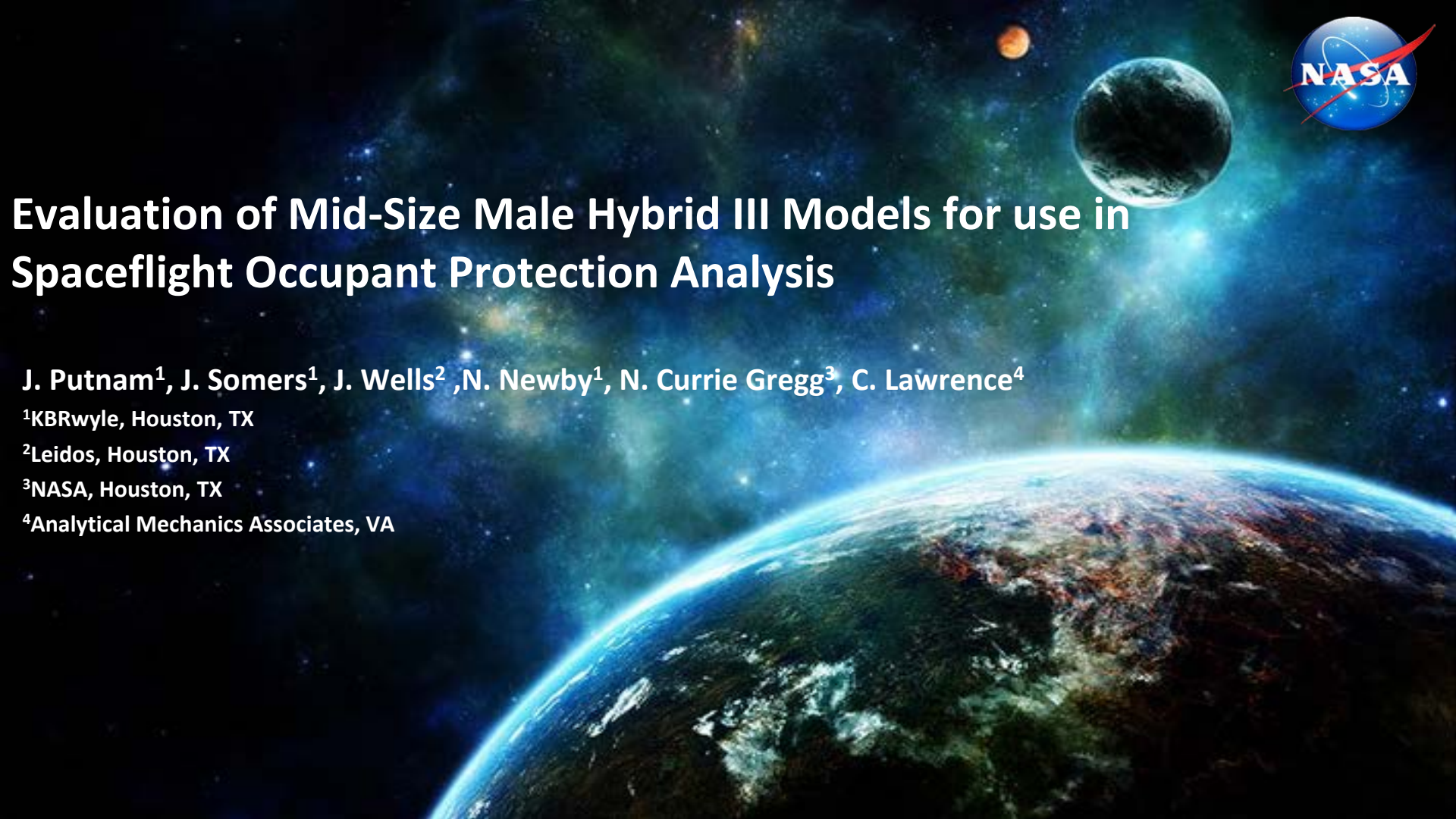

Evaluation of Mid-Size Male Hybrid III Models for use in Spaceflight Occupant Protection Analysis

J. Putnam[1], J. Somers[1], J. Wells[2] ,N. Newby[1], N. Currie Gregg[3], C. Lawrence[4]

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[2]Leidos, Houston, TX

[3]NASA, Houston, TX

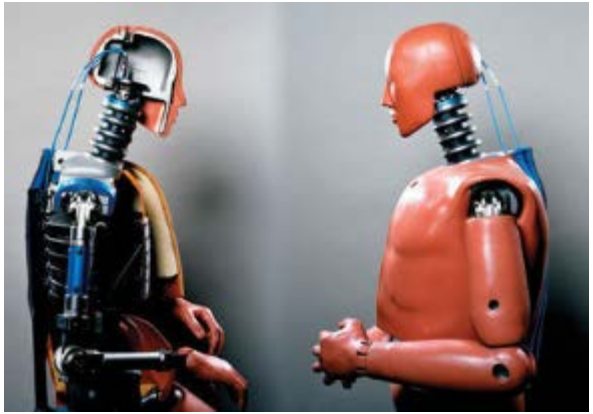
[4]Analytical Mechanics Associates, VA

Overview

- Background of the Hybrid III & FE Model
- NASA Occupant Protection Environment & Challenges
- Approach to meet those challenges (current study)
- Results & Interpretation
- What to do with these results

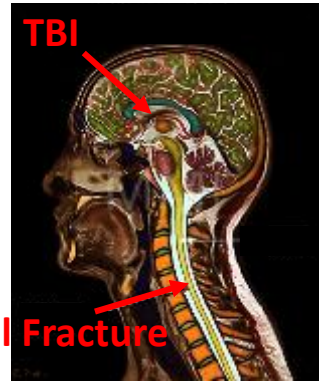
Hybrid III Anthropomorphic Test Device (ATD)

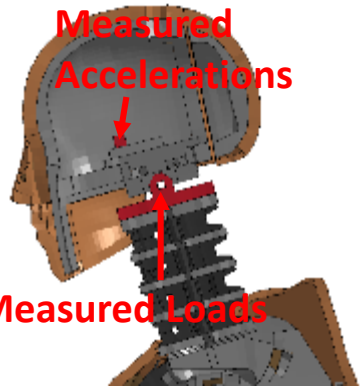
- **Mid-size male developed in the 1970s for automotive testing**
- **Designed for frontal, automotive, severe crashes**
- **Steel and rubber architecture**
- **Limitations**
  - Not intended for lateral use
  - Neck response limited outside design
  - Automotive Seating Posture



Implementation of Hybrid III

- **Injury Assessment Reference Values (IARV)**
  - Transfer function between mechanical response & human injury
  - Used to establish vehicle standards
- **Vehicle Testing**
  - Standard Evaluation
  - Design Optimization
- **Limitations**
  - Cost
  - Time

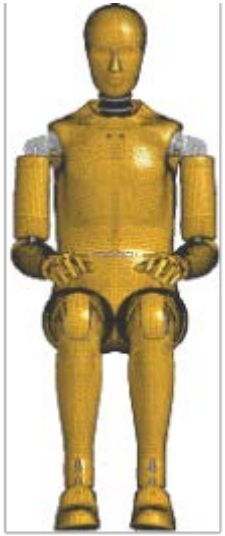




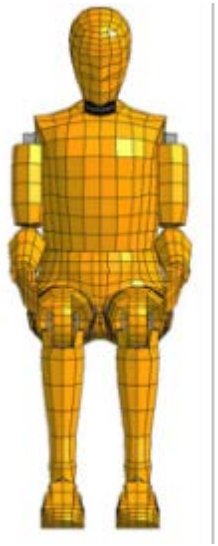
Finite Element (FE) Modeling

- **Intent**
  - Optimize vehicle design prior to testing
  - Evaluate vehicle safety outside testing scope

- **LSTC Hybrid III FE Models**
  - Developed 1990's
  - Use in Automotive Simulation
  - Approximated Mat. Properties
  - Calibrated to for intended use
  - *Extensibility?*



