THOR-05F Neck R&R, Biofidelity, and Durability

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Overview

- THOR-05F Neck R&R
- THOR-05F Neck Biofidelity
- THOR-05F Neck Durability
Motivation

• NHTSA developed the THOR-50M ATD to better evaluate injury risk of mid-sized adults
  • Alternative to Hybrid-III in frontal crash tests
  • Improved biofidelity and measurement capability
  • More thoroughly evaluate & improve advanced restraint systems

• Similarly, THOR-05F was developed to evaluate the risks and biomechanics of smaller female adults.
THOR-05F Neck Design

- Goal: Improve biofidelic response and improve measurement capability, while maintaining durability and R&R performance.
Neck R&R
Neck R&R

- Performed 4 test modes on 3 different ATDs.
  - Pendulum impacts that induce neck flexion, extension, lateral bending, & torsion.
  - Total of 90 neck tests: 5 trials of each test condition on each ATD.
  - CV < 10% for all measures of interest.
Neck R&R – Frontal Flexion & Extension

- **Inputs:** Pendulum impact to 6” aluminum honeycomb at 5.0 m/s
- **Outputs:**
  - Peak head Y-rotation
  - Peak head angular rate about Y-axis
  - Peak upper neck Z-force
  - Peak upper neck Y-moment

### Frontal Flexion:

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Rotation (°)</th>
<th>Angular Rate (°/s)</th>
<th>Z-Force (N)</th>
<th>Y-Moment (N·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>-79.4</td>
<td>-2128</td>
<td>760</td>
<td>16.7</td>
</tr>
<tr>
<td>StDev</td>
<td>1.62</td>
<td>41.35</td>
<td>57.34</td>
<td>0.89</td>
</tr>
<tr>
<td>CV</td>
<td>2.04%</td>
<td>1.94%</td>
<td>7.54%</td>
<td>5.32%</td>
</tr>
</tbody>
</table>

### Extension:

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Rotation (°)</th>
<th>Angular Rate (°/s)</th>
<th>Z-Force (N)</th>
<th>Y-Moment (N·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>87.6</td>
<td>2419</td>
<td>-1552</td>
<td>-16.9</td>
</tr>
<tr>
<td>StDev</td>
<td>1.28</td>
<td>40.50</td>
<td>101.15</td>
<td>0.86</td>
</tr>
<tr>
<td>CV</td>
<td>1.46%</td>
<td>1.67%</td>
<td>6.52%</td>
<td>5.08%</td>
</tr>
</tbody>
</table>
Neck R&R – Lateral Bending

• **Inputs:** Pendulum impact to 6” aluminum honeycomb at 3.4 m/s
• **Outputs:**
  - Peak head X-rotation
  - Peak head angular rate about X-axis
  - Peak upper neck X-moment

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Rotation (°)</th>
<th>Angular Rate (°/s)</th>
<th>X-Moment (N·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>52.9</td>
<td>1347</td>
<td>28.6</td>
</tr>
<tr>
<td>StDev</td>
<td>1.11</td>
<td>27.03</td>
<td>0.64</td>
</tr>
<tr>
<td>CV</td>
<td>2.10%</td>
<td>2.01%</td>
<td>2.22%</td>
</tr>
</tbody>
</table>

Statistic Rotation Angular Rate X-Moment

Lateral
Neck R&R – Torsion

- **Inputs:** Pendulum impact to 6” aluminum honeycomb at 3.4 m/s using the modified THOR-50M torsion fixture
- **Outputs:**
  - Peak head Z-rotation
  - Peak head angular rate about Z-axis
  - Peak upper neck Z-moment

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Rotation (°)</th>
<th>Angular Rate (°/s)</th>
<th>X-Moment (N·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>52.0</td>
<td>1256</td>
<td>20.2</td>
</tr>
<tr>
<td>StDev</td>
<td>1.09</td>
<td>20.53</td>
<td>0.37</td>
</tr>
<tr>
<td>CV</td>
<td>2.09%</td>
<td>1.63%</td>
<td>1.83%</td>
</tr>
</tbody>
</table>
Neck Biofidelity
Neck Biofidelity

- All corridors are scaled to 5th female sizes according to the procedures in the Biomechanical Response Manual for the THOR 5th Dummy\(^1\)
- THOR-05F and HIII 5th were BioRanked using updates to the method detailed in Rhule’s 2018 IRCOBI paper\(^2\)

<table>
<thead>
<tr>
<th>Test</th>
<th>Specifications</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal Flexion Pendulum</td>
<td>5.00 ± 0.05 m/s</td>
<td>Mertz and Patrick 1971</td>
</tr>
<tr>
<td>Lateral Bending Pendulum</td>
<td>3.40 ± 0.05 m/s</td>
<td>Patrick and Chou 1976</td>
</tr>
<tr>
<td>Frontal Flexion Mini-Sled</td>
<td>Neck Flexion T1 Pulse</td>
<td>Thunnissen et al 1995</td>
</tr>
</tbody>
</table>


