Initial Observations of Human Surrogate Response in Forward-facing Reclined Seats

Lauren Wood Zaseck, PhD
University of Michigan Transportation Institute

John Humm, PhD
Medical College of Wisconsin
Project Background

- Current safety standards are based on occupants seated in standard posture (~24° recline)
- Improvements to seats and restraint systems may be needed to ensure good protection for people in alternative postures
Project Organization and Participants

- NHTSA-funded frontal impact tests on PMHS with a focus on highly reclined occupants
- Primary outcome: cohesive dataset that can be used for future validation of ATDs and human body models
Subject Instrumentation

- Whole body kinematics
- Spine, head, pelvis, lower extremity accelerations and angular rotations
- Chest deflection
- Subject surface scans
Test Rigs

UMTRI
- Open seat back allowing for recline up to 90 degrees
- Simulated integrated restraints

MCW

SAE International®
Government/Industry Digital Summit
Seating Environment

• Controlled-response seat with seat pan and anti-submarining ramp (from Uriot et al., 2015)
• Mimics response of production seats but is well characterized, and easily reproduced and modeled
**Test Matrix**

<table>
<thead>
<tr>
<th>Number of Tests</th>
<th>Delta V (kph)</th>
<th>Seat Back Angle (deg)</th>
<th>Restraint Configuration</th>
<th>Knee Bolster</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>32</td>
<td>25</td>
<td>Baseline</td>
<td>Out of contact</td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>25</td>
<td>Baseline</td>
<td>Out of contact</td>
</tr>
<tr>
<td>3</td>
<td>32</td>
<td>45</td>
<td>Baseline</td>
<td>Out of contact</td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>45</td>
<td>Baseline</td>
<td>Out of contact</td>
</tr>
<tr>
<td>3</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>3</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>3</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>3</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

- MCW also conducting low speed (15 kph) tests on each PMHS prior to 32/56 kph tests
- Remainder of test matrix determined after completion of first 12 tests
Subject Positioning

• Based on UMTRI volunteer study (Reed et al., 2019)
  • 24 men and women
  • laboratory mockup
  • 4 seat back angles (23, 33, 43, 53 deg)
  • sitter-selected head support
  • posture measurement using FARO Arm
Subject Positioning

• Posture Prediction:
  • Statistical modeling of torso posture

• Inputs:
  • Stature
  • Erect Sitting Height
  • Body Weight
  • Seat Back Angle

• Outputs:
  • Head and torso landmarks
  • Torso joint center locations
  • Pelvis angle
### Subject Positioning

#### Variable Positioning

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis Segment Angle (deg)</td>
<td>Sideview angle of vector from hip joint to L5/S1 joint wrt vertical</td>
<td>84.8 - 1.37 BMI + 0.331 BA</td>
</tr>
<tr>
<td>Thorax Segment Angle (deg)</td>
<td>Sideview angle of vector from T12/L1 joint to C7/T1 joint wrt vertical</td>
<td>8.8 - 0.670 BMI + 0.919 BA</td>
</tr>
<tr>
<td>Head Segment Angle (deg)</td>
<td>Sideview angle of vector from tragion to infraorbitale wrt horizontal</td>
<td>-31.6 + 0.584 BMI + 0.907 BA</td>
</tr>
<tr>
<td>Knee Spacing (mm)</td>
<td>Lateral distance between suprapatellar landmarks</td>
<td>-459 + 0.35 Stature + 6.0 BMI</td>
</tr>
</tbody>
</table>

*BA = back angle*
50th Percentile Male, Initial Observations

• Two tests conducted at UMTRI to date

AV2003 - 32 kph, 25° recline

AV2002 - 32 kph, 45° recline

Warning: graphic body imagery
50th Percentile Male, Initial Observations

- Two tests conducted at UMTRI to date

<table>
<thead>
<tr>
<th>Test Reference ID</th>
<th>AV2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Male</td>
</tr>
<tr>
<td>Age</td>
<td>72</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>174.2</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>64.4</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>21.2</td>
</tr>
<tr>
<td>Cause of Death</td>
<td>COPD, Anemia</td>
</tr>
<tr>
<td>Skeletal anomalies:</td>
<td>C6/C7 spinal fusion, right forearm to hand missing postmortem</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Reference ID</th>
<th>AV2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Male</td>
</tr>
<tr>
<td>Age</td>
<td>91</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>174.9</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>76.1</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.9</td>
</tr>
<tr>
<td>Cause of Death</td>
<td>End stage heart failure, GI bleed, renal failure</td>
</tr>
</tbody>
</table>
50th Percentile Male, Initial Observations: Videos

