

A Finite Element Model of the THOR-K Dummy for Aerospace and Aircraft Impact Simulations

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Slide 1

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changed name from Wyle Laboratories

Author, 11/25/2013

Motivation

Improve Safety Analysis

- Spaceflight Safety Standards
- Restraint Systems & Seat Technology

Dummy Testing

- Test Device for Human Occupant Restraint (THOR)
- Potential in Aerospace Field
- Limited Multidirectional Evaluation

Dummy/ Human FE modeling

- Reduced Cost and Time
- Sensitivity and Design Optimization
- Human Kinetic Analysis

Multipurpose Crewed Vehicle (MPCV) - Water Landing



Pilot Ejection



Goals

- 1) Update and Improve the THOR Finite Element (FE) model to specifications of the latest mod kit (THOR-K)**
- 2) Evaluate the kinematic and kinetic response of the FE model in frontal, spinal, and lateral impact loading conditions**

THOR-K Dummy and Model Model

The latest version of THOR

Head/Neck: Re-designed (head parts, OC-Joint, cable guides)

Thorax: Implemented IR-TRACC thoracic displacement measurement

Pelvis: Re-designed

Lower Limb: Re-designed (knee joint, femur, foot)

Ridella, Stephen A., and Daniel P. Parent. "Modifications to improve the durability, usability and biofidelity of the THORNT dummy." Proceedings of the 22nd ESV Conference.

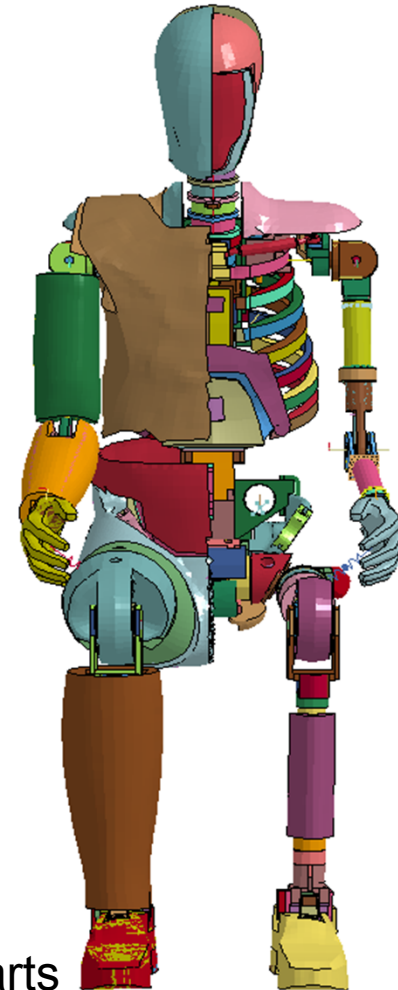
FE Model Updates

VT-Head/Neck

- ▶ Re modeled head parts
- ▶ Simplified OC-Joint

NHTSA Collaborators

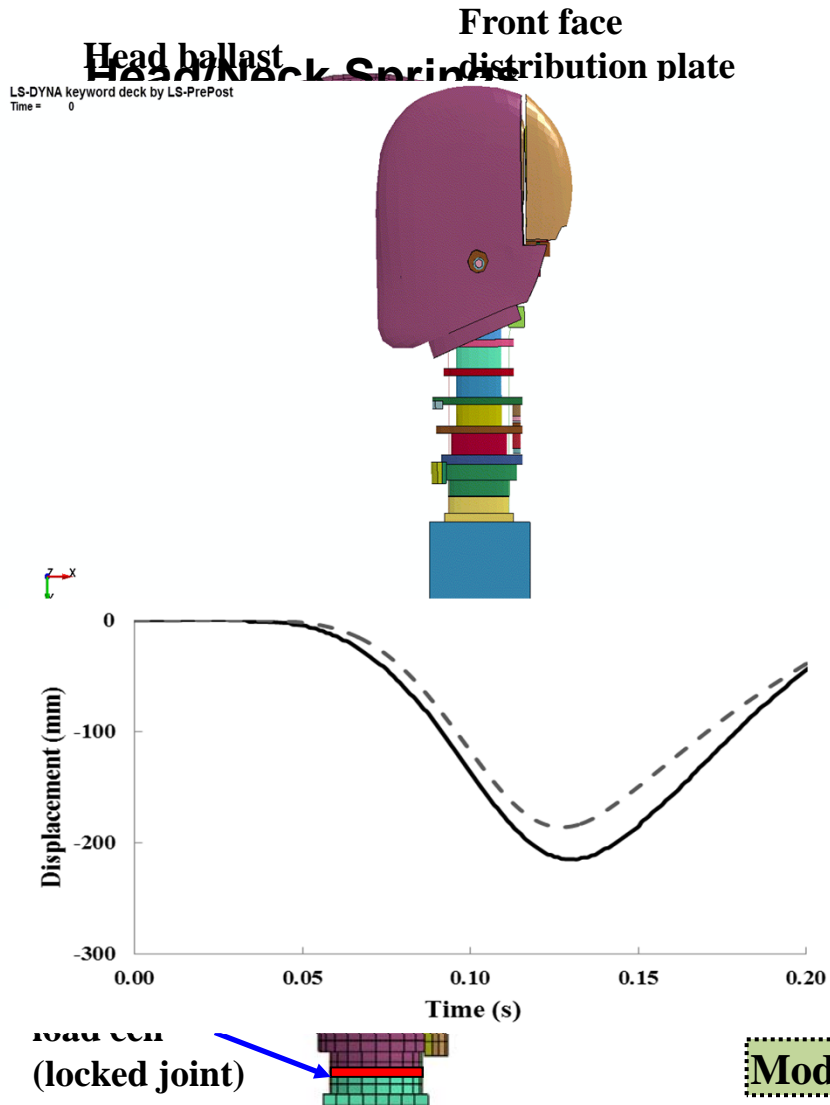
- ▶ Thorax, Pelvis, Lower Limb



424 parts
~ 221k nodes / 443k elements
~ 290k deformable elements
~ 0.063 μ s

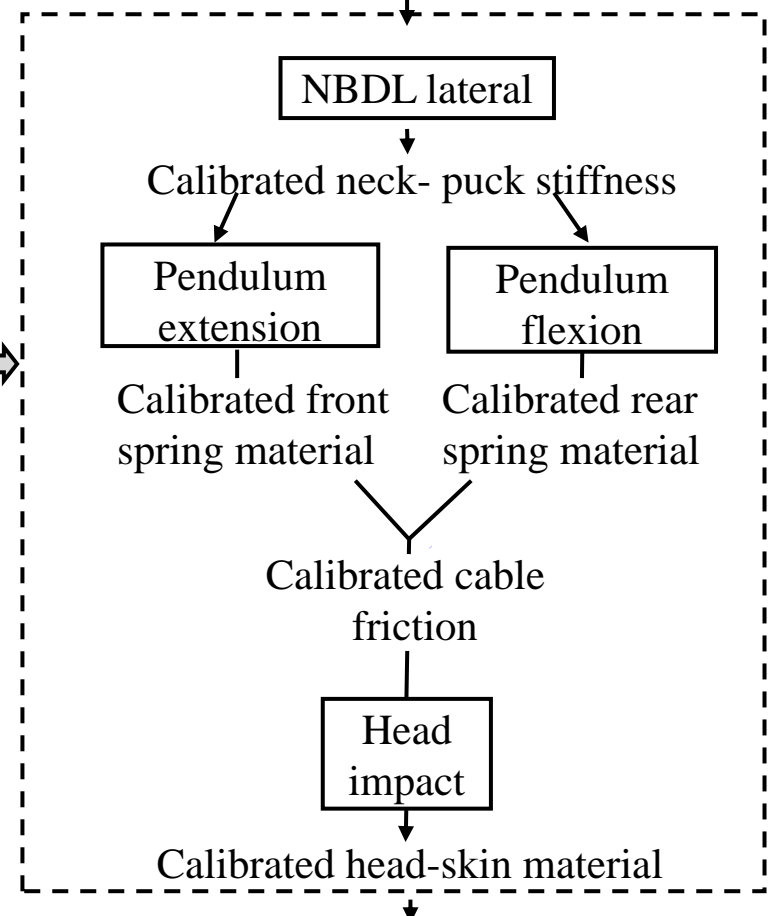
Development, Calibration and Validation of Head-Neck THOR-K FE Model

Part Updates



Model calibration

Developed THOR-K head-neck model



Calibrated THOR-K head-neck model

Model validation



Model Development: Head-Neck THOR-K FEM

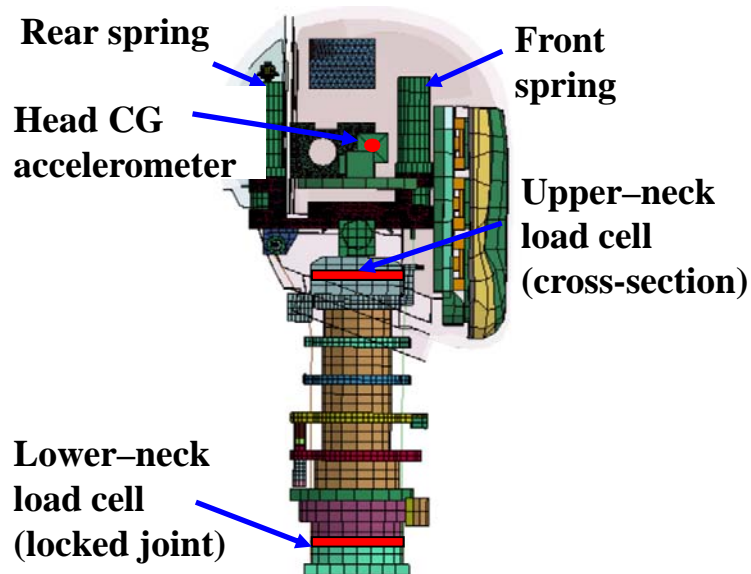
Part Updates

- Modeled CAD part geometries
- Simplification of OC-Joint

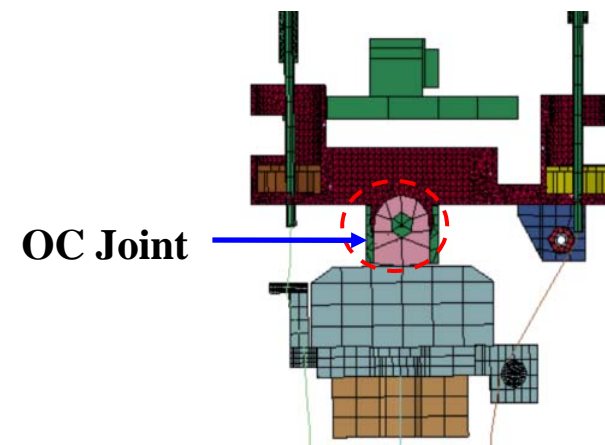
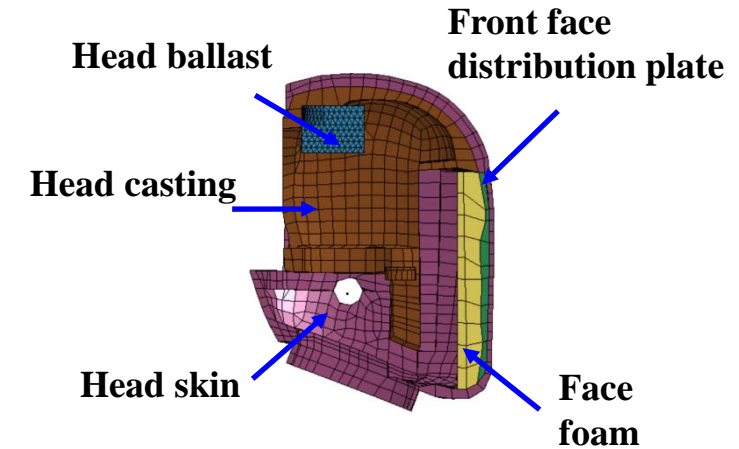
Head CG & Mass Validation

