ADVANCED ADAPTIVE RESTRAINT PROGRAM
AGENDA

INTRODUCTION
SENSING – PROCESSING - ACTING
CHALLENGES
TEST MATRIX
BASELINE TEST RESULTS
CONTRIBUTION OF BRIC TO THE INJURY RISK ASSESSMENT
TRADE-OFF BETWEEN BRIC AND CHEST OPTIMIZATION
DISCUSSION
The **Advanced Adaptive Restraint Program (AARP)** was initiated and partially funded by the **National Highway Traffic Safety Administration (NHTSA)**.

Starting in **November 2012**, this multi-year study will be completed in **June 2015**

**Motivation**

In real-world crashes, the exact location and posture of the occupant is unknown before and during the collision, which may influence the injury outcome.

**Objective**

Improve occupant safety for the driver and front right passenger by enabling individualization of restraint system performance, taking into account:

- **Crash type**
- **Crash severity**
- **Dummy size & weight**
- **Seating position & posture**
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Washington, DC
January 21, 2015

ADVANCED ADAPTIVE RESTRAINT PROGRAM
SENSING – PROCESSING – ACTING

Sensing
Crash sensing
Seat weight and position
Gathering of required system input parameters
Occupant posture detection

Processing
Calculation of optimum firing strategy based on underlying algorithm

Acting
Motorized seatbelt
Curtain with enhanced protrusion
Supplemental pelvic restraint
Adaptive frontal airbags
Individual setting of Advanced Adaptive Restraint Components

Crash sensing
Seat weight and position
Gathering of required system input parameters
Occupant posture detection

Calculation of optimum firing strategy based on underlying algorithm

Individual setting of Advanced Adaptive Restraint Components
ADVANCED ADAPTIVE RESTRAINT PROGRAM

CHALLENGES

- Increased pulse severity
  - Future light weight vehicles
- Extended occupant posture
  - Dynamic Out-of-position
- New assessment criteria
  - Multi-point-chest-deflection
  - BrIC
- New crash configuration
  - NHTSA oblique
- New dummy technology
  - THOR

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## ADVANCED ADAPTIVE RESTRAINT PROGRAM

### TEST MATRIX

<table>
<thead>
<tr>
<th>Test configuration</th>
<th>Driver</th>
<th>Front right passenger</th>
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<tbody>
<tr>
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<td>Angle</td>
<td>Pulse</td>
</tr>
<tr>
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<td>0deg</td>
<td>Soft</td>
</tr>
<tr>
<td>2</td>
<td>0deg</td>
<td>Soft</td>
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<tr>
<td>3</td>
<td>0deg</td>
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<tr>
<td>4</td>
<td>0deg</td>
<td>Hard</td>
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<tr>
<td>5</td>
<td>0deg</td>
<td>Hard</td>
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<tr>
<td>6</td>
<td>0deg</td>
<td>Hard</td>
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<tr>
<td>7</td>
<td>LT-15 deg</td>
<td>Soft</td>
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<tr>
<td>8</td>
<td>LT-15 deg</td>
<td>Soft</td>
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<td>9</td>
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<td>10</td>
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<tr>
<td>12</td>
<td>LT-15 deg</td>
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<tr>
<td>13</td>
<td>RT-15 deg</td>
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<td>14</td>
<td>0deg</td>
<td>Soft</td>
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<td>21</td>
<td>LT-15 deg</td>
<td>Hard</td>
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<td>22</td>
<td>LT-15 deg</td>
<td>Hard</td>
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<tr>
<td>23</td>
<td>LT-15 deg</td>
<td>Hard</td>
</tr>
<tr>
<td>24</td>
<td>RT-15 deg</td>
<td>Hard</td>
</tr>
</tbody>
</table>

### Parameter

- **Sled buck angle**
  - 0deg
  - LT-15 deg
  - RT-15 deg

- **Pulse characteristic**
  - Soft
  - Hard

- **Dummy size**
  - 5th
  - 50th
  - AM50dummy
  - AM95dummy

- **Seat position**
  - Full forward
  - Mid track
  - Full rear

- **Occupant posture**
  - Nominal
  - Forward
  - Outboard
  - Inboard
ADVANCED ADAPTIVE RESTRAINT PROGRAM
BASELINE TEST RESULTS – IN-POSITION

