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PANTHER: Development of a Predictive Multiscale Traumatic Brain Injury Model

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PANTHER

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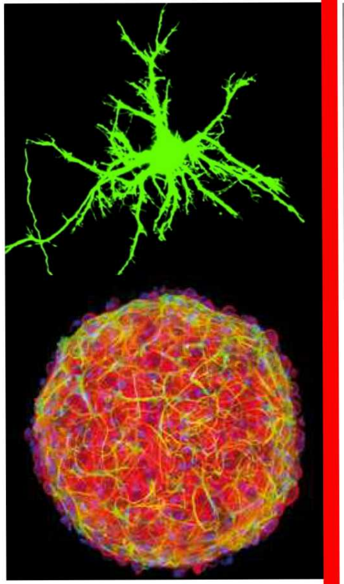
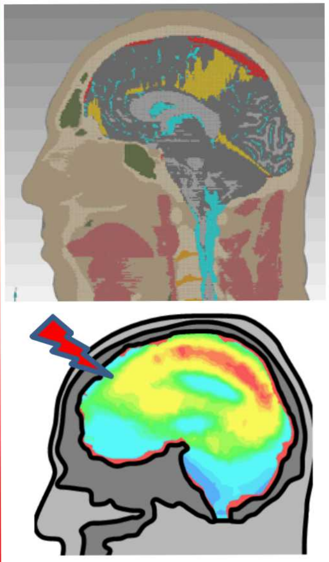
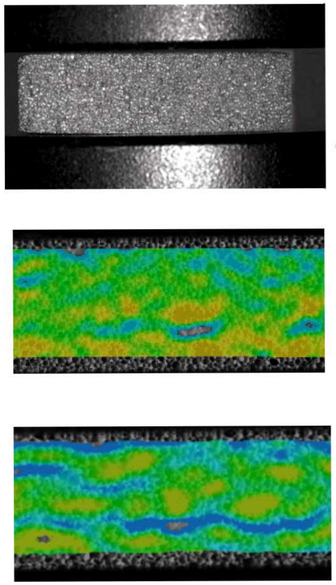
Background

Define neural injury tolerances	Predict injuries via high-fidelity head simulations	Develop impact and real-time head motion sensors	Characterize protective capacity of advanced materials	Design innovative helmets & test methods for brain protection
10^{-7} - 10^{-2}m	10^{-4} - 10^{-1}m	10^{-3} - 10^{-1}m	10^{-4} - 10^{-1}m	10^{0}m
10^{-3} - 10^{2}s	10^{-3} - 10^{-1}s	10^{-3} - 10^{2}s	10^{-3} - 10^{2}s	







Focus on injury initiation, detection & prevention from cells up to organism

OBJECTIVE

- The Sandia Injury Biomechanics Laboratory (SIBL) contributes to the PANTHER team through the development of a numerical framework of a high-fidelity human digital twin.
- The framework allows for the assessment of injury risk from head impact conditions, such as from the ACH Mil Spec, using PANTHER's cellular-based mild traumatic brain injury (cbmTBI) criterion.

TECHNICAL APPROACH

- GEOMETRY: We created a high-fidelity geometric model of the human head and neck, consisting of 5.7M hexahedral finite elements at a nominal resolution of 1-mm^3.

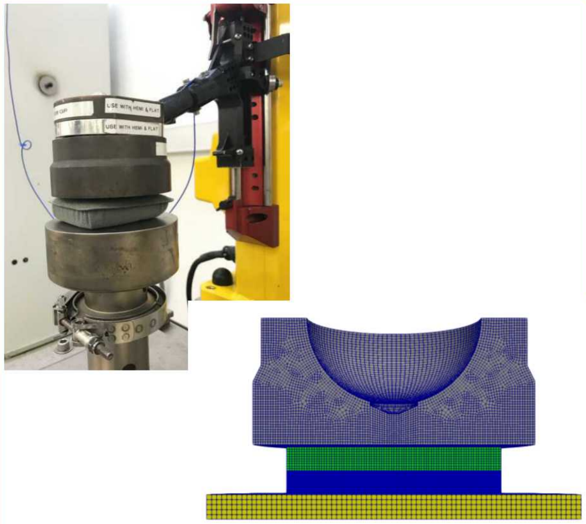
- MATERIALS: We created high-fidelity material models for the human tissues and helmet constituents, with emphasis on the hard/soft foam layers.

