Computational Modeling of Human Head Under Blast Loading

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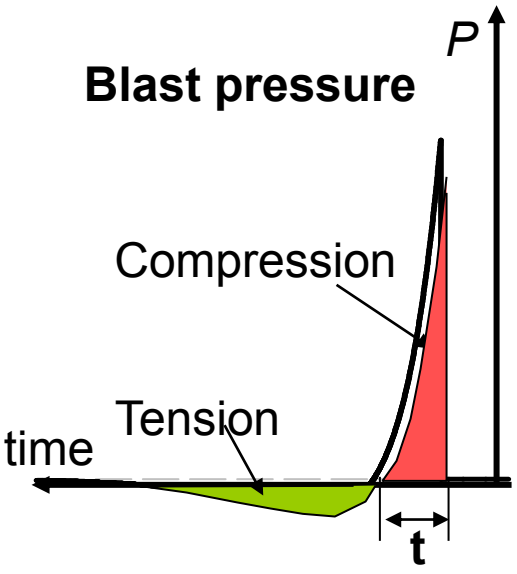
Introduction



Impact →TBI:
Head acceleration

Blast → TBI: not clear

$P \approx 0.4\text{-}1$ MPa (mild)
$t \approx 0.1\text{-}1$ ms
Lower acceleration
Global load: lower stress but high force

Two scales Investigation of TBI

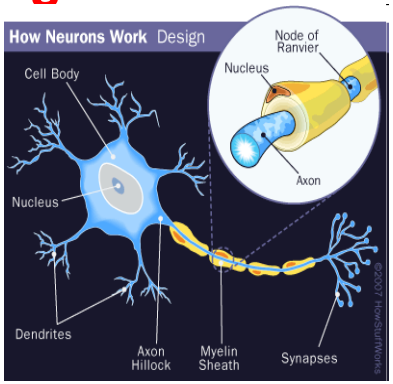
Brain mechanical properties

↓

e.g. Blast induced: Strain/stress, acceleration and deceleration

Brain: macro scale

Down scale



Neuron: micro scale

Cell mechanical properties

↓

Blast induced: Strain/stress,

Reference: Moss W.C. et al. (2009), Taylor P.A. et al. (2009), Leung L.Y. et al. (2008)

Objective

Research Objective: To understand underlying mechanisms of blast induced Traumatic Brain Injury (TBI) and develop mitigation strategies to prevent blast induced TBI.

Significance:

- In recent combat scenarios blast induced TBI insults has increased dramatically
- In asymmetric warfare involving IEDs (future trends) , blast wave protection becomes a very critical design factor.
- Helmets are not designed to protect against blast

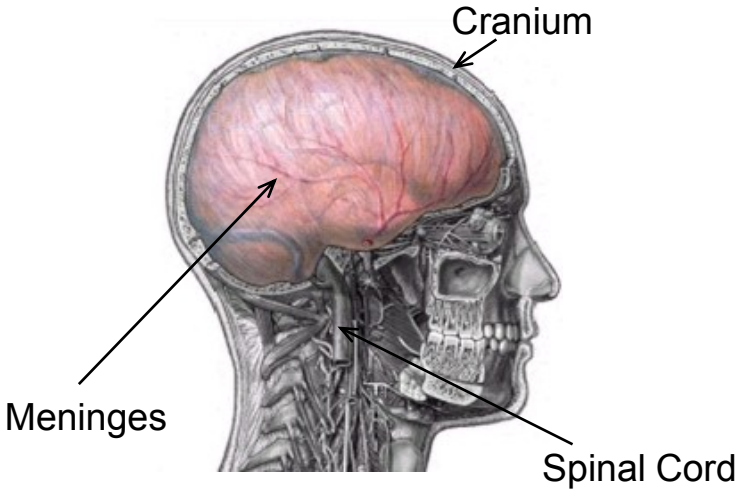
Challenges:

- Actual experiments are not possible
- Animal experiments only approximates the blast physics
- Complex wave action dominated phenomena as opposed to acceleration related brain damage

