



Joining of Human Head-Neck and Torso Models

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Funding for this work was provided through the Sandia Laboratory-Directed Research and Development (LDRD) program

The authors acknowledge the National Library of Medicine and the Visible Human Project as the source of the visible human data set used to construct the digital head-neck and torso models employed in this project.

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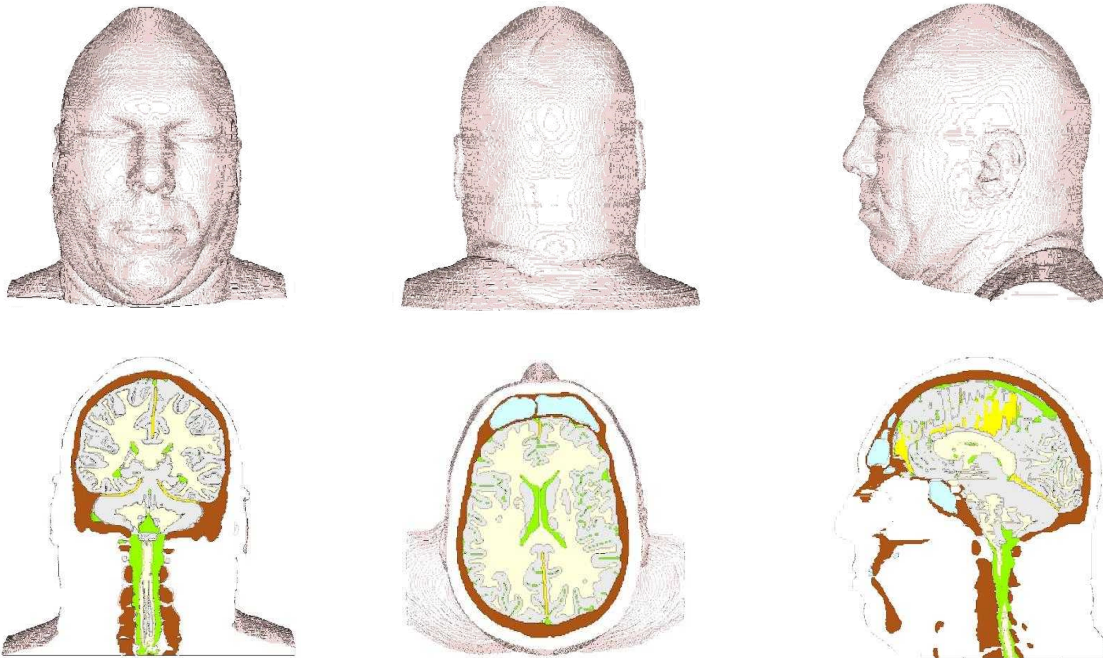
High-Fidelity Torso Model

- **Background:** Head-Neck (HN) model and Torso model
 - Previously completed HN model and Torso model provided proof of concept for wound injury modeling & simulation
- **Motivation:** Joining of the HN model with Torso model broadens the applicability of the model.
 - Allows for investigation into the validity of currently published theories on wound injury (e.g. suggestion that vasculature acts as a wave guide into the brain as a possible TBI mechanism)
 - Allows for investigation into the impact of boundary conditions on truncated models (HN or Torso only) and whether simulations utilizing truncated models are acceptable for use when computational expense is to be minimized.
- **Current Status:** Models joined
 - Analysis to verify continuity at junction completed
 - Assessments on boundary condition impact ongoing



Digital Head & Neck Model

- **Previously Completed Head-Neck Model [2]:**
 - Fully Compatible with torso model for use in joined head, neck, and torso simulations.
 - Anatomically correct distributions of bone, white & gray brain matter, membranes (falx & tentorium), cerebral spinal fluid (CSF), sinus air, & scalp/muscle in 1mm resolution.

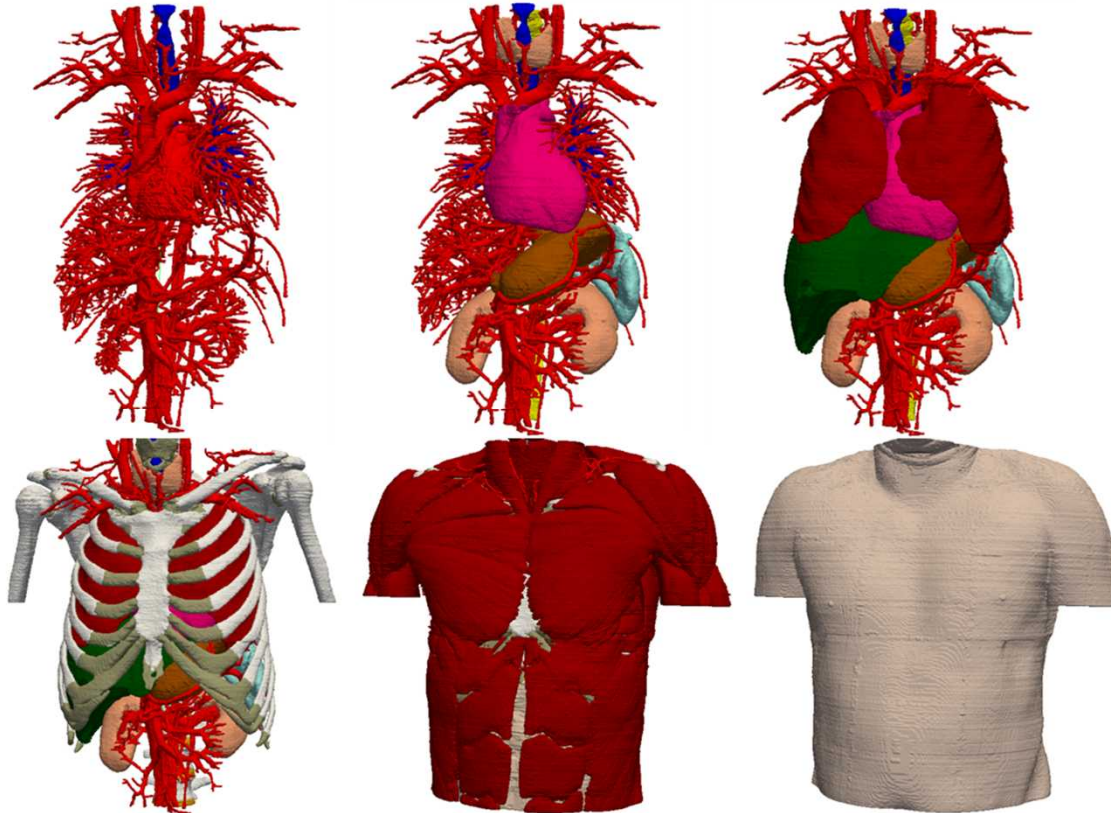


[2] Taylor P., Ludwigsen J., Ford C., “Investigation of Blast-Induced Traumatic Brain Injury,”
Brain Injury, 28(7), 879-895, 2013

Digital Torso Model

- Previously Completed Torso Model

- Anatomically correct distributions of bone, cartilage, intervertebral discs, vasculature/blood, airways, lungs, heart, kidneys, liver, stomach, stomach interior, spleen, spinal cord, cerebral spinal fluid, larynx, thyroid, stomach cavity, muscle and fat/skin in 1mm resolution.



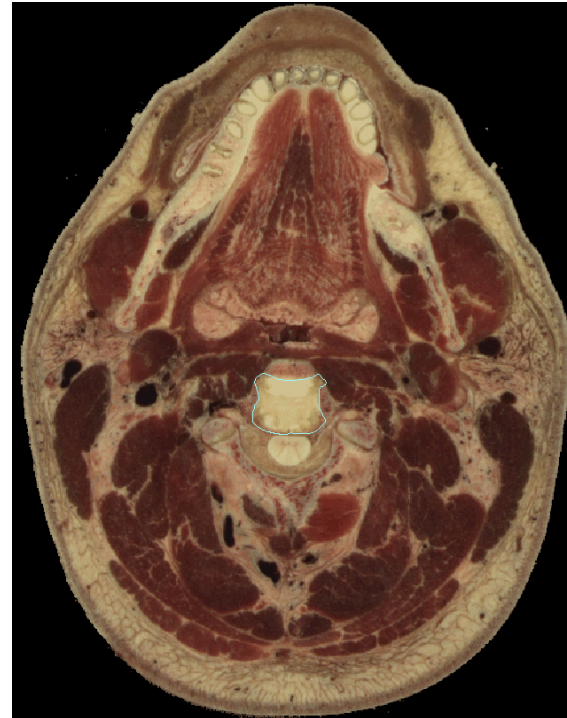
Head-Neck Model Modifications

- **Segmentation and Inclusion of Vasculature, Intervertebral Discs, Larynx, and Airway:** Constructed from CT and color images from the Visible Human Project [1] data.

Vasculature Segmentation

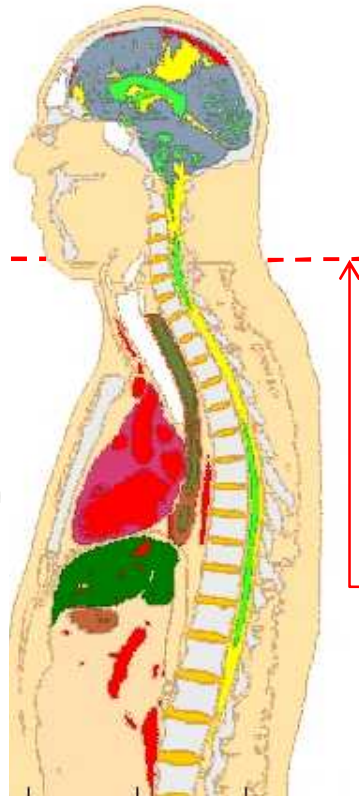


Intervertebral Disc Segmentation



[1] National Institutes of Health, 2007, "The Visible Human Project," National Library of Medicine
http://www.nlm.nih.gov/research/visible/visible_human.html

