Wheelchair Driver Airbag Interaction

Safety issues regarding the use and/or deactivation of frontal-impact airbags for wheelchair-seated front-seat occupants

Kyle Boyle

09/27/2016
Overview

- Background
- Sled testing used to develop WC models
- Parametric simulations
- Comparison to vehicle seat
- Oblique simulations
- Close proximity simulations
Vehicles are modified for wheelchair users that are unable to drive using the OEM vehicle seat and controls

- Positioning changes
- Kinematics change
- “Smart” features of advanced airbags are essentially overridden in modified vehicles
- Modifiers may deactivate airbags when they have concerns about clients being injured by deploying airbags
Methods

• Conduct frontal sled-impact tests with MM and SF ATDs with instrument panel, steering wheel, and airbag module using different belt-restraint conditions:
  • Good belt fit (open arm supports)
  • Poor belt fit (lap belt in front of arm supports)
  • Unbelted

• Develop and validate a Madymo model of wheelchair-seated driver with airbag deployment using results from sled tests

• Use validated Madymo model to explore potential scenarios in which drivers seated in wheelchairs may sustain injuries from interaction with deploying steering-wheel airbags.
## Sled Impact Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>WC1022</th>
<th>WC1023</th>
<th>WC1106</th>
<th>WC1107</th>
<th>WC1109</th>
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<tbody>
<tr>
<td>ATD</td>
<td>50th</td>
<td>50th</td>
<td>50th</td>
<td>50th</td>
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</tr>
<tr>
<td>Belt fit</td>
<td>Proper</td>
<td>Poor</td>
<td>Poor</td>
<td>Unbelted</td>
<td>Poor</td>
</tr>
<tr>
<td>Airbag</td>
<td>12ms</td>
<td>12ms</td>
<td>40ms</td>
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</table>

- 30mph crash pulse in all tests
## Sled Impact Tests

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<td>12ms</td>
<td>12ms</td>
<td>40ms</td>
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</tbody>
</table>
### Summary of NHTSA Injury Criteria / IARV

<table>
<thead>
<tr>
<th>Injury Criteria</th>
<th>Mid-sized Male</th>
<th>Small Female</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Head:</strong> HIC15 <em>(12% AIS3+)</em></td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td><strong>Neck:</strong> Nij <em>(22% AIS3+)</em></td>
<td>1.0</td>
<td>1.0</td>
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<tr>
<td>Critical Intercepts:</td>
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<tr>
<td>Tension and Compression (N)</td>
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<tr>
<td>Flexion (Nm)</td>
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<td>155</td>
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<tr>
<td>Extension (Nm)</td>
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<td>62</td>
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<tr>
<td><strong>Thorax:</strong></td>
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</tr>
<tr>
<td>Chest D (mm) <em>(52% AIS3+)</em></td>
<td>63</td>
<td>52</td>
</tr>
<tr>
<td>Chest Acc (g)</td>
<td>60</td>
<td>60</td>
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<tr>
<td><strong>Lower Ext:</strong> Femur F (kN) <em>(35% AIS2+)</em></td>
<td>10.0</td>
<td>6.8</td>
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</table>
# Sled Impact Tests

- **Injury measurements**

<table>
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<tr>
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<td>Midsize M</td>
<td>Midsize M</td>
<td>Midsize M</td>
<td>Small F</td>
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<tr>
<td>Belt fit</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
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<td>Poor</td>
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<tr>
<td>Airbag</td>
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<td>40ms</td>
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<td>Chest D (mm)</td>
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<td>58.8</td>
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<tr>
<td>Femur Force R (N)</td>
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<td>5049</td>
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<td>Femur Force L (N)</td>
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<td>4426</td>
<td>10606</td>
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</tbody>
</table>
MADYMO Model

- Retractor
- Pretensioner
- Load Limiter

- Airbag
- Steering Column
- Knee Bolster

- Poor Belt Fit

- Unbelted

- Surrogate WC
- WC Docking
Comparison of Sled Test and Model Kinematics

Midsize Male ATD

<table>
<thead>
<tr>
<th></th>
<th>Test</th>
<th>Simulation</th>
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<tbody>
<tr>
<td>HIC</td>
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<td>839</td>
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<tr>
<td>Femur Force L (N)</td>
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<td>1627</td>
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</table>