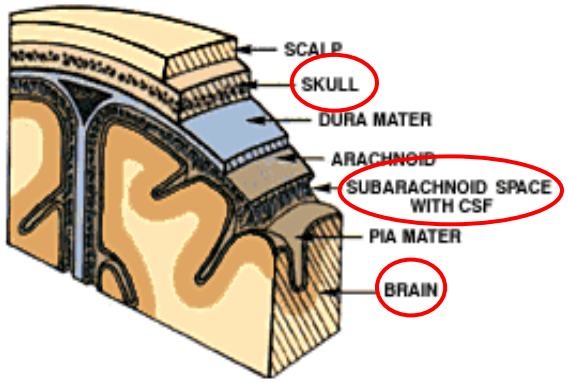
Presentation Objective:

- To understand role of helmet in blast induced Traumatic Brain Injury (TBI)
- To understand role of entrapped air (entrapped between helmet-cranium subspace) on stress , strain fields of the brain
- To compare Coupled Eulerian Lagrangian (CEL) approach with Lagrangian approach

Components of Human Head



Coverings of the Brain



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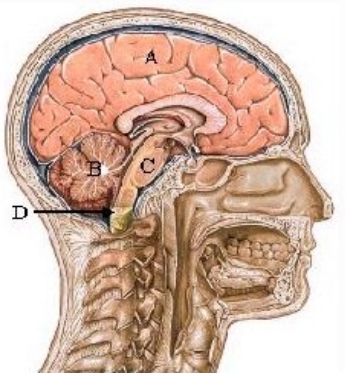


A. The Cerebrum
B. The Cerebellum
C. The Pons
D. The Medulla Oblongata

Sagittal View

I The Cerebrum

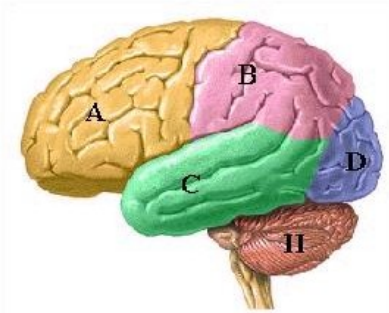
A - Frontal Lobe

B - Parietal Lobe

C - Temporal Lobe

D - Occipital Lobe

II The Cerebellum

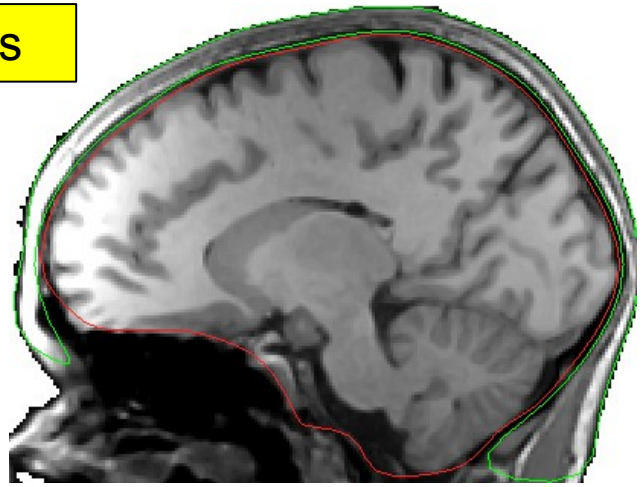


Lateral View

The Brain

Finite Element Models

Mimics



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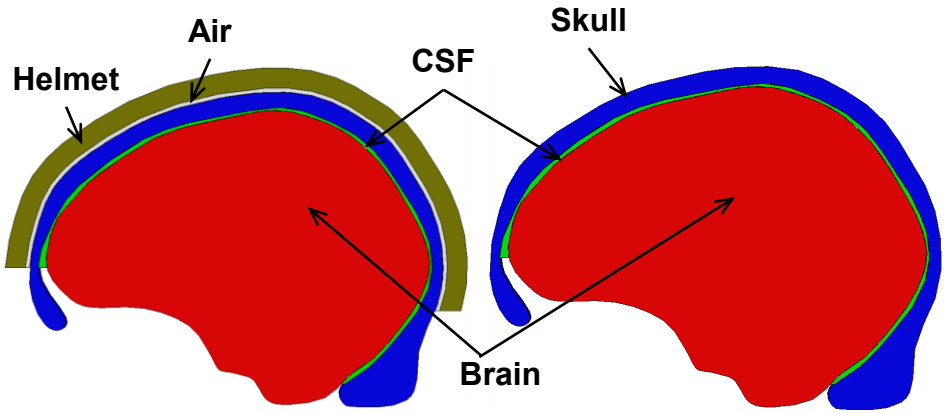
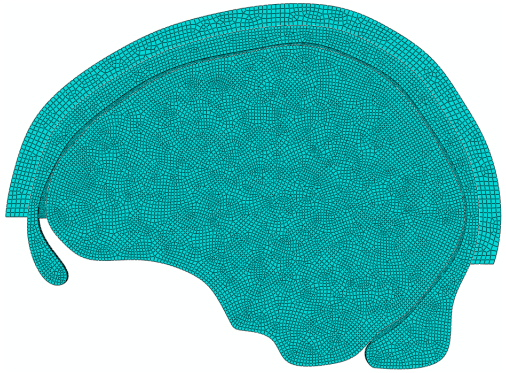
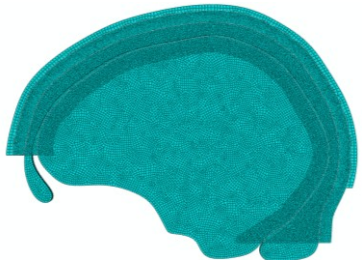


