ES-2 Biofidelity and Injury Assessment Capability

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National Highway Traffic Safety Administration

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People Saving People
Http://www.nhtsa.dot.gov
Presentation Overview

- ES-2 Research Program Time Line
- Flat top and the ES-2
- Biofidelity of the ES-2 and SID
- Injury Assessment Capability of the ES-2 and SID
- Back Plate Loads in the ES-2
- Conclusions
- Future Work

NHTSA Side Impact Research
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Why ES-2?

- NHTSA is evaluating the ES-2...
  - ...to improve safety for the US driving population, and
  - ...for interim regulatory harmonization of a side impact dummy
### ES-2 Research Testing

<table>
<thead>
<tr>
<th>3-5/00</th>
<th>7/00</th>
<th>8/00-4/01</th>
<th>5-7/01</th>
<th>8/01</th>
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</thead>
<tbody>
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</table>

#### Planned

- Six full scale tests with front and rear ES-2: two EU, two 214, & two side NCAP tests
- Thirteen torso & pelvis biofidelity sled tests & limited repeatability

**Second ES-2 Available**

- Three 214 tests/IIHS barrier
- Eight 201P pole comparison tests: ES-2 versus SIDH3
- Component tests: back plate interaction, flat top
- Sled tests: head/neck/shoulder biofidelity & kinematics

**High mass impactor tests to evaluate ES-2 proposed rib designs:** coated piston, ball bearing, & needle bearing

**TBD-** Eight 214/NCAP tests with current vehicles for fleet performance
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ES-2 and Flat-Top

- Flat-top is a period of constant rib deflection over time.

- Flat-top is merely evidence that the ribs and the spine are moving at the same velocity relative to ground.
  - Flat-top is not necessarily evidence of rib binding.
“High Mass” Impactor Tests

- Impactor: 907 kg at 5 m/s contacting the thorax and abdomen
- Test conditions: Impactor contacted the ES-2 at angles of 0, +10, +20, and -10 in the horizontal plane
- ES-2 rib modules designs: coated piston, ball and needle bearings
“High Mass” Impactor Tests - Results

- No evidence of flat-top in ES-2 needle bearing rib modules
- Higher deflections in ES-2 compared to Eurosid-1
High-mass Pendulum Tests

Rib Deflection, Minus Ten Degrees - Middle Rib Module

Displacement (MM)

Time (MS)

Eurosid-1 Coated Piston
ES-2 Needle Bearing
## High-mass Pendulum Tests

<table>
<thead>
<tr>
<th>Time (MS)</th>
<th>Displacement (MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>-10</td>
</tr>
<tr>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>0.10</td>
<td>10</td>
</tr>
<tr>
<td>0.15</td>
<td>20</td>
</tr>
</tbody>
</table>

**Graph:**

- **Rib Deflection, Zero Degrees - Middle Rib Module**

- **Y-axis:** Displacement (MM)
- **X-axis:** Time (MS)

**Legend:**
- **Eurosid-1 Coated Piston**
- **ES-2 Needle Bearing**
High-mass Pendulum Test

Rib Deflection, Ten Degrees - Middle Rib Module

- Displacement (MM)
- Time (MS)

Eurosid-1 Coated Piston
ES-2 Needle Bearing
High-mass Pendulum Tests

Rib Deflection, Twenty Degrees - Middle Rib Module

- Displacement (MM)
- Time (MS)

- Eurosid-1 Coated Piston
- ES-2 Needle Bearing
## ES-2 Phase I Full Scale Tests

<table>
<thead>
<tr>
<th>VEHICLE</th>
<th>DUMMY</th>
<th>TEST CONFIGURATION</th>
<th>SPEED (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>96 Taurus- 4dr*</td>
<td>Eurosid-1</td>
<td>EU Side</td>
<td>48.3</td>
</tr>
<tr>
<td>96 Taurus- 4dr</td>
<td>ES-2</td>
<td>EU Side</td>
<td>49.2</td>
</tr>
<tr>
<td>95 Metro- 3 dr*</td>
<td>Eurosid-1</td>
<td>EU Side</td>
<td>50.3</td>
</tr>
<tr>
<td>96 Metro- 3 dr</td>
<td>ES-2</td>
<td>EU Side</td>
<td>50.5</td>
</tr>
<tr>
<td>96 Taurus- 4dr</td>
<td>ES-2</td>
<td>FMVSS 214</td>
<td>53.3</td>
</tr>
<tr>
<td>96 Taurus- 4dr</td>
<td>ES-2</td>
<td>FMVSS 214</td>
<td>52.3</td>
</tr>
<tr>
<td>98 Chevy Cavalier-4dr</td>
<td>ES-2</td>
<td>US Side NCAP</td>
<td>61.6</td>
</tr>
<tr>
<td>2000 Grand Am- 2dr</td>
<td>ES-2</td>
<td>US Side NCAP</td>
<td>62.1</td>
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*Baseline Tests in 1997*
## ES-2 Phase I Full Scale Tests