- **Detailed HIII Model**
  - 451,768 Elements
  - Detailed joint definitions
  - Accurate Geometry
  - ~1.5 hour run time *(300ms pulse)*



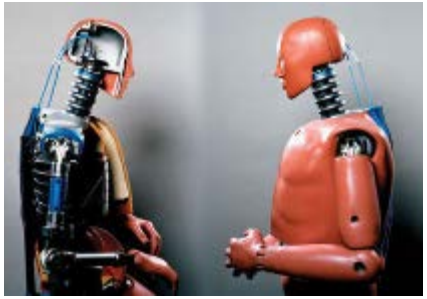
- **Fast HIII Model**
  - 4,310 Elements
  - Simplistic joint definitions
  - Simplified geometry
  - ~26 hour run time *(300ms pulse)*

Hybrid III Extended Uses

Aerospace

Military

Hybrid III ATD



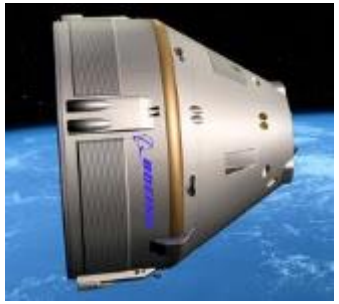
Spaceflight

Spaceflight's Need for Occupant Protection

- **New multipurpose crew vehicle (MPCV) Orion to be face of the National Space program**

Orion

- **Development of commercial space enterprises will see a dramatic increase in human space travel.**
  - ISS Transport
  - Recreation
  - Asteroid mining
  - Colonization



Boeing CCT-100

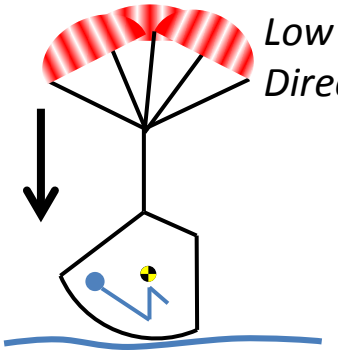
SpaceX Dragon

Challenge of Spaceflight Occupant Protection

- **Unique aspects of spaceflight**
  - "Crash" every time – need low probability of injury
  - Spacesuits – blunt trauma, load path
  - Deconditioning – understand how it changes impact tolerance
- **Variable Landing conditions**

Nominal

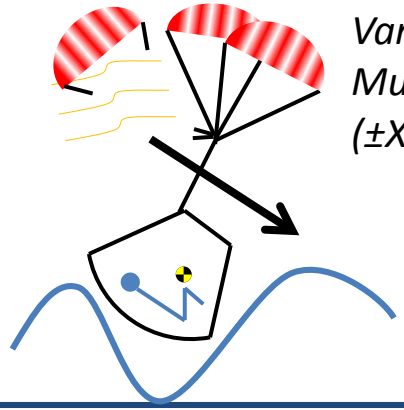
Planned



Low g impact
Directional control (+X)

Off - Nominal

Weather, Chute failure , abort, etc.

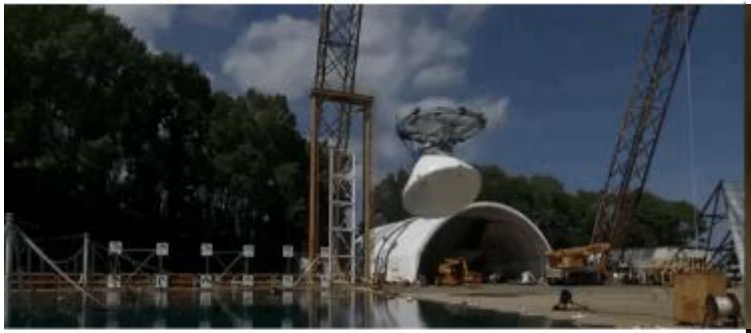


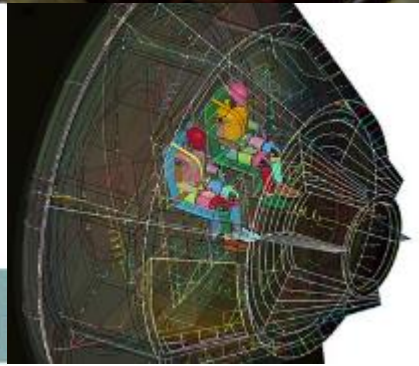
Variable g impact
Multi-directional
(±X, ±Y,+Z)

Current approach to Spaceflight Occupant Protection

- **Physical Testing**
  - Vehicle Qualification
  - Defined Hybrid III IARV limits
  - Extremely Costly

- **FE- Modeling**
  - Efficient (Time and Money)
  - Versatility
  - Used early in design
  - Accuracy?





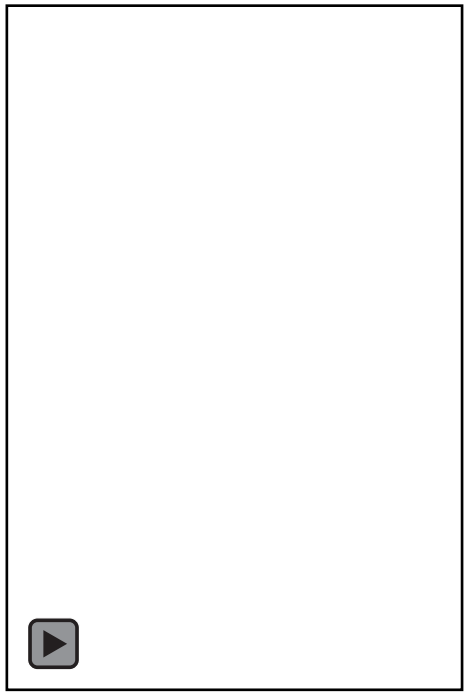
How accurate are current Hybrid III FE models in predicting the physical ATD under spaceflight loading conditions?

Testing Overview

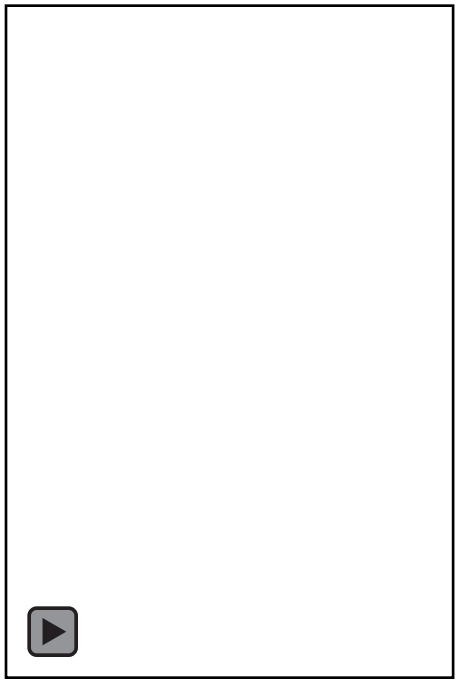
- **ATD sled test series**
- **Performed of WPAFB on HIA**
- **Auto & FAA Hybrid III**
- **Exercise ATD response**
  - Directional
  - Rate Dependence