BioRanking

• Phase differences were removed and then the BioRank score (B) was calculated for each response measurement:

\[ B = \frac{DCAD}{CCSD} = \frac{Dummy \ Cumulative \ Absolute \ Difference}{Cadaver \ Cumulative \ Standard \ Deviation} \]

• For each test condition, the average BioRank score (B_{avg}) from the response measurements was calculated

• The B value represents multiples of standard deviation away from the target response
Neck Biofidelity – Frontal Flexion Pendulum

HIII 5th Neck Flexion

THOR-05F Neck Flexion

Head Rotation (deg)

Moment My at OC (Nm)
Neck Biofidelity – Lateral Bending Pendulum

HIII 5th Neck Lateral Bending

THOR-05F Neck Lateral Bending
THOR-05F Neck Biofidelity – Flexion Sled

<table>
<thead>
<tr>
<th>Parameter</th>
<th>B</th>
<th>B_avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Resultant Acceleration (g)</td>
<td>2.26</td>
<td></td>
</tr>
<tr>
<td>Head Angle (deg)</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Head CGx (mm)</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>Head CGz (mm)</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>Neck Angle (deg)</td>
<td>0.97</td>
<td></td>
</tr>
</tbody>
</table>
**HIII 5th Neck Biofidelity – Flexion Sled**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>B</th>
<th>B_{avg}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Resultant Acceleration (g)</td>
<td>1.67</td>
<td></td>
</tr>
<tr>
<td>Head Angle (deg)</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>Head CGx (mm)</td>
<td>2.24</td>
<td>2.05</td>
</tr>
<tr>
<td>Head CGz (mm)</td>
<td>1.33</td>
<td></td>
</tr>
<tr>
<td>Neck Angle (deg)</td>
<td>4.43</td>
<td></td>
</tr>
</tbody>
</table>

**Graphs:**

- Head Resultant Acceleration (g) vs. Time (s)
- Head CGx Displacement (mm) vs. Time (s)
- Head Angle (deg) vs. Time (s)
- Head CGz Displacement (mm) vs. Time (s)
- Neck Angle (deg) vs. Time (s)
Neck Biofidelity – Flexion Sled

Parameter | B | $B_{avg}$
---|---|---
**THOR-05F**
Head Resultant Acceleration (g) | 2.26 | 1.17
Head Angle (deg) | 1.01 | 
Head CGx (mm) | 0.64 | 
Head CGz (mm) | 0.96 | 
Neck Angle (deg) | 0.97 | 

Parameter | B | $B_{avg}$
---|---|---
**HIII 5th**
Head Resultant Acceleration (g) | 1.67 | 2.05
Head Angle (deg) | 0.59 | 
Head CGx (mm) | 2.24 | 
Head CGz (mm) | 1.33 | 
Neck Angle (deg) | 4.43 |
Neck Biofidelity – Flexion Sled

THOR-05F

HIII 5th
Neck Durability
Neck Durability

- Neck Durability test matrix
- Ran the R&R test modes at increasing energy levels

<table>
<thead>
<tr>
<th>Location</th>
<th>Test</th>
<th>Energy Increase</th>
<th>Impact Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck</td>
<td>Neck Frontal Flexion</td>
<td>Initial Baseline</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% Energy Increase</td>
<td>5.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20% Energy Increase</td>
<td>5.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30% Energy Increase</td>
<td>5.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final Baseline</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Neck Lateral Bending</td>
<td>Initial Baseline</td>
<td>3.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% Energy Increase</td>
<td>3.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20% Energy Increase</td>
<td>3.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30% Energy Increase</td>
<td>3.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final Baseline</td>
<td>3.40</td>
</tr>
<tr>
<td></td>
<td>Neck Torsion</td>
<td>Initial Baseline</td>
<td>3.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% Energy Increase</td>
<td>3.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20% Energy Increase</td>
<td>3.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30% Energy Increase</td>
<td>3.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final Baseline</td>
<td>3.40</td>
</tr>
<tr>
<td></td>
<td>Neck Extension</td>
<td>Initial Baseline</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% Energy Increase</td>
<td>5.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20% Energy Increase</td>
<td>5.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30% Energy Increase</td>
<td>5.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final Baseline</td>
<td>5.00</td>
</tr>
</tbody>
</table>
Neck Durability – Frontal Flexion