ATD: 50th
Belt fit: Proper
Airbag: 12ms
Comparison of Sled Test and Model Kinematics

Midsize Male ATD

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>HIC</td>
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<td>215</td>
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<tr>
<td>Neck force Upper (N)</td>
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<td>Femur Force L (N)</td>
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ATD
Belt fit: Poor
Airbag: 12ms
Comparison of Sled Test and Model Kinematics

Small-Female ATD

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<tr>
<td>Femur Force R (N)</td>
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<td>2977</td>
</tr>
<tr>
<td>Femur Force L (N)</td>
<td>2081</td>
<td>2725</td>
</tr>
</tbody>
</table>

ATD
Belt fit Poor
Airbag 40ms
Parametric Simulations

• Key Parameters
  – Crash pulse (30 mph and ~22g, same as the test)
  – Belt load limit (3 kN) – different that for sled tests
  – Pretensioner deployment time (12 ms)
  – Steering column stiffness (measured, 3-4kN plateau)
  – Knee bolster stiffness (~100 N/mm)
  – Steering wheel stiffness (50 N/mm)
  – Belt fit (3 levels: good, poor, unbelted)
  – Airbag (2 levels: 12 ms deployment time and no-airbag)
  – ATD (2 levels: midsize male and small female)

• Simulation matrix
  – Matrix 1: midsize male / 6 simulations
  – Matrix 2: small female / 6 simulations
Summary of Parametric Study

- ATD re Airbag Kinematics – Midsize Male ATD
### Summary of Parametric Study

#### Peak Injury Variables – Midsize Male ATD

<table>
<thead>
<tr>
<th>No.</th>
<th>Belt fit</th>
<th>Airbag</th>
<th>HIC15</th>
<th>NIJ</th>
<th>ChestD</th>
<th>FemurL</th>
<th>FemurR</th>
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<tbody>
<tr>
<td>1</td>
<td>Good</td>
<td>Yes</td>
<td>88</td>
<td>0.18</td>
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<tr>
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<td>Poor</td>
<td>Yes</td>
<td>38</td>
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<td>3</td>
<td>Unbelted</td>
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<tr>
<td>4</td>
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<td>5147</td>
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Summary of Parametric Study

- ATD re Airbag Kinematics – Small Female ATD
## Summary of Parametric Study

### Peak Injury Variables – Small Female ATD

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<tr>
<th>No.</th>
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<th>FemurR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Good</td>
<td>Yes</td>
<td>123</td>
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<td>4</td>
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<td>5</td>
<td>Poor</td>
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<td>3379</td>
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<tr>
<td>6</td>
<td>Unbelted</td>
<td>No</td>
<td>240</td>
<td>1.40</td>
<td>56.3</td>
<td>4148</td>
<td>4090</td>
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</tbody>
</table>
Vehicle-seated occupant is positioned based on UMTRI seating model.
Vehicle Seated Small Female (Preliminary)

- Occupant Kinematics

Note: No rigorous validation on the vehicle seated model in this study
WC vs. Vehicle Seat (Preliminary)

- **WC-seated small female**

<table>
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<tr>
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<td>45.0</td>
<td>1610</td>
<td>1760</td>
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<td>0.26</td>
<td>37.9</td>
<td>4225</td>
<td>4210</td>
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<td>3</td>
<td>Good</td>
<td>No</td>
<td>372</td>
<td>0.45</td>
<td>30.3</td>
<td>1505</td>
<td>2480</td>
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<tr>
<td>4</td>
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<td>240</td>
<td>1.40</td>
<td>56.3</td>
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- **Vehicle-seated small female**

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<th>FemurR</th>
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<tr>
<td>1</td>
<td>Good</td>
<td>Yes</td>
<td>110</td>
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<td>2436</td>
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</table>

Note: No rigorous validation on the vehicle seated model in this study
Oblique Simulations

- Occupant Kinematics – Midsize Male ATD, Good Belt Fit

Note: No rigorous validation on the oblique model in this study
Oblique Simulations

