SAND2018-7475C

Numerical Cadaver Drop Test Framework to Quantify and Mitigate Injury Risk

Chad B. Hovey
chovey@sandia.gov

Candice Cooper
cfcoope@sandia.gov

Douglas A. Dederman
dadeder@sandia.gov

Award Period (5/11/18 to 9/30/20)
Presented: Wednesday July 18, 2018
Computational & Cellular Biology of Blast (C2B2) And Combat Casualty Care (CCC) Program Review

Development of a Predictive Multiscale Traumatic Brain Injury Model

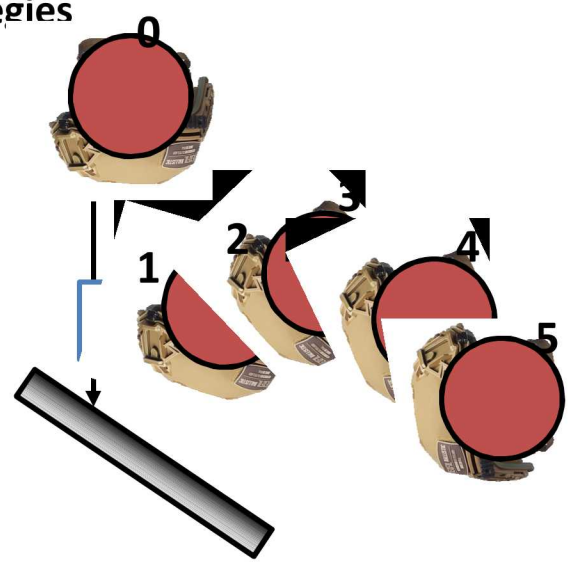
Description: Team Wendy - Investigate mechanisms of cavitation-induced brain tissue damage resulting from blast & impact to the Naval warfighter. Develop and extend the Sandia Head-Neck-Torso simulation framework in 3 phases – Verify simulations w/Experimental drop tests, Integrate the Brown mTBI cellular injury criteria into the computational framework, and evaluate Team Wendy pad suspension system foam using phase 1 and phase 2 results

Naval Need:

- Blast & blunt impact to naval warfighters may induce fluid cavitation within the brain potentially leading to TBI
- Investigating this phenomenon leads to an understanding of the injury mechanisms & provides tools to investigate injury mitigation strategies with advanced personal armor

FY18 Accomplishments:

- Bi-Weekly team telecon meetings
- Project Funding Received May 2018, Project Plan established
- Government use Hovey Tools distributed to project team – Digital Filter, HIC
- Sierra Solid Mechanics (SSM) testbed setup for 2x2 matrix sims
- Tracking experimental characterization of foams for SSM use
- Validation: Performing comparisons to Nahum *et al.* impact experiments on Cadavers with Bob head model



Impact: We provide an understanding of the mechanisms of brain injury resulting from blast & impact

FY18: Executing 3 phase project plan with internal & external teams

Abstract – Team Wendy

Sandia National Laboratories

- Our laboratory will develop and extend the Sandia Head-Neck-Torso simulation framework in support of the development of a predictive multiscale traumatic brain injury model. We will:
  - Phase 1: Verify simulations with Team Wendy experimental benchmark drop tests with the magnesium head form,
  - Phase 2: Integrate the Brown mTBI cellular injury criteria into the computational framework, and
  - Phase 3: Use Sandia's human head model and Brown's mTBI criteria, to predict mTBI in humans, given the 150 G peak drop test military specification and given the available material property envelope of the Team Wendy pad suspension system foam.

OBJECTIVE

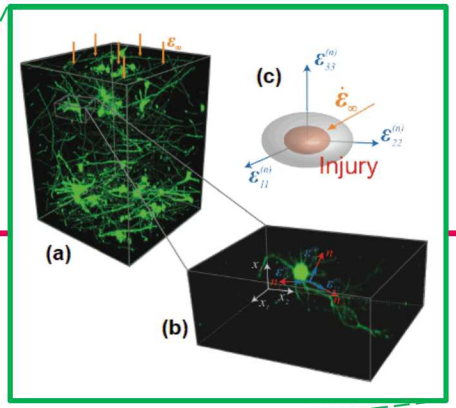
- **Navy warfighters have blast and blunt trauma exposure, thought to lead to TBI. Our objective is to quantify TBI risk mitigation from the TW helmet.**
- **We hypothesize that the helmet foam and suspension liner can offer significant reduction of traumatic brain injury risk, secondary to impact.**
- **Impact: Our work offers a verified framework to conduct numerical cadaver drop tests.**
- **Originality: high-fidelity 1 cubic mm resolution geometry. Exciting: work toward credible models.**

