The Challenges of Out of Position Occupants for Passive Safety in Automated Vehicles

SAE Government Industry Meeting
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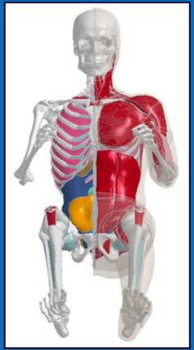
NHTSA
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Background

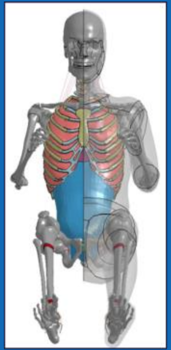
- Induced a change in occupant position
- Uncertainty in the interaction between the occupant, the restraints, and vehicle interior*

Objectives

1. Examine existing crash investigation cases for crashes that involve occupants that were not in a standard automotive seating posture.
2. Evaluate the suitability of the existing ATD and human body models to evaluate the kinematics and injury risk for occupants in other than traditional automotive seating postures.



GHBMC M50-O (detailed)



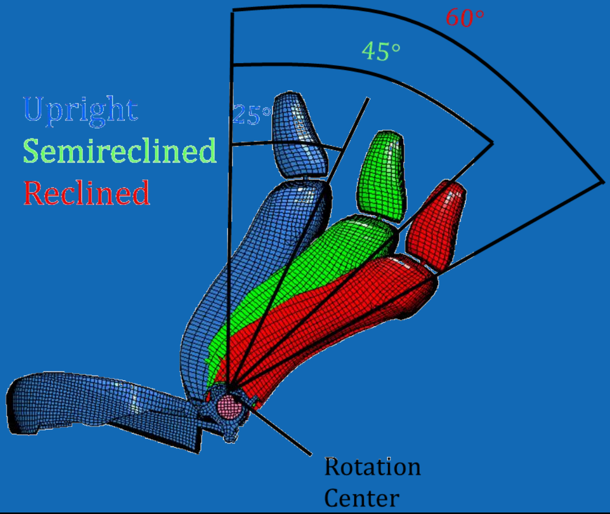
GHBMC M50-OS (simplified)

THOR FE (NTHSA)

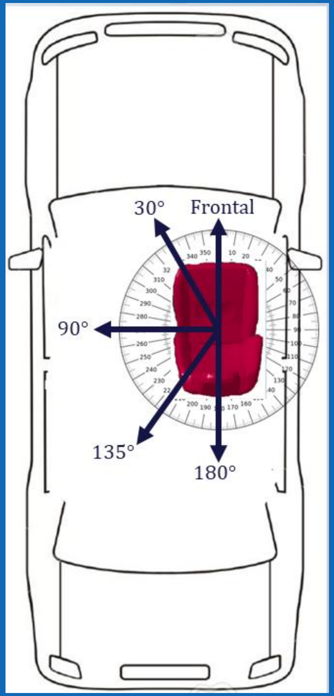
Vehicle Model

- 2012 Toyota Camry (Reicher et al., 2016).
  - Center for Collision Safety and Analysis (GMU)
  - 2.25M finite elements
  - Validated using 10 different full vehicle crash tests
- Major modifications
  - Seat recline angle (3 positions)
  - Seat orientation (5 positions)
  - Vehicle interior

2012 Toyota Camry



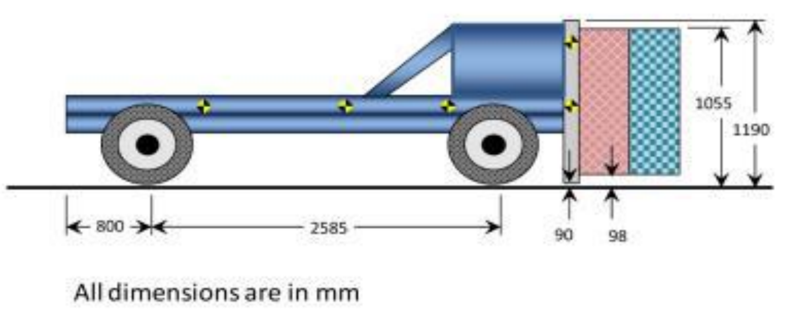
Seat recline



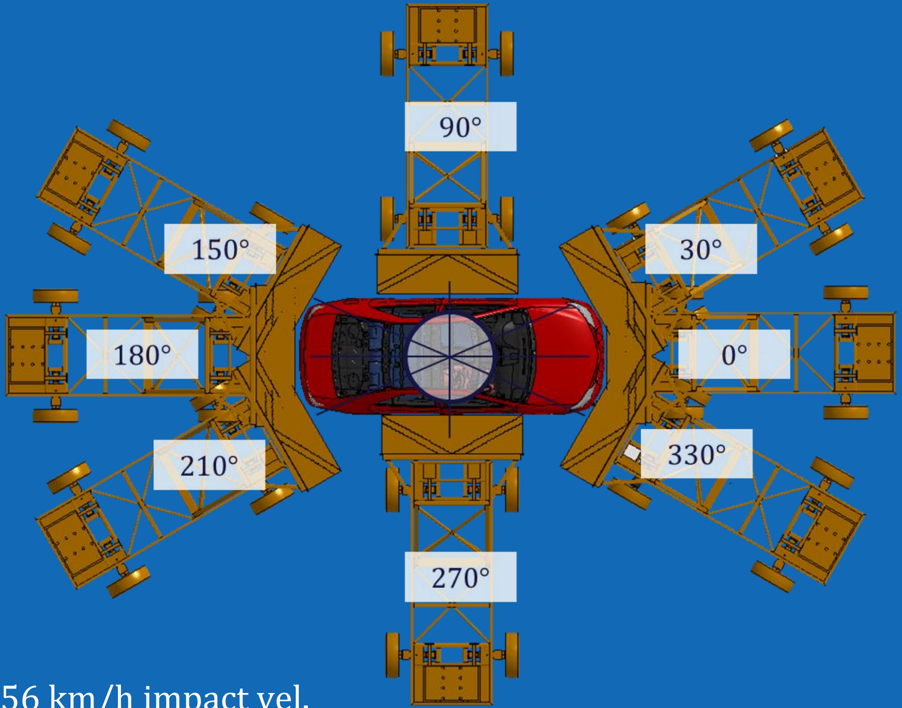
Seat orientation

Research Moving Deformable Barrier (RMDB)

- Designed for oblique and small overlap (Saunders et al., 2011)
- Easy to parameterize the multiple impacts
  - 8 crash directions evaluated
- Better simulation stability compared with rigid wall