Joined Head, Neck, & Torso (HNT) Model



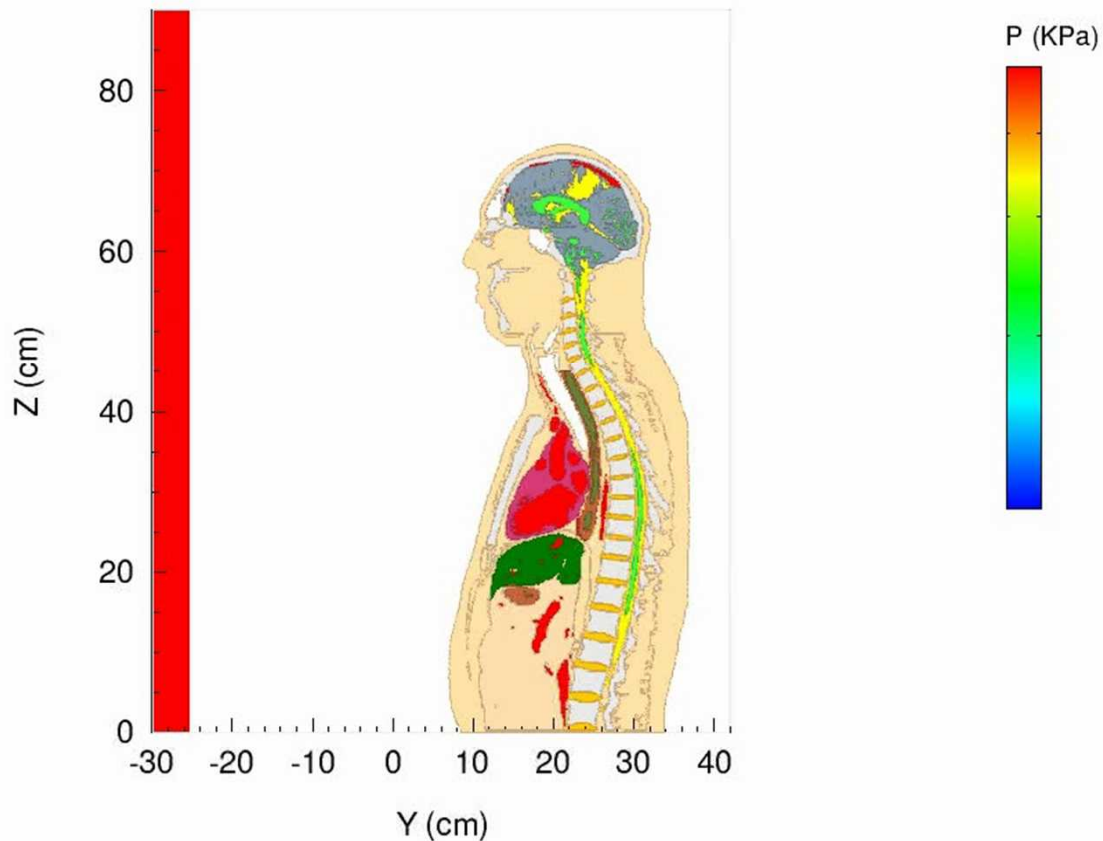
- Includes continuous structures such as the spinal cord and vasculature
- Musculature not currently included in HN portion. Musculature in torso portion currently modeled as the same skin/fat material that exists in HN.

junction location

Frontal Blast Simulations

- HN, Torso, and HNT models all subject to a 360kPa (260kPa overpressure) frontal blast simulation with identical boundary conditions.

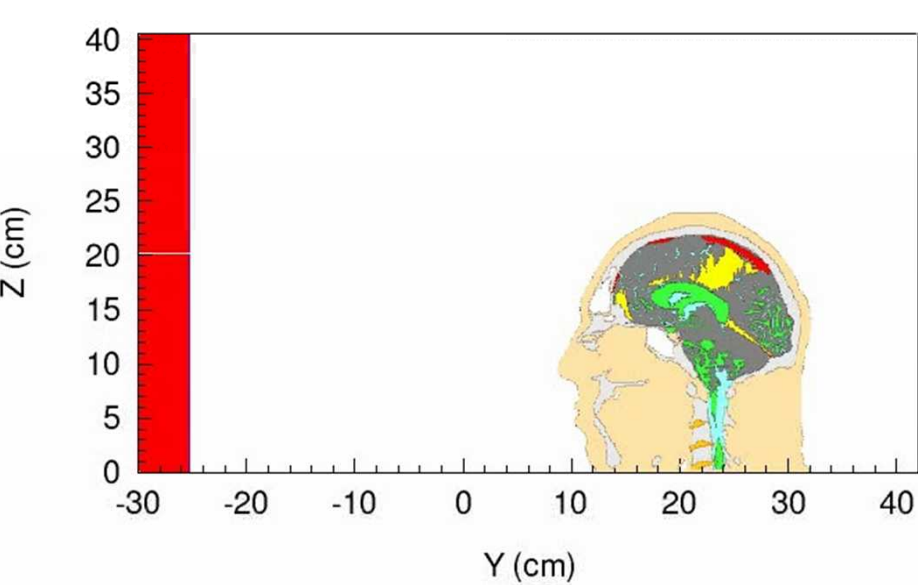
Pressure at 0.00e+00 sec



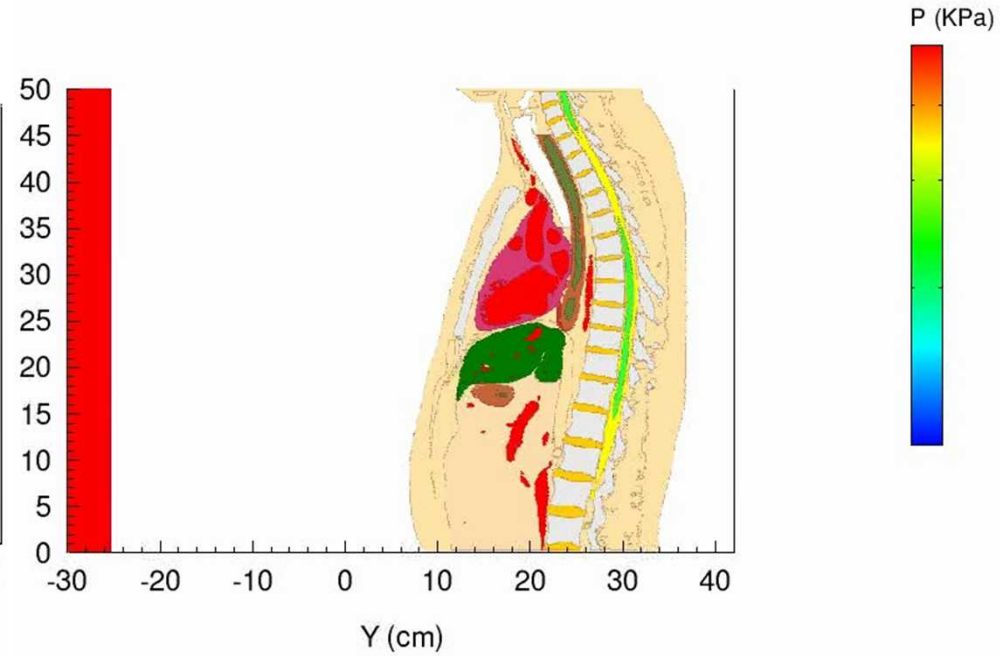


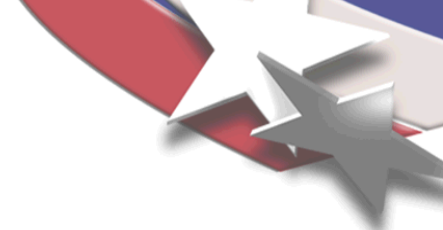
Frontal Blast Simulations Cont.

Pressure at 0.00e+00 sec



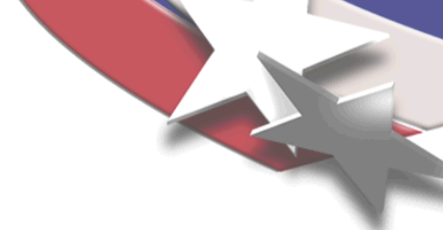
Pressure at 0.00e+00 sec





Continuity Verification

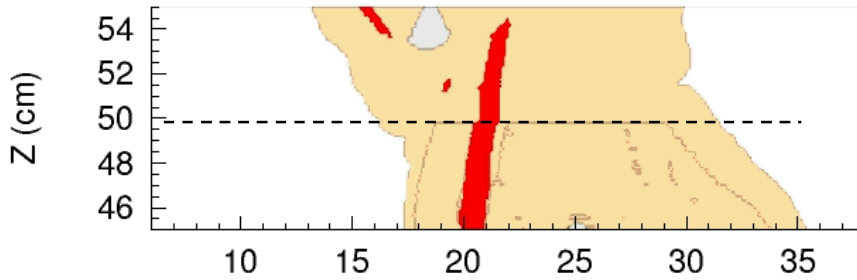
- **Continuity Across Junction**
 - Verifies that HN model is joined accurately to Torso model
 - Verifies that structures exist continuously across junction
 - Some structures are naturally discontinuous across the junction such as the junction between vertebrae and intervertebral discs
- **Qualitative & Quantitative Verification of Continuity Across Junction**
 - Qualitative assessment of pressure in several sagittal cross sections through time
 - Quantitative assessment of pressure, stresses and Lagrangian strains at tracer points placed across junction



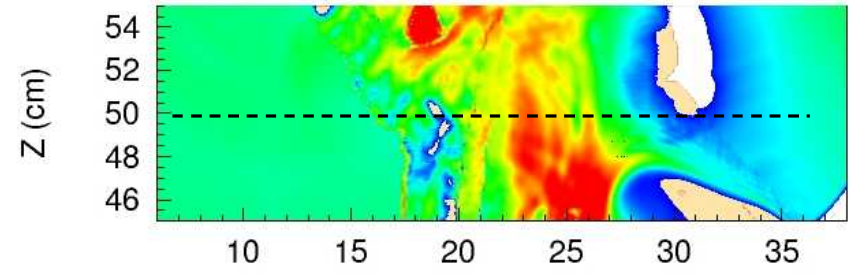
Continuity Verification

Qualitative Assessment Sagittal Cross Section (X=29)

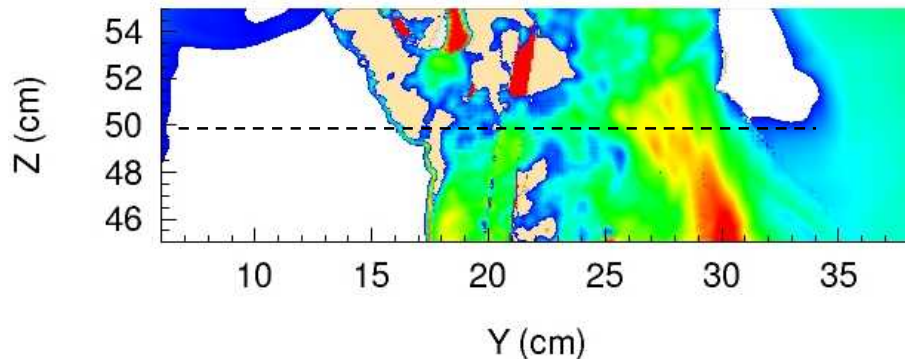
Pressure at 0.00 sec



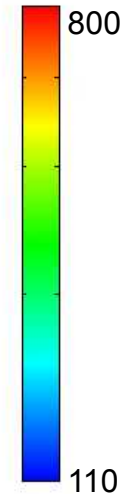
Pressure at 1.12e-3 sec



Pressure at 1.30e-3 sec



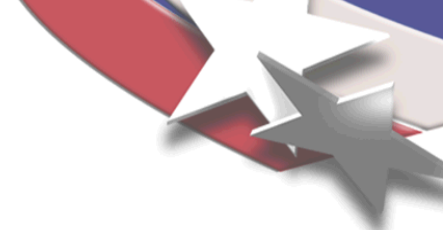
P (KPa)