Warning: graphic body imagery
50th Percentile Male, Initial Observations: Kinematics

25° recline

45° recline

Warning: graphic body imagery
### 50th Percentile Male, Initial Observations: Kinematics

**25° recline**

25° recline

---

**45° recline**

45° recline

<table>
<thead>
<tr>
<th>Max Translation (mm)</th>
<th>X</th>
<th>Z</th>
<th>X</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head CG</td>
<td>369.7</td>
<td>232.5</td>
<td>397.5</td>
<td>125.3</td>
</tr>
<tr>
<td>Sternum</td>
<td>120.3</td>
<td>52.4</td>
<td>154.1</td>
<td>90.0</td>
</tr>
<tr>
<td>T1</td>
<td>231.4</td>
<td>5.7</td>
<td>211.5</td>
<td>53.5</td>
</tr>
<tr>
<td>T8</td>
<td>148.5</td>
<td>3.7</td>
<td>169.0</td>
<td>47.8</td>
</tr>
<tr>
<td>T12</td>
<td>110.1</td>
<td>8.8</td>
<td>159.9</td>
<td>56.3</td>
</tr>
<tr>
<td>L4</td>
<td>91.0</td>
<td>20.0</td>
<td>127.8</td>
<td>20.7</td>
</tr>
<tr>
<td>Right Hip Joint</td>
<td>100.1</td>
<td>8.4</td>
<td>190.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Right Mid Femur</td>
<td>103.4</td>
<td>53.0</td>
<td>202.3</td>
<td>141.3</td>
</tr>
<tr>
<td>Right Mid Tibia</td>
<td>183.4</td>
<td>48.8</td>
<td>286.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>
50th Percentile Male, Initial Observations: Injuries

25° recline

45° recline

*Preexisting fx
### 50th Percentile Male, Initial Observations: Injuries

<table>
<thead>
<tr>
<th>Location</th>
<th>25° recline</th>
<th>45° recline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sternum</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Left Ribs</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Right Ribs</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>C5</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>C6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>T3</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>T4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>T7</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>T8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sacrum/Coccyx</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Pelvic Ring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max AIS</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
MCW Test Protocol

- Same seat/buck as UMTRI
- Same seating procedure
- Population: Small female and obese occupants
- 2 Tests/PMHS
  - 15 km/h → No pretensioner
  - 32 km/h → Pretension and load limiter
Obese Occupant, Initial Observations: Posture

<table>
<thead>
<tr>
<th>Test ID</th>
<th>ObO#1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Female</td>
</tr>
<tr>
<td>Age (years)</td>
<td>59</td>
</tr>
<tr>
<td>Stature (m)</td>
<td>1.626</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>105</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>39.7</td>
</tr>
<tr>
<td>Occupant Category</td>
<td>Obese</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Back Angle (deg)</td>
<td>45</td>
</tr>
<tr>
<td>Head Angle (deg)</td>
<td>32.4 ± 5</td>
</tr>
<tr>
<td>Thorax Angle (deg)</td>
<td>23.5 ± 5</td>
</tr>
<tr>
<td>Pelvis Angle (deg)</td>
<td>45.3 ± 5</td>
</tr>
<tr>
<td>Knee Spacing (mm)</td>
<td>348 ± 20</td>
</tr>
</tbody>
</table>
Obese Occupant, Initial Observations: Posture

<table>
<thead>
<tr>
<th></th>
<th>15 kph</th>
<th>32 kph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Angle (deg)</td>
<td>31.6</td>
<td>29.5</td>
</tr>
<tr>
<td>Thorax Angle (deg)</td>
<td>25.6</td>
<td>22.4</td>
</tr>
<tr>
<td>Pelvis Angle (deg)</td>
<td>42.6</td>
<td>47.8</td>
</tr>
<tr>
<td>Knee Spacing (mm)</td>
<td>350</td>
<td>350</td>
</tr>
</tbody>
</table>
Obese Occupant, Initial Observations: Posture
Obese Occupant, Initial Observations: Kinematics