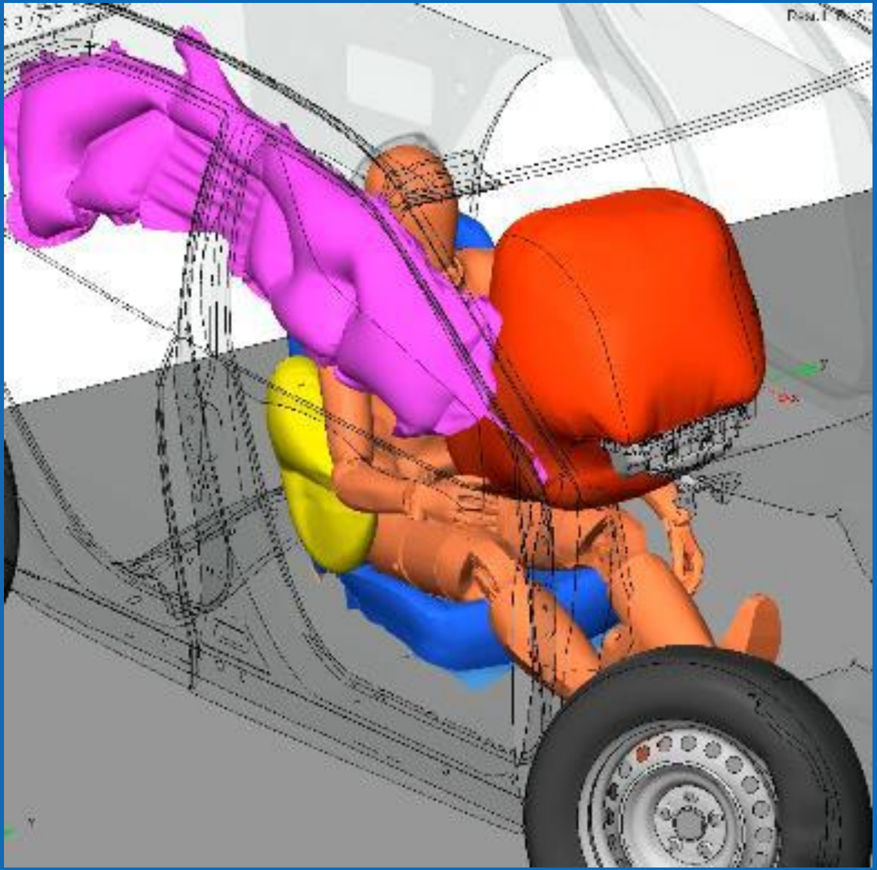
All dimensions are in mm



56 km/h impact vel.

Restraints

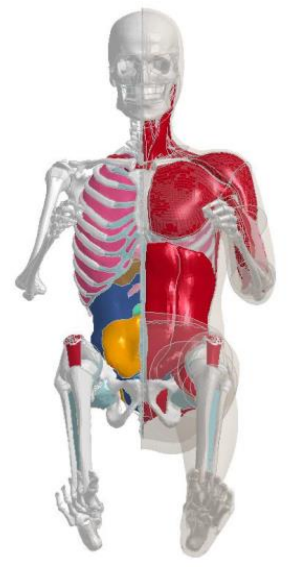
- Airbag models
  - From restrain supplier
    - Passenger airbag (PAB)
    - Curtain airbag (CAB)
    - Side airbag (SAB)
    - Trigger time t = 0ms



Occupant Models

Tissue-level criterion

Virtual instrumentation



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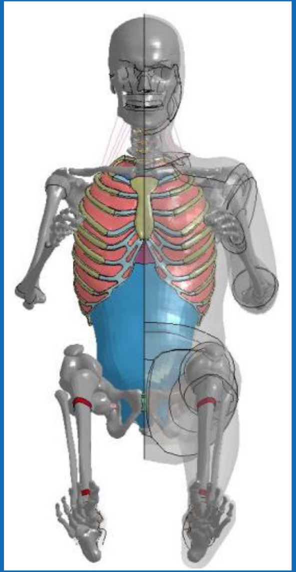


GHBMC M50-OS (simplified)

NHTSA THOR FE (v2.2_UVA)

Occupant, Seatbelt Integration

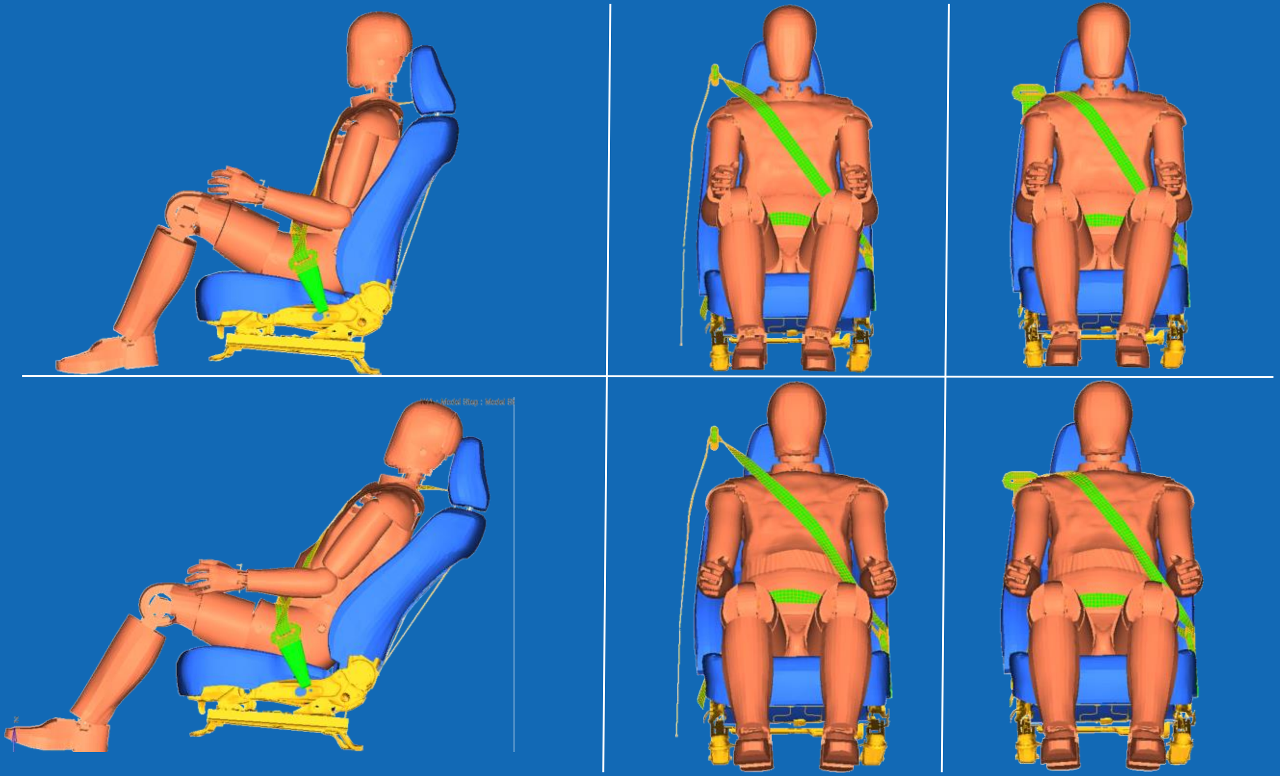
- THOR

Upright seat (25deg)

