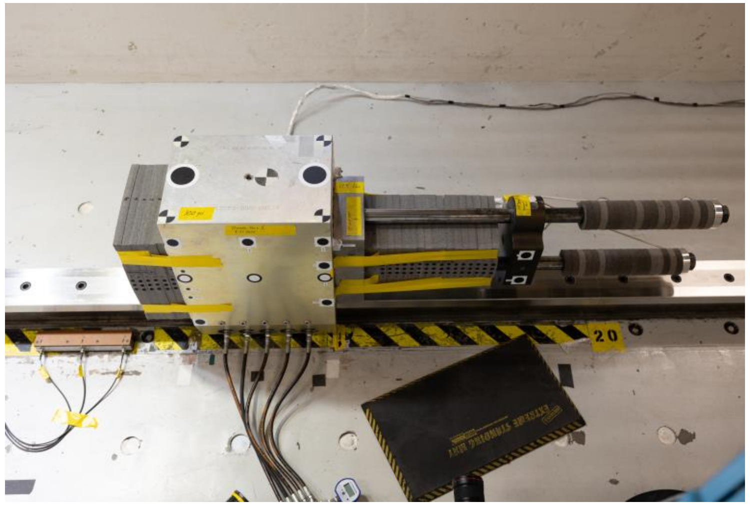
Exp.	Sim.	Material	Height of Stack [in]	Cross-Sectional Area [in^2]
✓	✓	F-3	3	39
				29.25
				20.25
			6	39
				29.25
				20.25
✓	✓	F-1	6	39
				29.25
				20.25
✓	✗	F-5	6	39
				29.25
				20.25
✓	✗	F-11	6	39
				29.25
				20.25

Method – High G Acceleration Cascading Impact Setup

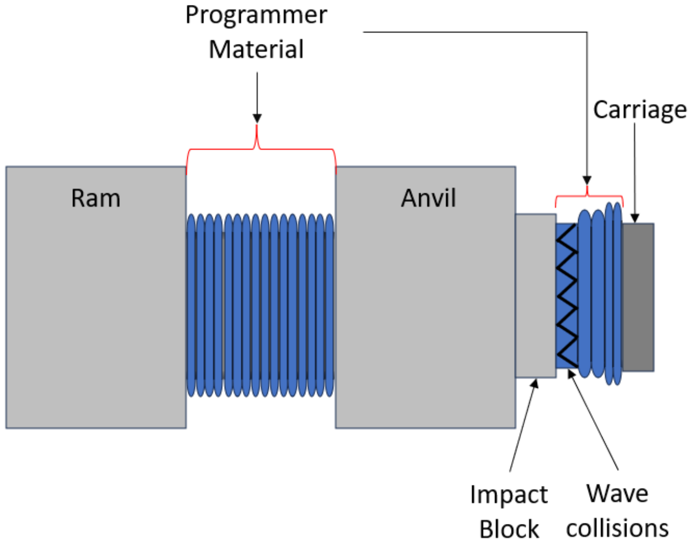
- Cascading Impact Test
  - Carriage velocity goal: 196 [ft/s]
  - Max Acceleration: 2200 [G]

- Validation shot compared to Test 1
  - Stack Height: 18 [in]
  - Anvil Velocity Change: 157 [ft/s]

- Parameters Investigated:
  - Programmer material
  - Carriage weight
  - Stack height
  - Cross-sectional area



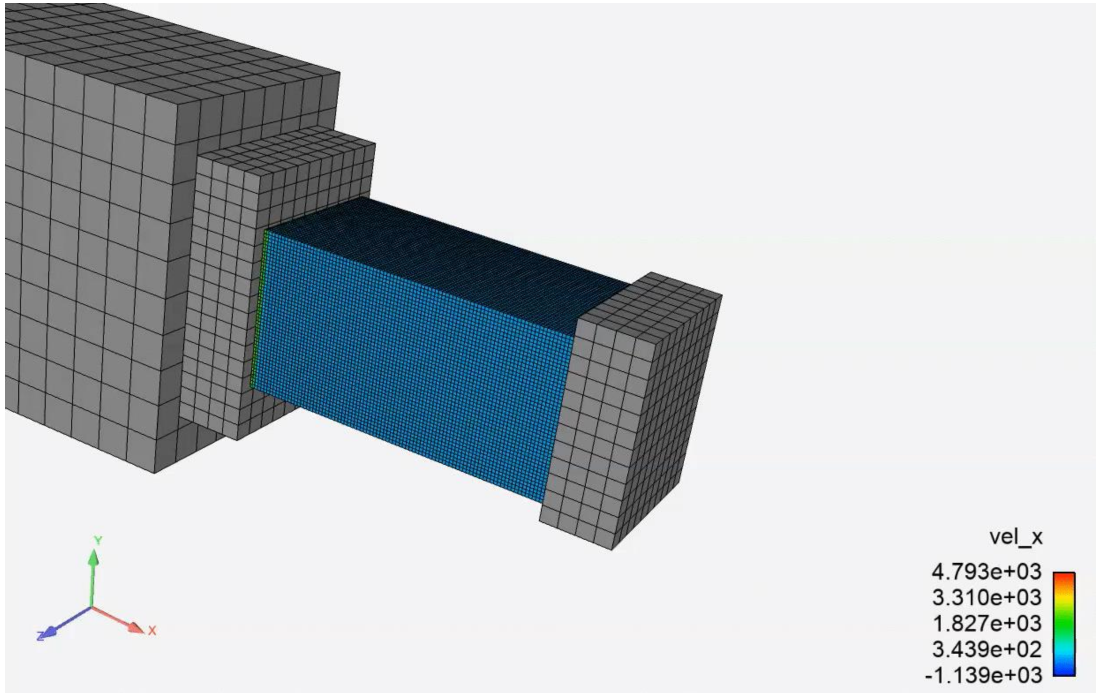
Test setup of Anvil - Carriage



3-Body Impact of Ram-Anvil-Carriage setup

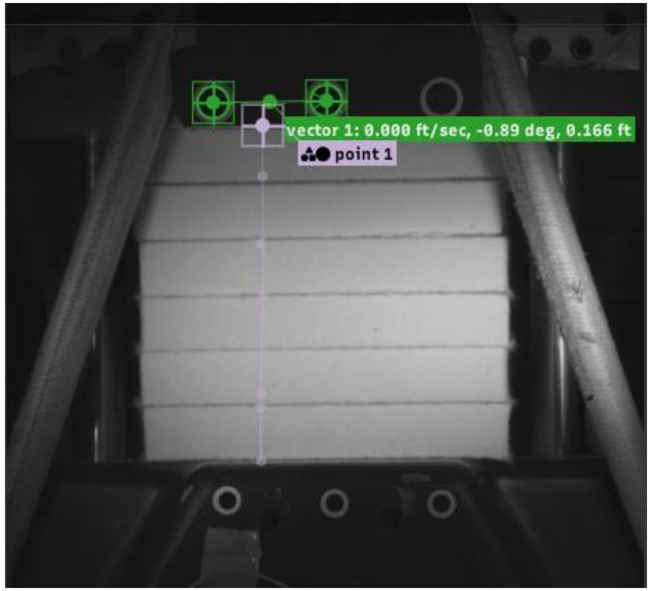
Method-Physical Test Cases

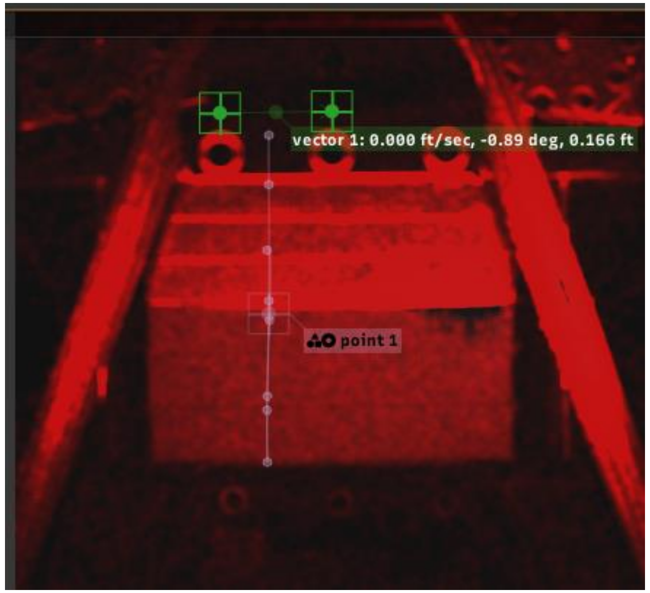
Test #	Stack Height [in] (F-3 felt)	Cross-Sectional Area [in^2]
1	18	81
2	24	76.5
3	3.5	81
4	24	2 of 81 22 of 40.5
5	24	2 of 81 22 of 40.5