Head Models With and Without Helmet

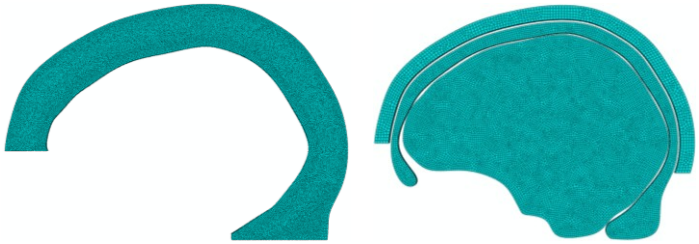


Pure Lagrangian Mesh

Lagrangian Approach



Overlapping Eulerian Lagrangian Mesh

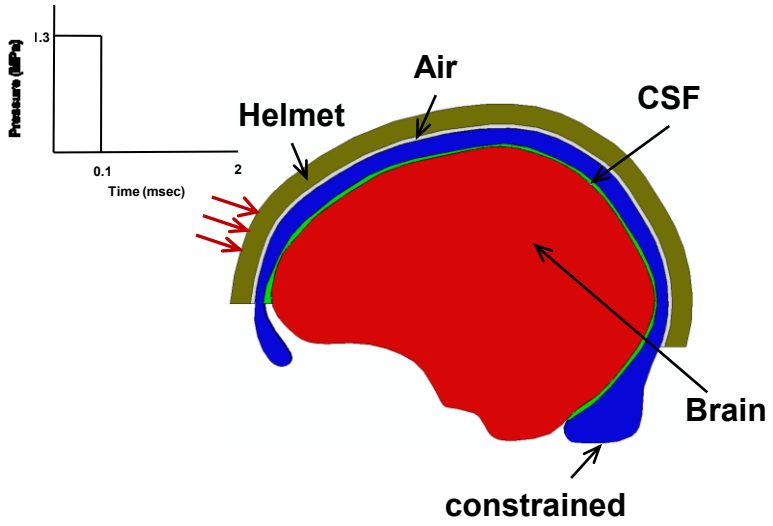


Eulerian Mesh

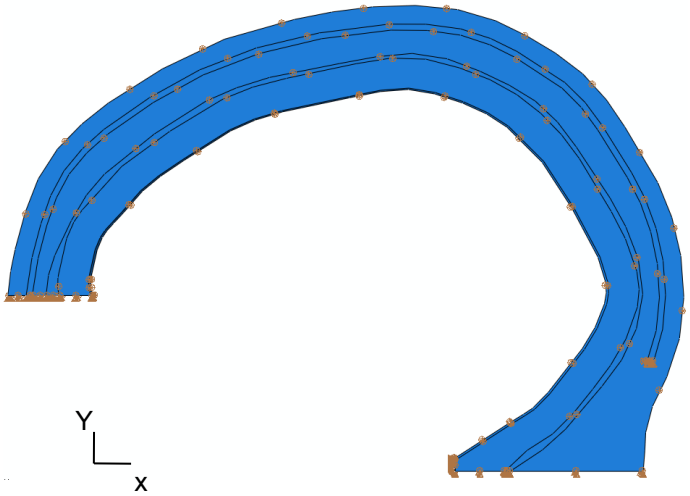
Lagrangian Mesh

Coupled Eulerian Lagrangian (CEL) Approach

Loading and Materials



Load and Boundary Conditions

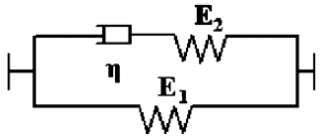


Velocity in Z-direction is set to zero for eulerian domain

Reference: Taylor P.A. et al. (2009)

