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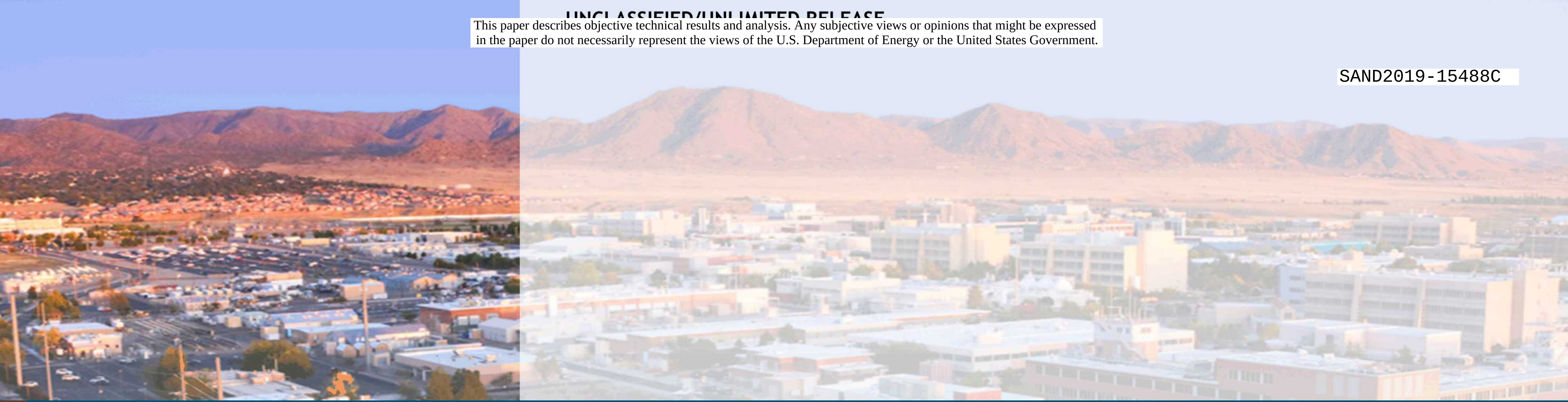

Pyroshock Attenuation Modeling in Cylindrical Structures

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Introduction & Motivation

Pyroshock events can be damaging for satellites

Structural features in the load path reduce the intensity of the shock
- Distance, Joints, Corners

Pyroshock attenuation is hard to predict and getting it wrong in either direction has consequences

NASA-HDBK-7005 [1] contains the following statement (Section 8.3, pg. 197) in reference to pyroshock effects on small electronic and optical components:
- With the rapidly increasing capabilities of computer hardware and software, it is possible that finite element method (FEM) models may be developed in the future that can successfully predict these local inputs with sufficient accuracy for design applications.

Sandia National Laboratories is a leader in high performance simulation
- Structural analysis codes support a wide range of programs
  - NW, Space, Civil

CHALLENGE ACCEPTED !

- **Can we use high performance simulation tools to estimate shock attenuation?**
- **Can we better understand how structural features attenuate shocks?**

Presentation Structure

Pyroshock Attenuation

- Quantities of Interest (QoIs)

Description of the Structure of Interest

- Geometric Features
- Loading

Structural Dynamics Simulations

- Description
- Results

Summary and Conclusions

Introduction & Motivation

What is Pyroshock?

- Potentially damaging, very short and high intensity events with high frequency content that are caused by the actuation of separating devices in satellites and launch vehicles

How do we deal with it?

- Shock intensity is attenuated by the structure
- The NASA and MIL standards based on experimental data from the 1960s
  - Could lead to under- /or over-designed products

Pyroshock Basics

Pyroshock events are short duration (< 20 msec) high amplitude, high frequency transient excitations

- Potentially damaging environments caused by the actuation of separating devices in satellites and launch vehicles

Pyroshock loads experienced by a component depend on the proximity of the component to the source of the shock

- Because of short duration and high frequency nature of a pyroshock, it is attenuated by the structural features in the load path

Decisions must be made regarding loads on potentially shock sensitive components

- This requires an understanding not only of the pyroshock excitation, but also of the load paths to the components of interest

The attenuation effects are handled empirically with guidelines or rules from NASA handbooks

Pyroshock Basics

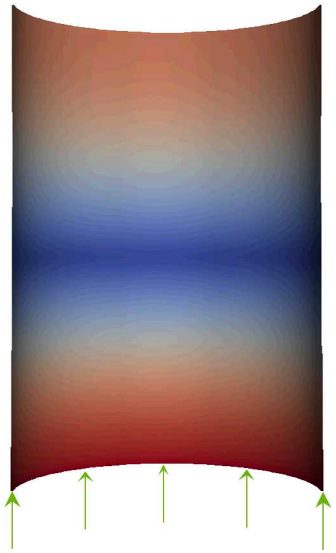
Structural features in the shock path affect the attenuation of the peak magnitude

- Distance is "distance travelled"

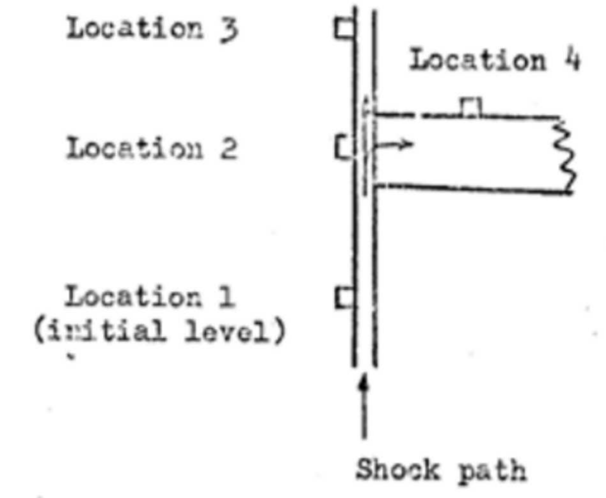
Shock axis is important

- Transverse shocks vs. Longitudinal shocks

Transverse shock

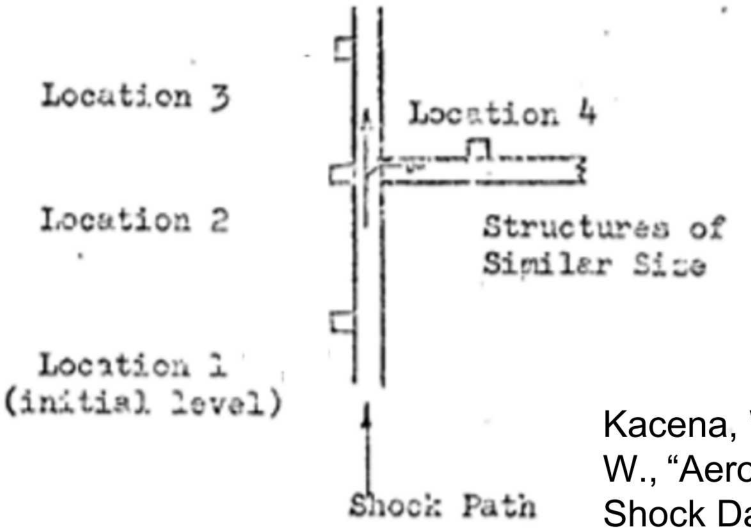


Longitudinal shock



Large amount of structure disperses shock

Location	Reduction of Level
2	0%
3	75%
4	30%



Location	Reduction of Level
2	0%
3	20%
4	70%

Kacena, W., McGrath, M., and Rader, W., "Aerospace Systems Pyrotechnic Shock Data (Ground Test and Flight)," Vol. 6, 1970.

Quantities of Interest

Shock attenuation is usually characterized by peak acceleration or SRS features

- Percentage of source value remaining vs distance from the source

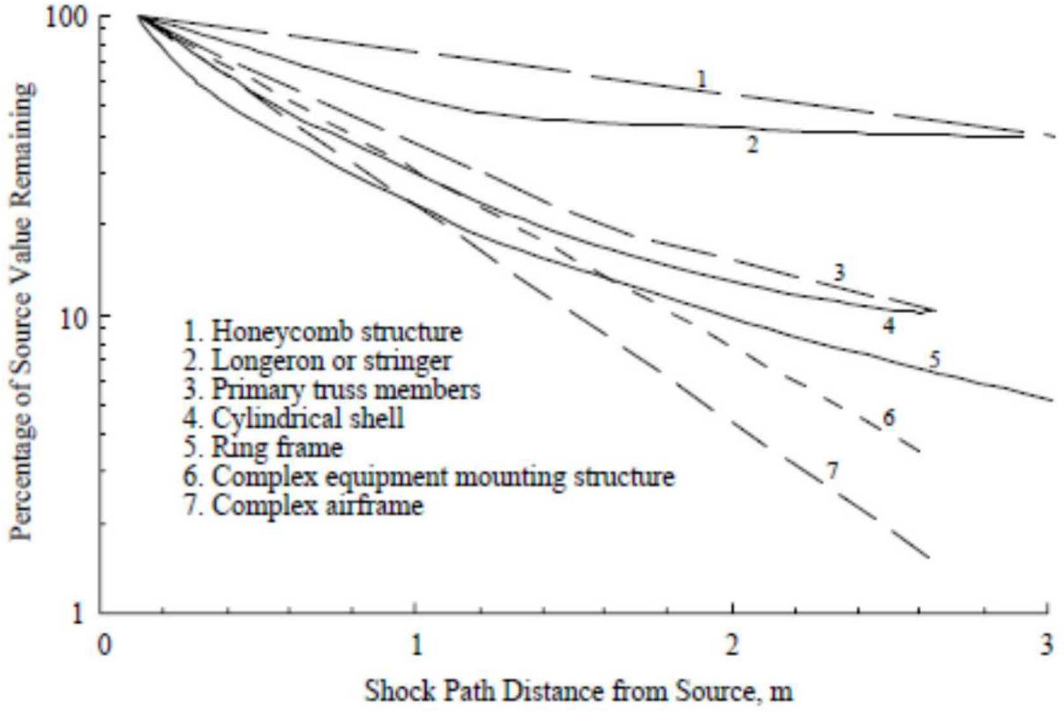


FIGURE 5.8. Peak Pyroshock Response Versus Distance from Pyrotechnic Source.