Y (cm)

----- Represents junction location

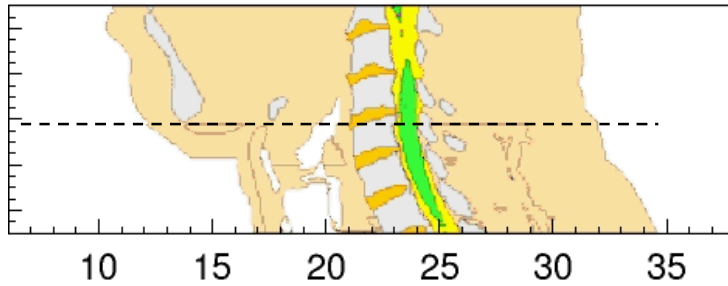
- Continuity across the junction appears to exist by assessment of pressure at X=29



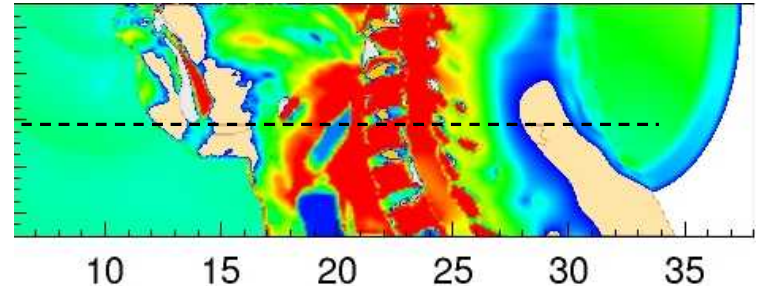
Continuity Verification

Qualitative Assessment Sagittal Cross Section (X=34)

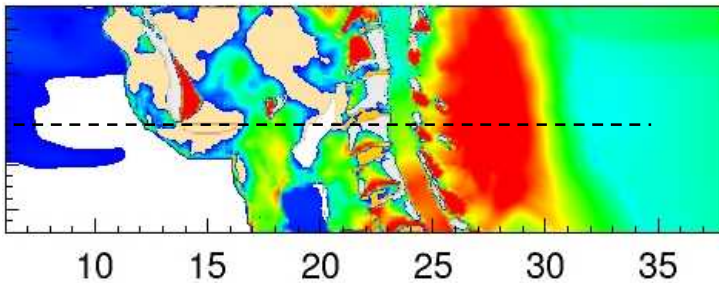
Pressure at 0.00 sec



Pressure at 1.12e-3 sec

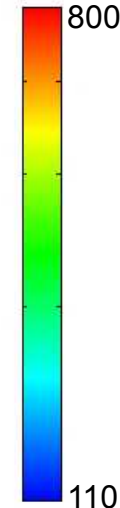


Pressure at 1.30e-3 sec



P (KPa)

800

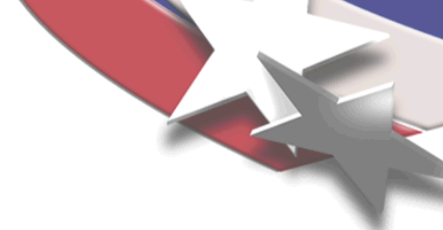


110

Y (cm)

----- Represents junction location

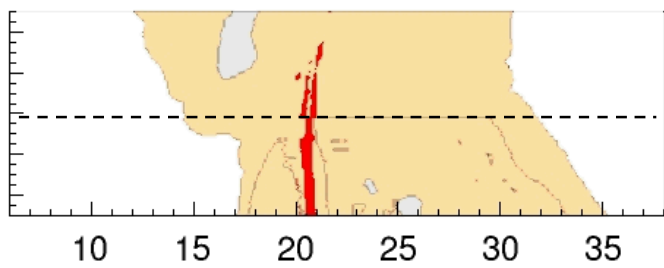
- Continuity across the junction appears to exist by assessment of pressure at X=34



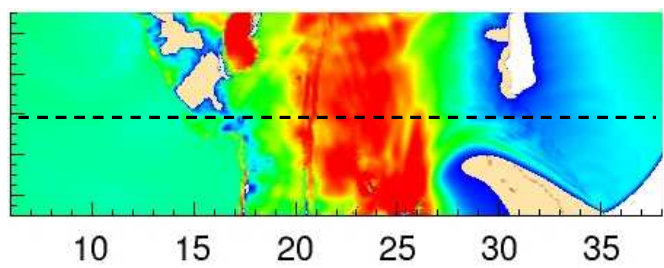
Continuity Verification

Qualitative Assessment Sagittal Cross Section (X=37)

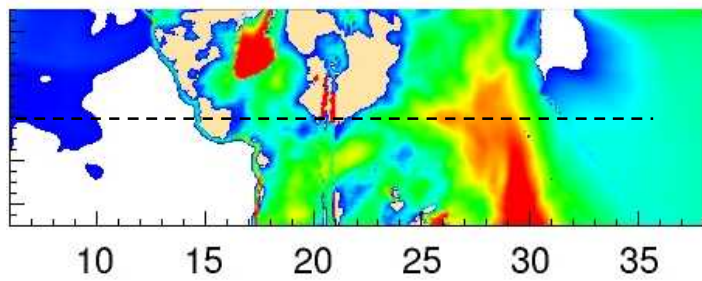
Pressure at 0.00 sec



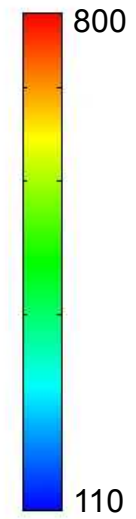
Pressure at 1.12e-3 sec



Pressure at 1.30e-3 sec



P (KPa)



Y (cm)

----- Represents junction location

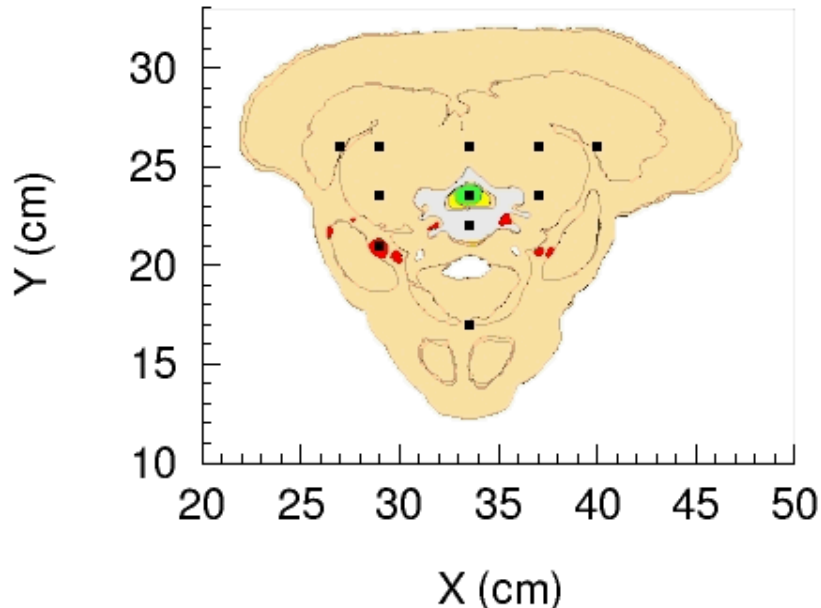
- Continuity across the junction appears to exist by assessment of pressure at X=37

Continuity Verification

Quantitative Assessment

- Quantitative Continuity Verification

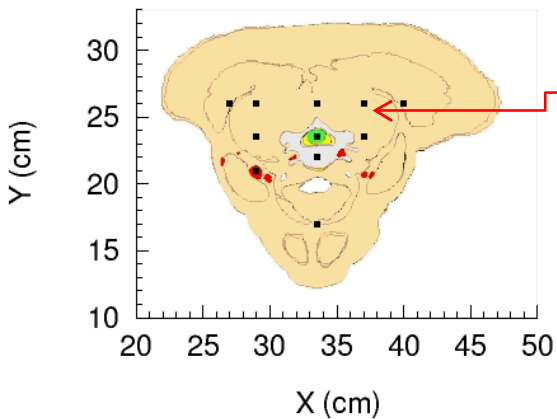
- Lagrangian tracers placed above and below junction to monitor stresses and strains
- Tracers placed in several (x,y) locations and duplicated in a column with each tracer spaced by 1mm in the z direction (spanning 4mm total).



- This image illustrates the tracer positions in the $z=49.65$ plane
- These tracers exist in the same (x,y) locations in the planes $z=49.75$, 49.85 , and 49.95
- Junction location exists at $z=49.80$

Continuity Verification

Quantitative Assessment Cont.

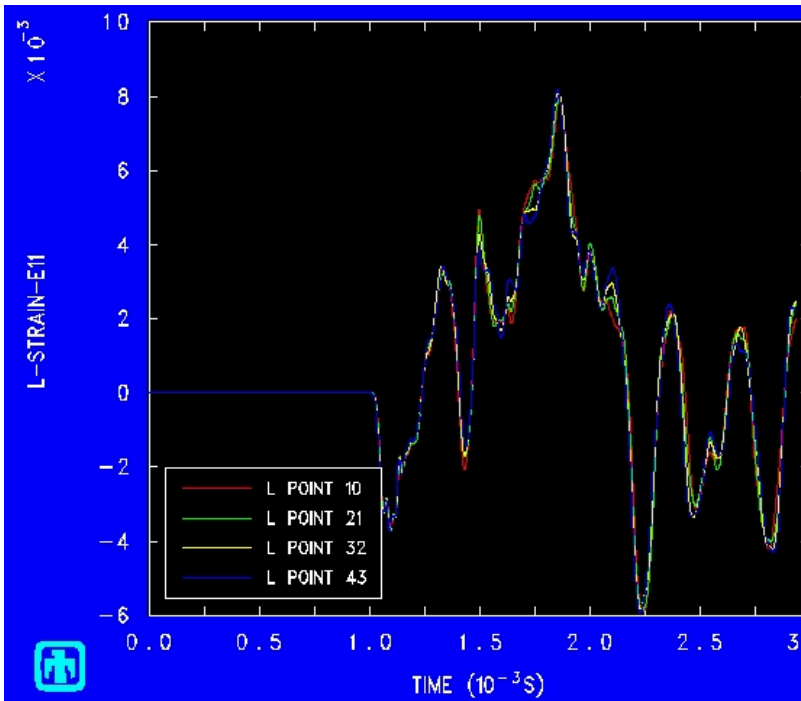
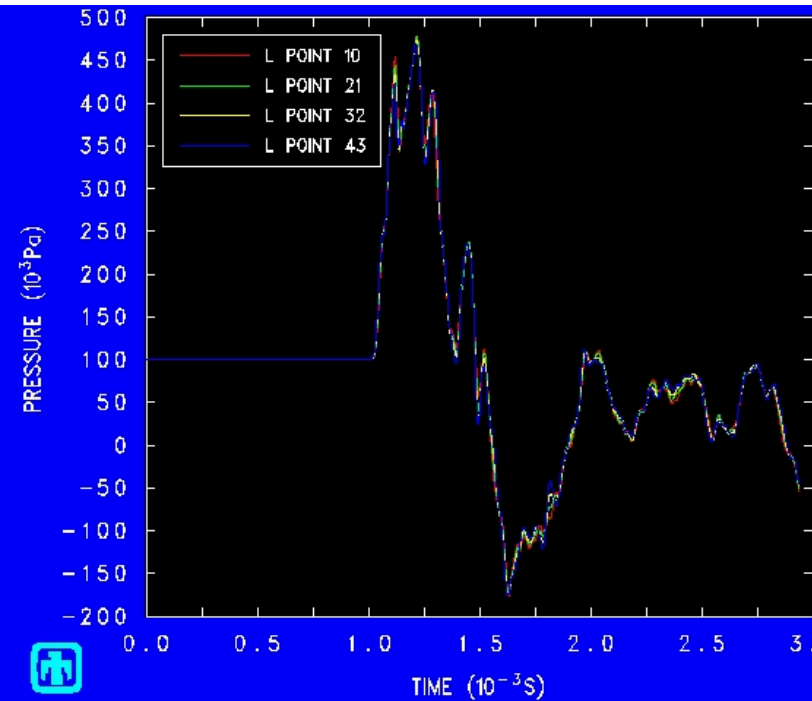


