LTV-xEVA Applied Injury Biomechanics

Keegan Yates, PhD[1]

Aaron Drake[1]

Kristine Davis[2]

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[1]KBR, Human Health and Performance Contract, Houston, TX

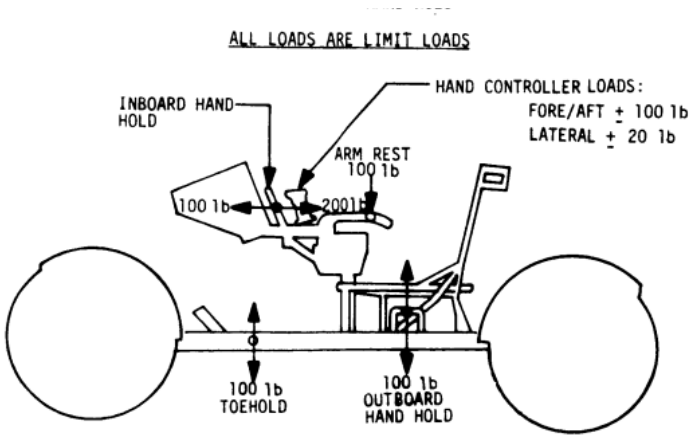
[2]NASA Johnson Space Center, Houston, TX

Background

- Operating a rover in reduced gravity while wearing a modern EVA suit is a loading condition with very few analogs
- The Apollo Lunar Roving Vehicle (LRV) is an obvious starting point
  - Apollo astronauts wore an EVA suit, though different from modern suits
  - The Apollo missions were in different terrain and lighting conditions than planned Artemis missions
  - Lunar Terrain Vehicles (LTVs) are different than the Apollo LRV
  - We don't know what the actual Artemis LTV will look like
- A short literature review was performed on the Apollo LRV

Apollo Notes

- One injury noted (wrist laceration) due to suit[1]
- Obstacles constantly encountered
- Visibility difficult
- “Vehicle traverse cross slope caused discomfort to the crewman on the down-slope side and was avoided whenever possible”[2]



[1] https://www.nasa.gov/wp-content/uploads/static/history/alsj/a16/A16_MissionReport.pdf
[2] https://ntrs.nasa.gov/api/citations/19730025089/downloads/19730025089.pdf

Background

- LTV operation has potential to cause injury
  - EVA suit inertia
  - Rollover risk
  - Blunt loading from suit rigid components
  - Restraints can’t interface with body directly
  - Obstacles may be difficult to see
- LTV injury probability difficult to predict with standard tools
  - Anthropomorphic test devices (ATDs) likely wont fit in an EVA suit
  - Brinkley ground rules are broken by presence of EVA suit
  - Types of injury most likely (bruising, abrasions, point loading) not considered by existing dynamic injury tools
- **Human body models (HBM) are compatible with EVA suits, and have potential to be used to predict LTV injury**

Methods

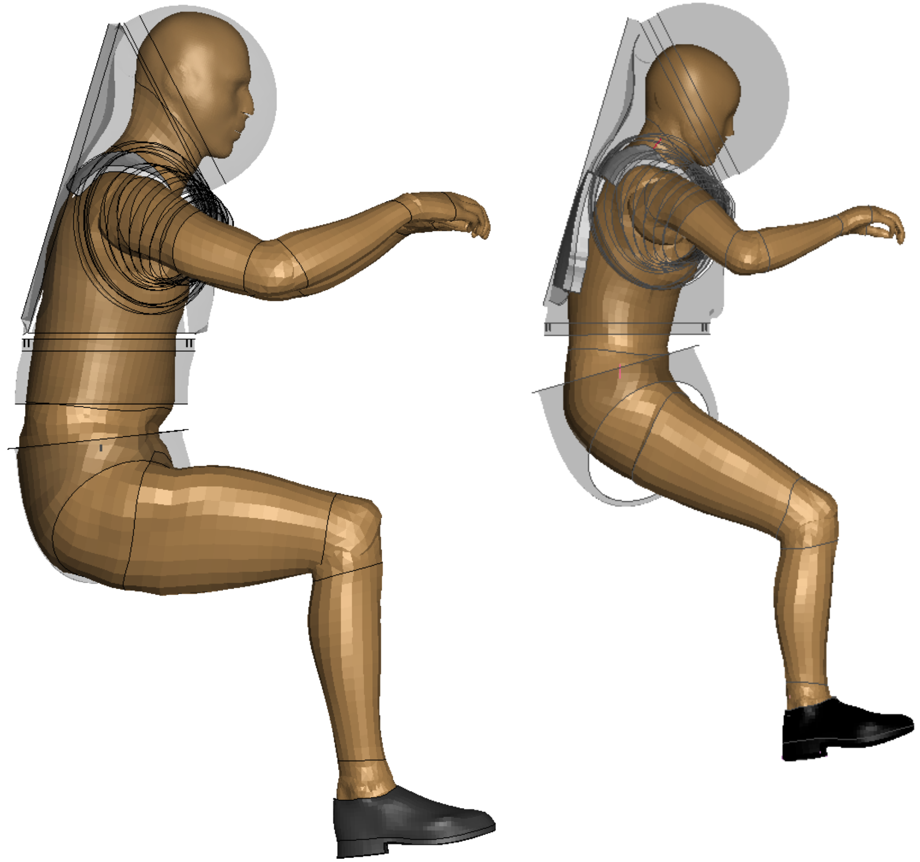
- Human body models placed into model of occupant facing xEMU suit hard goods
- Models positioned into two postures
- Models simulated through “worst-case allowable” loading conditions
- Model outputs compared to injury metrics

Human Body Models

- Global Human Body Models Consortium (GHBMC) 5th female, 50th male, and 95th male occupant models used
- Can be positioned like a human
- Provides outputs similar to ATDs (accelerations, forces, etc.)
- Can provide contact forces with suit components

Suit Model

- xEMU model used for all simulations
- M95 uses the large HUT
- Model consists of only the rigid suit components that face the occupant
  - Harness shoulder pads used in all cases
  - Back pad used for F05 model
- HBMs placed in suit in roughly the right posture
- Final positioning done as a pre-simulation
  - Allows HBM to come to final position with natural contact with the suit
  - Allows for deformation of the HBM flesh

