Numerical Investigation of Occupant Injury Risks during a Realistic Transport Aircraft Crash Conditions

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VIRGINIA TECH™

Fokker F28 Crash

Vehicle Specifications: 33,306 lb, 3+2 Seating, 85p capacity

Test Conditions: 32 ft/s Vertical & 65 ft/s Horizontal Velocity

Why it was done?

- **Non-traditional aircraft development is expanding**
  - Novel commercial aircraft designs - Composites
  - Novel aerospace vehicles and transportation markets – Advanced Air Mobility
- **Limitations in airframe level crashworthiness requirements**
  - Current occupant protection certification relies on airframe similarity to traditional aircraft design (14 CFR 2X.562)
  - Novel design will necessitate vehicle testing
  - Goldilocks regulation: safe without being too restrictive

Previous Evaluations

- Component crash analysis
- Full scale crash analysis
- Finite element (FE) models of anthropomorphic test device (ATD) developed and evaluated

Limitations of Previous Evaluations

- Limited Biofidelity of ATD
- Expensive
- Time Consuming

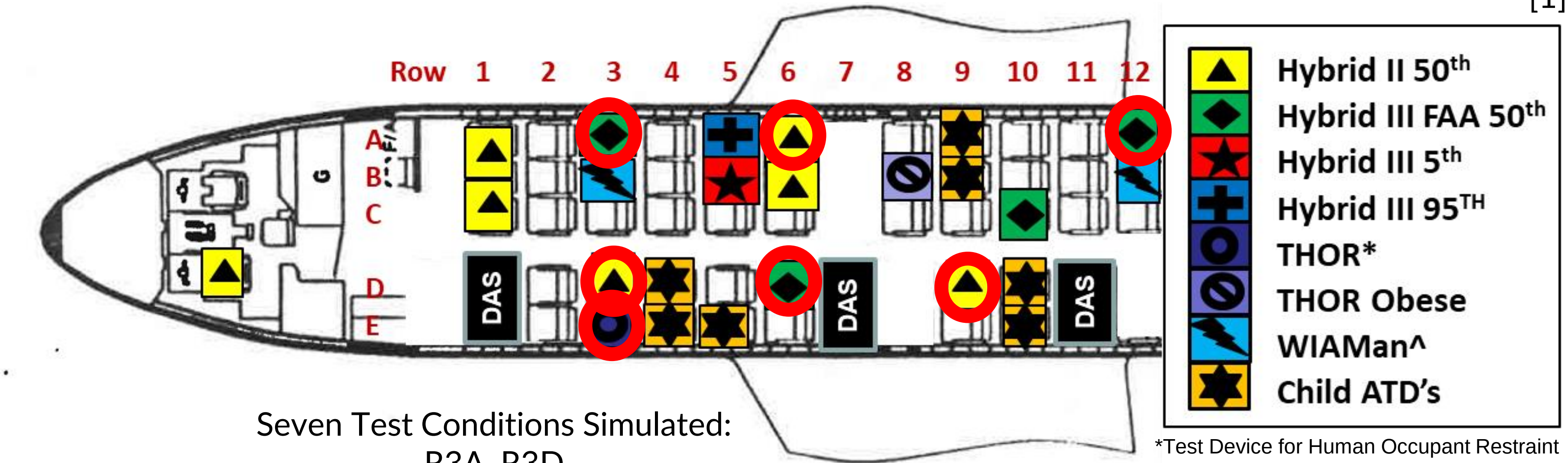
Goals

Assess the current quality of injury prediction from the two leading human body models

Evaluate and improve analytical tools used to predict aircraft crashworthiness

Tested Occupant Layout

[1]



