## Agenda

<table>
<thead>
<tr>
<th>Start Time</th>
<th>Presenter</th>
<th>Topic/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00am</td>
<td>Networking; Teleconference Setup</td>
<td></td>
</tr>
<tr>
<td>9:30am</td>
<td>S. Ridella (NHTSA)</td>
<td>Introduction and Ground Rules</td>
</tr>
<tr>
<td>9:40am</td>
<td>D. Parent (NHTSA)</td>
<td>NHTSA THOR Update</td>
</tr>
<tr>
<td>10:15am</td>
<td>NHTSA VRTC/TRC</td>
<td>Qualification Procedures, Repeatability and Reproducibility</td>
</tr>
<tr>
<td>11:30am</td>
<td>P. Depinet (Humanetics)</td>
<td>Durability, Usability Updates</td>
</tr>
<tr>
<td>12:00pm</td>
<td>A. Kim (OSRP)</td>
<td>THOR Test Plan</td>
</tr>
<tr>
<td>12:15pm</td>
<td>Lunch</td>
<td>Cafeteria</td>
</tr>
<tr>
<td>1:30pm</td>
<td>M. Masuda (JAMA/JARI)</td>
<td>Experience with THOR in full-vehicle tests, seat positioning, and future research plan.</td>
</tr>
<tr>
<td>1:45pm</td>
<td>M. Panzer (UVA)</td>
<td>THOR FE Model Update</td>
</tr>
<tr>
<td>2:15pm</td>
<td>J. Zhao (Takata)</td>
<td>Implementation of THOR FE Model in AARP Project</td>
</tr>
<tr>
<td>2:30pm</td>
<td>P. Lange (TRW)</td>
<td>Experience with THOR in sled testing</td>
</tr>
</tbody>
</table>
NHTSA THOR Update

- Background
- Hardware and Drawing Package
- Biofidelity Evaluation
- Qualification Procedures
- Repeatability and Reproducibility
- Durability
- Provisional Injury Criteria
- NHTSA Research Applications
- Finite Element Model
History – THOR 50th Percentile Male

• THOR = Test Device for Human Occupant Restraint
  ▪ 50th percentile male anthropomorphic test device (ATD)


• Intended to leverage advances in biomechanical response and injury prediction capabilities developed after or not included in the Hybrid III design

• Implemented in NHTSA research projects dating back to 1999
  ▪ >100 tests in Vehicle Database
  ▪ >600 tests in Biomechanics Database

• Funded by NHTSA throughout development
Hardware and Drawing Package

1992
TAD-50M Prototype

2001
THOR Alpha

2005
THOR-NT
N = 4

2011-2013
THOR Mod Kit
N = 4

2014
THOR Metric
N = 3

2D, 3D Drawings Released to Website
THOR 50th Drawing Package

http://www.nhtsa.gov/Research/Biomechanics++Trauma/THOR+50th+Male+ATD

Hardware Description
- 2D Drawing Package, Draft (AutoCAD)
- 2D Drawing Package, Draft (Adobe Acrobat)
- 3D Parametric Model, Draft (Autodesk Inventor 1.5GB)
- 3D Parametric Model, Draft (Generic STEP)
- Parts List, Draft (Adobe Acrobat)

Documentation
- User’s Manual
- Biomechanical Response Requirements
- Qualification Procedures
- Instrumentation Processing Software
- Procedures for Assembly, Disassembly, and Inspection (PADI)
Biofidelity Evaluation Strategy

- Biofidelity Ranking System (Rhule, 2002)
  - Quantitative assessment
  - “BRS” or “BioRank”
  - BRS Score < 2.0 = Good biofidelity
    - ATD response as similar to the PMHS corridor as another individual PMHS response
  - Requires +/- 1 standard deviation response corridors as time-histories
    - Many corridors need to be recalculated
**Biofidelity Evaluation Conditions**

- **Head**
  - Head drop
  - Forehead impact
  - Face rigid bar
  - Face rigid disk

- **Neck**
  - NBDL frontal, lateral flexion
  - Torsional response (Duke University)

- **Thorax**
  - Blunt sternal impact (2013 ESV)
  - Lower thorax oblique

- **Abdomen**
  - Upper abdomen steering rim
  - Lower abdomen rigid bar

- **Knee/thigh/hip**
  - Femur compressive load (Rupp, 2003)
  - Knee slider (Balasubramanian, 2004)

- **Lower Extremity**
  - Dorsiflexion, plantarflexion, inversion, eversion

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**New or Modified since 2005 THOR Biomechanical Response Requirements**

To be included in an update to the Biomechanical Response Requirements

Update will also include BioRank evaluation for all conditions

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Neck – Dynamic Torsion

- BrIC injury criterion defined by head rotational velocity about $X$, $Y$, and $Z$ axes
- Neck response in $X$ and $Y$ defined by existing biomechanical response requirements, but not $Z$
- Study by Duke University (2014) carried out to evaluate the THOR Metric neck, including torsion response
- THOR torsion response initially stiff, but reasonable in injurious range
  - PMHS: $21 \pm 5$ Nm @ $63 \pm 18$ deg.
  - THOR: $25$ Nm @ 60-65 deg.
  - Hybrid III: $22$ Nm @ 8 deg.