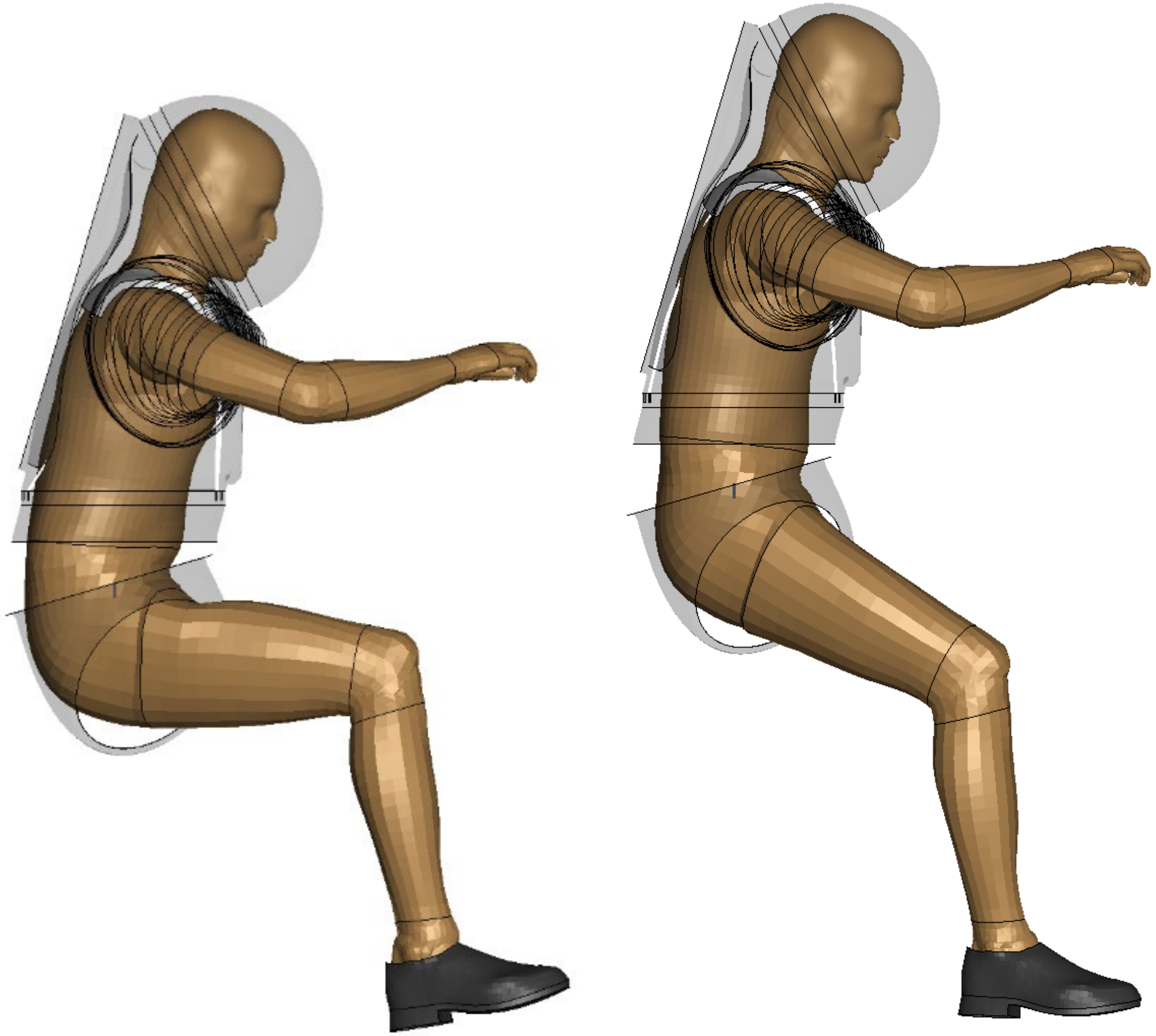


LTV Agnostic Model

- Restraints were modeled as a rigid attachment of the HUT to a seat and feet to floor
- Greatly simplifies modeling effort
  - Non-rigid restraints require modeling of seat, restraint system, and pressurized suit
  - Interaction between seat, restraint, and suit is also crucial to capture
- Rigid attachment may be the worst case for single events
  - Immediate transfer of loading from vehicle to suit
  - Only single events modeled in this effort
  - Non-rigid attachment may be better for single events
  - Repeated events with non-rigid attachment may cause amplification of loading
  - Non-rigid restraints could represent an injury risk not covered in this work

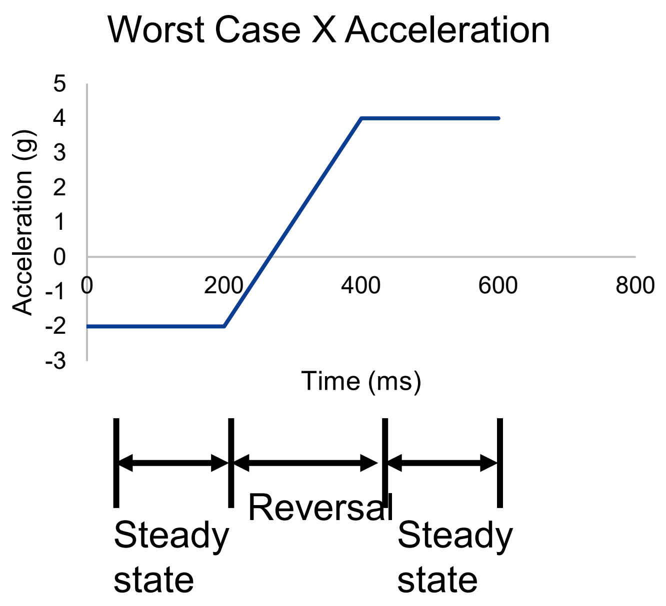
Postures

- Models placed in a seated posture as well a semi-standing “Leaning Post” configuration
  - Based on NASA Ground Test Unit designs
- Settling of occupant within suit performed as beginning of simulation



Loading Conditions

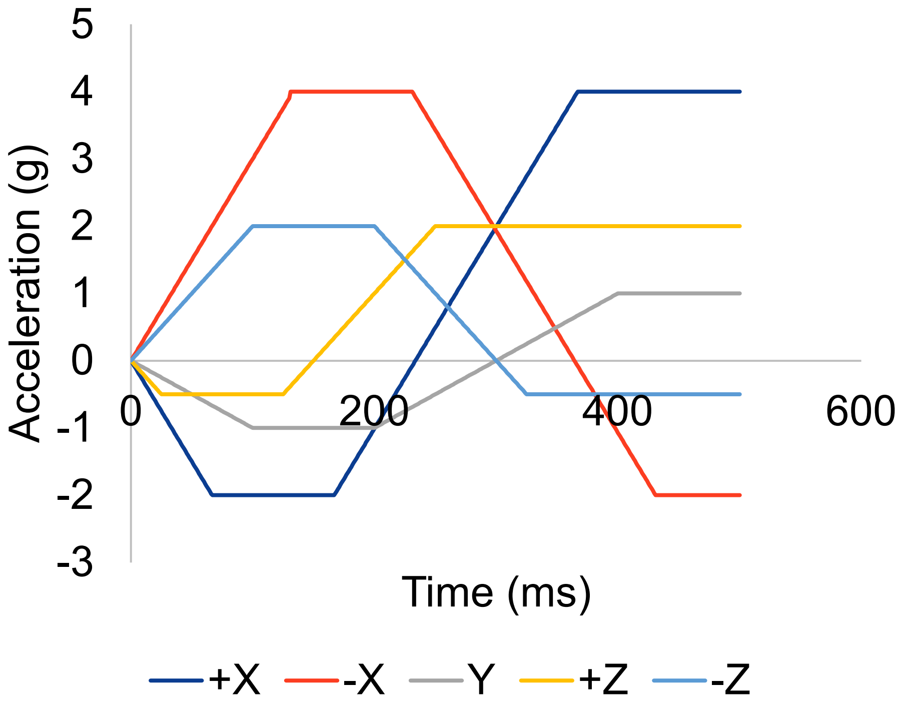
- Realistic lunar loading conditions currently unknown
- Requirements[1] specify maximum accelerations in all directions and maximum acceleration rate-of-change (jerk)
- "Worst-case allowable" impact starts at the maximum acceleration in one direction, then switches to the maximum acceleration in the other direction
- This process was applied to each direction and combination of directions
- **These are not representative of any particular LTV operation**



[1] Dolick, Kevin R., et al. "Lunar Transport Vehicle Occupant Protection Requirements." (2022).