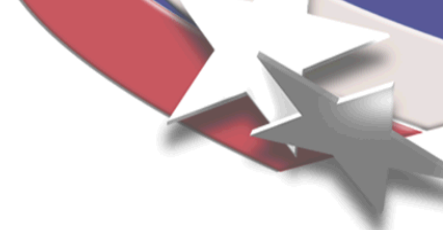
Tracer # 10 ($z=49.65$)

21 ($z=49.75$)

32 ($z=49.85$)

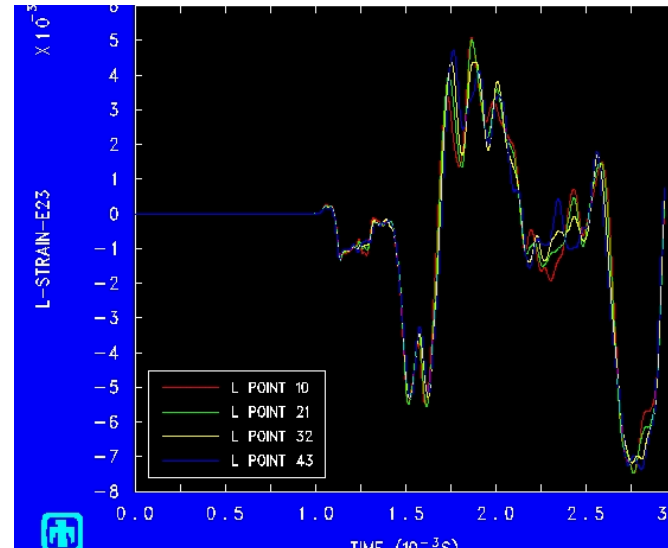
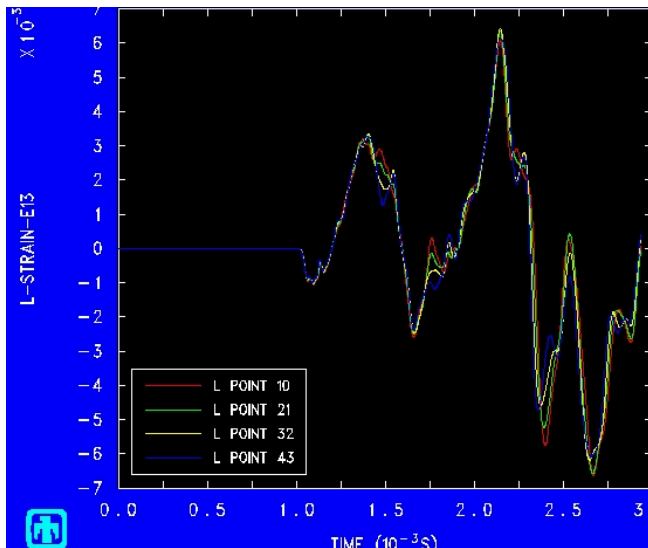
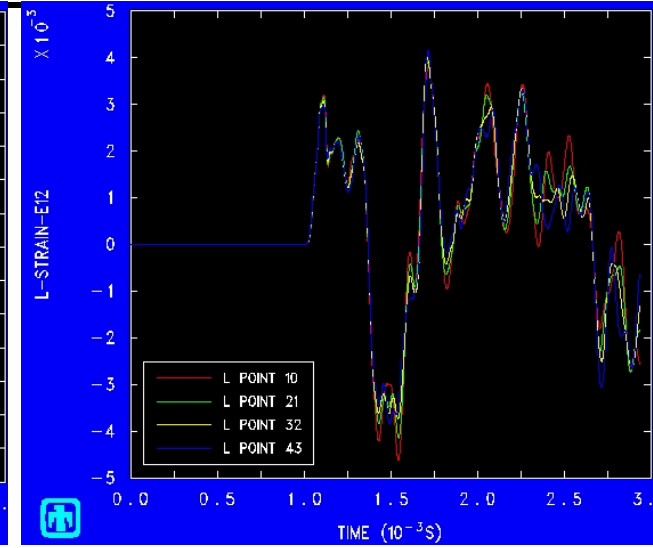
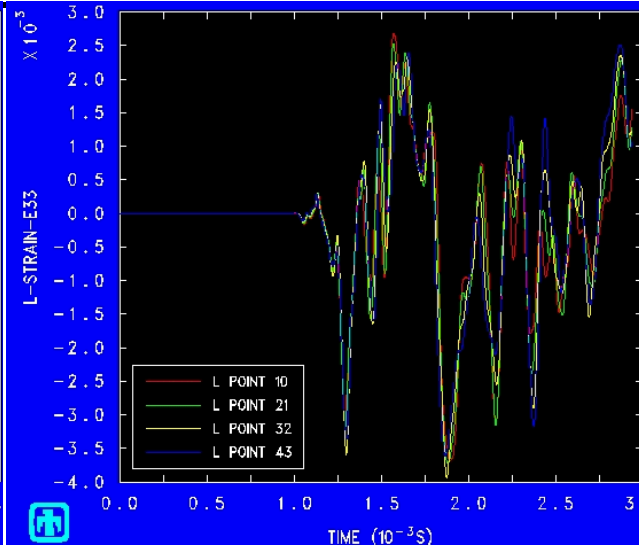
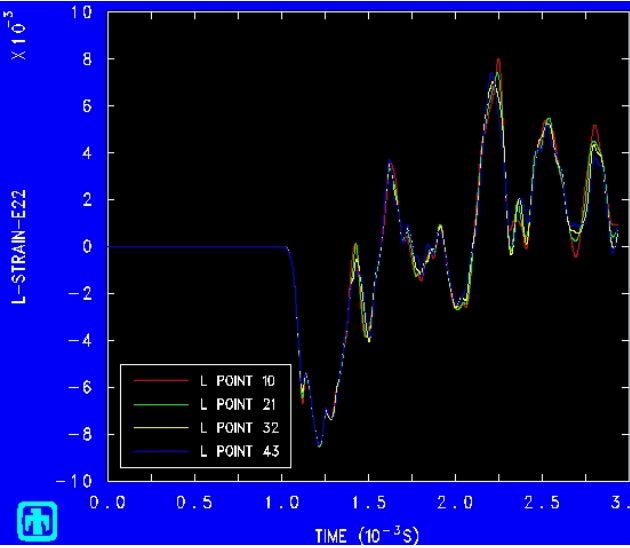
43 ($z=49.95$)





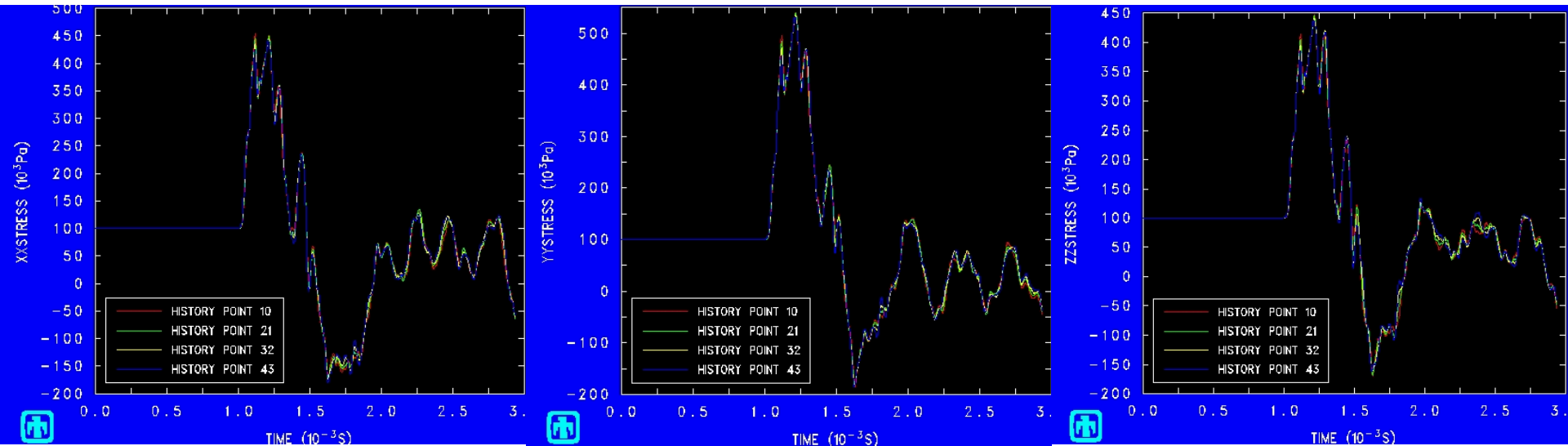
Continuity Verification

Quantitative Assessment Cont.



Continuity Verification

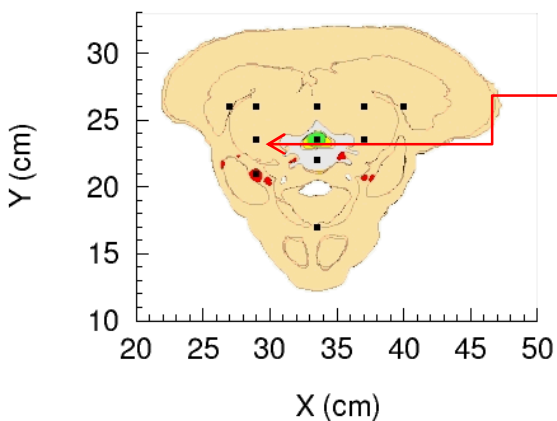
Quantitative Assessment Cont.



The stresses and strains in this column of tracers show continuity. There may be slight magnitude and time differences between the tracers, however, this is to be expected as it is a dynamic problem and the tracers span 4mm of space in the z direction.