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification Range</th>
<th>Initial Baseline</th>
<th>+10%</th>
<th>+20%</th>
<th>+30%</th>
<th>Final Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Upper Neck $M_y$ (Nm)</td>
<td>15.05 18.4</td>
<td>17.9</td>
<td>17.2</td>
<td>17.8</td>
<td>18.3</td>
<td>18.3</td>
</tr>
<tr>
<td>Maximum Upper Neck $F_z$ prior to 40 ms (N)</td>
<td>684 836</td>
<td>717</td>
<td>818</td>
<td>873</td>
<td>970</td>
<td>764</td>
</tr>
<tr>
<td>Minimum Head Angular Velocity $\omega_y$ (relative to earth) (deg/s)</td>
<td>-2340 -1915</td>
<td>-2229</td>
<td>-2184</td>
<td>-2264</td>
<td>-2298</td>
<td>-2110</td>
</tr>
<tr>
<td>Minimum Head Rotation (relative to pendulum) (deg)</td>
<td>-87.3 -71.5</td>
<td>-82.3</td>
<td>-84.8</td>
<td>-86.8</td>
<td>-90.1</td>
<td>-81.0</td>
</tr>
</tbody>
</table>
# Neck Durability – Left Lateral Bending

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification Range</th>
<th>Initial Baseline</th>
<th>+10%</th>
<th>+20%</th>
<th>+30%</th>
<th>Final Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Upper Neck $M_x$ after 40.0 ms (Nm)</td>
<td>25.8 31.5</td>
<td>30.0</td>
<td>31.4</td>
<td>32.4</td>
<td>33.8</td>
<td>29.2</td>
</tr>
<tr>
<td>Minimum Head Angular Velocity $\omega_x$ (relative to earth) (deg/s)</td>
<td>-1482 -1212</td>
<td>-1318</td>
<td>-1348</td>
<td>-1406</td>
<td>-1421</td>
<td>-1281</td>
</tr>
<tr>
<td>Minimum Head Rotation (relative to pendulum) (deg)</td>
<td>-58.2 -47.6</td>
<td>-49.2</td>
<td>-53.0</td>
<td>-56.0</td>
<td>-58.4</td>
<td>-51.0</td>
</tr>
</tbody>
</table>

**Graphs:**

- **Angular Rate (deg/s)**
  - Initial Baseline
  - +10%
  - +20%
  - +30%
  - Final Baseline

- **X-Moment (Nm)**
  - Initial Baseline
  - +10%
  - +20%
  - +30%
  - Final Baseline

- **Neck Rotation (deg)**
  - Initial Baseline
  - +10%
  - +20%
  - +30%
  - Final Baseline
## Neck Durability – Left Torsion

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification Range</th>
<th>Initial Baseline</th>
<th>+10%</th>
<th>+20%</th>
<th>+30%</th>
<th>Final Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Upper Neck $M_z$ (Nm)</td>
<td>18.2 22.2</td>
<td>20.4</td>
<td>21.6</td>
<td>22.5</td>
<td>23.4</td>
<td>20.3</td>
</tr>
<tr>
<td>Minimum Neck Fixture Rotation (deg)</td>
<td>-57.2 -46.8</td>
<td>-48.7</td>
<td>-52.2</td>
<td>-54.5</td>
<td>-57.6</td>
<td>-50.2</td>
</tr>
<tr>
<td>Minimum Upper Neck Angular Velocity $\omega_z$ (relative to earth) (deg/s)</td>
<td>-1381 -1130</td>
<td>-1245</td>
<td>-1269</td>
<td>-1322</td>
<td>-1379</td>
<td>-1224</td>
</tr>
</tbody>
</table>

### Diagrams

- **Angular Rate (deg/s)**
  - Initial Baseline
  - +10%
  - +20%
  - +30%
  - Final Baseline

- **Z-Moment (Nm)**
  - Initial Baseline
  - +10%
  - +20%
  - +30%
  - Final Baseline

- **Neck Rotation (deg)**
  - Initial Baseline
  - +10%
  - +20%
  - +30%
  - Final Baseline

- **Time (s)**
  - 0 to 0.2
**Neck Durability - Extension**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification Range</th>
<th>Initial Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Upper Neck My (Nm)</td>
<td>-18.6</td>
<td>-15.2</td>
</tr>
<tr>
<td>Minimum Upper Neck Fz (N)</td>
<td>-1708</td>
<td>-1397</td>
</tr>
<tr>
<td>Maximum Head Angular Velocity (deg/sec)</td>
<td>2177</td>
<td>2661</td>
</tr>
<tr>
<td>Maximum Head Rotation (deg)</td>
<td>78.9</td>
<td>96.4</td>
</tr>
</tbody>
</table>
Neck Durability

- Neck Plate contact during initial baseline extension test
Neck Durability

- Post Test Teardown
Summary

• THOR-05F neck R&R testing shows good results with CVs < 10%

• Biofidelity
  • Neck Pendulum tests: THOR-05F shows better qualitative biofidelity than HIII 5th
  • Neck Flexion Sled tests: THOR-05F has a better BioRank score than HIII 5th

• THOR-05F neck durability is under further investigation
THOR-05F Neck R&R, Biofidelity, and Durability

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