Loading Conditions

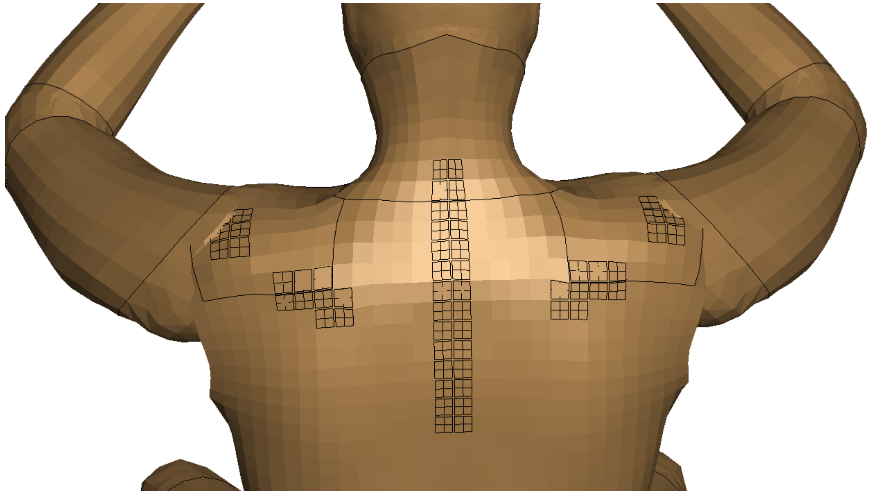
- Developed curves starting at 0, reaching a steady state in one direction, then reversing
- Steady-state is held for 100 ms
- There are 17 total combinations of these inputs

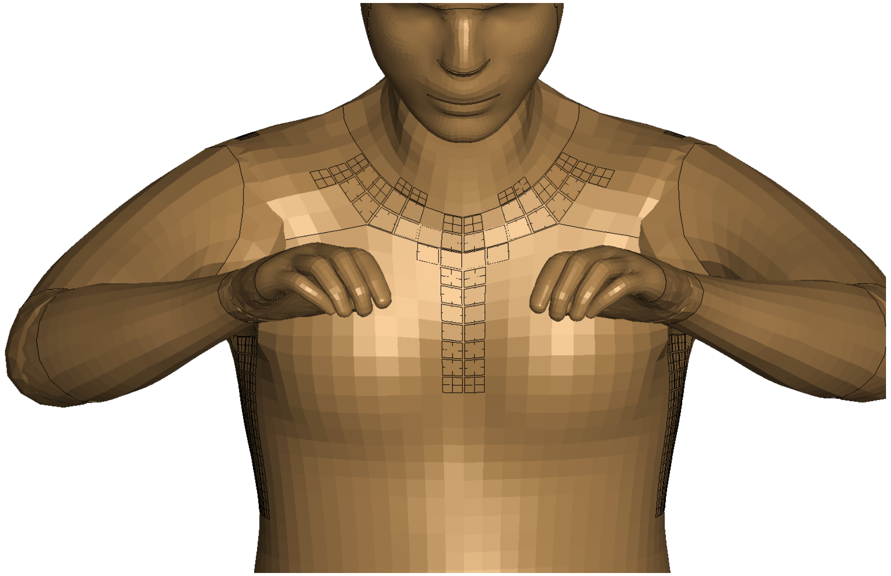


Case	+x	-x	y	+z	-z
1	X				
2		X			
3	X		X		
4		X	X		
5	X			X	
6	X				X
7		X		X	
8		X			X
9	X		X	X	
10	X		X		X
11		X	X	X	
12		X	X		X
13			X		
14			X	X	
15			X		X
16				X	
17					X

Simulation Outputs

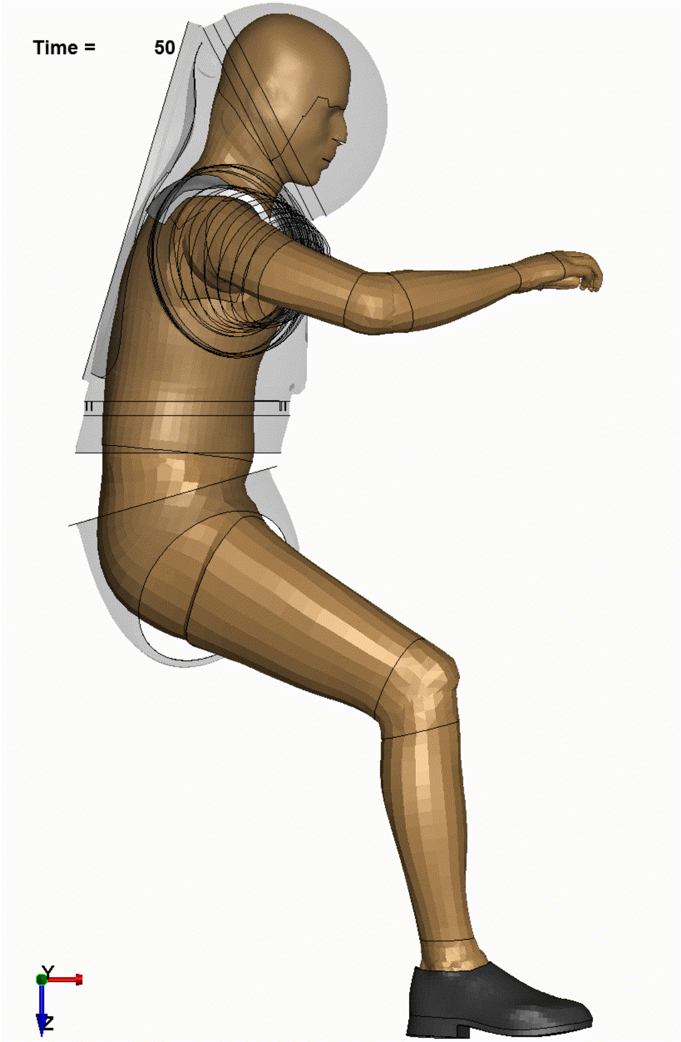
- Traditional injury metrics
  - Forces and moments in neck, shoulders, humeri, elbows, wrists, femurs, knees, and tibias
  - Accelerations in head, spine, and pelvis
  - Deflection of the chest
- Contact force between specific bony locations of concern and suit components
  - Able to be used for comparison with requirements
  - Intended to prevent blunt trauma
  - Not traditional





