Status of NHTSA’s Ejection Mitigation Research Program

2003 SAE Government-Industry Meeting
May 13, 2003
Ejection Mitigation
Problem Definition

- 52,900 Ejections per Year
  - 1% of all crash-involved occupants
- 10,300 Ejected Fatalities per Year
  - 32% of all fatalities
  - 6,000 through side windows
- 10,600 Rollover Fatalities per Year
  - 3,800 ejected through side windows
Ejection Mitigation Research Program Goals

- Demonstrate Countermeasure Feasibility
  - Evaluate ejection mitigation capability
  - Evaluate injury-causing potential
- Develop Occupant Retention Test
  - Full-scale rollover tests not repeatable
- Develop Rollover Sensor Test
Ejection Mitigation
Dynamic Rollover Fixture (DRF)

- Research Tool to Evaluate Countermeasures
- Produces Repeatable Full-Dummy Ejections
  - Allows dummy response measurements
- Produces Realistic Roll Rates
  - Up to 360 deg/sec
- Variable Occupant-to-Window Speeds
  - 15 to 30 kmph
- Variable Occupant Trajectories and Impact Locations
- Does Not Simulate Lateral Vehicle Accelerations
Ejection Mitigation
Countermeasure Candidates

- Inflatable Systems
  - Advanced Head Protection System (AHPS)
    - Simula Automotive Safety Devices
  - Prototype Window Curtain
    - TRW Automotive

- Advanced Side Glazings
  - Bi-laminate
  - Tri-laminate
  - Modified door frame

- Inflatable/Glazing Combination
  - Less door frame modifications
Ejection Mitigation

DRF Testing

- Window Treatments
  - Open window
  - Inflatable, glazings, combination
- Dummy Sizes
  - 50\textsuperscript{th} male
  - 5\textsuperscript{th} female
  - 6 year-old
- Seated Positions
  - Behind steering wheel
  - Inboard
Note: The data in this table are revised from those presented in paper #342 of the 18th ESV Conference.

<table>
<thead>
<tr>
<th>Dummy Position</th>
<th>Test Number</th>
<th>HIC₃₆</th>
<th>Axial Compression N (% IARV)</th>
<th>Axial Tension N (% IARV)</th>
<th>Lateral Shear N</th>
<th>Lateral Bending N-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind Wheel</td>
<td>DRF_20</td>
<td>43</td>
<td>447 (11%)</td>
<td>862 (21%)</td>
<td>327</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>DRF_29</td>
<td>34</td>
<td>0 (0%)</td>
<td>723 (17%)</td>
<td>290</td>
<td>19</td>
</tr>
<tr>
<td>Inboard</td>
<td>DRF_30</td>
<td>55</td>
<td>0 (0%)</td>
<td>972 (23%)</td>
<td>296</td>
<td>16</td>
</tr>
</tbody>
</table>

**Open Window**

<table>
<thead>
<tr>
<th>Dummy Position</th>
<th>Test Number</th>
<th>HIC₃₆</th>
<th>Axial Compression N (% IARV)</th>
<th>Axial Tension N (% IARV)</th>
<th>Lateral Shear N</th>
<th>Lateral Bending N-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind Wheel</td>
<td>DRF_38</td>
<td>25</td>
<td>32 (1%)</td>
<td>601 (23%)</td>
<td>221</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>DRF_43</td>
<td>41</td>
<td>51 (2%)</td>
<td>623 (24%)</td>
<td>268</td>
<td>15</td>
</tr>
<tr>
<td>Inboard</td>
<td>DRF_44</td>
<td>69</td>
<td>0 (0%)</td>
<td>818 (31%)</td>
<td>329</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>DRF_45</td>
<td>90</td>
<td>172 (7%)</td>
<td>871 (33%)</td>
<td>307</td>
<td>17</td>
</tr>
</tbody>
</table>

**50th Male**

<table>
<thead>
<tr>
<th>Dummy Position</th>
<th>Test Number</th>
<th>HIC₃₆</th>
<th>Axial Compression N (% IARV)</th>
<th>Axial Tension N (% IARV)</th>
<th>Lateral Shear N</th>
<th>Lateral Bending N-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind Wheel</td>
<td>DRF_31</td>
<td>10</td>
<td>282 (7%)</td>
<td>238 (6%)</td>
<td>716</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>DRF_32</td>
<td>50</td>
<td>1770 (44%)</td>
<td>909 (22%)</td>
<td>1020</td>
<td>53</td>
</tr>
<tr>
<td>Inboard</td>
<td>DRF_33</td>
<td>41</td>
<td>51 (2%)</td>
<td>623 (24%)</td>
<td>296</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>DRF_34</td>
<td>25</td>
<td>32 (1%)</td>
<td>601 (23%)</td>
<td>221</td>
<td>14</td>
</tr>
</tbody>
</table>