TECHNICAL APPROACH

- **Baseline:**
  - **Drexel foam experiments and Brown material models characterize nominal helmet liner.**
  - **TW drop test experiments of magnesium headform, helmeted and not, verify simulations.**
- **Sandia numerical cadaver head/neck substituted for magnesium headform, numerical drop tests.**
- **Brown cellular TBI criterion used with brain model to assess injury. Seek pad/liner optimization.**
- **Technical merit: credibility of *component* foam behavior and of *system* drop test framework.**
- **Risk: translate Bob from FV to FE. Plan in place.**

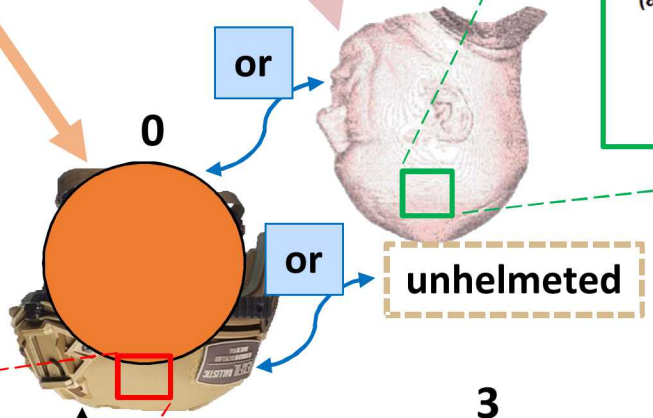
Scenario (i,k)	**Mg Head Form (k) = [Mg, !Mg = Hu]**	
Helmeted (i) = [no, yes]	(no, Mg)	(no, Hu)
	(yes, Mg)	(yes, Hu)

Cellular TBI Criterion (Brown)

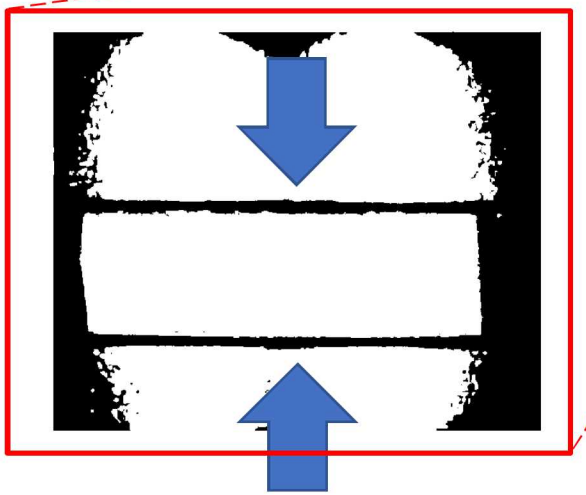


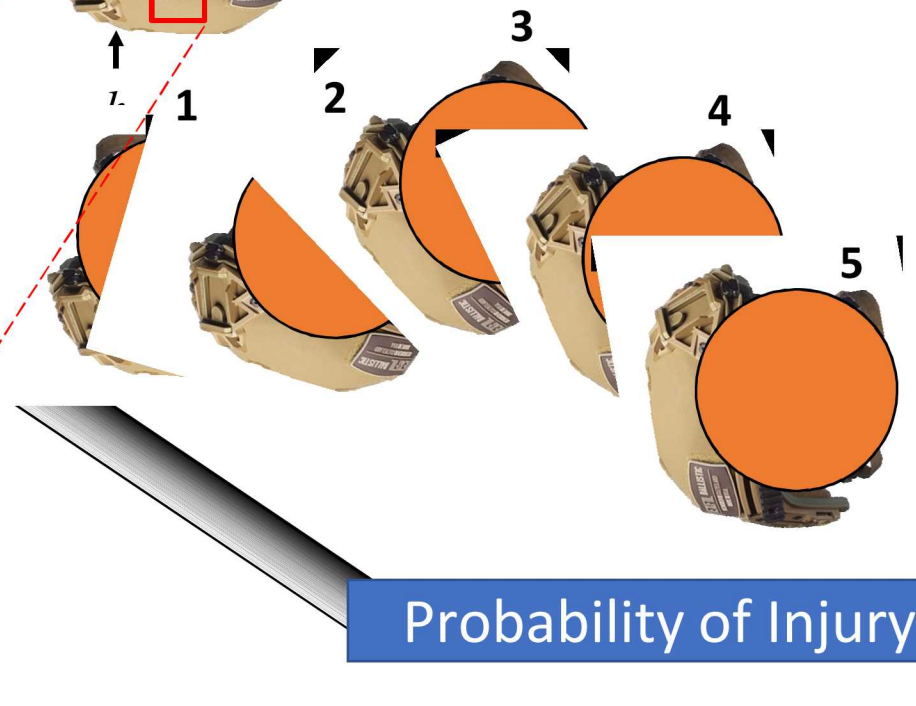
Headform,

- **with or without a helmet,**
- **with a non-zero drop height**
- **dropped onto an anvil of**
  - **zero or non-zero incline,**
- **translating to impact, then rotating**



