VIRGINIA TECH WAKE FOREST UNIVERSITY
School of Biomedical Engineering and Sciences

CIB

A finite element model of the THOR-k dummy for aerospace and aircraft impact simulations

Authors:
Jacob Putnam*
Costin D. Untaroiu*
Jeffrey T. Somers**
Joseph Pellettiere***

Affiliations:
*Virginia Tech
**Wyle Laboratories
***Federal Aviation Administration

Motivation

- **Improve Safety Analysis**
  - Estimated 85% survivability of all aircraft crashes. [Shanahan 2004]
  - Spaceflight Safety Standards
  - Restraint Systems & Seat Technology
- **Dummy Testing**
  - Test Device for Human Occupant Restraint (THOR)
  - Potential in Aerospace Field
  - Limited Multidirectional Evaluation
- **FE modeling**
  - Reduced Cost and Time
  - Less Limited
  - Sensitivity and Design Optimization

Multipurpose Crewed Vehicle (MPCV) - Water Landing

Pilot Ejection

http://i88.photobucket.com/albums/k188/trademarq/ejection-seat.jpg

Goals

1) Update and Improve the THOR 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

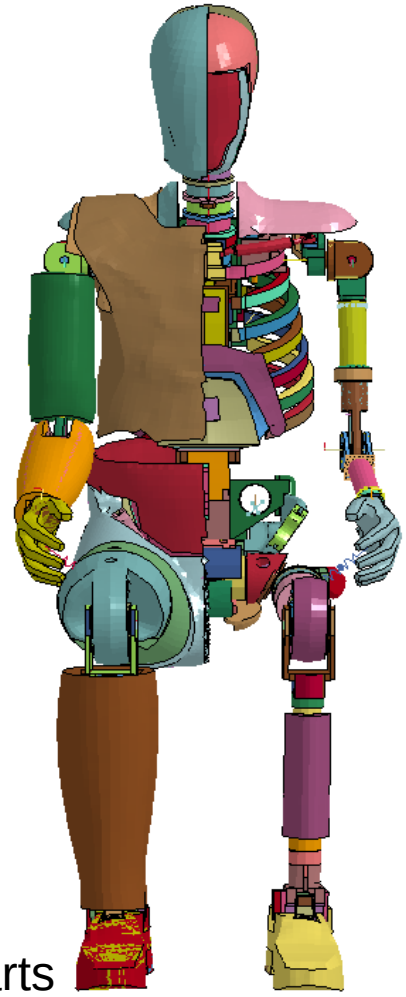
The latest version of THOR

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

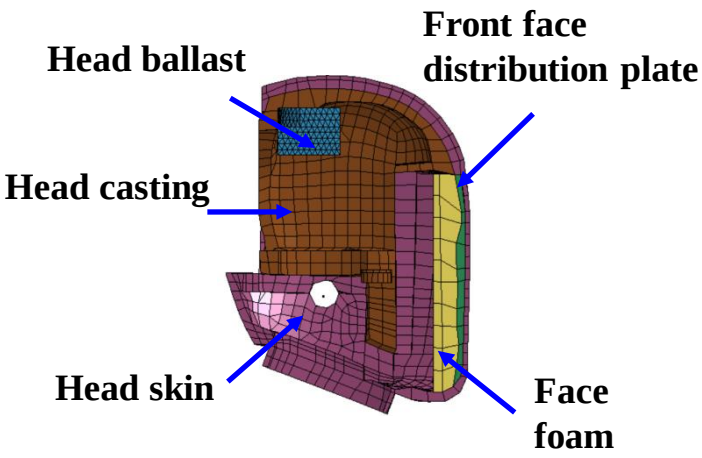
- **VT-Head/Neck**
  - Re modeled head parts
  - Simplified OC-Joint
- **NHTSA Collaborators**
  - Thorax, Pelvis, Lower Limb



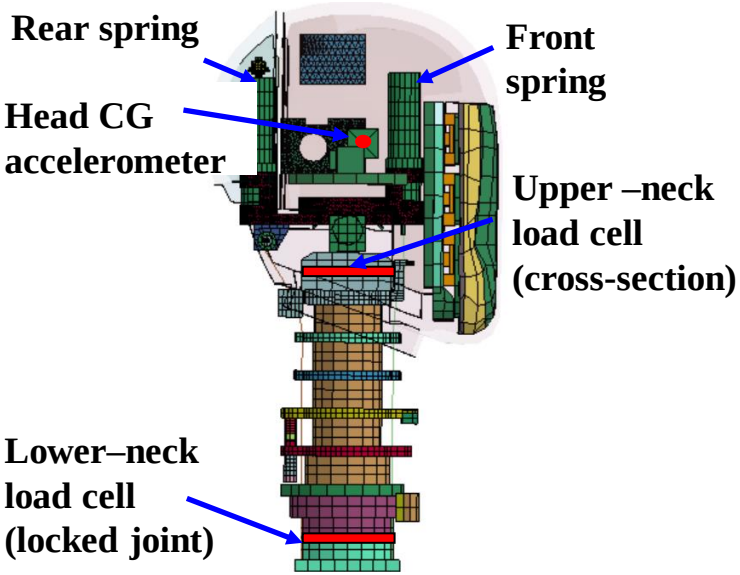
424 parts
~ 221k nodes / 443k elements
~ 290k deformable elements
~ 0.063 μs

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

Part Updates

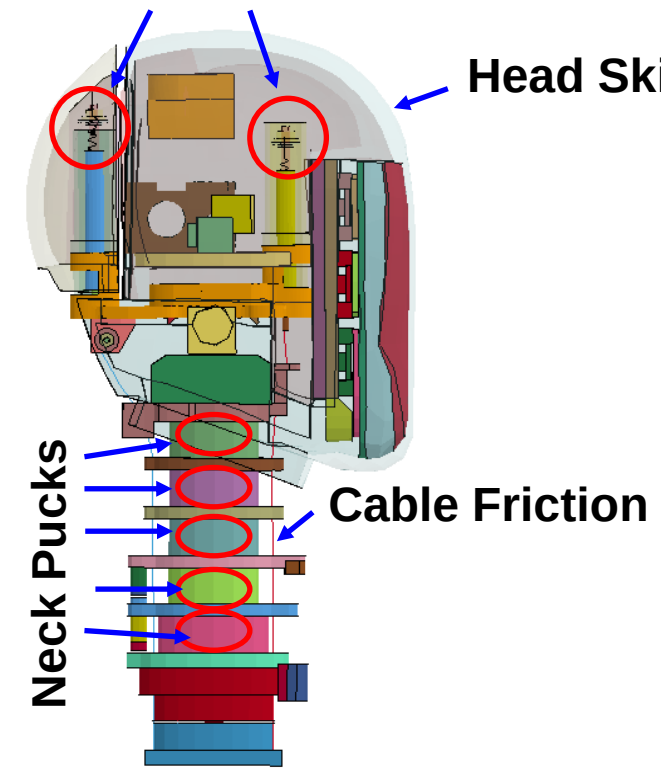


Instrumentation



Developed THOR-k head-neck model

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

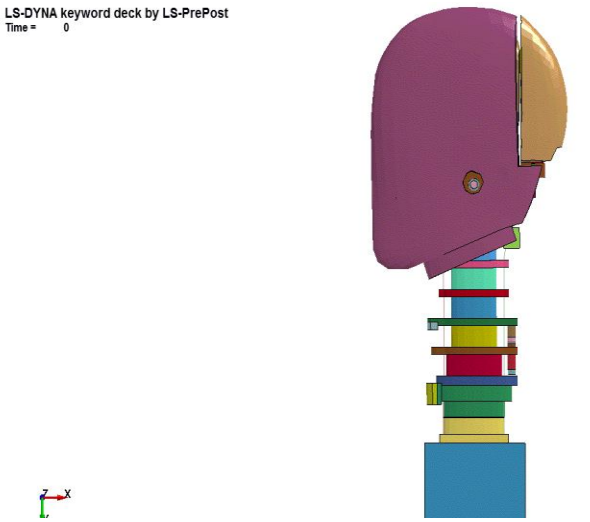


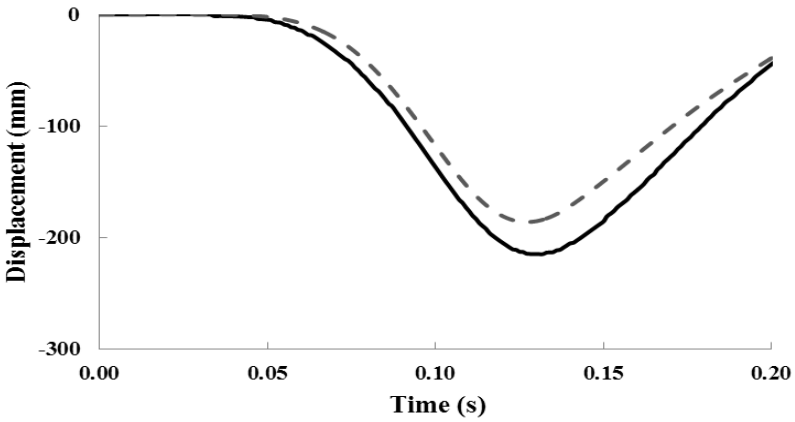
Model calibration

Developed THOR-k head-neck model

- NBDL lateral
  - Calibrated neck- puck stiffness
    - Pendulum extension → Calibrated front spring material
    - Pendulum flexion → Calibrated rear spring material
      - Calibrated cable friction
        - Head impact → Calibrated head-skin material

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





Model calibration

Developed THOR-k head-neck model

- NBDL lateral
- Calibrated neck- puck stiffness
  - Pendulum extension → Calibrated front spring material
  - Pendulum flexion → Calibrated rear spring material
- Calibrated cable friction
- Head impact
- Calibrated head-skin material

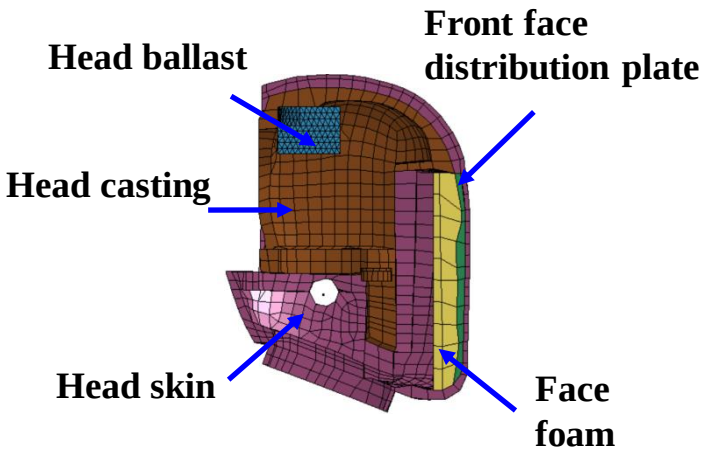
Calibrated THOR-k head-neck model

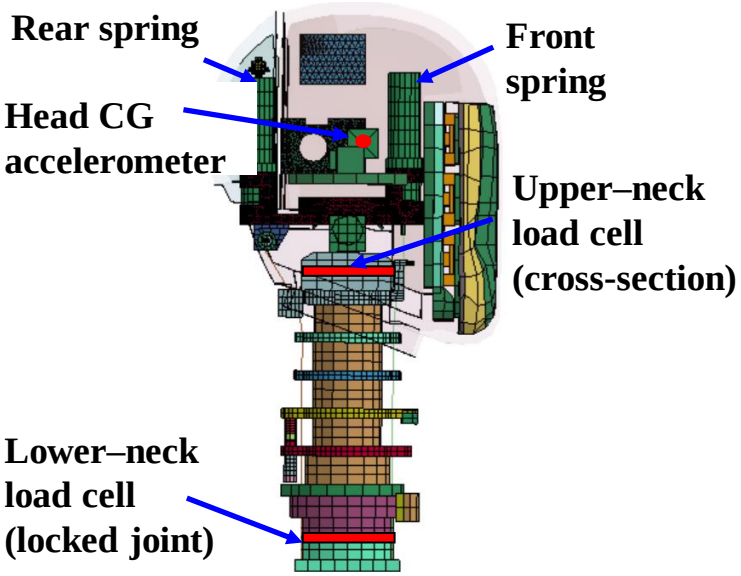
Model validation → NBDL frontal, Pendulum lateral

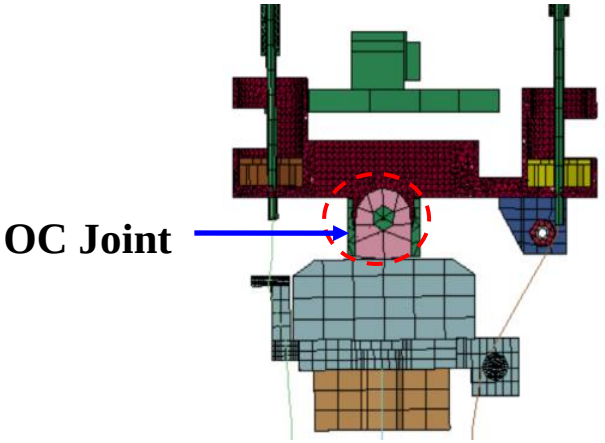
Updates to Head-Neck THOR-k FE Model: Development