**TRW Air Curtain**

<table>
<thead>
<tr>
<th>Dummy Position</th>
<th>Test Number</th>
<th>HIC₃₆</th>
<th>Axial Compression N (% IARV)</th>
<th>Axial Tension N (% IARV)</th>
<th>Lateral Shear N</th>
<th>Lateral Bending N-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind Wheel</td>
<td>DRF_36</td>
<td>22</td>
<td>617 (24%)</td>
<td>375 (14%)</td>
<td>511</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>DRF_37</td>
<td>15</td>
<td>697 (28%)</td>
<td>757 (29%)</td>
<td>754</td>
<td>35</td>
</tr>
<tr>
<td>Inboard</td>
<td>DRF_40</td>
<td>7</td>
<td>352 (14%)</td>
<td>345 (13%)</td>
<td>668</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>DRF_47</td>
<td>15</td>
<td>352 (14%)</td>
<td>345 (13%)</td>
<td>668</td>
<td>42</td>
</tr>
</tbody>
</table>

**50th Male**

<table>
<thead>
<tr>
<th>Dummy Position</th>
<th>Test Number</th>
<th>HIC₃₆</th>
<th>Axial Compression N (% IARV)</th>
<th>Axial Tension N (% IARV)</th>
<th>Lateral Shear N</th>
<th>Lateral Bending N-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind Wheel</td>
<td>DRF_65</td>
<td>19</td>
<td>2203 (55%)</td>
<td>1075 (26%)</td>
<td>315</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>DRF_66</td>
<td>21</td>
<td>2369 (59%)</td>
<td>494 (12%)</td>
<td>388</td>
<td>52</td>
</tr>
<tr>
<td>Inboard</td>
<td>DRF_67</td>
<td>15</td>
<td>0 (0%)</td>
<td>290 (11%)</td>
<td>491</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>DRF_68</td>
<td>15</td>
<td>0 (0%)</td>
<td>605 (23%)</td>
<td>586</td>
<td>33</td>
</tr>
</tbody>
</table>

**Simula AHPS**

<table>
<thead>
<tr>
<th>Dummy Position</th>
<th>Test Number</th>
<th>HIC₃₆</th>
<th>Axial Compression N (% IARV)</th>
<th>Axial Tension N (% IARV)</th>
<th>Lateral Shear N</th>
<th>Lateral Bending N-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind Wheel</td>
<td>DRF_69</td>
<td>16</td>
<td>1126 (28%)</td>
<td>427 (10%)</td>
<td>344</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>DRF_70</td>
<td>19</td>
<td>2203 (55%)</td>
<td>1075 (26%)</td>
<td>315</td>
<td>60</td>
</tr>
<tr>
<td>Inboard</td>
<td>DRF_71</td>
<td>21</td>
<td>2369 (59%)</td>
<td>494 (12%)</td>
<td>388</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>DRF_60</td>
<td>10</td>
<td>0 (0%)</td>
<td>283 (11%)</td>
<td>447</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>DRF_61</td>
<td>12</td>
<td>0 (0%)</td>
<td>290 (11%)</td>
<td>491</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>DRF_62</td>
<td>15</td>
<td>0 (0%)</td>
<td>605 (23%)</td>
<td>586</td>
<td>33</td>
</tr>
</tbody>
</table>

**50th Male**

<table>
<thead>
<tr>
<th>Dummy Position</th>
<th>Test Number</th>
<th>HIC₃₆</th>
<th>Axial Compression N (% IARV)</th>
<th>Axial Tension N (% IARV)</th>
<th>Lateral Shear N</th>
<th>Lateral Bending N-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind Wheel</td>
<td>DRF_72</td>
<td>84</td>
<td>2084 (52%)</td>
<td>364 (9%)</td>
<td>667</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>DRF_73</td>
<td>57</td>
<td>895 (36%)</td>
<td>307 (12%)</td>
<td>200</td>
<td>19</td>
</tr>
<tr>
<td>Inboard</td>
<td>DRF_64</td>
<td>121</td>
<td>1230 (49%)</td>
<td>515 (20%)</td>
<td>345</td>
<td>26</td>
</tr>
</tbody>
</table>

