Side Impact Vehicle Testing: Development of A Lateral Test Procedure for Child Restraints

Taryn Rockwell, ACE Systems Technologies, Inc.
Background

- TREAD Act – Nov. 2000
- Mandated that NHTSA determine whether to:
  - Apply scaled injury criteria performance levels developed for FMVSS No. 208, to CRS covered in FMVSS No. 213
  - Include CRS in NCAP crash tests
- In response, NHTSA:
  - Issued NPRM to address proposed changes to 213 (Docket No. 2002-11707-3) – proposed 208 scaled injury performance levels
  - Issued ANPRM for child protection in side & rear impact
  - Conducted frontal & side NCAP vehicle tests with CRABI 12MO & Hybrid III 3YO in CRS
Ongoing Research to Address Issues Raised in the ANPRM

- Evaluating real world side impact data
  - CHOP, NASS, FARS, SCI
- Evaluating different lateral test procedures for evaluating CRSs
  - ISO, Japan NCAP, Australia, Euro NCAP
- Sled testing
  - Countermeasures
  - Dummies
    - Q3 vs. Hybrid III
  - IARVs
- Vehicle testing
  - NCAP and R&D
Objectives of This Research

- Address some of the issues raised in the ANPRM including:
  - Determining child injury mechanisms in side impact vehicle tests
  - Compare performance in vehicle tests to that of suggested 90° sled tests
Vehicle Selection

8 vehicles selected:
- 5 from list of vehicles to be selected for 2002 SINCAP
- 3 vehicles piggy-backed to R&D tests with ES-2 dummy

The following considered when selecting vehicles:
- Difficulty of correctly positioning rear SID dummy – exempt from side NCAP testing
- Popular models
- Covered various vehicle classes (2-dr. pass. cars, 4-dr. pass. cars, SUVs, vans, pickups)
- Vehicle availability
  * Did NOT attempt to get cross-sample from vehicle manufacturers
Vehicle Configuration

For any one particular vehicle, the following were identical for both outboard rear seating positions:

- Model of CRS
- CRS orientation
- CRS belt configuration
- Child dummy
Model of CRS

- Safety 1\textsuperscript{st} Forerunner
  - 5-point harness
  - Convertible
    - 5-35 lbs. rear-facing
    - 22-40 lbs. forward-facing
  - Equipped with lower anchorages & tether (LATCH)

- Evenflo On-My-Way
  - 5-point harness
  - Rear-facing only (Infant seat)
    - 5-20 lbs.
  - Equipped only with tether – not used
CRS Belt Configuration & Orientation

- Safety 1st Forerunner
  - VSB, no tether, RF
  - VSB, tether, FF
  - LATCH, FF
  - Lower anchorages, no tether, RF

- Evenflo On-My-Way
  - VSB, no tether, RF
Child Dummy Selection & Instrumentation

- Hybrid III 3YO dummy
- 12MO CRABI dummy

Equipped with:
- Upper & lower neck load cells
- Tri-axial head, chest, and pelvis accelerometers
- Chest lateral spring potentiometer for 3YO only
Side NCAP Test Procedure

- **MDB**
  - 27° crabbed angle
  - 62.0 km/h (38.5 mph)

- **Target vehicle**
  - Positioned at 63° to the line of forward motion
  - Stationary
  - Impacted on driver’s side

- Simulates car moving at 55 km/h hitting another car moving at 27 km/h
Video of Crash Test – Vehicle B (Pickup)
Post-Test CRS Examination

Post-test examinations showed:

- No CRS damaged
- No plastic (permanent) deformation of lower anchorages in vehicle or connection hooks on CRS
- All vehicle seat belts intact and without damage
### Injury Criteria

<table>
<thead>
<tr>
<th>INJURY CRITERION</th>
<th>12MO CRABI</th>
<th>3YO Hybrid III</th>
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<tr>
<td>HIC 15</td>
<td>390</td>
<td>570</td>
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<tr>
<td>3 ms Chest Clip</td>
<td>50</td>
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<tr>
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<td>Extension</td>
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- Suggested in ANPRM issued to address side impact protection for child occupants – Docket No. 02-12151
- Examination of IARVs for side impact dummies only used as a baseline comparison
Head Injury Criterion