Semi-reclined seat (40deg)

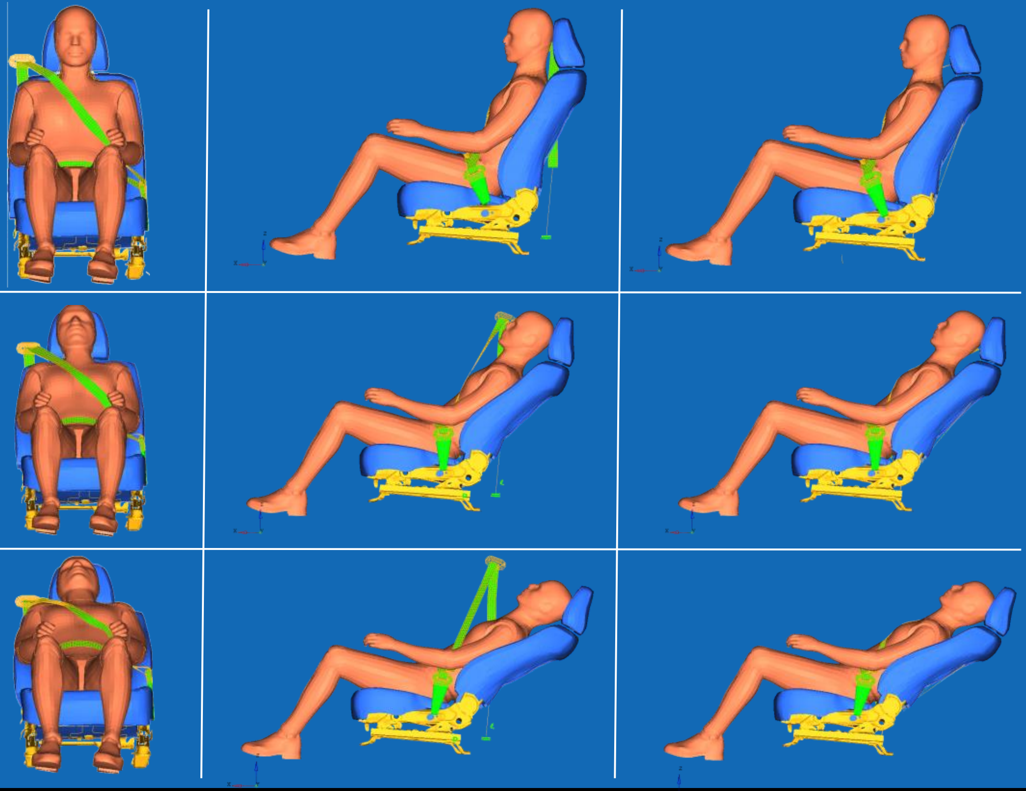
Standard belt

Integrated belt



Occupant, Seatbelt Integration

- GHBMC M50-OS/M50-O



Standard belt

Integrated belt

Upright seat (25deg)

Semi-reclined seat (45deg)

Reclined seat (60deg)

Instrumentation and Injury Assessment

Capability of injury assessment for THOR, GHBMC M50-OS and M50-O models

Injury Criteria (reference)	THOR	M50-OS	M50-O
HIC$_{15}$ (Versace, 1971)	🟩	🟩	🟩
BrIC (Takhounts, 2013)	🟩	🟩	🟩
N$_{ij}$ (Eppinger, 1999)	🟩	🟥	🟨
cN$_{ij}$ (TBD)	🟥	🟨	🟨
NIC (Bostrom, 1998)	🟥	🟨	🟨
Shoulder Load (Petitjean, 2012)	🟩	🟥	🟥
Clavicle Load (Qi, 2014)	🟥	🟩	🟨
Multi-point Thoracic Injury Criterion or PCA (Crandall, 2013)	🟩	🟨	🟩
Rib Strain (TBD)	🟥	🟩	🟩
Abdomen Compression (Kent, 2008)	🟩	🟨	🟨
Lateral Shoulder, Chest and Abdomen deflection (Petitjean, 2012)	🟥	🟨	🟨
Lumbar Spine Load (TBD)	🟥	🟨	🟨
ASIS Load (TBD)	🟩	🟥	🟨
Sacral Iliac Load (TBD)	🟥	🟨	🟨
Acetabulum Load (Martin, 2011)	🟩	🟨	🟨
Pubic Symphysis Load (Petitjean, 2012)	🟥	🟨	🟨
Femur Axial Load (Kuppa, 2001)	🟩	🟨	🟨
Revised Tibia Index (Kuppa, 2001)	🟩	🟨	🟨
Distal Tibia Axial Force (Kuppa, 2001)	🟩	🟨	🟨
Proximal Tibia Axial Force (Kuppa, 2001)	🟩	🟨	🟨

Green: The default model <u>has the required instrumentation</u> to output the injury metric;

Yellow: The default model <u>does not have the required instrumentation</u> to output the injury metric, but we added instrumentation to calculate the injury criteria

Red: The default model <u>is not capable of predicting</u> the injury metric for current modeling method;