*Test Device for Human Occupant Restraint
^Warrior Injury Assessment Manikin

Seven Test Conditions Simulated:
R3A, R3D
R3E, R6A
R6D, R9D
R10C

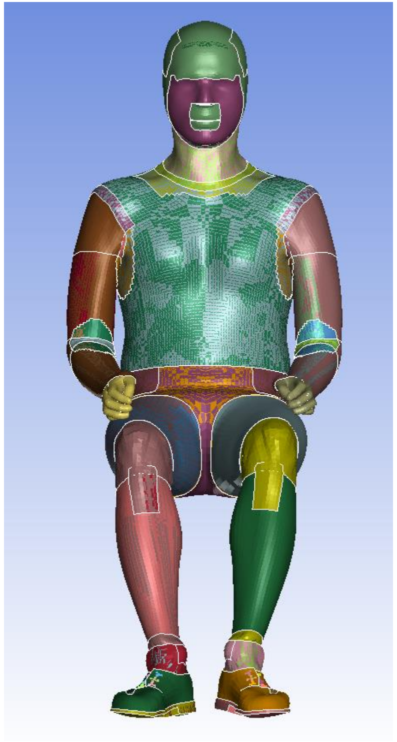
Introduction- Model Comparisons

<u>Global Human Body Model Consortium (GHBMC)</u>

Male 50th percentile
Occupant Detailed model
Version 6.0

Units: Kg, mm, msec

Features:
-Included more advanced Instrumentation
-Included Shoes

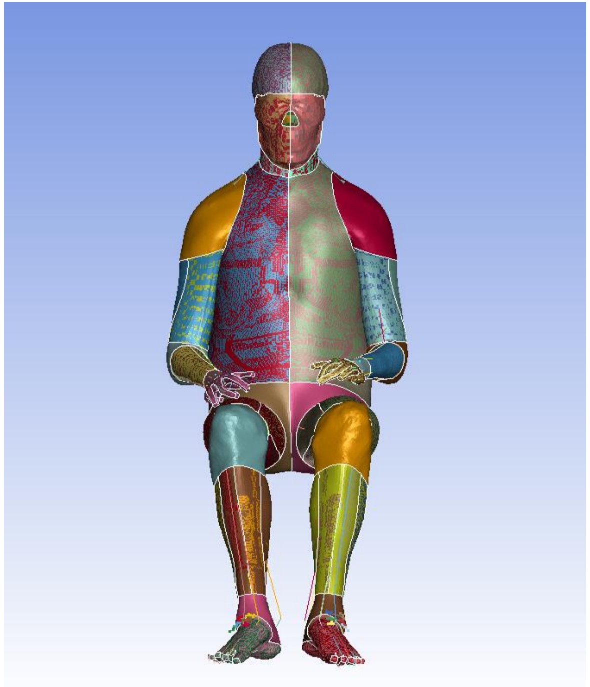


<u>Total Human Model for Safety (THUMS)</u>

Male 50th percentile
Occupant model
Version 6.1

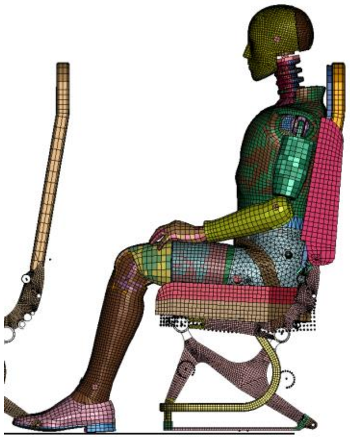
Units: Ton, mm, sec

Features:
-Free Access
-Limited Instrumentation

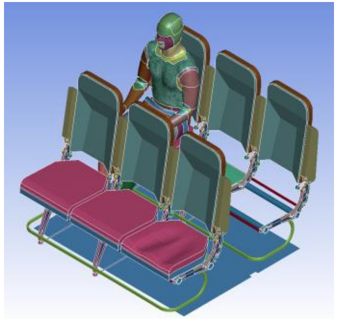
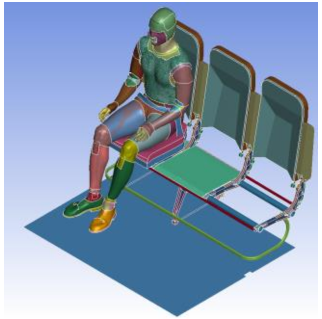
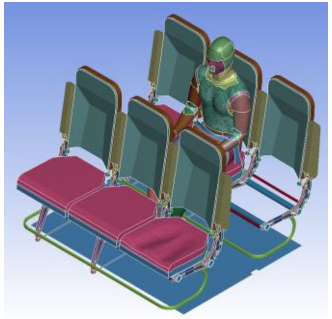
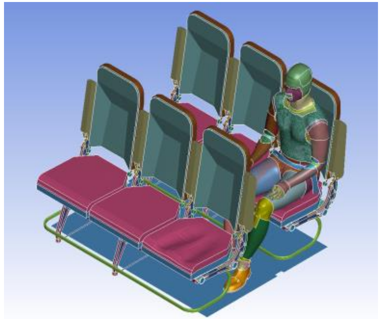