Testing Overview: Impacts

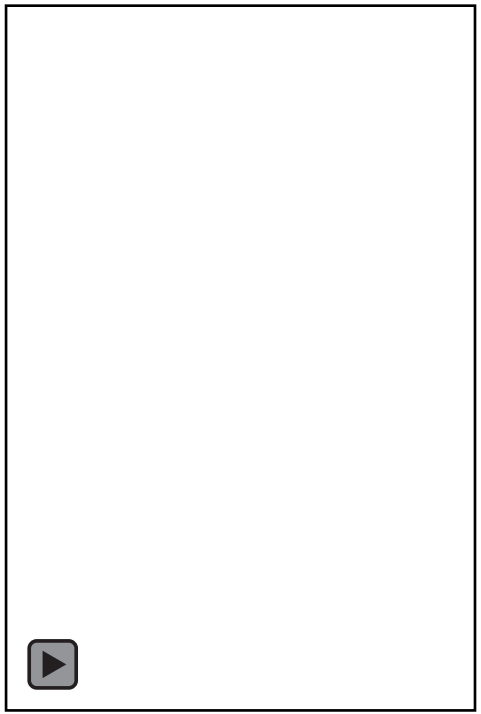
Frontal Impact



Spinal Impact

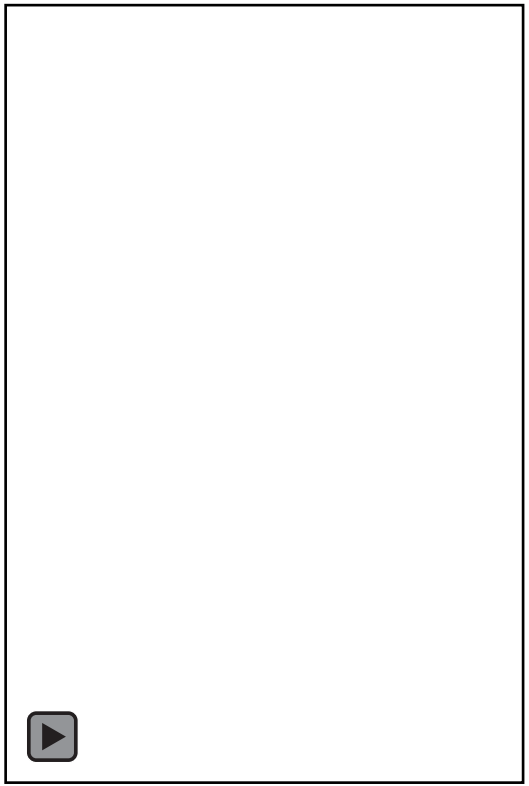


Rearward Impact

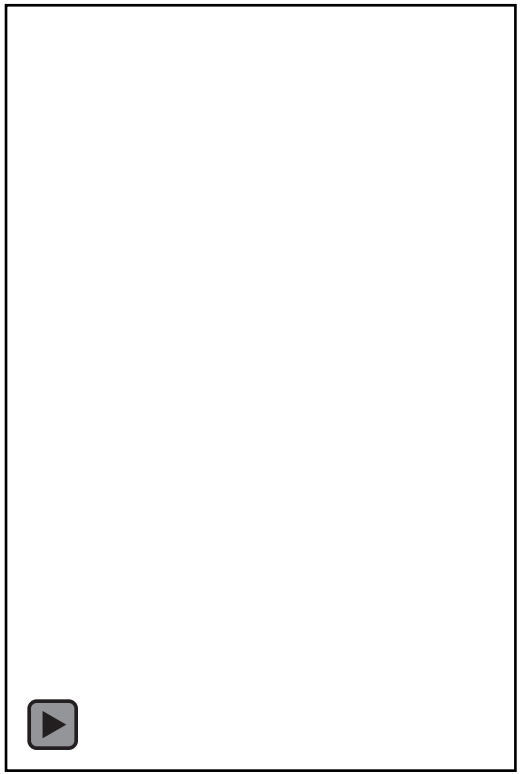


Testing Overview: Impacts

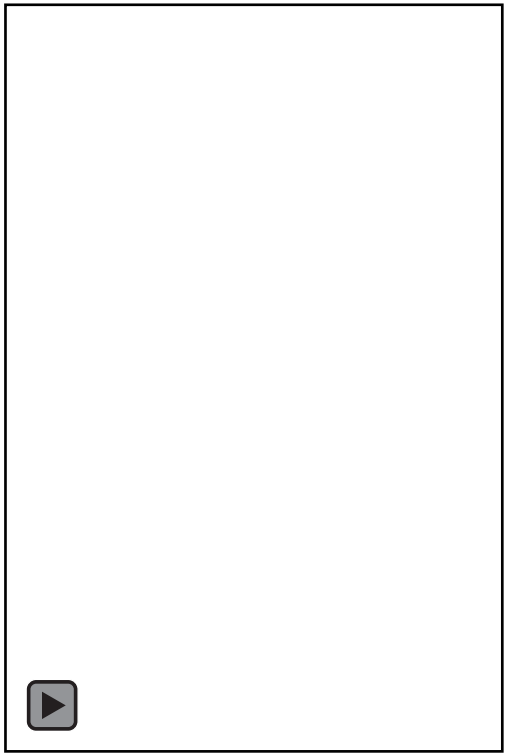
Lateral Impact: No Side Restraints



Shoulder & Leg Restraints



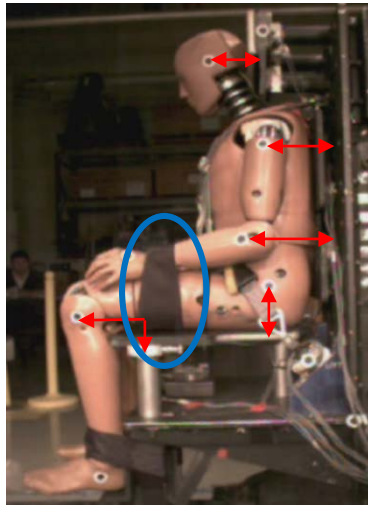
Full Lateral Restraint

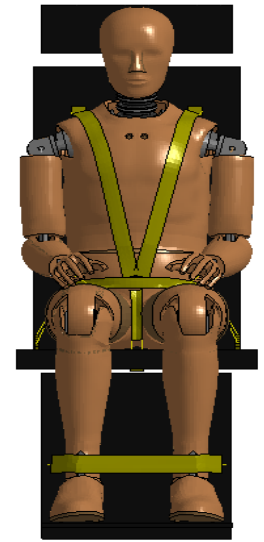


Modeling Setup

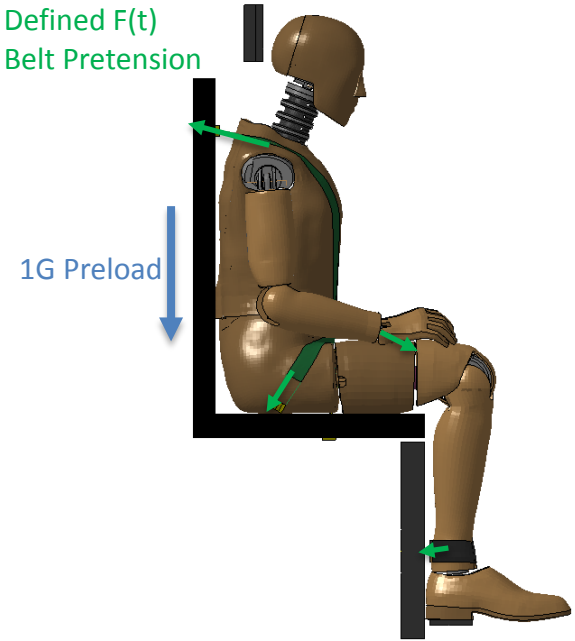
- **Rigid generic seat (mitigate model uncertainty)**
- **5 point belt: as spaceflight design**
- **Limitations**
  - Initial position
  - Unknown Arm restraints
    - Sensitivity showed minor effect