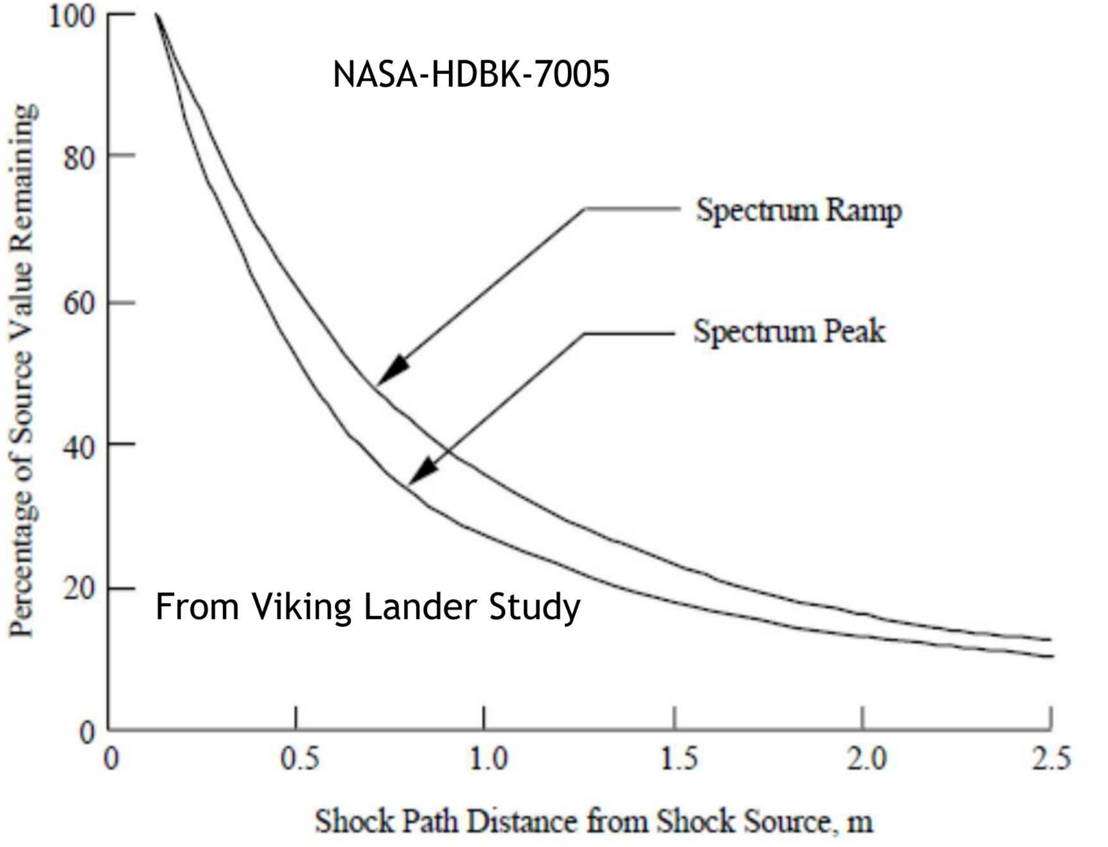


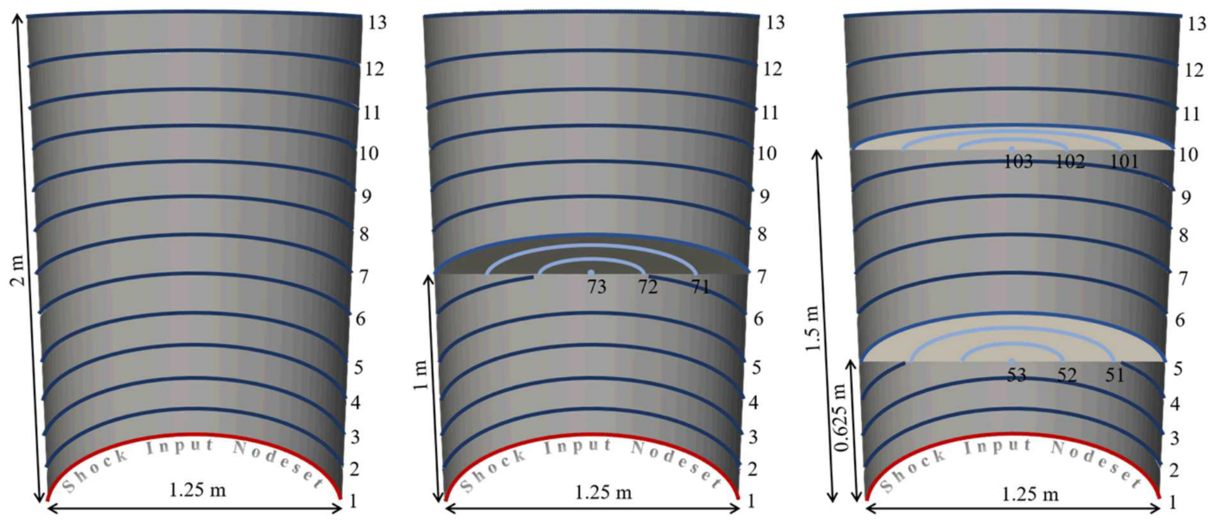
FIGURE 5.7. Shock Response Spectrum Versus Distance from Pyroshock Source.

Himelblau, H., Kern, D. L., Manning, J. E., Piersol, A., and Rubin, S., “Dynamic environmental criteria,” NASA Technical Handbook, Vol. 7005, 2001.

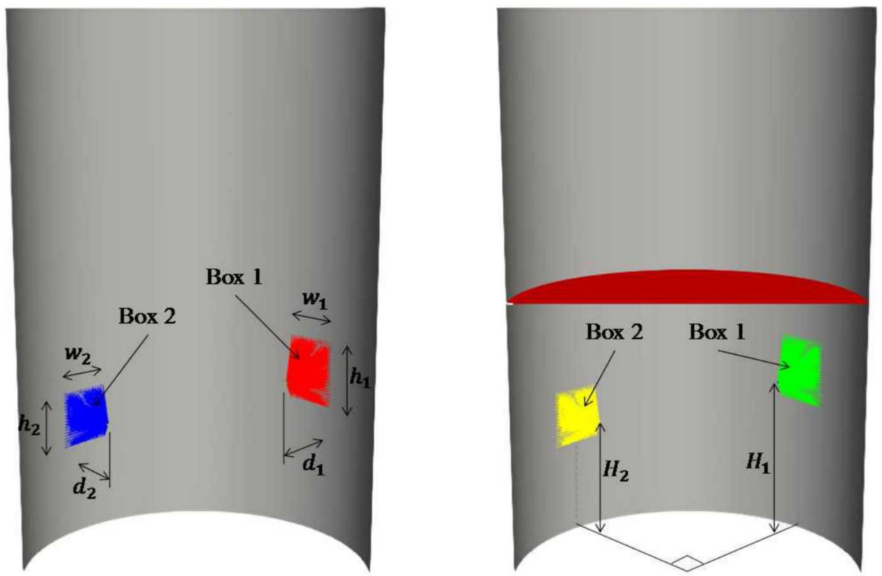
Structure of Interest

Al cylinder
- Diameter = 1.25 m
- Length = 2 m and 4 m
- Wall thickness = 4.75 mm

Structural features
- Bulkheads
  - Thin – Al plate
  - Thick – Al honeycomb
    - 25 mm – 200 mm
    - 4.75 mm face sheets
- Electronic boxes
  - 2.5 kg
- Holes
  - Round
  - Square



Dimension	Value
h_1	0.196 m
w_1	0.256 m
d_1	0.150 m
H_1	0.625 m
h_2	0.196 m
w_2	0.217 m
d_2	0.150 m
H_2	0.460 m

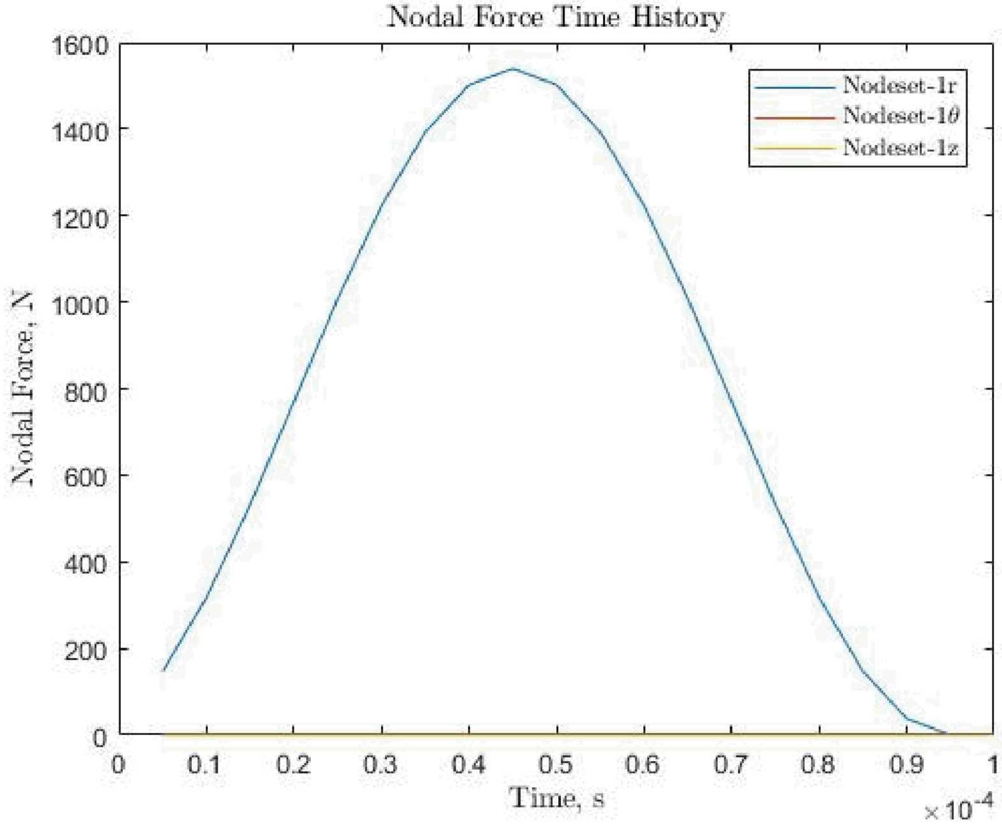


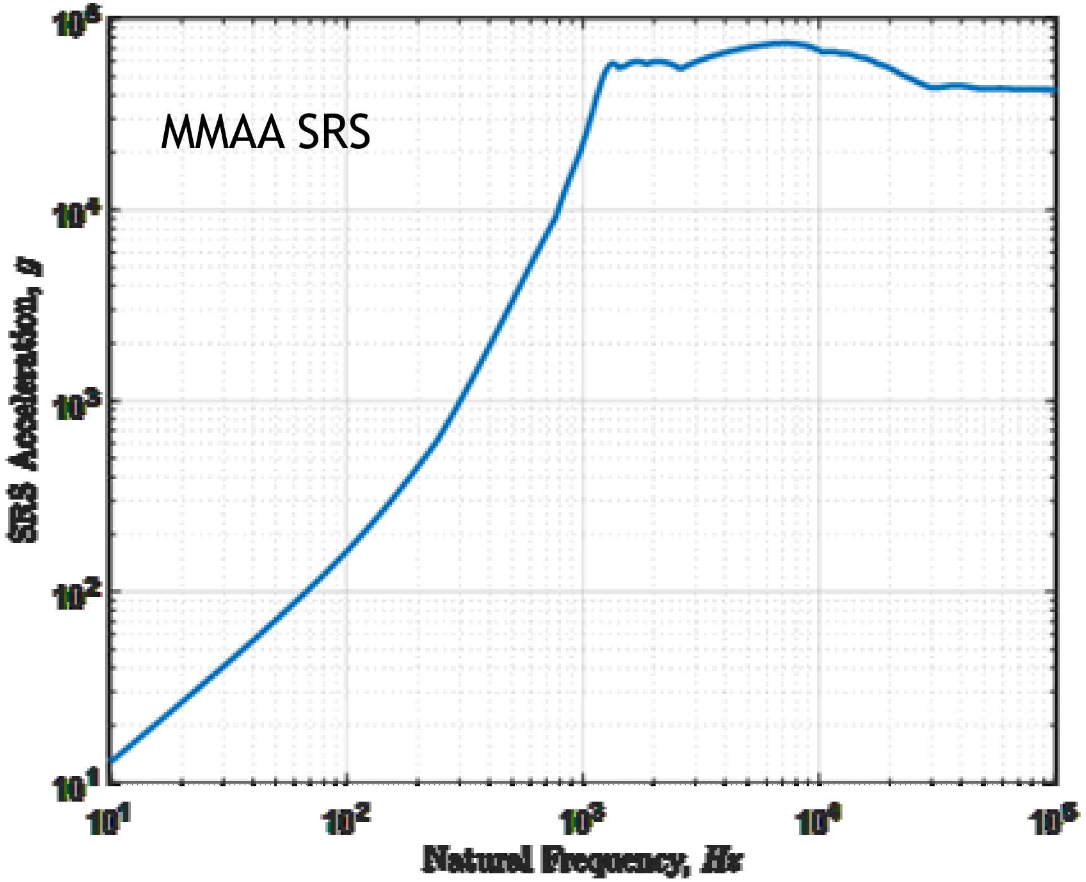
Loading

Pyroshock is simulated by a haversine force pulse

SRS has the characteristics of a pyroshock

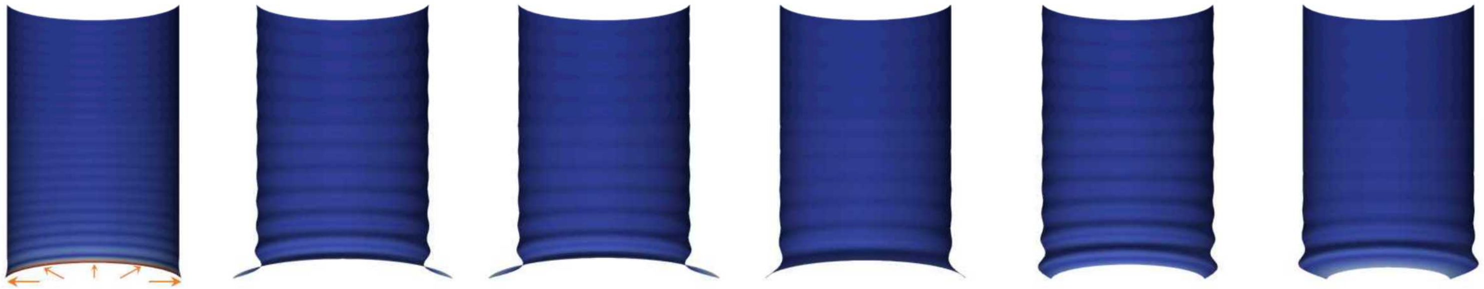
- Flat plateau at 42 kG
- 1300 Hz Knee frequency
- Ramp slope ≥ 2 (~3)