Material model:

Brain: SLS model



	Instantaneous Shear Modulus (kPa)	Long-term Shear Modulus (kPa)	Relaxation time (sec)
Brain	41.0	7.8	0.00142857

CSF and Air: Mie-Grüneisen equations of state

- provides a hydrodynamic material model in which the material's volumetric strength is determined by an equation of state
- A common fit to the Hugoniot data is

$$p_H = \frac{\rho_0 c_0^2 \eta}{(1 - s\eta)^2}$$

p_H - hugoniot pressure,

ρ_0 - reference density

c_0 - reference sound speed, s - slope of U_s–U_p curve

η - nominal volumetric compressive strain

	Density (kg/m³)	Bulk Modulus (GPa)
CSF	1000	2.19
Air	1.21	0.142e-3

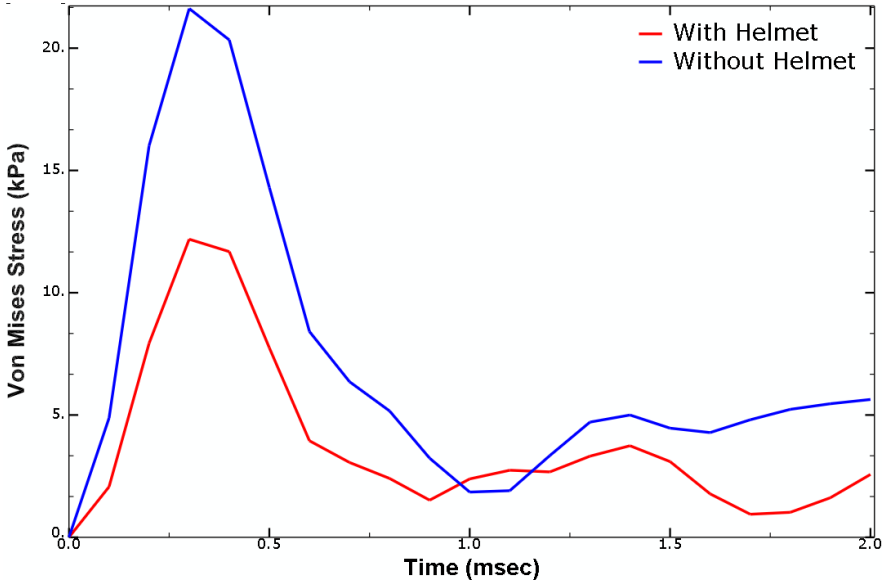
Helmet and skull: Linear Elastic Isotropic

	Density (kg/m³)	Young's Modulus (GPa)	Poisson's Ratio
Skull	1710	5.37	0.19
Helmet	1380	76	0.30

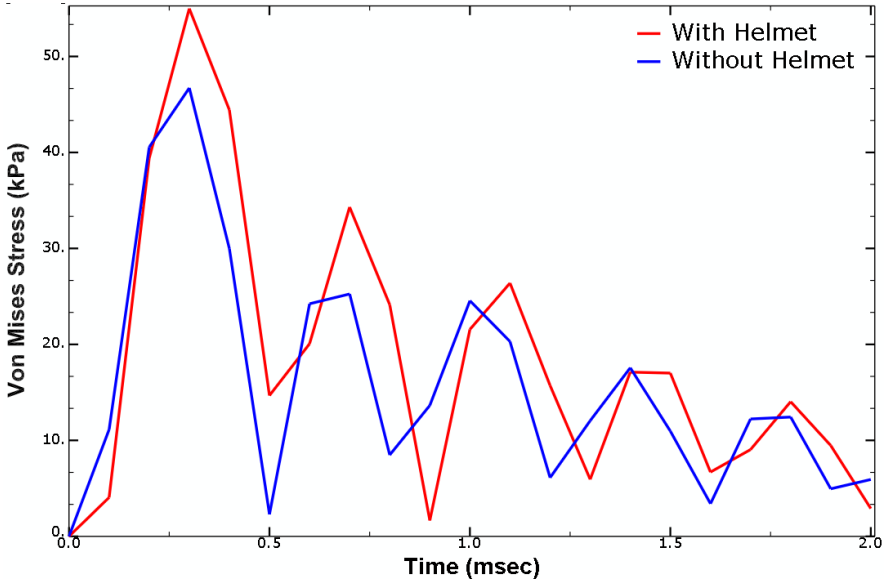
Summary of Simulation Cases

Case/Approach → ↓	Lagrangian	Eulerian
Without Helmet	✓	✓
With Helmet	✓	✓
With Helmet and entrapped air		✓