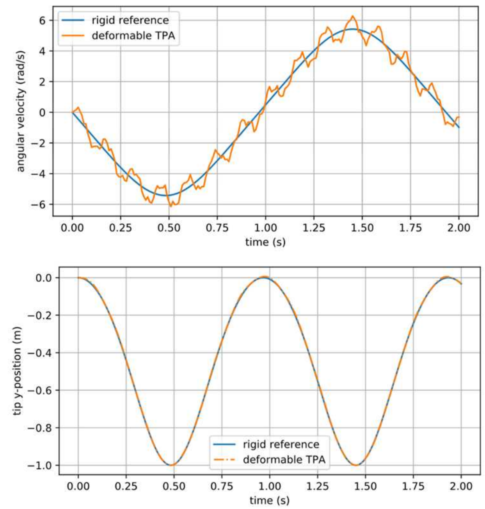
- SOLVER: With the Sandia Sierra Solid Mechanics (SSM) solver and post-processing algorithms, we quantified brain strain and strain rate, for use in the cbmTBI criterion.

ACCOMPLISHMENTS

- Foam characterization.
- Three-point angular velocity (tpav) algorithm.
- Invariant strain and strain rate implementations and verifications.
- Angular rotation cases.
- Application of cellular-based injury risk criterion.

Success Stories





Then, the **Mises Green-Lagrange strain rate** is

$$\dot{\mathsf{E}}_{\mathrm{VM}} = \sqrt{\frac{2}{3}\,\mathrm{dev}(\dot{\mathbf{E}}) : \mathrm{dev}(\dot{\mathbf{E}})} = \sqrt{\frac{4}{3} J_2(\dot{\mathbf{E}})}.$$

Similarly, the **Mises Green-Lagrange strain** is

$$\mathsf{E}_{\mathrm{VM}} = \sqrt{\frac{2}{3}\,\mathrm{dev}(\mathbf{E}) : \mathrm{dev}(\mathbf{E})} = \sqrt{\frac{4}{3} J_2(\mathbf{E})}.$$

Foam Characterization

Sandia characterized foam pad using two approaches: component and system.

The component approach considered the hard foam (protective layer) in isolation, then the soft foam (comfort layer) in isolation. Material properties were matched to these individual constituents.

Then, the entire pad, composed of the two foam layers and the cloth/plastic enclosure were modeled, to achieve a system response.

tpav Algorithm

During and after impact, the head deforms but can also rotate, leading to potentially injury strain and strain rates.

To quantify the quasi-rigid body motion of a deformable model, a method was developed and verified.

The three-point angular velocity (tpav) algorithm allows for characterization of large-scale head angular motion from a deformable model.