15 kph

32 kph
Obese Occupant, Initial Observations: Kinematics

- Head
- T1
- T8
- T12
- L4
- Arms
- Femurs
- Tibias

15 kph
Obese Occupant, Initial Observations: Kinematics

15 kph
Obese Occupant, Initial Observations: Kinematics

32 kph
## Small Female Occupant, Initial Observations: Posture

<table>
<thead>
<tr>
<th>Test ID</th>
<th>SFO#1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Female</td>
</tr>
<tr>
<td>Age (years)</td>
<td>64</td>
</tr>
<tr>
<td>Stature (m)</td>
<td>1.53</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>59.1</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.2</td>
</tr>
<tr>
<td>Occupant Category</td>
<td>Small Female</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Back Angle (deg)</td>
<td>24.0 ± 5</td>
<td>32.4 ± 5</td>
</tr>
<tr>
<td>Head Angle (deg)</td>
<td>33.2 ± 5</td>
<td>23.5 ± 5</td>
</tr>
<tr>
<td>Thorax Angle (deg)</td>
<td>65.1 ± 5</td>
<td>45.3 ± 5</td>
</tr>
<tr>
<td>Pelvis Angle (deg)</td>
<td>228 ± 20</td>
<td>348 ± 20</td>
</tr>
<tr>
<td>Knee Spacing (mm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Image contains PMHS
Small Female Occupant, Initial Observations: Kinematics

32 kph
Obese Occupant, Initial Observations: Injuries

<table>
<thead>
<tr>
<th>ObO #01</th>
<th>AIS</th>
</tr>
</thead>
</table>

**Musculoskeletal Injuries**

Rib Fx’s
- L Ribs 1-3
- R Ribs 1-6

450203.3

<table>
<thead>
<tr>
<th>Rib #</th>
<th>Total # Fx</th>
<th>Fx #</th>
<th>Aspect</th>
<th>V (cm) Down</th>
<th>S (cm) Over</th>
</tr>
</thead>
<tbody>
<tr>
<td>1L</td>
<td>1</td>
<td>1</td>
<td>ant</td>
<td>0</td>
<td>5.0</td>
</tr>
<tr>
<td>2L</td>
<td>1</td>
<td>1</td>
<td>ant</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>3L</td>
<td>1</td>
<td>1</td>
<td>ant</td>
<td>7.5</td>
<td>4.5</td>
</tr>
<tr>
<td>1R</td>
<td>1</td>
<td>1</td>
<td>ant</td>
<td>0</td>
<td>5.0</td>
</tr>
<tr>
<td>2R</td>
<td>1</td>
<td>1</td>
<td>ant</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>3R</td>
<td>2</td>
<td>1</td>
<td>ant</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>4R</td>
<td>2</td>
<td>1</td>
<td>ant</td>
<td>10.0</td>
<td>8.0</td>
</tr>
<tr>
<td>5R</td>
<td>1</td>
<td>1</td>
<td>ant</td>
<td>14.5</td>
<td>9.0</td>
</tr>
<tr>
<td>6R</td>
<td>1</td>
<td>1</td>
<td>ant</td>
<td>17.3</td>
<td>10.2</td>
</tr>
</tbody>
</table>

No evidence of abdominal injuries
### Small Female Occupant, Initial Observations: Injuries

<table>
<thead>
<tr>
<th>SFO #01</th>
<th>AIS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Musculoskeletal Injuries</strong></td>
<td></td>
</tr>
<tr>
<td>Rib Fx’s</td>
<td>450203.3</td>
</tr>
<tr>
<td>• L Rib(s): 2,3</td>
<td></td>
</tr>
<tr>
<td>• R Rib(s): 3</td>
<td></td>
</tr>
<tr>
<td>Sternum: Body Fx (non-displaced) immediate to sternal angle</td>
<td>450804.2</td>
</tr>
</tbody>
</table>

No evidence of abdominal injuries
Summary

• Results from 2 PMHS
• MCW: 4 PMHS 45 deg recline angle – 32 km/h
  • 2 Obese
  • 2 Small Female
• Posture based on seated study of volunteers
• Kinematics of head, spine, and extremities
• Conduct 20 PMHS in the next 12 months
• Include higher speed tests 56 km/h
• Compare results UMTRI and MCW
Thank You

- Sponsor – National Highway Traffic Safety Administration, Contract No. DTNH2215D00017

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- UMTRI
  - Dr. Matt Reed, Dr. Jonathan Rupp, Dr. Jingwen Hu
  - Carl Miller, Ann Bonifas, Nichole Orton, Miranda StAmour, Kyle Boyle, Brian Eby, Jen Bishop

- MCW
  - Dr. Frank Pintar, Dr. Narayan Yoganandan
Contact Info

Lauren Wood Zaseck  
University of Michigan Transportation Research Institute  
2901 Baxter Rd, Ann Arbor MI  
734-615-3408  
laurekat@umich.edu

John Humm  
Medical College of Wisconsin  
Zablocki, VA Medical Center  
5000 W. National Ave, Res 151  
Milwaukee, WI 53295  
414-384-2000 x43512  
jhumm@mcw.edu