Automotive Hybrid III

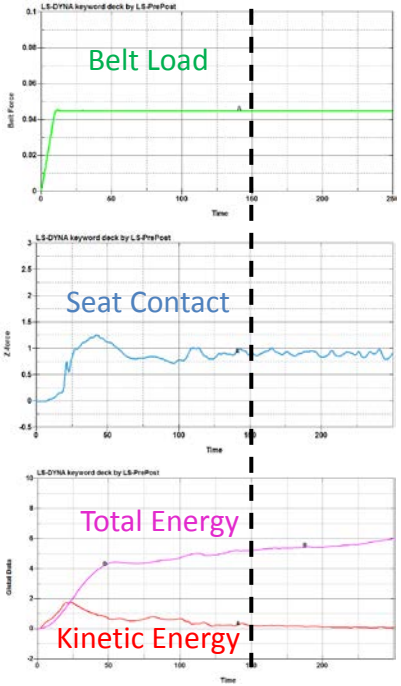




Modeling Overview: Initialization Checks



Pre-Load : 150 ms

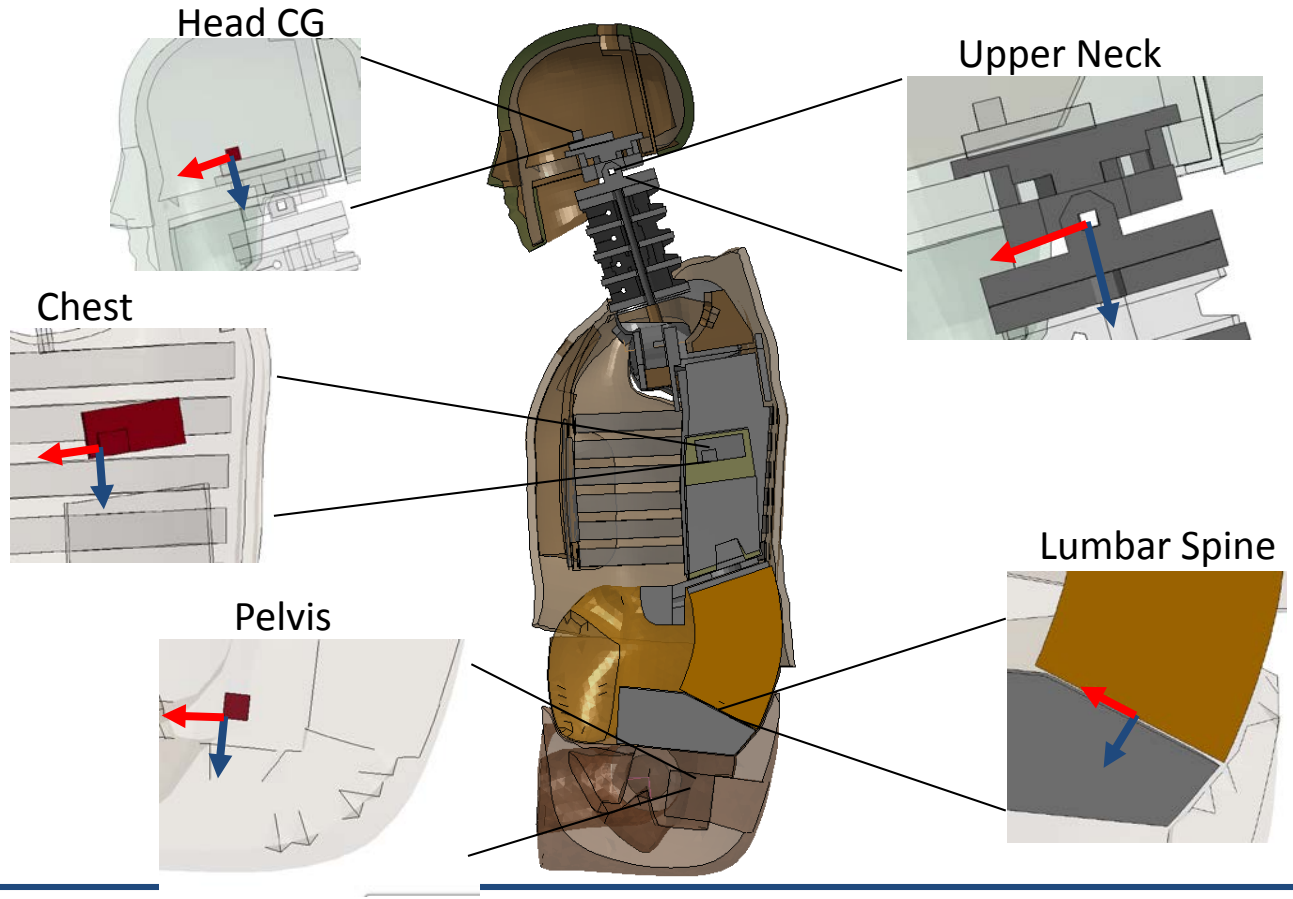


Belt Tension: 20 lb

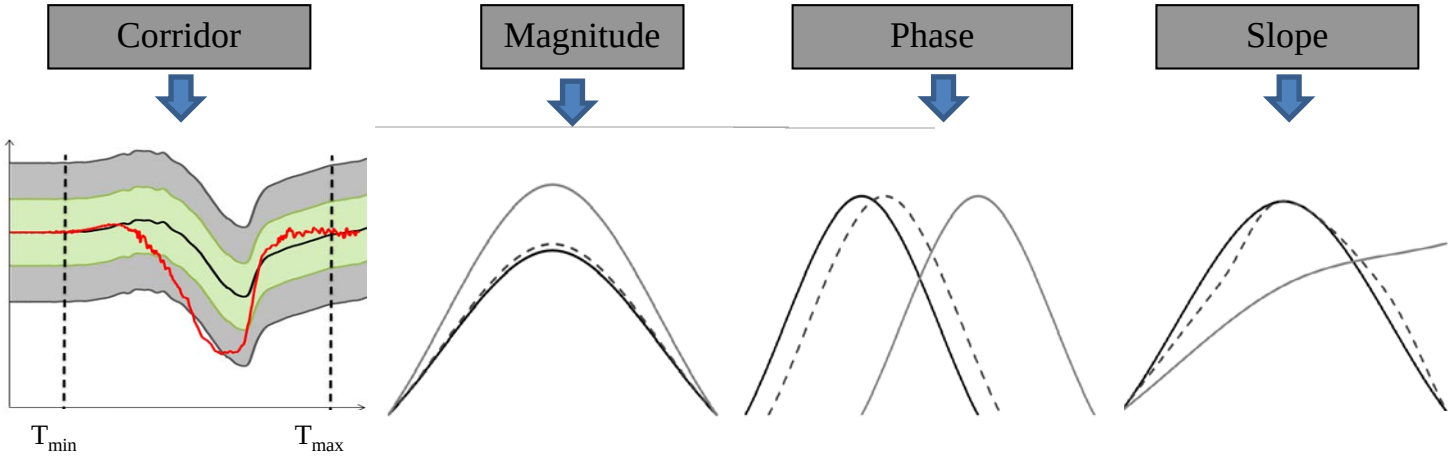
1g

Ratio=.04

Instrumentation



ISO Curve Comparisons



$(.4xS_c)$ + $(.2xS_m)$ + $(.2xS_p)$ + $(.2xS_p)$

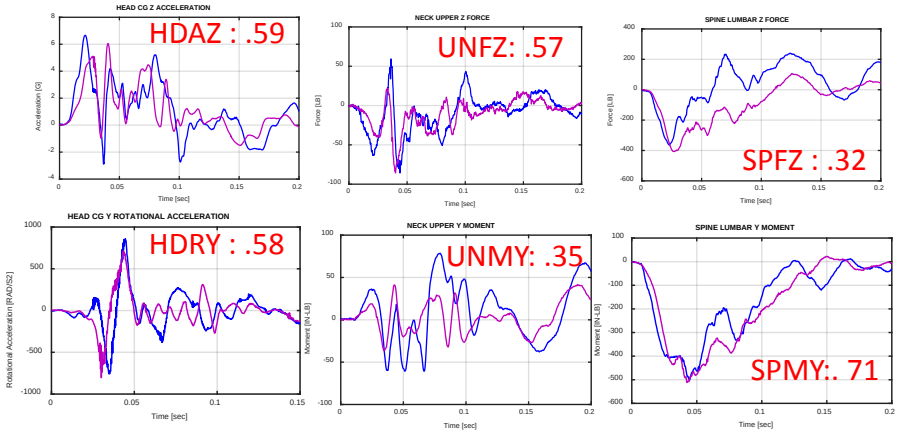
=

ISO Score (/1)