Foam Experiments (Drexel)

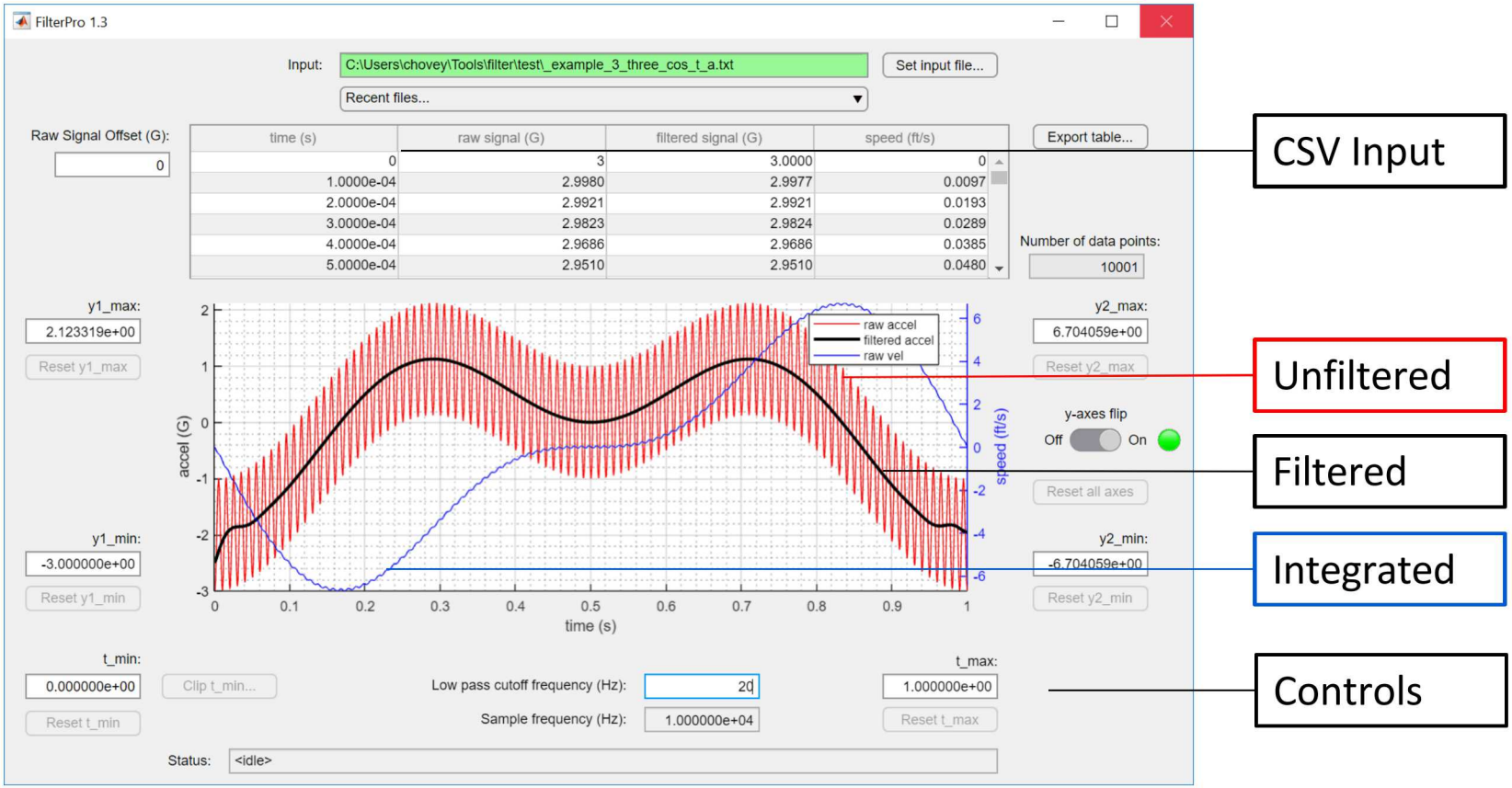




ACCOMPLISHMENTS

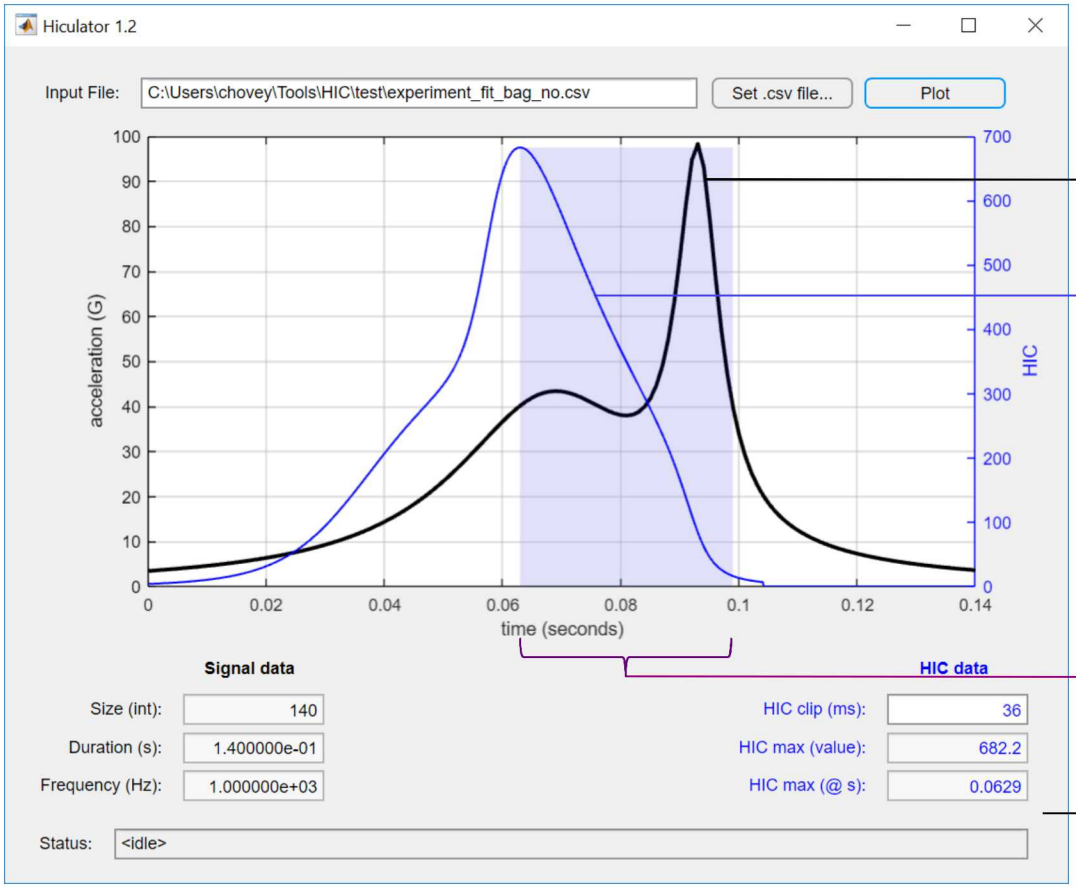
- Bi-Weekly team telecon meetings
- Project Plan (Funding Received May 2018)
  - Impact: Clear direction for execution
- Sandia GitLab repository
  - Impact: Version control, effective teaming
- Digital Filter and HIC tools distributed to team
  - Impact: Team has uniform signal process tools
- Sierra Solid Mechanics (SSM) foam testbed
  - Impact: Credibility of *component* simulation from experiment
- Validation: Ongoing V&V with experiments
  - Impact: Credibility of *system* simulation from experiment

ACCOMPLISHMENTS



- What: A low-pass Butterworth filter implementation, installed as a Windows application.
- Impact: Team members have a consistent and correct tool, avoid “reinventing the wheel.”

ACCOMPLISHMENTS



Input: acceleration versus time

Output: head injury criterion (HIC)

Control: HIC clip duration (ms)

Controls

- What: A head injury criterion (HIC) calculator, installed as a Windows application.
- Impact: Team members have a consistent and correct tool, avoid “reinventing the wheel.”

ISSUES

- Delays in funding caused delays in technical progress.