Role of Helmet in Brain Protection



Lagrangian Approach

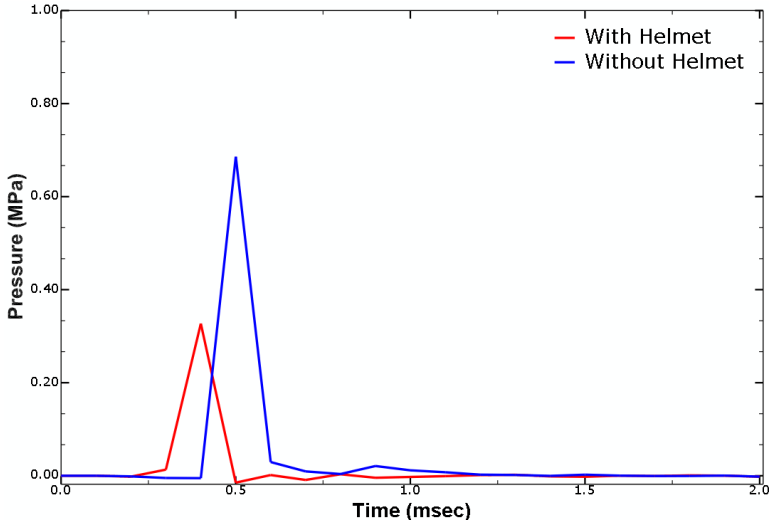


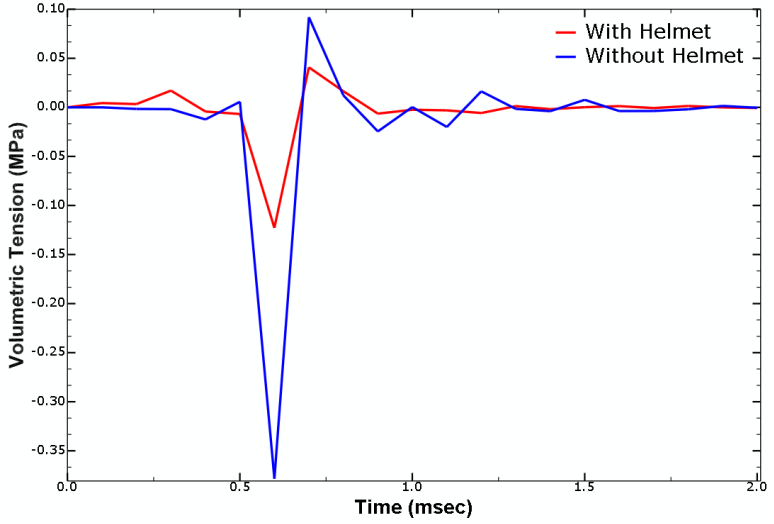
Coupled Eulerian Lagrangian (CEL) Approach

Maximum mises stress in the brain

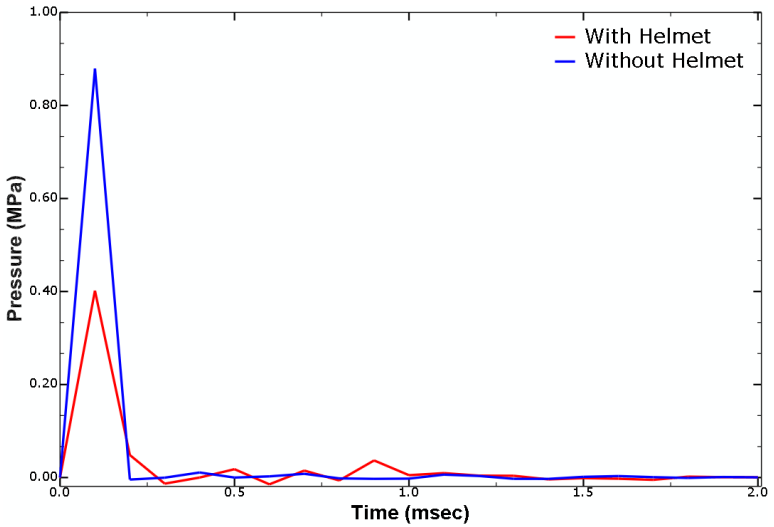
- Lagrangian approach underestimates maximum mises stress in the brain
- Helmet is not be effective in reducing mises stress in the brain