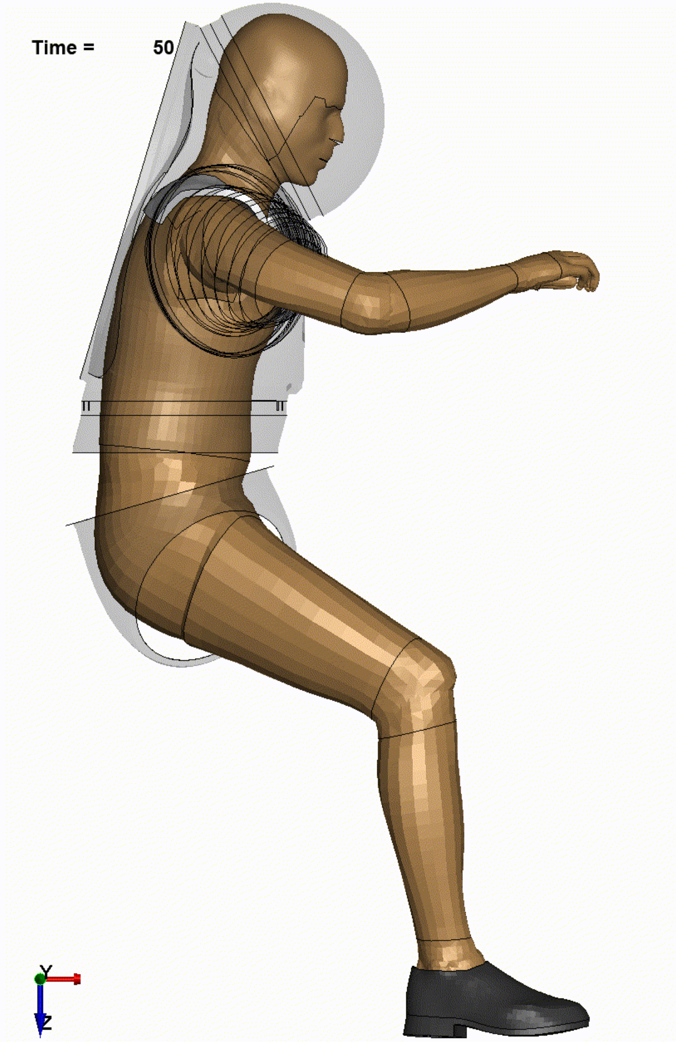
Simulations - Directionality

Positive X



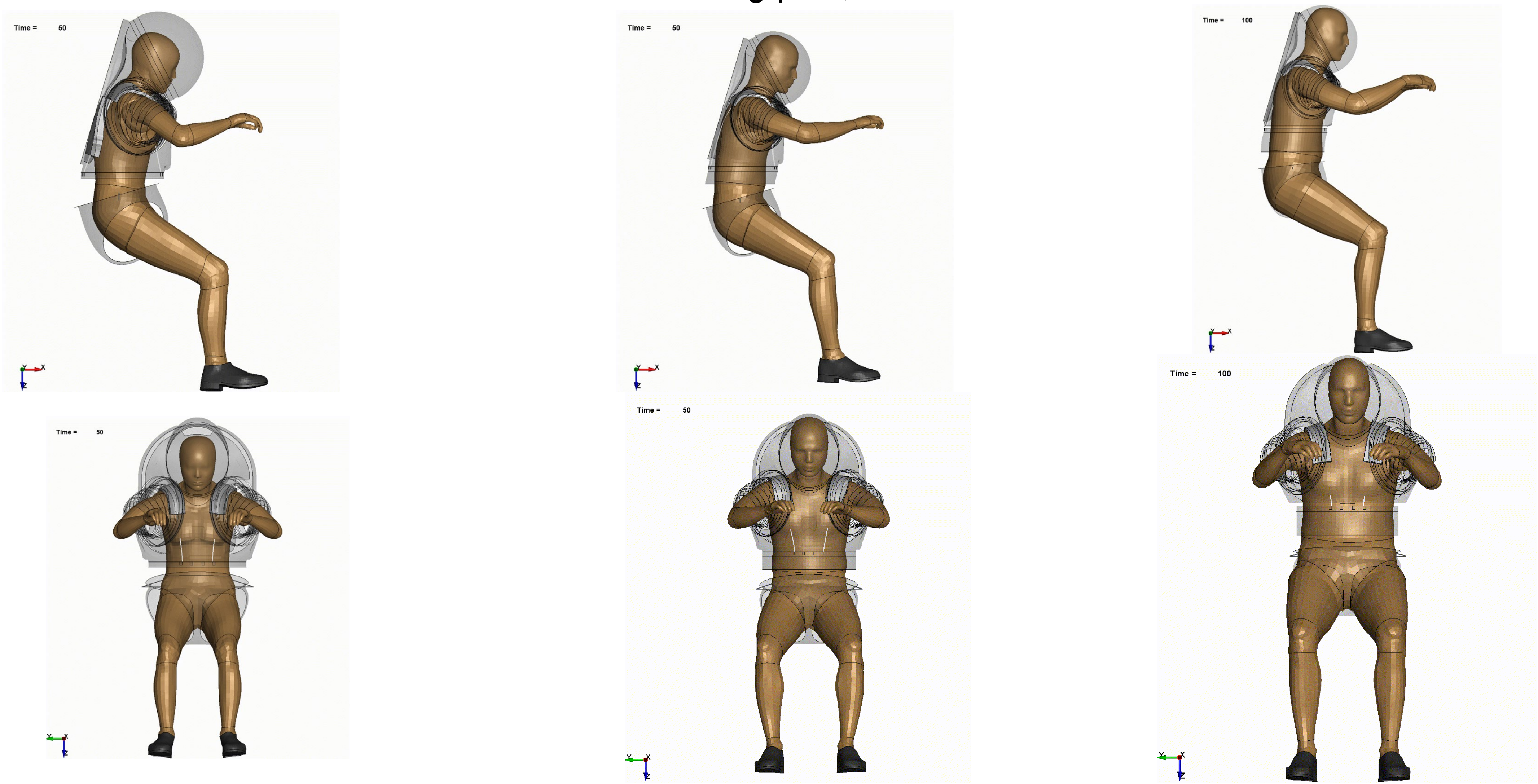
M50, Leaning post, S1

Negative X

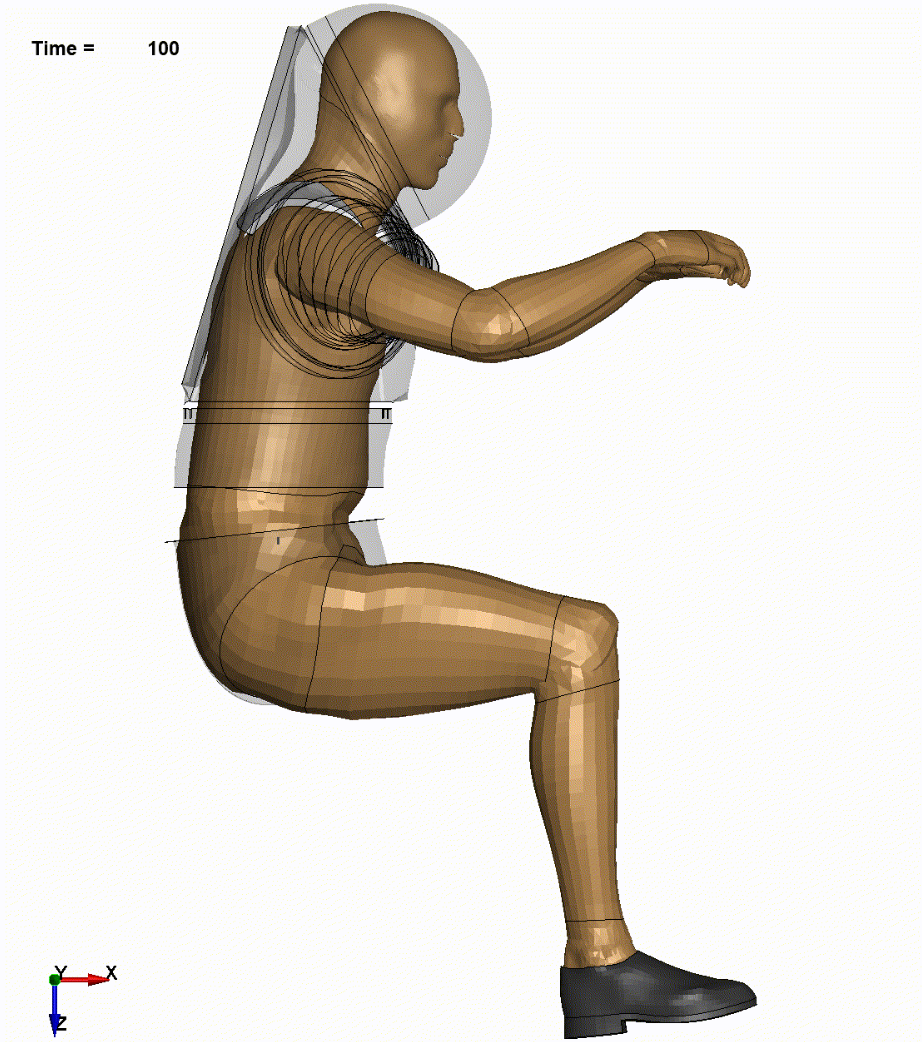


