Assessing Rollover Crashworthiness in Dynamic vs. Static Testing

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Problem: Rollover Crashes

Since 2005:

- >33% Vehicle Occupant Fatalities in Crashes with ROLLOVER
- 2013: 7,017 People Killed (33.2% of Occ. Fat.) -1.7% of Crashes

In 2010:

- 2% Vehicle Crashes
- 20% Fatal Crashes

UVA Rollover Research 2009-Present

Long-Term Research Goals:

• Identify and investigate injuries, mechanisms, and sources
• Evaluate and improve dummy biofidelity
• Investigate potential for repeatability
• **Determine what can be learned about vehicle crashworthiness by a dynamic test**
• Develop a suite of computational models for modeling crashes, vehicles, and occupants.
Standardized Rollover Crashworthiness Evaluations

FMVSS 216 Roof Crush Resistance

Required: SWR ≥ 3.0

"Good" Rating: SWR ≥ 4.0

(Updated 2009)
Roof Strength: Peak Strength to Weight Ratio

Injury Risk: Head, Neck, Face, Spine

Moffatt and Padmanaban 1995
Padmanaban et al. 2005
Padmanaban and Moffatt 2008

NHTSA: TSF RN 2010
(DOT HS 811365)

IIHS 2008
Brumbelow et al. 2008
Brumbelow et al. 2009

IIHS 2008
TSF RN 2010
(DOT HS 811365)

NHTSA: Austin et al. 2005
Strashny 2007

Roof Deformation: Intrusion

• Retrospective Analyses
• Simplify Numerous Factors
• Statistical Correlation
Goal

To examine the relationship between roof strength, roof intrusion, and injury risk by testing:

*Compare the dynamic response to rollover of two vehicles with the same SWR*
1) Rotated to Test Velocity and Test Angle
2) Dropped onto Moving Road Surface
3) Rolls Across Moving Road Surface
4) Vertical Motion Is Arrested
5) Rotational Motion is Arrested
Dynamic Rollover Test System (DRoTS)

- Research Tool
  - Repeatability
  - Dummy Biofidelity
  - Injury Risk
  - Dynamic vs. Static
- Development
  - Kerrigan et al. 2011
- Operation/Performance
  - Kerrigan et al. 2013
- Dummy Biofidelity
  - Zhang et al. 2013/2014
  - Lessley et al. 2014
- Repeatability
  - Seppi et al. 2015
  - Roberts et al. 2015
- Crash Fidelity
  - Kerrigan et al. 2015
  - Roberts et al. 2016
Dynamic Rollover Test System Constraints

Vehicle Support Cradle

Roll Axis Remains Within A Stationary Plane

Roll Axis

Pitch Axis

Longitudinal Translation

Vertical Translation

Roadbed Motion

Jason R. Kerrigan

November 8, 2015
## Touchdown Conditions

### Vehicle GOAL Volvo Hyundai

<table>
<thead>
<tr>
<th></th>
<th>GOAL</th>
<th>Volvo</th>
<th>Hyundai</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch Angle (deg)</td>
<td>-7.6</td>
<td>-8.1</td>
<td>-8.6</td>
</tr>
<tr>
<td>Roll Angle (deg)</td>
<td>-143</td>
<td>-142</td>
<td>-144</td>
</tr>
<tr>
<td>Roll Rate (deg/s)</td>
<td>-245</td>
<td>-247</td>
<td>-246</td>
</tr>
<tr>
<td>Road Speed (m/s)</td>
<td>7.5</td>
<td>7.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Vertical Velocity (m/s)</td>
<td>1.55</td>
<td>1.53</td>
<td>1.51</td>
</tr>
</tbody>
</table>
Exterior Video

Volvo XC60

Hyundai Accent
Leading Side Impact

Roll Rate
Roll Angle

Angular Velocity (deg/s)

Volvo XC60

Hyundai Accent

134 deg/s Increase in first 24 deg

Both Reduce Roll Rate
Roll Rate
Roll Angle

Trailing Side Impact

Volvo XC60
Hyundai Accent

Both Increase Roll Rate Again

Angular Velocity (deg/s)

Roll Angle (deg)
Deformation Measurement

3 String Potentiometers + Trilateration Algorithm = Local Frame X, Y, Z, Displacements
**Volvo XC60**
Max: 83 mm (203 deg)
Residual: 38 mm
(55% Reduction)

**Hyundai Accent**
Max: 126 mm (207 deg)
Residual: 70 mm
(45% Reduction)
Hyundai Compact
Max: 90 mm (197 deg)
Residual: 48 mm
(47% Reduction)

Volvo SUV
Max: 36 mm (203 deg)
Residual: 14 mm
(61% Reduction)
Roof Deformations

**VOLVO**
Avg. Deformation:
- 14 mm
- -6 mm

**HYUNDAI**
Avg. Deformation:
- 27 mm
- -14 mm
Two Hybrid-III ATDs in Each Vehicle

- No Curtain Airbags Deployed
- No Seatbelt Pretensioners Deployed
- NCAP Seating

Volvo XC60

Hyundai Accent

November 8, 2015
Injury Risk

**Volvo XC60**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Nij (CE)</td>
<td>1.25</td>
</tr>
<tr>
<td>Compression Force</td>
<td>6220 N</td>
</tr>
<tr>
<td>HIC15</td>
<td>363 (135-139 ms)</td>
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</table>

**Hyundai Accent**

<table>
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<th>Value</th>
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<tr>
<td>Nij (CE)</td>
<td>1.55</td>
</tr>
<tr>
<td>Compression Force</td>
<td>6022 N</td>
</tr>
<tr>
<td>HIC15</td>
<td>51 (108-123 ms)</td>
</tr>
</tbody>
</table>
Volvo XC60

Hyundai Accent

Resultant

Fz @ 90 % Peak

Nij @ 45% Peak

Nij + Fz @ 80-87% Peak

Deformation (mm)

Time (s)
**Roof Strength:**
Peak Strength to Weight Ratio

**Injury Risk:**
Head, Neck, Face, Spine

**IIHS Predicted?**

**Same SWR**
Similar Injury Risk Prediction

**Roof Deformation:**
Intrusion

**Same SWR**
50%-250% more deformation

**Similar Injury Risk Prediction**
50%-250% more deformation
All ATD kinematic responses were substantially different from PMHS.

Dummies move in direction opposite from PMHS

Injury Risk Assessments are Dummy Specific
Conclusions

• Despite similar kinematics, vehicles had vastly different deformations

• Static Roof Crush Resistance (SWR) →
  – Does not correlate with Dynamic or Final (Plastic) Deformation
  – Roofs unload to 45-61% of peak deformation

• Using the Hybrid III →
  – Similar injury risk for vastly different deformations

• For these two vehicles, in this one condition:
  – Should consider other vehicles and conditions