Methods - Model Positioning

Translation/Rotation in LS-prepost → Marionette repositioning of the appendages → Settling Simulation

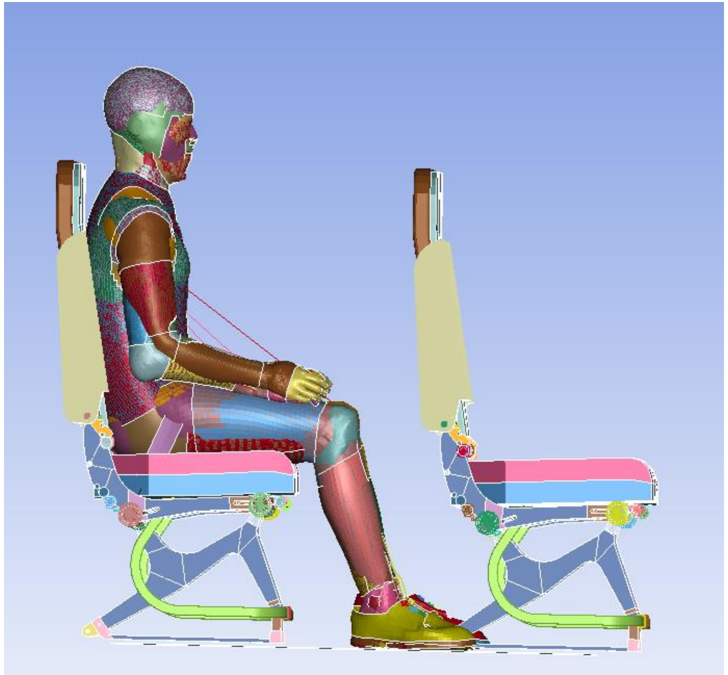


Methods - Model Positioning

Seat A/D	Seat 9 D	Seat B/E	Seat C
			
R3A R3D R6A R6D	R9D	R3E	R10C

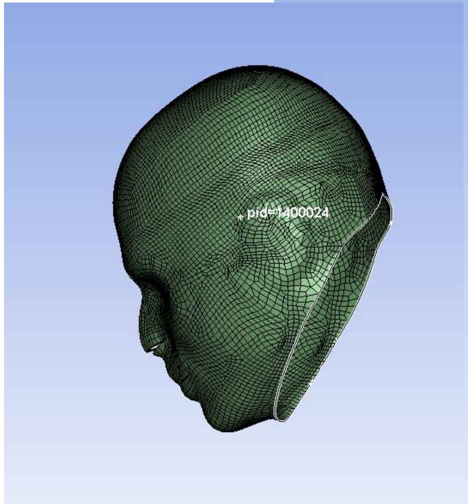
Methods - Model Positioning

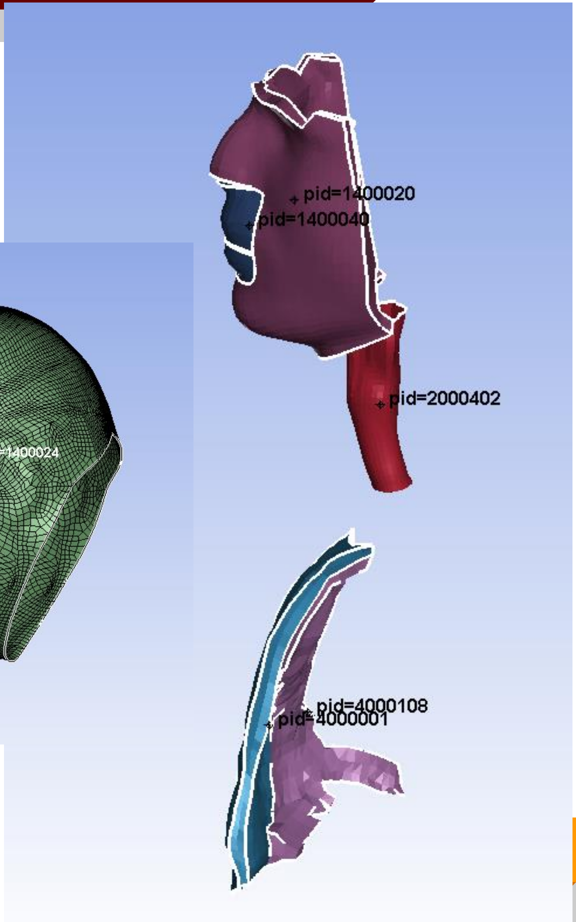
Overlay of Final Positioning



Methods: Model Modification - GHBMC

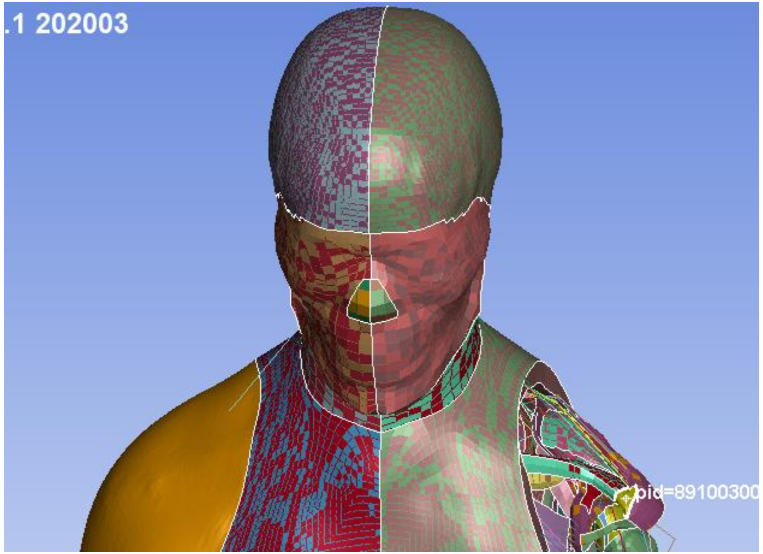
-Erosions Added:
Part IDs:
1400040 (mouth flesh)
1400020 (nose flesh)
4000001 (Anterior_Fat_Pad)