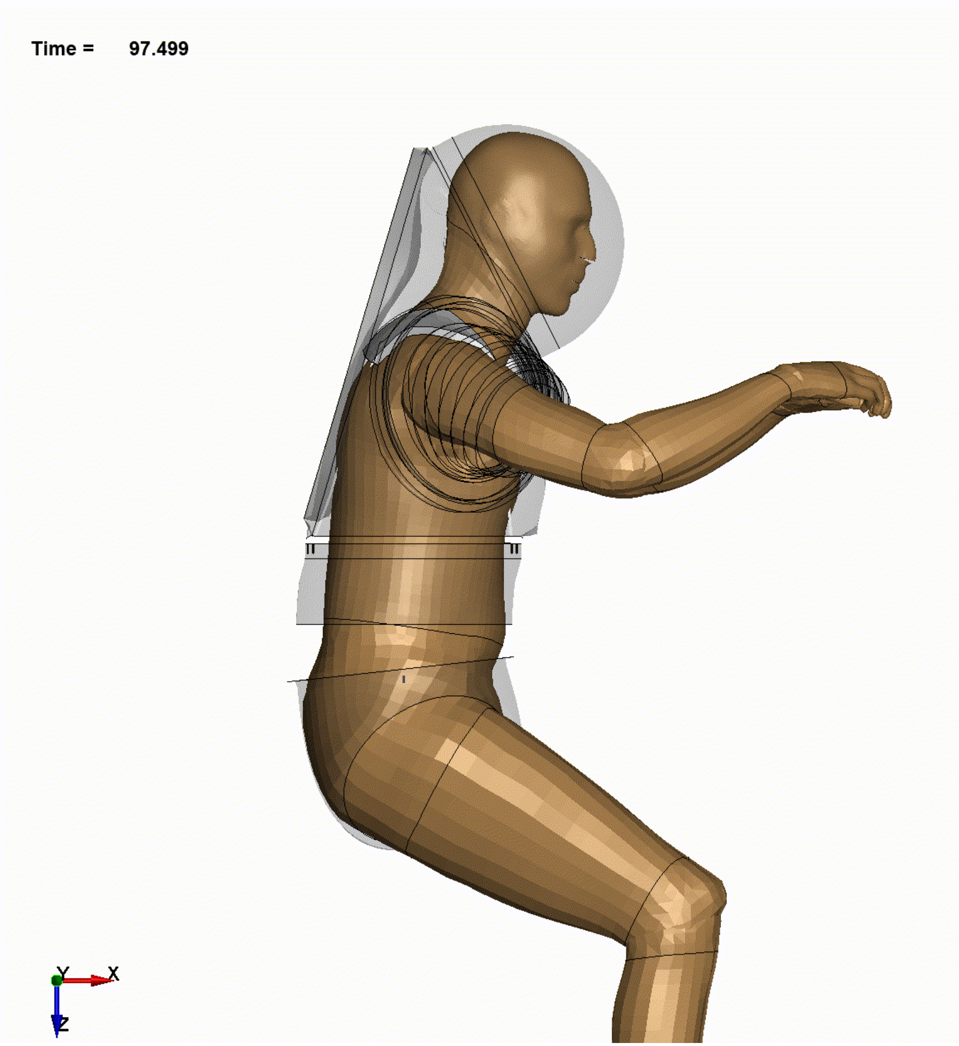
Simulations – Size Variation

Leaning post, S9



Simulations – Posture Variation

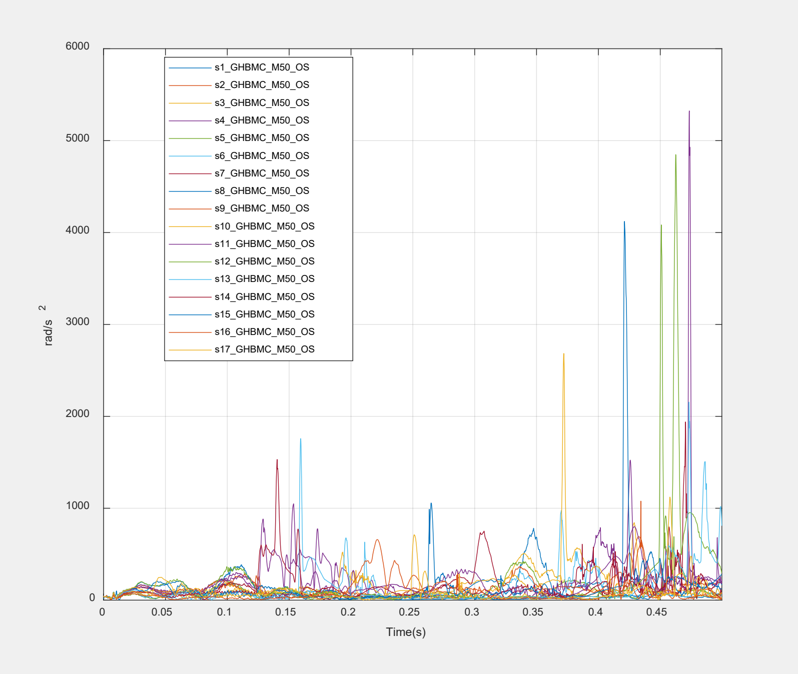