**Head Injury Criterion 15 milliseconds (HIC 15)**

- **Near-Side**
- **Far-Side**

*4.42 - Value off chart*

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Pickup</th>
<th>Pickup</th>
<th>Van</th>
<th>4-dr car</th>
<th>4-dr car</th>
<th>4-dr car</th>
<th>2-dr car</th>
<th>SUV</th>
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<td>L</td>
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<td>12MO</td>
<td>3YO</td>
<td>3YO</td>
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</table>
Head Injury Criterion – Vehicle E (4-dr. car)
Intrusion – Vehicle E (4-dr. car)
Intrusion at Window Sill

Vehicle Intrusion at Window Sill

Intrusion (mm)

Distance From Impact (mm)
Thoracic Criteria – Chest Acceleration

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Pickup</th>
<th>Pickups</th>
<th>Van</th>
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<td>12MO</td>
<td>12MO</td>
<td>12MO</td>
<td>3YO</td>
<td>3YO</td>
</tr>
</tbody>
</table>
Intrusion – Vehicle F (4-dr. car)

Dummy’s chest at approx. window sill level
Intrusion at Window Sill

Vehicle Intrusion at Window Sill

Distance From Impact (mm)

Intrusion (mm)

A
B
C
D
E
F
G
H

-1500 -1000 -500 0 500 1000 1500 2000 2500 3000 3500

-200 -100 0 100 200 300 400
### Dummy Positioning

**Rankings 1-8**

1 = closest to door  
8 = farthest away from door

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<td>1</td>
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<td>1</td>
<td>5</td>
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</tr>
<tr>
<td>G</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>21</td>
<td>6</td>
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<tr>
<td>H</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>20</td>
<td>4</td>
</tr>
</tbody>
</table>

**Vehicle Types**

- 4-dr. car
- SUV
- Pickup
- 2-dr. car
- Van

**Diagram**

- Y—Z View
- Dummy Positioning

- Child Dummy Closer to Door
Thoracic Criteria – Chest Deflection

- 3YO dummy only
  - 3 vehicles – F, G, & H
- Dummy readings normalized to 34 mm
- All recorded injuries well below IARV
  - Negligible for far-side dummy
- Highest recorded value: 0.58 – near-side dummy in vehicle F
Neck Criteria - Nij

\[ Nij = \max\left[ \frac{F_{\text{axial}}}{F_{\text{critical}}} + \frac{M_{\text{oc}}}{M_{\text{critical}}} \right] \]

- F\text{axial} = Fz
- F\text{critical} = \text{Max. force in z-direction (tens./comp.)}
- M\text{oc} = \text{My} + (\text{correction factor})Fx
- M\text{critical} = \text{Max. moment about y-axis (flex./ext.)}

<table>
<thead>
<tr>
<th>Dummy</th>
<th>Tension (N)</th>
<th>Compression (N)</th>
<th>Flexion (N-m)</th>
<th>Extension (N-m)</th>
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<td>12MO</td>
<td>1460</td>
<td>-1460</td>
<td>43</td>
<td>-17</td>
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<tr>
<td>3YO</td>
<td>2340</td>
<td>-2120</td>
<td>68</td>
<td>-30</td>
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</table>

Neck Criteria - Nij

Maximum Nij

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Near-Side</th>
<th>Far-Side</th>
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<tbody>
<tr>
<td>Pickup</td>
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<td>3YO</td>
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<td>3YO</td>
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</tbody>
</table>

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Nij – Failure Modes for 12MO CRABI

- Diamond formed by Nij intercepts
- My & Fz injury values at time of max. Nij found
- Exceed 1 of 4 modes of neck motion if recorded moment/force combination falls outside diamond

### Maximum Nij Moment and Force Levels for Near Side and Far Side 12-Month-Old CRABI Dummies in Side NCAP CRS Tests

- **Near Side Dummy**
- **Far Side Dummy**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<tbody>
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<tr>
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<td>12MO</td>
<td>12MO</td>
<td>12MO</td>
<td>12MO</td>
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</tbody>
</table>
Nij – Failure Modes for 12MO CRABI

- **Neck tension** – head up relative to neck or chest down relative to neck
- **Neck extension** – chin up, away from sternum, forcing head back

Tension/Extension in vehicle C (van)
Nij – Neck Motion for 3YO Hybrid III

Maximum Nij Moment and Force Levels for Near Side and Far Side 3-Year-Old Hybrid III Dummies in Side NCAP CRS Tests