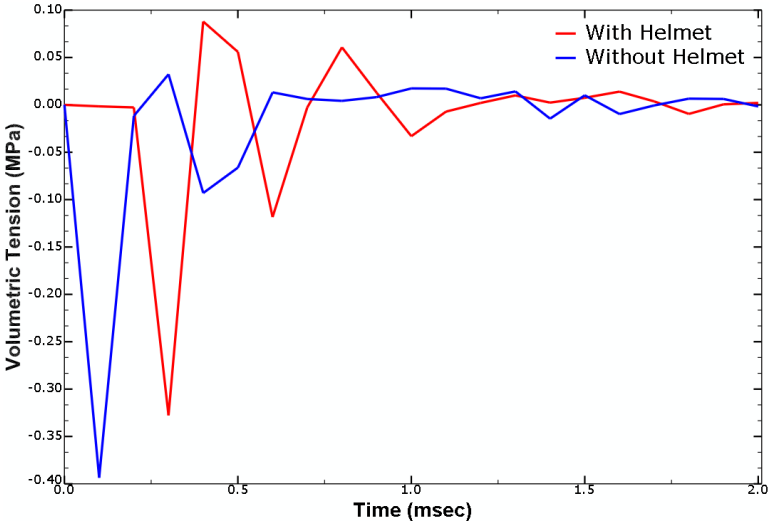
Role of Helmet in Brain Protection





Lagrangian Approach



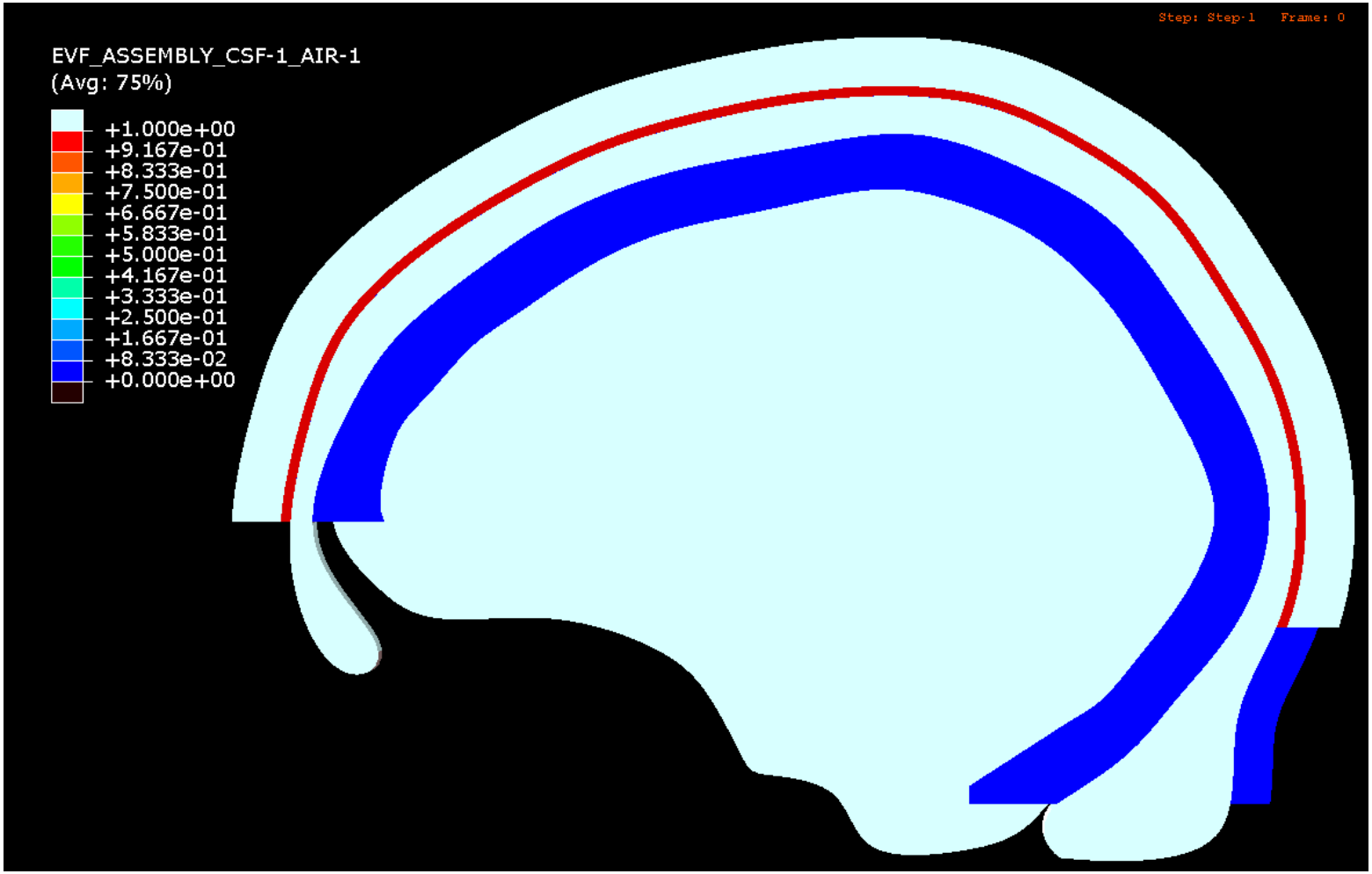


Coupled Eulerian Lagrangian (CEL) Approach

Maximum pressure and volumetric tension in the brain

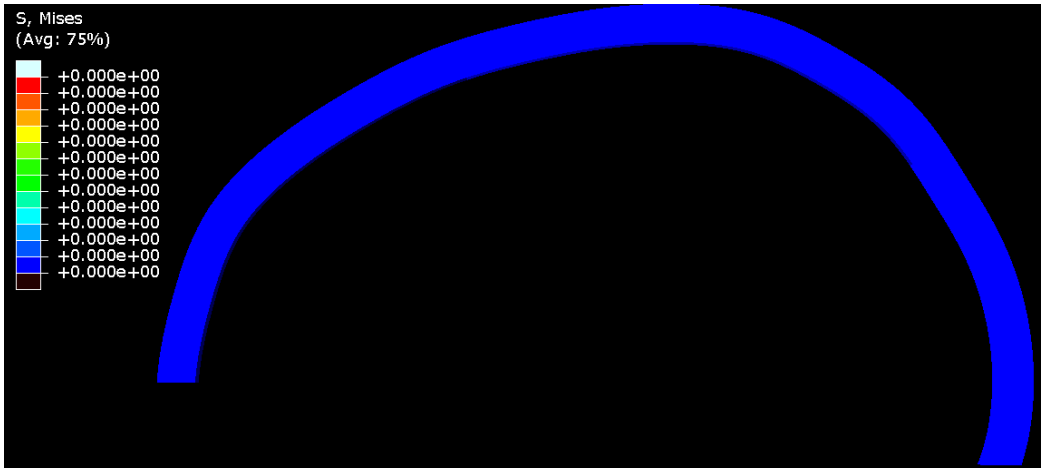