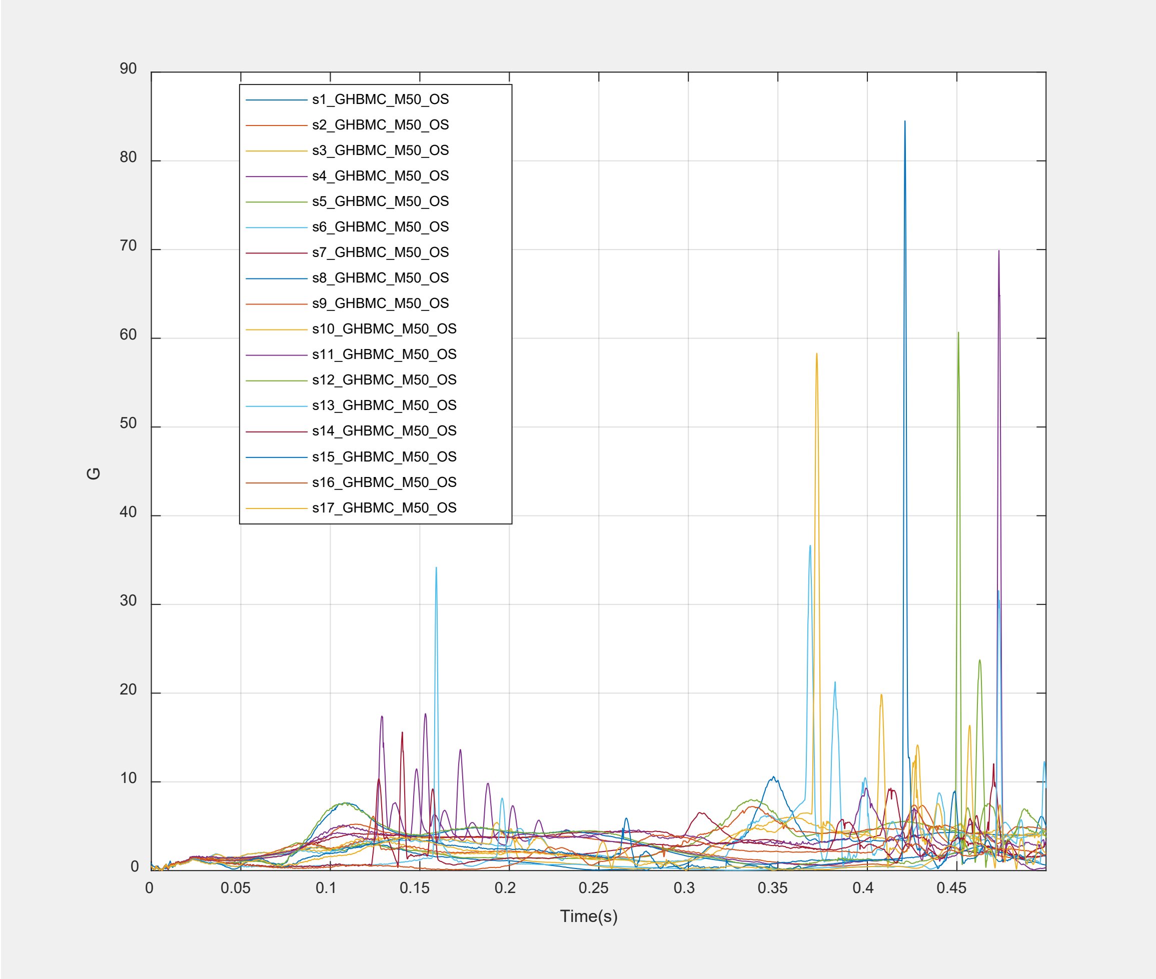
Simulation Results - General

- Very short duration head impact spikes seen when head contacts the hut
- Energy of impact relatively low