Continuity Verification

Quantitative Assessment Cont.

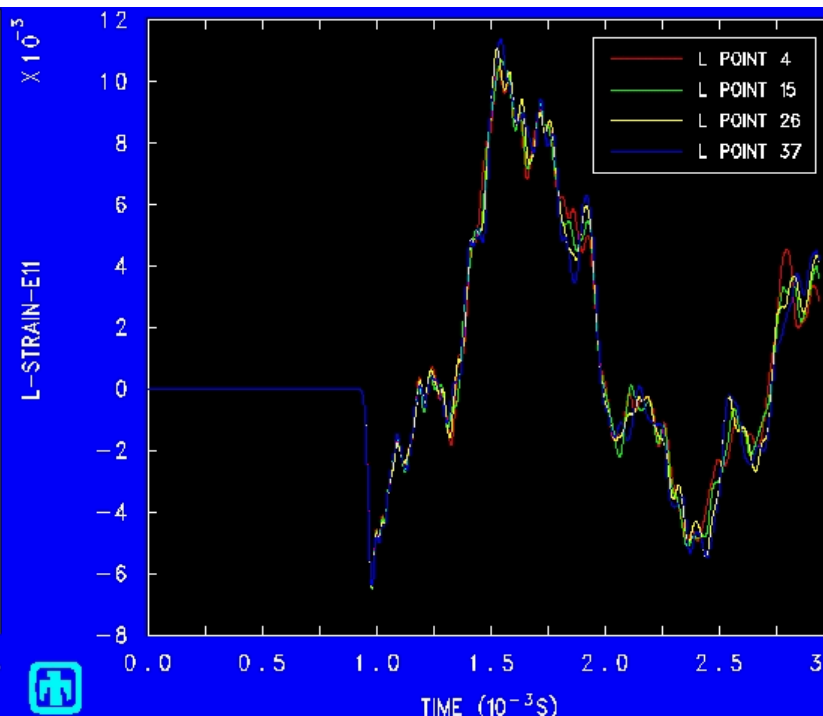
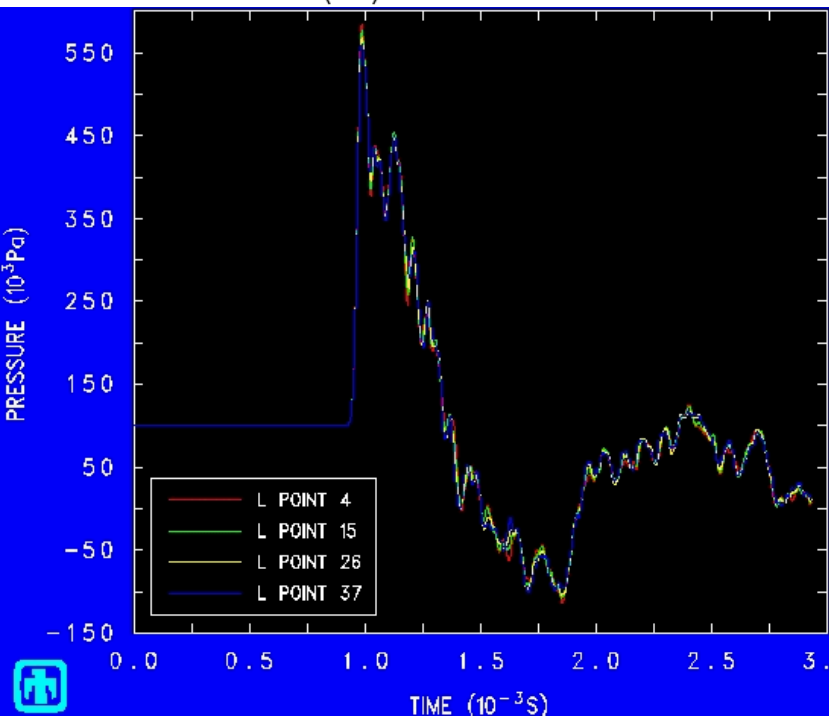


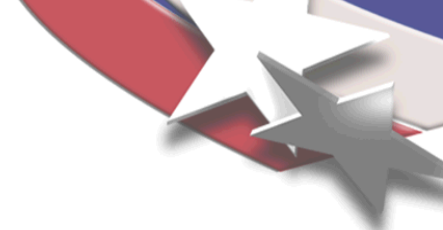
Tracer # 4 ($z=49.65$)

15 ($z=49.75$)

26 ($z=49.85$)

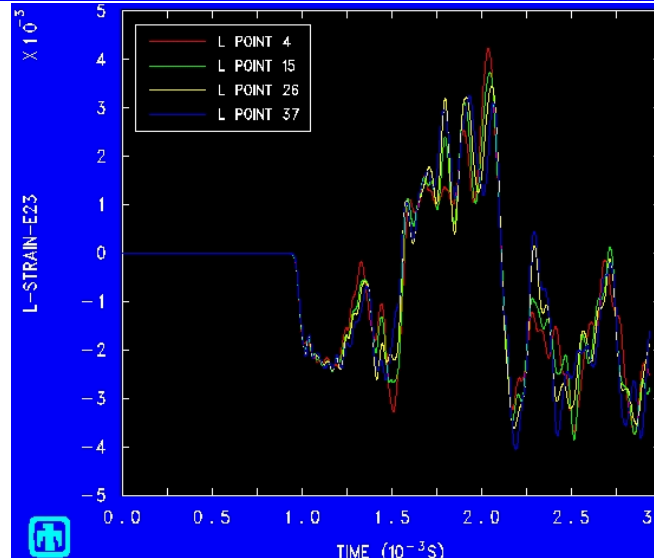
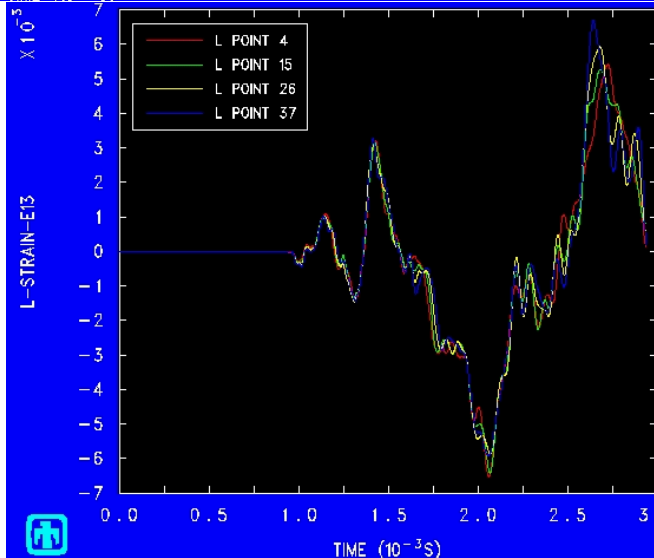
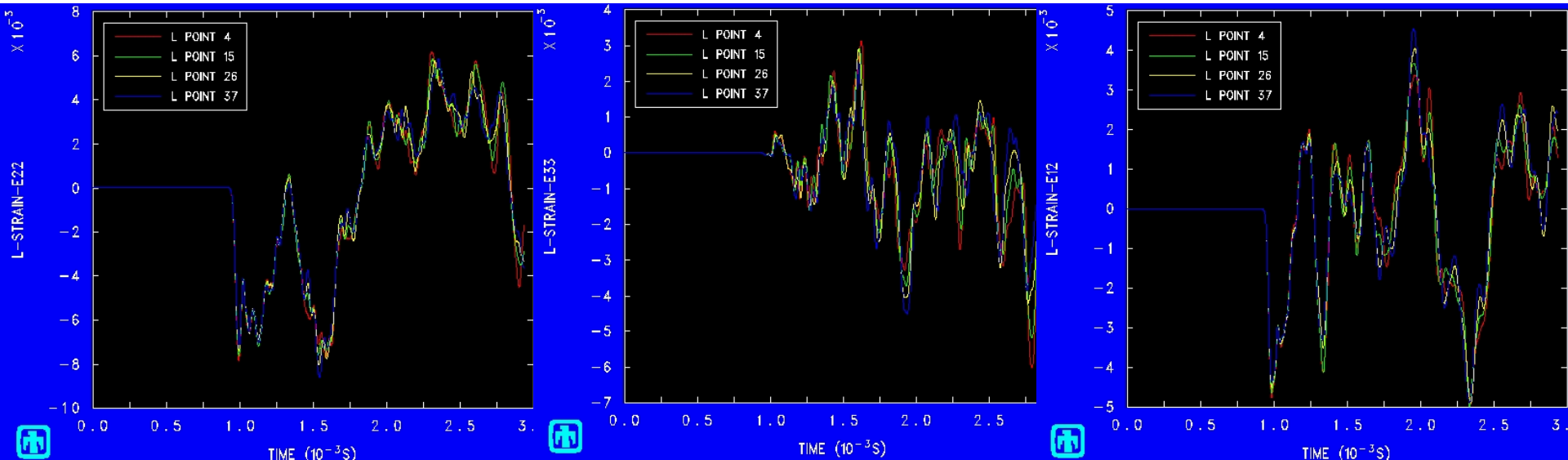
37 ($z=49.95$)





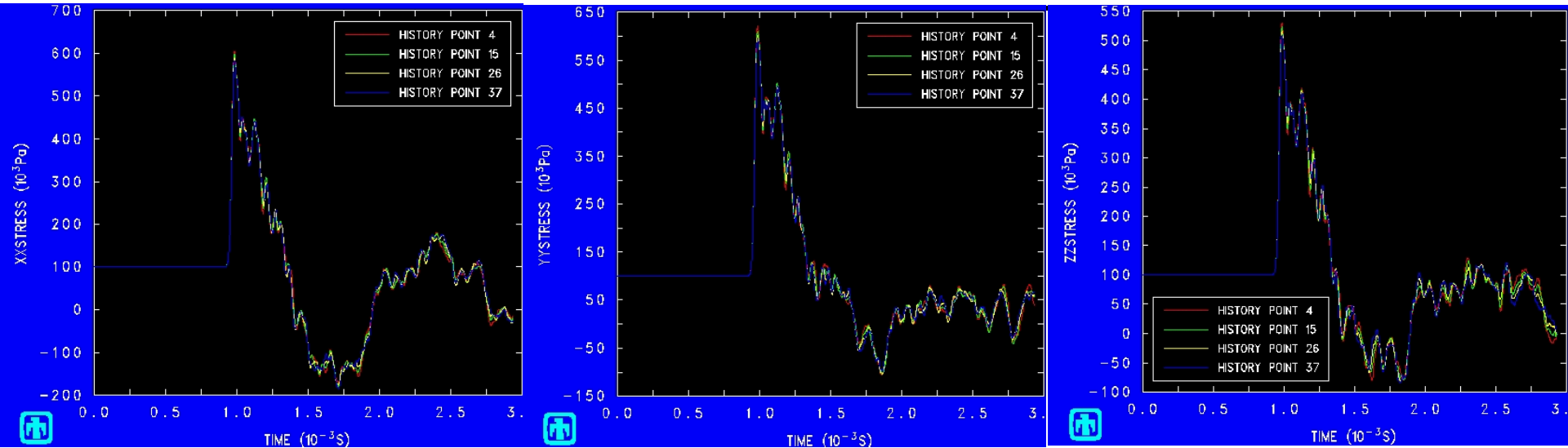
Continuity Verification

Quantitative Assessment Cont.