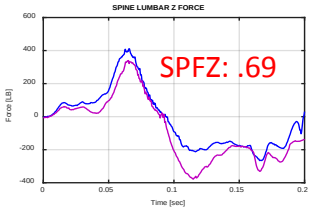
Results: Test Repeatability

- **Min. 1 Tests repeat per direction**
- **>.75 ISO threshold for analysis**
  - Limited kinematic responses removed

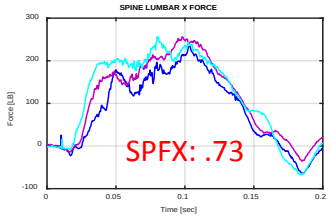
Rearward: .80



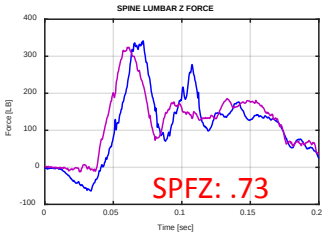
Frontal .86



Spinal .82



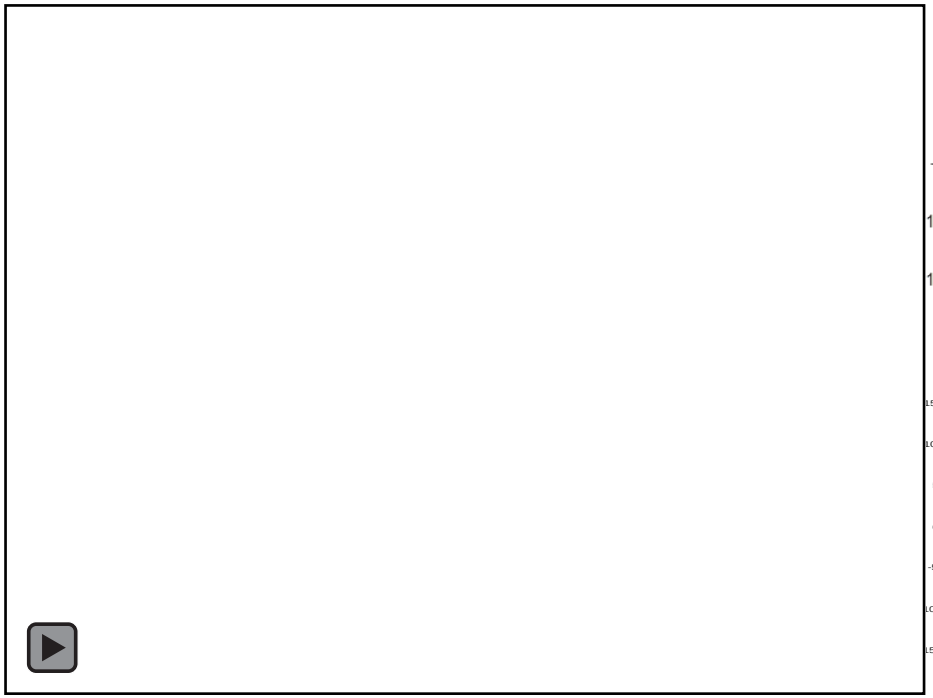
Lateral .78

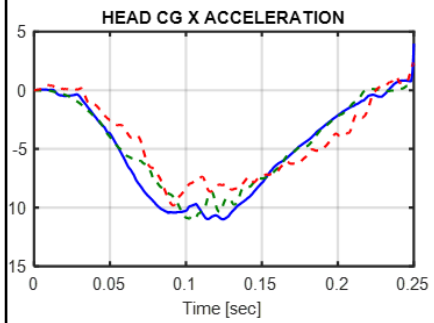


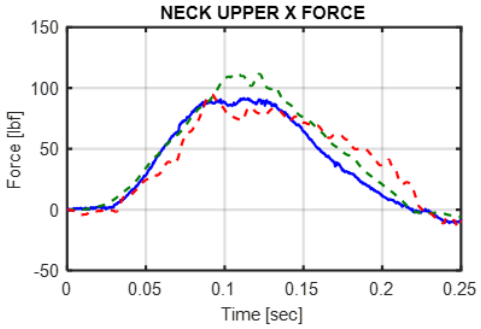
Frontal Impact : Predicted Responses

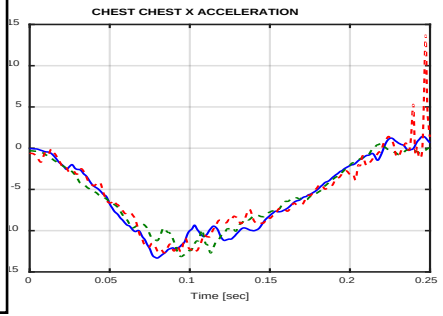
- **Accurately Predicted Frontal kinematics**
  - Forward flexion

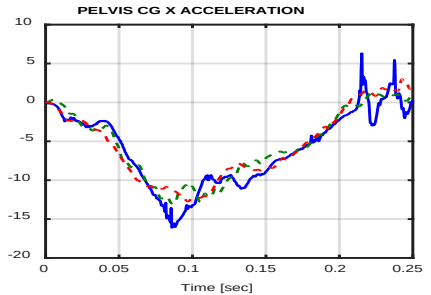
-Test --FE Detailed --FE FAST









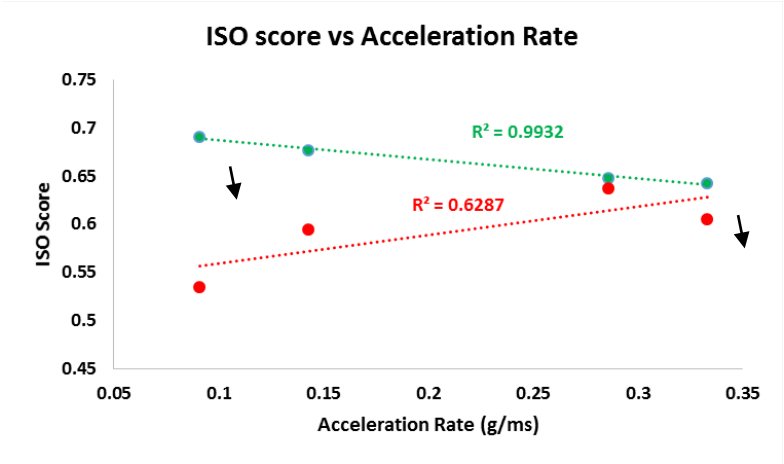


Frontal Impact: Areas Concern

- **FAST FE lumbar spine response**

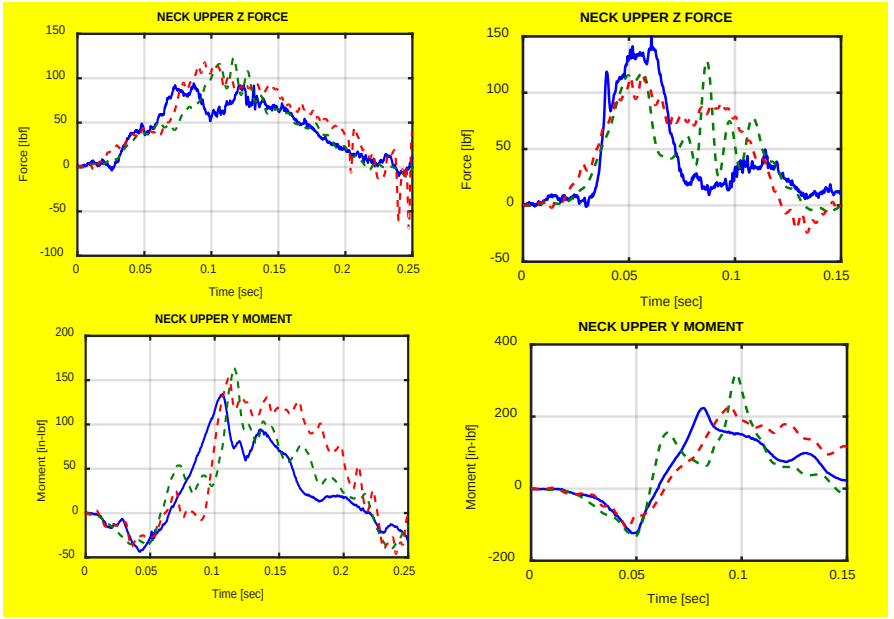
Frontal Impact : Rate Dependence

- **Acceleration Rate (Peak / Rise Time) dependence**
- **Detailed FE : Head/Neck rotation response**