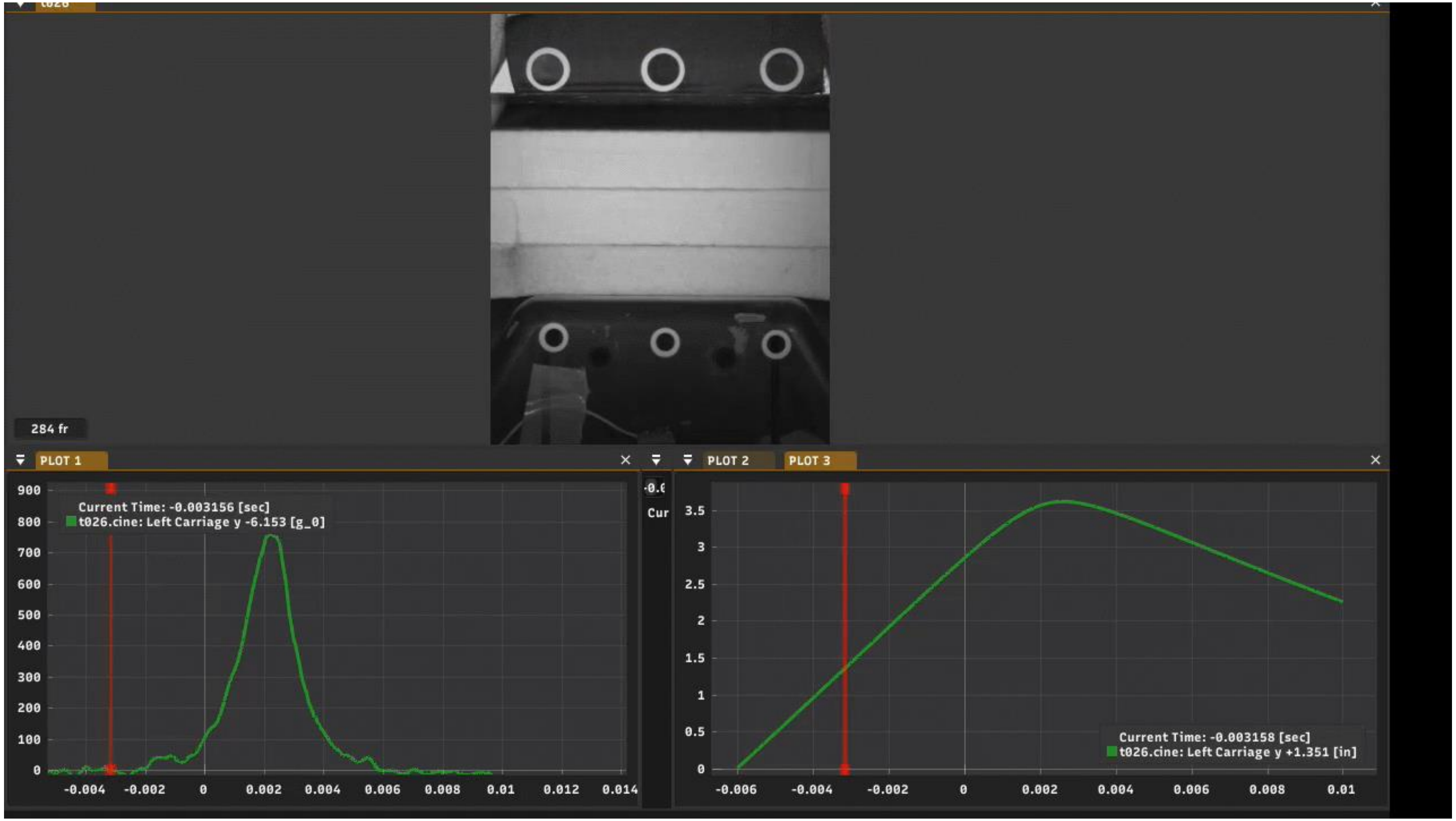
Method– Photometrics

- Internal photometric software
- Tracking Ability
  - Acceleration
  - Velocity
  - Displacement
- Filtering and Windows
  - Butterworth
  - Savitzky-Golay
  - Rolling Average
- Background Oriented Schlieren
  - Allows for tracking of wave through the programmer material





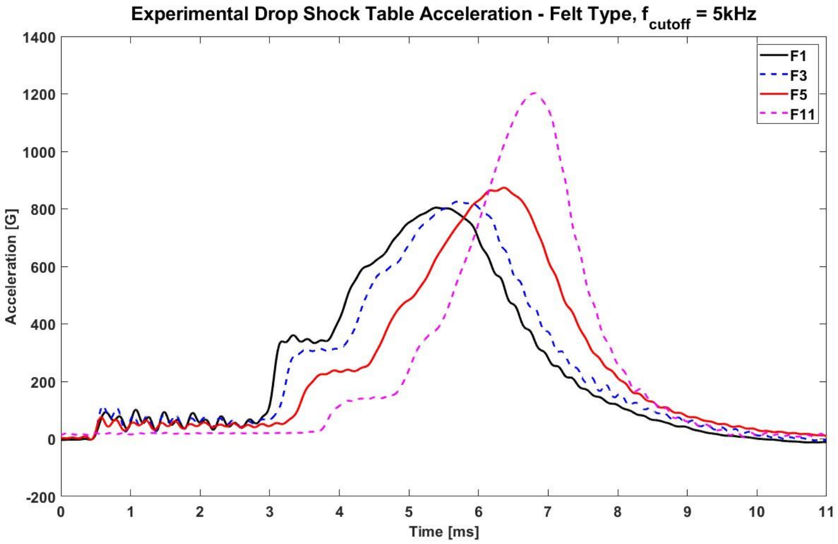
Results – Drop Shock Photometric Response