- **Part Updates**
  - Modeled CAD part geometries
  - Simplification of OC-Joint
- **Head CG Validation**
  - Ballast Adjustment
  - Spec. Tolerance
- **Instrumentation**

Part Updates







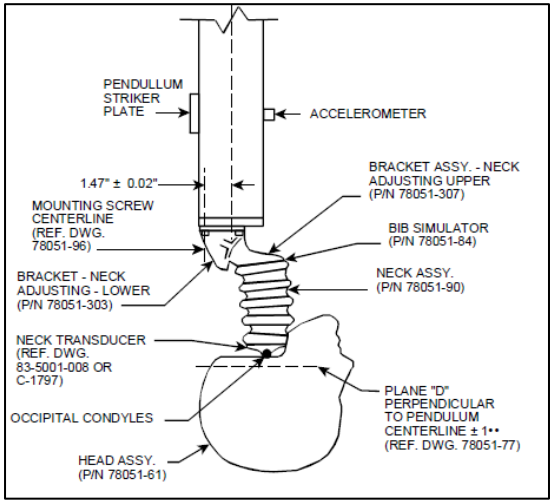
Updates to Head-Neck THOR-k FE Model: Calibration Tests

Biomechanical Requirement NBDL Test Series

Frontal & Lateral

Yaguchi et. al 2007

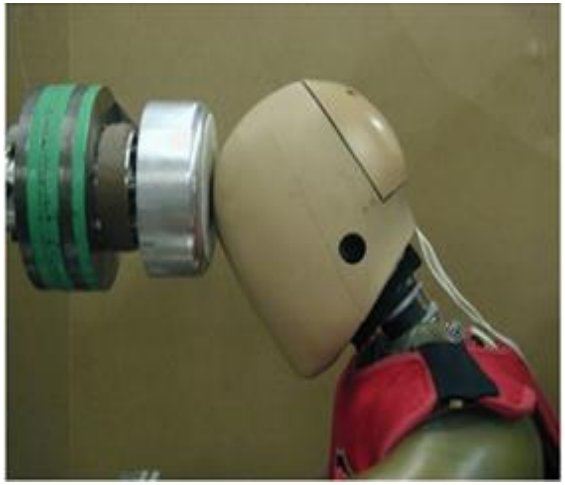
Certification Pendulum Test Series



Frontal, Lateral, & Rearward

FMVSS 216

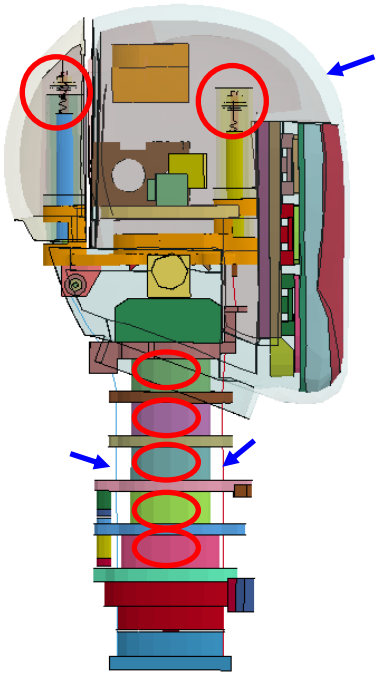
Certification Test Head Impact



Frontal Impact

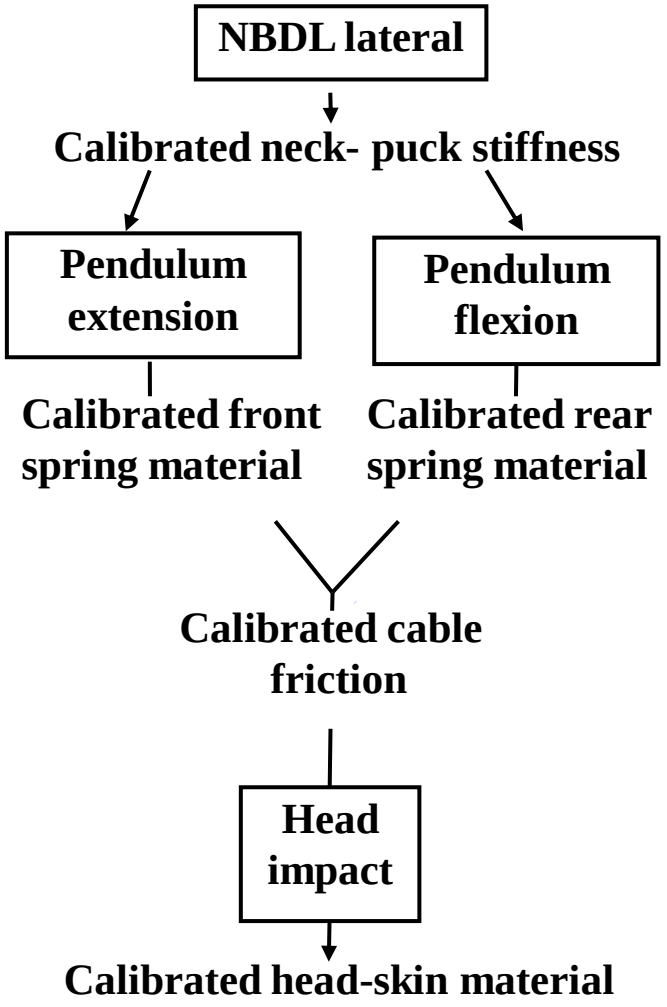
GESAC-05-04

Updates to Head-Neck THOR-k FE Model: Calibration Protocol



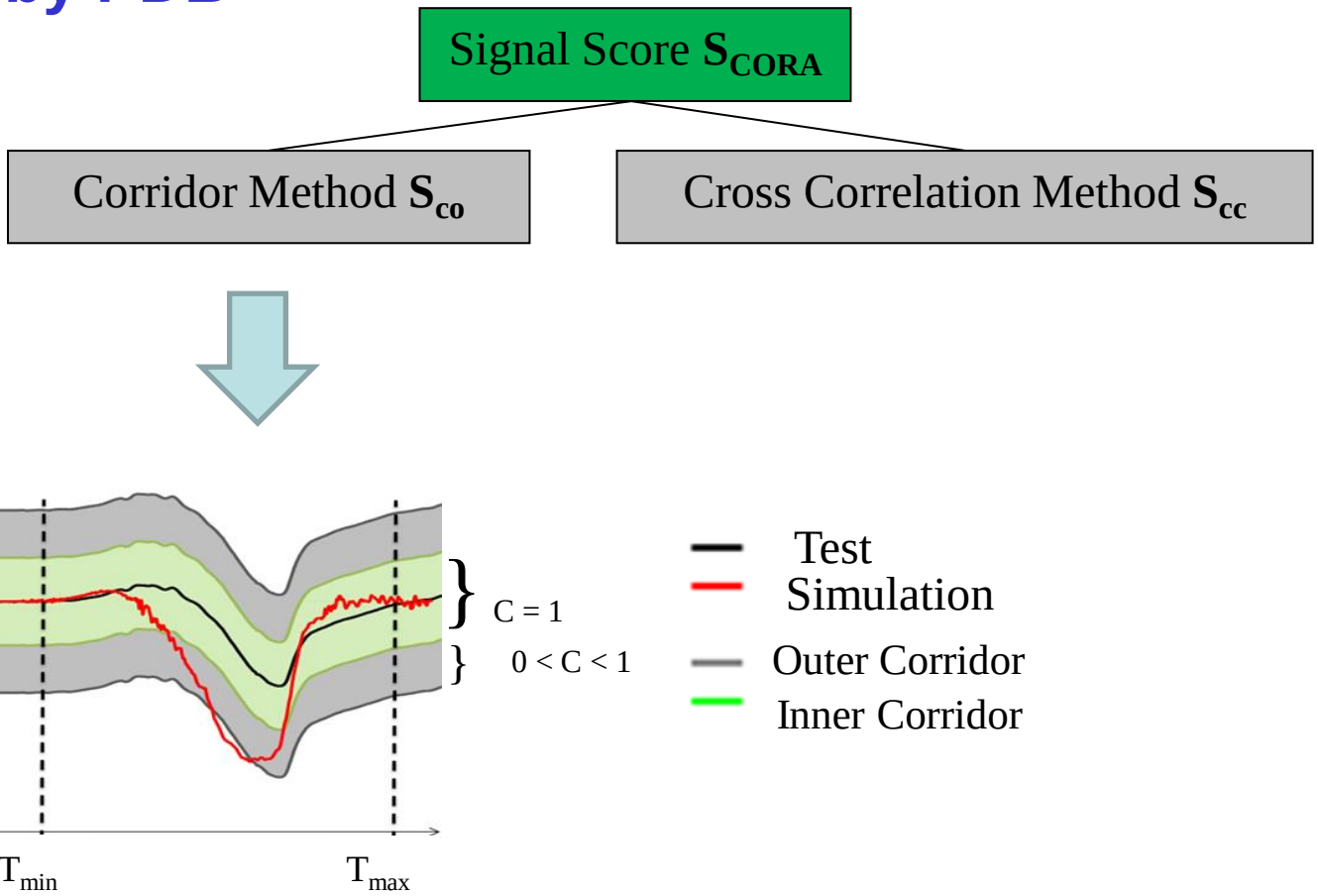
LS-DYNA keyword deck by LS-PrePost
Time = 0

Model calibration



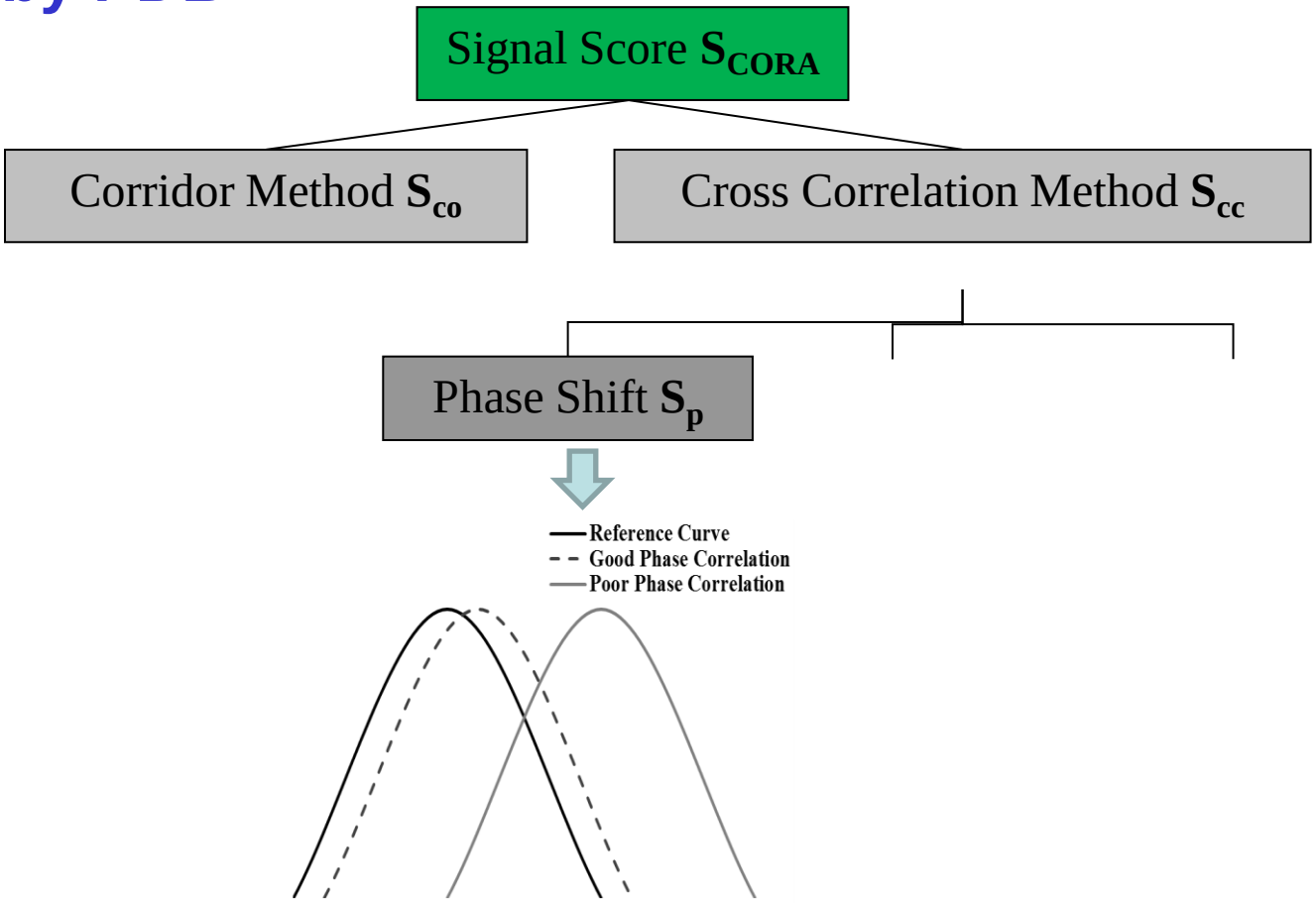
CORA (CORrelation and Analysis) Rating Score