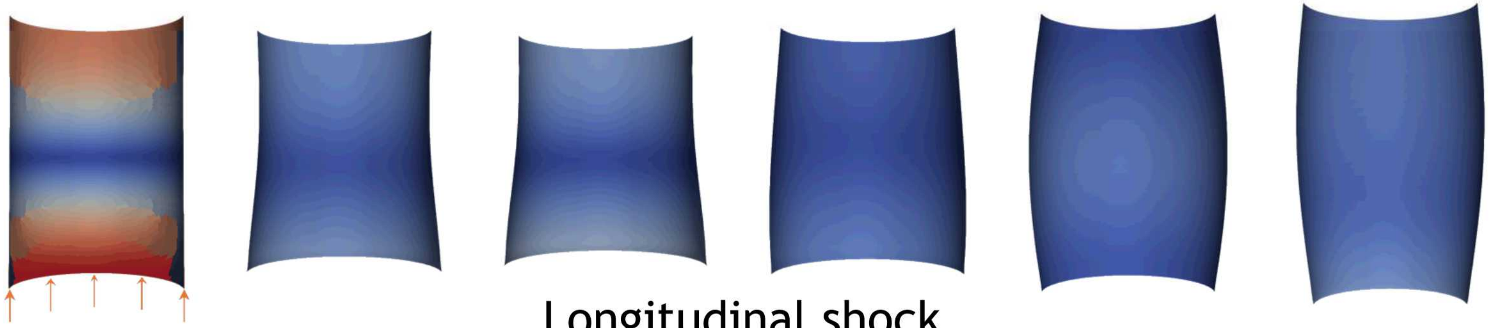


Radial vs. Longitudinal Shocks

- Radial shock induces a transverse wave
- Longitudinal shock induces an axial wave along the skin
- The axial wave is reflected by the free end
  - Very different shock attenuation characteristics



Radial (Transverse) Shock



Longitudinal shock

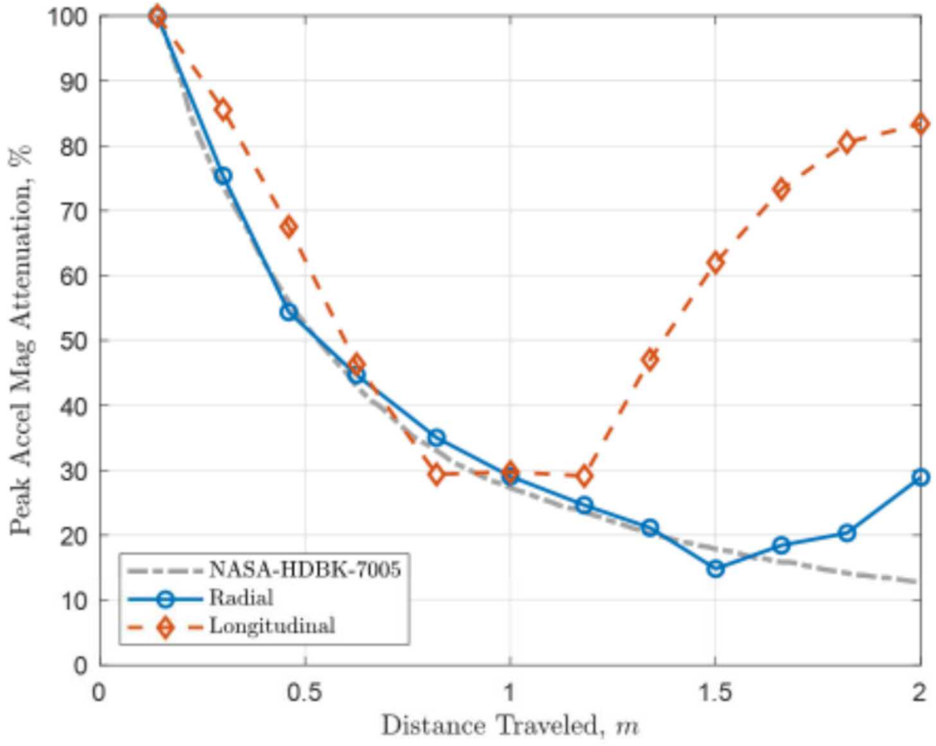


Fig. 5 Radial vs. longitudinal shock attenuation curves

Simulations

Model Details

- 4-node quadrilateral elements
- 3-node tri shell elements
- Electronic boxes were point masses attached to cylinder with RBE elements
- Honeycomb material was represented as layered shell elements

Simulation Parameters

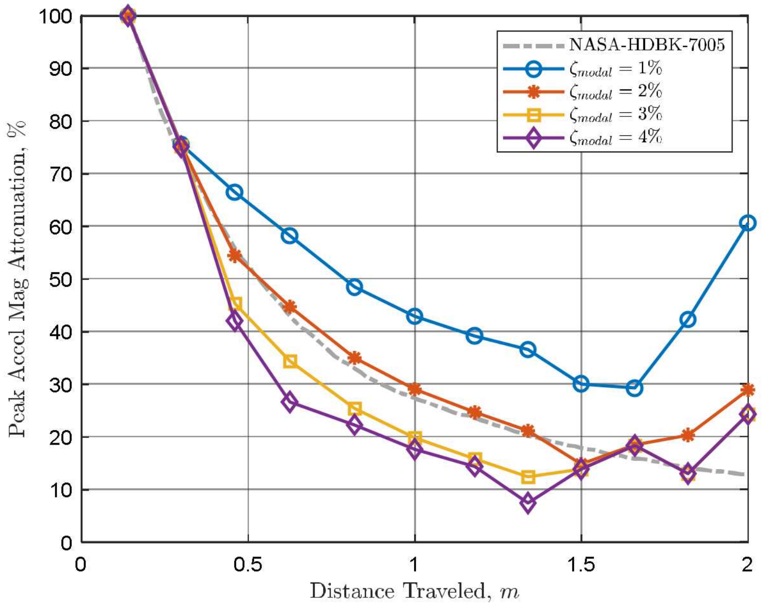
Model	No. of Elements	No. of Nodes	No. of Processors	Runtime
No-bulkhead	49,920	50,232	20	0:06:39*
One-bulkhead	66,920	58,577	32	0:07:47*
Two-bulkhead	83,968	66,946	32	0:07:56*
No-bulkhead w/ Boxes	50,619	50,234	20	0:08:45*
One-bulkhead w/ boxes	67,233	58,386	20	2:42:19
No-bulkhead w/ holes	49,243	49,618	20	1:38:30

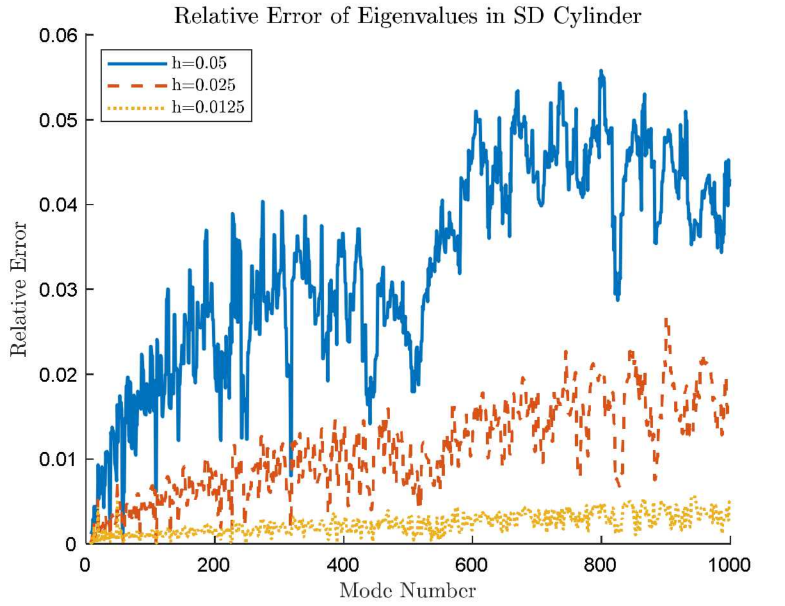
* Reusing the modes

Simulations

Initial analyses were performed to understand and calibrate the model

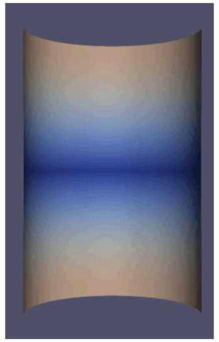
- Frequency range
  - ~1000 modes below 2000 Hz
- Mesh refinement
  - Uniform mesh - h = 12.5 mm
- Modal damping factor
  - Selected $\zeta = 0.02$
- End effects



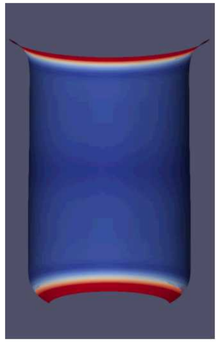


SD Model – Mode Shapes

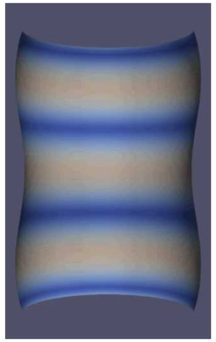
Cylinder only
- 4.75 mm thick skin
- Highest frequency symmetric mode at 1665 Hz



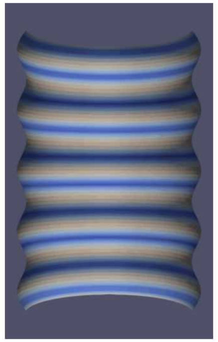
Mode 212
749 Hz



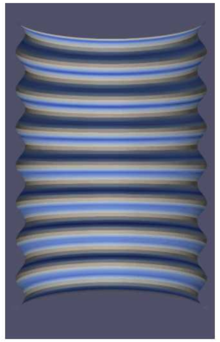
Mode 490
1242 Hz



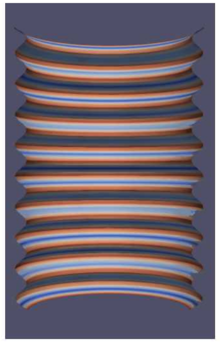
Mode 495
1250 Hz



Mode 545
1298 Hz

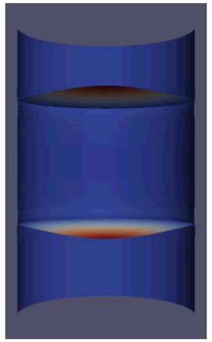


Mode 677
1481 Hz

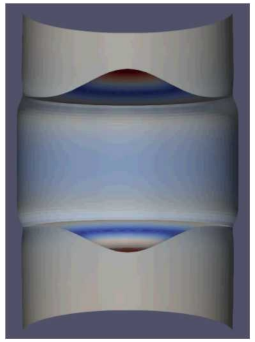


Mode 796
1665 Hz

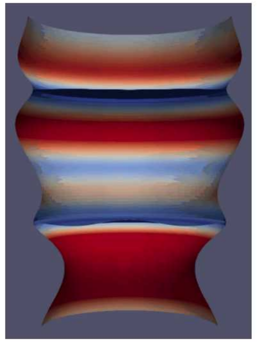
Cylinder with two bulkheads
- 4.75 mm thick skin
- 50 mm thick bulkheads