Lagrangian approach underestimates pressure and volumetric tension in the brain.

Role of Entrapped Air in Brain Protection

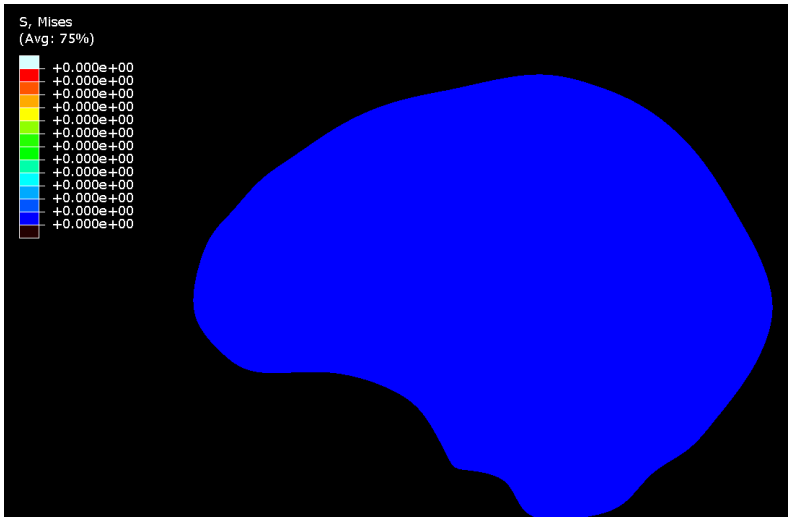


Air reflects most part of the incident wave and hence decreases the rate and amount of energy transferred to the brain