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



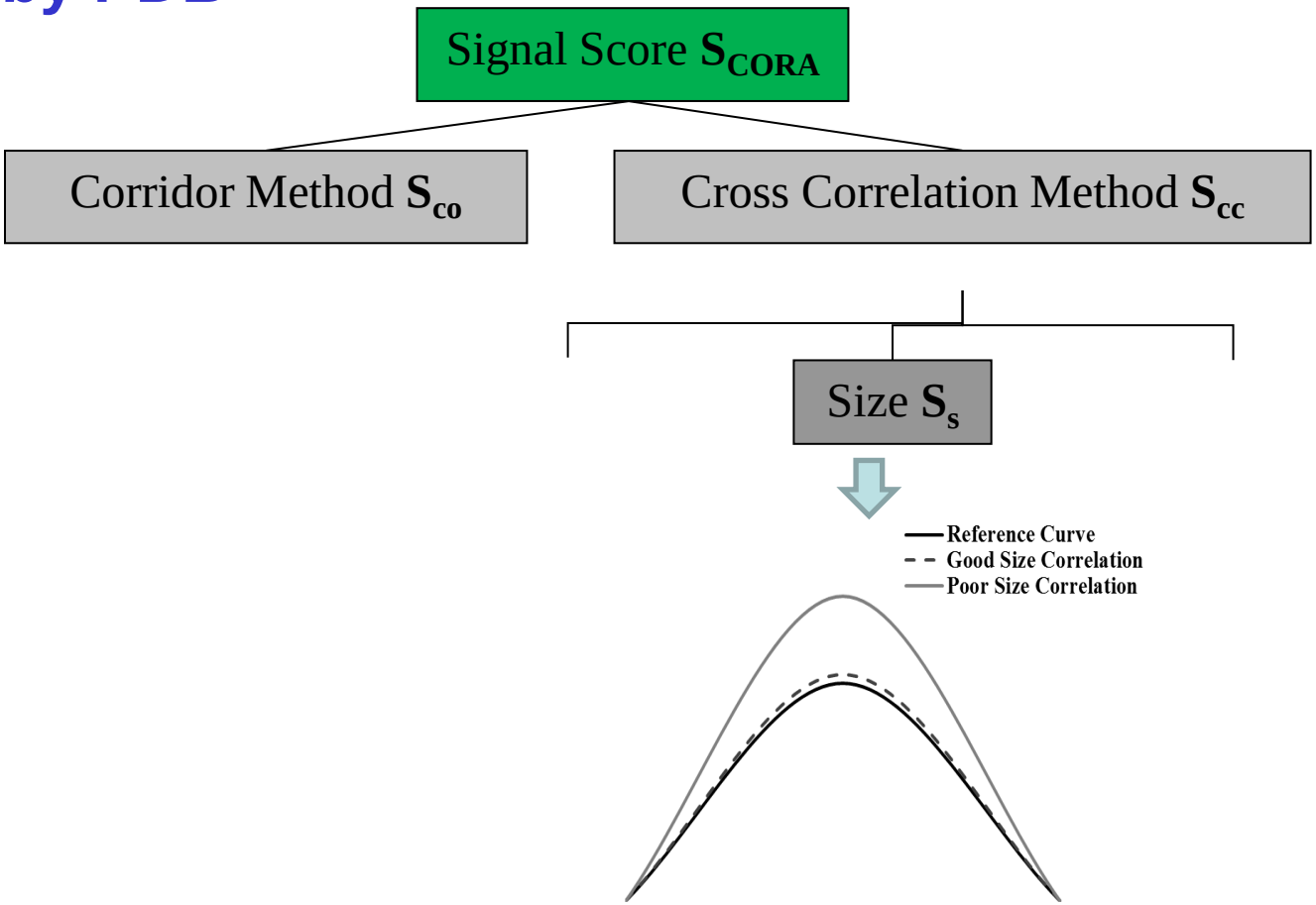
CORA (CORrelation and Analysis) Rating Score

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



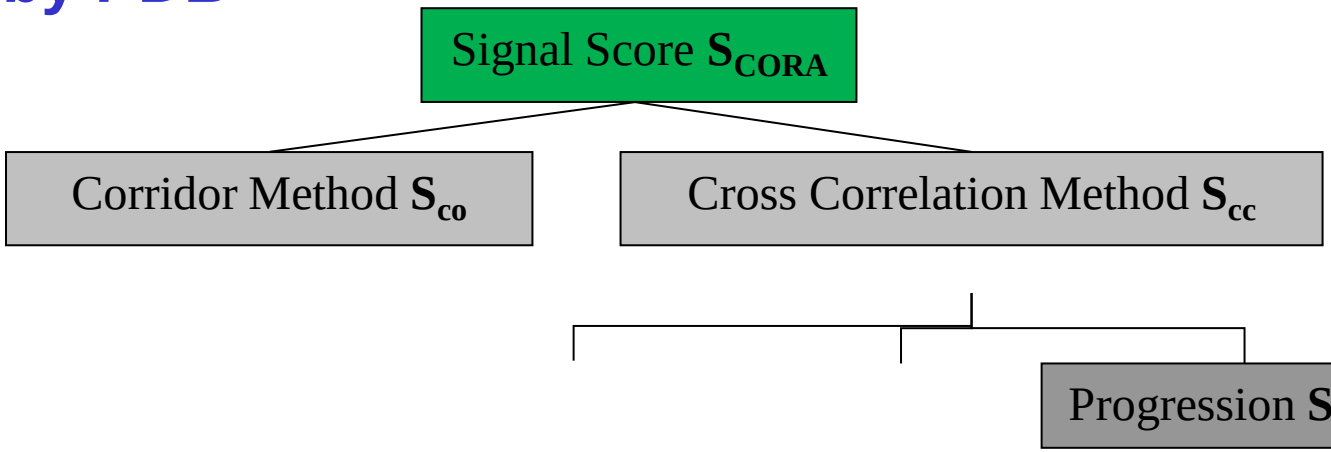
CORA (CORrelation and Analysis) Rating Score

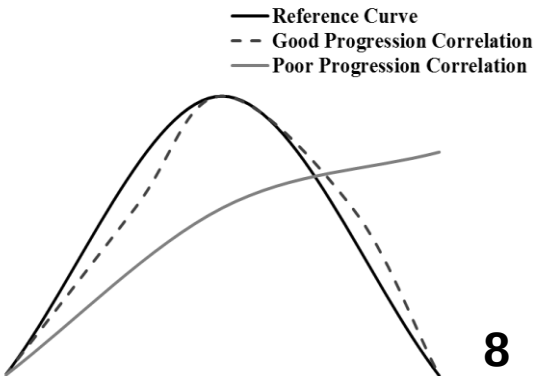
- Multi-aspect curve rating system
- Proposed SAE ISO Standard
- Developed by PDB



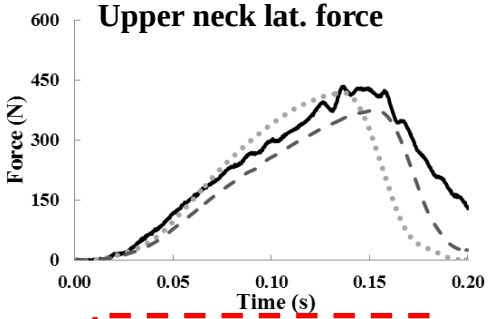
CORA (CORrelation and Analysis) Rating Score

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

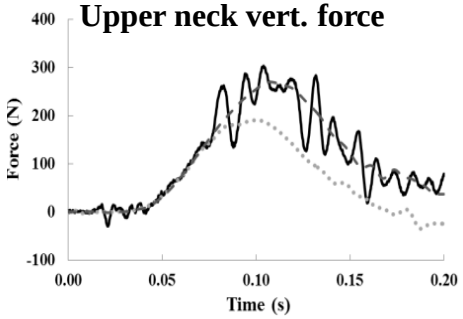




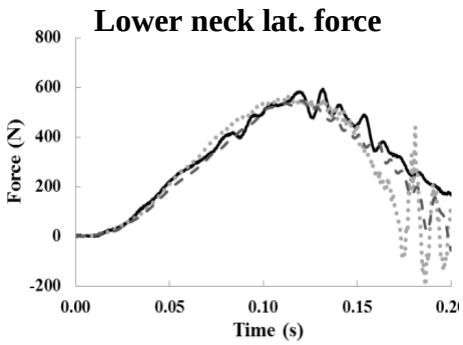
Updates to Head-Neck THOR-k FE Model: Calibration (example)