- Ballast Adjustment
- Spec. Tolerance

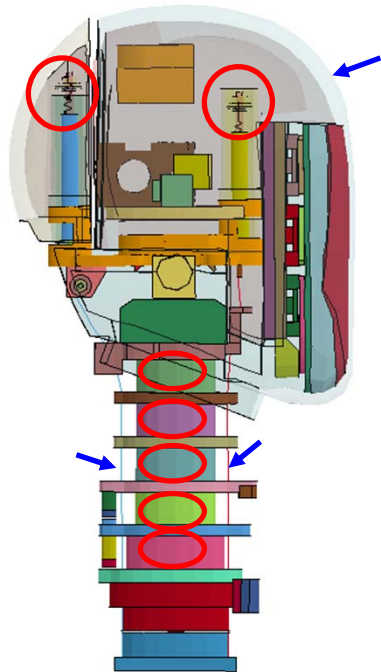
Instrumentation



Part Updates



Model Calibration: Head-Neck THOR-K FEM



Model calibration



NBDL lateral

Calibrated neck- puck stiffness

Pendulum extension

Pendulum flexion

Calibrated front spring material

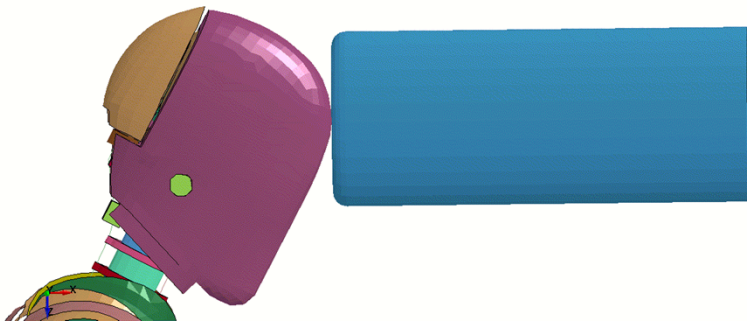
Calibrated rear spring material

Calibrated cable friction

Head impact

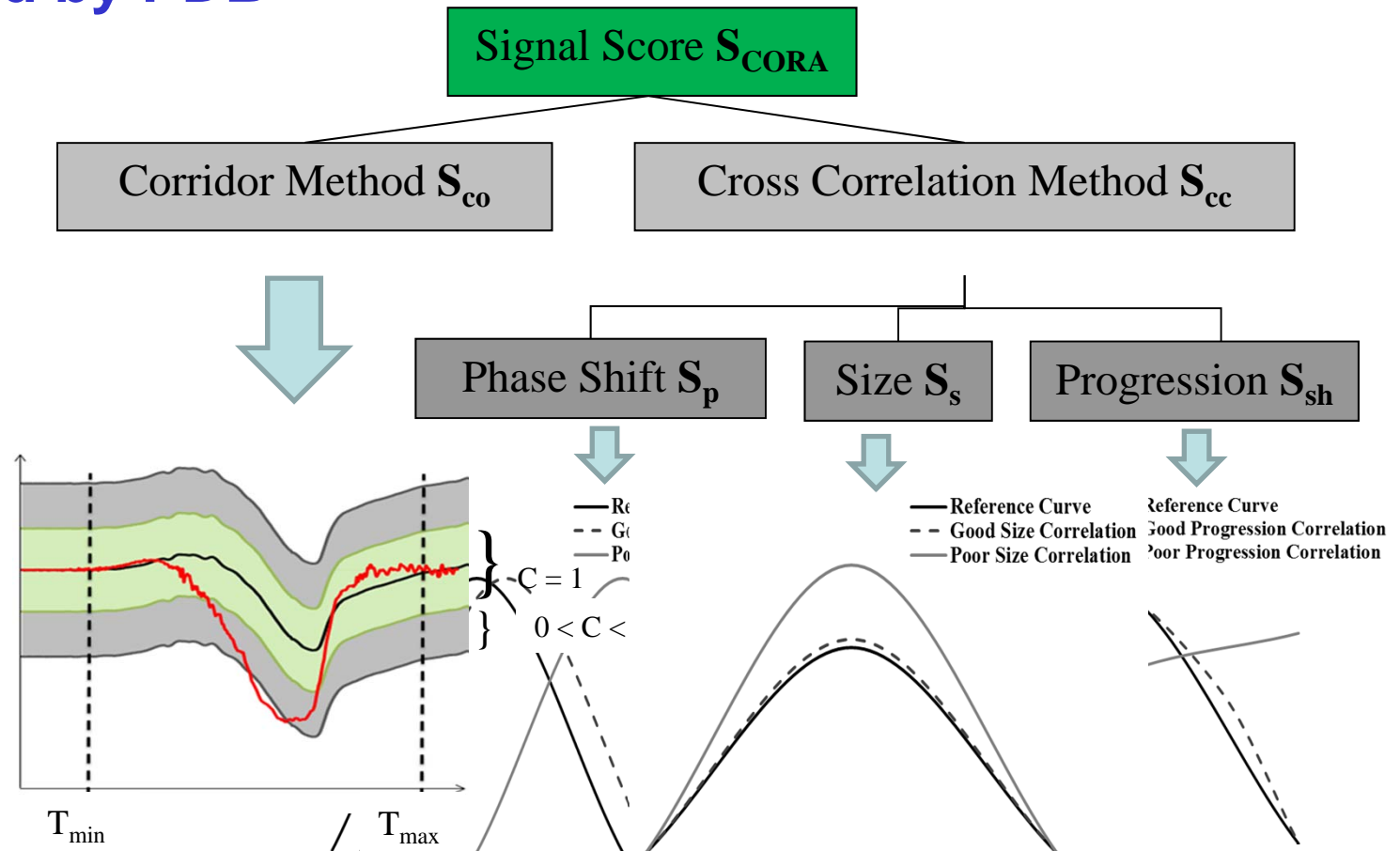
Calibrated head-skin material

LS-DYNA keyword deck by LS-PrePost
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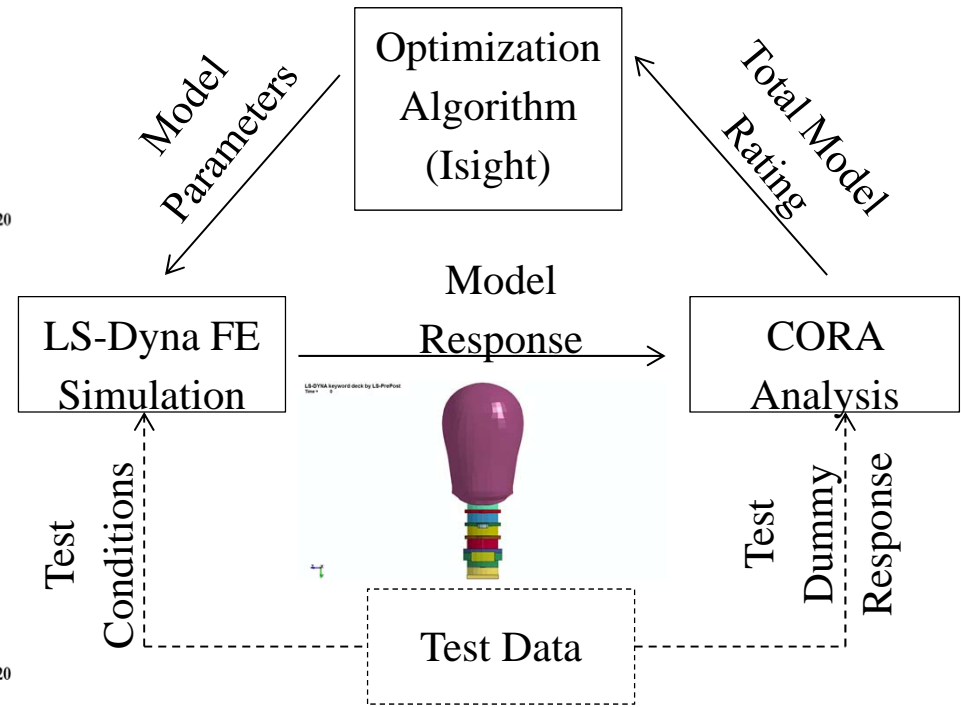
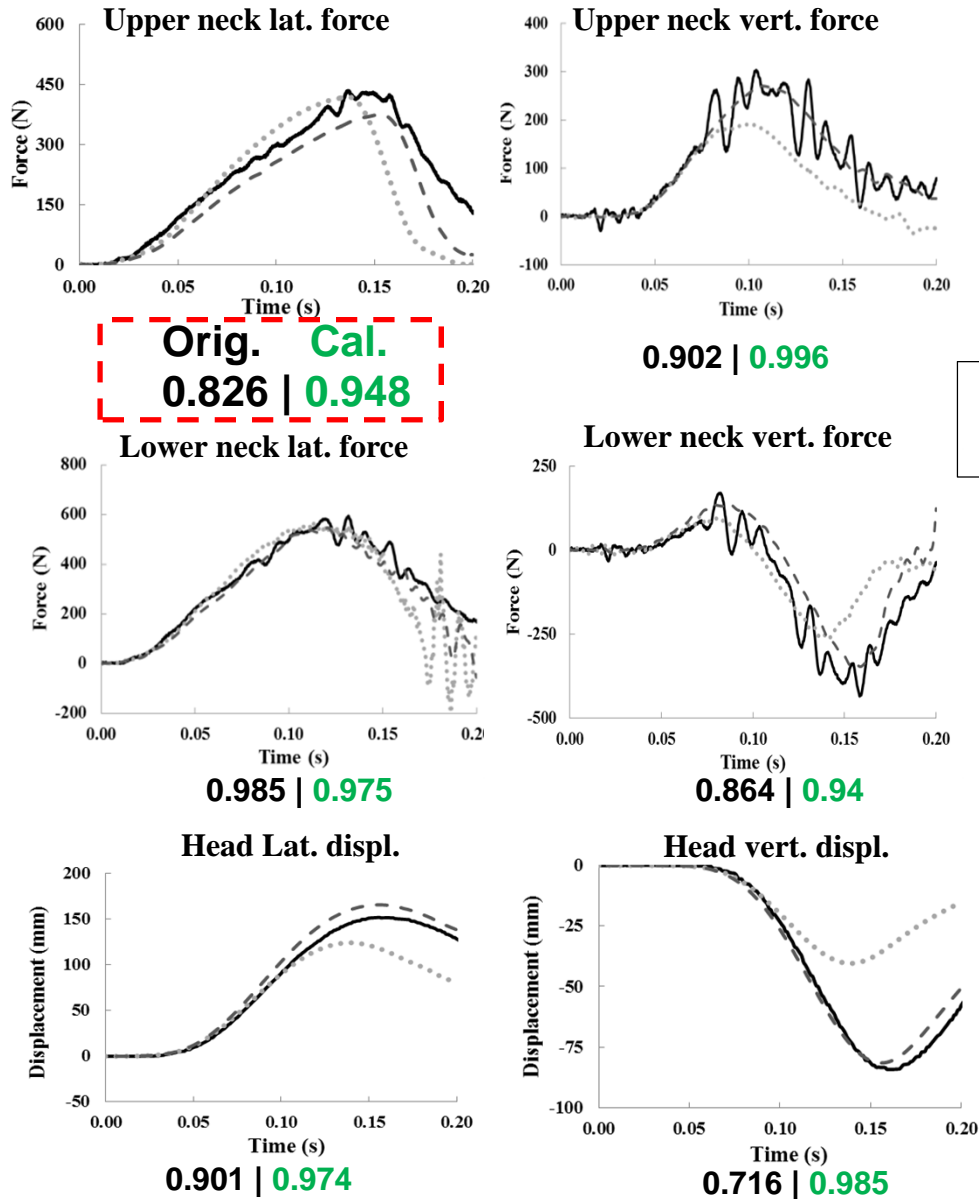


CORA (CORrelation and Analysis) Rating Score

- Multi-aspect curve rating system
- Proposed SAE ISO Standard
- Developed by PDB



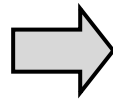
Model Calibration (example)