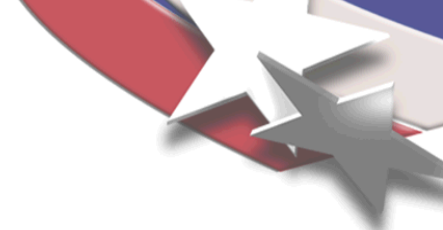


Continuity Verification

Quantitative Assessment Cont.

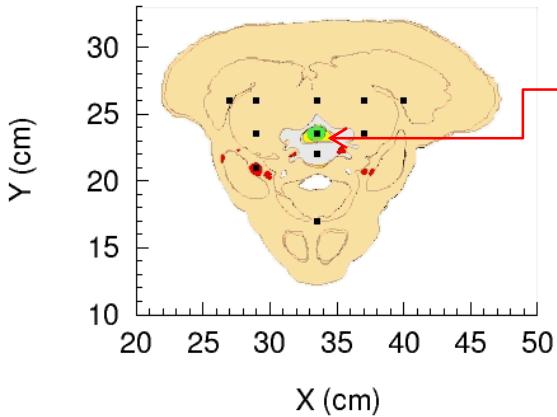


The stresses and strains in this column of tracers show continuity. There may be slight magnitude and time differences between the tracers, however, this is to be expected as it is a dynamic problem and the tracers span 4mm of space in the z direction.



Continuity Verification

Quantitative Assessment Cont.

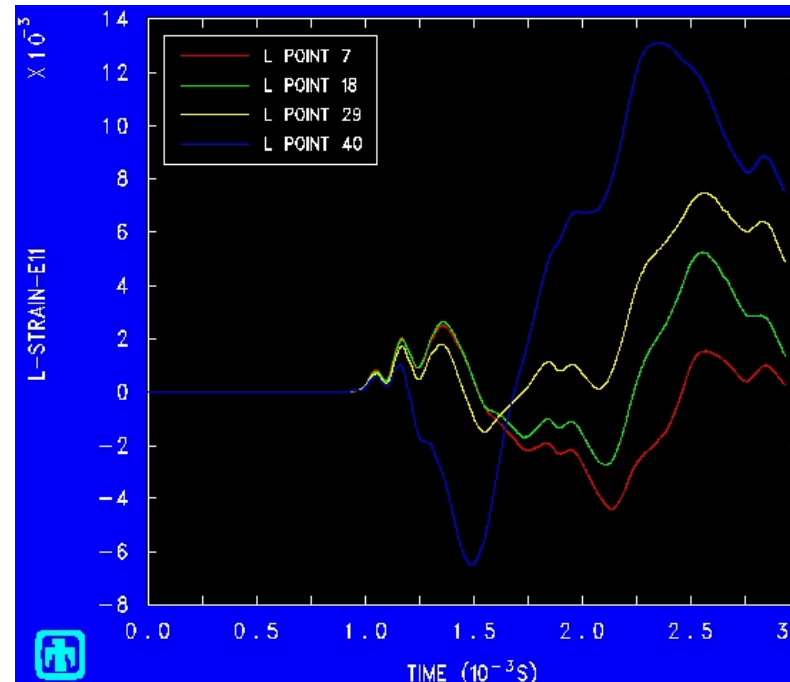
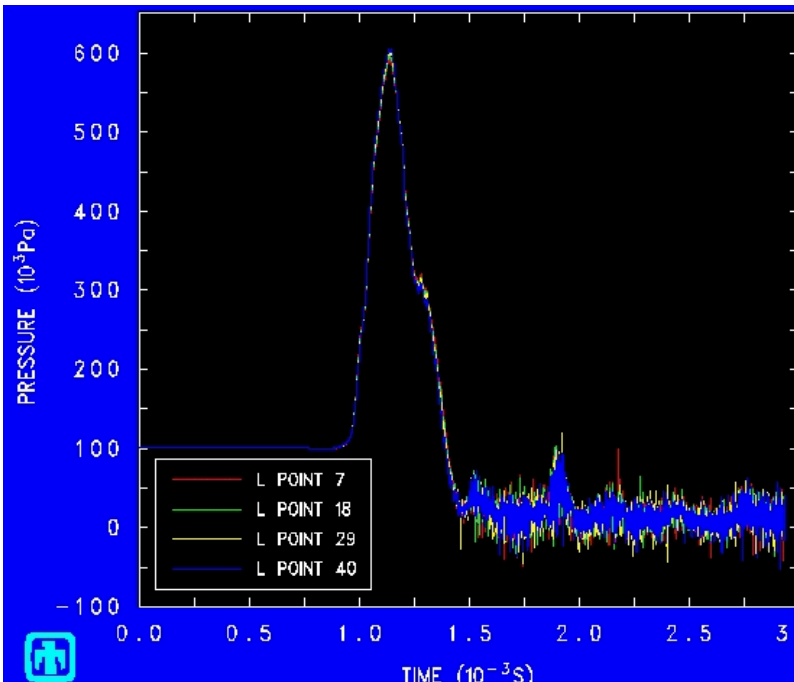


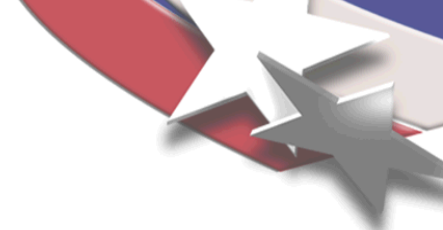
Tracer # 7 ($z=49.65$)

18 ($z=49.75$)

29 ($z=49.85$)

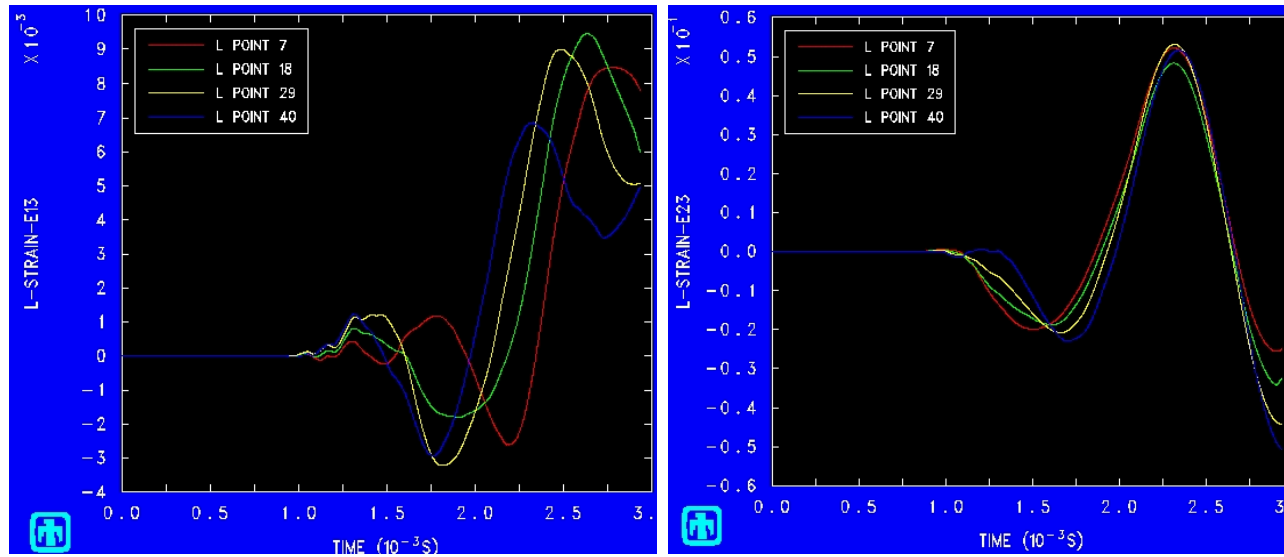
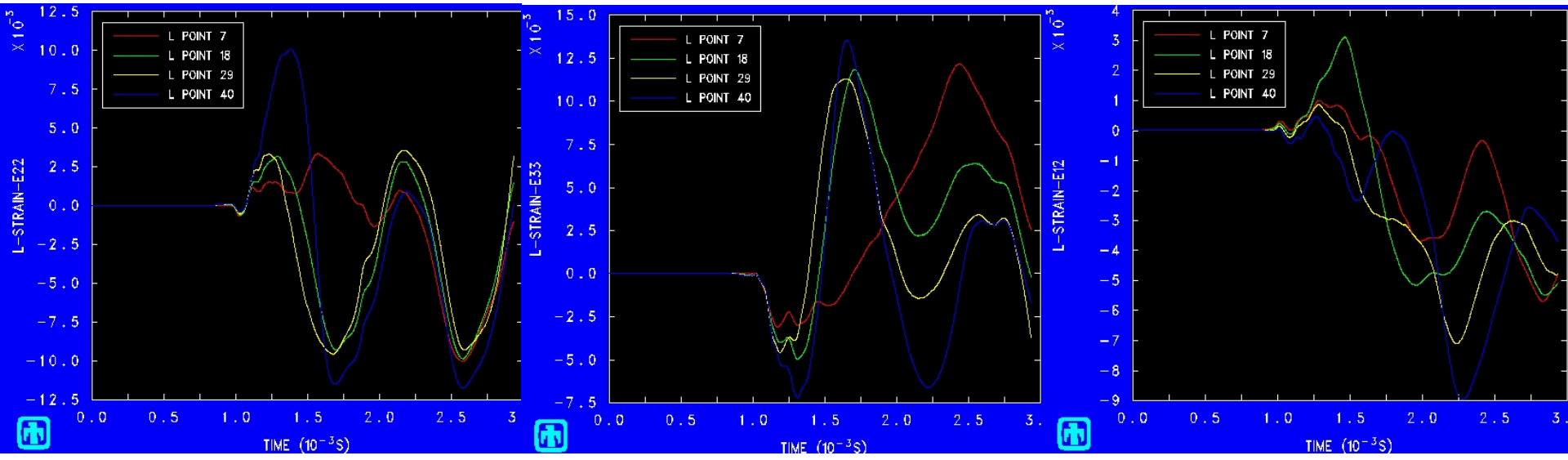
40 ($z=49.95$)