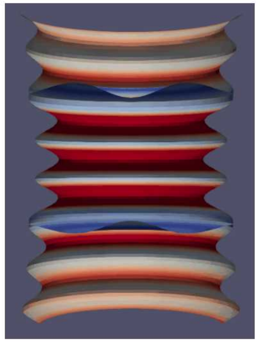
Mode 12
157 Hz



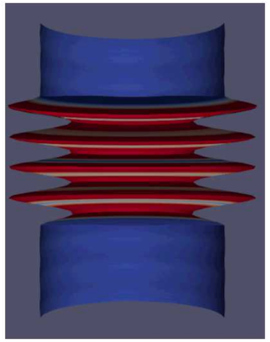
Mode 197
759 Hz



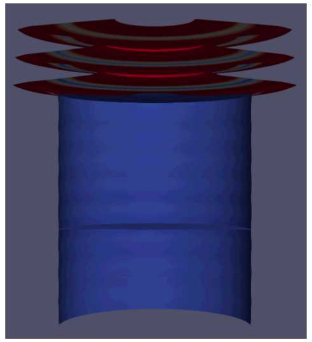
Mode 472
1262 Hz



Mode 635
1482 Hz

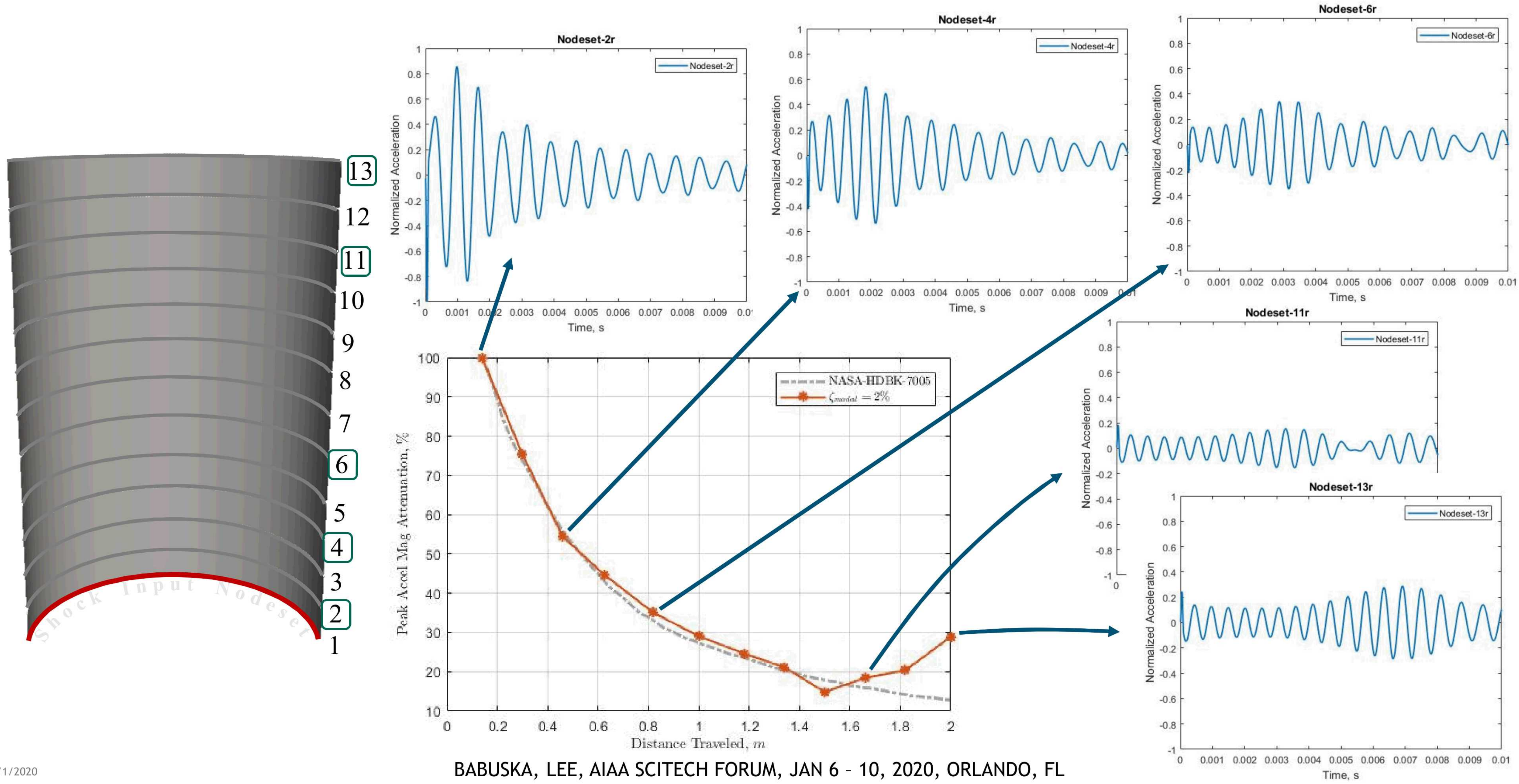


Mode 802
1717 Hz



Mode 932
1930 Hz

Results - Peak Acceleration Time of Occurrence

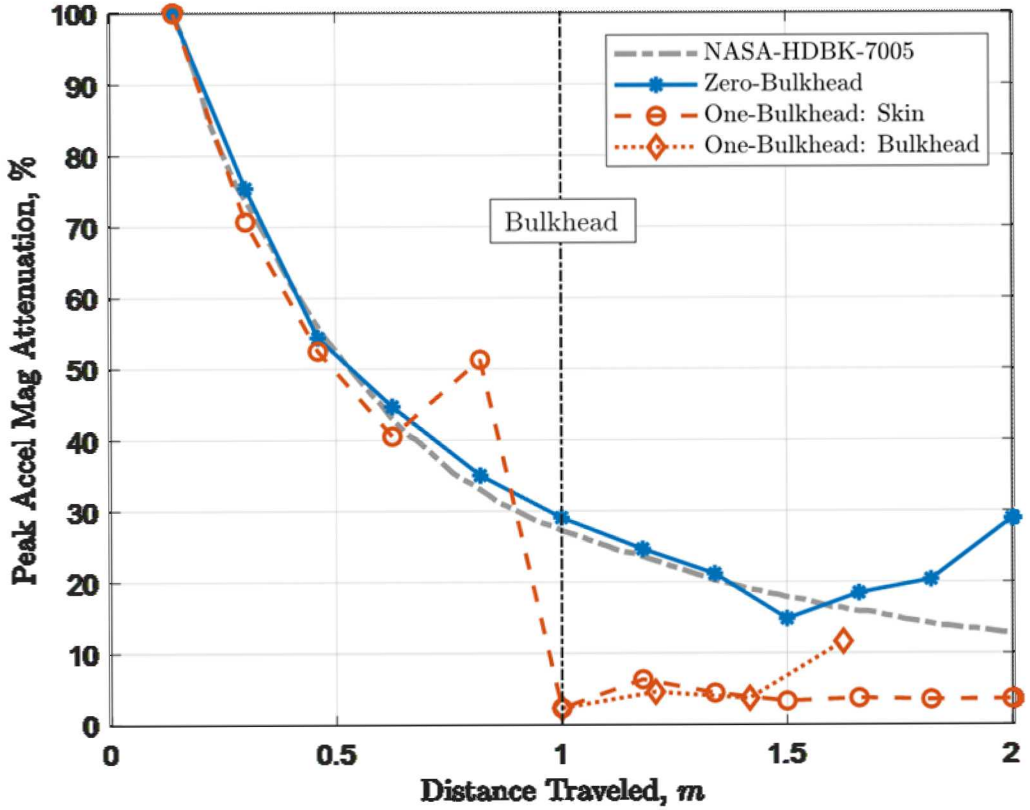


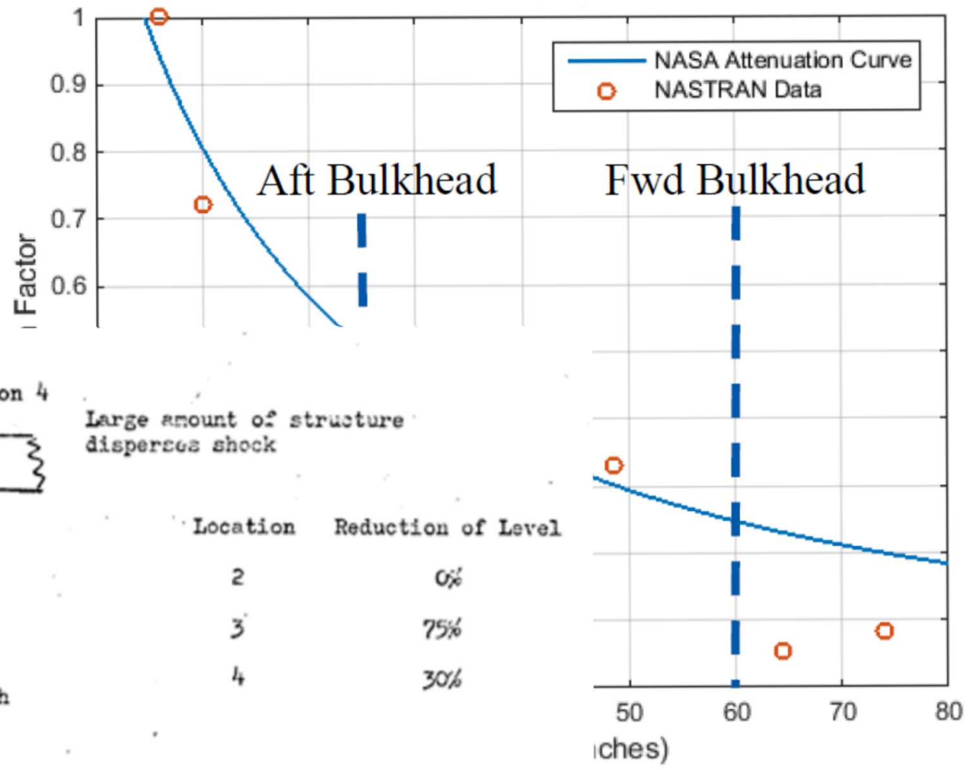
BABUSKA, LEE, AIAA SCITECH FORUM, JAN 6 – 10, 2020, ORLANDO, FL

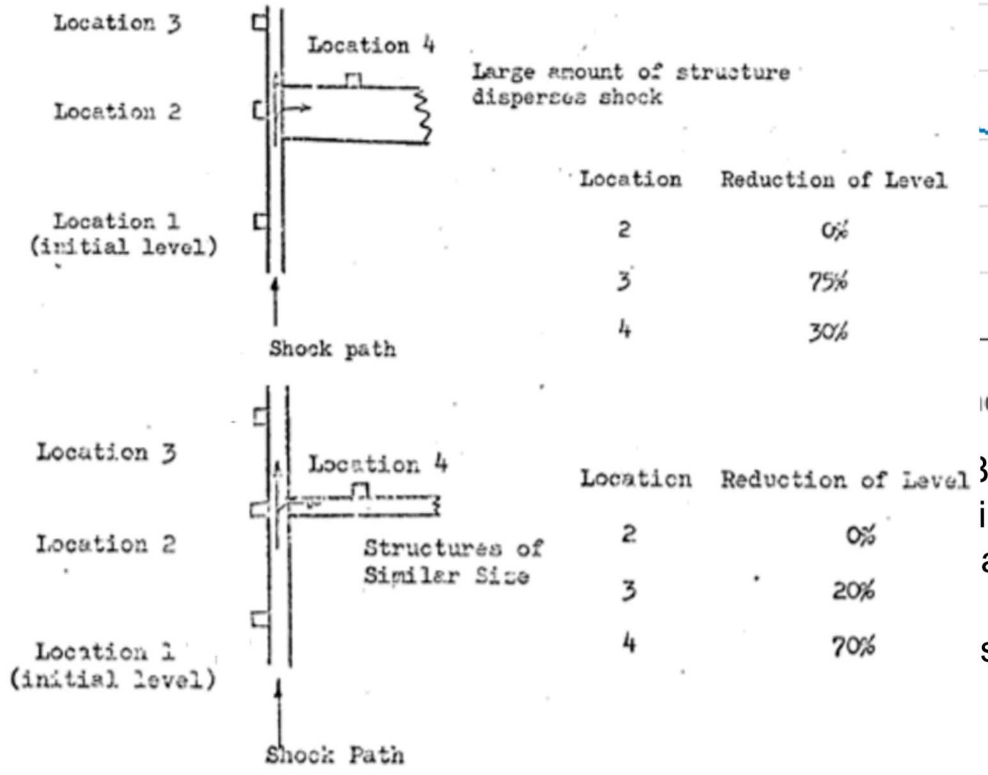
Effects of Bulkheads

1 bulkhead

- A bulkhead attenuates the shock peak amplitude by more than 90%
- This is greater than the Kacena Report
- This is greater than the attenuation estimated by other similar studies







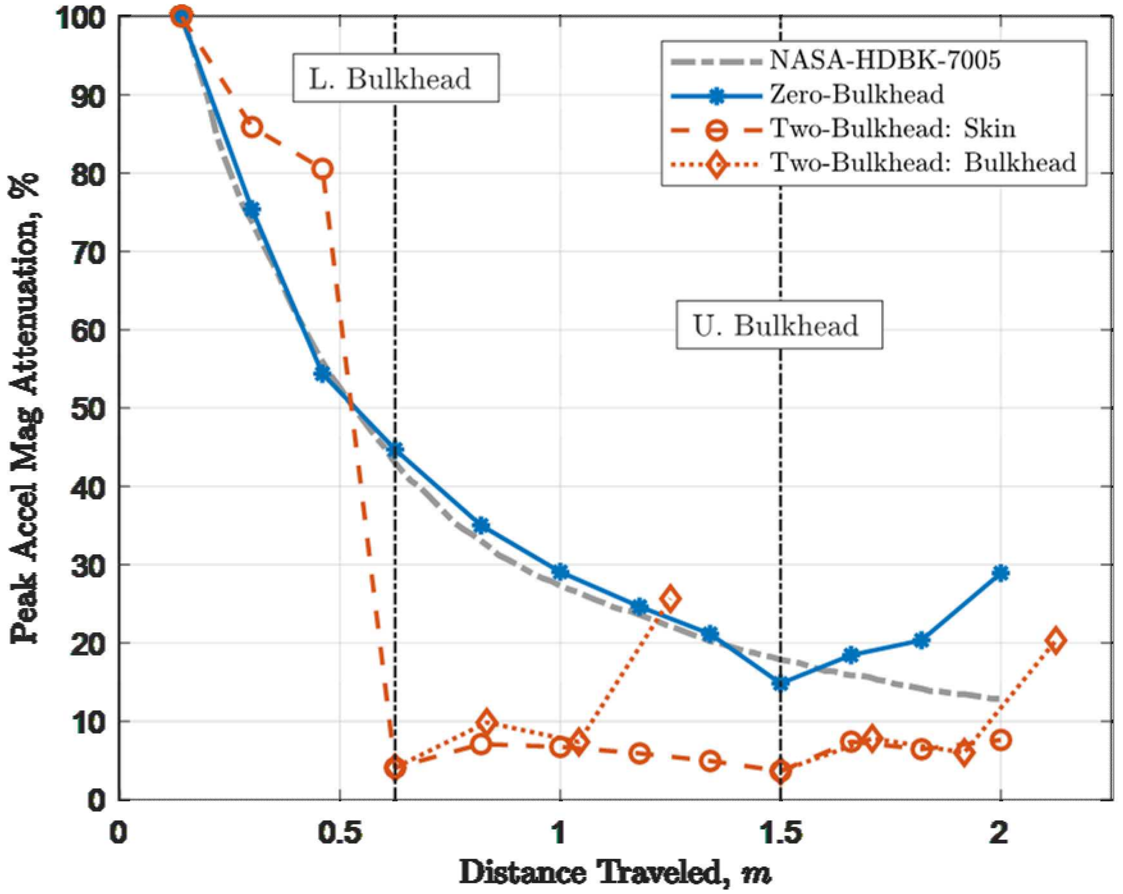
3etter Approach to
ironments and
and Launch Vehicle