4000108 (Posterior_Fat_Pad)
2000402 (NK_CA_Anterior-Tissue)
1400024 (Head Skin)
Toggled:
Nose Failure
Disk Avulsion off
Hourglass Update:
Hgid: 1500003
qm 1.2-> 0.20
R3D:
5500000 and 5500011 (Hand Ero)





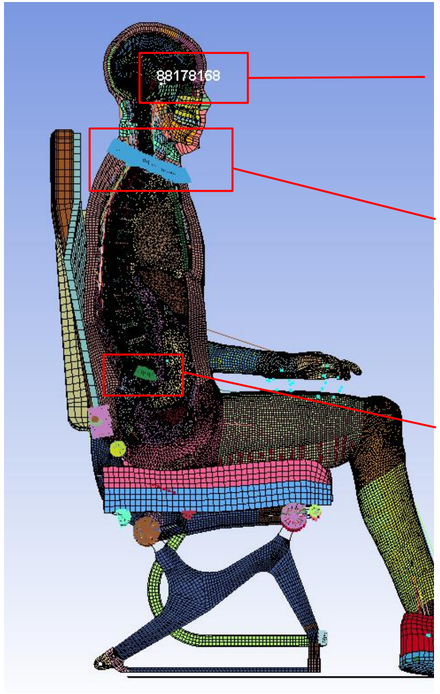
Methods: Model Modification - THUMS

-Erosions Added:
Part IDs:
89100300
-Required significant timestep reduction
-Implementation of Shoes
-Implementation of detailed Instrumentation



Model Comparison THUMS Instrumentation

GHBMC Instrumentation

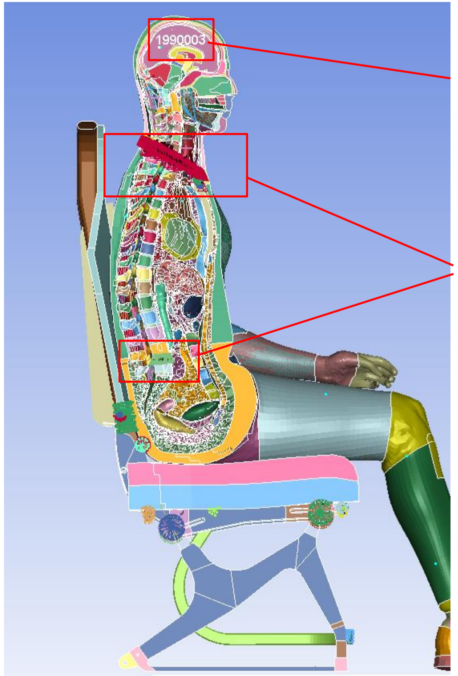


Head center of gravity (CG)