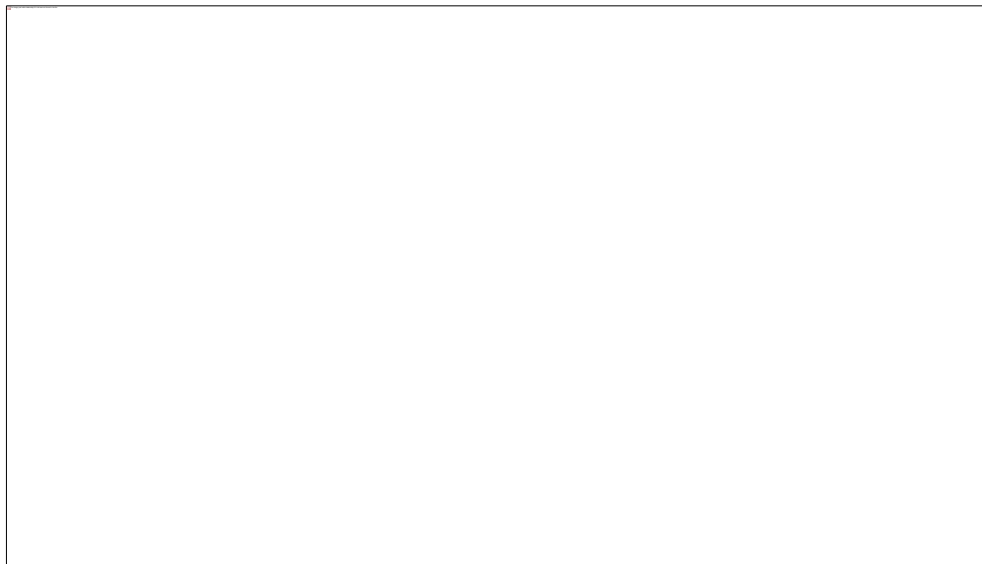
NBDL lateral
Bending Score
Original **Calibrated**
0.845 | 0.971

Model Validation: Head-Neck THOR-K FEM

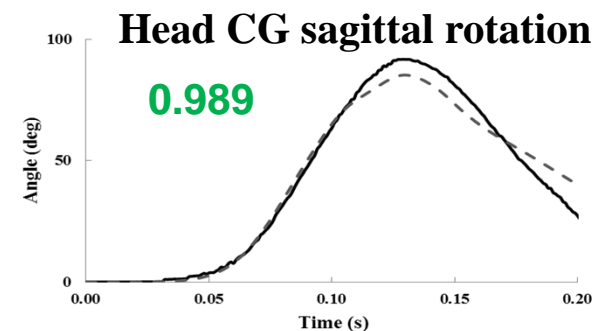
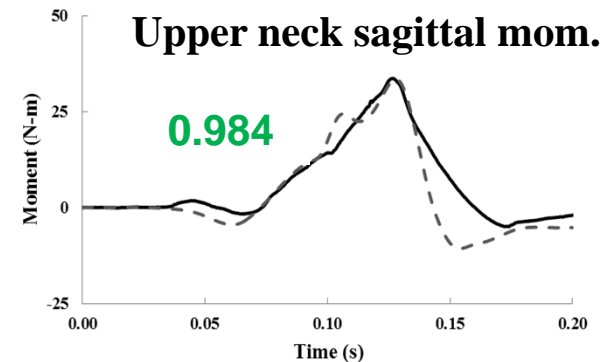
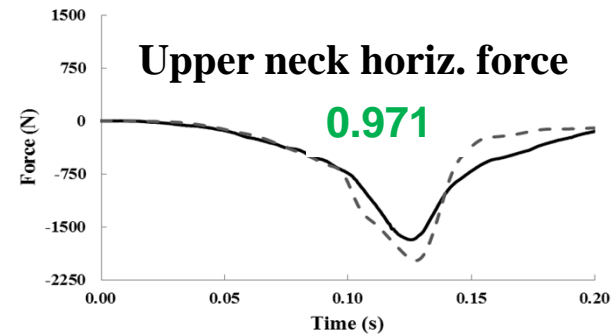
Model validation



NBDL frontal

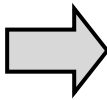


Cora Score: 0.948



Model Validation: Head-Neck THOR-K FEM

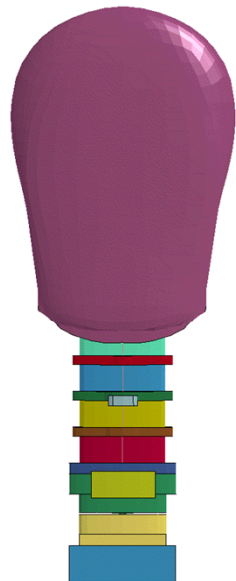
Model validation



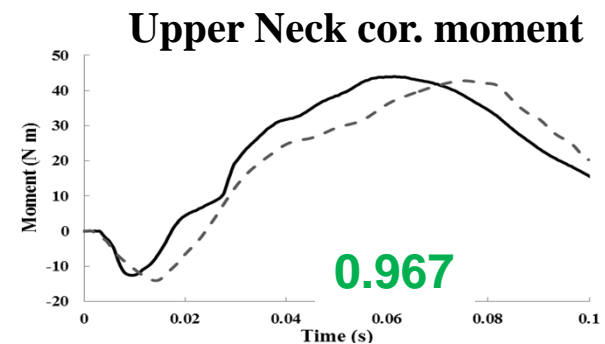
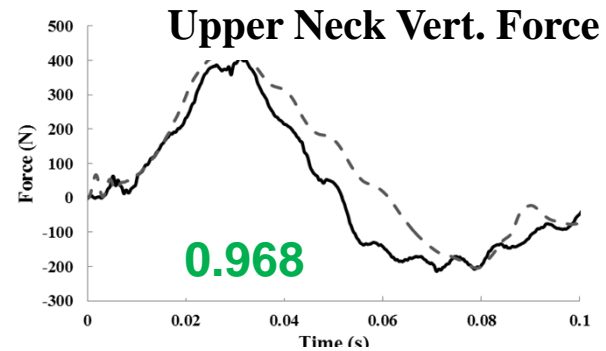
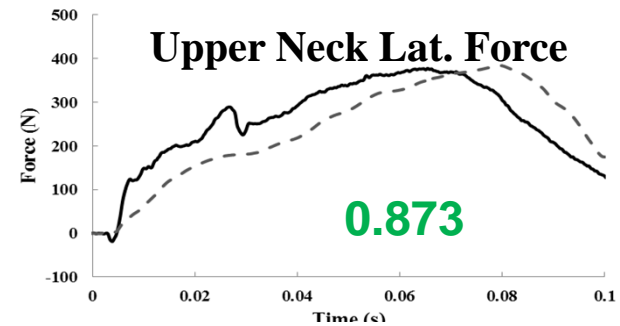
NBDL frontal

Pendulum lateral

LS-DYNA keyword deck by LS-PrePost
Time = 0



Cora Score: 0.936



Full THOR-K Dummy Testing

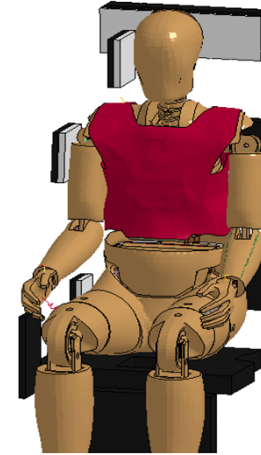
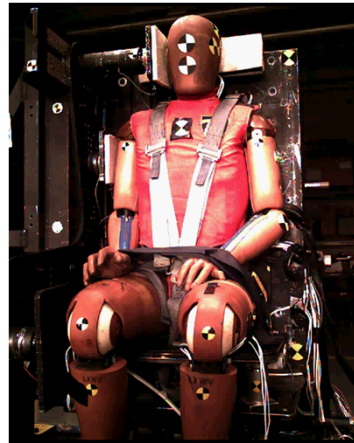
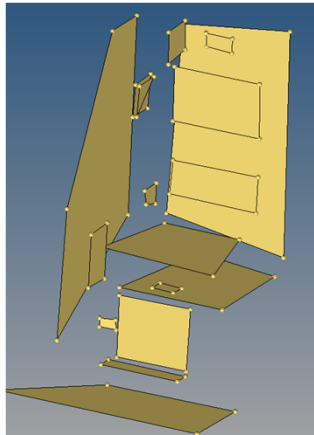
- **Performed at WPAFB**
 - Based on Historic Volunteer Tests
 - THOR-K ATD
 - Hybrid III ATD
 - Horizontal impulse accelerator

- **Test Directions**
 - Frontal
 - Spinal
 - Lateral



Simulation Setup

Chair Model



Belt Model



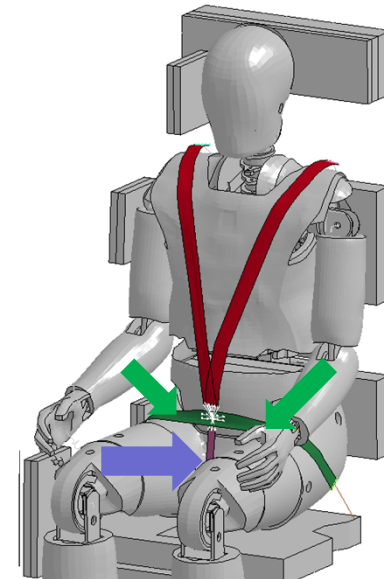
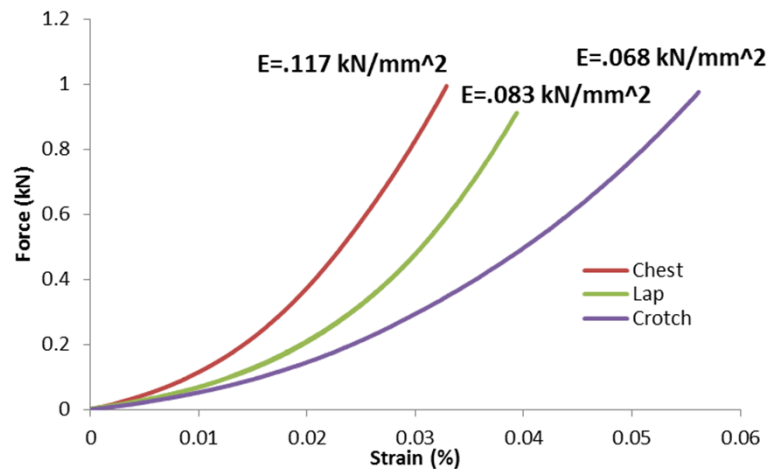
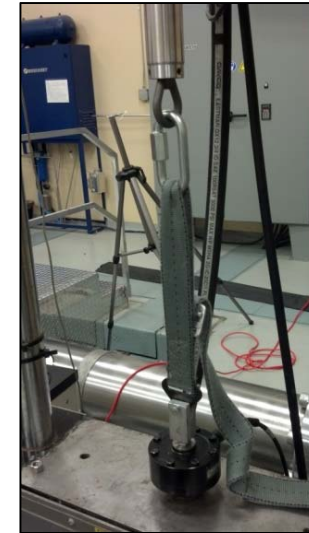
Belt Material Characterization

Testing

- Uniaxial Loading
- 250-lb load @ 1 mm/s

Results

- Developed Force/Strain Curve
 - ▶ Belt material
- Estimated Elastic Modulus
 - ▶ Fabric Material