Driver

Passenger

AIS 3+
Probability of Injury

5th D 50th D 95th D 5th P 50th P 95th P
5th D 50th D 95th D 5th P 50th P 95th P
5th D 50th D 95th D 5th P 50th P 95th P
5th D 50th D 95th D 5th P 50th P 95th P
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5th D 50th D 95th D 5th P 50th P 95th P
Advanced Adaptive Restraint Program
Baseline Test Results – Extended Occupant Position

![Graph showing AIS 3+ probability of injury for Driver and Passenger categories, with various test conditions detailed.]
**Test configuration**

**Load case**
- 0 degree full frontal hard pulse
- 15 degree oblique hard pulse

**Dummy**
- THOR NT mod kit

**Posture**
- In-position (according to FMVSS 208)

---

**Test results**

<table>
<thead>
<tr>
<th></th>
<th>HIC15</th>
<th>BrlC</th>
<th>Nij</th>
<th>Chest def.</th>
<th>Femur Force</th>
<th>Chest acc. a(^3)ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 deg full frontal hard pulse</td>
<td>301.00</td>
<td>0.72</td>
<td>0.50</td>
<td>59.93</td>
<td>5.14</td>
<td>60.95</td>
</tr>
<tr>
<td>15 deg oblique hard pulse</td>
<td>400.00</td>
<td>1.73</td>
<td>0.45</td>
<td>60.61</td>
<td>6.87</td>
<td>61.67</td>
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</tbody>
</table>

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**Kinematic**

- 0 deg full frontal hard pulse
- 15 deg oblique hard pulse

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ADVANCED ADAPTIVE RESTRRAINT PROGRAM
CONTRIBUTION OF BrIC TO THE INJURY RISK ASSESSMENT

**Formula**

\[
BrIC = \sqrt{\frac{\text{max}(\omega_x)}{\omega_x}^2 + \frac{\text{max}(\omega_y)}{\omega_y}^2 + \frac{\text{max}(\omega_z)}{\omega_z}^2}
\]

\[
\text{max}(\omega_{x,y,z}) = \text{Maximum of the absolute value of the angular velocity time-history of the head about the local [x, y, z] axis. Note that the peak angular velocities about the local x, y, and z axes may occur at different times.}
\]

\[
\omega_{x,y,z} = \text{Critical values for the angular velocity of the head about the local [x, y, z] axis (from Takhouris et al., 2013; Table 3, last column).}
\]

\[
\omega_x = 66.25 \text{ rad/s}
\]

\[
\omega_y = 56.45 \text{ rad/s}
\]

\[
\omega_z = 42.87 \text{ rad/s}
\]

**Risk curves**

\[
P(\text{AIS } 1+) = 1 - e^{-\left(\frac{\text{BrIC}}{0.120}\right)^{2.84}}
\]

\[
P(\text{AIS } 2+) = 1 - e^{-\left(\frac{\text{BrIC}}{0.602}\right)^{2.84}}
\]

\[
P(\text{AIS } 3+) = 1 - e^{-\left(\frac{\text{BrIC}}{0.987}\right)^{2.84}}
\]

\[
P(\text{AIS } 4+) = 1 - e^{-\left(\frac{\text{BrIC}}{1.291}\right)^{2.84}}
\]

\[
P(\text{AIS } 5+) = 1 - e^{-\left(\frac{\text{BrIC}}{1.292}\right)^{2.84}}
\]

A BrIC value of **0.87** corresponds to a **50% risk** of AIS 3+ brain injury.

**BrIC Level**

BrIC level in AARP Full frontal load cases between **0.6-0.8** during the coupling phase to the Airbag.

**Head angular velocity about Y-axis**

- **Baseline test**
- **Adaptivity test #1**
- **Adaptivity test #2**

**Face upwards**

**Face downwards**

- Time [ms]
- Angular velocity [rad/s]
Optimization of Seatbelt and Airbag performance required to define a Balance between both body regions (Head / Chest)

BrIC

Correlation between Bric and chest deflection in hard pulse load cases

Chest deflection
**Load case:**
- Passenger 5th percentile H-III dummy
- In-board leaning position
- Hard pulse 15 deg

---

<table>
<thead>
<tr>
<th>Test #</th>
<th>Passenger airbag</th>
<th>Cushion adaptivity</th>
<th>Seatbelt</th>
<th>TTF AV</th>
<th>TTF FL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>BDSJ0154 conventional symmetric 3D shape</td>
<td>---</td>
<td>Single stage load limiter</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>AARS</td>
<td>optimized to all body regions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BDSK0306</td>
<td>modified asymmetric 3D shape with extended volume to the left hand side and the upper portion of the airbag</td>
<td>Active vent</td>
<td>Dual stage load limiter</td>
<td>50 ms</td>
<td>50 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td>AARS</td>
<td>optimized to BrIC solely</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>BDSK0341</td>
<td></td>
<td>Active vent</td>
<td>Dual stage load limiter</td>
<td>45 ms</td>
<td>no fire</td>
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### Normalized Injury Measure