- Tension-Extension
- Tension-Flexion
- Compression-Extension
- Compression-Flexion

Vehicle F

<table>
<thead>
<tr>
<th>F</th>
<th>G</th>
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<tbody>
<tr>
<td>4-dr car</td>
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<tr>
<td>3YO</td>
<td>3YO</td>
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</table>

Moment (N-m)

Force (N)
Nij – Neck Motion for 3YO
Hybrid III

Tension/Extension in
vehicle G (2-dr. car)

Tension/ Flexion in
vehicle F (4-dr. car)

- Neck tension – head up relative to neck or chest down relative to neck
- Neck flexion – chin down toward sternum & head curls forward
Resultant Pelvis Acceleration

Resultant Pelvis Acceleration (G's)

Vehicles

A
B
C
D
E
F
G
H

Near-Side
Far-Side

Pickup
Pickup
Van
4-dr car
4-dr car
4-dr car
2-dr car
SUV

NL
NL
L
L
L
L
L
NL

RF
RF
RF
RF
FF
FF
FF
FF

12MO
12MO
12MO
12MO
12MO
3YO
3YO
3YO

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## Summary of Injury

Several vehicles exceeded numerous injury criteria.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Dummy Type</th>
<th>Dummy Position</th>
<th>HIC 15</th>
<th>Chest G’s</th>
<th>Nij</th>
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<tr>
<td>A Pickup</td>
<td>12MO</td>
<td>Near-Side</td>
<td>0.28</td>
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<td></td>
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<td>Far-Side</td>
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<td>1.00</td>
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<td>0.33</td>
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Comparison of Sled Tests to Vehicle Tests
Suggested Lateral Sled Tests to Be Added to 213

- ANPRM suggested 2 Options:
  - 90°, no rigid wall
    - 20 mph
    - ½ sine pulse or upgraded 213 pulse
    - Tethered CRS
    - Impose 20” head excursion limit
  - 90°, rigid-wall
    - 15 mph
    - Grand Am pulse – derived from pulse of Pontiac Grand Am when tested both under 214 (15 mph w/ 21g peak accel.) & side NCAP (21 mph w/ 26 g peak accel.)
    - No head excursion limit necessary
Comparison of 90° (No wall) TRC Sled Tests to SINCAP Vehicle Tests

Near-side dummy readings for HIC 15 & chest G in sled tests (no wall) much lower than in vehicle tests
Comparison of 90° (No wall) TRC Sled Tests to SINCAP Vehicle Tests

- Inconclusive whether HIC 15 & chest G readings for far-side dummy in vehicle tests greater than in sled tests (no wall)
Comparison of TRC 90° Rigid Wall Sled Tests to SINCAP Vehicle Tests

90° Y-acceleration on rear floorpan for five vehicles

Right Rear Floorpan 90 degrees (Y)

- G (2-dr. car)
- F (4-dr. car)
- H (SUV)
- E (4-dr. car)
- A (Pickup)
Comparison of TRC 90° Rigid Wall Sled Tests to SINCAP Vehicle Tests

Average acceleration curve in y-direction for 5 vehicles (\(v = 17.38\) mph) vs. pulse for 15 mph rigid wall sled test

~ 8 G’s

~ 0.01 sec.

Note different shape
Comparison of TRC 90° Rigid Wall Sled Tests to SINCAP Vehicle Tests

In general, near-side dummy readings for HIC 15 & chest G in 15 mph rigid wall sled tests are similar to readings in SINCAP vehicle tests.
Preliminary Observations

Based on limited test series:

- CRSs withstand severity of side impact crash conditions
- Near-side dummy readings generally greater than far-side dummy readings
  - Contributors: Intrusion & lower anchorage locations – changes relative position of dummy
Preliminary Observations

Sled tests vs. vehicle tests:

- Sled test (no wall)
  - Near-side dummy - readings for HIC 15 & chest G much lower than in vehicle tests
  - Far-side dummy – inconclusive

- Sled test (rigid wall)
  - Near-side dummy – readings for HIC 15 & chest G for test at 15 mph similar to dummy readings for vehicle tests
Next Steps

- Evaluation of countermeasures
- Evaluation of biofidelity of dummies for side impact
- Additional vehicle testing
- Possible development of lateral impact test procedure for CRS