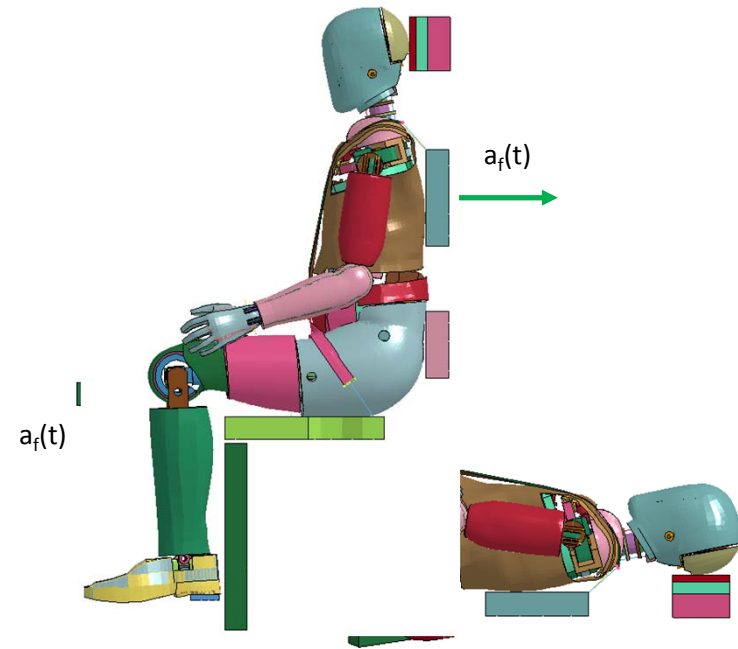
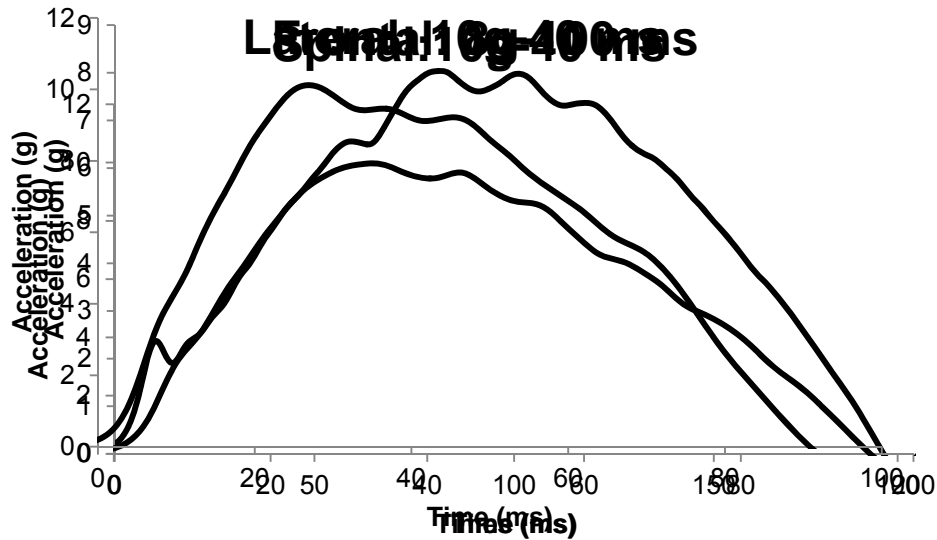


Simulation Conditions

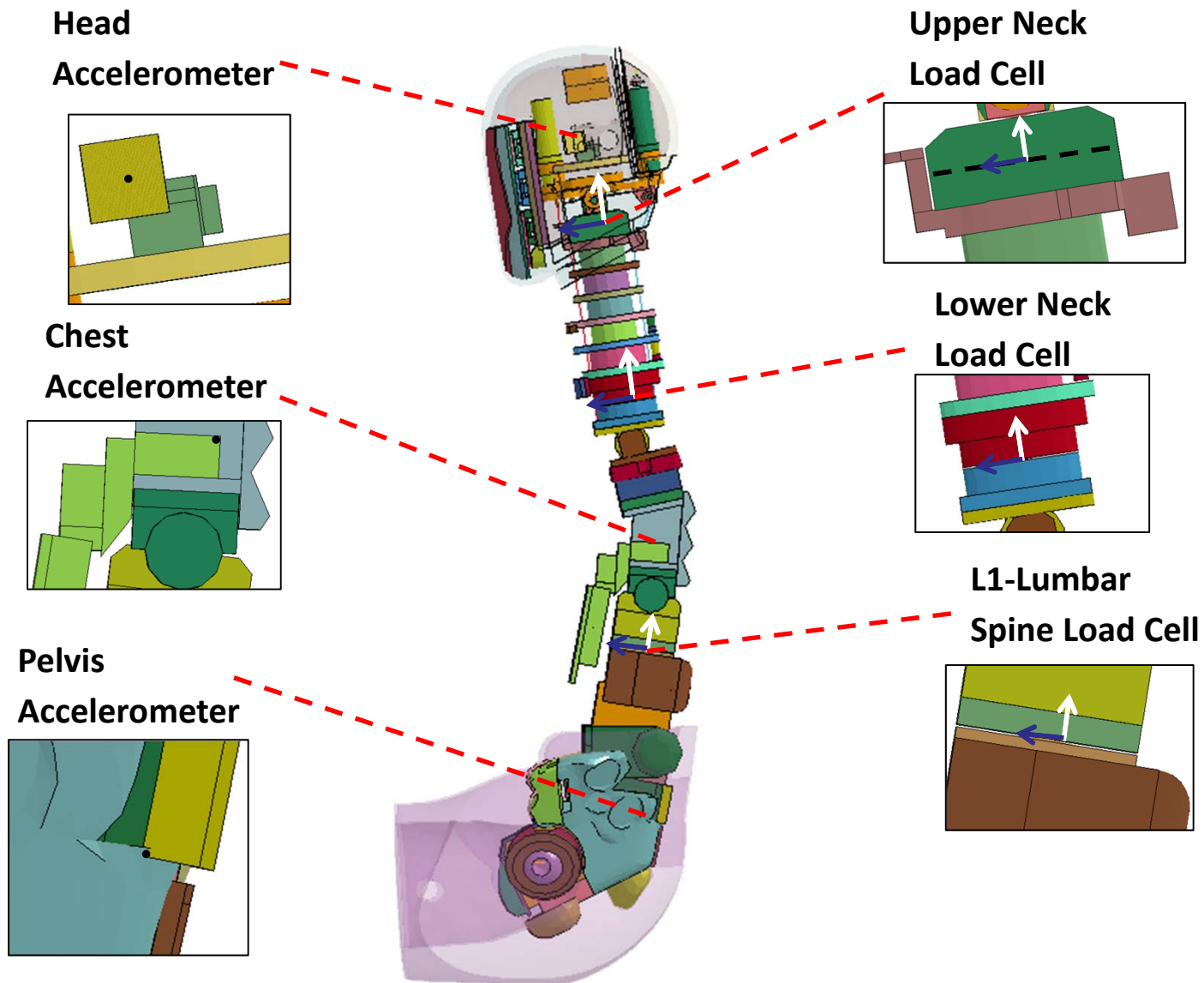
Boundary Conditions

- Sled Acceleration
- Gravity Applied to all Parts
- Stress Initialization
- Belt Constraints

