Rear Seat Occupant Protection: Safety Beyond Seat Belts

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Background

- What are the leading injuries in rear seat?

Data based on Kuppa et al. 2005 and Arbogast et al. 2012
Research Objective & Tasks

Objective:
• To design, optimize, and fabricate prototype advanced restraint systems to provide protection for rear seat occupants of different sizes in frontal crashes with different crash pulses and directions.
Crash Conditions

- **Rear seat compartment**
  - Based on a compact vehicle
- **Crash pulse**
  - NCAP fleet severe vs. NCAP fleet soft
- **Crash angle**
  - 0 deg vs. 15 deg to the right
- **ATD Occupants**
  - H-III 6YO / H-III 5th / THOR 50th / H-III 95th
- **Front seat position**
  - Mid (left) vs. more forward (right)
# Front Seat Position

<table>
<thead>
<tr>
<th>Driver</th>
<th>Passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Back Angle</td>
<td>Seat Position (Knee/Seat Offset)</td>
</tr>
<tr>
<td>6 Year Old</td>
<td>12 deg</td>
</tr>
<tr>
<td>Small Female (5&lt;sup&gt;th&lt;/sup&gt;)</td>
<td>12 deg</td>
</tr>
<tr>
<td>Mid Size Male (50&lt;sup&gt;th&lt;/sup&gt;)</td>
<td>12 deg</td>
</tr>
<tr>
<td>Large Male (95&lt;sup&gt;th&lt;/sup&gt;)</td>
<td>12 deg</td>
</tr>
</tbody>
</table>
Objective & Constraints

• Objective Function
  – Chest injury probability for 5th, THOR, and 95th (based on chestD and associated injury risk curves for different sizes of ATDs)

• Constraints
  – Head: Head excursion, HIC, and BrIC
  – Neck: Neck C&T, NIJ
  – Chest: 6YO chestD
## Design Targets

<table>
<thead>
<tr>
<th></th>
<th>Head</th>
<th>Neck</th>
<th>Chest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Excursion (mm)</td>
<td>HIC</td>
<td>BrIC</td>
</tr>
<tr>
<td>6 Year Old</td>
<td>&lt;480</td>
<td>&lt;700</td>
<td>&lt;0.87</td>
</tr>
<tr>
<td>5th</td>
<td>&lt;500</td>
<td>&lt;700</td>
<td>&lt;0.87</td>
</tr>
<tr>
<td>THOR</td>
<td>&lt;580</td>
<td>&lt;700</td>
<td>&lt;0.87</td>
</tr>
<tr>
<td>95th</td>
<td>&lt;600</td>
<td>&lt;700</td>
<td>&lt;0.87</td>
</tr>
</tbody>
</table>

**Combined Probability of Chest Injury for 5th, THOR, & 95th**

*All injury measures should be less than those in the baseline tests*
Baseline Test Summary

- Crash pulse and occupant size are the two dominating factors affecting the rear-seated ATD kinematics and injury measurements.
- Most injury measures are over the IARVs, especially under the severe pulse.
- Submarining was observed in most tests with 6YO, 5\textsuperscript{th}, and THOR.
- No head-to-front-seat contact occurred in any of the tests.
# Restraint Technology Review

<table>
<thead>
<tr>
<th>Belt Configurations</th>
<th>Pre-Tensioning</th>
<th>Load Limiting</th>
<th>Inflatable</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Pt Belt</td>
<td>Retractor PT</td>
<td>Constant LL</td>
<td>Inflatable Belt</td>
</tr>
<tr>
<td>4-Pt Belt ‘X’</td>
<td>Buckle PT</td>
<td>Progressive LL</td>
<td>Bag In Roof</td>
</tr>
<tr>
<td>Anchor PT</td>
<td>Digressive LL</td>
<td>Switchable LL</td>
<td>SCaRAB</td>
</tr>
</tbody>
</table>
Self Conforming Rearseat Air Bag - SCaRAB

- Concept Description
  - Low energy air bag: DI10.1G36/46 – Driver inflator
  - Small Bag Volume: 40-60 liters
  - Conforms to various front seat positions (enabled by open space)
  - Moves laterally minimizing head rotation
  - Mounted in the roof or front seat back (door mounting also possible)
  - Primary reaction surface is seat back regardless of mounting location.
Sled Tests with 6YO - Videos

Baseline (w booster) 3-pt Belt with PT and LL

PT: None     EM: None  PT: Ret&Buck     EM: 9.5mm CLL
PT: Retractor EM: 9.5mm CLL Bag: SCaRAB  PT: Retractor EM: 9.5mm CLL Bag: BlR

SCaRAB Bag in Roof

Crash condition: 0 deg with severe pulse
Sled Tests with 6YO – Injury Measures

The 3-pt baseline belt condition was without booster, and other conditions were with booster.