Parametric Simulation Suite

- Vehicle/Sled input deck
  - Camry
    - 40_camry_full.k
    - 49_camry_floor.k
  - Sled
    - 31_setup_sled.k
    - 41_camry_sled.k
    - 91_seat_to_sled.k
    - 92_pab_to_sled.k
    - 93_cab_to_sled.k
    - 96a_belt_standard_to_sled.k
  - RMDB
    - 50_rmdb.k
  - System
    - 10_control.k
    - 20_database.k
    - 30_setup.k
  - Seat
    - 60_seat_GHBMC_OS_25RE.k
    - 60_seat_GHBMC_OS_45RE.k
    - 60_seat_GHBMC_OS_60RE.k
    - 60_seat_THOR_25RE.k
    - 60_seat_THOR_40RE.k
  - Occupants
    - 81a_THOR_v2.2_25deg.k
    - 81b_THOR_v2.2_40deg.k
    - 82a_GHBMC_M50-OS_v1-8-3-1_20150928_NODE_25RE.k
    - 82a_GHBMC_M50-OS_v1-8-3_sensors_25RE.k
    - 82a_GHBMC_M50_OS_v1-8-3_Main_25RE.dyn
    - 82b_GHBMC_M50-OS_v1-8-3-1_20150928_NODE_45RE.k
    - 82b_GHBMC_M50-OS_v1-8-3_sensors_45RE.k
    - 82b_GHBMC_M50_OS_v1-8-3_Main_45RE.dyn
    - 82c_GHBMC_M50-OS_v1-8-3-1_20150928_NODE_60RE.k
    - 82c_GHBMC_M50-OS_v1-8-3_sensors_60RE.k
    - 82c_GHBMC_M50_OS_v1-8-3-1_Main_60RE.dyn
    - 82_GHBMC_M50-OS_v1-8-3-1_20150928_WITHOUT_NODES_1.k
    - 82_GHBMC_M50-OS_v1-8-3-1_Encrypt.k
    - 82_GHBMC_M50-OS_v1-8-3_modification.k
    - 82_GHBMC_M50_OS-v1-8-3-1_ModelTree.k
    - 82_GHBMC_M50_OS_v1-8-3-1_control.k
    - 82_GHBMC_M50_OS_v1-8-3-1_Shoes.k
  - Restraints
    - 71_pab.k
    - 71_pab_encrypted.k
    - 72_cab.k
    - 72_cab_encrypted.k
    - 73a_sab_25RE.k
    - 73b_sab_40RE.k
    - 73c_sab_45RE.k
    - 73d_sab_60RE.k
    - 73_sab_encrypted.k
    - 74a_belt_standard_THOR_25RE.k
    - 74b_belt_standard_THOR_40RE.k
    - 74c_belt_standard_GHBMC_M50_OS_25RE.k
    - 74d_belt_standard_GHBMC_M50_OS_45RE.k
    - 74e_belt_standard_GHBMC_M50_OS_60RE.k
    - 75a_belt_integrated_THOR_25RE.k
    - 75b_belt_integrated_THOR_40RE.k
    - 75c_belt_integrated_GHBMC_M50_OS_25RE.k
    - 75d_belt_integrated_GHBMC_M50_OS_45RE.k
    - 75e_belt_integrated_GHBMC_M50_OS_60RE.k
  - Interactions
    - 91_seat_to_floor.k
    - 92_pab_to_camry.k
    - 93_cab_to_camry.k
    - 94_sab_to_camry.k
    - 95_floor_to_camry.k
    - 96a_belt_standard_to_camry.k
    - 96b_belt_integrated_to_camry.k

Post-processing-Data structure

477 channels

GHBMCOS.mat

THOR.mat

GHBMC.mat

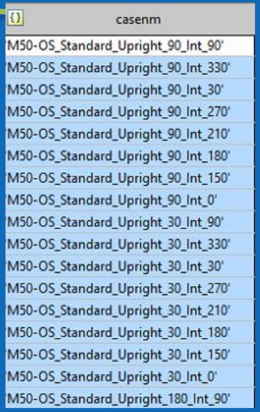
case name

acceleration

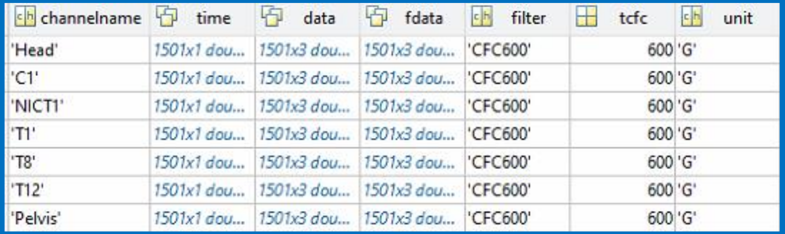
angular rate

force

moment



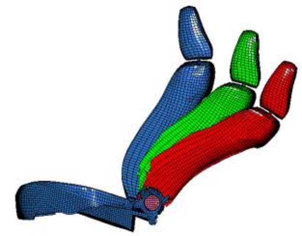
casenm
'M50-OS_Standard_Upright_90_Int_90'
'M50-OS_Standard_Upright_90_Int_330'
'M50-OS_Standard_Upright_90_Int_30'
'M50-OS_Standard_Upright_90_Int_270'
'M50-OS_Standard_Upright_90_Int_210'
'M50-OS_Standard_Upright_90_Int_180'
'M50-OS_Standard_Upright_90_Int_150'
'M50-OS_Standard_Upright_90_Int_0'
'M50-OS_Standard_Upright_30_Int_90'
'M50-OS_Standard_Upright_30_Int_330'
'M50-OS_Standard_Upright_30_Int_30'
'M50-OS_Standard_Upright_30_Int_270'
'M50-OS_Standard_Upright_30_Int_210'
'M50-OS_Standard_Upright_30_Int_180'
'M50-OS_Standard_Upright_30_Int_150'
'M50-OS_Standard_Upright_30_Int_0'
'M50-OS_Standard_Upright_180_Int_90'

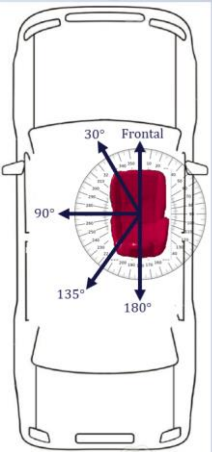


channelname	time	data	fdata	filter	tcfc	unit
'Head'	1501x1 dou...	1501x3 dou...	1501x3 dou...	'CFC600'	600	'G'
'C1'	1501x1 dou...	1501x3 dou...	1501x3 dou...	'CFC600'	600	'G'
'NICT1'	1501x1 dou...	1501x3 dou...	1501x3 dou...	'CFC600'	600	'G'
'T1'	1501x1 dou...	1501x3 dou...	1501x3 dou...	'CFC600'	600	'G'
'T8'	1501x1 dou...	1501x3 dou...	1501x3 dou...	'CFC600'	600	'G'
'T12'	1501x1 dou...	1501x3 dou...	1501x3 dou...	'CFC600'	600	'G'
'Pelvis'	1501x1 dou...	1501x3 dou...	1501x3 dou...	'CFC600'	600	'G'

Automated Vehicle Evaluation Plan

- Study A: Effects of reclining the seat
- Study B: Effects of seat orientation
- Study C: Effects of a turned occupant
- Study D: Effects of having an occupant sleeping on the belt path
- Study E: Effects of having an occupant seated far back from the instrument panel





Simulation Summary

- **175** full vehicle simulations + positioning simulations
- **800,000** core hours of CPU time to run (11 years / 8core machine)
- Output of **477 x 175** channels of instrumentation data
- Output of **3 x 175** videos of the simulations