**Advanced Glazing (Laminated Glazing)**

<table>
<thead>
<tr>
<th>Dummy Position</th>
<th>Test Number</th>
<th>HIC₃₆</th>
<th>Axial Compression N (% IARV)</th>
<th>Axial Tension N (% IARV)</th>
<th>Lateral Shear N</th>
<th>Lateral Bending N-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind Wheel</td>
<td>DRF_80</td>
<td>34</td>
<td>310 (12%)</td>
<td>260 (10%)</td>
<td>338</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>DRF_82*</td>
<td>27</td>
<td>345 (14%)</td>
<td>147 (6%)</td>
<td>237</td>
<td>14</td>
</tr>
<tr>
<td>Inboard</td>
<td>DRF_81</td>
<td>10</td>
<td>731 (29%)</td>
<td>413 (16%)</td>
<td>442</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>DRF_83*</td>
<td>9</td>
<td>1220 (48%)</td>
<td>564 (22%)</td>
<td>650</td>
<td>13</td>
</tr>
</tbody>
</table>

**Combination: TRW Air Curtain/Laminated Glass**

<table>
<thead>
<tr>
<th>Dummy Position</th>
<th>Test Number</th>
<th>HIC₃₆</th>
<th>Axial Compression N (% IARV)</th>
<th>Axial Tension N (% IARV)</th>
<th>Lateral Shear N</th>
<th>Lateral Bending N-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind Wheel</td>
<td>DRF_84*</td>
<td>13</td>
<td>351 (14%)</td>
<td>220 (8%)</td>
<td>317</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>DRF_86*</td>
<td>10</td>
<td>576 (23%)</td>
<td>265 (10%)</td>
<td>161</td>
<td>14</td>
</tr>
<tr>
<td>Inboard</td>
<td>DRF_85</td>
<td>21</td>
<td>2960 (82%)</td>
<td>525 (20%)</td>
<td>385</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>DRF_87*</td>
<td>10</td>
<td>743 (29%)</td>
<td>452 (17%)</td>
<td>223</td>
<td>24</td>
</tr>
</tbody>
</table>

* Dummy Positioned Closer to Steering Wheel with Foam Block Spacer
Ejection Mitigation

DRF Testing Results – Dummy Containment

- Open Window
  - Complete ejection in every case
- Inflatable Systems
  - Prevented complete ejections
  - Shoulders & arms escaped below bag
- Advanced Glazing (tri-laminate only)
  - Prevented complete and partial ejections
- Combination Systems
  - Prevented complete and partial ejections
Ejection Mitigation
Dummy Containment
Ejection Mitigation

DRF Testing Results – Dummy Responses

- **Low Head Injury Potential**
  - Maximum $HIC_{36} = 121$

- **Low Neck Tension**
  - Maximum - 33% IARV (per FMVSS 208)

- **Generally Low Neck Compression**
  - Maximum - 82% IARV (per FMVSS 208)
  - All the rest below 60%
  - Higher values from contact with side roof rail while engaged with countermeasure
Ejection Mitigation
DRF Testing Results – Dummy Responses

Lateral Neck Loading

- Maximum Shear Loads
  - 50th male – 1020 N
  - 5th female – 754 N

- Maximum Bending Moments
  - 50th male – 61 N-m
  - 5th female – 42 N-m

- No Established Injury Criteria
Ejection Mitigation
Guided Impactor

- 18 kg mass
- Featureless Headform
  - Average of front & side of head
- Measures Deflection
- Positioned Inside Vehicle
- Impact a Variety of Locations
## Ejection Mitigation

### Guided Impactor Testing

<table>
<thead>
<tr>
<th>Impact Location on Side Window Area</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 kmph</td>
<td>20 kmph</td>
<td>24 kmph</td>
<td>16 kmph</td>
</tr>
<tr>
<td>Advanced Glazing Systems Only</td>
<td>6 sec</td>
<td>1.5 sec</td>
<td>1.5 sec</td>
<td></td>
</tr>
<tr>
<td>Inflatable Systems Only</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflatable Systems With Glazing (pre-broken)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflatable Systems With Glazing (unbroken)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ejection Mitigation
Side Window Impact Locations

1 2 3 4
Ejection Mitigation
Production System
Ejection Mitigation
Guided Impactor Test Results

• Considerable Previous Testing of Advanced Glazing Systems
  – Containment up to 24 kmph
  – Excursions of 100 to 250 mm

• Very Limited Testing of Inflatable Systems
  – At some locations, containment up to 24 kmph
    • Little or no excursion
  – At other locations, no containment capability
Ejection Mitigation
Guided Impactor

- May Be Suitable For Evaluating Occupant Retention
- Potentially More Stringent Than DRF
  - More concentrated loading area
  - Stringency can be varied by:
    - Selection of impact locations
    - Impact speed
    - Excursion criterion
Ejection Mitigation
Ongoing Research

- DRF Testing of More Systems
  - Full-dummy retention
  - Injury causing potential
- Guided Impactor Testing
  - Most of the work still to be done
  - Evaluate systems
  - Establish test parameters, criterion
- Rollover Sensor Performance Test
  - Evaluate existing and/or develop new methods
THE END