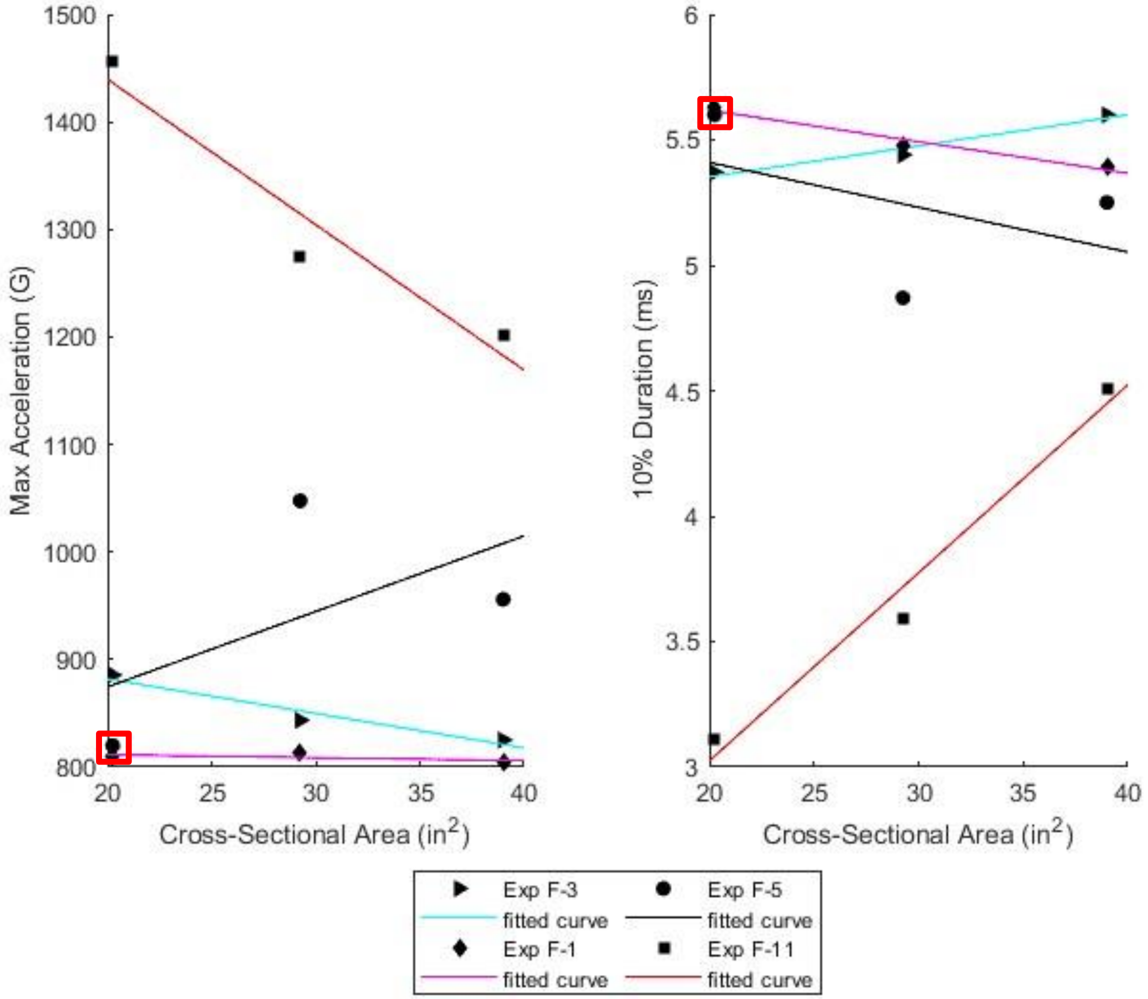


Drop Shock Pulse Properties: Programmer Materials

Key Points:

- Cross-Sectional Area: Increases
  - Max Acceleration: Decreases
  - Duration: Increases (F-1 Decreases)
- Density: Increases
  - Max Acceleration: Decreases
  - Duration: Increases
- Exception: F-5 has an outlier



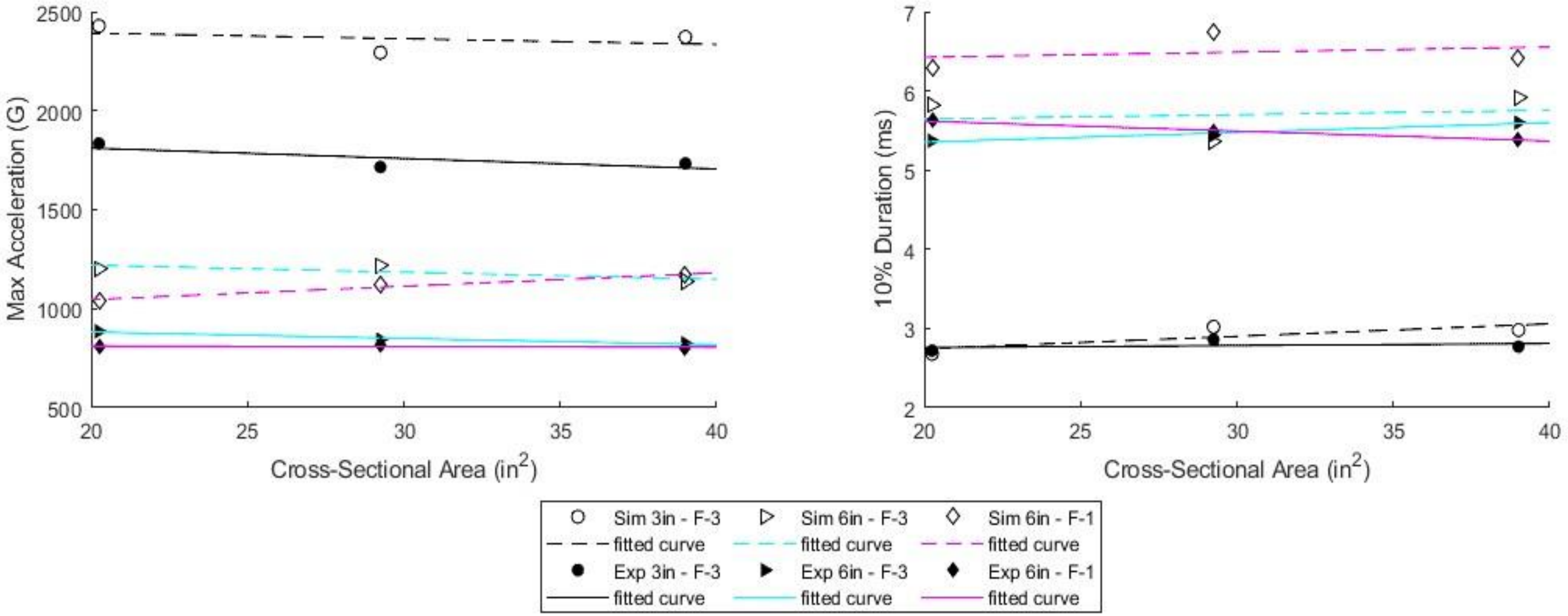


Drop Shock : Felt Stack Height & Cross-Sectional Area

Key Points:

- Stack Height: Increases
  - Acceleration: Decreases
  - Duration: Increases
- Simulation overpredicts experiment
- Little difference between F-1 and F-3

Similar linear relationship seen in experimental and simulation.