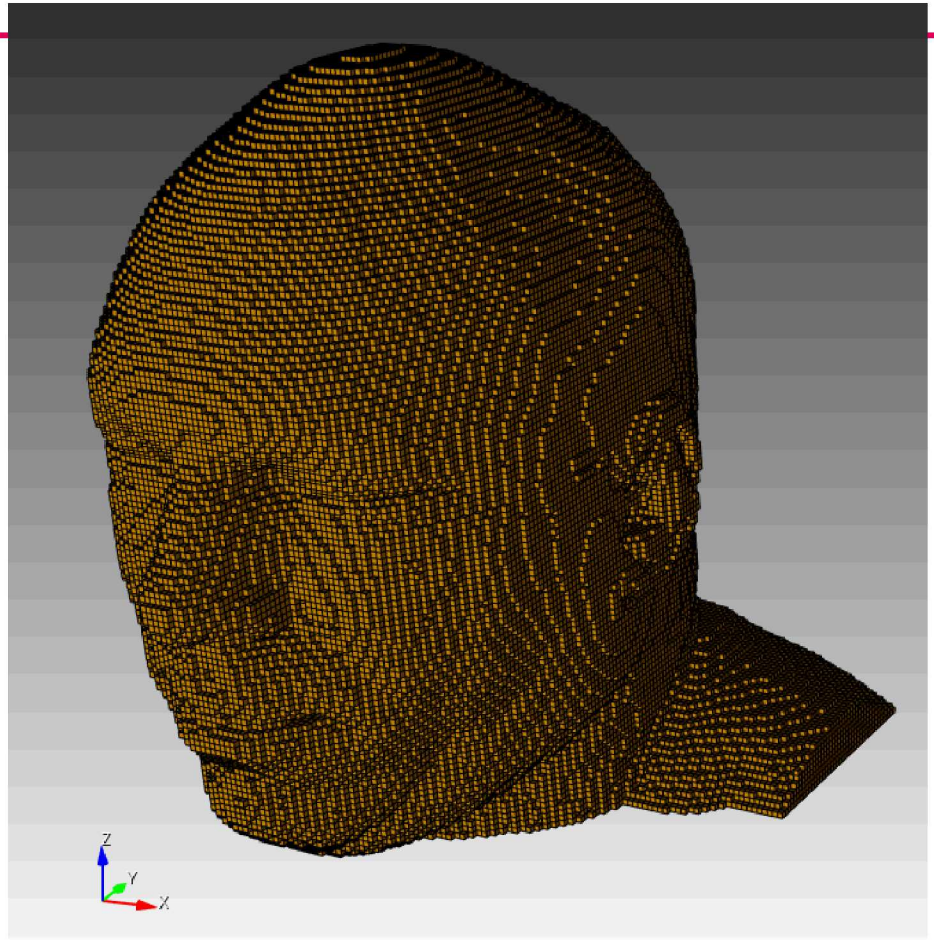
- FV to FE: years of established research with Bob as FV with blast and CTH.
  - Drop test scenarios compelled migration to FE framework.
  - Thus, Bob as FV model needs to be translated to a FE model.

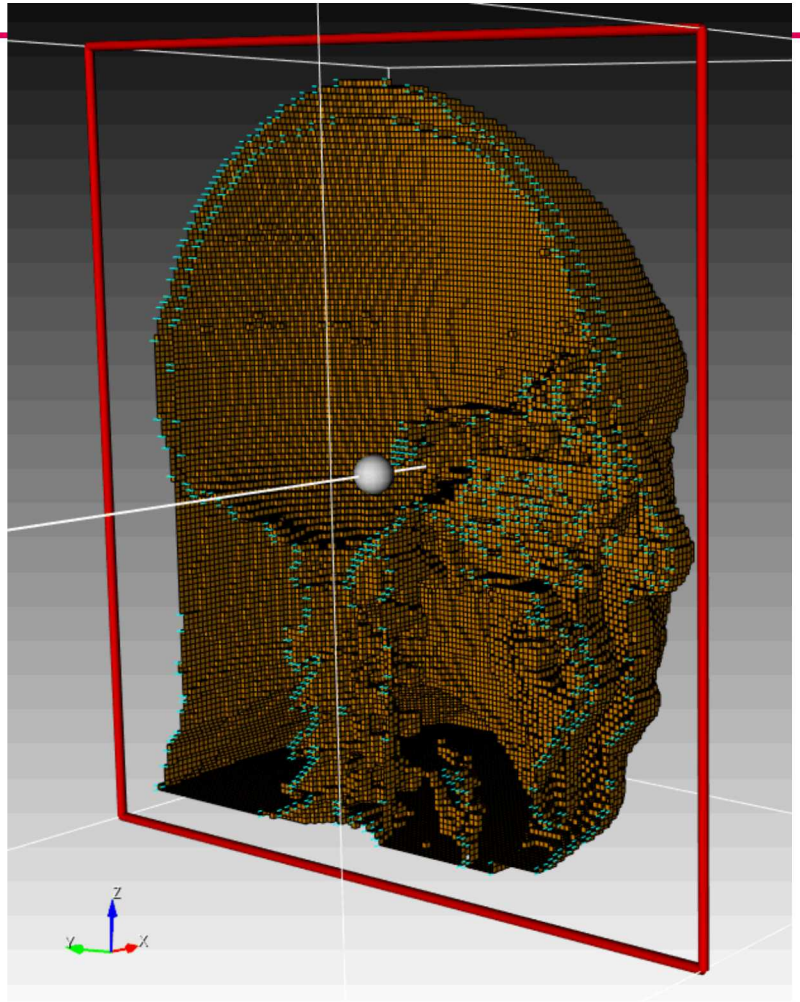
Simulation Tool **Decision Matrix** 2018-05-03