Termination Results Summary

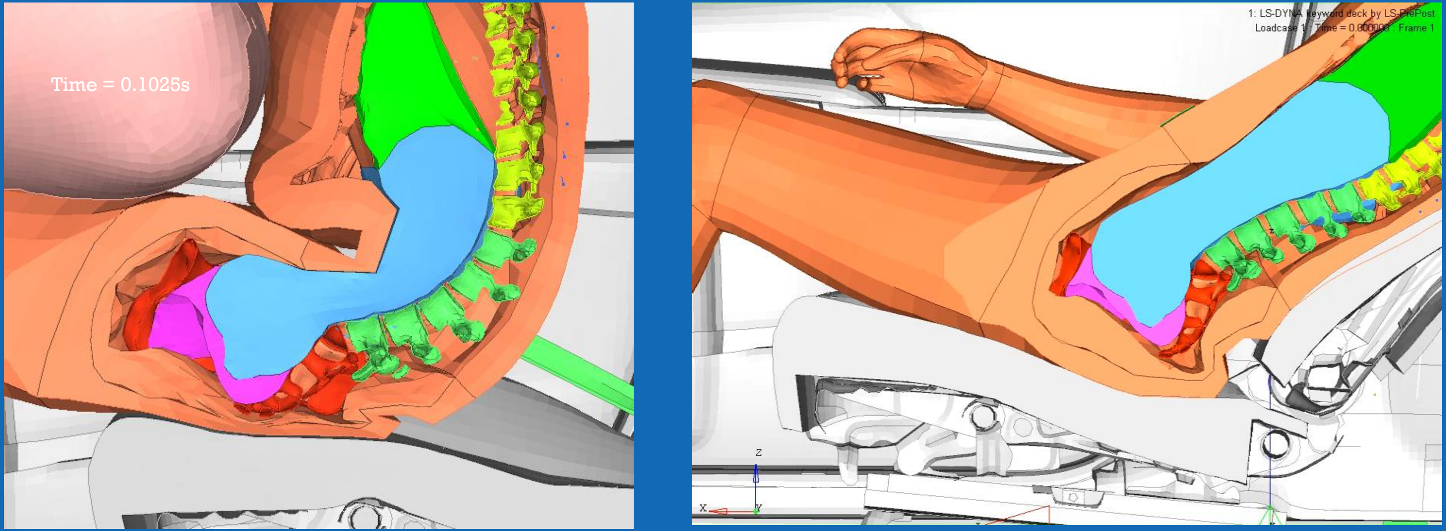
- **158 of 175 simulations terminated successfully**
- **Of the 17 simulations in error**
  - **7/67 for THOR,**
  - **3/95 for M50-OS,**
  - **7/13 for M50-O.**

Error report

Occupant model	Part responsible
THOR	Abdominal block
	Jacket
	Upper AB Foam
M50-OS	Thigh
	Sacroiliac joint
M50-O	Pelvis
	Neck muscle
	Foot skin
	Abdomen muscle

Outstanding Issues for M50-OS

- Unrealistic flesh sliding off of the pelvis

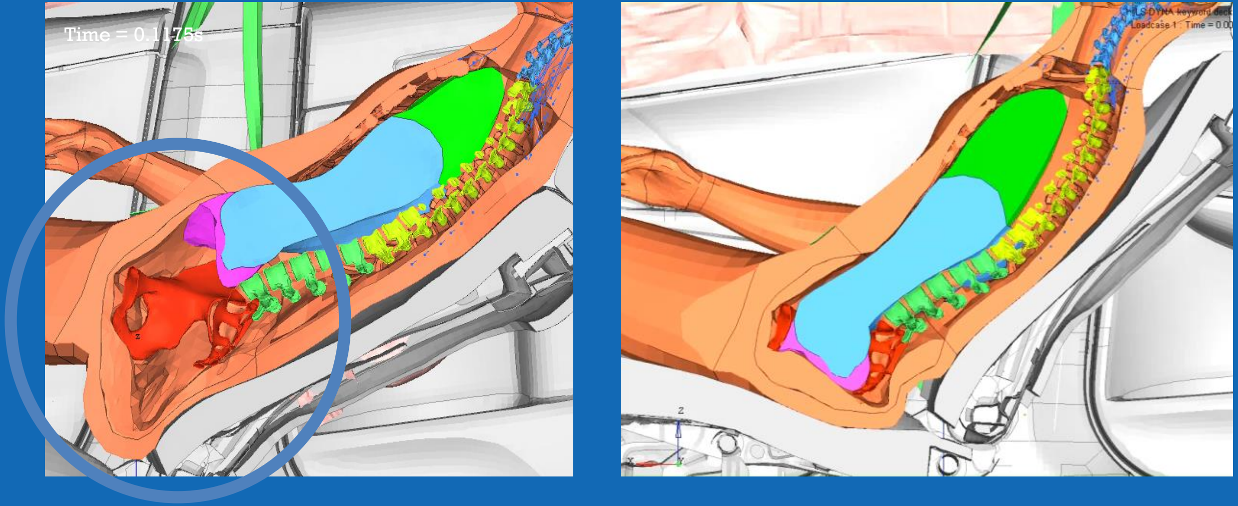


Reclined M50-OS, standard seatbelt, frontal impact

Note:
Substantial shear force resulting in the sliding over and around the pelvis. This has a substantial effect on submarining response.

Outstanding Issues for M50-OS

- Unrealistic internal organ response and flesh response
- Failure to maintain internal cavity volume



Semi-reclined M50-OS, standard seatbelt, rear impact

Note:

- M50-OS model lacks a continuity definition between flesh, skeleton and underlying organs.
- Pelvis flesh stuck in the crease between seat cushion and back deformed a lot.

Lessons Learned (simulation study)

- Positioning seat in vehicle
- Occupant fit for non-frontal facing

} Interference issues – non-trivial

Positioning

- ▶ GHBMC-M50 spine too stiff for natural settling
- ▶ GHBMC-M50-O is stiffer than M50-OS during positioning
- ▶ THOR cannot go fully reclined (only ~40 deg) – Dummy design issue

Stability

- ▶ GHBMC_M50_OS abdomen causing negative volume
- ▶ Unrealistic internal cavity organs' connection for GHBMC_M50_OS
- ▶ THOR face flesh deforms substantially during simulation
- ▶ M50-OS is more stable than THOR FE
- ▶ Non reinforced seatback deforms under rear impact