Neck Cross Section

Lumbar Spine Cross Section at L5 Vertebra

THUMS Instrumentation



Head CG node constrained to the entire brain structure

Developed cross sections of spine and neck to match GHBMC

Methods: Injury Measures

Body Component	Injury Equation
Head [1]	$P(AIS\ 3+) = \Phi\left(\frac{\ln(HIC_{15}) - 7.45231}{0.73998}\right)$
Brain [2]	$P(AIS\ 3+) = 1 - e^{-\left(\frac{BrIC - 0.523}{0.531}\right)^{1.8}}$
Neck [3]	$P(AIS\ 3+) = \frac{1}{1+e^{(3.227-1.969*N_{ij})}}$
Lumbar Vertebra [4]	$P(Single\ Fracture) = 1 - e^{-\left(\frac{F}{0.16}\right)^{2.52}}$

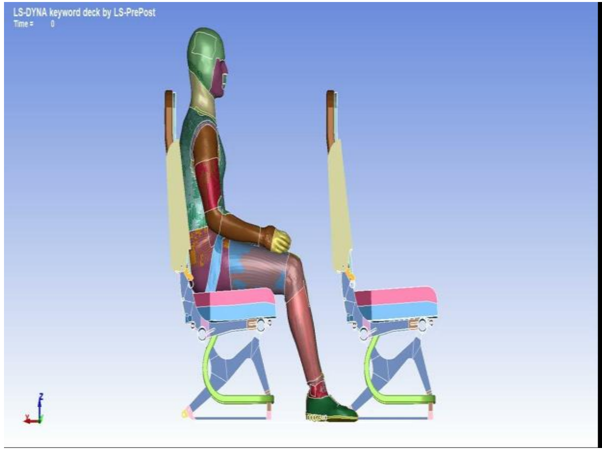
Results: Average Injury Risk

Body Component	GHBMC	THUMS	ATD
Head	33.94%	3.41%	24.51%
Brain	83.54%	60%	Not Calculated
Neck	21.85%	6.66%	36.88%
Lumbar Vertebra	100%	100%	100%