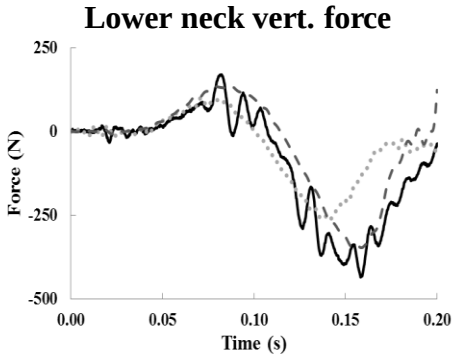
Orig. Cal.
0.826 | 0.948



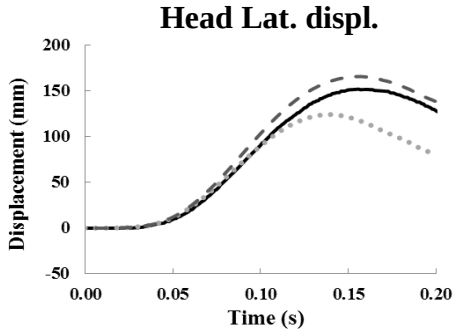
0.902 | 0.996



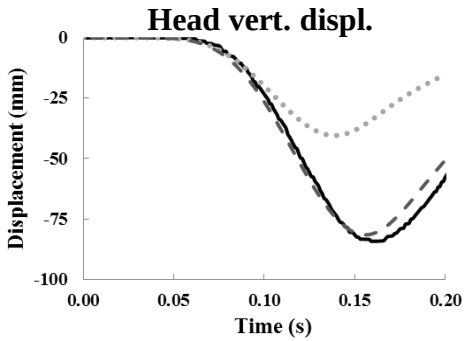
0.985 | 0.975



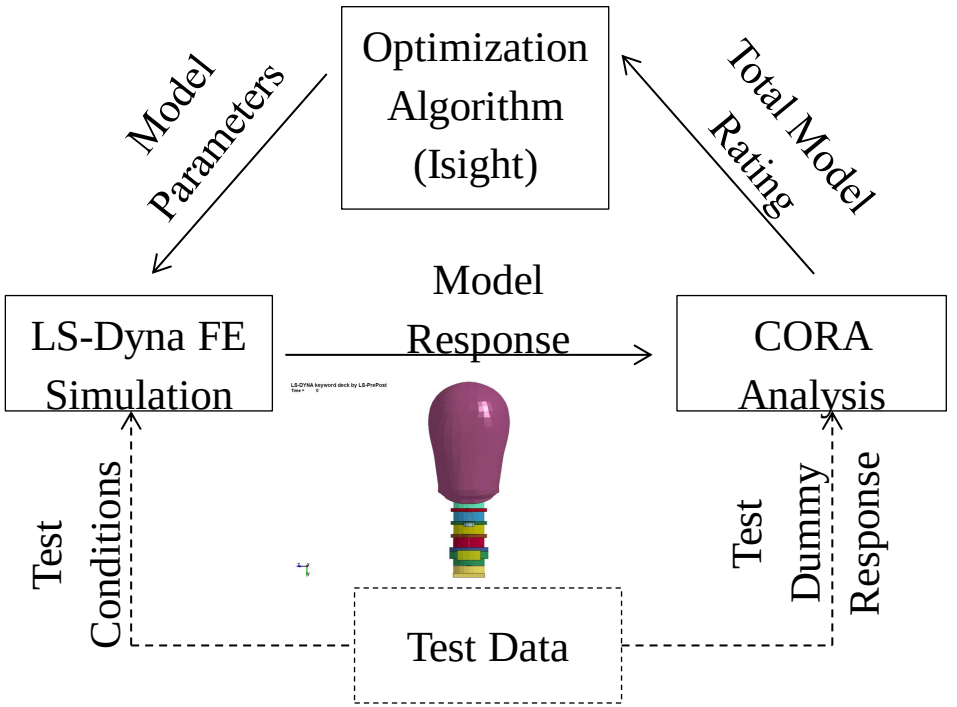
0.864 | 0.94



0.901 | 0.974



0.716 | 0.985



- Test
- Original FE
- Calibrated FE

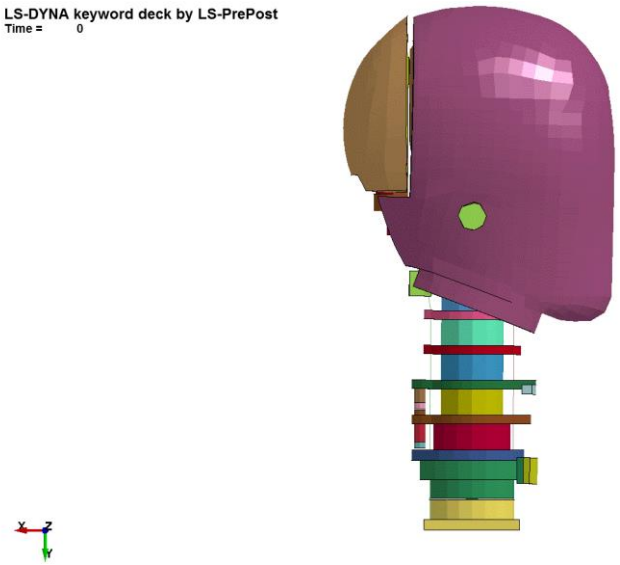
NBDL lateral Bending Score

Original **Calibrated**

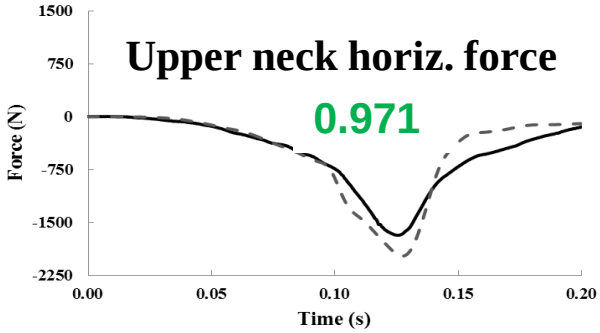
0.845| 0.971

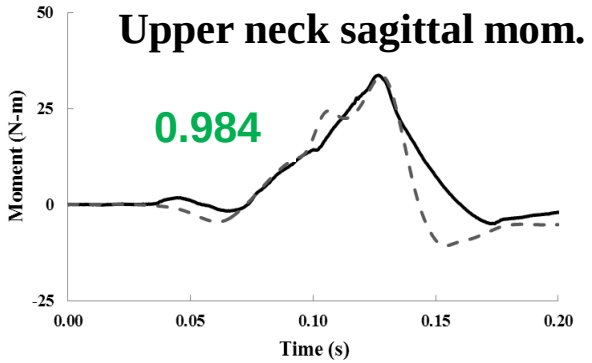
Updates to Head-Neck THOR-k FE Model: Validation

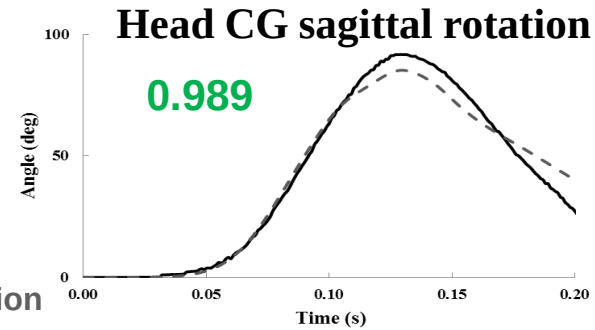
Model validation → **NBDL frontal**



Cora Score: 0.948



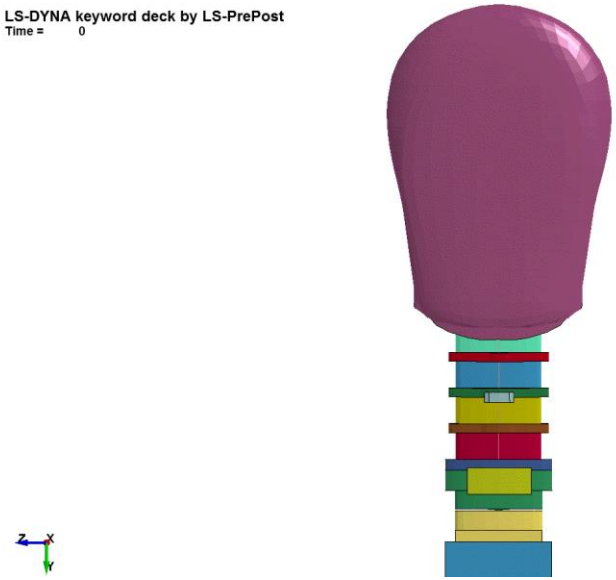




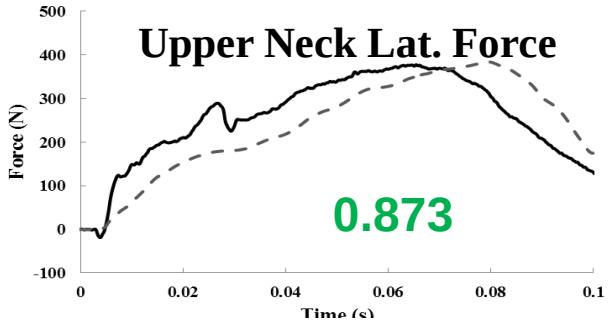
- Test
-- FE Simulation

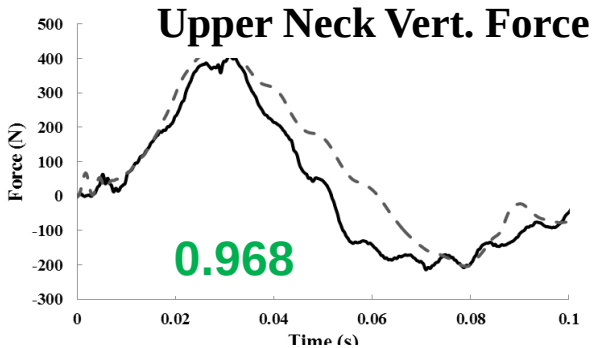
Updates to Head-Neck THOR-k FE Model: Validation

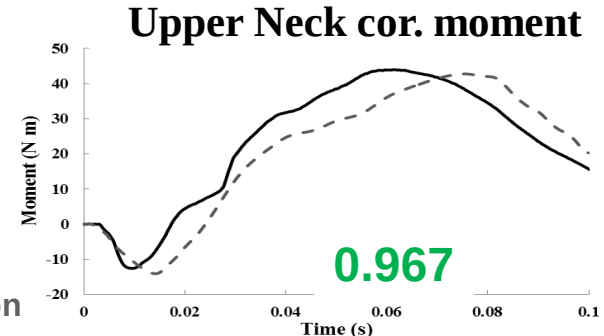
Model validation → **NBDL frontal** | **Pendulum lateral**



Cora Score: 0.936



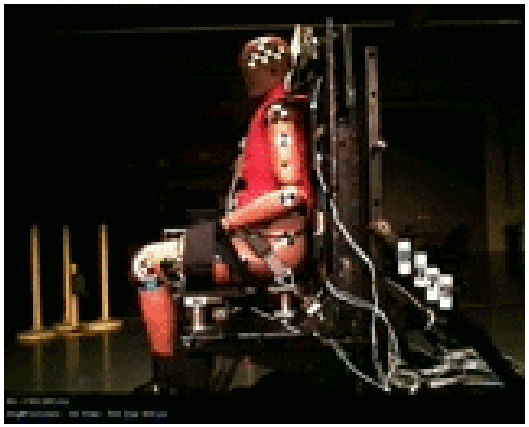


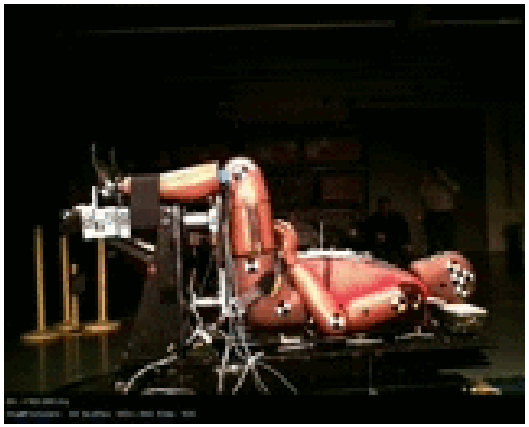


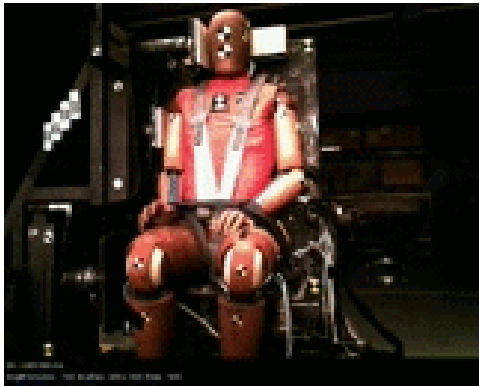
- Test
-- FE Simulation

Full Dummy Testing

- **Performed at WPAFB**
  - THOR-K ATD
  - Based on Historic Volunteer Tests
  - Horizontal impulse accelerator
- **Test Directions**
  - Frontal
  - Spinal
  - Lateral

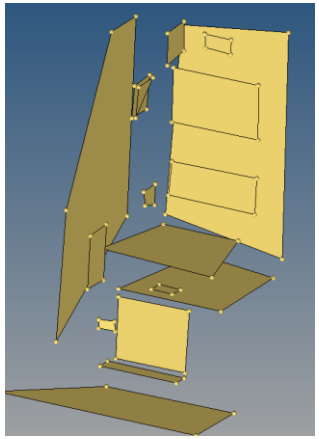
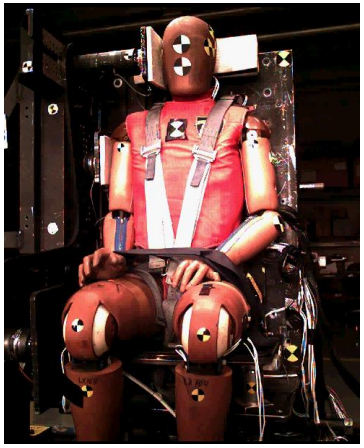
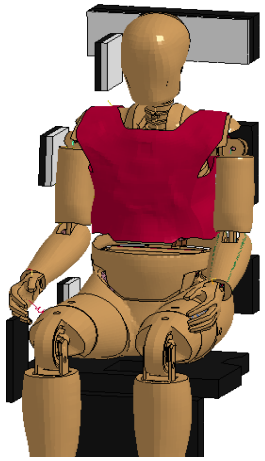




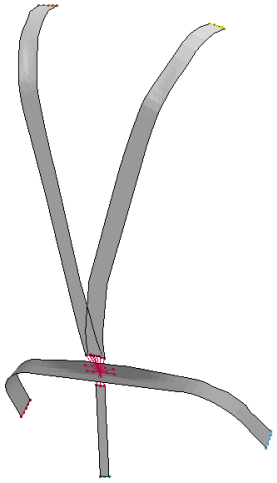


Simulation Setup

- **Seat Model**

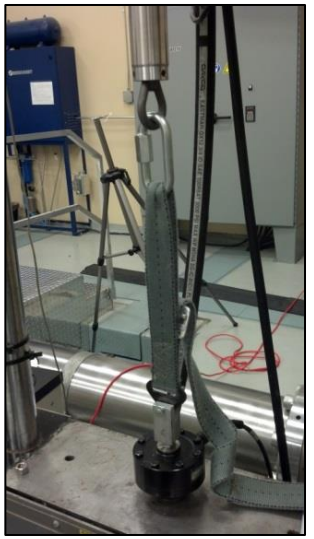




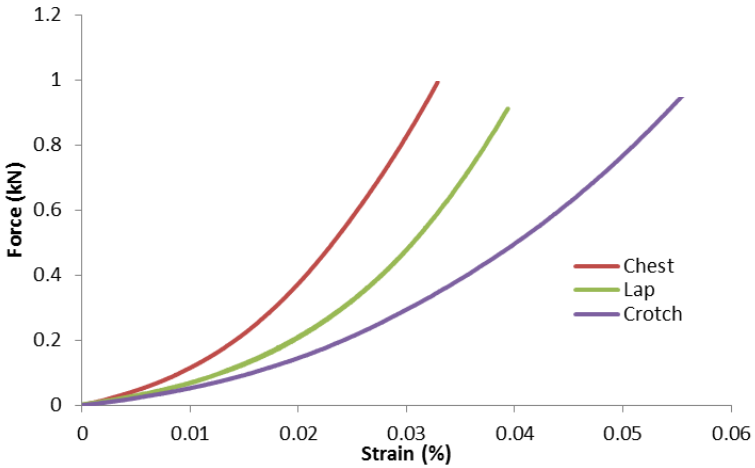
- **Belt Model**

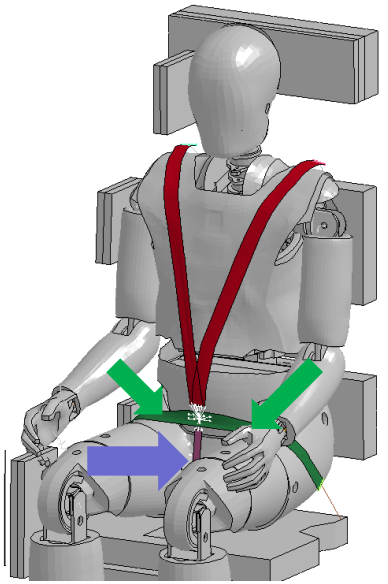



Belt Material Characterization

- **Testing**
  - **Uniaxial Loading**
  - **1 kN load @ 1 mm/s**
- **Results**
  - **Developed Force/Strain Curve**
    - Belt material