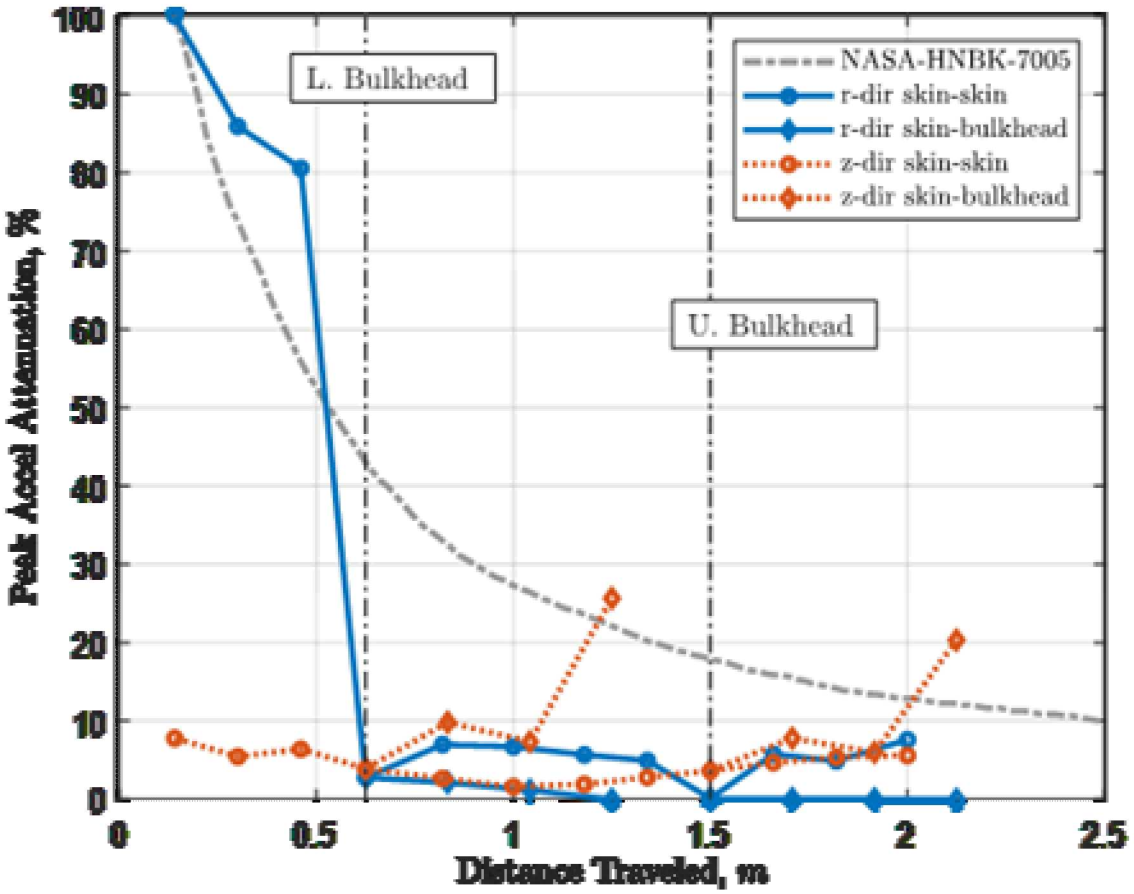
shop," 2018.

Effect of Bulkheads

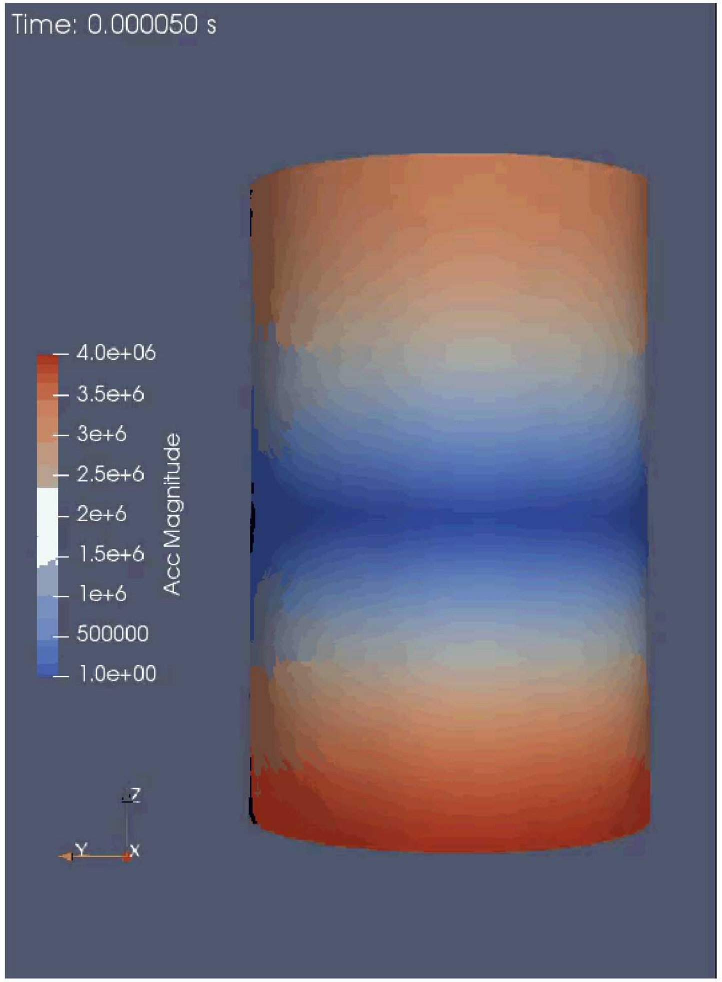
2 bulkheads

- The second bulkhead has very little impact
- The first bulkhead did not prevent propagation of the z-axis waves in the second bulkhead