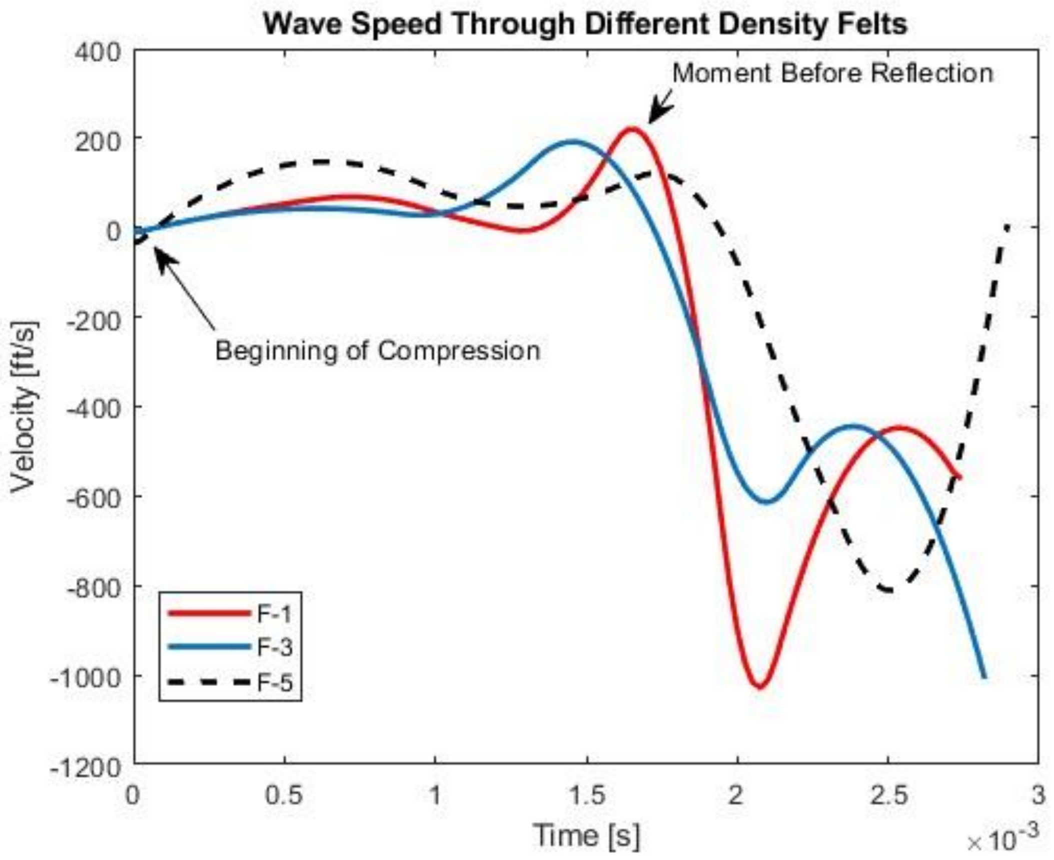
Photometrics Experimental Drop Shock

Wave Speed Before Reflection:

- F-1 = 219.7 ft/s
- F-3 = 191.6 ft/s
- F-5 = 121.1 ft/s

Key Point:

- Denser felt = higher speed at the first impact.

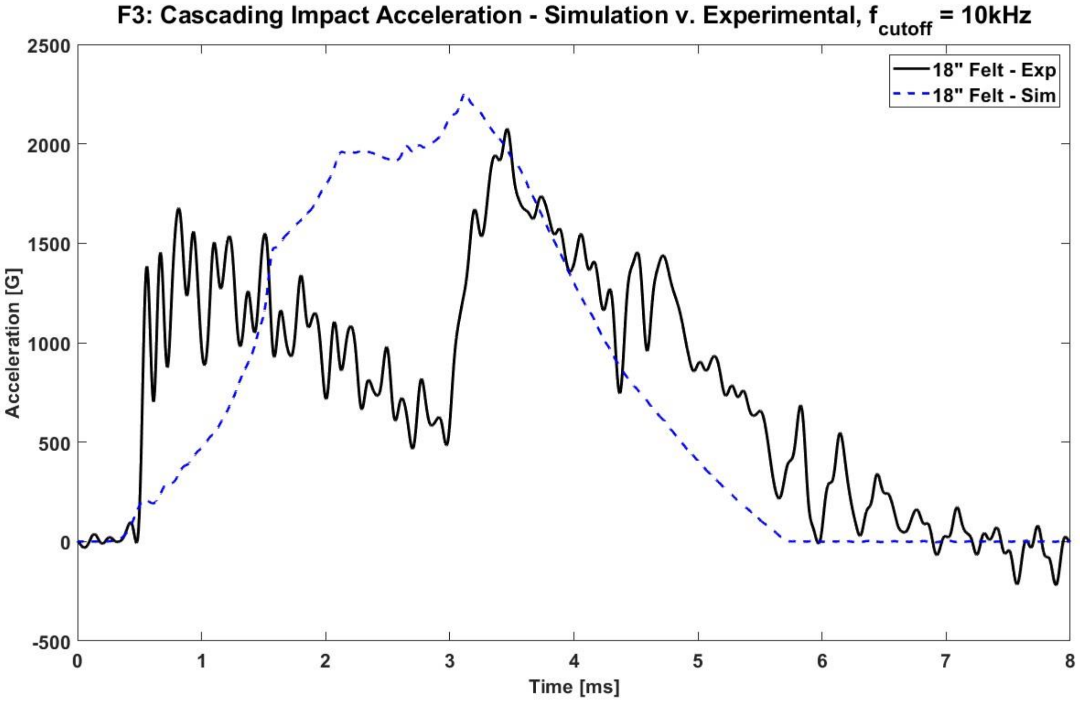


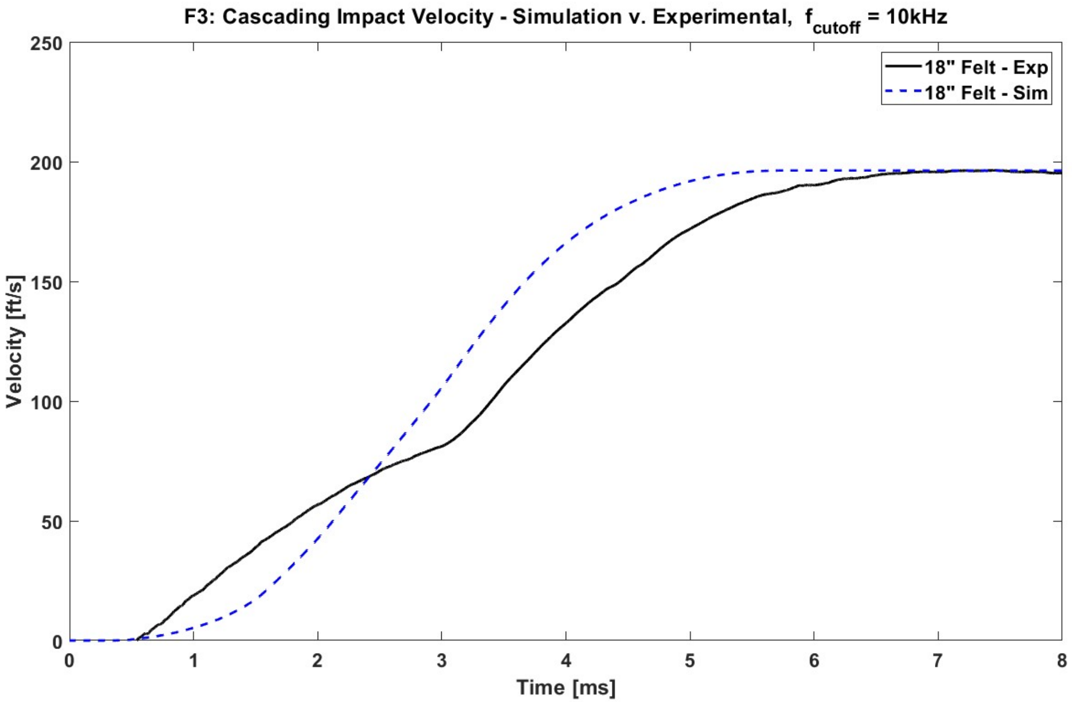
Results– Cascading Apparatus

Cascading Apparatus – Simulation v. Experimental

Key Points:

- Similar area under the acceleration curve is demonstrated by the velocity curve.
- Demonstrate simulation's ability to model key features of the pulse