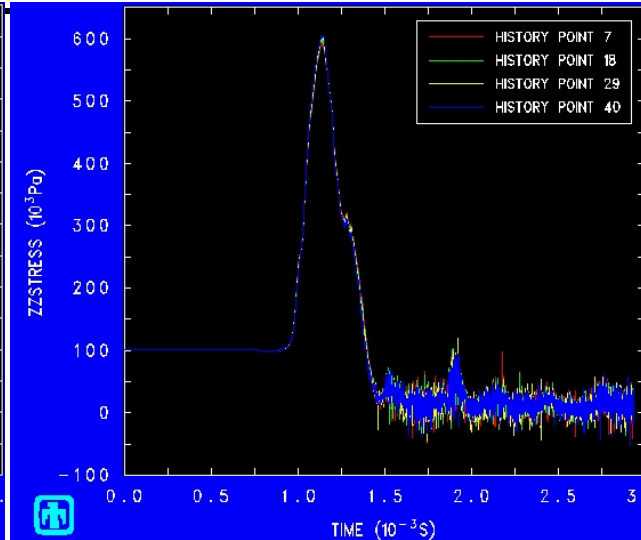
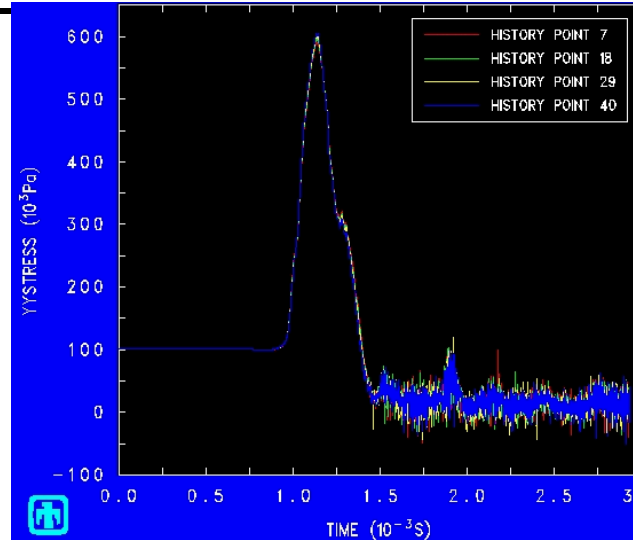
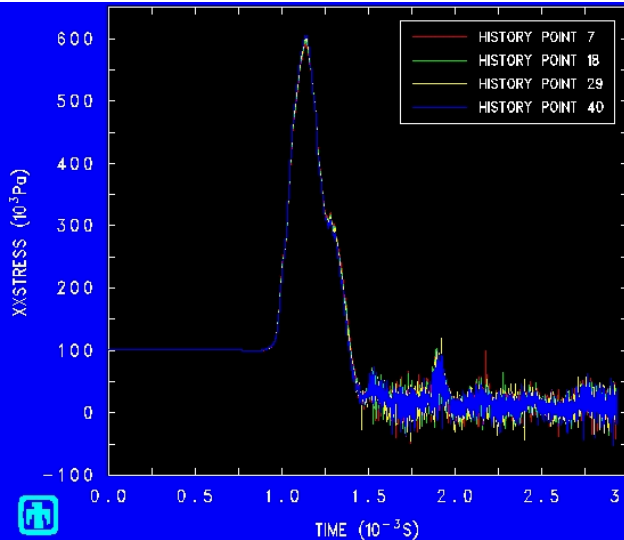
Continuity Verification

Quantitative Assessment Cont.



Continuity Verification

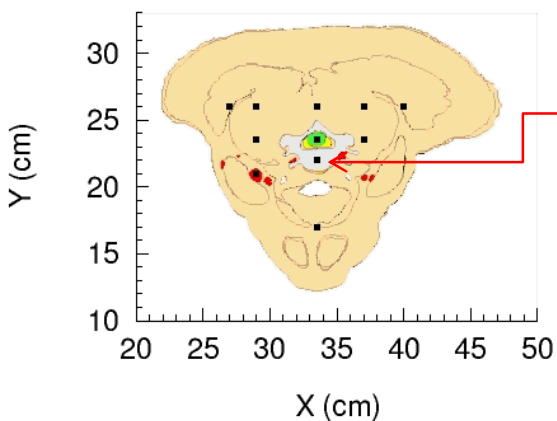
Quantitative Assessment Cont.



It can be seen that there are some differences in these tracers noticeable in the strain plots. These differences are because the tracers are located in mixed material cells. These cells contain various fractions of white matter, grey matter, and cerebrospinal fluid. These variations between cells, and therefore tracers, account for the differences we see. Keeping these variations due to material mixtures in mind, continuity is still thought to be supported by this data.

Continuity Verification

Quantitative Assessment Cont.

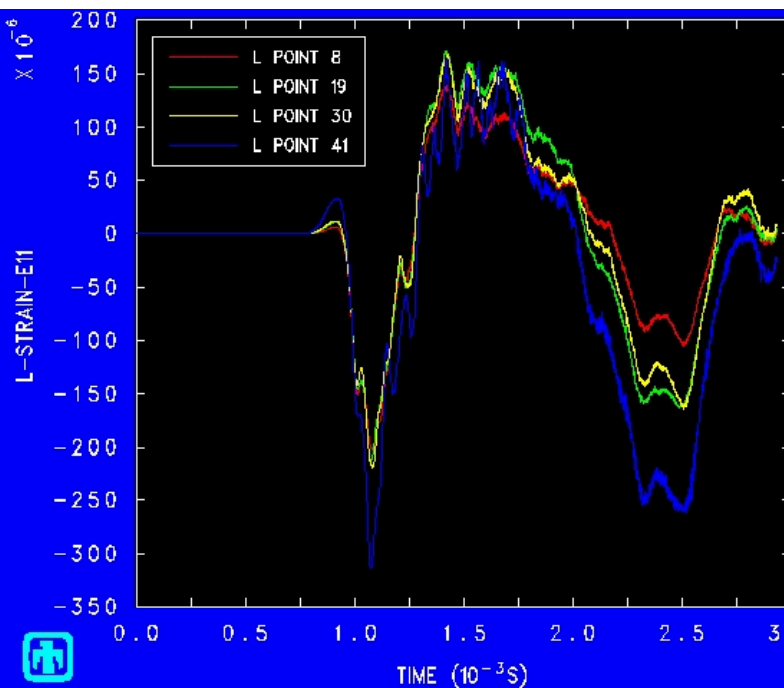
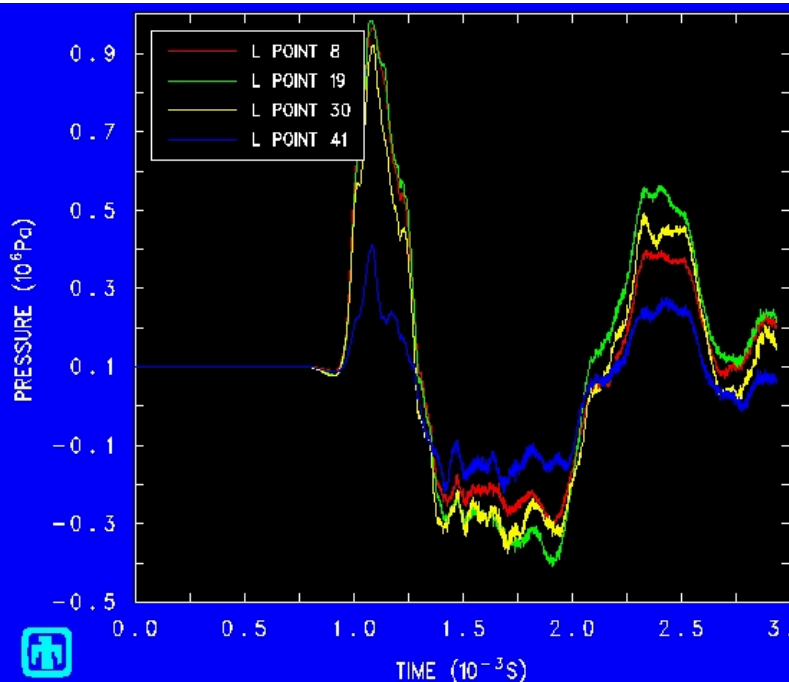


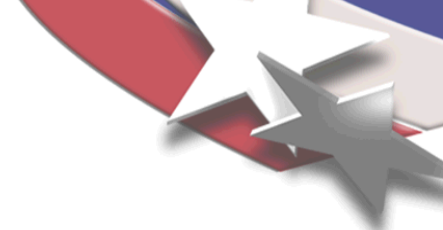
Tracer # 8 ($z=49.65$)

19 ($z=49.75$)

30 ($z=49.85$)

