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

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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.
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
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

56 km/h impact vel.
Restraints

- Airbag models
  - From restrain supplier
- Passenger airbag (PAB)
- Curtain airbag (CAB)
- Side airbag (SAB)
- Trigger time $t = 0\text{ms}$
Occupant Models

Tissue-level criterion

- GHBMCM50-O (detailed)
- GHBMCM50-OS (simplified)

Virtual instrumentation

- NHTSA THOR FE (v2.2_UVA)
Occupant, Seatbelt Integration

- THOR

- Upright seat (25deg)

- Semi-reclined seat (40deg)

<table>
<thead>
<tr>
<th>Standard belt</th>
<th>Integrated belt</th>
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Occupant, Seatbelt Integration

- GHBMC M50-OS/M50-O

<table>
<thead>
<tr>
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<tr>
<td>Upright seat (25deg)</td>
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<td>Semi-reclined seat (45deg)</td>
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<td>Reclined seat (60deg)</td>
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</table>
## Instrumentation and Injury Assessment

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

<table>
<thead>
<tr>
<th>Injury Criteria (reference)</th>
<th>THOR</th>
<th>M50-OS</th>
<th>M50-O</th>
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<tbody>
<tr>
<td>HIC&lt;sub&gt;13&lt;/sub&gt; (Versace, 1971)</td>
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<td>BrIC (Takounts, 2013)</td>
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<td>N&lt;sub&gt;i&lt;/sub&gt; (Eppinger, 1999)</td>
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<td>cN&lt;sub&gt;i&lt;/sub&gt; (TBD)</td>
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<td>NIC (Bostrom, 1998)</td>
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<td>Shoulder Load (Petitjean, 2012)</td>
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<td>Clavicle Load (Qi, 2014)</td>
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<tr>
<td>Multi-point Thoracic Injury Criterion or PCA</td>
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<tr>
<td>Rib Strain (TBD)</td>
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<tr>
<td>Abdomen Compression (Kent, 2008)</td>
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<tr>
<td>Lateral Shoulder, Chest and Abdomen deflection (Petitjean, 2012)</td>
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<tr>
<td>Lumbar Spine Load (TBD)</td>
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<td>ASIS Load (TBD)</td>
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<tr>
<td>Sacral Iliac Load (TBD)</td>
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<td>✨</td>
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<tr>
<td>Acetabulum Load (Martin, 2011)</td>
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<tr>
<td>Pubic Symphysis Load (Petitjean, 2012)</td>
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<tr>
<td>Femur Axial Load (Kuppa, 2001)</td>
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<tr>
<td>Revised Tibia Index (Kuppa, 2001)</td>
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<td>✨</td>
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<tr>
<td>Distal Tibia Axial Force (Kuppa, 2001)</td>
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<tr>
<td>Proximal Tibia Axial Force (Kuppa, 2001)</td>
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</table>

- **Green**: The default model has the **required instrumentation** to output the injury metric;
- **Yellow**: The default model does not have the **required instrumentation** to output the injury metric, but we added instrumentation to calculate the injury criteria
- **Red**: The default model is not capable of predicting the injury metric for current modeling method;
Post-processing Data structure

477 channels

- GHBM COS.mat
- THOR.mat
- GH BMC.mat

- case name
- acceleration
- angular rate
- force
- moment

- Table showing channel names, time, data, filter, and unit for different cases.
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 / 8-core 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.

<table>
<thead>
<tr>
<th>Error report</th>
<th>Part responsible</th>
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</thead>
<tbody>
<tr>
<td><strong>Occupant model</strong></td>
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<tr>
<td>THOR</td>
<td>Abdominal block</td>
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<tr>
<td></td>
<td>Jacket</td>
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<tr>
<td></td>
<td>Upper AB Foam</td>
</tr>
<tr>
<td>M50-OS</td>
<td>Thigh</td>
</tr>
<tr>
<td></td>
<td>Sacroiliac joint</td>
</tr>
<tr>
<td>M50-O</td>
<td>Pelvis</td>
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<tr>
<td></td>
<td>Neck muscle</td>
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<tr>
<td></td>
<td>Foot skin</td>
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<tr>
<td></td>
<td>Abdomen muscle</td>
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</tbody>
</table>
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

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.

Semi-reclined M50-OS, standard seatbelt, rear impact
Lessons Learned (simulation study)

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

Interference issues – non-trivial

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

Stability
- GH BMC_M50_OS abdomen causing negative volume
- Unrealistic internal cavity organs’ connection for GH BMC_M50_OS
- TH OR face flesh deforms substantially during simulation
- M50-OS is more stable than TH OR 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

- 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

- Neck flexion \(\rightarrow\) M50-O has larger neck flexion compared with M50-OS.
- Pelvis kinematics \(\rightarrow\) 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**

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

Upright seat (25deg) | Semi-reclined seat (45deg) | Reclined seat (60deg)

Standard Belt

Integrated Belt

M50-O | M50-OS

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

Upright seat (25deg)

Semi-reclined seat (45deg)
Lessons Learned (simulation study)

- Positioning seat in vehicle
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- 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

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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