<table>
<thead>
<tr>
<th>Test #</th>
<th>HIC15</th>
<th>BrIC</th>
<th>Nij</th>
<th>Chest def.</th>
<th>Femur Force</th>
<th>Chest acc.</th>
<th>TTF AV</th>
<th>TTF FL</th>
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<tr>
<td>Baseline</td>
<td>BDSJ0154</td>
<td>698.00</td>
<td>1.54</td>
<td>0.45</td>
<td>32.75</td>
<td>0.78</td>
<td>60.68</td>
<td>---</td>
</tr>
</tbody>
</table>

Chest acceleration will only be considered as a constraint (< 60 g)

### Probability of Injury AIS 3+

<table>
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<th>Test #</th>
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<th>Femur Force</th>
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<tr>
<td>BDSJ0154</td>
<td>0.111</td>
<td>0.971</td>
<td>0.088</td>
<td>0.141</td>
<td>0.010</td>
</tr>
</tbody>
</table>

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TAKATA
**Advanced Adaptive Restraint Program**

Balancing Restraint System Performance

<table>
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<td>0.78</td>
<td>60.68</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>AARS optimized to all body regions</td>
<td>BDSK0306</td>
<td>461.00</td>
<td>1.35</td>
<td>0.49</td>
<td>29.98</td>
<td>1.09</td>
<td>51.68</td>
<td>50 ms</td>
<td>50 ms</td>
</tr>
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</table>

Chest acceleration will only be considered as a constraint (< 60 g)

---

**Normalized Injury Measure**

- **Baseline**

<table>
<thead>
<tr>
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<tr>
<td>BDSK0306</td>
<td>-34.0%</td>
<td>-12.3%</td>
<td>9.4%</td>
<td>-8.5%</td>
<td>39.1%</td>
<td>-14.8%</td>
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**Probability of Injury AIS 3+**

- **Baseline**

<table>
<thead>
<tr>
<th>Probability of Injury</th>
<th>HIC15</th>
<th>BrIC</th>
<th>Nij</th>
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<td>0.141</td>
<td>0.010</td>
</tr>
<tr>
<td>BDSK0306</td>
<td>0.037</td>
<td>0.912</td>
<td>0.095</td>
<td>0.123</td>
<td>0.011</td>
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### ADVANCED ADAPTIVE RESTRAINT PROGRAM

**BALANCING RESTRAINT SYSTEM PERFORMANCE**

<table>
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</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>BDSJ0154</td>
<td>698,00</td>
<td>1,54</td>
<td>0,45</td>
<td>32,75</td>
<td>0,78</td>
<td>60,68</td>
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</tr>
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<td>BDSK0306</td>
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<td>1,35</td>
<td>0,49</td>
<td>29,98</td>
<td>1,09</td>
<td>51,68</td>
<td>50 ms</td>
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<tr>
<td>AARS optimized to BrIC solely</td>
<td>BDSK0341</td>
<td>561,00</td>
<td>0,94</td>
<td>0,41</td>
<td>33,79</td>
<td>0,87</td>
<td>64,71</td>
<td>45 ms</td>
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</table>

Chest acceleration will only be considered as a constraint (< 60 g)

### Normalized Injury Measure

#### Probability of Injury AIS 3+

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<tr>
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<th>HIC15</th>
<th>BrIC</th>
<th>Nij</th>
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<td>BDSK0341</td>
<td>0,065</td>
<td>0,581</td>
<td>0,082</td>
<td>0,148</td>
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ADVANCED ADAPTIVE RESTRAINT PROGRAM
INDIVIDUALIZATION OF RESTRAINT SYSTEM PERFORMANCE

• HIGH COMPLEXITY IN THE ADVANCED ADAPTIVE RESTRAINT PROGRAM

• ADDITIONAL SENSORS ARE REQUIRED TO DETERMINE THE OCCUPANT POSTURE

• REDUCTION OF BRAIN INJURIES WILL BE ONE OF THE MAJOR CHALLENGES OF THE NEAR FUTURE
Questions?

Thank you very much for your attention!