Acceleration Pulse

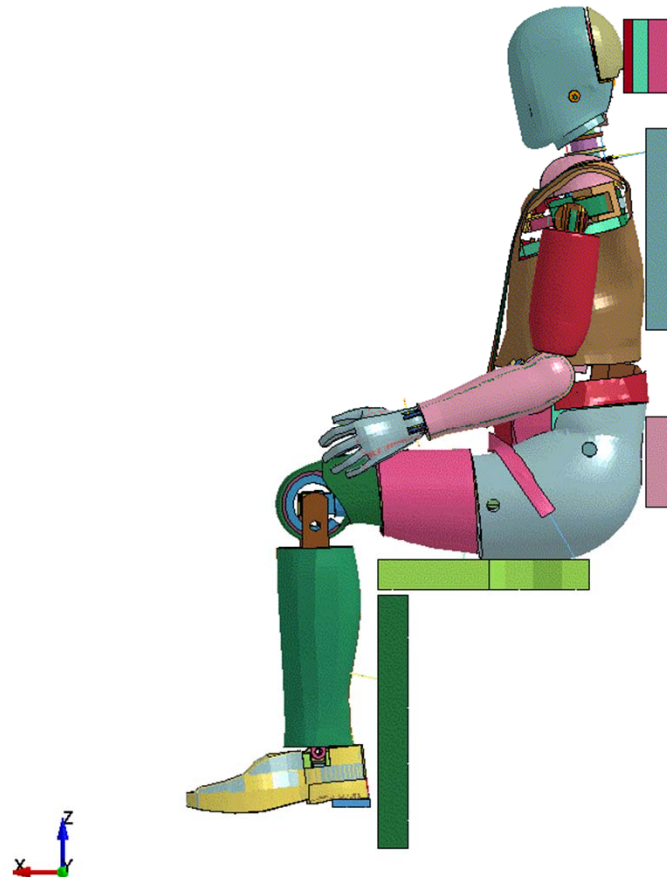


Instrumentation



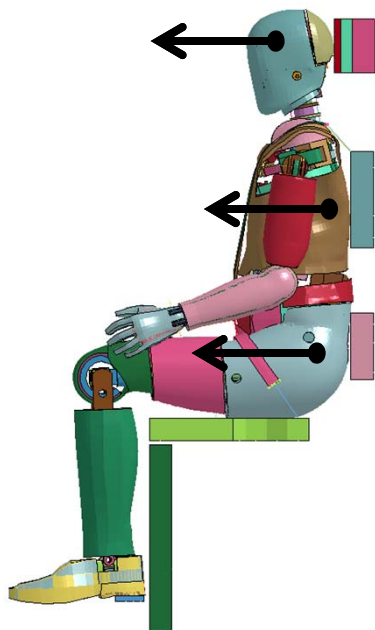
Frontal Results - Overview

LS-DYNA keyword deck by LS-PrePost
Time = 152



CORA Rating: .906

Frontal Results – Frontal Acceleration

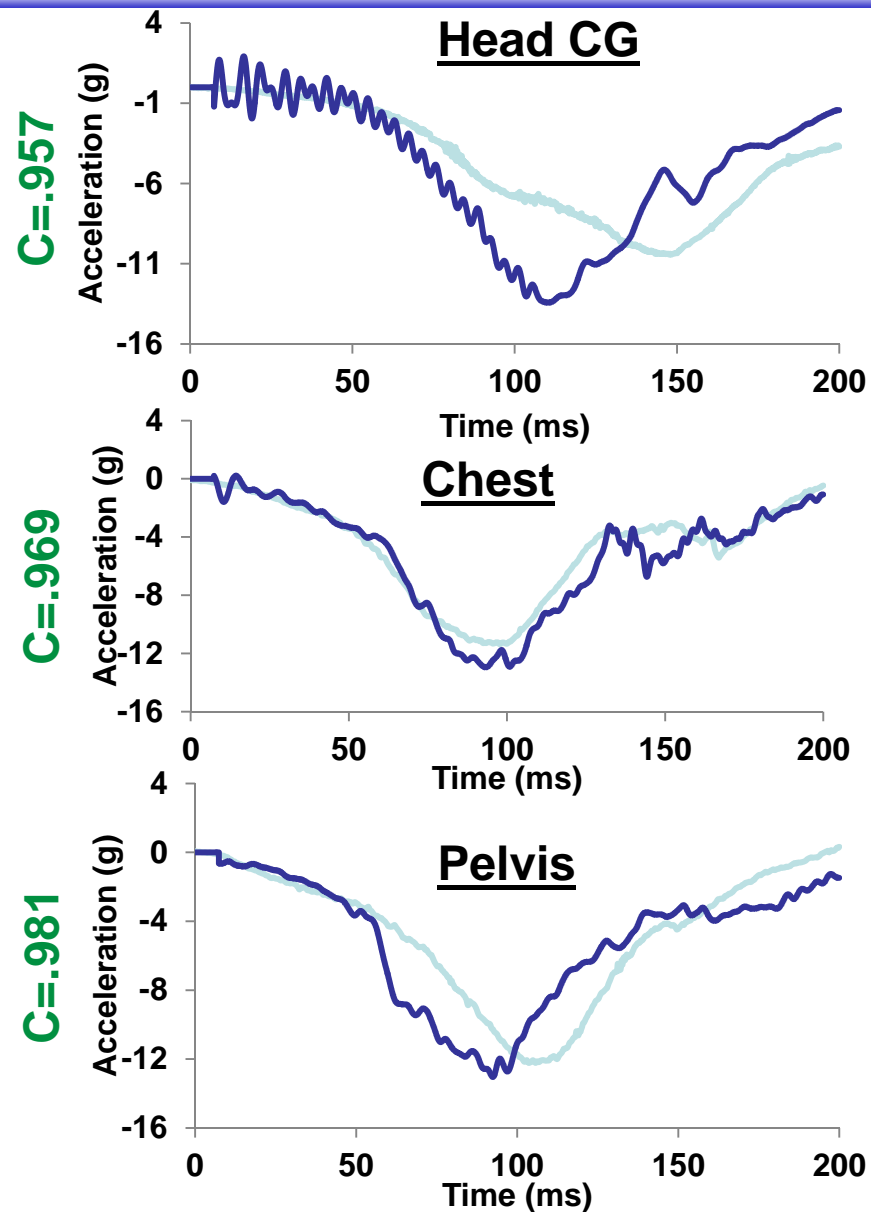


— THOR ATD — THOR FE

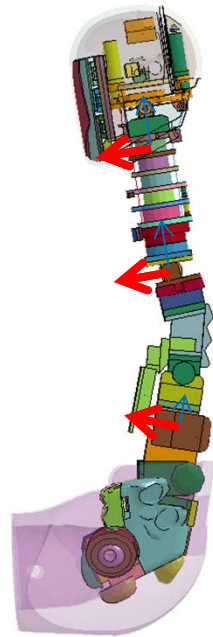


Kinematics

- High CORA Rating
- Similar Peaks
- Faster rise time in head and pelvis



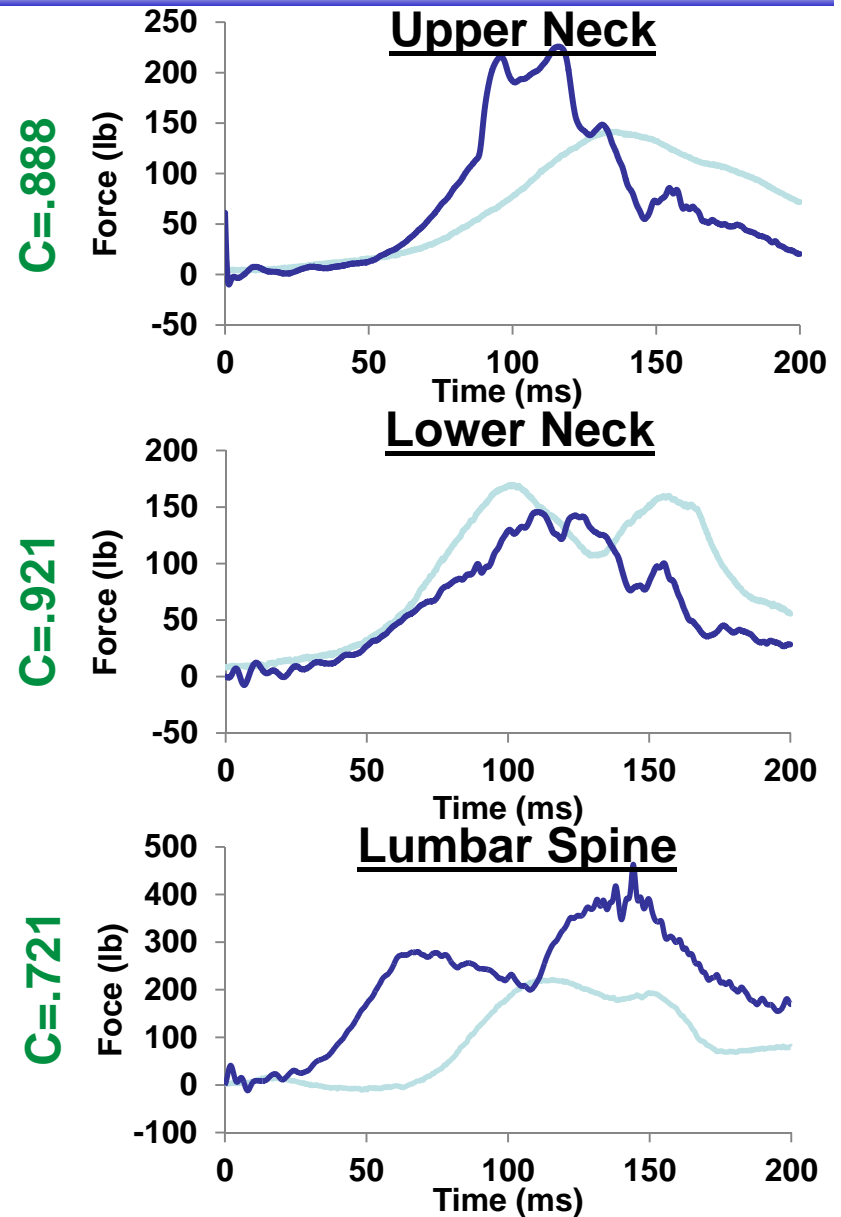
Frontal Results – Frontal Force



— THOR ATD — THOR FE

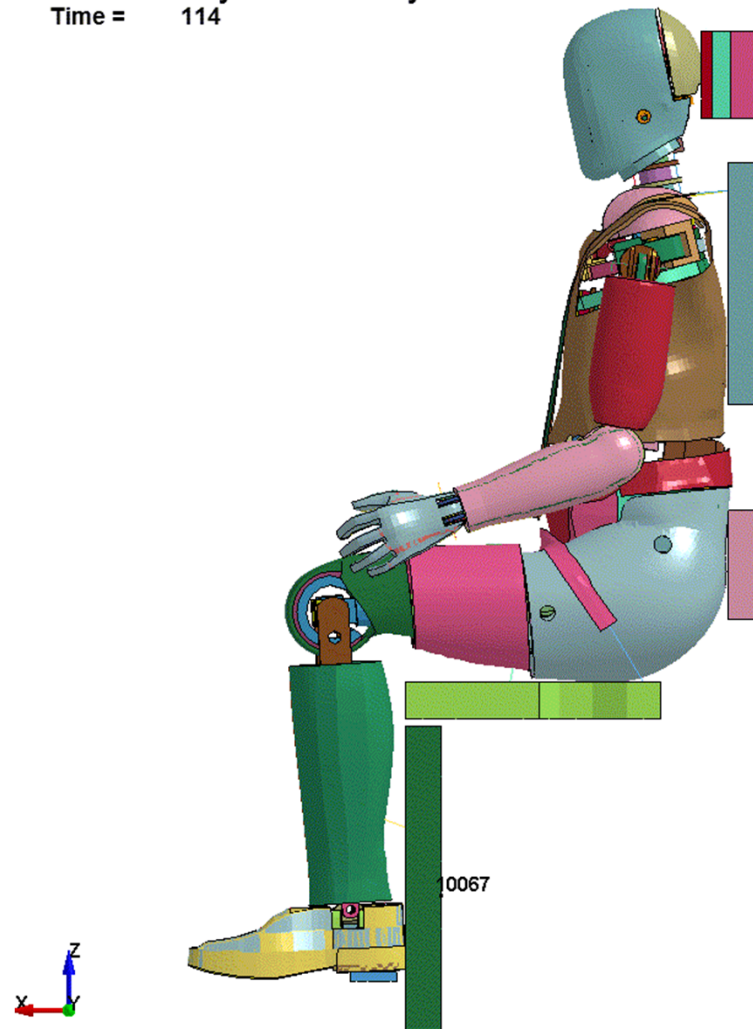
Kinetics

- Similar response in lower neck
- Upper Neck & Lumbar Spine
 - ▶ Faster Rise
 - ▶ Larger Peak



