Moving Deformable Barrier Test Procedure for Evaluating Small Overlap/Oblique Crashes

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Presentation Outline

- Background
- Part 1: Vehicle Characteristics
  - Compare Oblique Vehicle-to-Vehicle to Oblique RMDB-to-Vehicle
  - Results of new vehicle design testing
    - Small Overlap / Oblique
    - Compare Small Overlap to Oblique
- Part 2: Dummy Characteristics
Background

- Bean et al, 2009: Poor structural engagement resulted in largest number fatalities, excluding exceedingly severe crashes
- Rudd et al, 2011: NASS/CIREN study showed Knee Thigh Hip AIS 3+ most frequent injuries followed by chest and lower leg
- Saunders et al, 2011: Demonstrated that the use of the current FMVSS 214 barrier was not suitable for this type of test procedure
RMDB Barrier Characteristics

All dimensions are in mm

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Oblique Vehicle-to-Vehicle comparison to RMDB-to-Vehicle
Bullet vehicle speed was determined to achieve a 35 mph DV, in full frontal, in the stationary vehicle.
Top View of VtV to RMDBtV comparison
Acceleration and Velocity PCb
Interior Intrusion and Exterior Crush

![Graph showing intrusion points and crush data]

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New Model Testing
Constant-energy test procedure

- Moving deformable barrier impacts each vehicle at the same velocity
  - Compare results across the fleet
  - Procedure is more severe for smaller cars
  - Potential to drive convergence of vehicle front-end stiffness
Vehicle Selection

- Vehicles introduced or redesigned in 2010-2011
- Good structural rating from IIHS
- Different classes of vehicles ranging from the lightest to the heaviest
- Compare heavy vehicle with body-on-frame and uni-body design
- 8 SOI and 7 Oblique

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# Test Setup

<table>
<thead>
<tr>
<th>Small Overlap (SOI)</th>
<th>Oblique</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Setup</strong></td>
<td><strong>Rationale</strong></td>
</tr>
<tr>
<td><strong>Barrier Closing Speed</strong></td>
<td>56 mph</td>
</tr>
<tr>
<td><strong>Overlap</strong></td>
<td>20%</td>
</tr>
<tr>
<td><strong>Angle Relative to Track</strong></td>
<td>7 degrees</td>
</tr>
</tbody>
</table>

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PC2 SOI and Oblique Top View
PU1 SOI and Oblique Video
PC1 and SUV1 SOI Video
Velocity Traces

Small Overlap

Oblique
Intrusions
AvgGs comparison between SOI and Oblique

![Graph showing AvgGs comparison between SOI and Oblique](image-url)
Summary

- VtV to RMDBtV Comparison
  - Oblique test procedure using the RMDB as a surrogate for a vehicle was generally able to replicate VtV

- New Vehicle Study
  - DV decreased as mass of the vehicle increase
  - SOI condition did not always produce greater intrusion when compared to Oblique test procedure
Moving Deformable Barrier Test Procedure for Evaluating Small Overlap/Oblique Crashes

Part 2: Occupant Response

SAE 2012 World Congress
Detroit, Michigan
4/25/2012

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Presentation Overview

- Field exposure
- Description of test device (THOR)
- Vehicle-to-vehicle vs. RMDB
- Occupant response
  - SOI Kinematics
  - SOI Restraint interaction
  - SOI Injury Assessment
  - Oblique vs. SOI
- Summary
Review of CIREN and NASS Cases (Rudd 2011)

- **Requirements**
  - Belted drivers with at least one AIS 3+ injury
  - Vehicle model year 1998 and newer
  - Front or left side damage
  - $320^\circ < \text{PDOF} < 0^\circ$
  - No under-, over-ride

- **SOI**
  - Engagement outside of left longitudinal

- **Left Offset**
  - Left longitudinal engaged

- **AIS 3+: KTH > Chest > Head**
  - Independent of mode

\[ \text{SOI (N=124)} \quad \text{Left Offset (N=152)} \quad \text{SOI and Left Offset (N=276)} \]

% of Cases

- Head AIS 3+
- Chest AIS 3+
- KTH AIS 3+
- Leg/Foot AIS 2+

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4/25/2012
Occupant Response Assessment: THOR ATD

- THOR-NT with Mod Kit (Ridella, 2011)
  - Improvements to biofidelity, repeatability, durability, usability

- Designed to demonstrate improved biofidelic kinematics vs. Hybrid III
  - Flexible joints in thoracic and lumbar spine
  - Improved restraint interaction