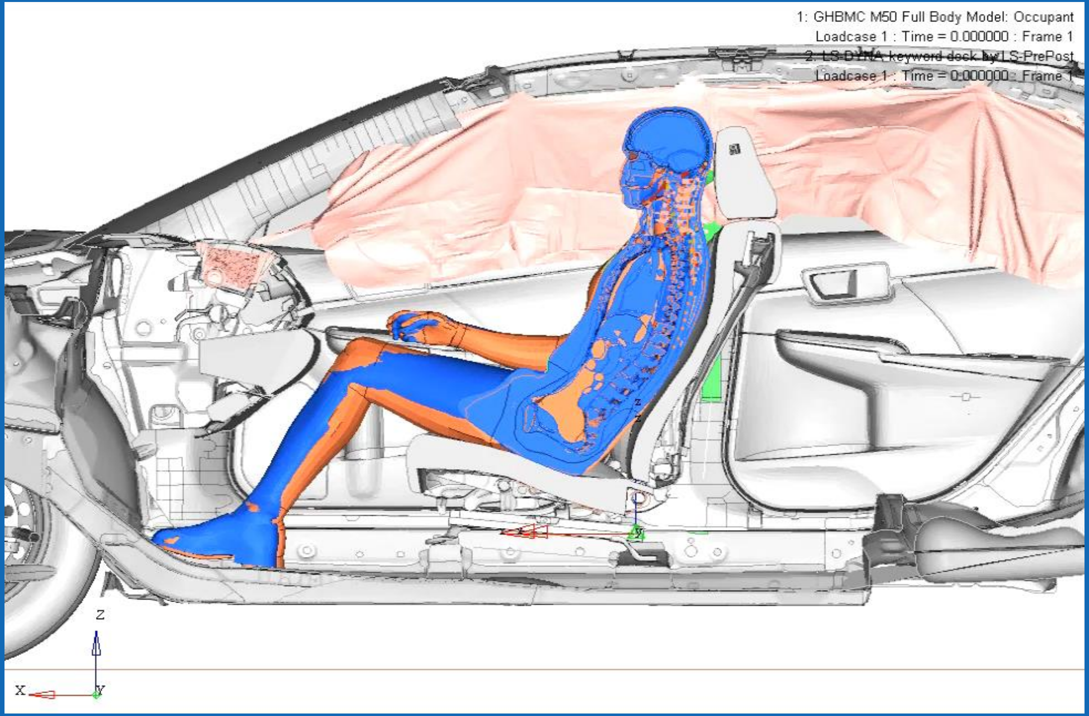
Forward-facing, upright seat with standard seat belt, frontal impact

Comparison between M50-OS and M50-O

━ M50-O

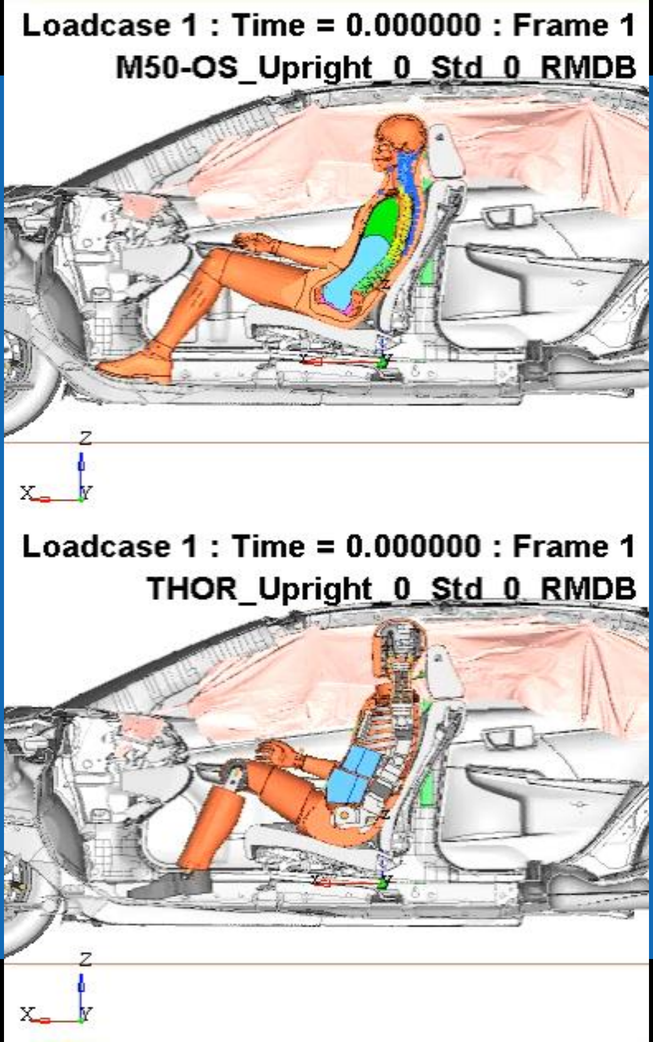
━ M50-OS

- Neck flexion →M50-O has larger neck flexion compared with M50-OS.
- Pelvis kinematics→M50-OS slides forward, tilts back more than M50-O.



Forward-facing, upright seat with standard seat belt, frontal impact

- M50-OS has larger flexion in the thoracic spine, and engages PAB
- M50-OS engages knee bolster earlier (initial position and longer thighs)
- THOR does not engage PAB well, and has large cervical spine flexion as a result
- THOR pelvis has less motion than M50-OS
- THOR head hits roof at windshield



Forward-facing, semi-reclined with integrated belt, frontal impact

Comparison between M50-OS and M50-O

— M50-O

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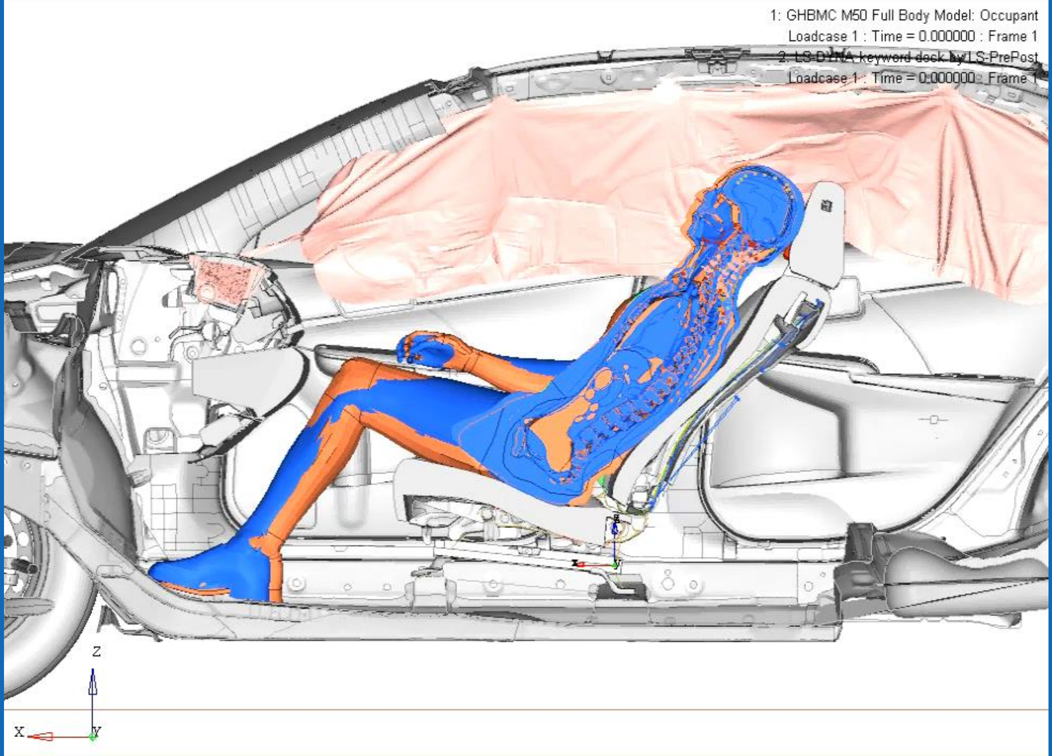
- Neck flexion →M50-O has larger neck flexion compared with M50-OS.
- Pelvis kinematics→M50-OS slides forward, tilts back more than M50-O.