Average Injury risk across all 7 crash conditions

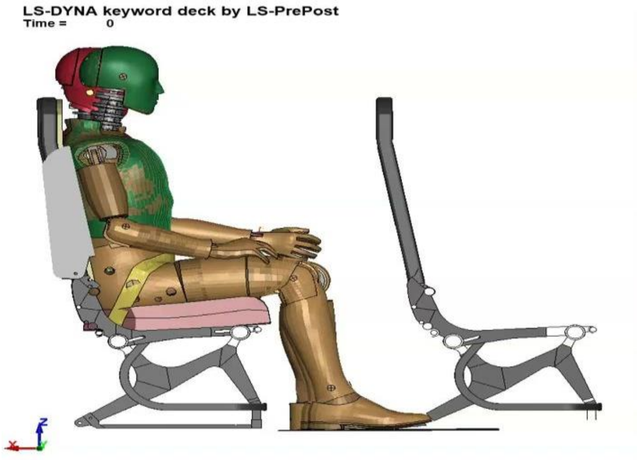
R3D Model Comparison

GHBMC



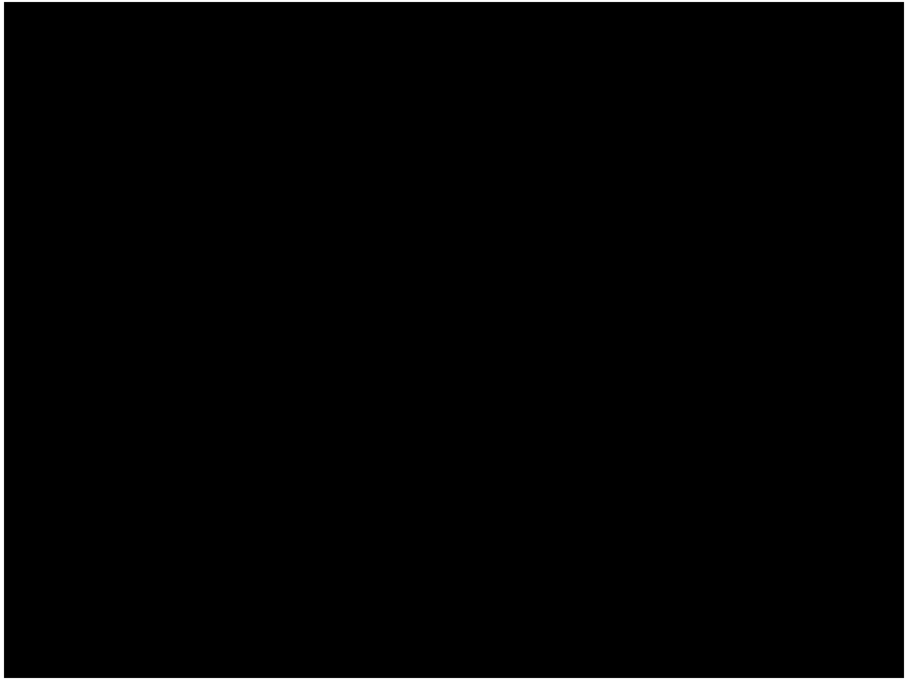
THUMS

H3 / THOR side by side



Results: Impact comparison - R3D

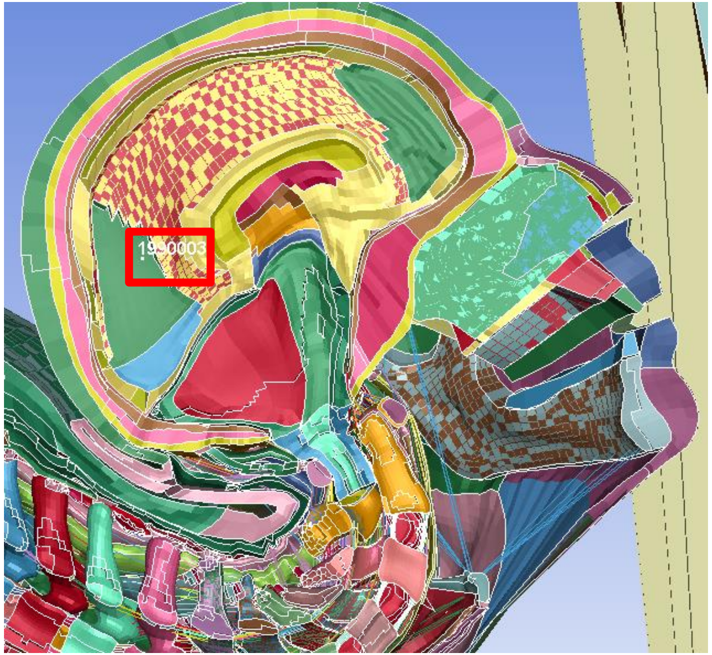
GHBMC



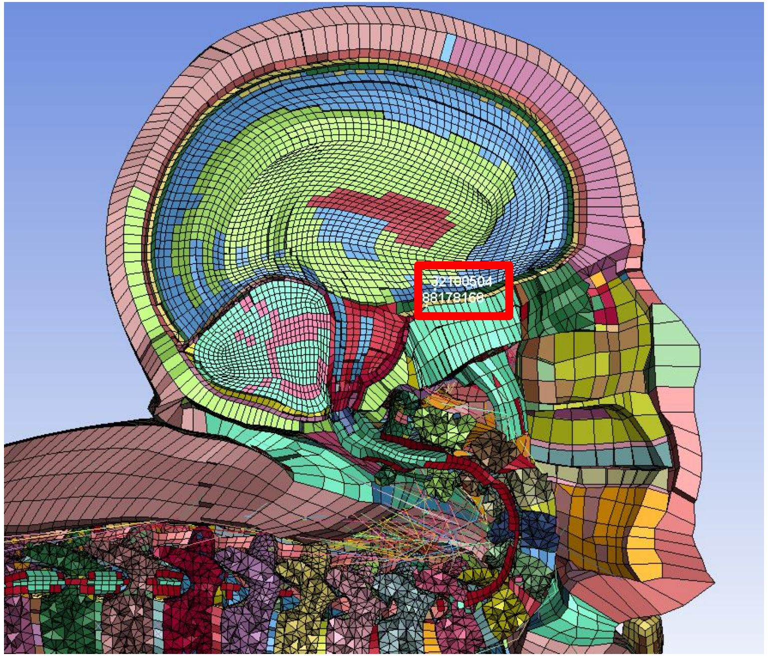
THUMS

Impact comparison - R3D Neck/Head comparison

GHBMC



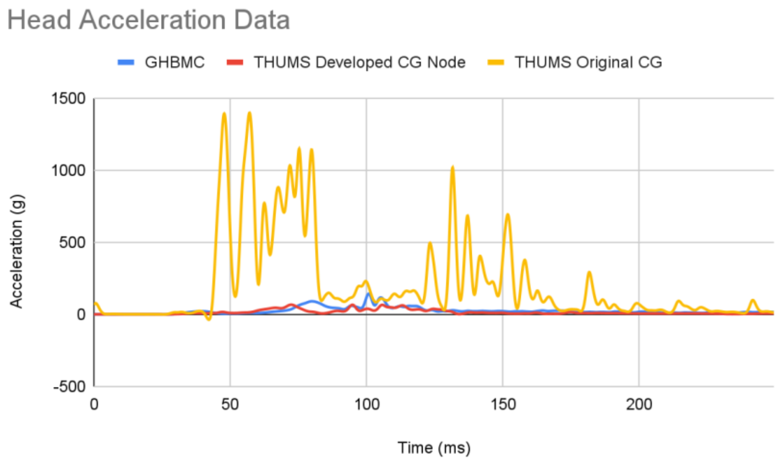
THUMS



Head CG node at t = 70 ms

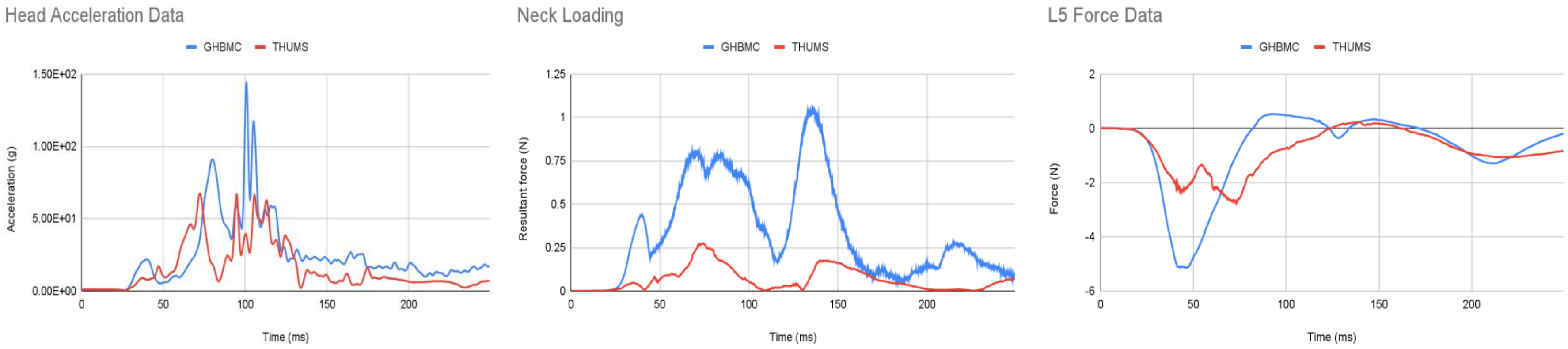
R3D Data Comparison

Body Component	GHBMC	THUMS	Included THUMS CG Node
Head	17.30%	0.46%	100%
Brain	82.62%	51.46%	47.07%
Neck	24%	6.37%	
Lumbar Vertebra	100%	100%	



Injury risk calculated for simulation R3D with included THUMS CG node Compared to developed CG Node

R3D Data Comparison - Continued



-THUMS Model showed lower peak values for all 3 primary outputs
-The THUMS developed Head CG node showed significantly more similar reactions than the original node
-Neck force reaches local maximums at similar points

Discussion

- THUMS Neck and head kinematics were validated utilizing the original head CG node
- GHBMC neck and head kinematics were validated utilizing the included instrumentation used in this study
- Both models predicted 100% spinal injury risk concurrent with previous studies utilizing ATD models
- THUMS models predicted injury risk significantly lower than both GHBMC and ATD models
- THUMS model required significantly longer computational time to run simulations (approximately 12 hours for GHBMC and 80 hours for THUMS)

Conclusions

- GHBMC model is currently a more intuitive model for the high loading environments of aircraft modeling simulations due to:
  - Lower computational time
  - More validated Instrumentation
- THUMS model provides significant benefits in:
  - Free access
  - Similar kinematics to GHBMC
  - Less modifications required
- Further development and validation of THUMS model instrumentation is needed for these high loading environments

Questions?