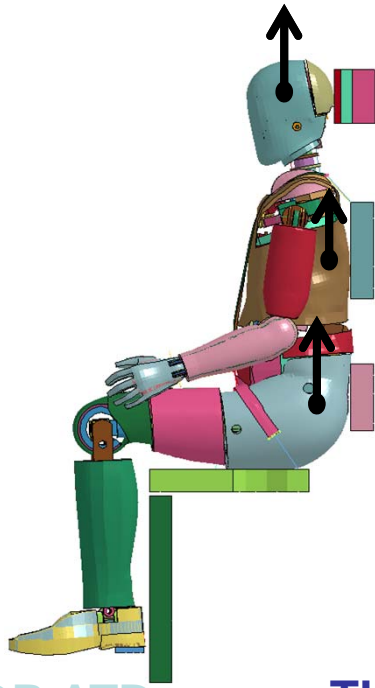
Spinal Results - Overview

LS-DYNA keyword deck by LS-PrePost
Time = 114



CORA Rating: .874

Spinal Results – Anterior Acceleration



THOR ATD

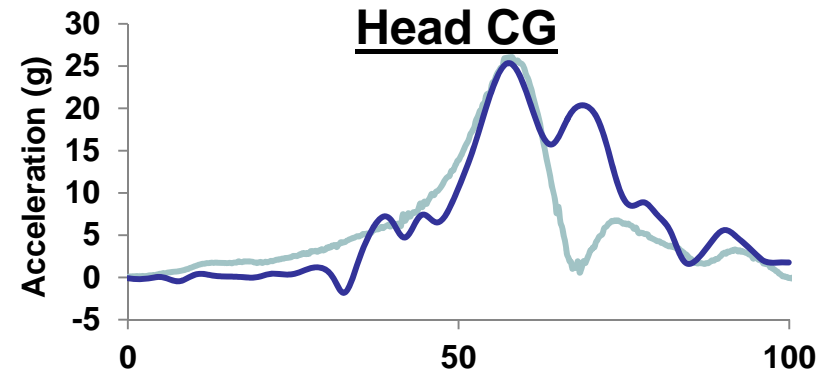
THOR FE



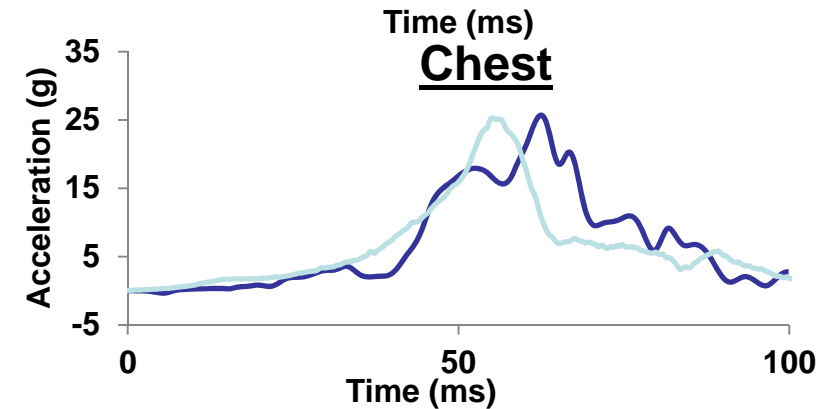
Kinematics

- Similar Peaks
- Similar Rise in head and chest
- “Bouncing” Pelvis

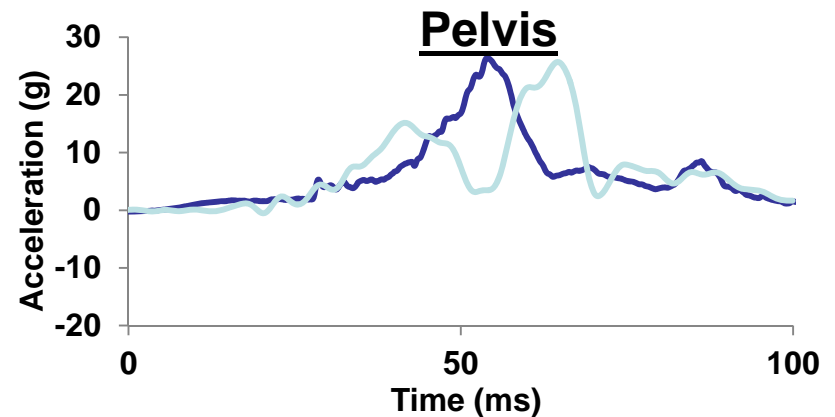
C=.874



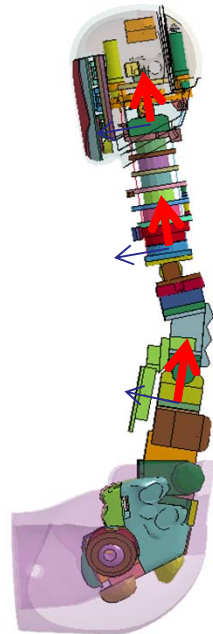
C=.925



C=.834



Spinal Results- Anterior Force

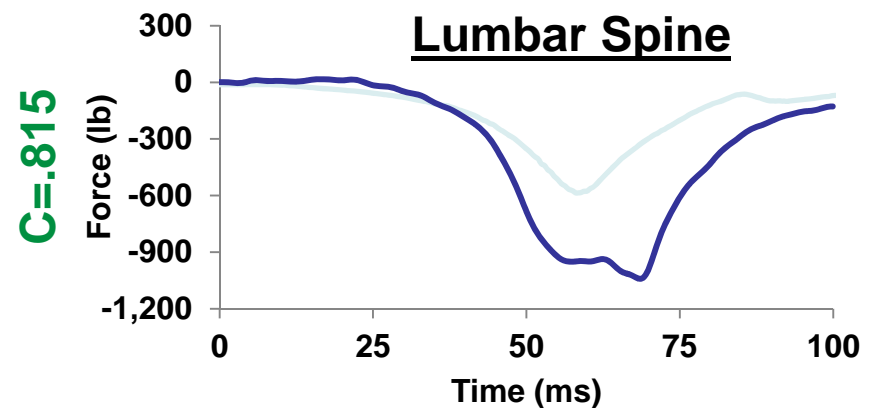
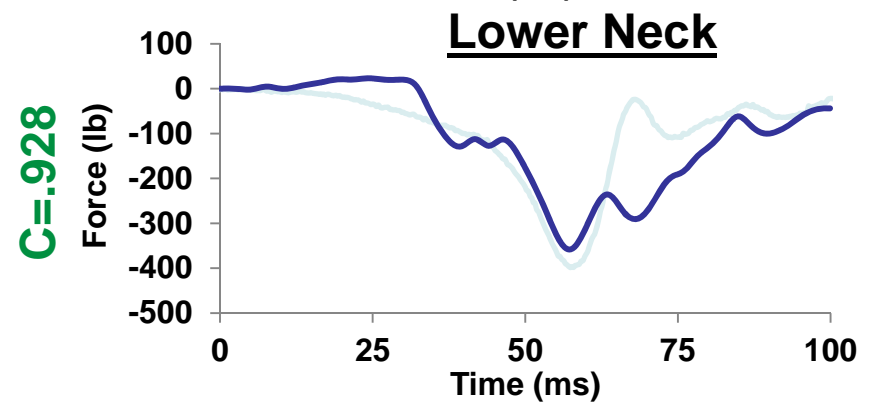
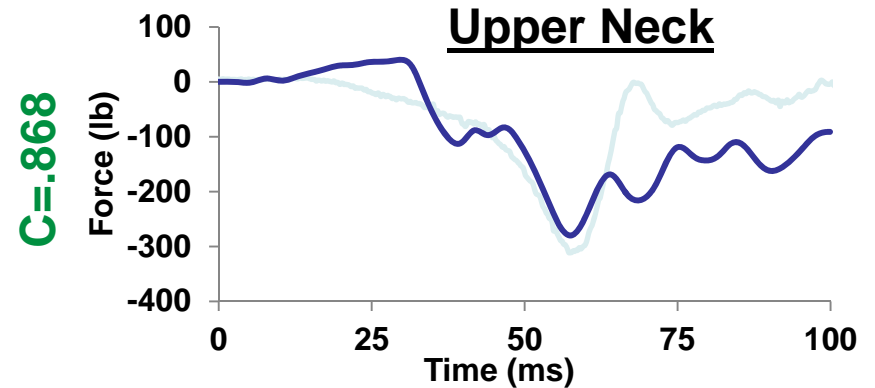


— THOR ATD — THOR FE



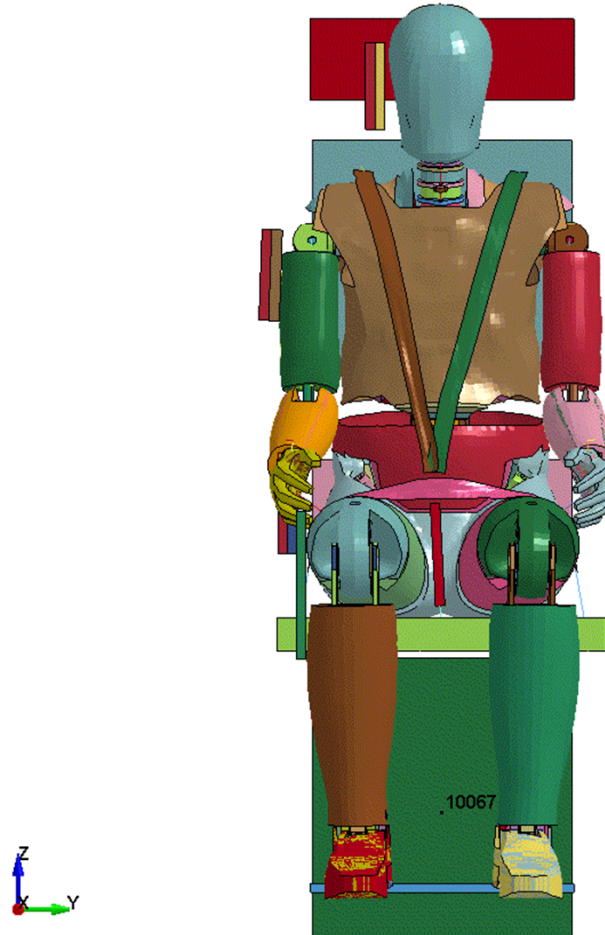
Kinetics

- Similar upper body
- High lumbar over prediction



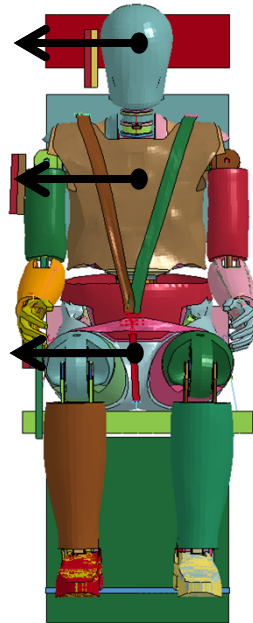
Lateral Results - Overview

LS-DYNA keyword deck by LS-PrePost
Time = 152



CORA Rating: .838

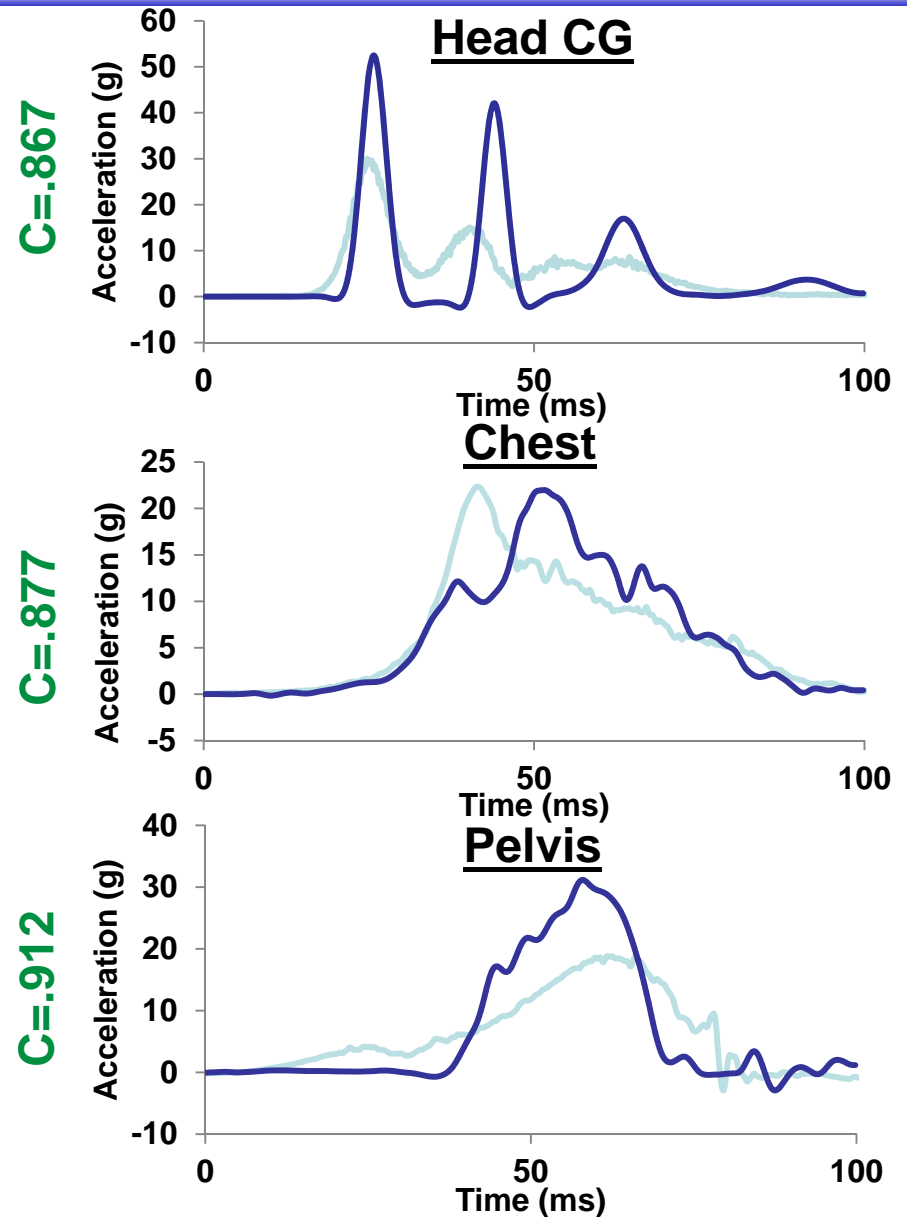
Lateral Results – Lateral Acceleration



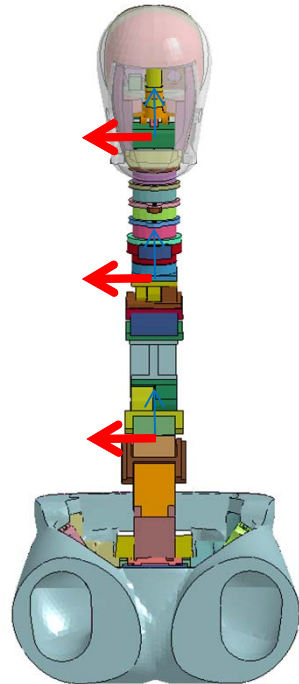
— THOR ATD — THOR FE

Kinematics

- Similar timing
- Large peaks in head & pelvis
- Largely dependent on positioning of impact plates