10g - 110 ms

10g – 30 ms

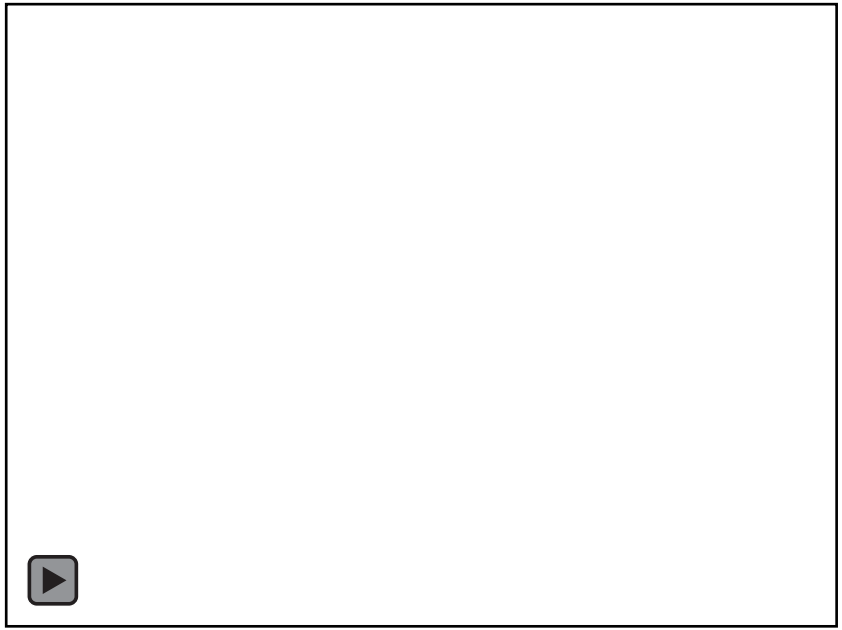


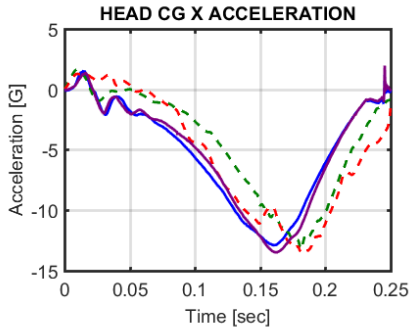
-Test --FE Detailed --FE FAST

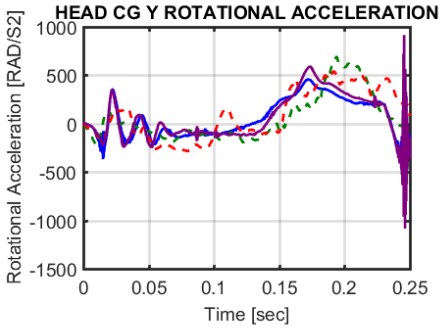
Spinal Impact: Predicted Responses

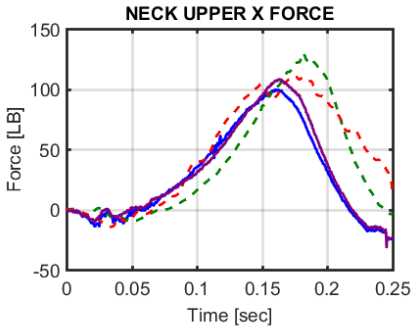
- **Accurately Predicts Off-axis kinematics**
  - Forward flexion