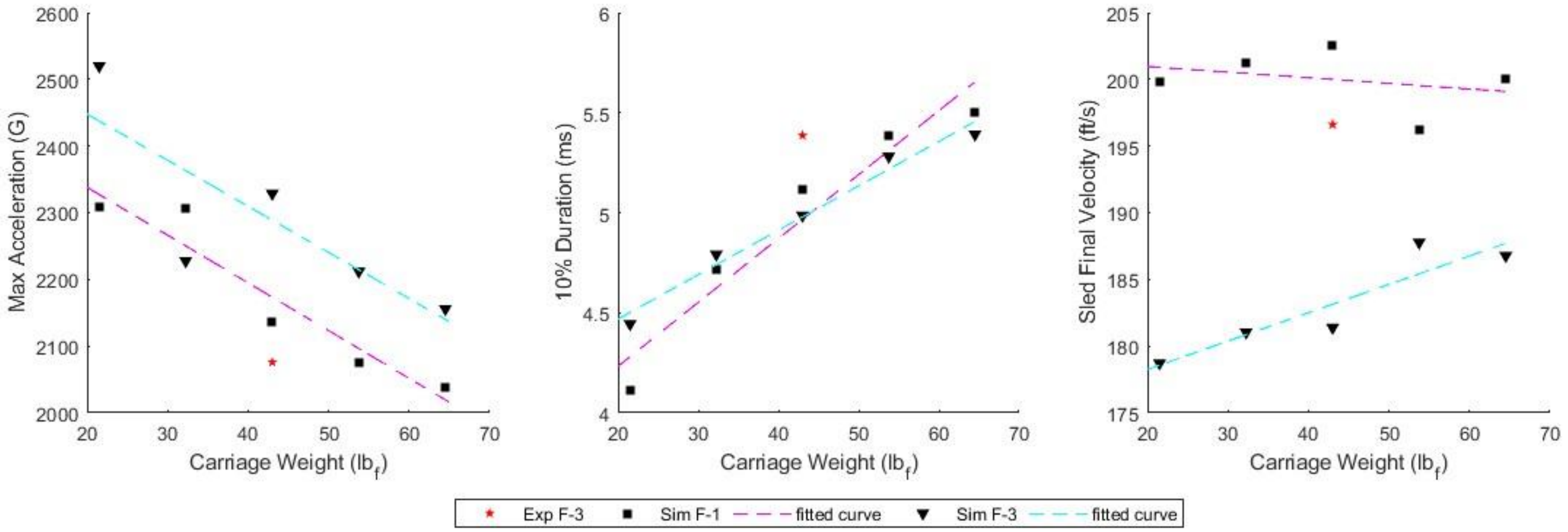




Cascading Apparatus – Carriage Weight Simulation Study

Key Points:

- Carriage Weight: Increases
  - Max Acceleration: F-1 Decreases, F-3 Decreases
  - Duration: F-1 Increase, F-3 Increase
  - Velocity: F-1Inconclusive, F-3 Inconclusive



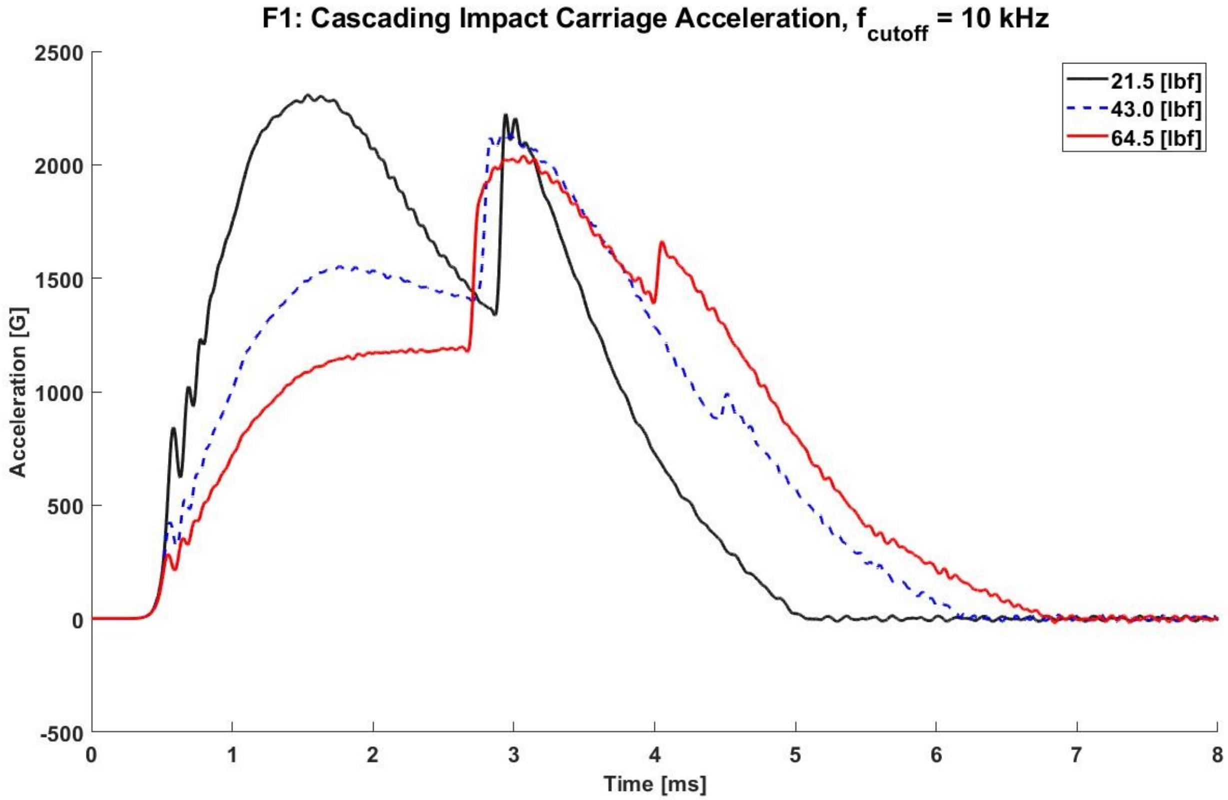
Cascading Apparatus – Pulses (Simulation)

Key Points:

Increasing carriage weight = better Haversine

Carriage Weight: Increases

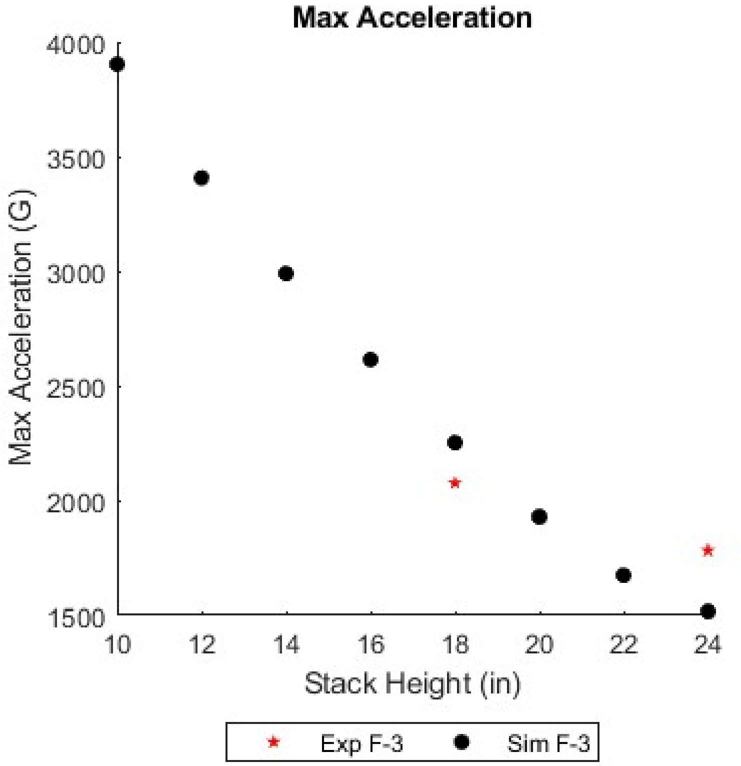
- First shelf or hump: Decreases

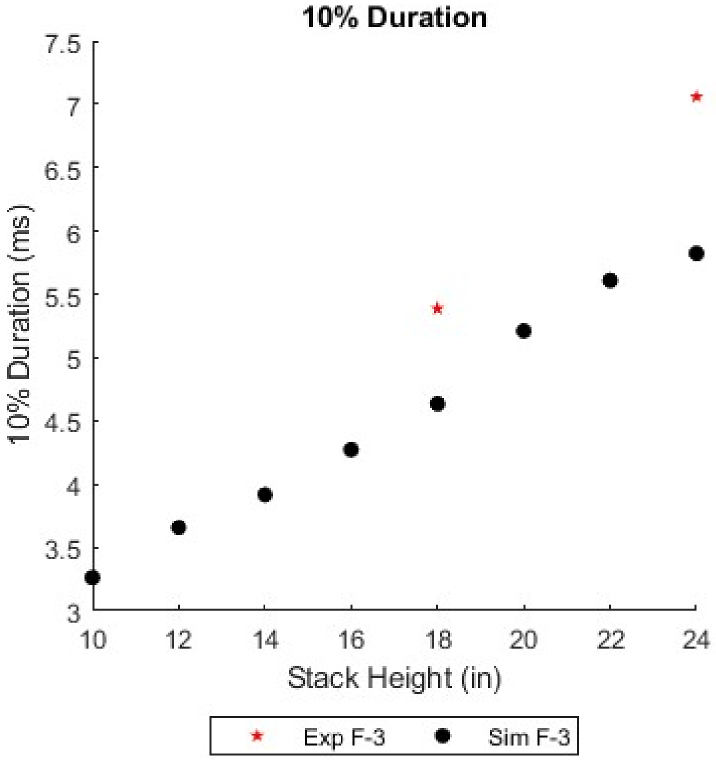


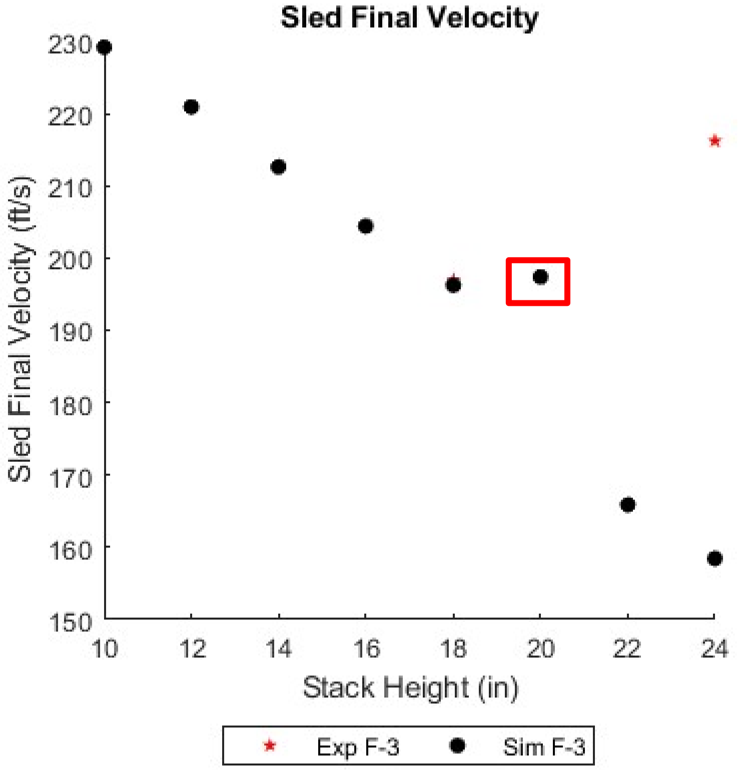
Cascading Apparatus: Stack Height Simulation Study

Key Points:

- Stack Height: Increases
  - Max Acceleration: F-3 Decreases
  - Duration: F-3 Increases
  - Velocity: F-3 Decreases





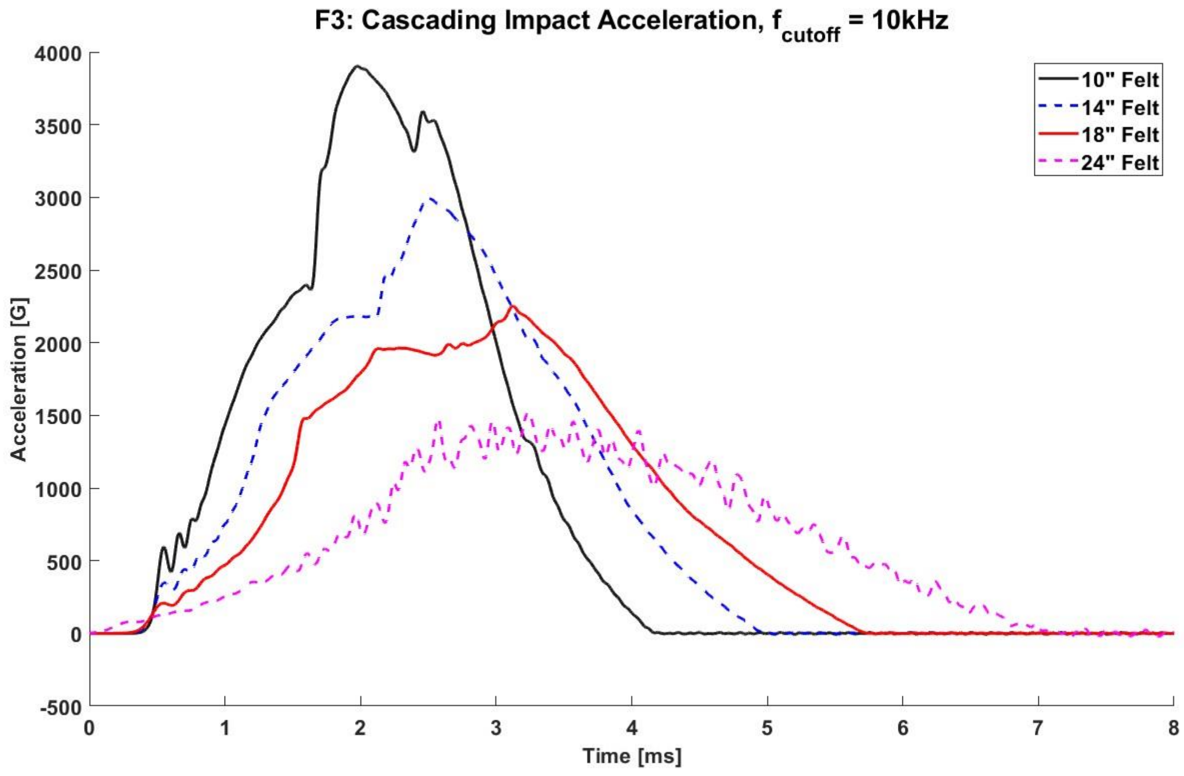


Cascading Apparatus Stack Height Simulation Study

Key Points:

- Stack Height: Increases
  - First shelf or hump: Decreases

Increasing stack height = better Haversine!