Forward-facing, semi-reclined with integrated belt, frontal impact

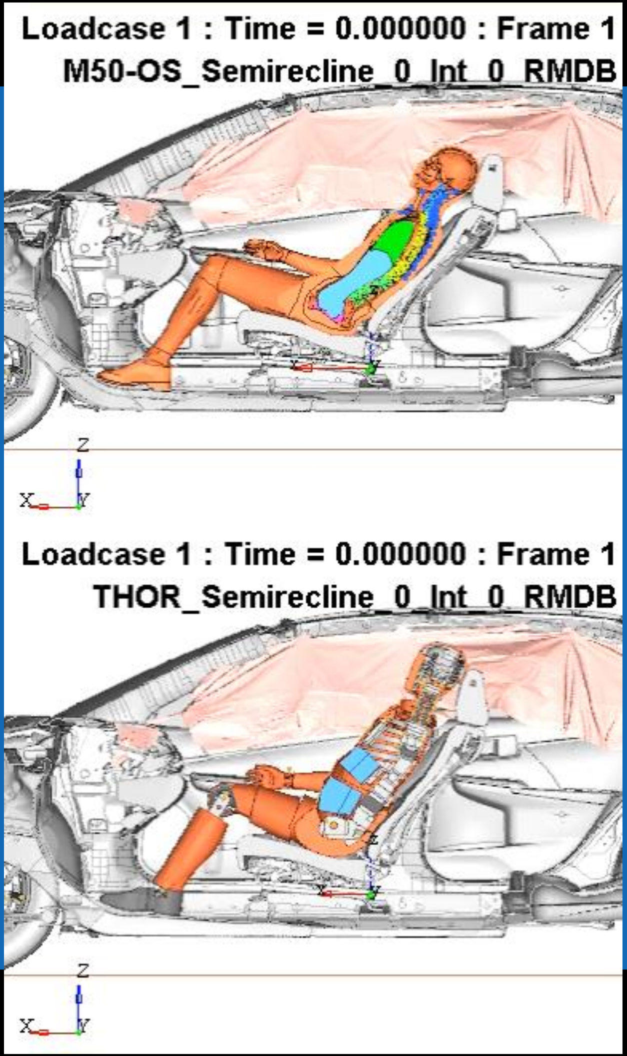
- THOR semi-reclined: 40°
- M50-OS semi-reclined: 45°

- M50-OS engages knee bolster earlier (initial position and longer thighs)

- Neither model engages PAB well

- THOR has larger cervical spine flexion compared to M50-OS

- THOR pelvis has less motion than M50-OS



Forward-facing, reclined seat with integrated belt, frontal impact

Comparison between M50-OS and M50-O

— M50-O

— M50-OS

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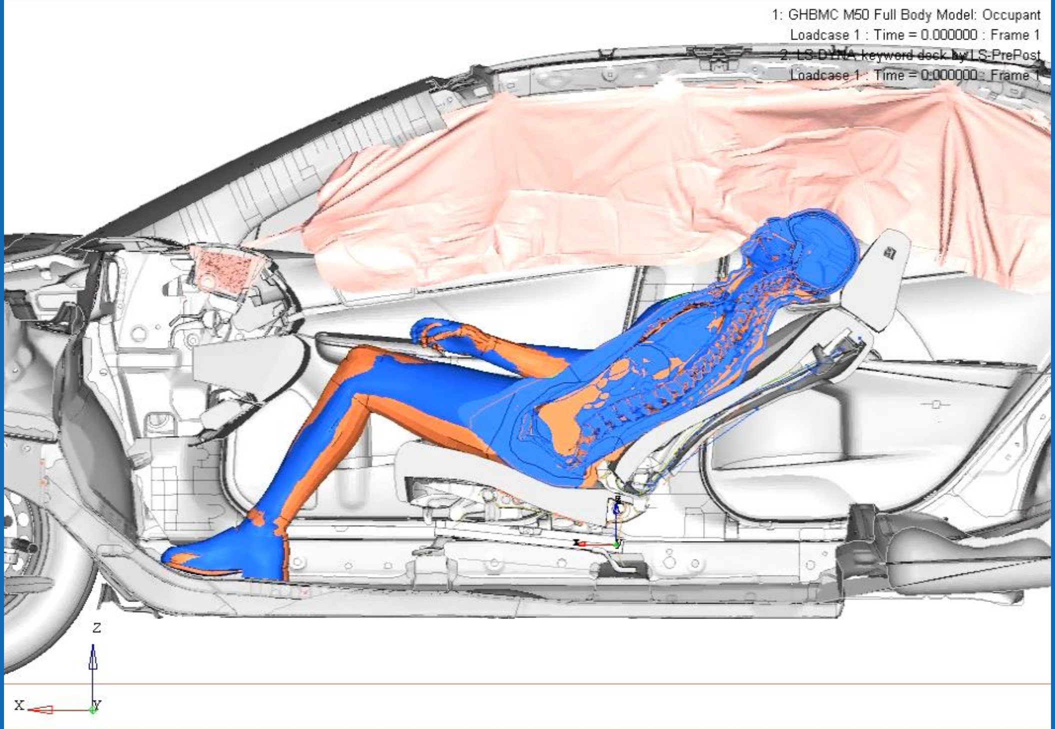
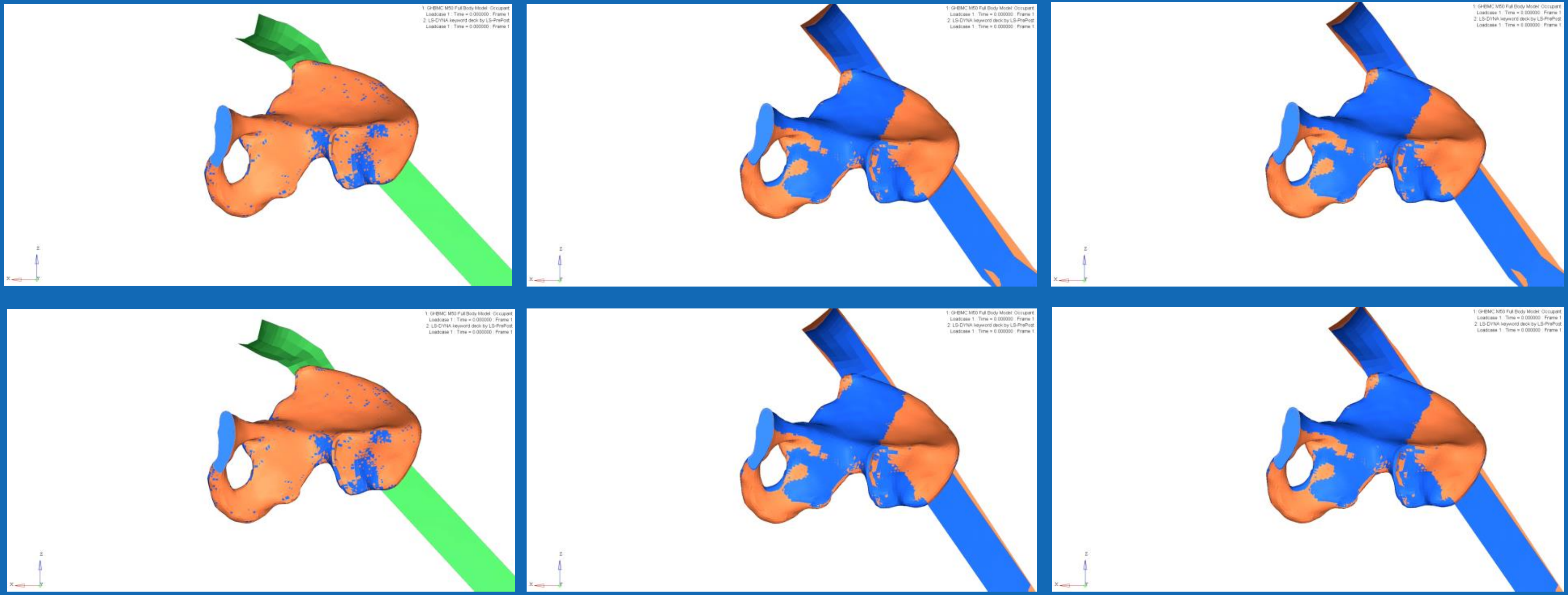