- **Occupant Kinematics – Midsize Male ATD, Good Belt Fit**

  Note: No rigorous validation on the oblique model in this study
Oblique Simulations

- **Occupant Kinematics – Midsize Male ATD, Poor Belt Fit**

Note: No rigorous validation on the oblique model in this study
Oblique Simulations

- Occupant Kinematics – Midsize Male ATD, Poor Belt Fit

Note: No rigorous validation on the oblique model in this study
## Oblique Simulations

**Midsize Male ATD**

<table>
<thead>
<tr>
<th>No.</th>
<th>Angle</th>
<th>Belt Fit</th>
<th>Airbags</th>
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<th>NIJ</th>
<th>ChestD</th>
<th>FemurL</th>
<th>FemurR</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>15 deg</td>
<td>Good</td>
<td>Both</td>
<td>92</td>
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<td>2761</td>
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<td>33.7</td>
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<tr>
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<td>Both</td>
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<td>0.68</td>
<td>19.6</td>
<td>4545</td>
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</table>

Note: No rigorous validation on the oblique model in this study
Oblique Simulations

- Occupant Kinematics – Small Female ATD, Good Belt Fit

Note: No rigorous validation on the oblique model in this study
Oblique Simulations

- Occupant Kinematics – Small Female ATD, Good Belt Fit

Note: No rigorous validation on the oblique model in this study
Oblique Simulations

- **Occupant Kinematics – Small Female ATD, Poor Belt Fit**

Note: No rigorous validation on the oblique model in this study
Oblique Simulations

- Occupant Kinematics – Small Female ATD, Poor Belt Fit

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<td>Both</td>
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<td>41.6</td>
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<td>Good</td>
<td>Curtain Only</td>
<td>273</td>
<td>0.64</td>
<td>35.4</td>
<td>1164</td>
<td>582</td>
</tr>
<tr>
<td>7</td>
<td>30 deg</td>
<td>Poor</td>
<td>Both</td>
<td>88</td>
<td>0.39</td>
<td>31.3</td>
<td>3495</td>
<td>2132</td>
</tr>
<tr>
<td>8</td>
<td>30 deg</td>
<td>Poor</td>
<td>Curtain Only</td>
<td>111</td>
<td>0.45</td>
<td>21.0</td>
<td>3382</td>
<td>2331</td>
</tr>
</tbody>
</table>

Note: No rigorous validation on the oblique model in this study
Close Proximity Simulations

- Occupant Kinematics – Midsize Male ATD

Note: No rigorous validation on the close proximity model in this study
Close Proximity Simulations

**Midsize Male ATD**

<table>
<thead>
<tr>
<th>No.</th>
<th>Dist. To SW</th>
<th>Belt Fit</th>
<th>Airbag</th>
<th>HIC15</th>
<th>NIJ</th>
<th>ChestD</th>
<th>FemurL</th>
<th>FemurR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 inch</td>
<td>Good</td>
<td>Yes</td>
<td>140</td>
<td>0.52</td>
<td>53.8</td>
<td>2638</td>
<td>2022</td>
</tr>
<tr>
<td>2</td>
<td>1 inch</td>
<td>Good</td>
<td>No</td>
<td>82</td>
<td>0.48</td>
<td>36.3</td>
<td>3346</td>
<td>2389</td>
</tr>
<tr>
<td>3</td>
<td>1 inch</td>
<td>Poor</td>
<td>Yes</td>
<td>105</td>
<td>0.48</td>
<td>51.1</td>
<td>4096</td>
<td>4177</td>
</tr>
<tr>
<td>4</td>
<td>1 inch</td>
<td>Poor</td>
<td>No</td>
<td>133</td>
<td>1.18</td>
<td>34.0</td>
<td>4344</td>
<td>4411</td>
</tr>
<tr>
<td>5</td>
<td>5 inch</td>
<td>Good</td>
<td>Yes</td>
<td>131</td>
<td>0.60</td>
<td>44.9</td>
<td>1069</td>
<td>1478</td>
</tr>
<tr>
<td>6</td>
<td>5 inch</td>
<td>Good</td>
<td>No</td>
<td>52</td>
<td>0.60</td>
<td>29.9</td>
<td>1826</td>
<td>1788</td>
</tr>
<tr>
<td>7</td>
<td>5 inch</td>
<td>Poor</td>
<td>Yes</td>
<td>77</td>
<td>0.60</td>
<td>51.2</td>
<td>5304</td>
<td>5449</td>
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<tr>
<td>8</td>
<td>5 inch</td>
<td>Poor</td>
<td>No</td>
<td>49</td>
<td>0.60</td>
<td>37.3</td>
<td>5391</td>
<td>5353</td>
</tr>
</tbody>
</table>