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<td>EU Side</td>
<td>50.5</td>
</tr>
<tr>
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<td>FMVSS 214</td>
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<td>US Side NCAP</td>
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* Baseline Tests in 1997
Full Scale Test Rib Responses
EU Tests: ES-2 Versus Eurosid-1

- Deflection flat tops reduced but still present for ES-2
- Higher deflection for ES-2
Post-event oscillations in most rib deflections and minor oscillations near main event in a few deflections
Full Scale Test Rib Responses
214/Side NCAP Tests: ES-2

NHTSA Side Impact Research

- With one “exception” deflection flat tops not present

214 Taurus #1 with ES-2
Driver Rib Deflections

Side NCAP Grand Am with ES-2
Passenger Rib Deflections
Full Scale Test Rib Responses
214/Side NCAP Tests: ES-2

NHTSA Side Impact Research

- One rib deflection (of 24) exhibited flat top behavior ... close to full dynamic range of rib module.
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Biofidelity – What is Important?

- First and foremost, a dummy should interact with the vehicle environment in a human-like manner.
  - Human-like force-area-time histories between occupant and vehicle.

- Secondly, those measures necessary to calculate injury criteria should be similar to the same measures on the human.
IHRA Side Impact Torso and Pelvis Sled Test Requirements

- Shoulder to Pelvis evaluation
- Based upon 45 NHTSA sponsored cadaver tests
- Two door speeds - 6.7 and 8.9 m/s (15 and 20 mph)
- Two door stiffnesses - Padded and rigid
- Four door surface geometries
IHRA Side Impact Sled Test
Load Wall Geometry
IHRA Side Impact Sled Requirements

- Door Forces at the thorax, abdomen, pelvis and legs
- Deflection of the upper and lower thorax, and mid abdomen.
- Acceleration – spine, pelvis and ribs
## Rating Dummy Biofidelity - DCV/CCV Ratio

<table>
<thead>
<tr>
<th>DCV/CCV Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq \frac{DCV}{CCV} &lt; 1$</td>
<td>Excellent - Dummy is less variant than the cadaver sample.</td>
</tr>
<tr>
<td>$\frac{DCV}{CCV} = 1$</td>
<td>Excellent - Dummy is as variant as the cadaver sample.</td>
</tr>
<tr>
<td>$1 &lt; \frac{DCV}{CCV} \leq 2$</td>
<td>Good - Dummy is between one and two times as variant as the cadaver sample.</td>
</tr>
<tr>
<td>$2 &lt; \frac{DCV}{CCV} \leq 3$</td>
<td>Moderate - Dummy is between two and three times as variant as the cadaver sample.</td>
</tr>
<tr>
<td>$N &lt; \frac{DCV}{CCV} \leq N+1$</td>
<td>Poor - Dummy is between $n$ and $n+1$ times as variant as the cadaver sample.</td>
</tr>
</tbody>
</table>

Marcus et al, 1986
Results - Door Force DCV/CCV Ratio

Thorax | Abdomen | Pelvis | Average
-------|---------|--------|--------
ES-2   | SID     |        |        

Increasing Biofidelity

Samaha et al 2001 ESV
DCV/CCV Ratio – Acceleration

Samaha et al 2001 ESV
DCV/CCV Ratio – Deflection

Samaha et al 2001 ESV
**DCV/CCV Ratio vs. Test Condition**

- **Rigid 8.9 m/s Padded 8.9 m/s**
- **Rigid 6.7 m/s Padded 6.7 m/s**

**Test Condition**

- **ES-2 Ribs bottomed out in this condition**

**Increasing Biofidelity**

Samaha et al 2001 ESV
# Previous work - ISO Biofidelity Ratings

Note: Larger numbers indicate better biofidelity.