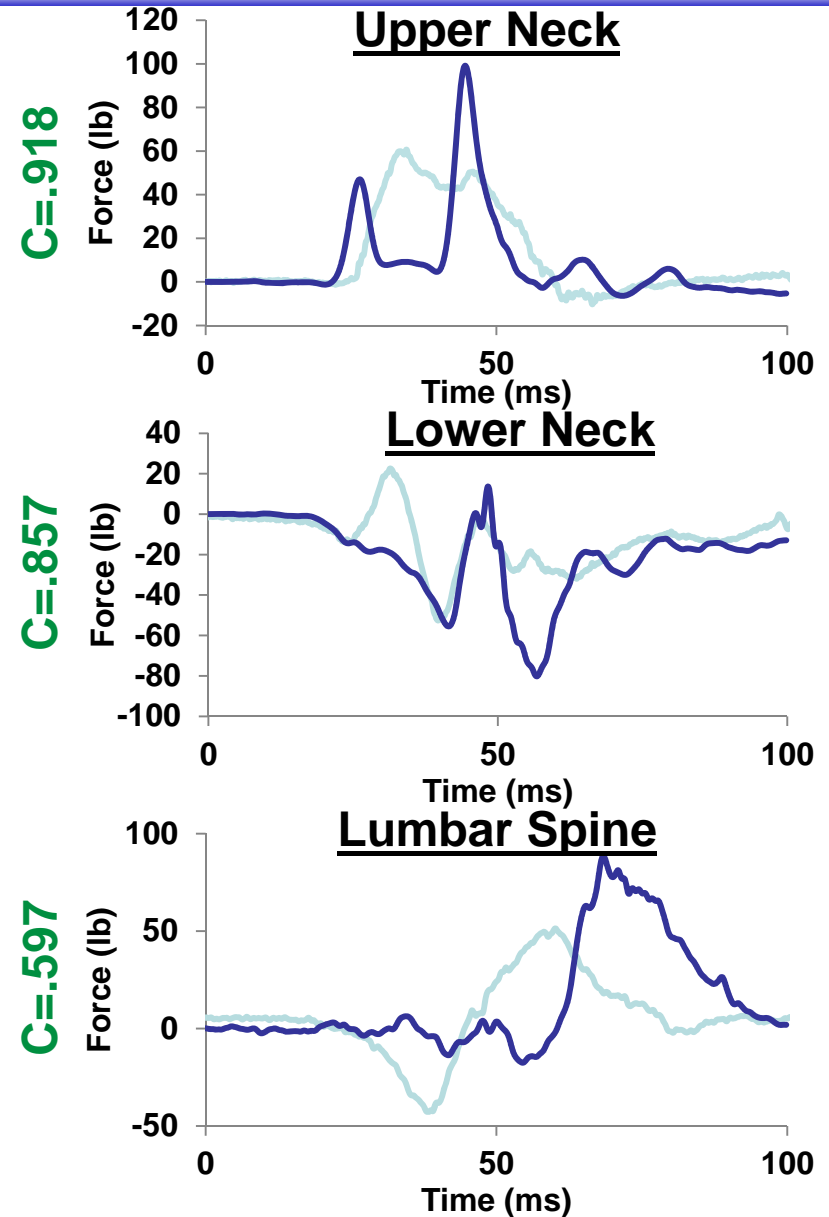
Lateral Results – Lateral Force



— THOR ATD — THOR FE

Kinetics

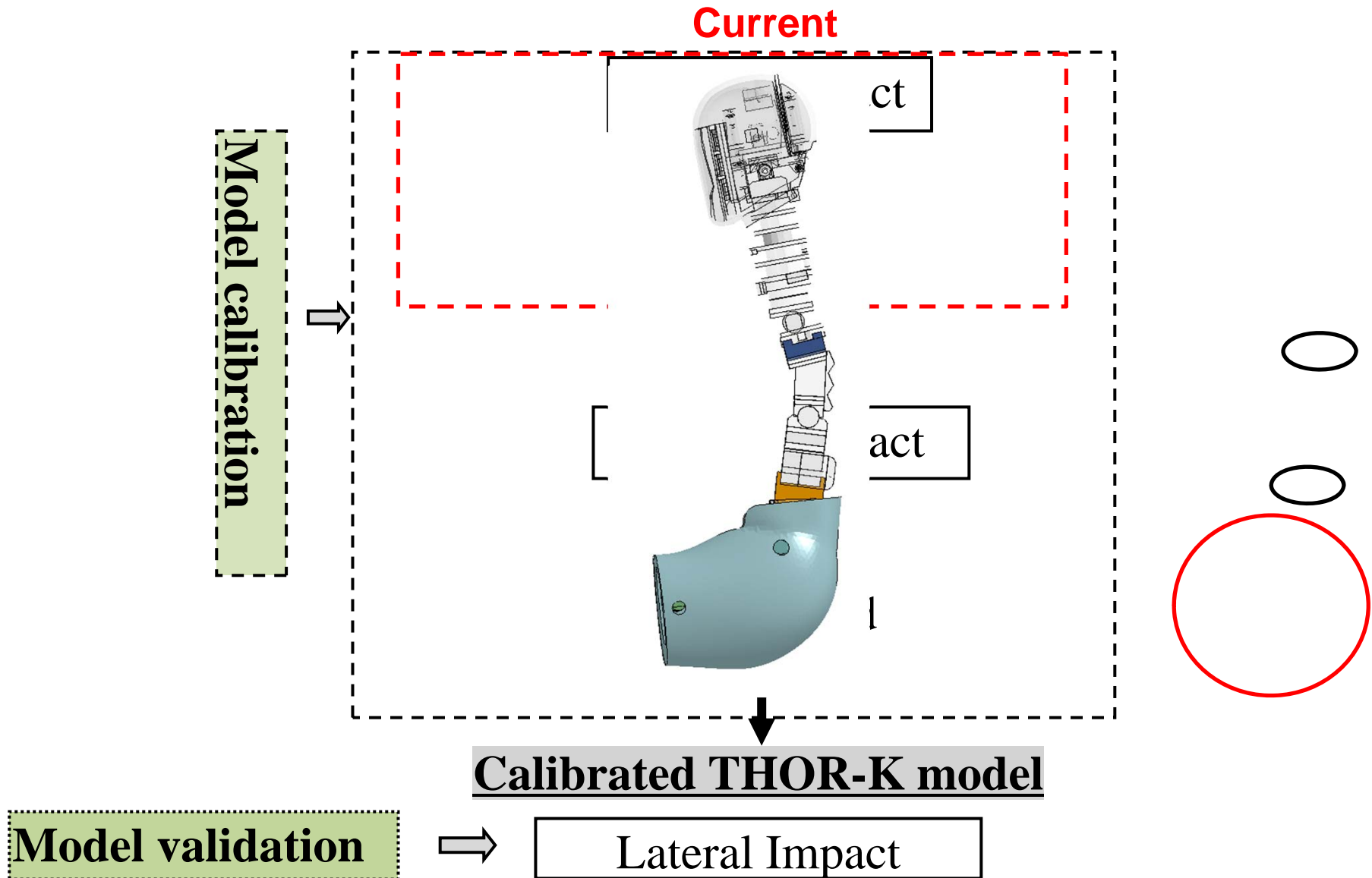
- “Bouncing” response
- Larger secondary impact



Conclusions

- **The THOR-K FE Head/Neck model validated.**
- **The THOR FE model accurately represents the THOR-K dummy in frontal, lateral, and spinal tests.**
- **Significant differences are observed in spinal flexibility and pelvis stiffness between models.**

Next Steps: Full Calibration



Pelvis Calibration – Quasi Static

Pelvis Compression Test

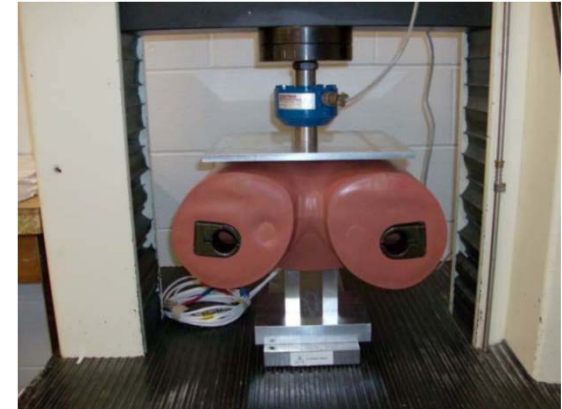
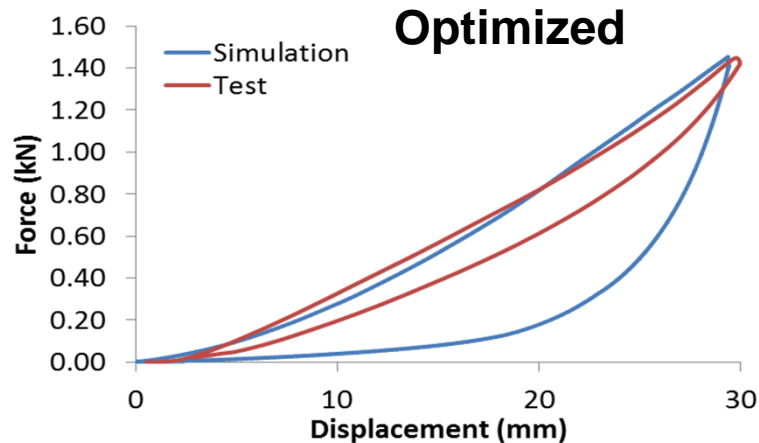
- Performed by Denton (Humanetics)
- Pelvis Skin & Flesh
- 30-mm Compression @ 250 mm/min

Material Model Optimization

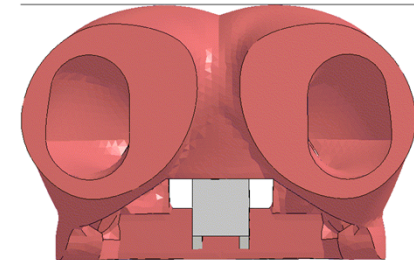
- Objective: Force/Displacement
- Variables: Stiffness Scale Factor

Results

- Decreased Stiffness



LS-DYNA keyword deck by LS-PrePost
Time = 0

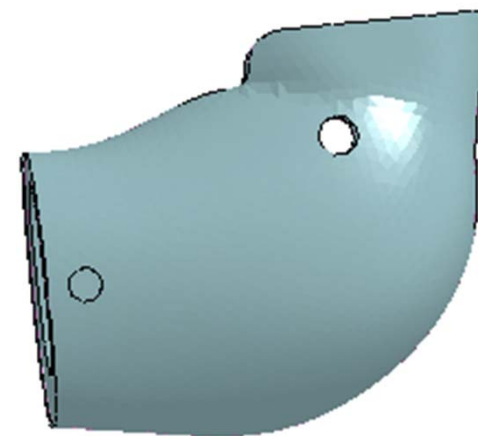
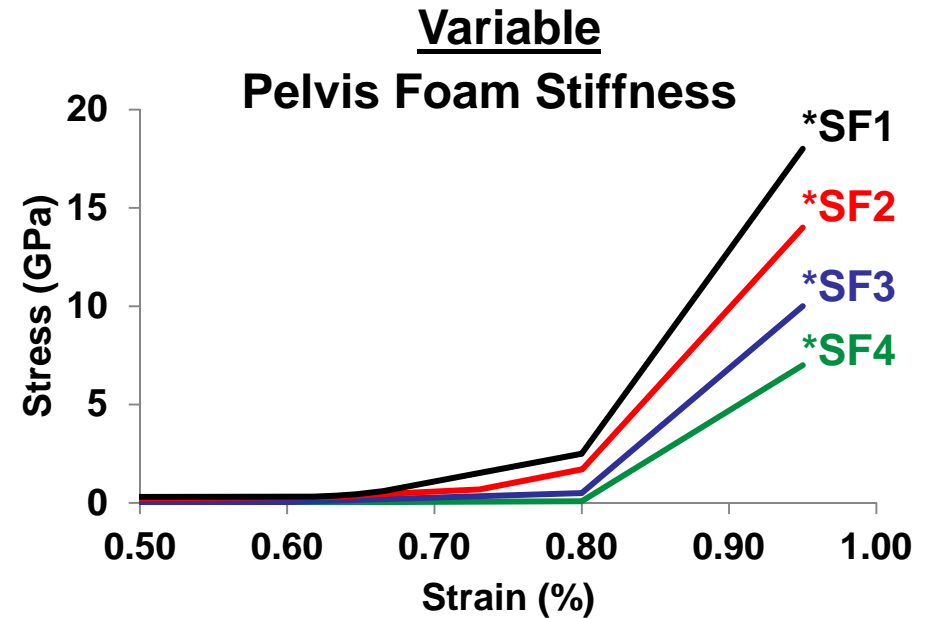
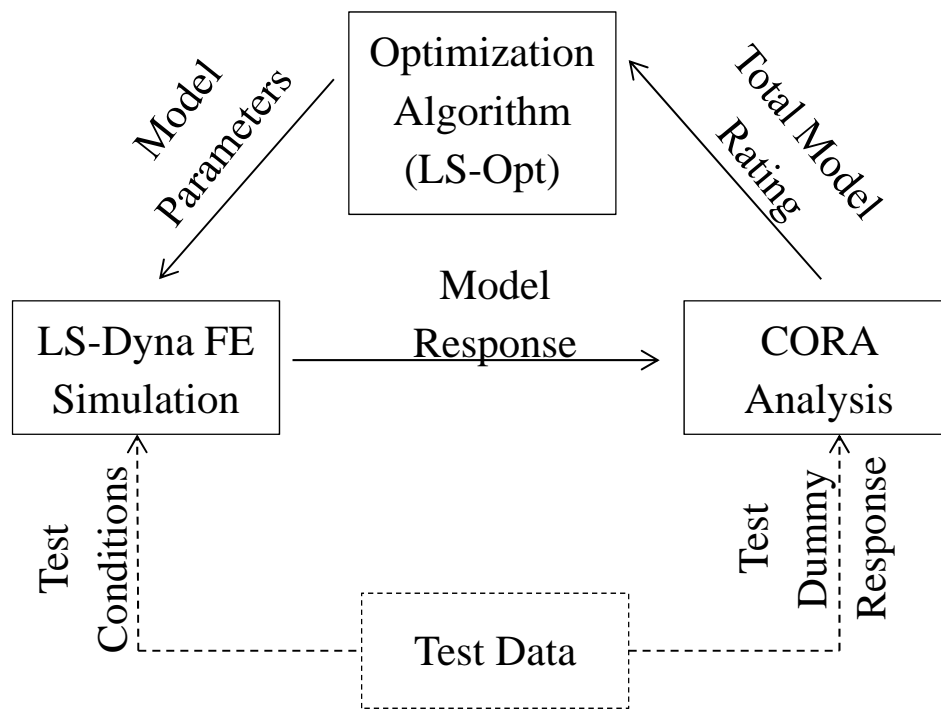