Note: No rigorous validation on the close proximity model in this study.
Close Proximity Simulations

- Occupant Kinematics – Small Female ATD

Note: No rigorous validation on the close proximity model in this study
Close Proximity Simulations

- Small Female ATD

<table>
<thead>
<tr>
<th>No.</th>
<th>Dist. To SW</th>
<th>Belt Fit</th>
<th>Airbag</th>
<th>HIC15</th>
<th>NIJ</th>
<th>ChestD</th>
<th>FemurL</th>
<th>FemurR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 inch</td>
<td>Good</td>
<td>Yes</td>
<td>327</td>
<td>1.04</td>
<td>46.6</td>
<td>1730</td>
<td>1394</td>
</tr>
<tr>
<td>2</td>
<td>1 inch</td>
<td>Good</td>
<td>No</td>
<td>158</td>
<td>0.43</td>
<td>28.1</td>
<td>1444</td>
<td>1762</td>
</tr>
<tr>
<td>3</td>
<td>1 inch</td>
<td>Poor</td>
<td>Yes</td>
<td>283</td>
<td>0.65</td>
<td>38.6</td>
<td>2555</td>
<td>2611</td>
</tr>
<tr>
<td>4</td>
<td>1 inch</td>
<td>Poor</td>
<td>No</td>
<td>93</td>
<td>0.38</td>
<td>33.7</td>
<td>2605</td>
<td>2949</td>
</tr>
<tr>
<td>5</td>
<td>5 inch</td>
<td>Good</td>
<td>Yes</td>
<td>169</td>
<td>0.55</td>
<td>57.7</td>
<td>1532</td>
<td>1532</td>
</tr>
<tr>
<td>6</td>
<td>5 inch</td>
<td>Good</td>
<td>No</td>
<td>149</td>
<td>0.43</td>
<td>31.6</td>
<td>1609</td>
<td>2293</td>
</tr>
<tr>
<td>7</td>
<td>5 inch</td>
<td>Poor</td>
<td>Yes</td>
<td>174</td>
<td>0.52</td>
<td>55.0</td>
<td>2978</td>
<td>3120</td>
</tr>
<tr>
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<td>5 inch</td>
<td>Poor</td>
<td>No</td>
<td>81</td>
<td>0.48</td>
<td>32.9</td>
<td>3383</td>
<td>3552</td>
</tr>
</tbody>
</table>

Note: No rigorous validation on the close proximity model in this study
1) Five sled tests were conducted with steering-wheel airbags for WC-seated ATDs in driver configuration (4 with midsize male ATD and 1 with small female ATD).

2) Madymo models of midsize-male and small-female wheelchair seated drivers were developed and validated against sled tests, and reasonable correlations were achieved.

3) Parametric simulation study did not show any evidence of airbag-induced injuries in all the simulated conditions.

4) Airbag reduces the HIC and Nij values effectively for both mid-size male and small female drivers, and reduces chest deflection for unbelted drivers in the simulated conditions.
5) During oblique crash situations, driver airbag reduces the HIC and Nij values effectively for both mid-size male and small female drivers compared to use of curtain airbag only.

6) In worst case scenario OOP testing of airbags, chest deflection may place small occupant at higher risk of injury.
Thank You

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Test Setup
• Figure 1 – Wheelchair-seated driver with poorly positioned lap belt over armrest and high on the abdomen.

• Figure 2 – Wheelchair-seated driver with poorly positioned lap belt over wheelchair armrest.