Pelvis Motion and Submarining Response - M50-OS vs M50-O



M50-O

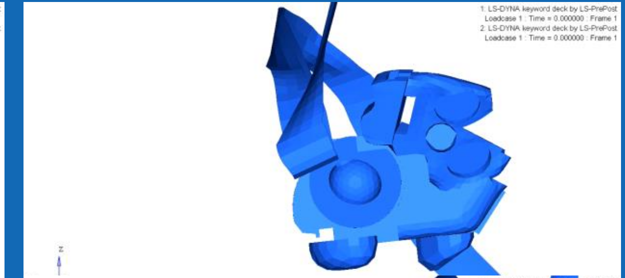
M50-OS

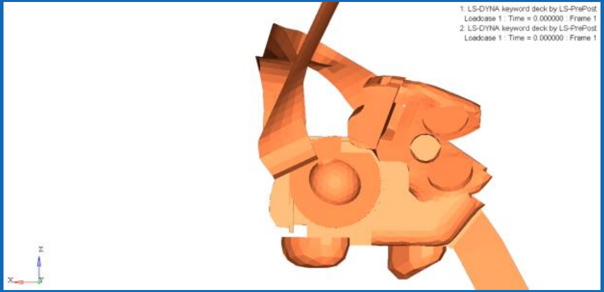
Pelvis Motion and Submarining Response - M50-OS vs M50-O vs THOR

Upright seat (25deg)

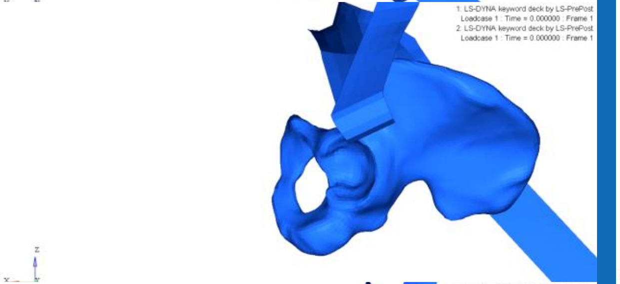
Semi-reclined seat (45deg)

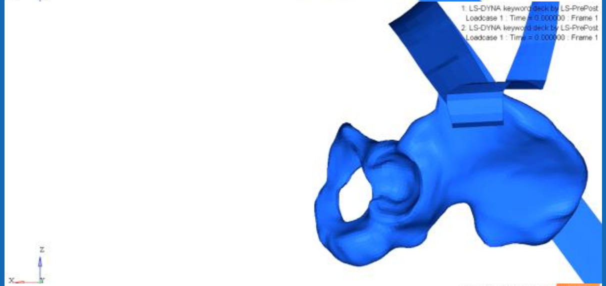
THOR



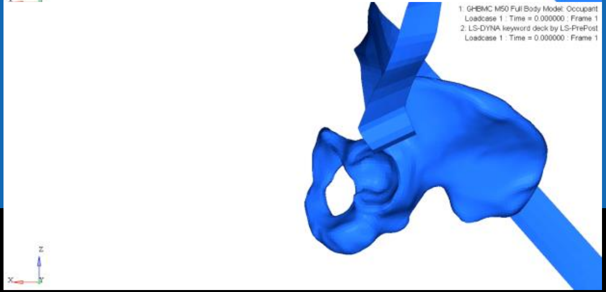


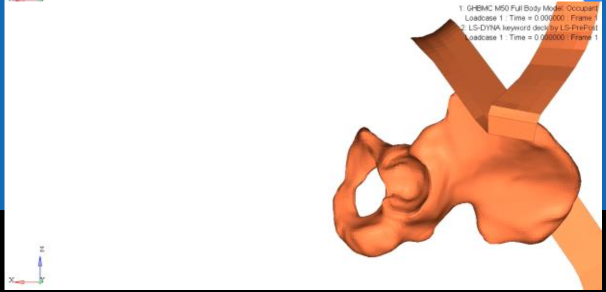
M50-OS





M50-O





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Positioning

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- THOR cannot go fully reclined (only ~40 deg) – Dummy design issue

Stability

- GHBMC_M50_OS abdomen causing negative volume
- Unrealistic internal cavity organs' connection for GHBMC_M50_OS
- THOR face flesh deforms substantially during simulation
- M50-OS is more stable than THOR FE
- Non reinforced seatback deforms under rear impact

Restraint

- THOR FE pelvis rotates opposite direction compared to GHBMC (frontal impact)
- GHBMC-OS shows greater lap belt penetration into abdomen than GHBMC-O

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