<table>
<thead>
<tr>
<th></th>
<th>Eurosid-1</th>
<th>SID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>3.33</td>
<td>0.0</td>
</tr>
<tr>
<td>Neck</td>
<td>3.70</td>
<td>2.55</td>
</tr>
<tr>
<td>Shoulder</td>
<td>3.90</td>
<td>0.0</td>
</tr>
<tr>
<td>Thorax</td>
<td>4.78</td>
<td>5.02</td>
</tr>
<tr>
<td>Abdomen</td>
<td>3.23</td>
<td>4.38</td>
</tr>
<tr>
<td>Pelvis</td>
<td>1.76</td>
<td>2.76</td>
</tr>
<tr>
<td>Overall</td>
<td>3.22</td>
<td>2.78</td>
</tr>
</tbody>
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## Comparison of ES-2 and SID/H3 Instrumentation

<table>
<thead>
<tr>
<th>Measurement</th>
<th>ES-2</th>
<th>SID/H3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Neck</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Lower Loads</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Shoulder</td>
<td>U</td>
<td></td>
</tr>
<tr>
<td>Load/Rotation</td>
<td>U</td>
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</tr>
</tbody>
</table>
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<th>SID/H3</th>
</tr>
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<tbody>
<tr>
<td>Thorax</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deflection</td>
<td>U</td>
<td>U</td>
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<tr>
<td>Acceleration</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Abdomen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force</td>
<td>U</td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceleration</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Force</td>
<td>U</td>
<td></td>
</tr>
</tbody>
</table>
ES-2 Torso Injury Assessment Capability Compared to SID

- Compare SID and ES-2 instrumentation output in flat wall and abdominal offset conditions
- Correlate instrumentation output with injuries in similar cadaver tests
ES-2 Torso Injury Assessment Capability Compared to SID

- Cadaver Test B4218
  - AIS 4 Kidney Laceration
  - 5 fractured Ribs
ES-2 Torso Injury Assessment Capability Compared to SID

• Cadaver Test B4268
  • AIS 3 Kidney Laceration
  • 7 fractured Ribs
## ES-2 Torso Injury Assessment Capability Compared to SID

<table>
<thead>
<tr>
<th></th>
<th>Flat Wall</th>
<th>Abdominal Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SID</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTI (85 g)</td>
<td>71 g</td>
<td>52 g</td>
</tr>
<tr>
<td>Pelvis Acceleration (120 g)</td>
<td>67 g</td>
<td>53 g</td>
</tr>
<tr>
<td><strong>ES-2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest Deflection (42 mm)</td>
<td>52 mm</td>
<td>31 mm</td>
</tr>
<tr>
<td>Abdominal Force (2500 N)</td>
<td>1402 N</td>
<td>8585 N</td>
</tr>
</tbody>
</table>

### Cadaver Autopsy Results

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractured Ribs</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Soft Tissue</td>
<td>None</td>
<td>Kidney Laceration</td>
</tr>
</tbody>
</table>
ES-2 Torso Injury Assessment Capability Compared to SID

- Conclusion - ES-2 abdominal load measurement capability detects injuries the SID misses.
ES-2 Pelvis

- ES-2 measures Pelvis Acceleration and Pubic Symphysis Load (PSL), while SID only measures acceleration.

- PSL may be a better measure of the load which is directed into the hip joint, and thus may be a better predictor of serious pelvic injury.
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ES-2 Back-plate
ES-2 Back-plate

- Force Balance on ES-2 Spine
Full-Scale Vehicle Test – Driver Impulse Analysis

![Graph showing impulse analysis for various vehicle models and impact categories. The graph compares the impulse (in Newtons x seconds) for different regions of the body, including Neck, Back Plate, Lumbar Spine, and Rib + Shoulder, across various vehicles like Metro, Taurus, Taurus #1, Taurus #2, Cavalier, and Grand AM. The data is presented for different impact categories: EU, 214, and NCAP.](image-url)
Full-Scale Vehicle Test – Passenger Impulse Analysis

Y Impulse (Newtons x seconds)

Metro | Taurus | Taurus #1 | Taurus #2 | Cavalier | Grand AM

EU | 214 | NCAP
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Conclusions

- The ES-2 thorax is less biofidelic than the SID while the ES-2 abdomen and pelvis biofidelity are roughly equivalent.
- ES-2 detects abdominal injuries that the SID misses.
- ES-2 has the potential to better detect serious pelvic injuries.
- More research is necessary to understand the biofidelity of the head/neck complex.
- ES-2 modifications appear to have addressed rib binding which is one mechanism of rib deflection flat top.
- Loads from the seat back through the ES-2 back plate transfer little momentum to the spine of the dummy.
Additional ES-2 Research

- Additional component/sled tests to provide an assessment of head/neck/shoulder biofidelity and kinematics (summer 01)

- Additional component test to ensure that the ES-2 ribs are not binding and that the dummy is repeatable (summer 01)

- Component tests to assess back plate interaction with the seat back (summer 01)

- Application of injury criteria for the ES-2 dummy (summer 01)
Thank you!