Head Rotational Acceleration – M50 Leaning Post



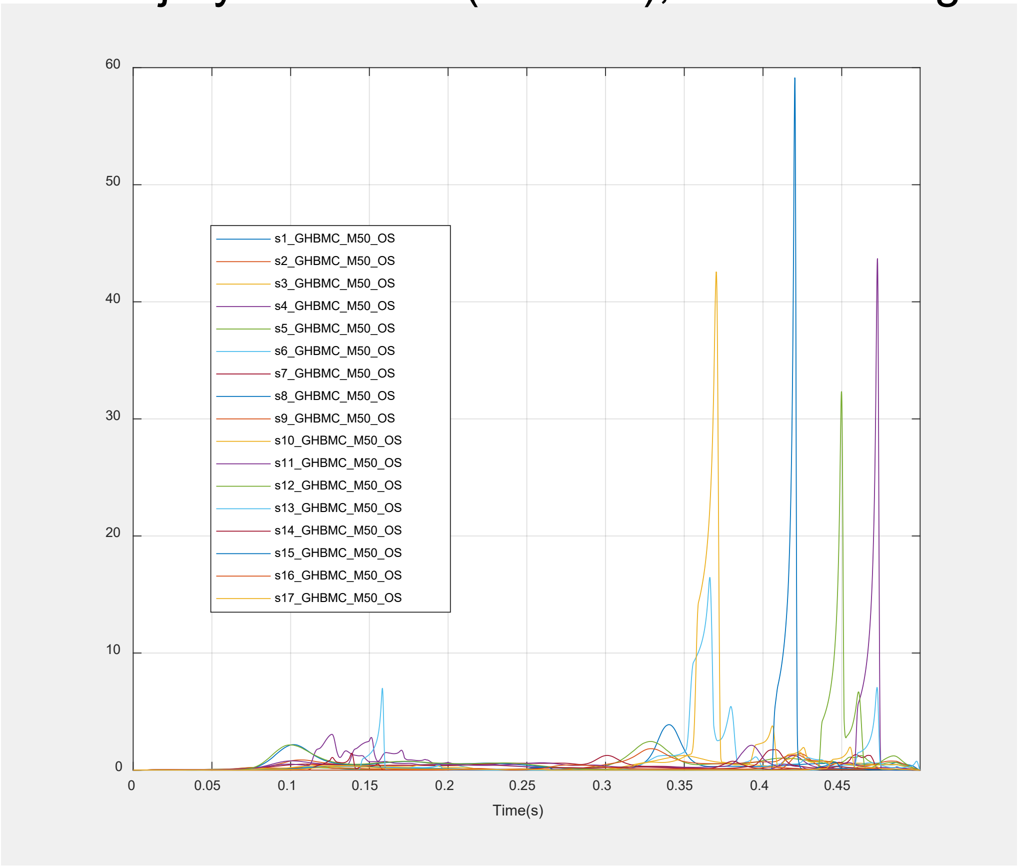
Head Acceleration – M50 Leaning Post



Simulation Results - General

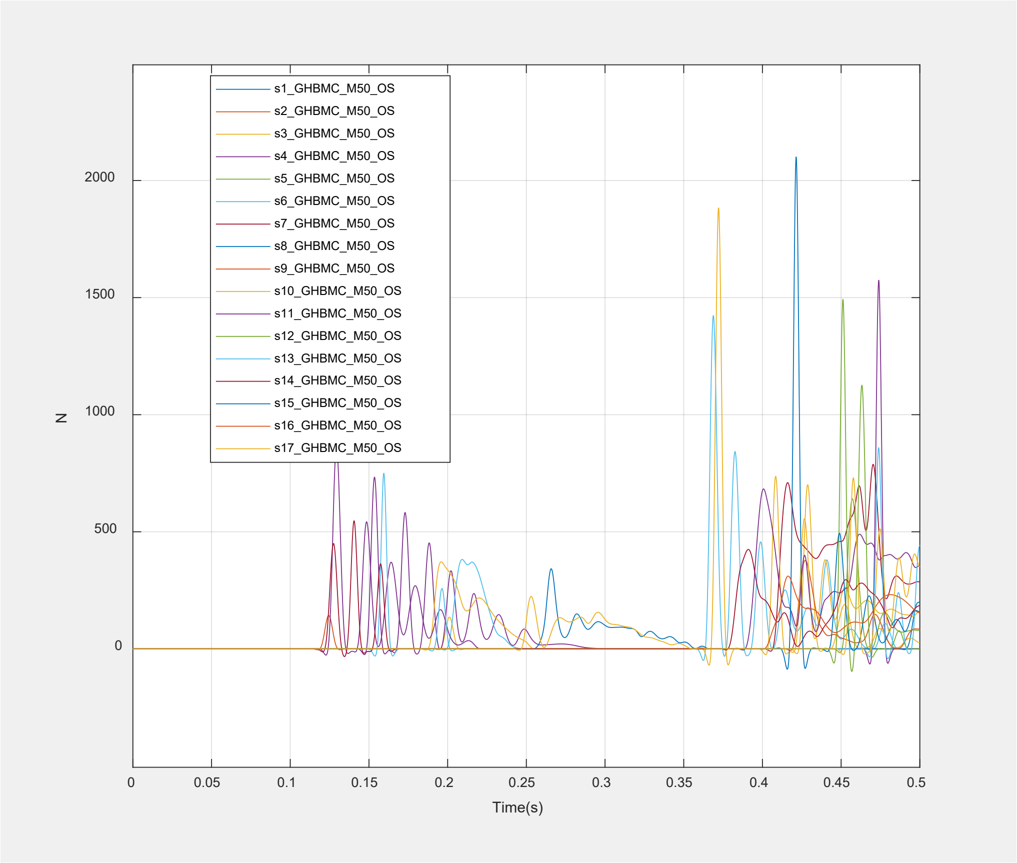
- Traditional injury metrics low in all cases, but some contact forces high

Head Injury Criterion* (unitless), M50 Leaning Post



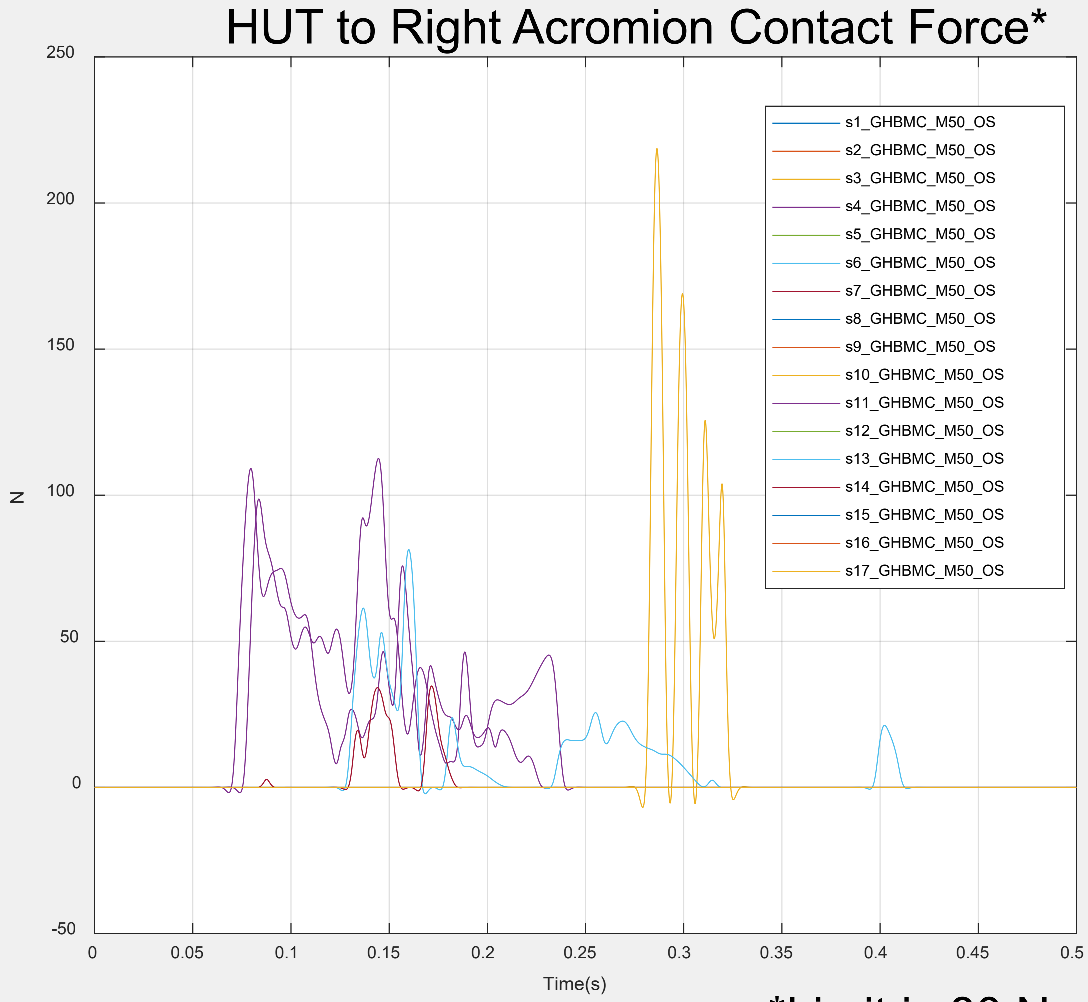
* Limit is 340

Head to HUT contact Force



Simulation Results - General

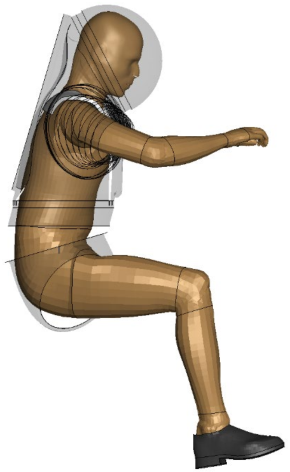
- Some simulations passed blunt trauma limits in some body parts
- Limits primarily passed in the acromions, clavicles, and scapular spines
  - F05 primarily passed in acromions and clavicles
  - M50 primarily passed in acromions, clavicles, scapular spines
  - M95 primarily passed in scapular spines