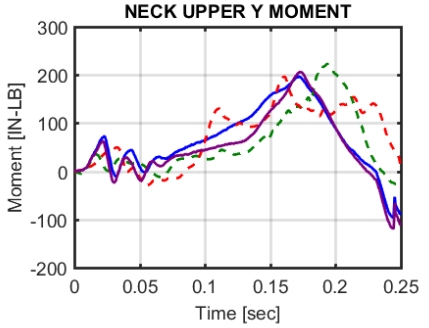
-Test1--FE Detailed --FE FAST
-Test2





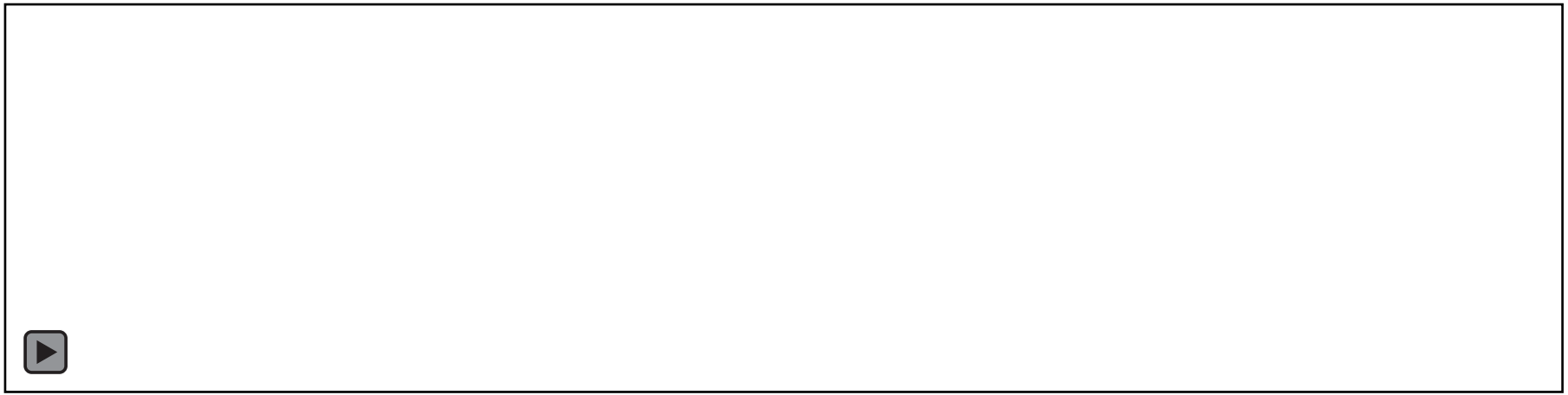






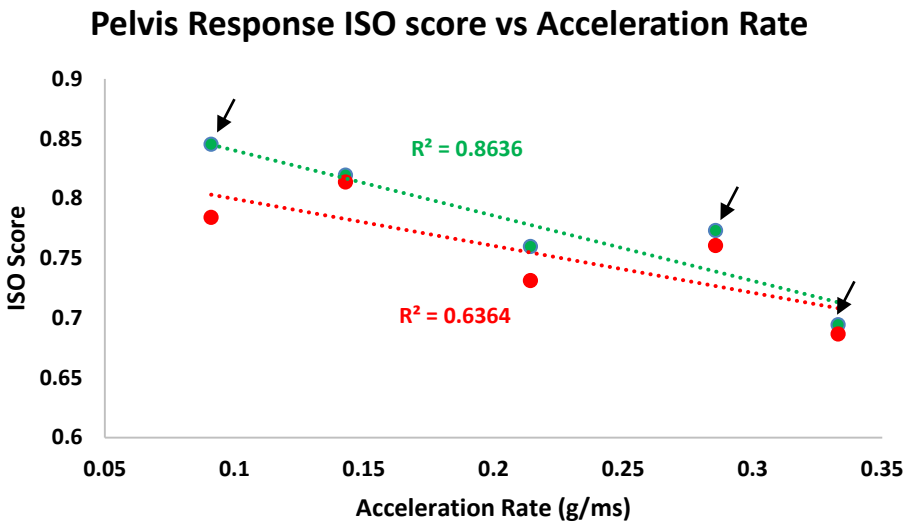
Spinal Impact: Areas of Concern

- **On Axis Response**
- **Detailed FE**

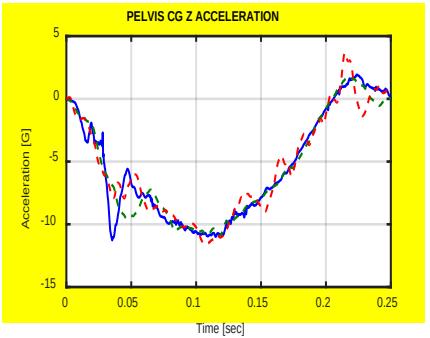


Spinal: Rate dependency

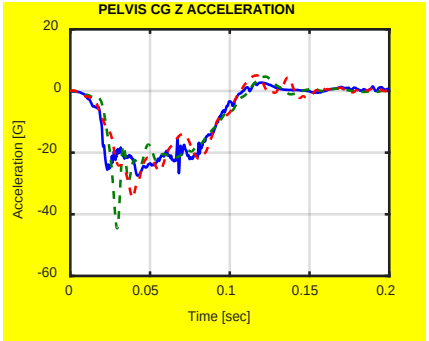
- **Acceleration Rate (Peak / Rise Time) dependence**
- **Both FE: Pelvis Acceleration**