Crash condition: 0 deg with severe pulse.
Sled Tests with 5th - Videos

Baseline
PT: None  EM: None

3-pt Belt with PT and LL
PT: Retractor  EM: 9.5mm CLL

SCaRAB
PT: Retractor  EM: 9.5mm CLL  Bag: SCaRAB

Bag in Roof
PT: Retractor  EM: 9.5mm CLL  Bag: BiR

Crash condition: 0 deg with severe pulse
Sled Tests with 5th – Injury Measures

Crash condition: 0 deg with severe pulse
Sled Tests with THOR - Videos

Baseline
- PT: None
- EM: None

3-pt Belt with PT and LL
- PT: Retractor
- EM: 10.5mm CLL

SCaRAB
- PT: Retractor
- EM: 9.5mm CLL
- Bag: SCaRAB

Bag in Roof
- PT: Retractor
- EM: 9.5mm CLL
- Bag: BiR

Crash condition: 0 deg with severe pulse
Sled Tests with THOR – Injury Measures

Crash condition: 0 deg with severe pulse
Sled Tests with 95th - Videos

Baseline
- PT: None
- EM: None
- SCaRAB Bag in Roof

3-pt Belt with PT and LL
- PT: Retractor
- EM: 10.5mm CLL
- SCaRAB Bag in Roof

Capture 0deg 0.15gS

Crash condition: 0 deg with severe pulse
Sled Tests with 95th – Injury Measures

Crash condition: 0 deg with severe pulse
Model Validation

- Hundreds of simulations have been run.
- Generally, good correlations have been achieved for each ATD with each advanced restraint system.
3-Point Belt DoE - CLL

• **Baseline System**
  – Retractor Pre-tensioner
  – Constant Load Limiter (CLL)

• **Factors**
  – Additional Pre-tensioners: Anchor and/or Buckle
  – Load Limiter Levels: 8 to 10.5 mm torsion bar
  – Dynamic Locking Tongue (DLT)

• **Observations (768 simulations)**
  – Severe Pulse – None met the constraints
  – Soft Pulse – 10 % (QTY 5) met the constraints

### Constraints Matrix

<table>
<thead>
<tr>
<th></th>
<th>Pulse</th>
<th>6yo</th>
<th>5th</th>
<th>THOR</th>
<th>95th</th>
<th>Comb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe</td>
<td>0%</td>
<td>13%</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Soft</td>
<td>27%</td>
<td>75%</td>
<td>63%</td>
<td>67%</td>
<td>10%</td>
<td></td>
</tr>
</tbody>
</table>
### 3-Point Belt DoE

- Breakdown of Soft Pulse Configurations (CLL)

<table>
<thead>
<tr>
<th>Run No</th>
<th>Anchor PT</th>
<th>Buckle PT</th>
<th>DLT</th>
<th>Pulse</th>
<th>Type</th>
<th>Load Limiter Levels</th>
<th>Comb Chest Probability</th>
<th>System Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Soft</td>
<td>Frontal</td>
<td>9</td>
<td>10%</td>
<td>285%</td>
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<tr>
<td>122</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Soft</td>
<td>Frontal</td>
<td>9</td>
<td>13%</td>
<td>206%</td>
</tr>
<tr>
<td>98</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Soft</td>
<td>Frontal</td>
<td>9</td>
<td>14%</td>
<td>190%</td>
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<tr>
<td>123</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Soft</td>
<td>Frontal</td>
<td>9.5</td>
<td>15%</td>
<td>206%</td>
</tr>
<tr>
<td>99</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Soft</td>
<td>Frontal</td>
<td>9.5</td>
<td>20%</td>
<td>190%</td>
</tr>
</tbody>
</table>

System Cost based on material cost above current material cost of a rear seat system – standard retractor & buckle
Airbag DoE – Adv Features

- **Baseline System**
  - Retractor Pre-tensioner
  - Constant Load Limiter

- **Factors**
  - Advanced Feature: SCaRAB or BiR
  - Additional Pre-tensioners: Anchor / Buckle
  - Load Limiter Levels: 8 to 9 mm torsion bar
  - Dynamic Locking Tongue (DLT)

- **Observations (384 simulations)**
  - 6 designs met all 4 occupants and left & right side constraints
  - 12 designs met all but one of the 4 occupants and left & right side constraints