Attribute distinguisher	Importance weighting	**CTH** finite volume Eulerian	**Sierra** SD finite element Lagrangian
Gravity drives rebound	High	(x) Moot: both have gravity	
Cavitation material model	Medium: (Nice to have?)	(+) Well-established	(-) Either experimental and nascent development cost
Geometric description of head/neck domain	High	(+) Well-established	(-) Experimental and nascent development cost
Long-time simulation, from 10 to 40 ms	High	(-) Advection, likely to smear interface boundaries, as well as materials together, cannot be changed, inherent to fluids formulation	(+) Well-established
Friction at head-to-ground interface, to cause finite head rotation post-impact	High	(-) CTH "glues together" interfaces on contact, cannot be changed, inherent to fluids formulation	(+) Well-established
Pre-stress equilibrium after cinching but before drop/impact.	High	(-) Extra EOS step, given density and temperature to get pressure, Sierra to Exodus to CTH tractable but more moving parts/process	(~) Neutral, no EOS
Collaboration (e.g., Haneesh)	Medium	(-) Does not do Eulerian	(+) Does Lagrangian

Sierra selected: 2018-05-15

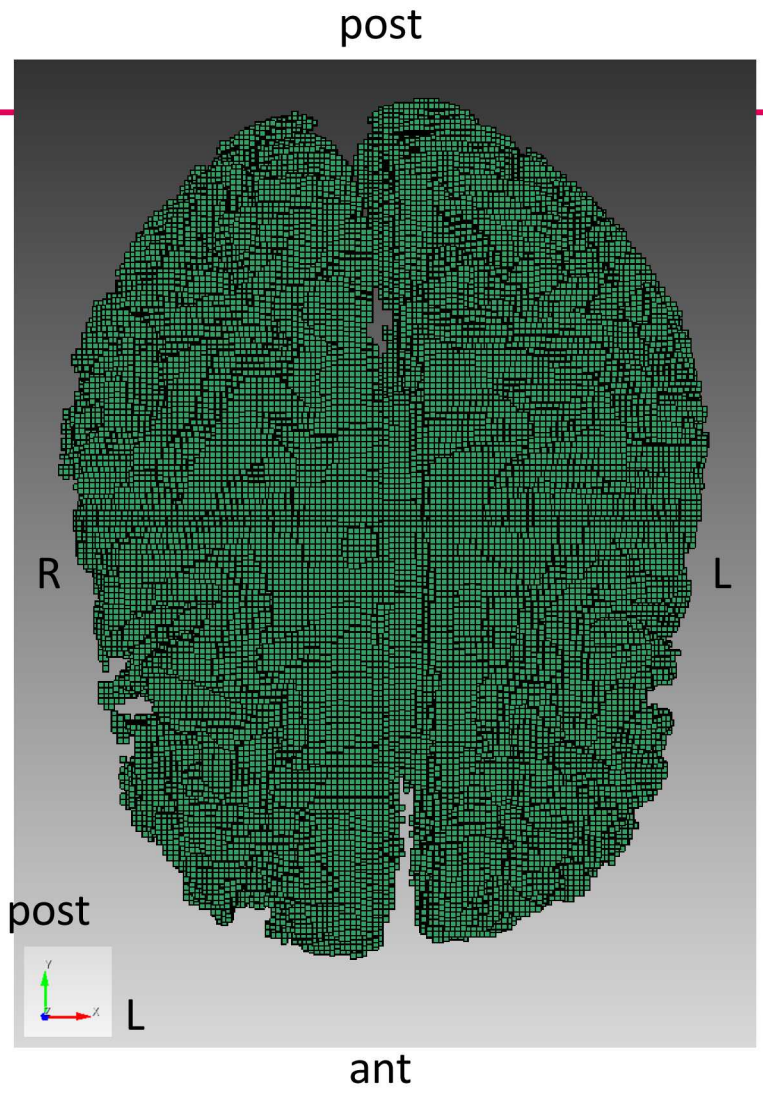