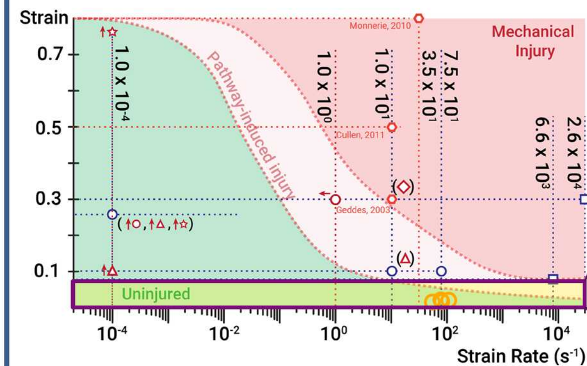
Invariant Strain and Rate Measures

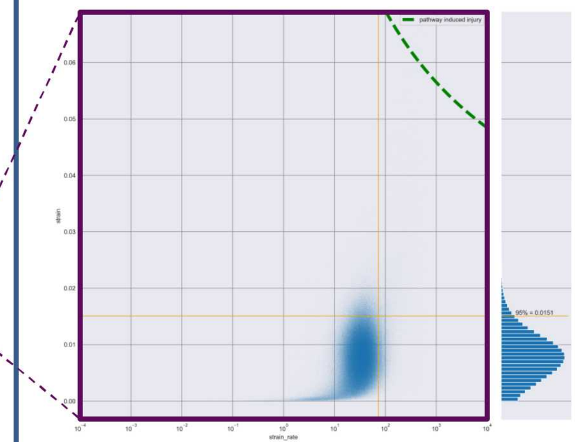
The existing Sierra Solid Mechanics (SSM) solver natively uses the rate of deformation tensor, **d**.

However, our experimental collaborators needed the strain and rate quantities expressed in the Green-Lagrange framework for meaning comparison with their experimental data.

We implemented several invariant measures to match the solver output with collaborators' natural experimental metrics.

Success Stories





Rotational Cases

After successfully simulating the standard Military Specification (translation-only) case, we moved to simulating rotations.

Initially, we used an offset angle to impart rotations. Subsequently, we found the lack of the chinstrap to be troublesome for comparison of simulation to experimental results.

Thereafter, we began using experimental translation and rotation data as boundary conditions to the bone layer, with success.

Applications

We plot strain and strain rate of the brain's gray and white matter atop the conceptual injury risk diagram.

For the translational cases, we found the strain and strain rates to be below the threshold for pathway-induced injury.

For rotational cases, we found strain and strain rate metrics to be elevated. This result has motivated the call to modify the current Mil-Spec to include a rotational component.

Applications (cont.)

Several tools were built in Python for verification and validation, characterization, data processing, post-processing, and visualization.

One example of these tools is the strain versus strain rate histogram, which demonstrates the spread of strain and strain rate for an entire population of brain (gray and white) voxels. The 95th percentile is used as upper-bound metric to avoid reporting noise and outliers.

ISSUES

- No issues.

CONCLUSIONS

- We have completed a numerical **framework** of a high-fidelity human head/neck **digital twin** to quantify strain and strain rate of the brain.

- This quantification, used with the cellular injury risk criterion, allows for the **prediction** of head **injury** following exposure to blunt impact.

- The Navy and the Traumatic Brain Injury Community have cellular-based injury risk tool, which now can be used in **assessments** of personal protective equipment (**PPE**).

PATH FORWARD

Activities Schedule	FY17	FY18	FY19	FY20	FY21	FY22	FY23
Verification and Validation							
Materials harmonization					◆ (Start)		
Results harmonization (2D versus 3D results)					● (Milestone)		
Voxel convergence study					● (Milestone)		
Geometry refinement					● (Milestone)		
Project Closeout (6/30/21)					◆ (Tests, Demos, & Key Events)		

◆ Start ◆ Tests, Demos, & Key Events ● Milestone ▲ S&T Delivery

PUBLICATIONS, PATENTS, PRESENTATIONS, & AWARDS

- Submitted: MHSRS Abstract:

  Why the Helmet Military Specification Test Should be Revised to Include a Rotational Component

- Work in progress (“Mil-Spec Paper”).

COOPERATIVE DEVELOPMENT

- **The current work builds on previous development**
  - **Head/Neck model supported by James Mackiewicz ONR Code 30.**
  - **Leveraged Air Force Life Cycle Management Center program for development and verification of digital filtering.**
  - **Leveraged internal program, Environment Safety & Health, to utilize two Python framework tools (HIC and Butterworth**

COLLABORATION & DISCUSSION

- **Future proposed work on Verification and Validation would include "harmonization" tasks would be done in collaboration with Rika Wright Carlsen, Ph.D., of Robert Morris University.**