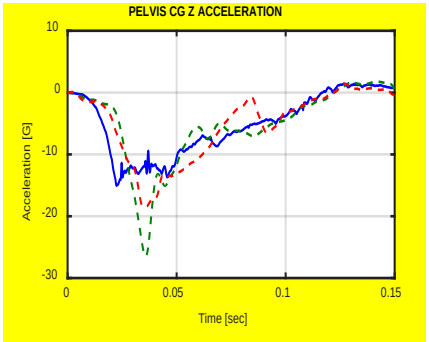
10g - 110 ms



20g - 70 ms



10g - 30 ms

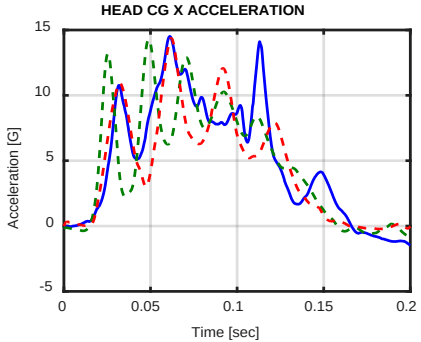


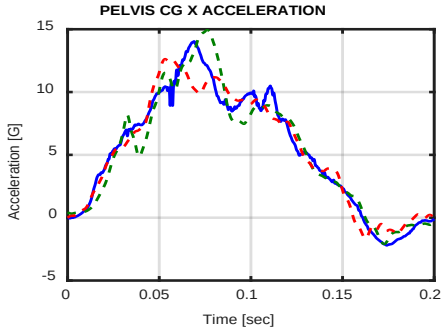
-Test --FE Detailed --FE FAST

Rearward: Predicted Responses

- **Head & Pelvis**

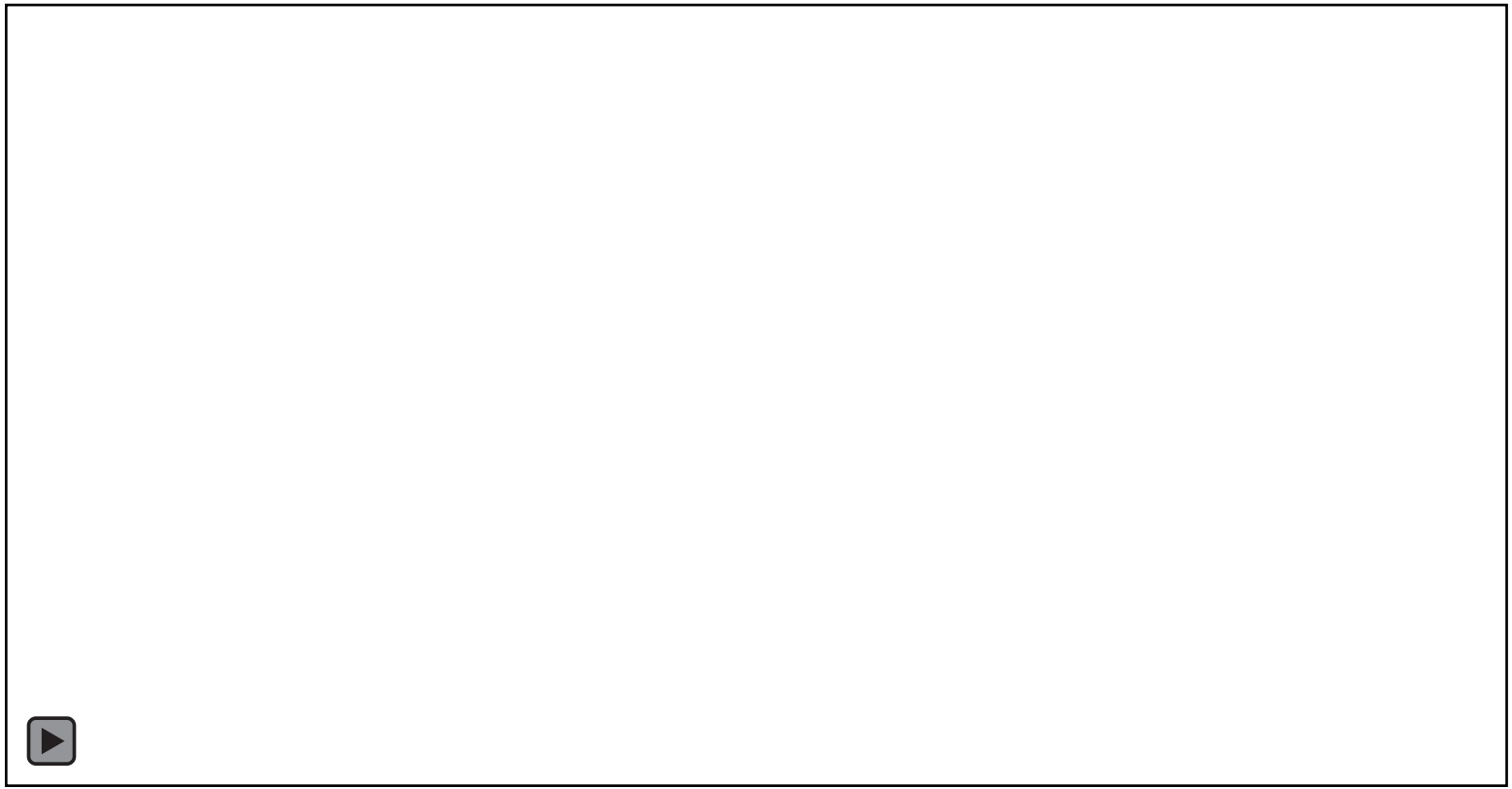
-Test --FE Detailed --FE FAST





Rearward: Areas of Concern

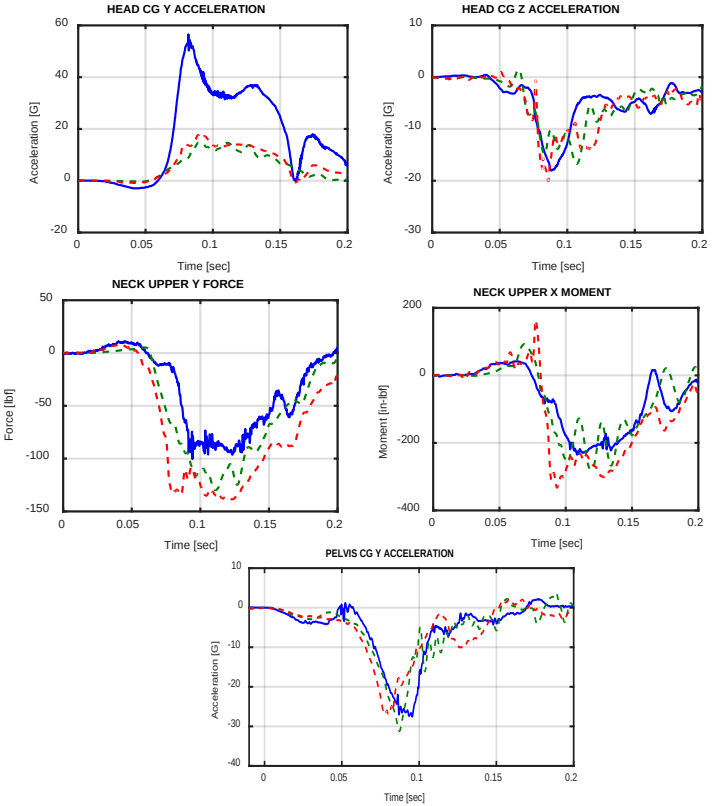
- **Chest & Neck**



Lateral: No Side Restraints

- **Overall well correlated**
- **Head Y acceleration not picked up**

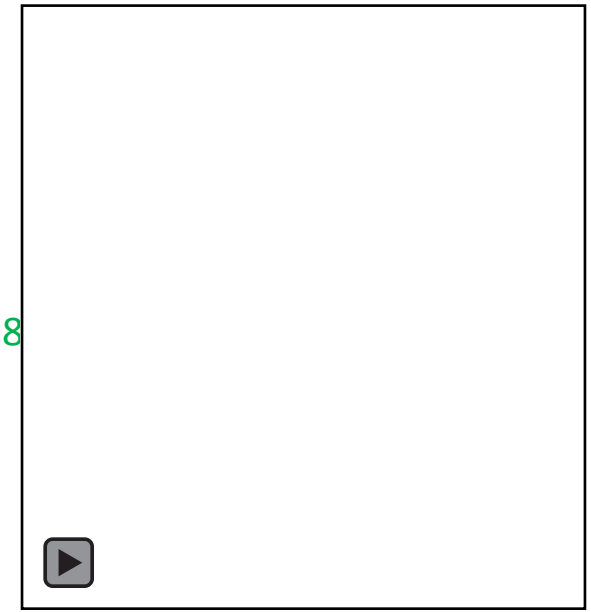
-Test --FE Detailed --FE FAST



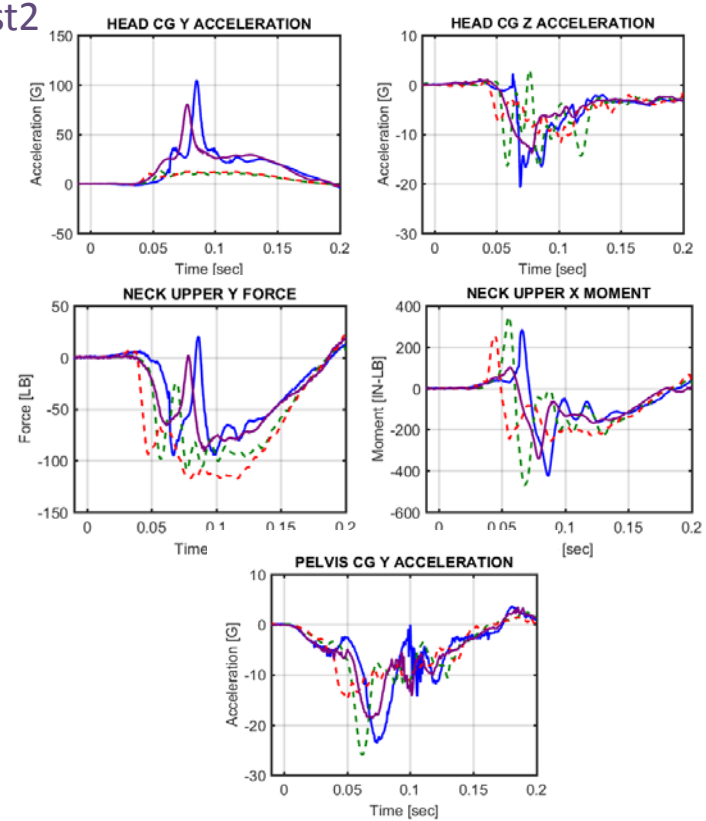
Lateral: Shoulder & Leg Restraints

- **Shape and Size prediction**
- **Head Y acceleration not picked up**

.58



-Test1--FE Detailed --FE FAST
-Test2



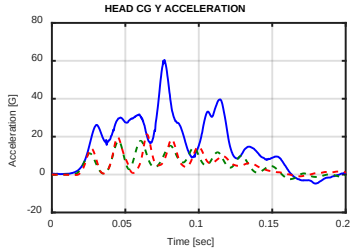
Lateral: Full Restraints – Rate Dependence

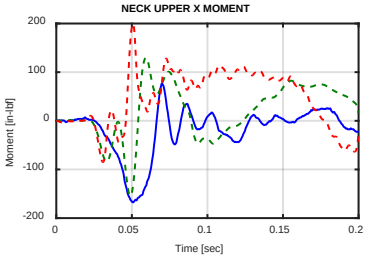
- **Head Y acceleration not picked up**
- **Pelvis: Detailed rate dependence**
- **Shape and Size prediction**

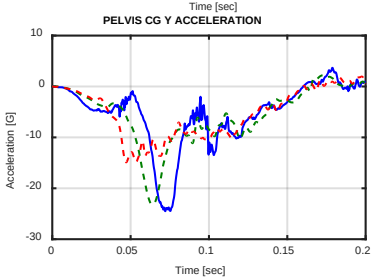
.50

-Test --FE Detailed --FE FAST

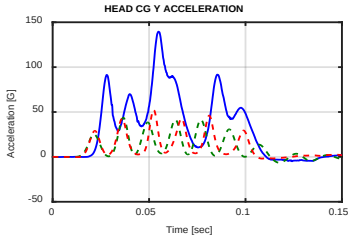
10g - 70 ms

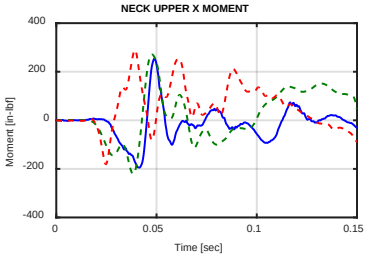


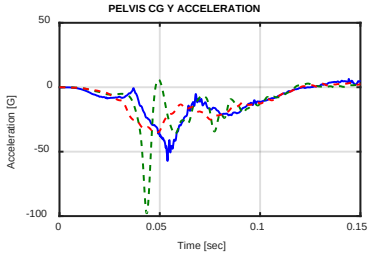




20g - 70 ms







Overall Conclusions

- **Directional dependence**
  - Consistent to field of design
- **Detailed vs. Fast**
  - Detailed though marginal
- **Belt driven motion**
  - Both models demonstrate accuracy
- **Seat driven motion**
  - Detailed model demonstrates incorrect rate effects

- **Questions?**
  - Simplified shape = improved rate dependence?
    - Shape + Material compensation?

Future Work

- **Tease out model Inconsistencies**
- **Component evaluation**
  - Rate Dependence
  - Geometry Effects
- **Sensitivity Analysis**
  - Identify positioning effects
  - Rate thresholds

- **Expand use**
  - Flexible Seat environment
  - Combined Loading
  - Full crew loads analysis

Thank You!