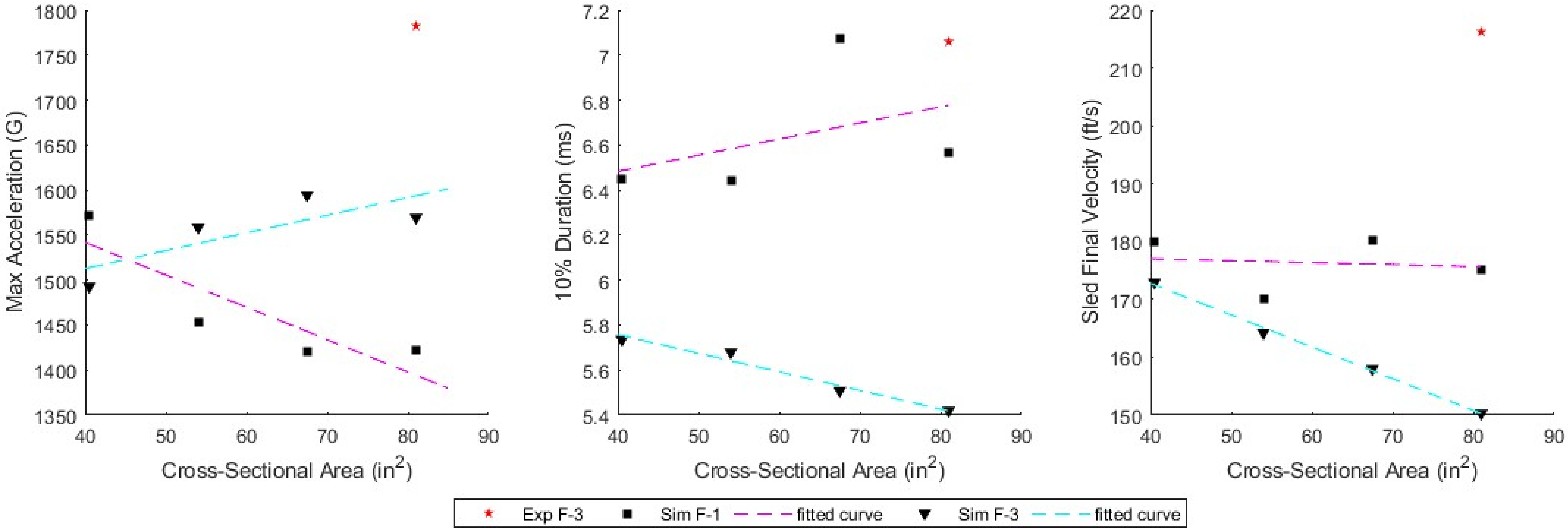


Cascading Apparatus: Cross-Sectional Area Simulation Study

More data would help us gain better insight.

Key Points:

- Cross-Sectional Area: Increases
  - Max Acceleration: F-1 Decreases, F-3 Increases
  - Duration: F-1 Inconclusive (outlier), F-3 Decreases
  - Velocity: F-1Inconclusive, F-3 Decreases

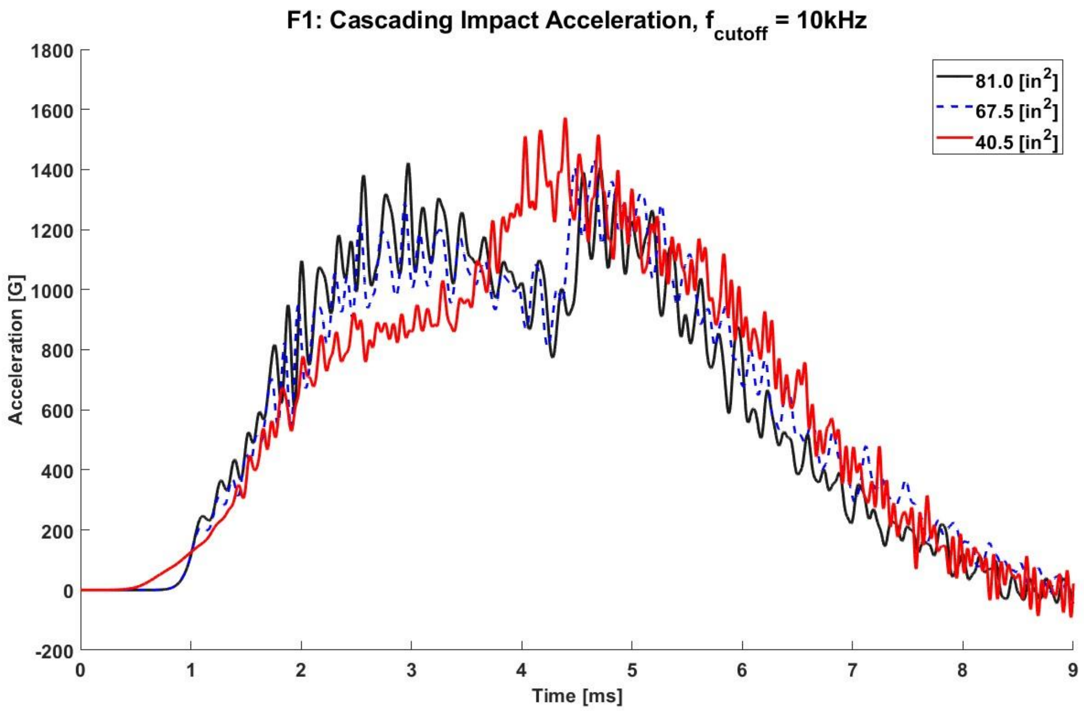


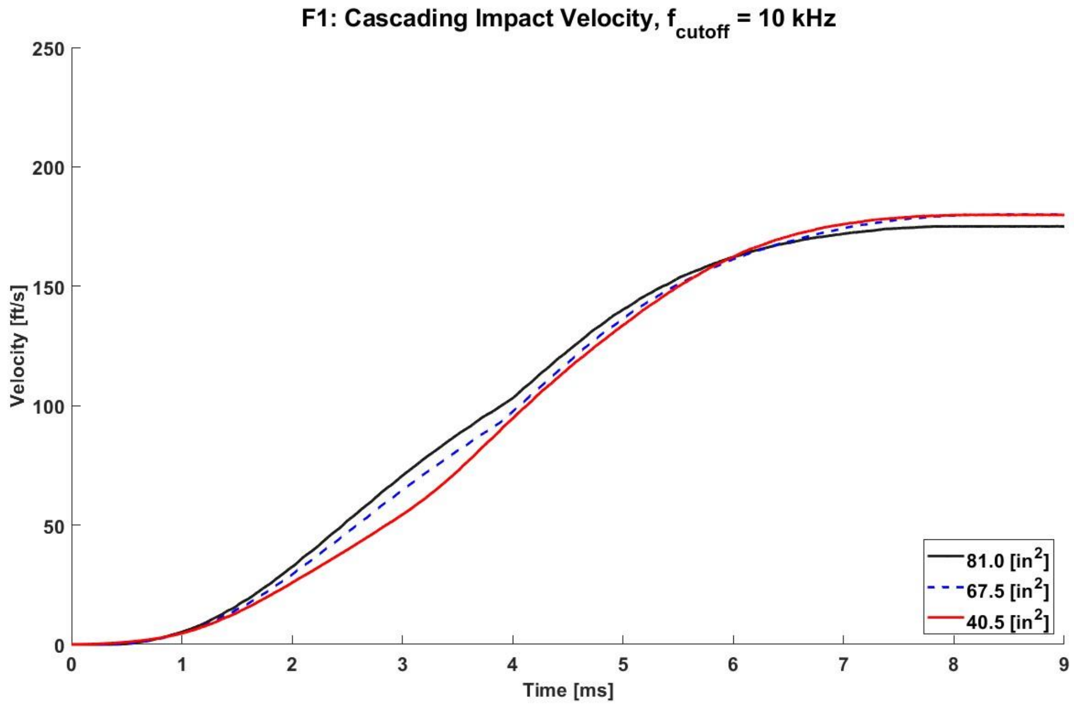
Cascading Apparatus: Cross-Sectional Area Simulation Study

Less cross-sectional area = better Haversine!