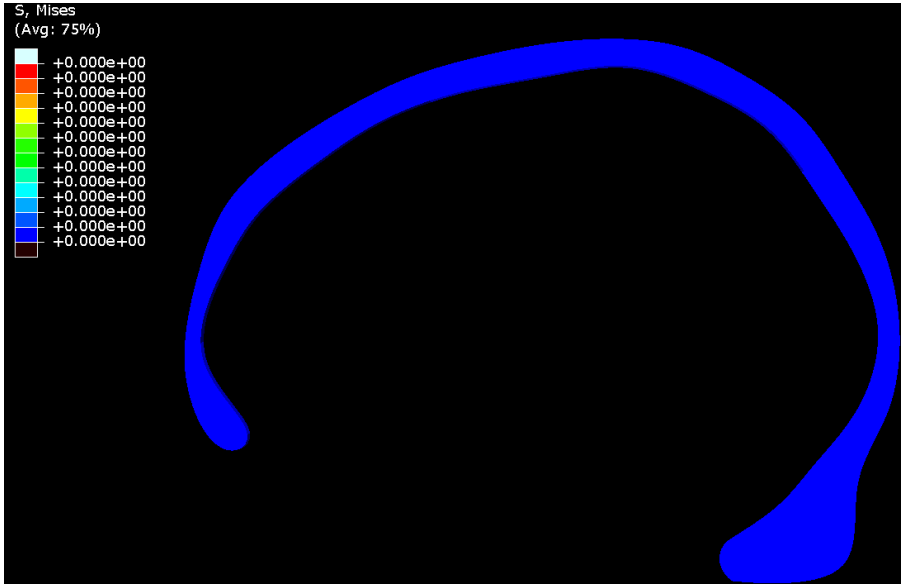
Role of Entrapped Air in Brain Protection



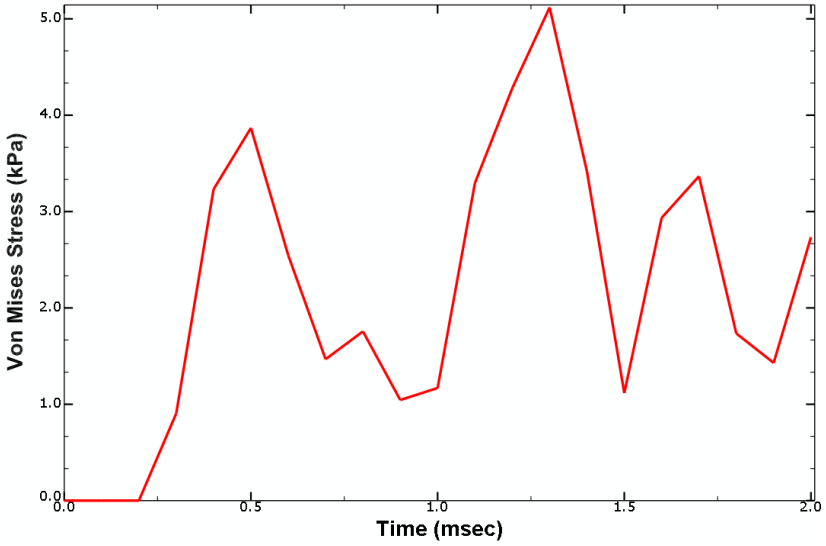
Mises Stress in the Helmet



Mises Stress in the Brain



Mises Stress in the Skull



Maximum mises Stress in the Brain

Conclusions

- This study pertains only when the pressure wave is directly applied on the helmet; For that case,
  - Results shows that maximum values of pressure, volumetric tension and shear stress in the brain reduces **significantly** from without helmet to with helmet case using **lagrangian approach.**
  - With **coupled eulerian lagrangian (CEL)** approach value of pressure, volumetric tension reduces slightly and there is slight increase in shear stress from without helmet to with helmet case .
- The results shows that air within the helmet-cranium subspace decreases rate and amount of energy transferred to the brain. However foam pads which are in direct contact with helmet and head are not modeled and pressure wave is directly applied on the helmet hence these results should be interpreted carefully.