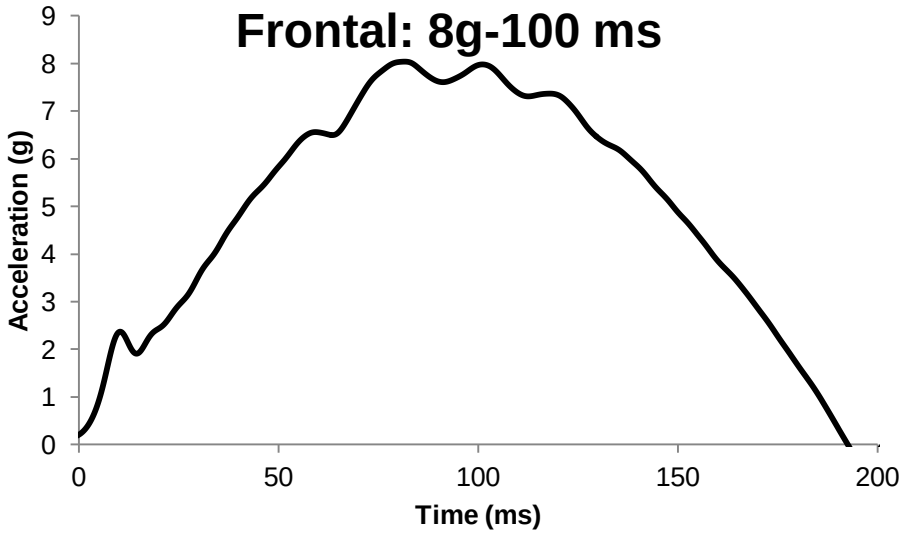


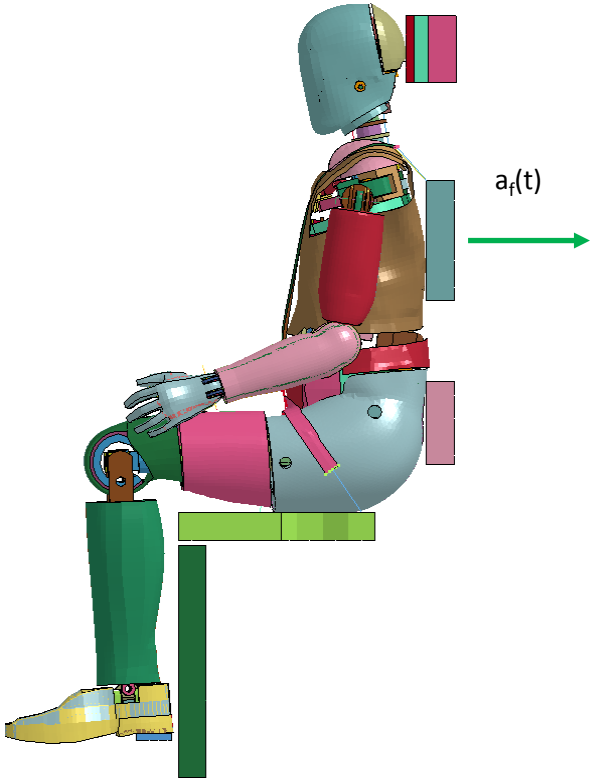




Simulation Conditions

- **Boundary Conditions**
  - Sled Acceleration
  - Gravity Applied to all Parts
  - Stress Initialization
  - Belt Constraints
- **Acceleration Pulse**

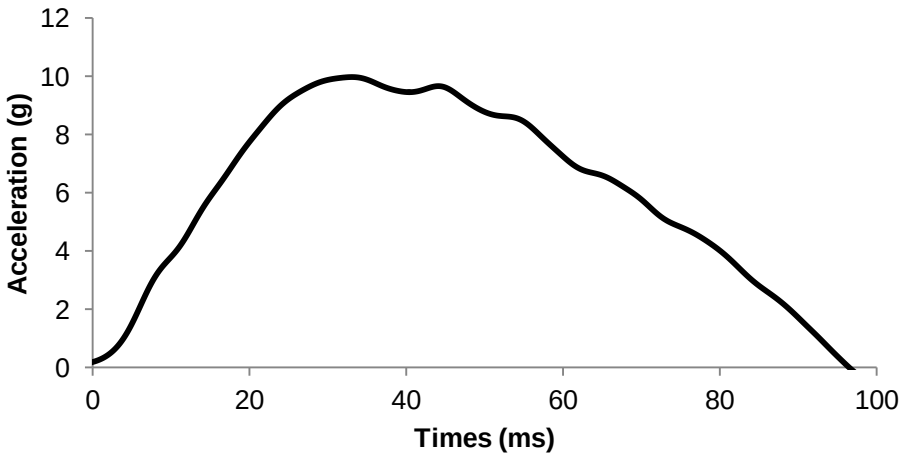


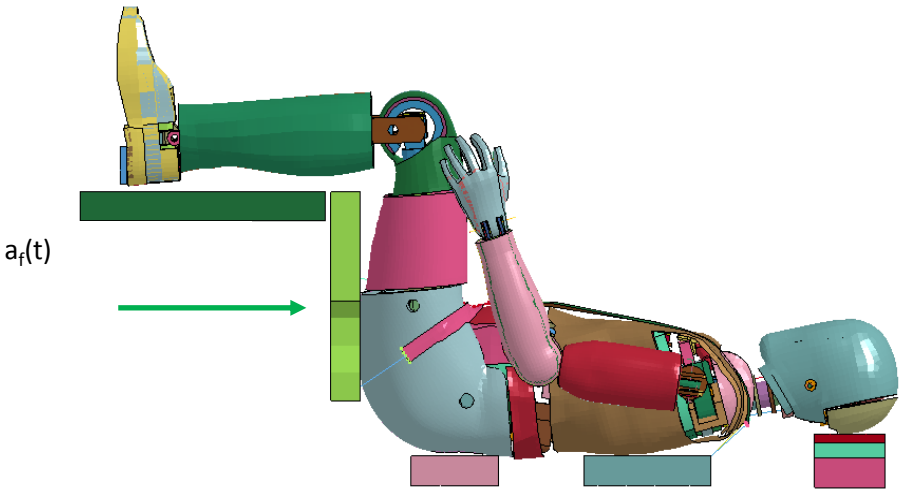


Simulation Conditions

- **Boundary Conditions**
  - Sled Acceleration
  - Gravity Applied to all Parts
  - Stress Initialization
  - Belt Constraints
- **Acceleration Pulse**

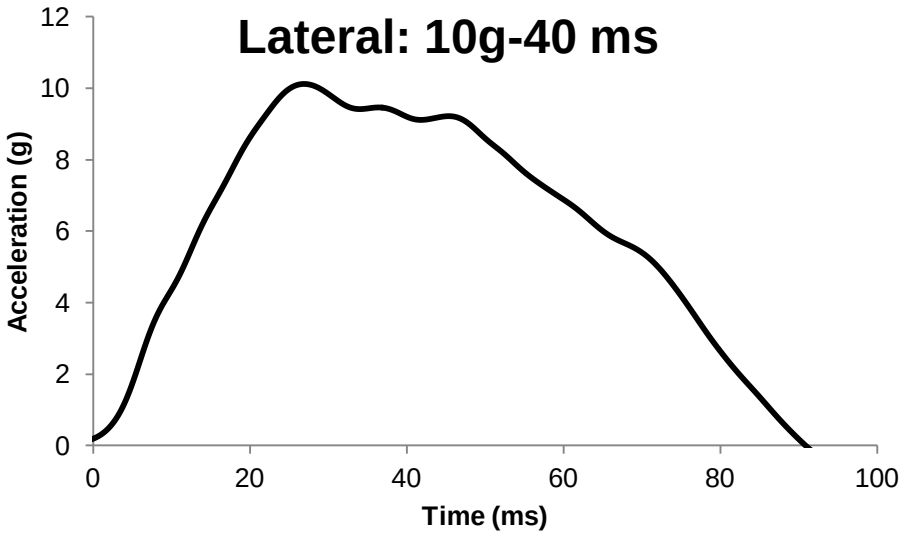
Spinal:10g-40 ms

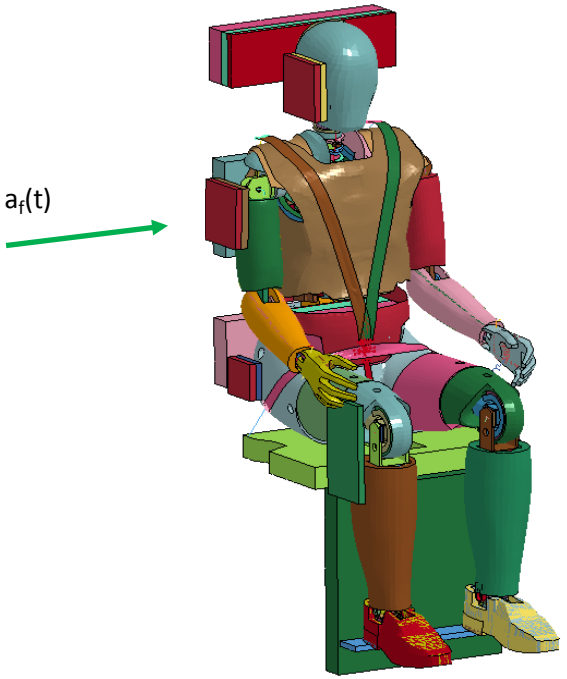




Simulation Conditions

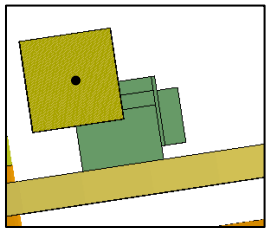
- **Boundary Conditions**
  - Sled Acceleration
  - Gravity Applied to all Parts
  - Stress Initialization
  - Belt Constraints
- **Acceleration Pulse**