- Increased measurement capability vs. Hybrid III
  - Thorax: 4-point, 3-dimensional chest deflection
  - Abdomen: 2-point, 3-dimensional lower abdomen deflection
  - Knee-thigh-hip: Acetabulum load cells
  - Lower Extremity: Upper, lower tibia loads; ankle rotations

- Limitation: Injury Assessment Reference Values (IARVs) not yet established
  - Provisional IARVs used for this study
  - THOR-specific IARVs to be developed 2012-2013
  - Example: Rotational Brain Injury Criterion (BRIC)
Rotational Brain Injury Criterion (BRIC)

\[
BRIC = \frac{\omega_{\text{max}}}{\omega_{cr}} + \frac{\alpha_{\text{max}}}{\alpha_{cr}}
\]

- \(\omega\) = angular velocity at head CG
- \(\alpha\) = angular acceleration at head CG
- \(\text{max}\) = maximum resultant value
- \(\text{cr}\) = critical value

- THOR-specific critical values determined (per Takhounts 2011)
  - Basis = 31 THOR small overlap/oblique tests
  - Result = injury risk curves
    - \(f(BRIC) = p(\text{AIS 3+})\) and \(p(\text{AIS 4+})\)

<table>
<thead>
<tr>
<th>Critical Values</th>
<th>(\omega_{\text{cr}}) (rad/s)</th>
<th>(\alpha_{\text{cr}}) (rad/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid III</td>
<td>46.41</td>
<td>39.775</td>
</tr>
<tr>
<td>THOR</td>
<td>63.5</td>
<td>19.501</td>
</tr>
</tbody>
</table>

\(BRIC = 0.89 \rightarrow 30\% \text{ AIS 3+}\)
SOI: Head Response

Test: Head Contact Locations

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Airbag</th>
<th>Side Curtain</th>
<th>Roof Rail</th>
<th>Door Panel</th>
<th>IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC2</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PC3</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC4</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC5</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC6</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUV1</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PU1</td>
<td>X</td>
<td></td>
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</tbody>
</table>

Field Injury Source
(Rudd, 2011) 4% 28% 12%

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SOI: Chest Deflections

- NASS/CIREN SOI: Chest injury sources
  - Belt: 38%
  - Door: 32%
  - Steering wheel: 16%

- SOI Tests: Chest deflection sources
  - Primarily belt interaction
  - No evidence of door contact
    - Door often deformed outward
  - Evidence of steering wheel interaction in smaller vehicles (e.g. PC2)

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4 test exceeded acetabulum IARV
2 tests exceeded femur IARV

2 tests that exceeded acetabulum IARV did not exceed femur IARV
- Rudd (2011) showed that over half of acetabulum injuries occurred in absence of femur injury

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SOI: Lower Extremity

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Head response, SOI vs. Oblique

SOI (PC2)

Oblique (PC2)

HIC15

IAV / IARV

Max
Mean+SD
Mean
Mean-SD
Min
Oblique vs. SOI: Head, Chest

Chest Deflection

SOI    Oblique    All

Max
Mean+SD
Mean
Mean-SD
Min

AvgGs X

0.0    5.0    10.0    15.0    20.0    25.0    30.0
PC1    PC2    PC3    PC4    PC5    PC6    SUV1    PU1

SOI Oblique All
Max
Mean+SD
Mean
Mean-SD
Min

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Oblique vs. SOI: Knee-Thigh-Hip

Peak Acetabulum Force

Peak Femur Axial Force

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Oblique vs. SOI: Lower Extremity

**Maximum Tibia Index**

- SOI
- Oblique
- All

**Maximum Ankle Rotation**

- SOI
- Oblique
- All

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SOI Test vs. Real World

- NASS/CIREN data from case study of MY 1998 to 2009 with AIS3+ head, chest, and/or KTH
- NASS/CIREN data represents older vehicle designs
Oblique Test vs. Real World

NASS/CIREN data from case study of MY 1998 to 2009 with AIS3+ head, chest, and/or KTH
NASS/CIREN data represents older vehicle designs

- **Injury Distribution**
  - NASS/CIREN Left Offset (N=152)
  - Percent of Cases

- **IAV > IARV**
  - Oblique Tests (N=7)
  - Percent of Tests

4/25/2012
Summary

- RMDB test shows similar occupant kinematics to Vehicle-to-vehicle test

- SOI and Oblique test conditions show similar kinematics but different injury risk
  - Head, chest higher risk in Oblique
  - Knee-thigh-hip higher risk in SOI
  - Lower extremity similar risk in Oblique and SOI

- SOI and Oblique conditions demonstrate field injury risk

- SOI and Oblique test conditions demonstrated usability, durability, and utility of Mod Kit THOR ATD