ISSUES

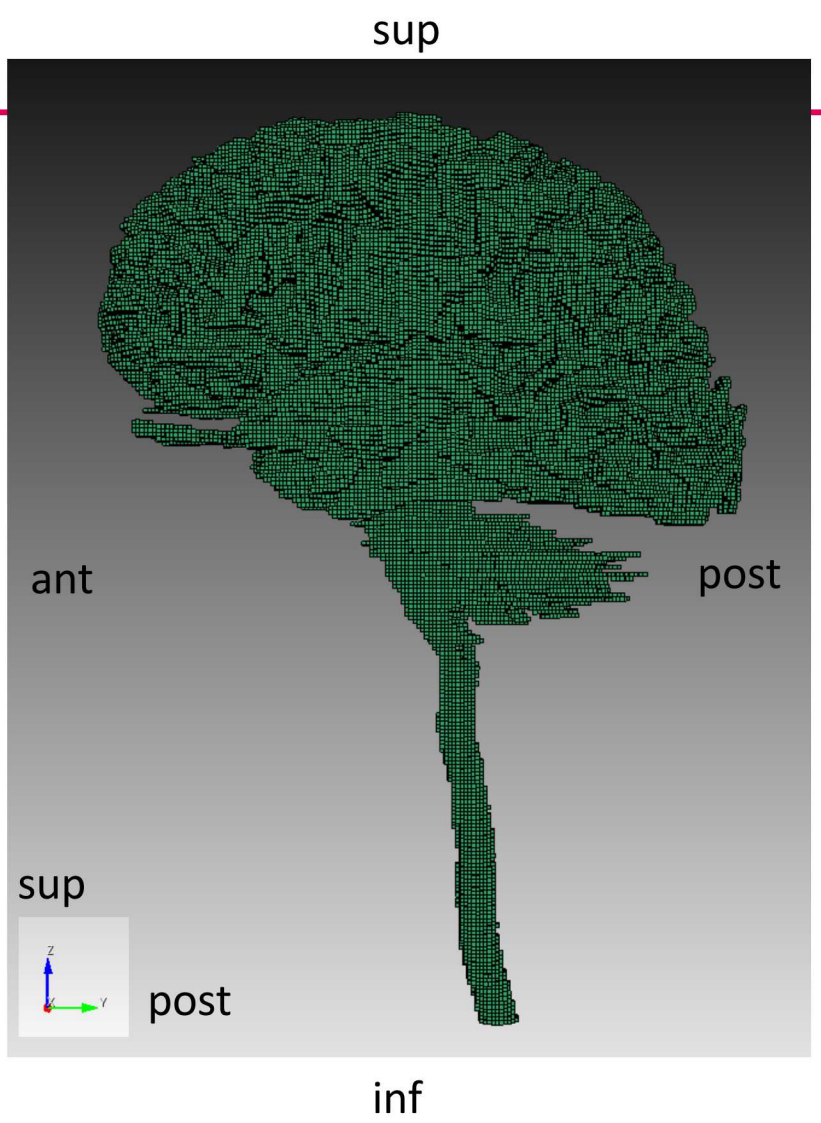




Reference: C:\Users\chovey\sibl\bob\skin.g

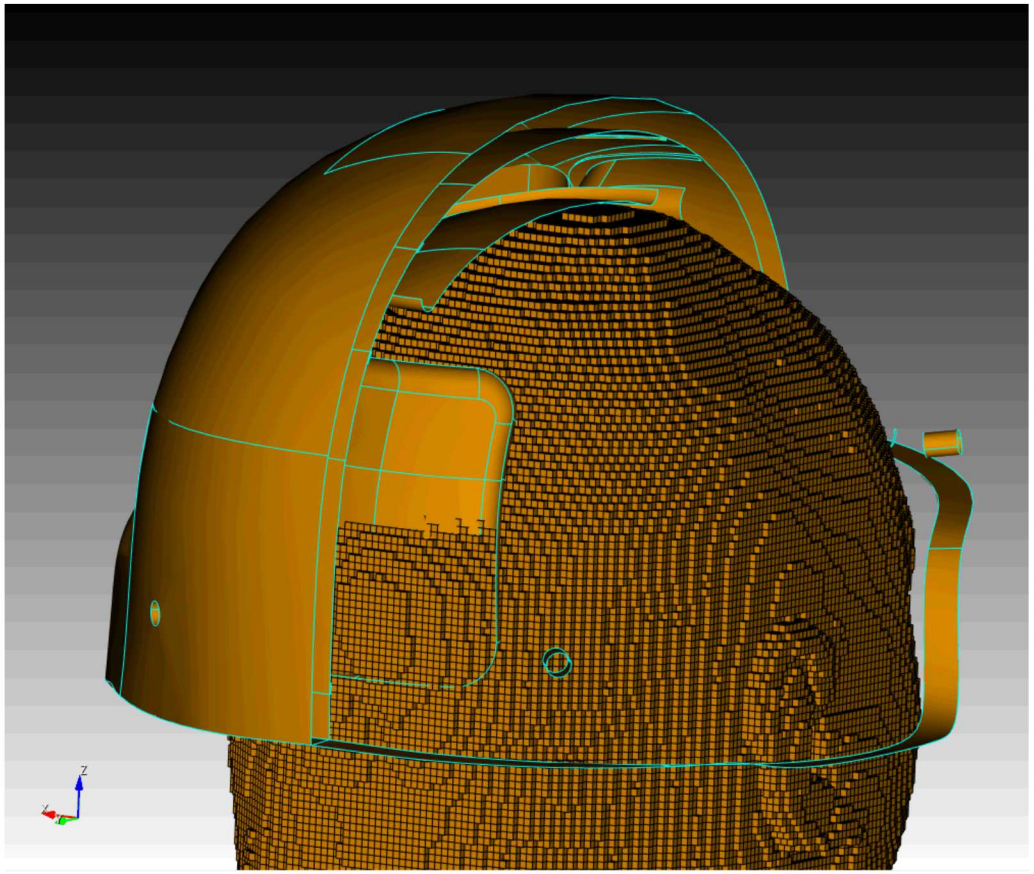
ISSUES



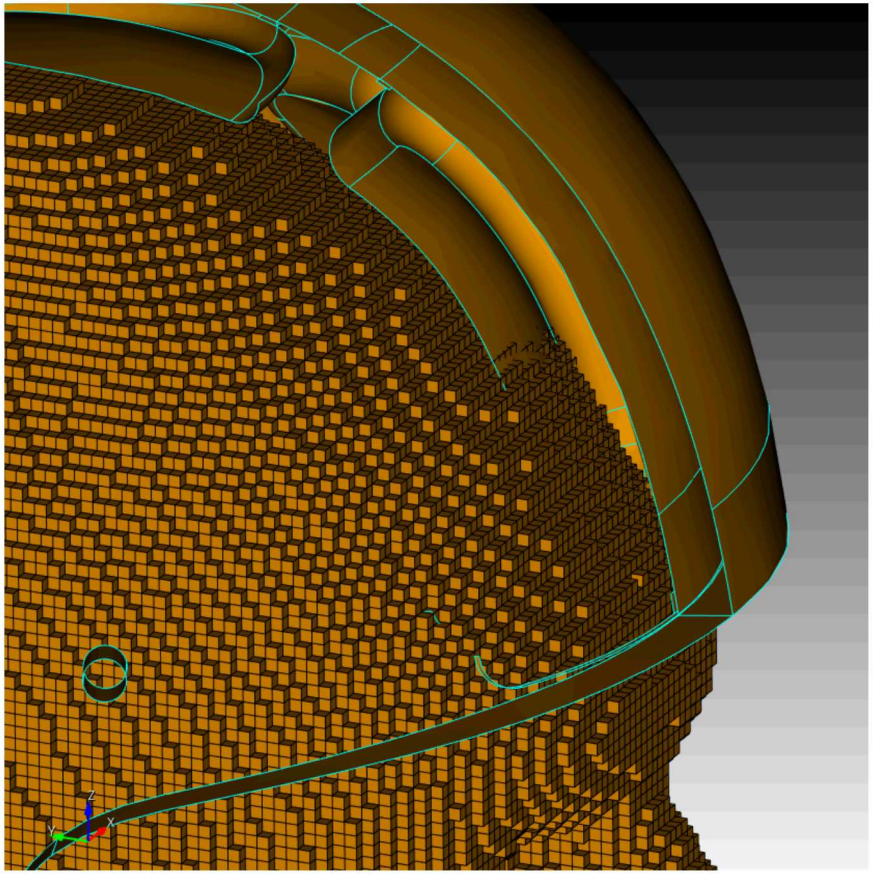


Reference: /projects/sibl/bob/TBI_gen_files/wm.g (white matter Genesis file), file size: 34.7 MB

ISSUES



Posterior



Anterior

CONCLUSIONS

- Clear plan and scope, just need to execute.
- Anticipated findings:
  - The nominal TW helmet provides a $x\%$ traumatic brain injury risk reduction over the non-helmeted baseline.
  - If the foam properties are modified to y, an additional $z\%$ TBI risk reduction is achieved.
- Anticipated impact:
  - First known study that combines verified foam and high-fidelity numerical cadaver models, credible simulations, and cellular-based TBI criterion to quantify injury risk reduction of TW helmet during impact.

PATH FORWARD

- Continue to work the plan. In the coming year:
  - FE Bob from FV Bob.
  - Robust, repeatable, and pedigreed workflow for numerical foam model validation based on experiments.
  - Implementation of Brown foam material model (Henann lab, ABAQUS) into Sierra.
  - FE mesh of TW magnesium headform, helmet, and pad/suspension system.
  - Verification of simulation framework with TW experimental drop tests, helmeted and not.

PUBLICATIONS, PATENTS, PRESENTATIONS & AWARDS

- Deployed Sandia Injury Biomechanics Laboratory website: www.sandia.gov/biomechanics
- Created two UUR SAND reports
  - Head impact (fall from height study).
    - Impact: Adds context to current project results
  - Bayly "brain slosh" experiments (previous Sandia verifications existed, but were never brought to UUR publication level).
    - Impact: Credibility of *system* simulation from experiment
- Anticipate peer-reviewed publications to share work with scientific community.

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 deploy Butterworth filtering and head injury criterion (HIC) tools.

COLLABORATION & DISCUSSION

- Might using two criteria, the to-be-developed cellular-based TBI criterion and the head injury criterion (HIC), off enhanced contextualization of injury risk versus just using the cellular-based criterion alone?
- Does considering two criteria
  - make the work more appealing or more acceptable to the scientific community?
  - create scope creep, and potentially dilute efforts to execute plan in place?