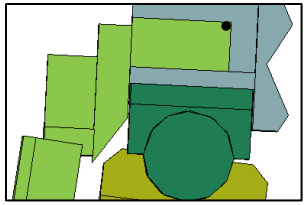


Instrumentation

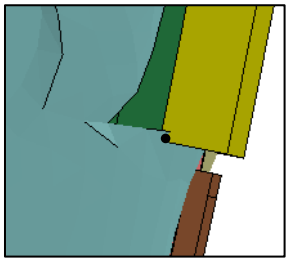
Head Accelerometer

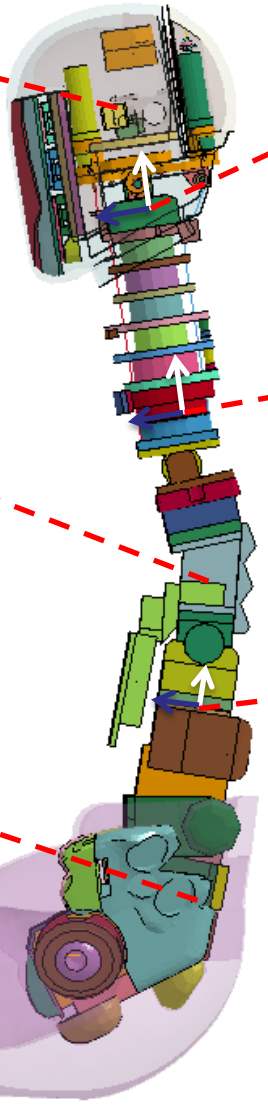


Chest Accelerometer

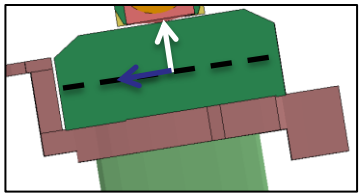


Pelvis Accelerometer

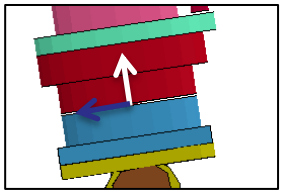




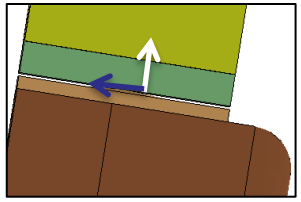
Upper Neck Load Cell



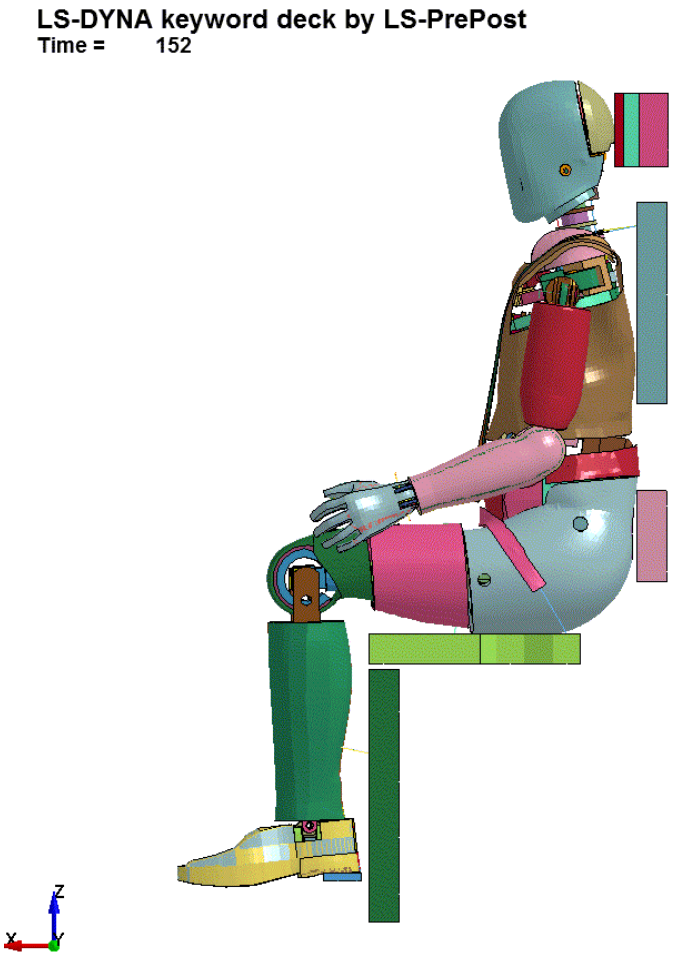
Lower Neck Load Cell



L1-Lumbar Spine Load Cell

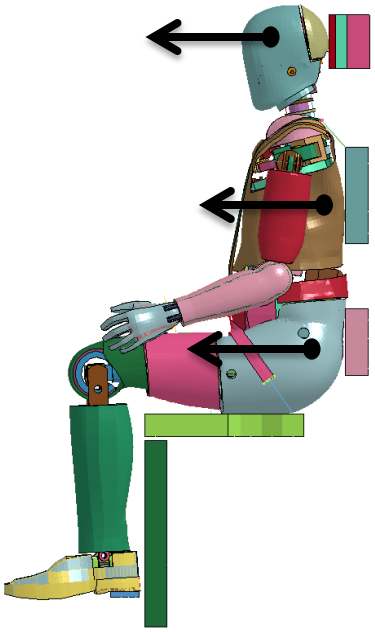


Frontal Results - Overview



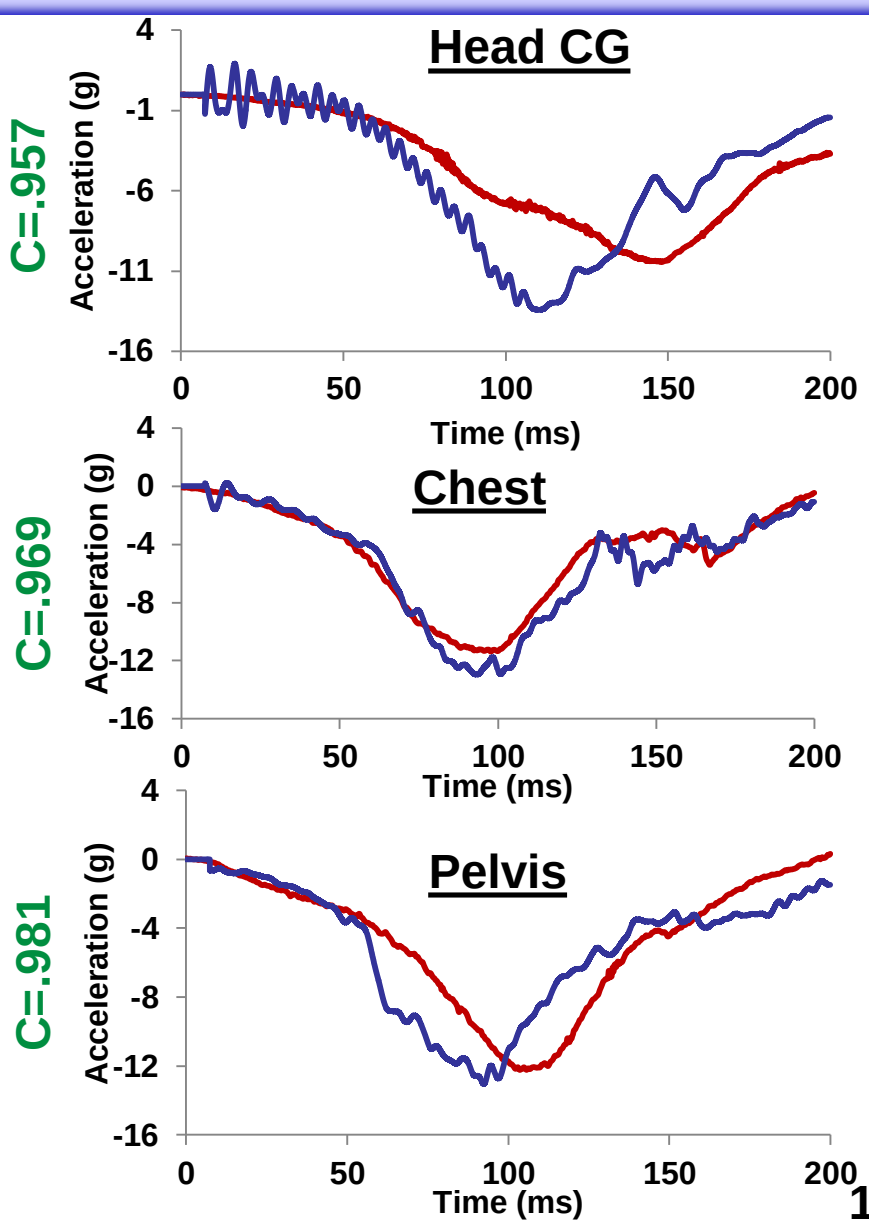
CORA Rating: .906

Frontal Results – Frontal Acceleration

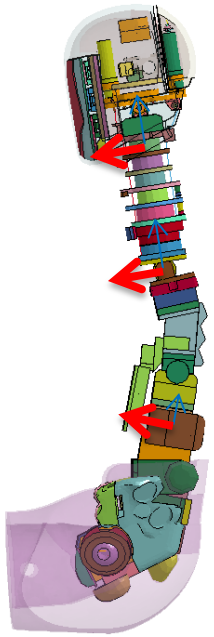


THOR ATD THOR FE

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

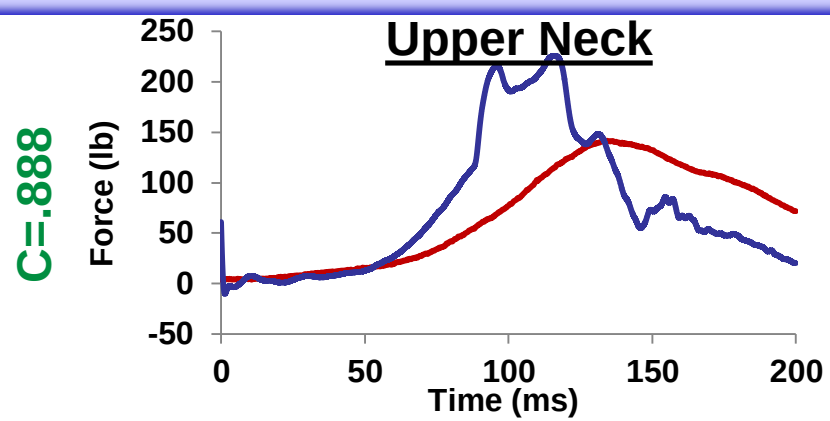


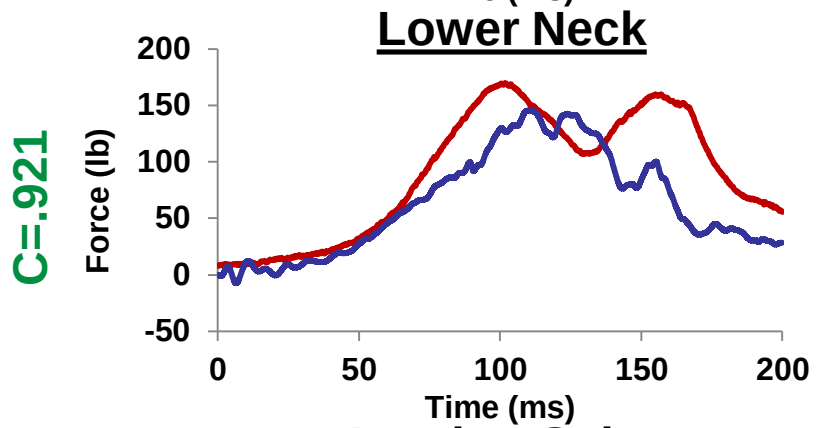
Frontal Results – Frontal Force

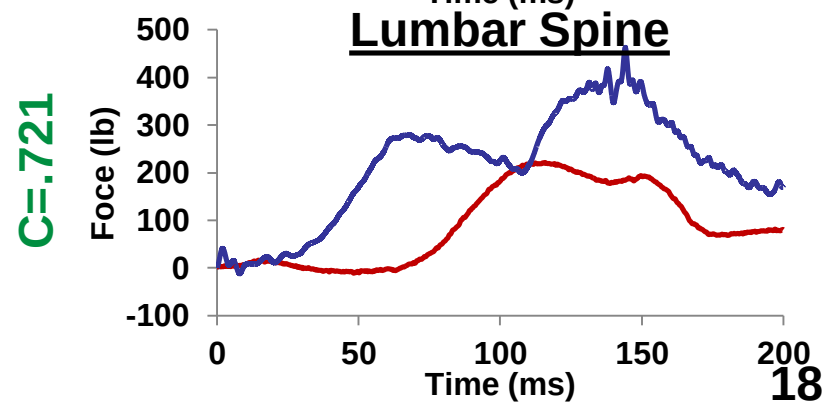


THOR ATD THOR FE

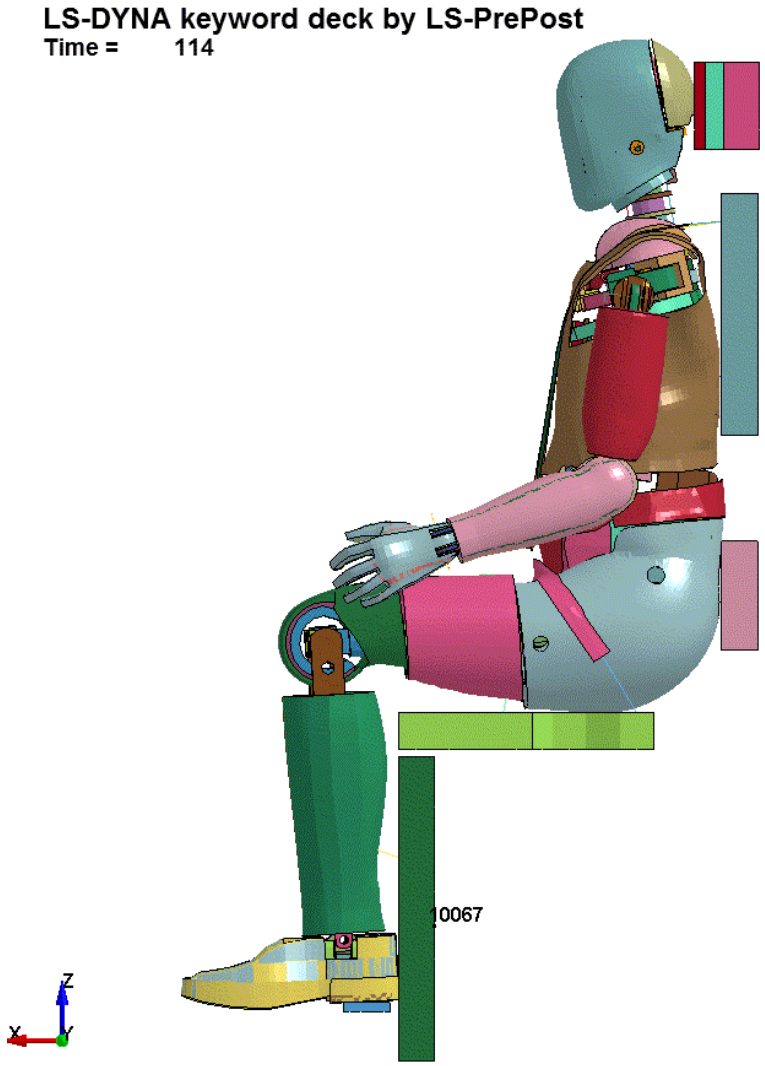
- **Kinetics**
  - **Similar response in lower neck**
  - **Upper Neck & Lumbar Spine**
    - Faster Rise
    - Larger Peak