Key Points:

- Cross-Sectional Area: Decreases
- Double hump: less pronounced/Decreases



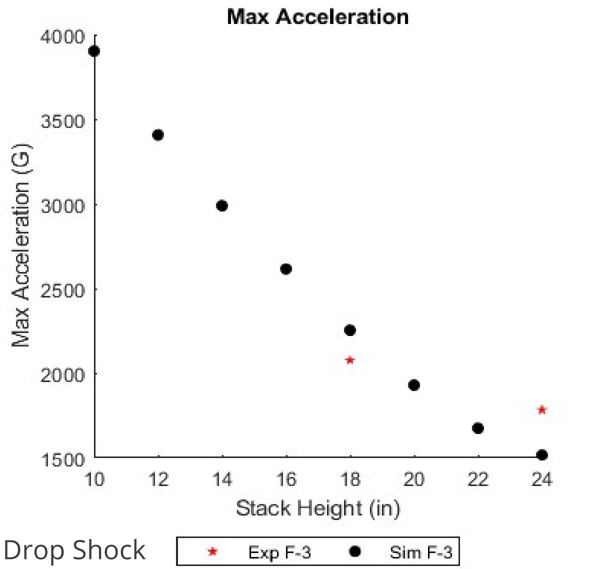


Conclusions

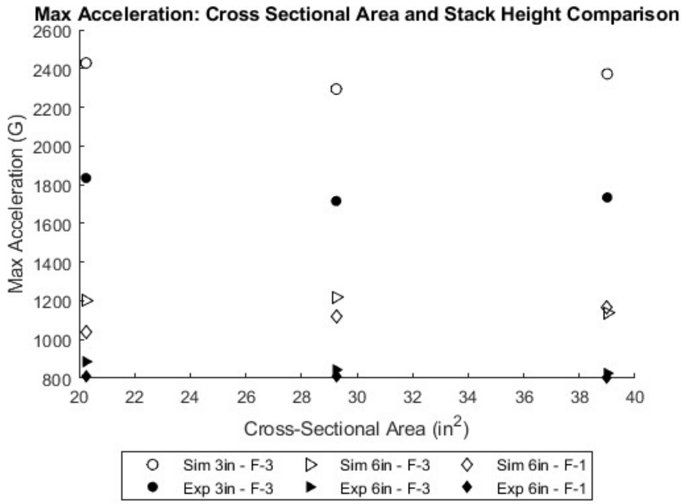
- Simulation overpredicts acceleration compared to experiment

- Drop Shock & Cascading Apparatus Similarities
  - Stack Height: Increases
    - Max Acceleration: Decreases
    - Duration: Increases
  - Cross-Sectional Area: Increases
    - Max Acceleration: Decreases
    - Duration: Increases
    - **Exception**: F-1 was Inconclusive for Cascading Apparatus

Cascading Apparatus

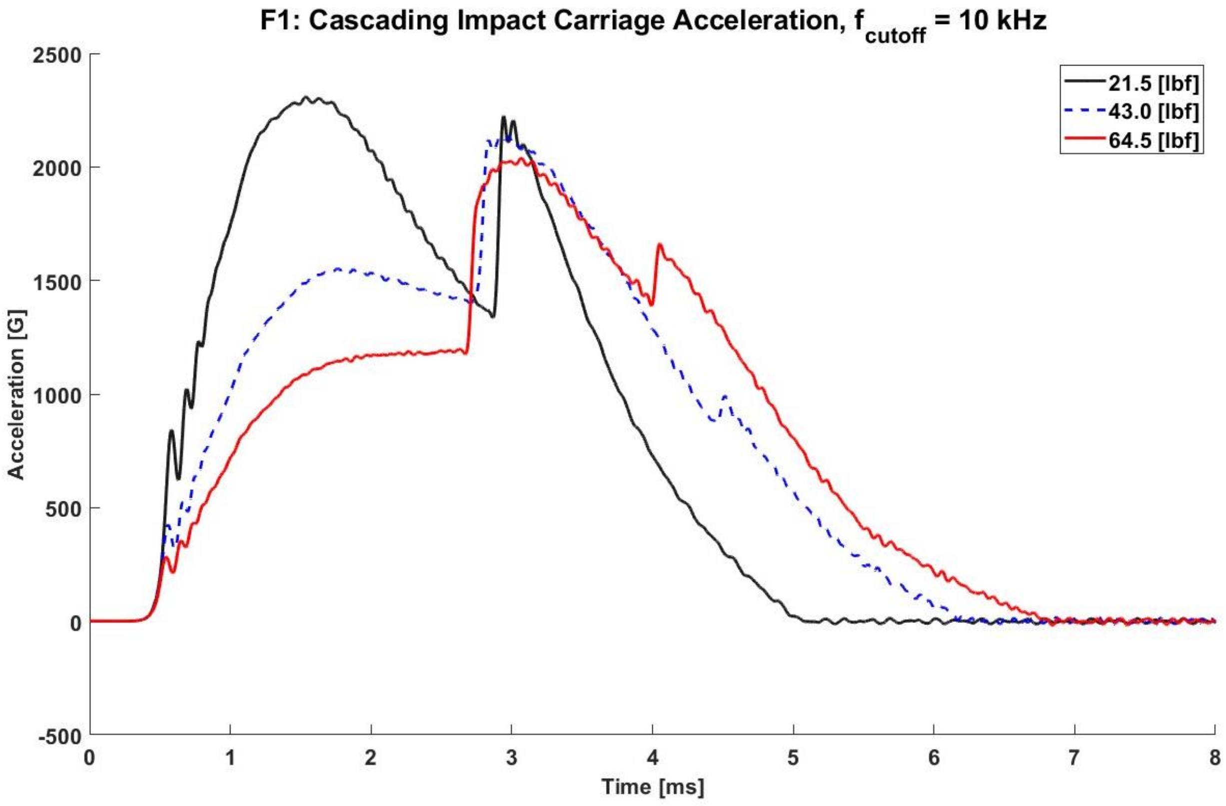


Drop Shock



Conclusions

- Decreasing Double Hump
  - Stack Height: Increase (Does decrease max acceleration)
  - Cross Sectional Area: Decrease (Potential for buckling)
  - Material Density: Decrease
  - Carriage Weight: Decrease



Future Work

- Create stress-strain curve using:
  - photometrics
  - accelerometer data
- Characterize F-5 and F-11 wool felt/Generate material input deck
  - Hopkinson Bar Test
  - OR photometrics
  - OR pre-existing accelerometer data
- Wider & finer parameter sweep for cascading impact test
- Conduct a graded-density felts test study

References

[1] “Airplane,” *Britannica Kids*, 2000. https://kids.britannica.com/kids/article/airplane/352719

[2] R. Brooks and F. Mathews, “Mechanical Shock Testing Techniques and Equipment ,” Sandia Corporation, Jul. 1966.

[3] “F-3 Industrial Wool Felt, 1" Thick x 60" Wide,” *The Felt Company*. https://www.thefeltcompany.com/f-3-industrial-wool-felt-1-thick-x-60-wide/

[4]“F-5 Wool Felt, 1" Thick x 60" Wide,” *The Felt Company*. https://www.thefeltcompany.com/f-5-wool-felt-1-thick-x-60-wide/

[5] *Wool Felt Specifications*. McHenry, IL: Superior Felt and Filtration.

[6] Neilsen, Michael et. Al. *Flex Foam Model Parameters for Programming Material (White Felt Grey Felt Manila Folder*. Sandia National Laboratories, 2018. SAND2018-5543CTF.

[7] Alvis, Tyler., Simulations of complex mechanical shock.pptx (A PowerPoint file).

Acknowledgements

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Acknowledgements

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