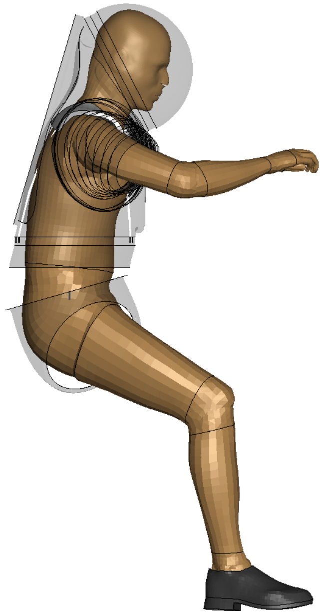


*Limit is 80 N

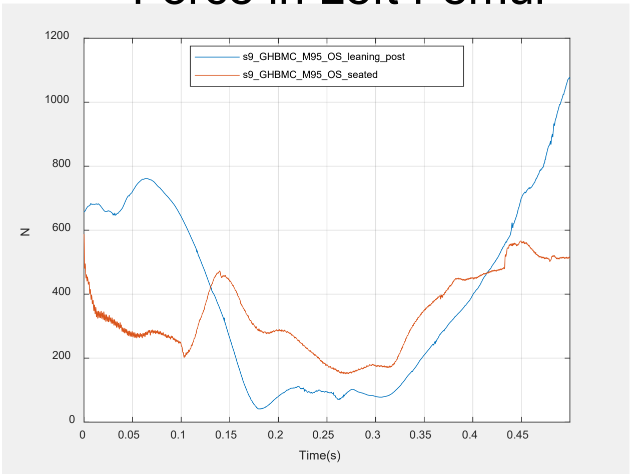
Simulation Results - Posture

- For most injury metrics, posture affected phase of responses
- Peak loads largely the same
- Position of head/torso within suit largely the same in both postures*
- Metrics in lower extremities different, but still low for all cases

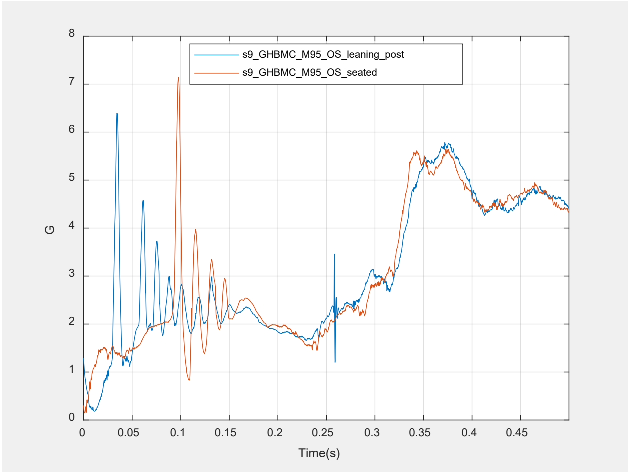




Force in Left Femur

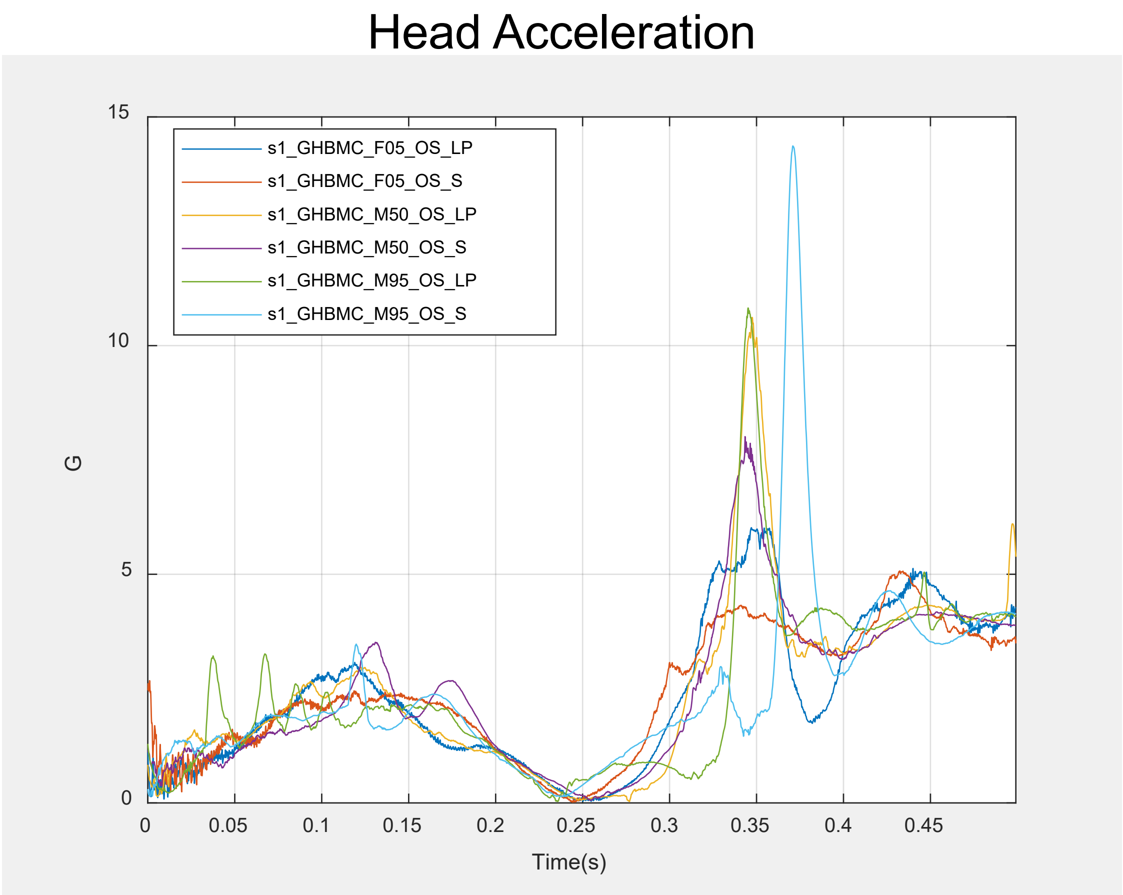


Head Acceleration



Simulation Results – Model Size

- All model sizes stayed clear of traditional injury metric limits
- M50 model showed the most cases passing blunt trauma limit
- Only three conditions did not pass any blunt trauma limit for at least one model



Limitations

- This work focused on rigid restraints only
  - May not fully capture injury risk to lower extremities
- Models used in these studies do not respond to loading with active muscle
- Elements inside of the suit other than the harness not modeled
- All cases modeled are allowable during nominal operation of the LTV
  - Off nominal cases not modeled
- Rigid suit components in other parts of the body not modeled

Limitations

- Suit/LTV designs and loading conditions not representative of Artemis
  - Techniques developed intended to be design agnostic
  - Loading conditions were all purely linear, i.e. no rotational component
- HBM sizes not all encompassing
  - HBMs can be resized to any particular size
- Model positioning idealized
- Effects of repeated events not captured by this work
  - Repetition can cause amplification
  - Repeated loading on a body part could cause injury

Conclusions

- Traditional injury metrics (e.g., head injury criterion, neck and spine loads) show a low risk of injury
- Blunt loading limits are occasionally passed
  - Limits based on half of force required to fracture the weakest clavicle in a set of cadavers
  - The clavicle was deemed to be the “weakest link” in the torso
  - Model contained no padding other than harness pad (and back pad for F05)
- Head contact forces high, but it is unclear if the short duration could be responsible for injury
  - Study on boxer punches showed similar impulse, but more head acceleration[1]
- Poorest performance relative to the blunt loading requirements seen in M50
  - Back pad in F05 model may have helped to prevent high closing velocities
- The data don’t show a preference between seated and the semi-standing posture

[1]Walilko, Timothy J., David C. Viano, and Cynthia A. Bir. "Biomechanics of the head for Olympic boxer punches to the face." *British journal of sports medicine* 39.10 (2005)

Acknowledgements

- Many people contributed to this work from across NASA
- This work was funded by the NASA Extravehicular Activity and Human Surface Mobility Program (EHP)

Questions?

- keegan.m.yates@nasa.gov