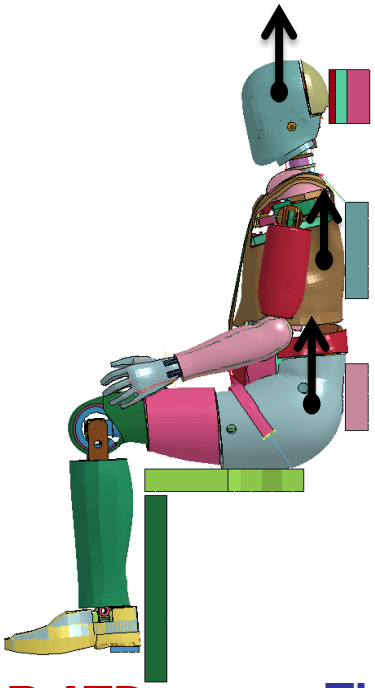


Spinal Results - Overview



CORA Rating: .874

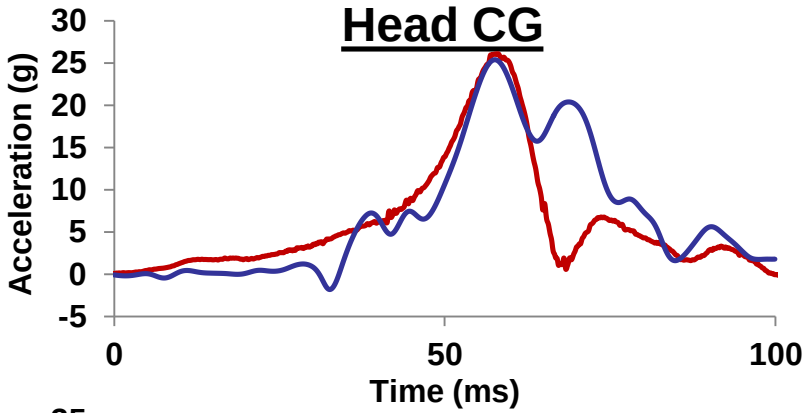
Spinal Results – Anterior Acceleration



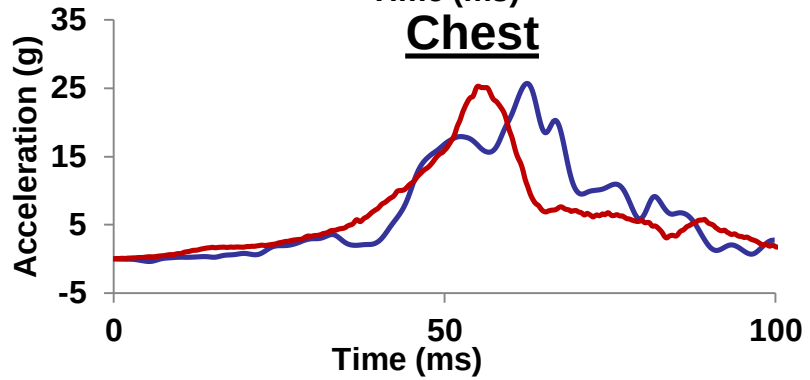
THOR ATD THOR FE

- **Kinematics**
  - Similar Peaks
  - Similar Rise in head and chest
  - "Bouncing" Pelvis

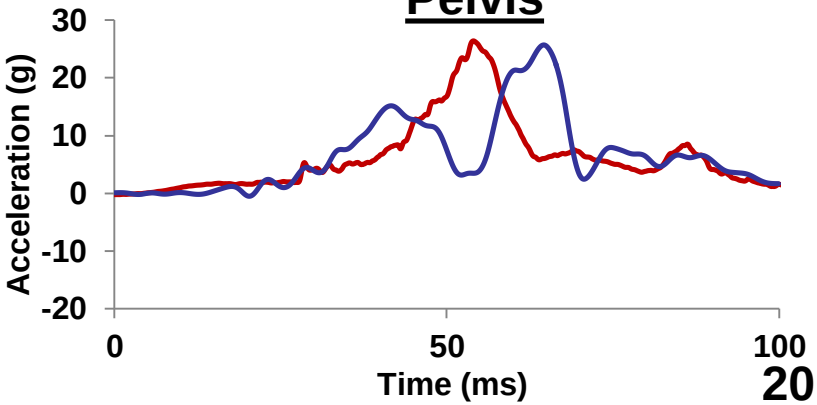
C=.874



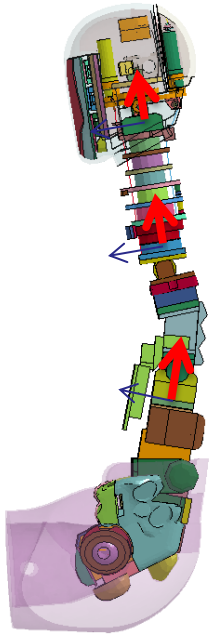
C=.925



C=.834

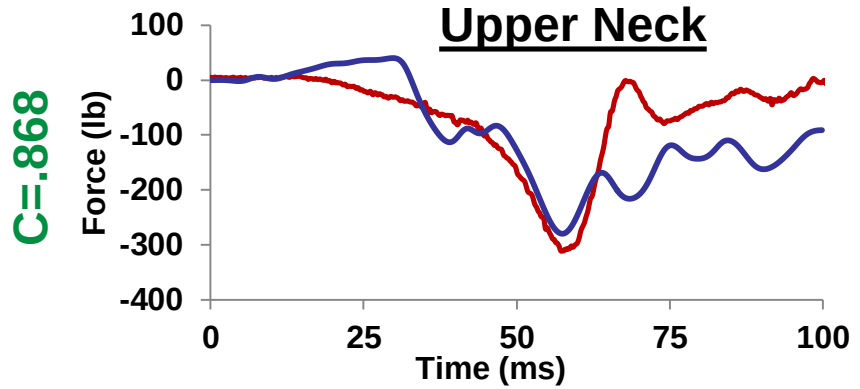


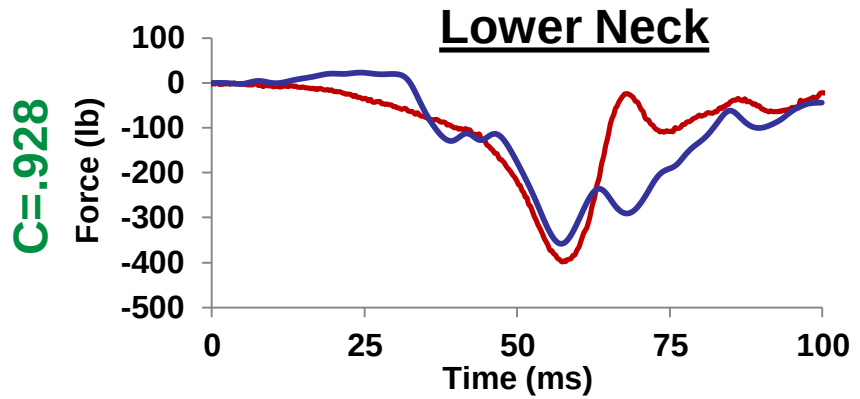
Spinal Results- Anterior Force

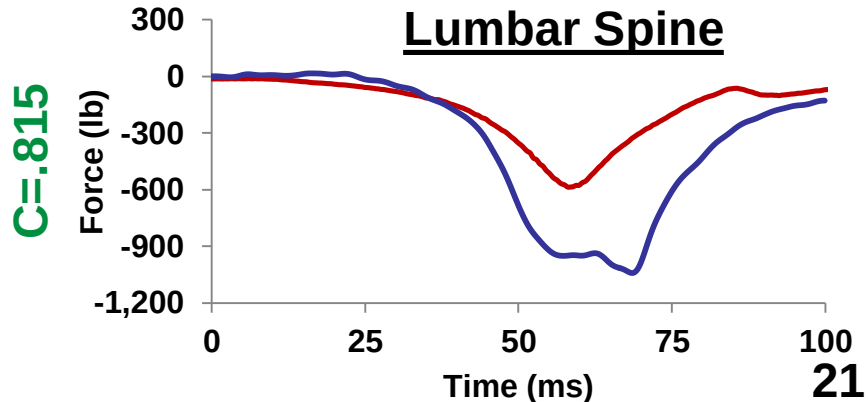


THOR ATD THOR FE

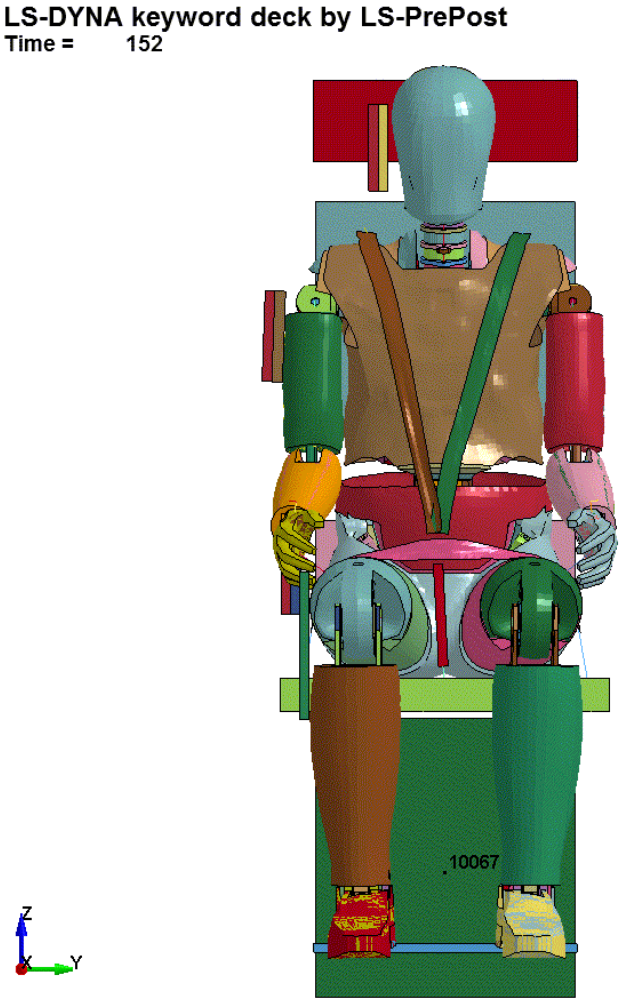
- **Kinetics**
  - Similar upper body
  - High lumbar over prediction