<table>
<thead>
<tr>
<th>Constraints Met</th>
<th>SCaRAB</th>
<th>BiR</th>
</tr>
</thead>
<tbody>
<tr>
<td>6yo</td>
<td>94%</td>
<td>58%</td>
</tr>
<tr>
<td>5th</td>
<td>79%</td>
<td>98%</td>
</tr>
<tr>
<td>THOR</td>
<td>58%</td>
<td>23%</td>
</tr>
<tr>
<td>95th</td>
<td>88%</td>
<td>100%</td>
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</table>

0 deg Severe Pulse Only
Airbag DoE Analysis

- Breakdown of Severe Pulse Configurations (with Advanced Features)

<table>
<thead>
<tr>
<th>Run No</th>
<th>Advanced</th>
<th>Anchor PT</th>
<th>Buckle PT</th>
<th>DLT</th>
<th>Load Limiter Level</th>
<th>Constraints Met of 8</th>
<th>Comb Chest Probability</th>
<th>System Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>9</td>
<td>8</td>
<td>41.5%</td>
<td>520%</td>
</tr>
<tr>
<td>68</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>9</td>
<td>8</td>
<td>44.4%</td>
<td>442%</td>
</tr>
<tr>
<td>55</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>8.5</td>
<td>8</td>
<td>46.9%</td>
<td>520%</td>
</tr>
<tr>
<td>50</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>9</td>
<td>8</td>
<td>48.5%</td>
<td>504%</td>
</tr>
<tr>
<td>62</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>9</td>
<td>8</td>
<td>49.0%</td>
<td>426%</td>
</tr>
<tr>
<td>49</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>8.5</td>
<td>8</td>
<td>50.7%</td>
<td>504%</td>
</tr>
<tr>
<td>104</td>
<td>BiR</td>
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<td>Yes</td>
<td>Yes</td>
<td>9</td>
<td>7</td>
<td>44.8%</td>
<td>587%</td>
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<td>SCaRAB</td>
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<td>Yes</td>
<td>Yes</td>
<td>8.5</td>
<td>7</td>
<td>49.9%</td>
<td>442%</td>
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<tr>
<td>116</td>
<td>BiR</td>
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<td>No</td>
<td>Yes</td>
<td>9</td>
<td>7</td>
<td>51.3%</td>
<td>508%</td>
</tr>
<tr>
<td>60</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>8</td>
<td>7</td>
<td>52.9%</td>
<td>426%</td>
</tr>
<tr>
<td>67</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>8.5</td>
<td>7</td>
<td>53.1%</td>
<td>442%</td>
</tr>
<tr>
<td>98</td>
<td>BiR</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>9</td>
<td>7</td>
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</tr>
<tr>
<td>66</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>8</td>
<td>7</td>
<td>53.9%</td>
<td>442%</td>
</tr>
<tr>
<td>61</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>8.5</td>
<td>7</td>
<td>53.9%</td>
<td>426%</td>
</tr>
<tr>
<td>54</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>8</td>
<td>7</td>
<td>54.4%</td>
<td>520%</td>
</tr>
<tr>
<td>110</td>
<td>BiR</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>9</td>
<td>7</td>
<td>57.2%</td>
<td>492%</td>
</tr>
<tr>
<td>48</td>
<td>SCaRAB</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>8</td>
<td>7</td>
<td>57.6%</td>
<td>504%</td>
</tr>
<tr>
<td>74</td>
<td>SCaRAB</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>9</td>
<td>7</td>
<td>60.7%</td>
<td>426%</td>
</tr>
</tbody>
</table>

System Cost based on material cost above current material cost of a rear seat system – standard retractor & buckle
Recommendations – Soft Pulse

- Anchor PT / Buckle PT / 9mm TB / no airbag
  - Driver side / Passenger side
Recommendations – Severe Pulse

- Anchor PT / Buckle PT / DLT / 9mm TB / SCaRAB
  - Driver side
Recommendations – Severe Pulse

- Anchor PT / Buckle PT / DLT / 9mm TB / SCaRAB
  - Passenger side
Summary

• Crash pulse and occupant size are the two dominating factors affecting the rear-seated ATD kinematics and injury measurements.

• Advanced seatbelt features, including pre-tensioner and load limiter, have the potential to help provide additional protection for rear-seat occupants with diverse occupant sizes. However, direct conflict exists between head excursion and chest deflection.

• Airbag concepts, including BiR and SCaRAB, have the potential to allow further reduction of seat belt load limit without resulting in a hard head contact to the front seat, when compared to 3-point seatbelt only designs.

This analysis only represents a compact vehicle, and does not represent the whole vehicle fleet.
Acknowledgements

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  – Funding support

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Thanks! Questions?

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