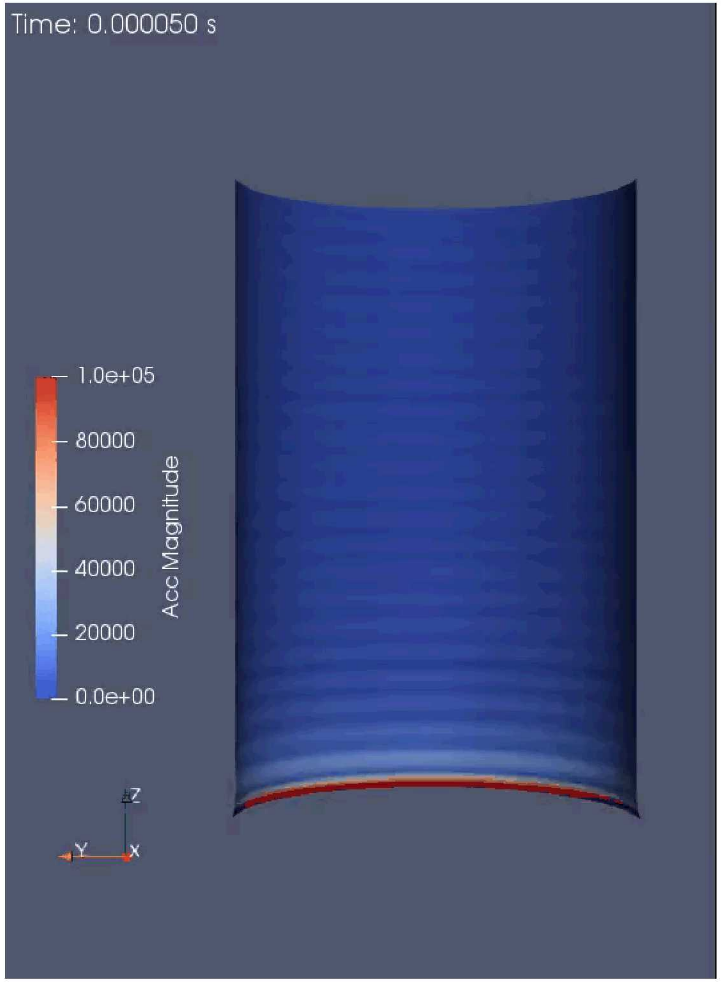




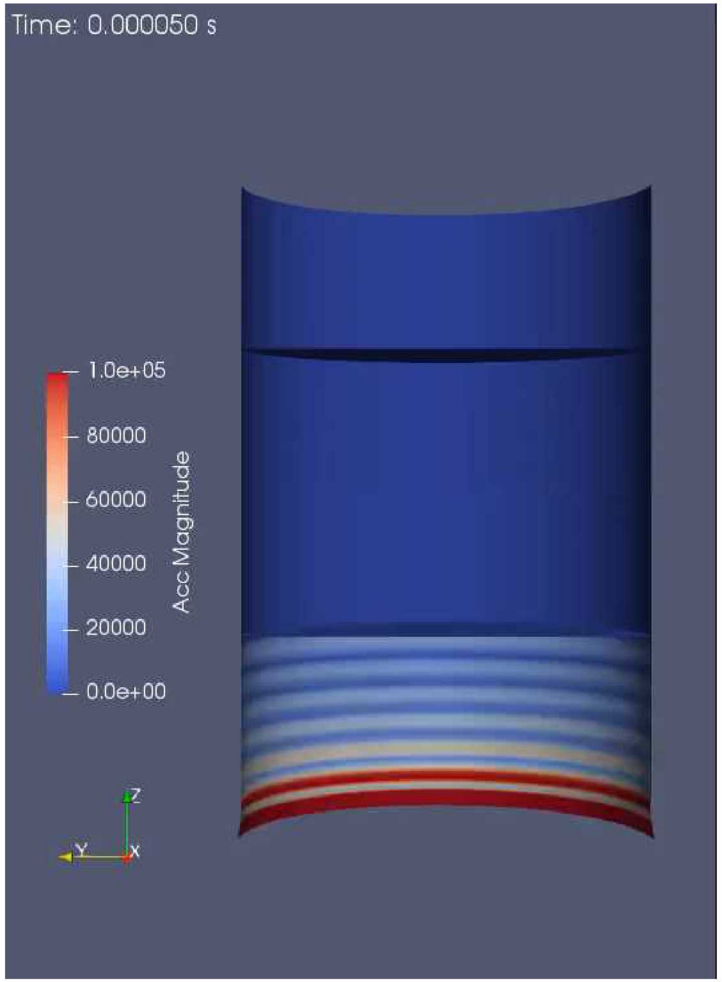
SD Simulation Videos



Longitudinal Shock no bulkhead
Quad mesh



Radial Shock no bulkhead
Quad mesh

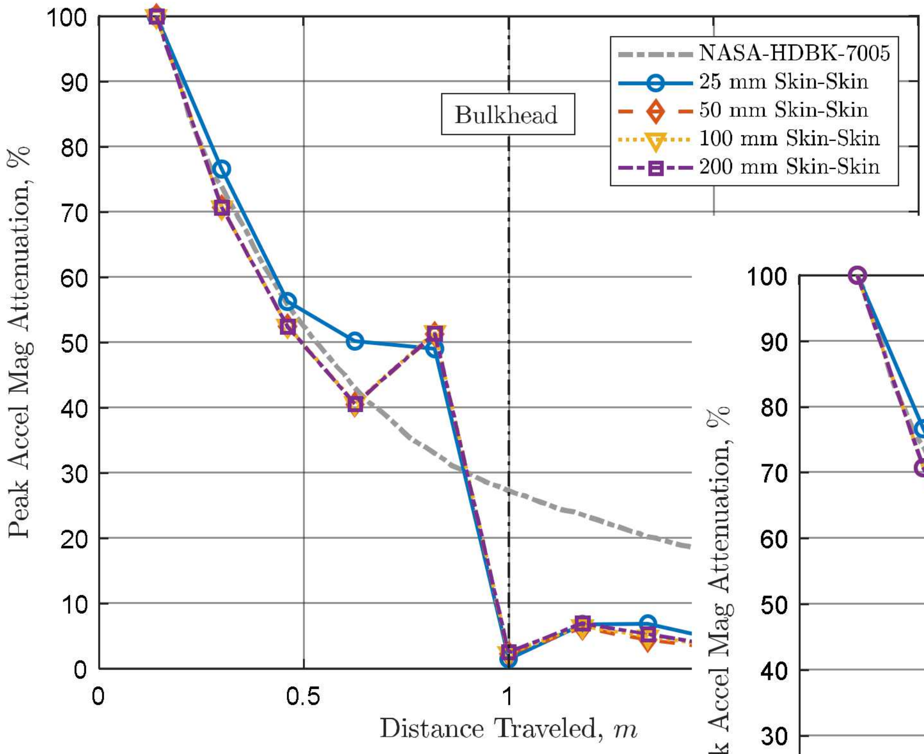


Radial Shock 2 thick bulkheads
Quad mesh

Effects of bulkhead thickness

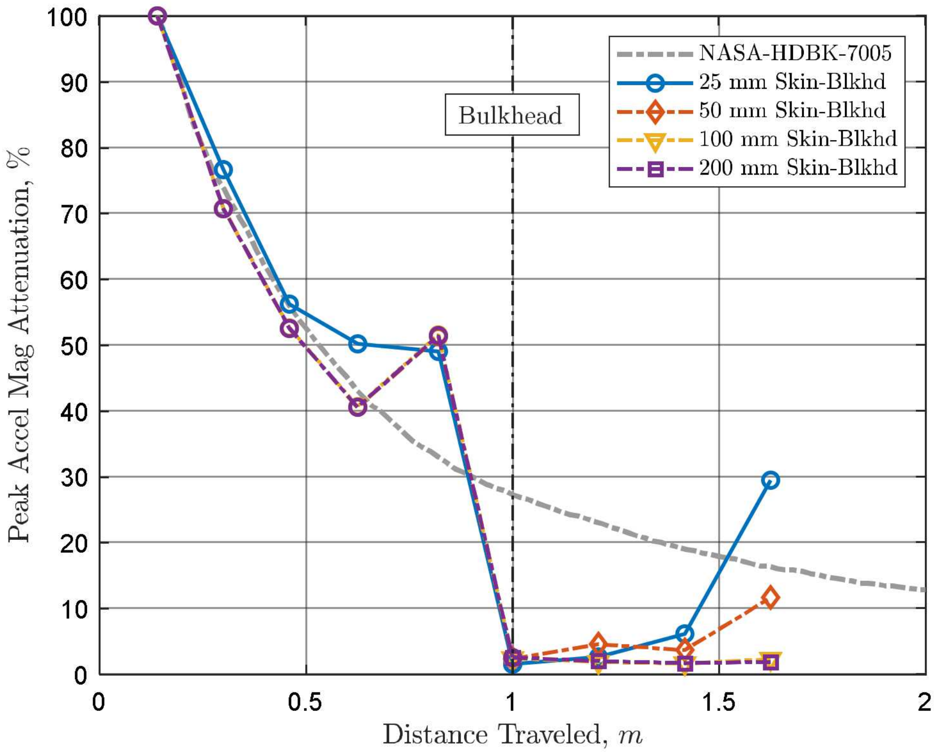
We found that the mere presences of a bulkhead was more consequential than the thickness

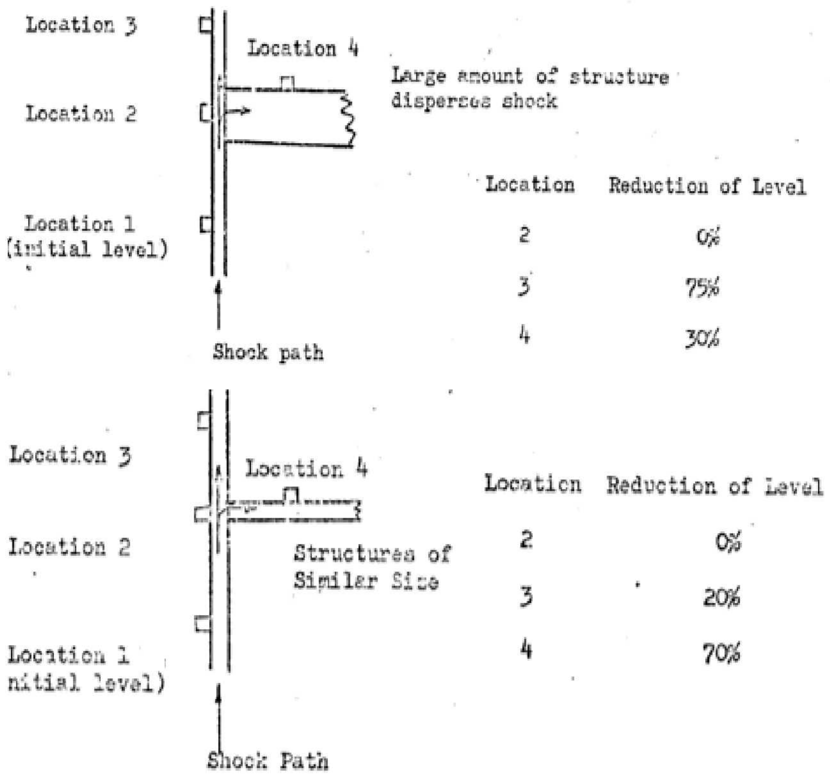
- This is not consistent with previously published results



On the cylinder skin

On the bulkhead



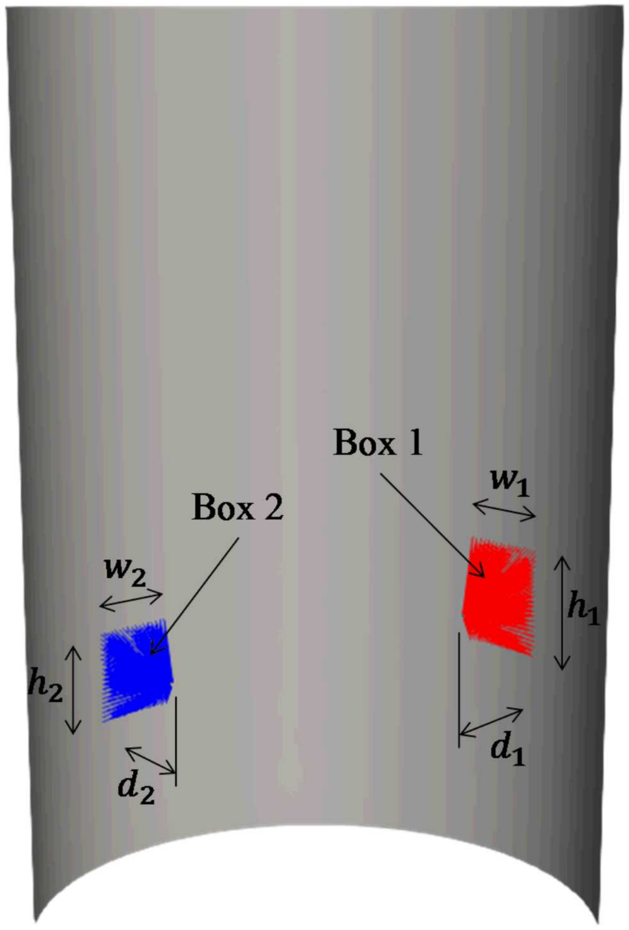


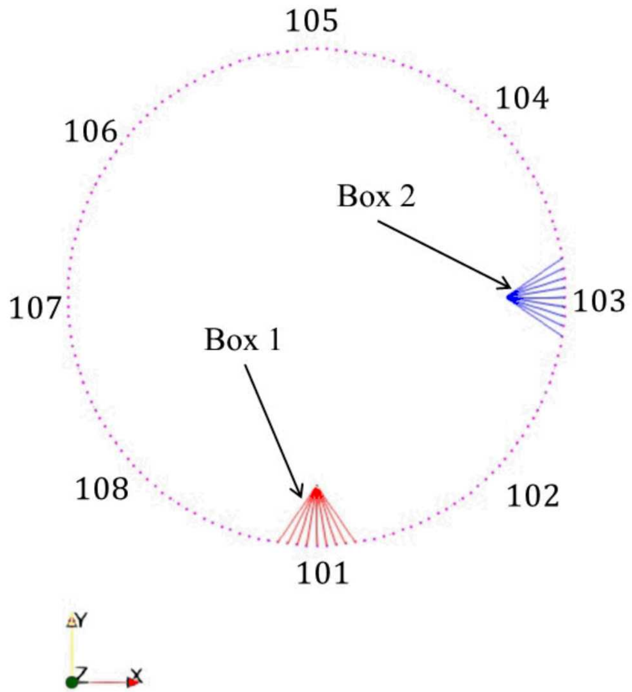
Kacena, W., McGrath, M., and Rader, W., "Aerospace Systems Pyrotechnic Shock Data (Ground Test and Flight)," Vol. 6, 1970.

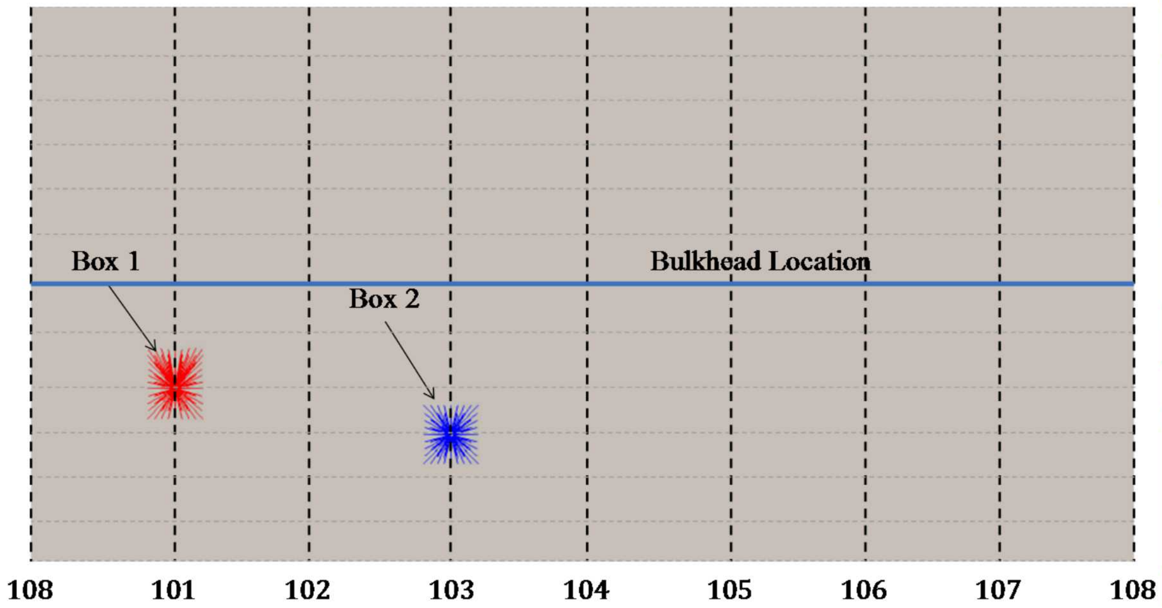
Effects of Electronics Boxes

What effect does mass have on the shock peak acceleration?