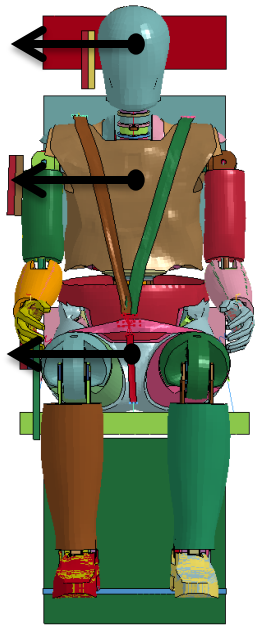


Lateral Results - Overview



CORA Rating: .838

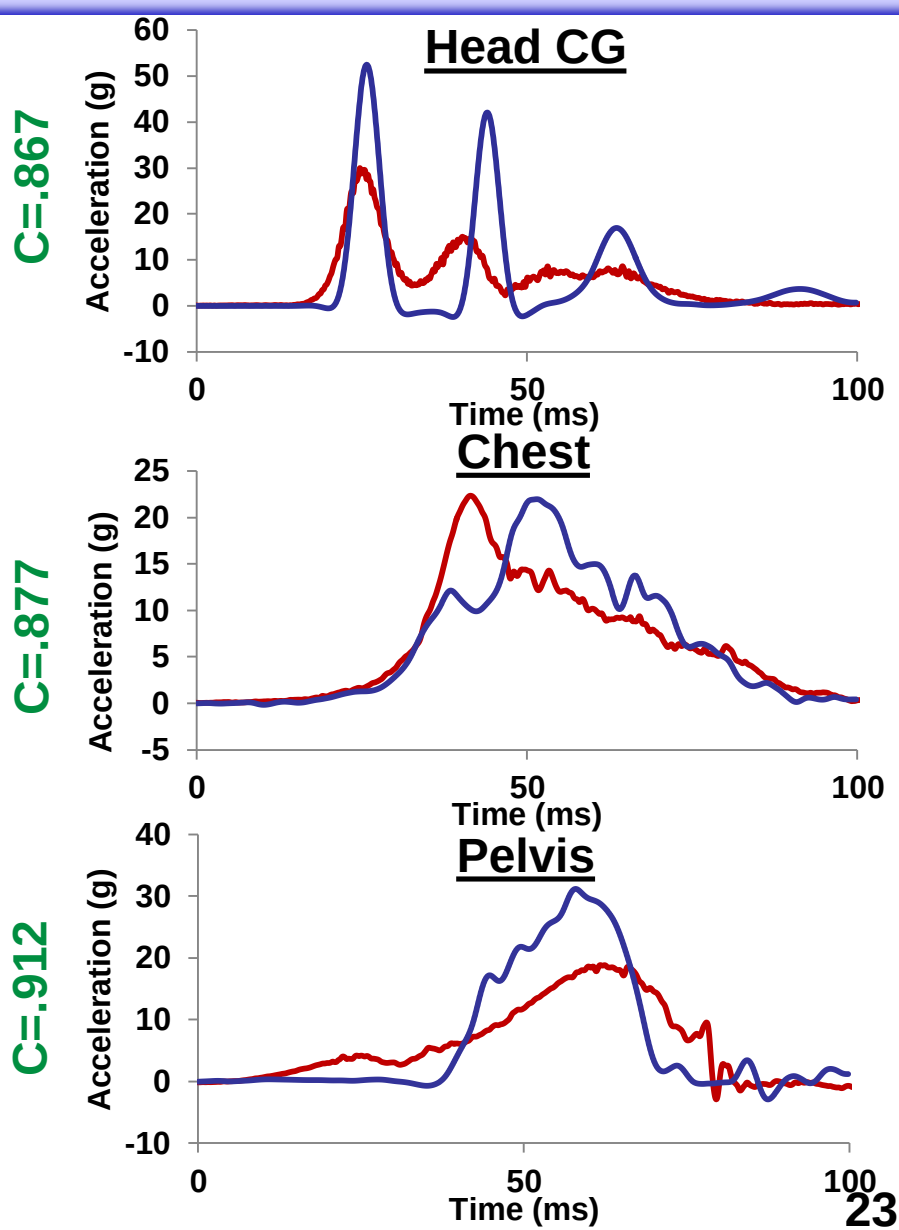
Lateral Results – Lateral Acceleration



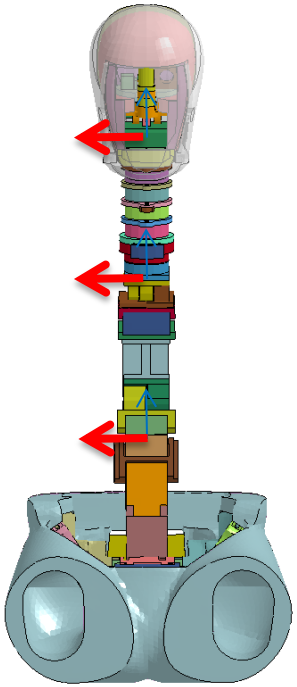
THOR ATD THOR FE

Kinematics

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

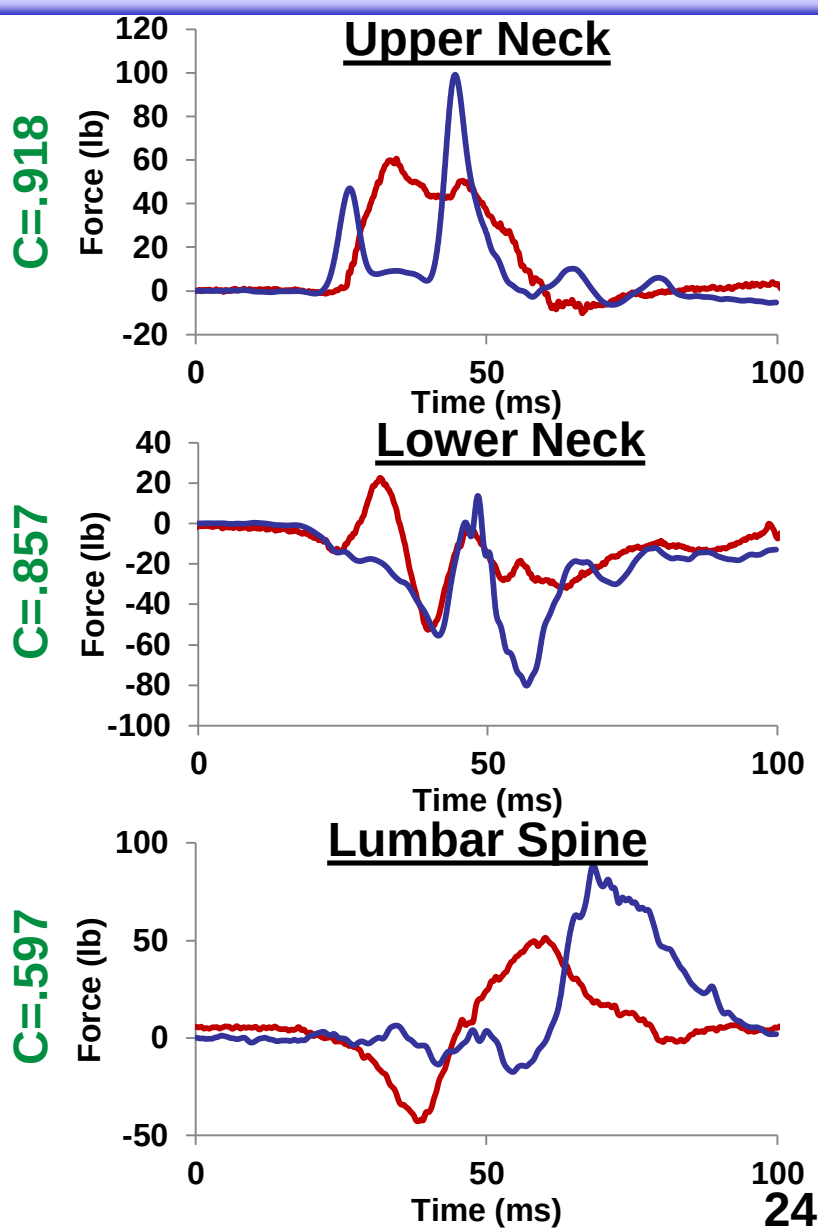


Lateral Results – Lateral Force



THOR ATD THOR FE

- Kinetics
  - "Bouncing" response
  - Larger secondary impact



Conclusions

- The THOR-K FE Head/Neck model was validated.
- The THOR FE model reasonably predicts the THOR-K dummy response in the tests evaluated.
- Differences are observed in the model response which indicate necessary calibration of the model.

Next Steps: Full Calibration

Current

Model calibration

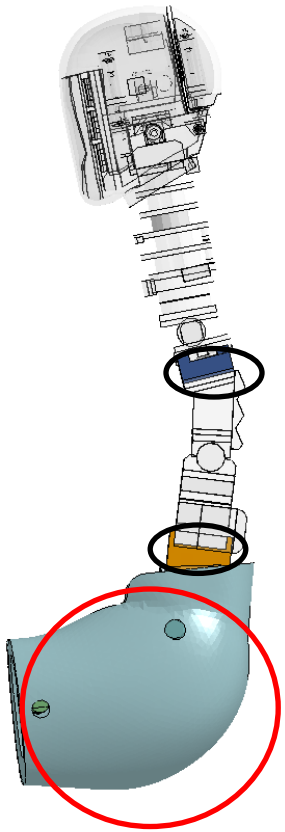
Spinal Impact

Pelvis Foam

Frontal Impact

Spinal Mold

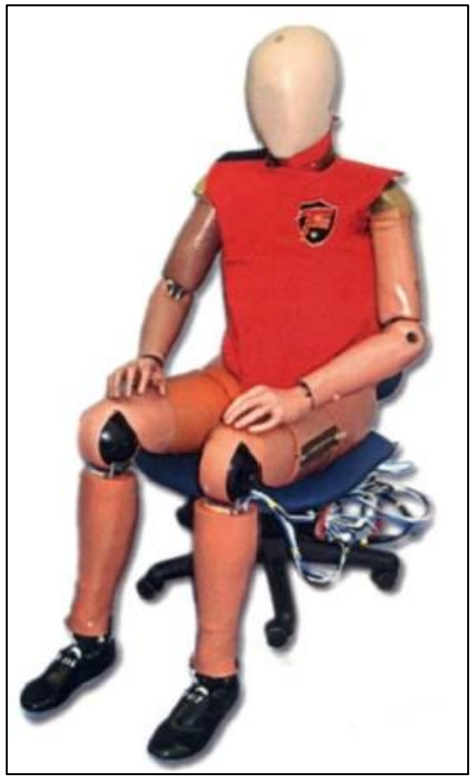
Calibrated THOR-k model



Model validation

Lateral Impact

Next Steps: Human Model Comparison



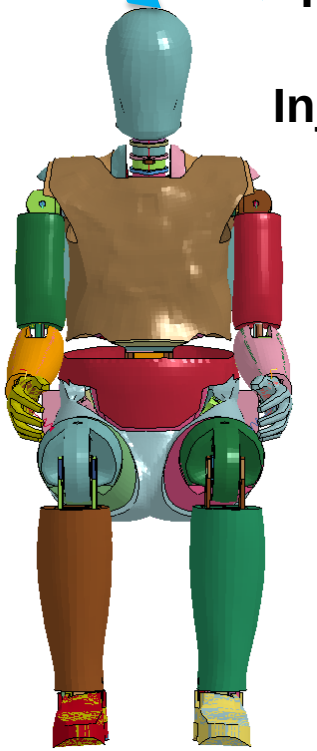
Matching Test Conditions

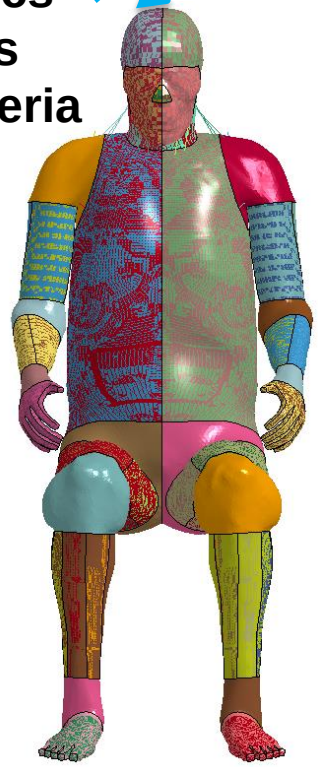
Full Model Validation

Kinematic Validation

Comparison
Analysis

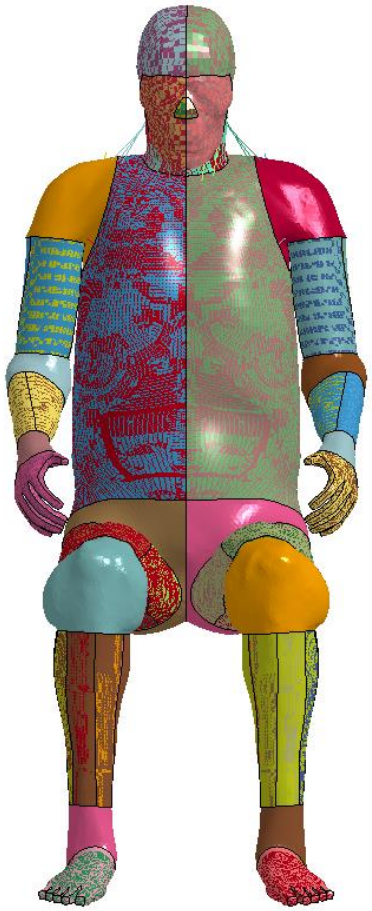
Kinematics
Kinetics
Injury Criteria



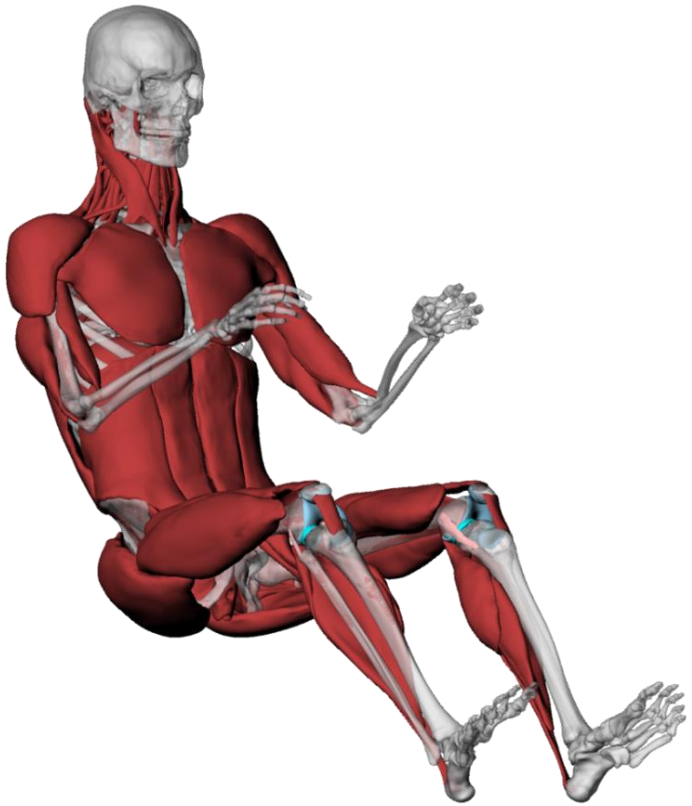


Next Steps: THUMS & GHBMC Comparison

THUMS



GHBMC



Limitations & Future Work

Limitations

- Lack of material 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

Acknowledgements

- NASA
- Wyle
- NHTSA
- Simulia
- JARI
- TOYOTA
- WPAFB

Questions?