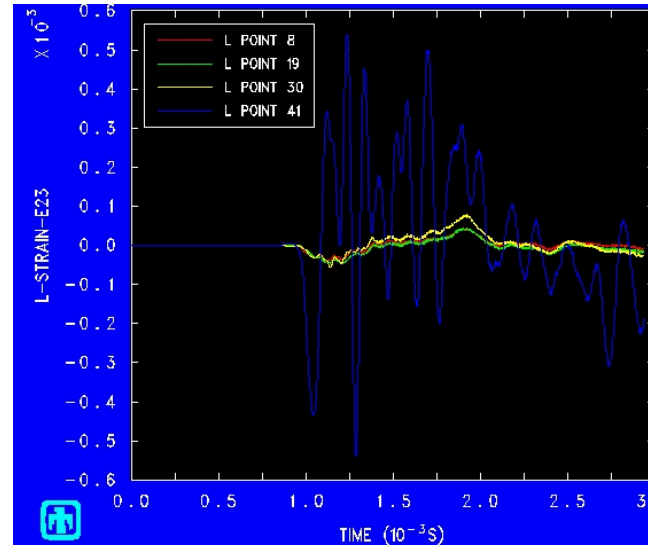
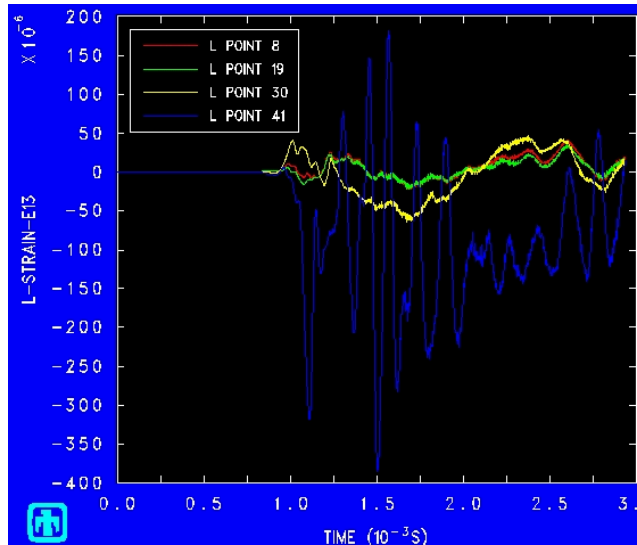
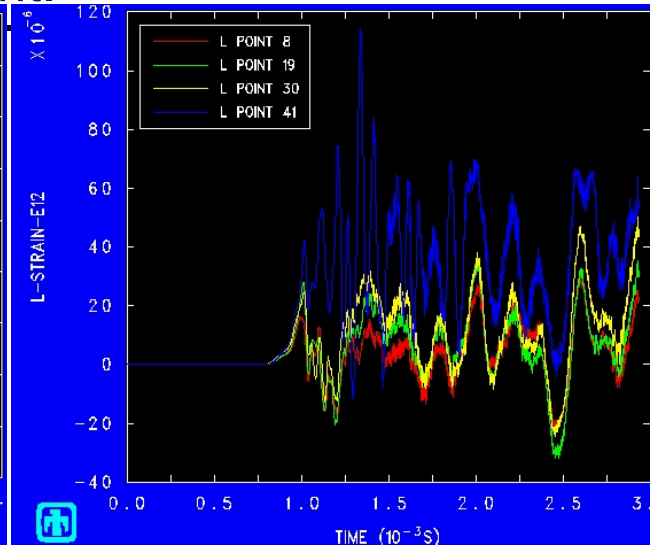
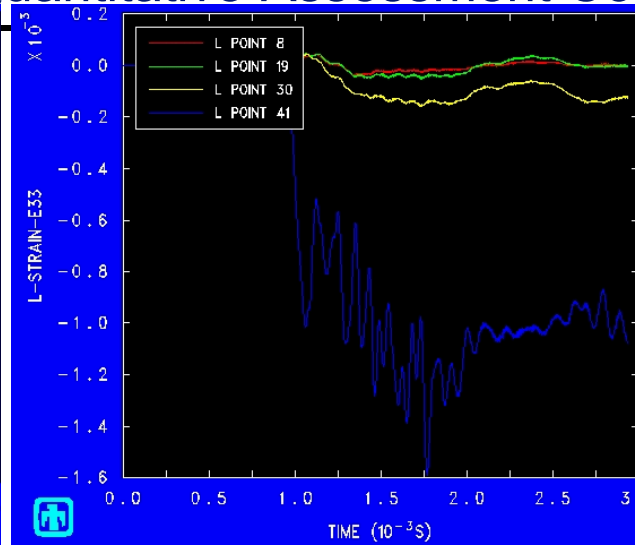
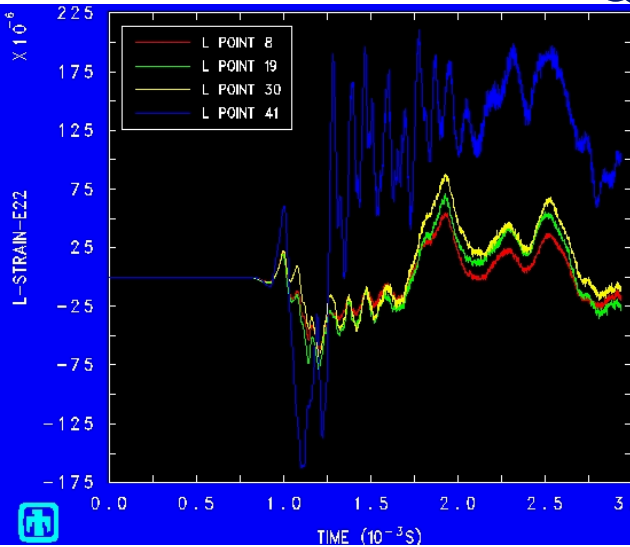
41 ($z=49.95$)





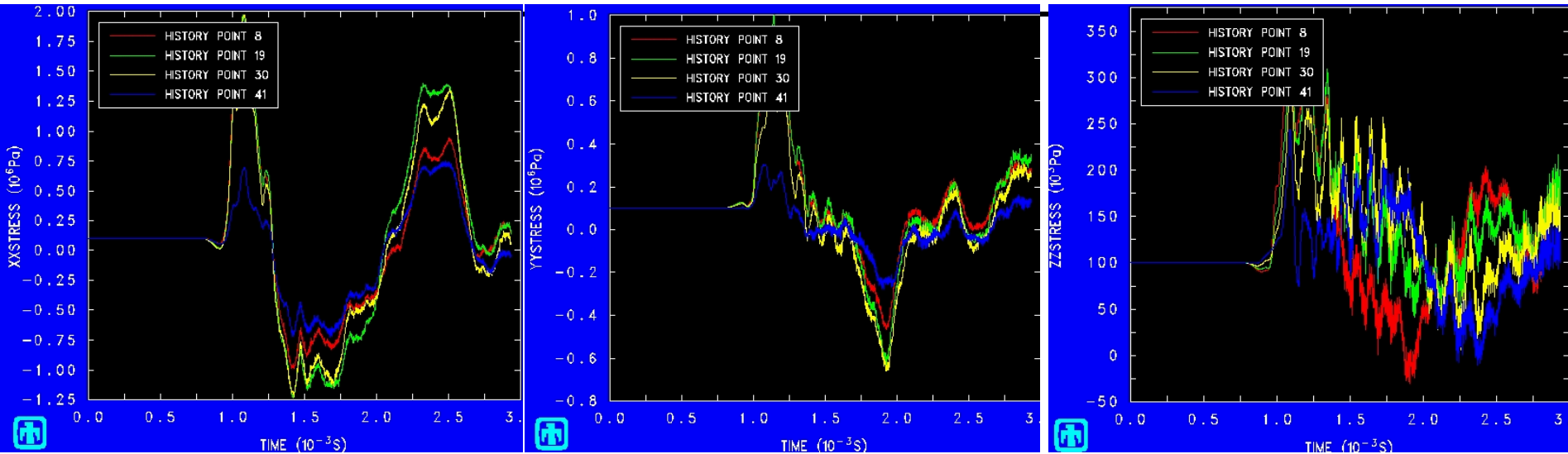
Continuity Verification

Quantitative Assessment Cont.



Continuity Verification

Quantitative Assessment Cont.

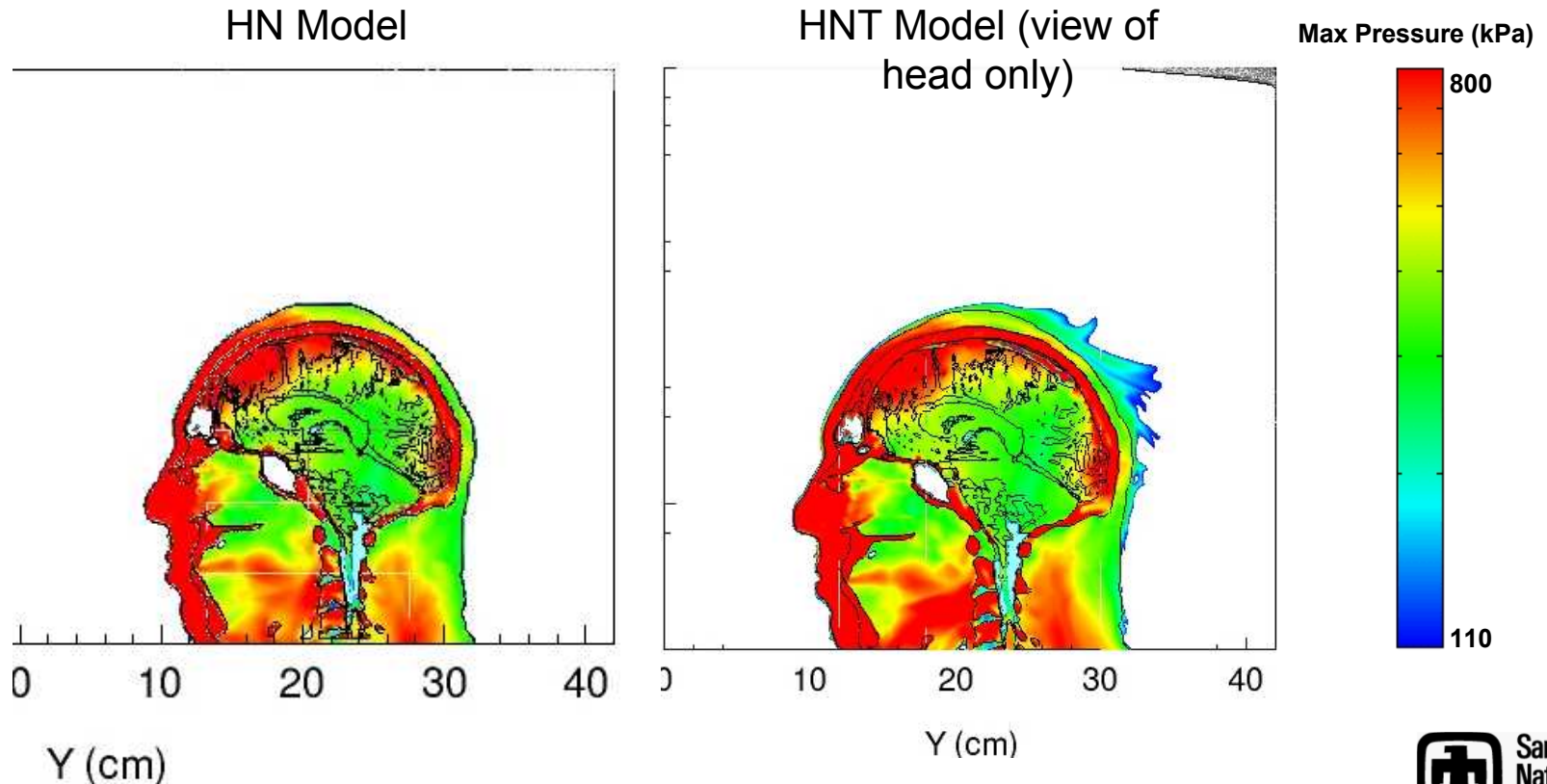


It can be seen that tracer 41 varies from tracers 8, 19, and 30. This is because tracer 41 exists in a mixed material cell consisting of both bone (from the vertebra) and cartilage (from the intervertebral disc) whereas tracers 8, 19, and 30 exist in cells consisting solely of bone. With the variation in tracer 41 accounted for and keeping in mind variations in magnitude and time due to the spatial span of the tracers, this data supports continuity.

Boundary Condition Impact

Qualitative Assessment of Maximum Pressure

- Maximum Pressure at the simulation end time (3.0×10^{-3} sec) of HN model is assessed in comparison with HNT model to qualitatively evaluate possible boundary condition impacts.





Boundary Condition Impact noted limitations

- Pressure waves develop at the upper boundary of the Torso model blast simulation at late times.
- Reflective boundaries must be sufficiently far away from models to prevent reflective pressure waves from impacting the model multiple times. This increases the computational space and the computational expense.



Summary

- Joining the HN and Torso models reduces boundary condition limitations and allows for broader applicability
- The increased size and computational space necessary for the HNT model creates an increase in computational expense above the truncated models of about 3.5x (~48 hr for HN, ~168 hr for HNT)
- A quick qualitative assessment of the variation in maximum pressure between HN and HNT simulations suggests that for certain problems where computational expense is to be kept to a minimum, the truncated model may be an appropriate substitute. Further work must be conducted in assessing variations. The problem details would ultimately drive the decision to utilize the full model or truncated model.