- We placed 2.5 kg electronic boxes at 2 locations on the cylinder
- Point masses connected to the shell with RBE element spiders





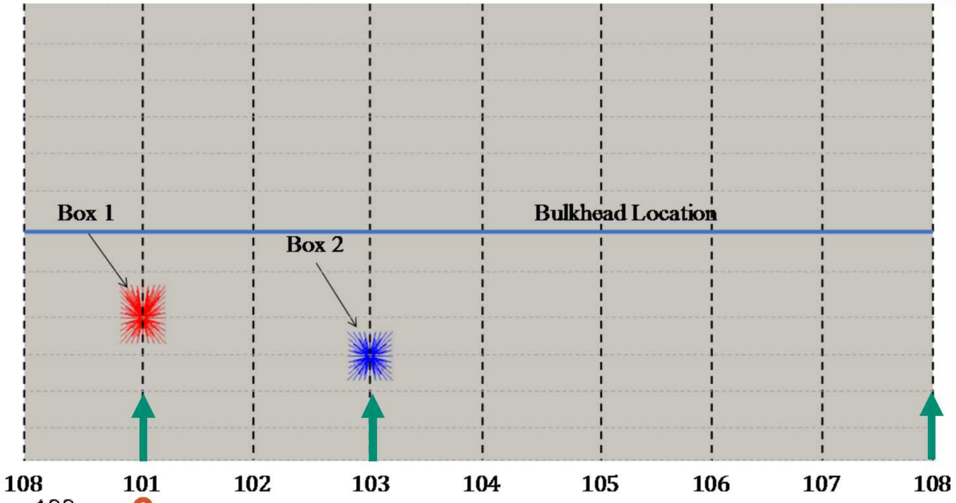


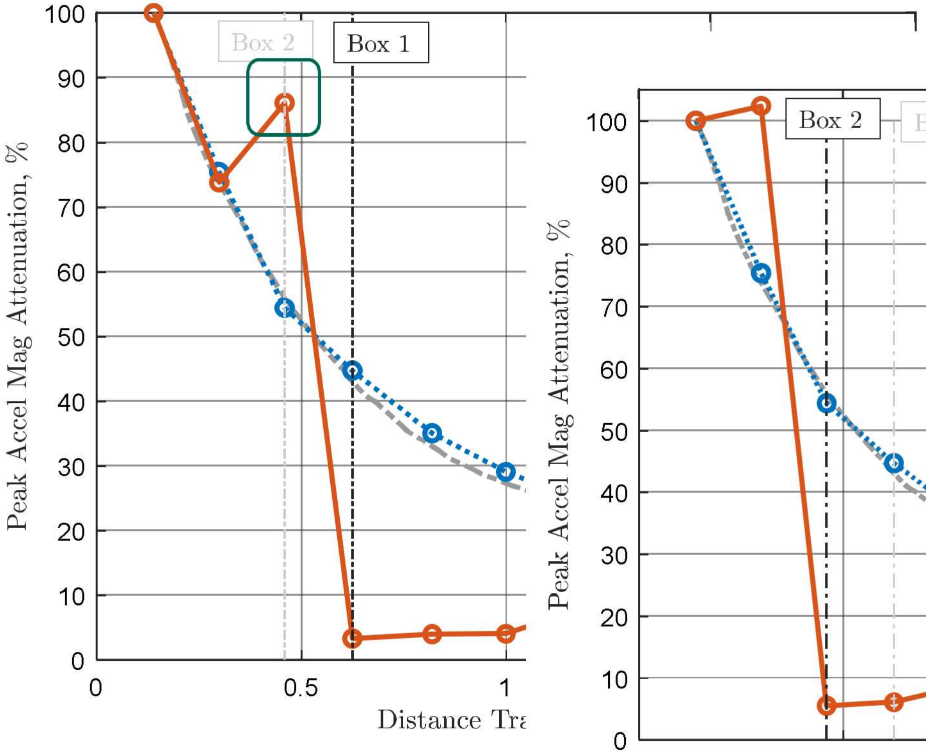
Effects of Electronic Boxes on Peak Acceleration

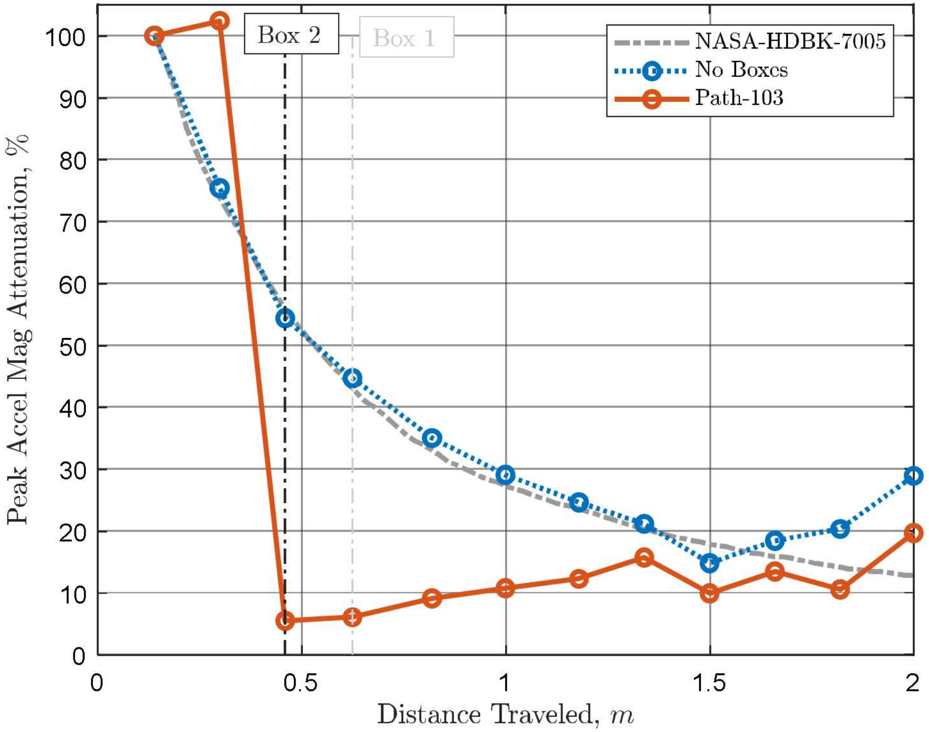
The electronic boxes have a local effect

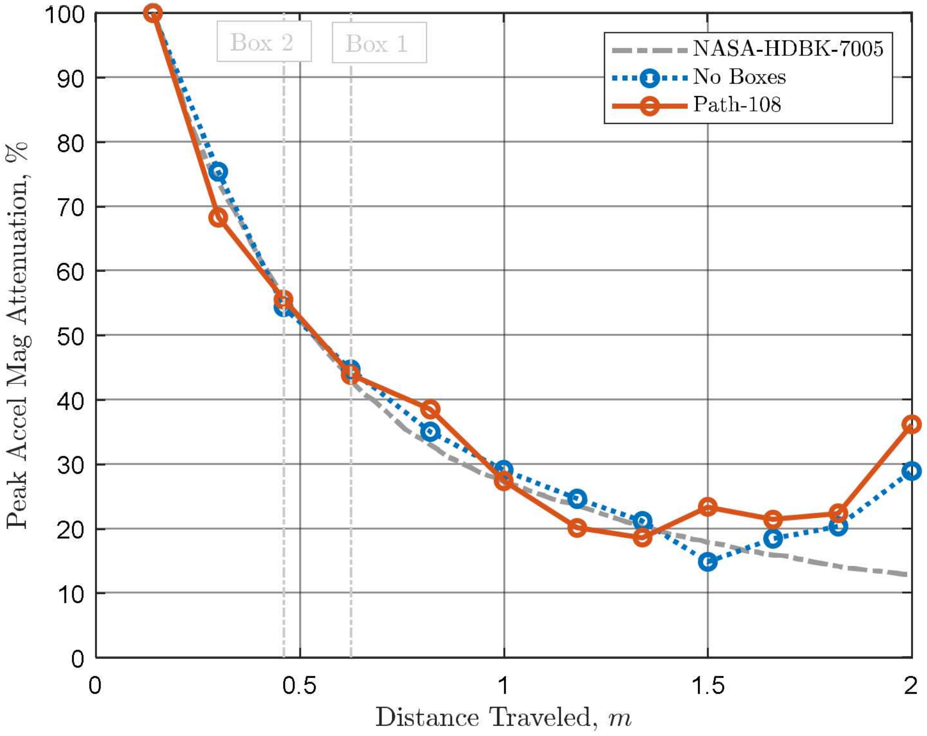
- Shock amplitude behind the box is reduced by more than 90%

Peak shock levels along lines away from the boxes are not affected









Effects of Electronic Boxes on Peak Acceleration

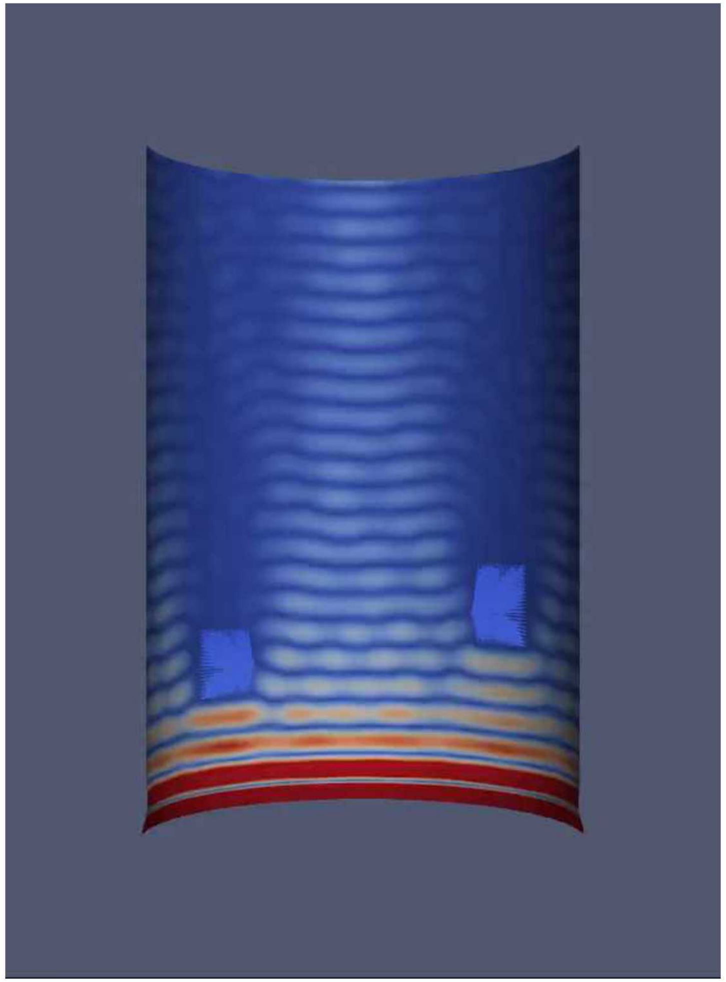
Videos show that electronic boxes are like boulder in a stream

- Local energy sink or absorber

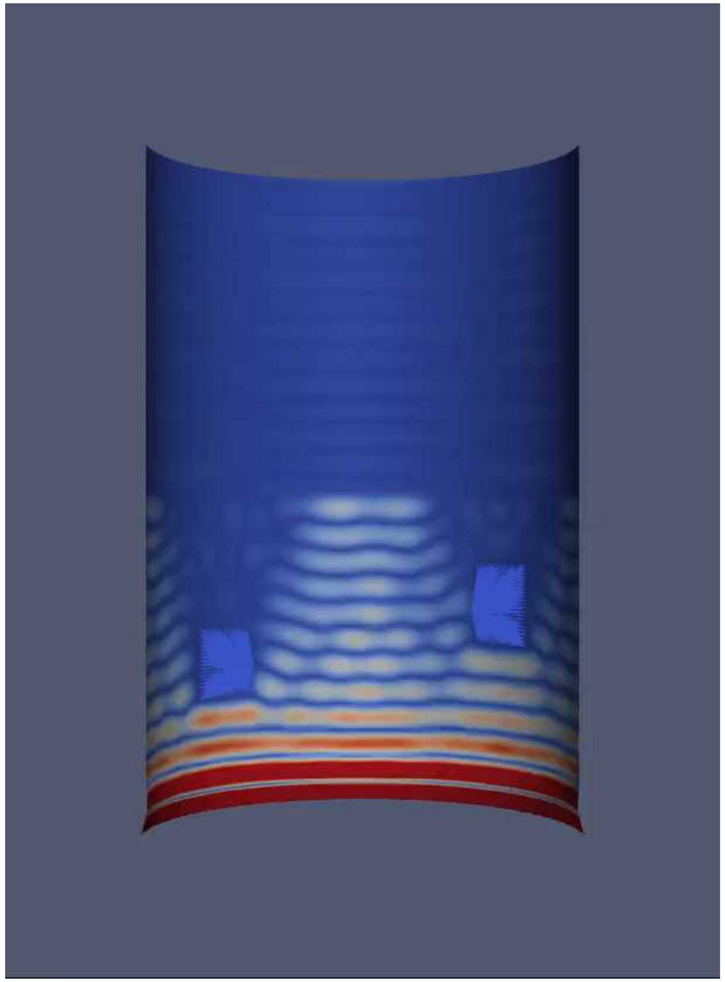
Perhaps placing a mass in front of a shock sensitive component could be a shock migration strategy