Pelvis Calibration - Dynamic

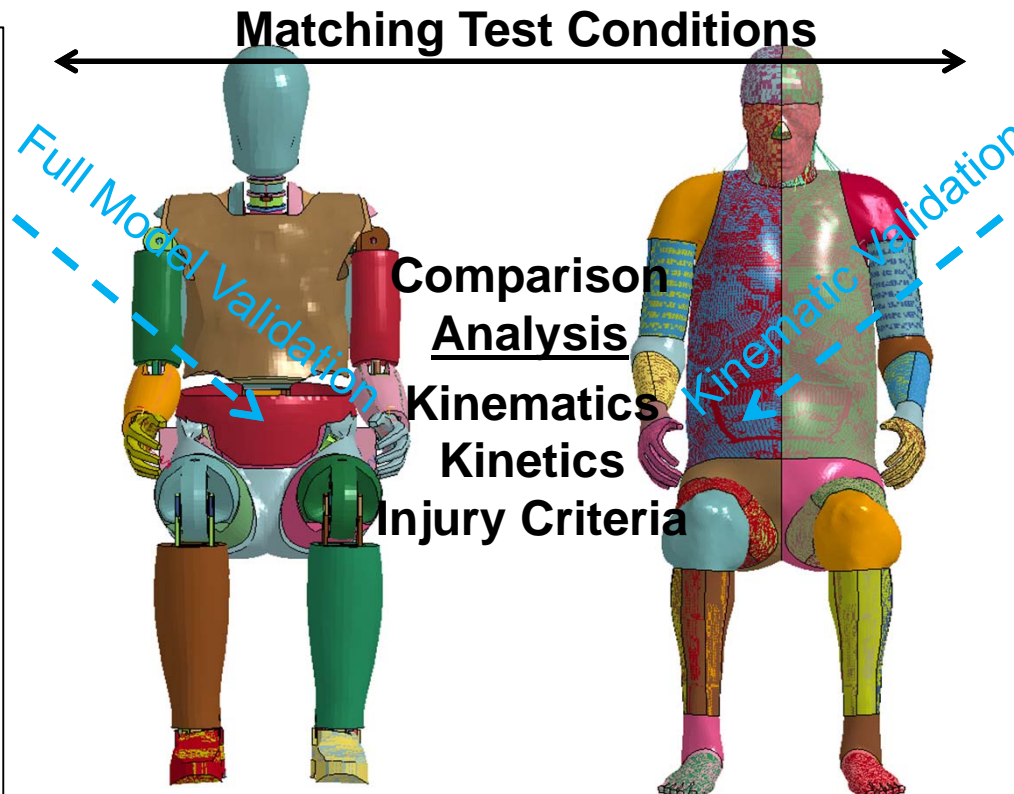
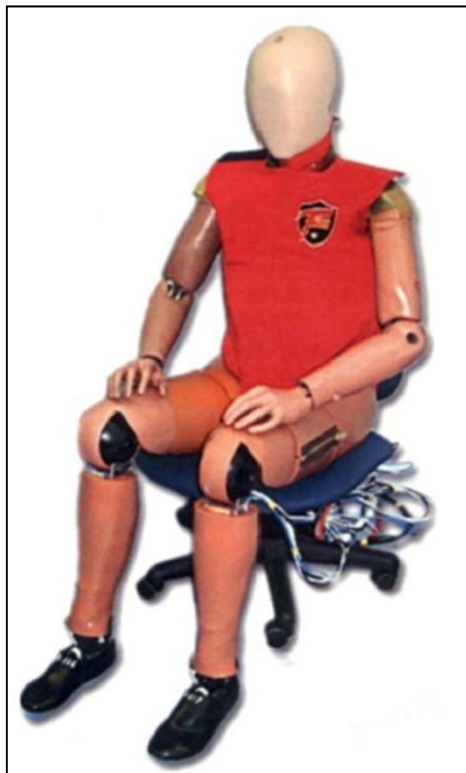
Simulation

- Spinal WPAFB Test
- 10 g @ 40 ms

Procedure

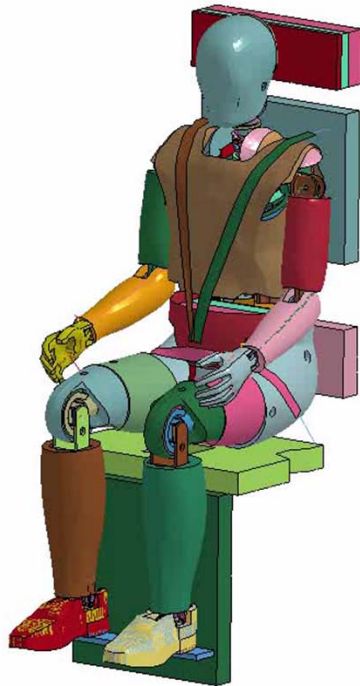


Next Steps: Human Model Comparison

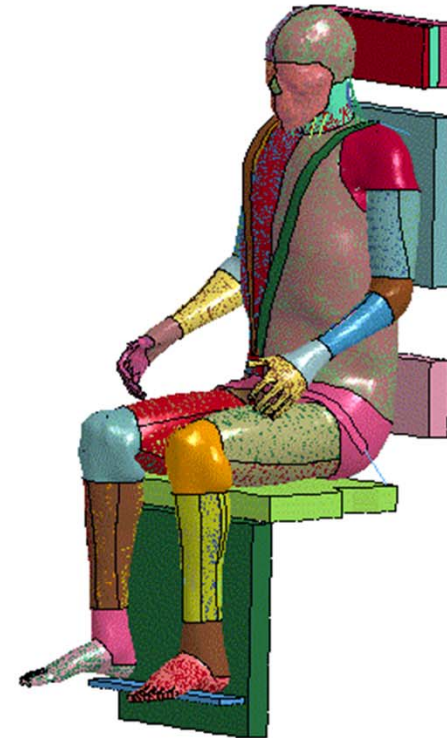


Human Model Comparison: Simulation ex.

LS-DYNA keyword deck by LS-PrePost
Time = 114

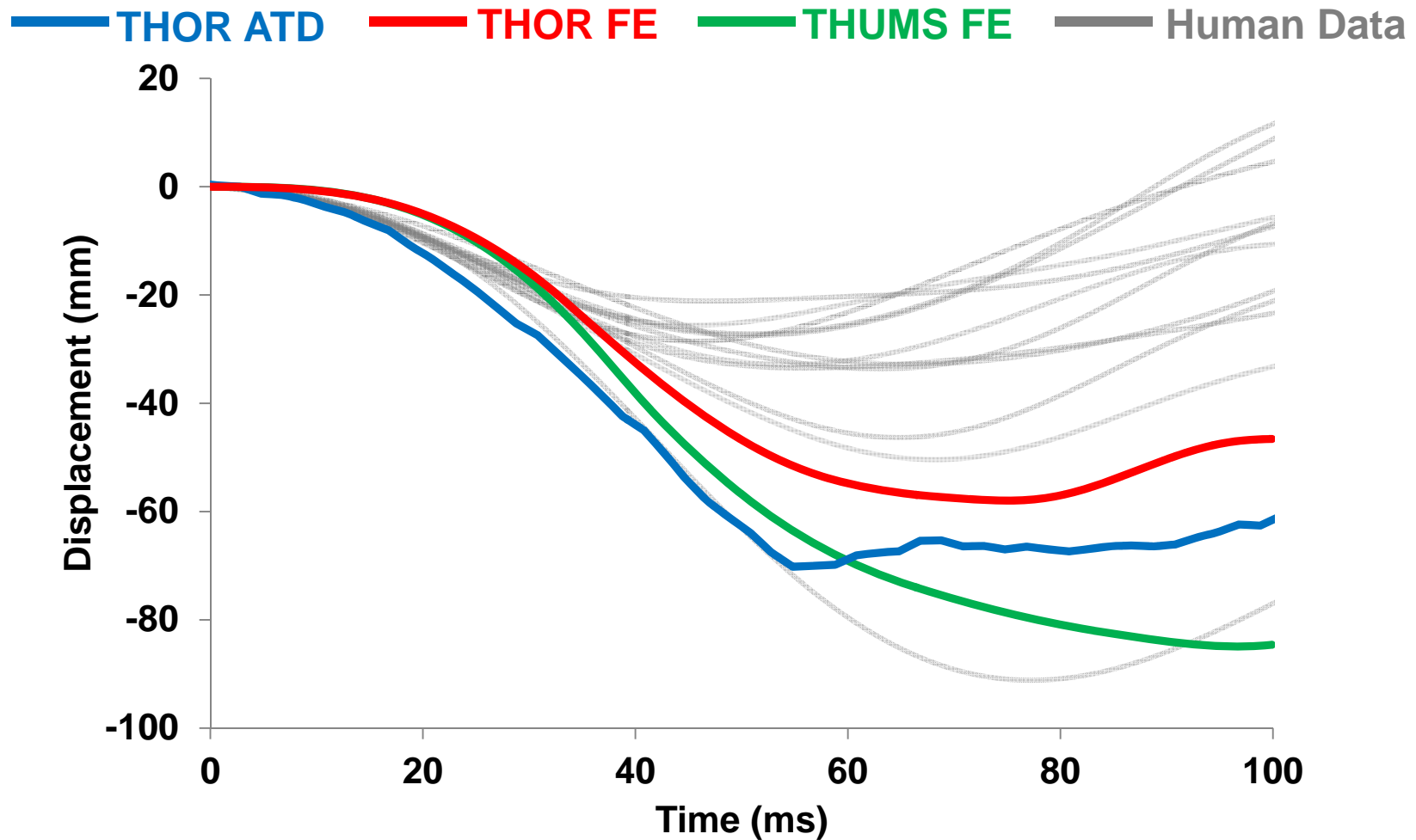


LS-DYNA keyword deck by LS-PrePost
Time = 0



Human Model Comparison: Kinematics ex.

Head CG Vertical Displacement



Limitations & Future Work

Limitations

- Lack of material dynamic part testing for THOR-K material model characterization.

Future Work

- Calibration and Validation of the full THOR-K FE model
- Simulate the same tests with Human FE Models (THUMS and GHBMC)
- Compare Human FE model data against historic volunteer test data recorded at Wright Patterson Air Force Base.
- Simulate Full Scale Aerospace Crashes
- Use Dummy and Human FE Models to Optimize Seat Designs in Aerospace Safety Applications

Questions?

Head/Neck CG calculations

	FE-Model	THOR-K Head	Difference	Tolerance
X-CG (mm)	10.0616	8.87	1.1916	2.5
Y-CG (mm)	0.064745	0.02	0.044745	2.5
Z-CG (mm)	-59.432	-57.99	-1.442	2.5
Mass (Kg)	4.538792	4.539	-0.0002079	0.005