The bulkhead does not add much reflection

- Peak acceleration levels behind the boxes are similar



Radial Shock no bulkhead
2 electronic boxes



Radial Shock 1 bulkhead
2 electronic boxes

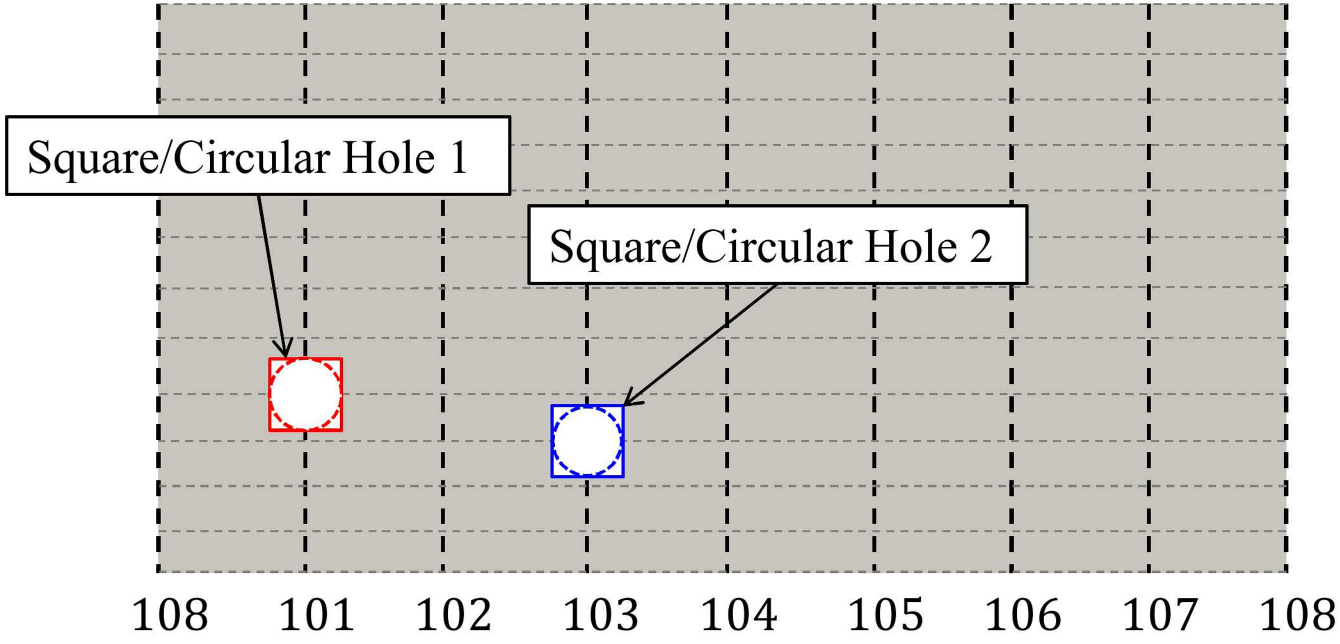
Effects of Holes on Peak Acceleration

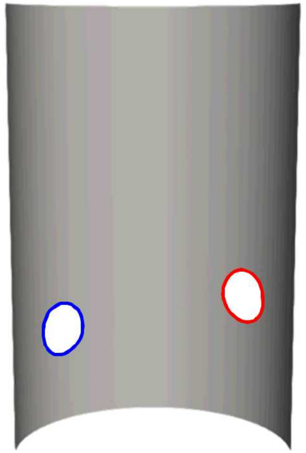
A hole is the structural opposite of an electronics box

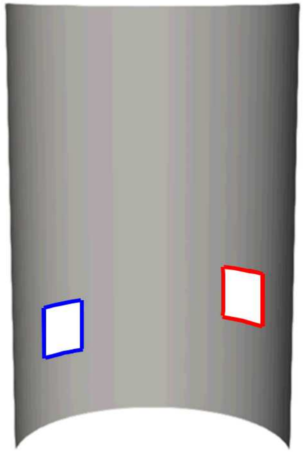
- Remove mass and structure

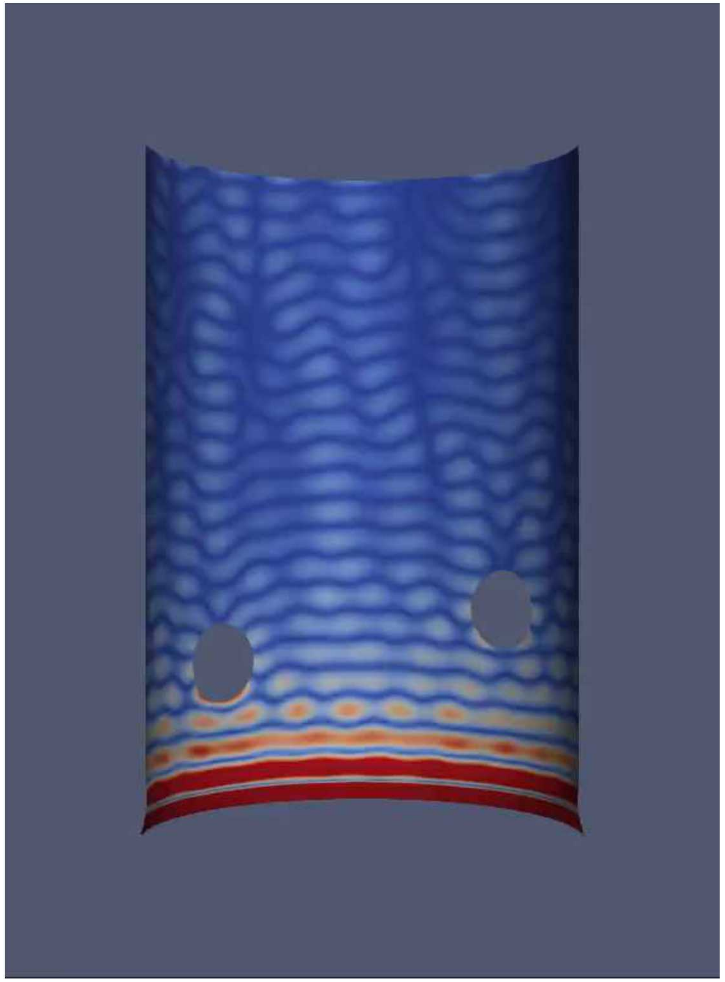
We replaced the electronic boxes with holes

- Round holes and square holes
- Same locations and similar size









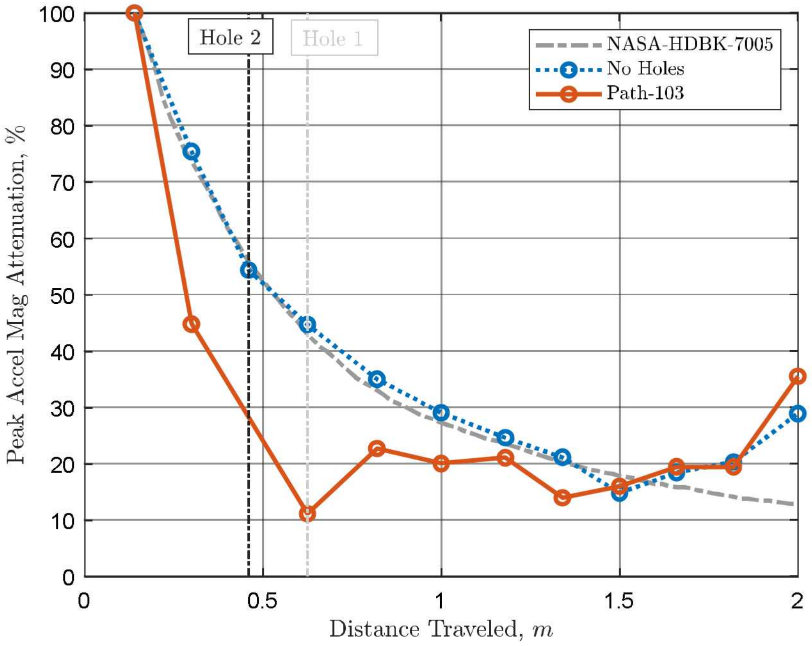
Radial Shock no bulkhead
2 round holes

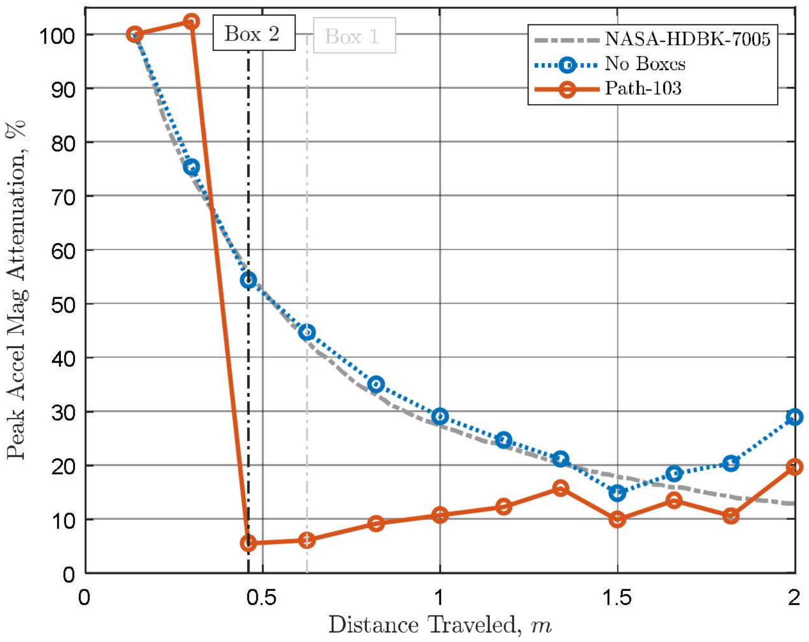
Effects of Holes on Peak Acceleration

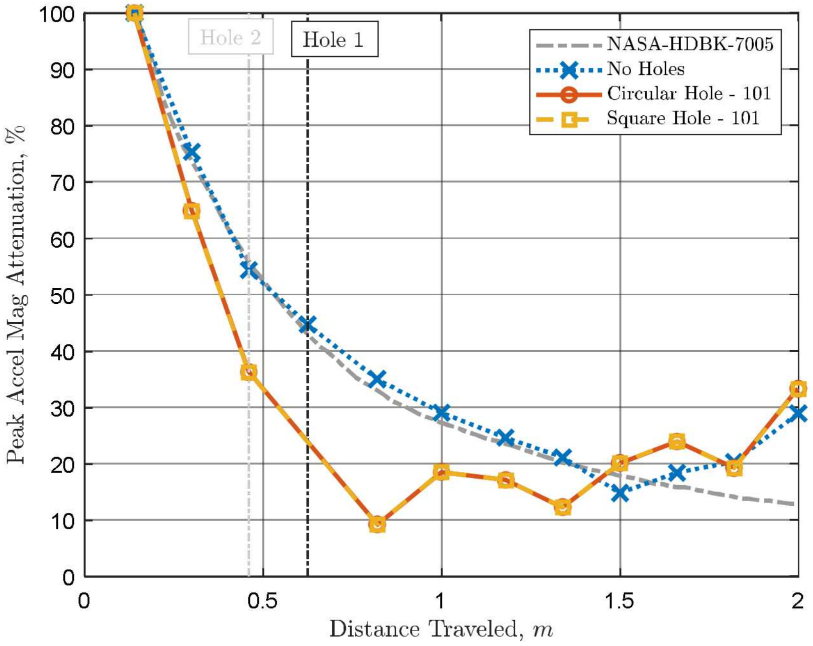
Holes disrupt the uniformity of the acceleration field

Holes do not attenuate peak acceleration as much as boxes
- Shock goes past them
  - No relative increase in peak acceleration before the hole
- Peak accelerations return to no hole levels downstream

The shape of the hole had no effect on the level of attenuation
- Suggests that adding mass is more effective attenuating shock than removing structure / mass







Summary and Conclusions

We modeled the response of a cylinder to a pyroshock
- Transverse and longitudinal shocks
- Structural features – bulkheads, electronic boxes, holes

Calibrated the model to the attenuation curve in NASA-HDBK-7005
- Applicable to transverse shock loading not longitudinal loading

Structural features such as bulkheads and electronic boxes attenuated the peak acceleration more than predicted by NASA references
- Structural features should have mass to attenuate peak acceleration
- NASA references are conservative
- Shock sensitive part could be protected by putting a mass in the shock path, before the shock sensitive part

Finite element analysis tools are capable enough to model shock response in the mid-field and far-field

Finite element analysis can be a valuable tool to give insights on the effects of structural features
- **Even without experimental data to validate a model**

- Can we use high performance simulation tools to estimate shock attenuation? YES
- Can we better understand how structural features attenuate shocks? YES

THANK YOU