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Thorax – Blunt Thoracic Impact

“Thoracic Biofidelity Assessment Of The THOR Mod Kit ATD” (Parent, 2013 ESV)

Kroell Corridor
23.4kg @ 4.3m/s

LeBarbé Corridor
23.4kg @ 4.3m/s

Bio Rank

Hybrid III | THOR-NT | THOR Metric w/SD-3

$\sqrt{R}_{deft}$ | $\sqrt{R}_{force}$ | $\sqrt{R}_{avg}$

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2005 THOR Biomechanical Response Requirements
- Based on Yoganandan, 1996
- 23.4kg impactor
- 150mm diameter rigid disk
  - 19mm thick Rubatex R-451N
- 4.3m/s impact velocity
- Response requirement:
  - Force-deflection response
  - Force time history
  - Deflection time history

Revised Biomechanical Response Requirements
- Same test conditions as above
- Revised corridor for response requirements
  - Recreated from test reports
  - Aligned by minimum cumulative variance
  - Corridor of 1 standard deviation about mean
Abdomen – Upper Abdomen Steering Rim

- 2005 THOR Biomechanical Response Requirements
  - Based on Nusholtz, 1994
  - 18kg impactor
  - Steering rim impactor
  - 8.0m/s impact velocity
  - Response requirement:
    - Force-deflection response

- Revised Biomechanical Response Requirements
  - 6.7m/s impact velocity
  - Revised corridor for response requirements
    - Recreated from Nusholtz raw data
    - Aligned by minimum cumulative variance
    - Corridor of 1 standard deviation about mean
KTH – Femur Compressive Load

- 2005 THOR Biomechanical Response Requirements
  - N/A

- Revised Biomechanical Response Requirements
  - Based on Rupp 2003
  - Pot femoral head in acetabulum cup
  - Load molded knee interface
  - 250kg platform at 1.2m/s
  - Response requirement:
    - Force-deflection response
2005 THOR Biomechanical Response Requirements

- Not explicitly stated (uses stock Hybrid III knee slider)

Revised Biomechanical Response Requirements

- Based on Balasubramanian 2004

- Same test as Hybrid III knee slider
  - 12kg impact to 1kg transfer mass at 2.75m/s

- Response requirement:
  - Force at 5mm deflection (Primary)
  - Force at 10mm deflection (Secondary)
  - Force at 18mm deflection (Primary)
Qualification Procedures

- Until now: THOR Certification Procedures Manual, 2005 (NHTSA website)

- Updates underway during R&R @ VRTC to:
  - Simplify
    - Minimize post-processing
    - Remove high-velocity pendulum tests
    - Remove difficult to acquire/specify foams
  - Improve documentation of procedures, post-processing
  - Update qualification requirements ("cert boxes") based on THOR Metric response

- Draft of Qualification Procedures Manual will be posted to THOR 50th website for review

- Longer-term updates
  - Add qualification tests for neck torsion, thoracic and lumbar spine flexion, and neck occipital condyle joint rotation
Methodology

- Perform repeated tests in all qualification conditions
  - 16 tests x 5 tests/ATD x 3 ATDs = 240 tests
- Quantify results using coefficient of variation (CV) and correlation analysis

Findings to date

- See VRTC presentation
Failures have occurred in sled tests (rear seat, frontal oblique)

Failures have been repaired by welding, but some have broken again

Modification of part is necessary

- Humanetics presented design update at THOR meeting after IRCOBI
- Cellbond ATD presented design update at ISO meeting
- NHTSA-VRTC investigating other options
Durability – Delamination

• Separation of rubber from metal in molded parts

• Typically indicated through visual inspection
  ▪ Neck (472-2120)
  ▪ Thoracic spine flex joint (472-3646)
  ▪ Lumbar spine flex joint (472-3746)
  ▪ Ribs (472-33[1-7]0)

• Influence on response should be assessed by qualification test
  ▪ Neck – flexion, extension, lateral bending
  ▪ Thoracic spine flex joint – under development
  ▪ Lumbar spine flex joint – under development
  ▪ Ribs – blunt thoracic impact or lower thorax oblique impact
Durability in Vehicle Crash Tests

- NHTSA Oblique Testing
  - ~45 NHTSA-sponsored tests at Calspan
  - ~30 OEM-sponsored vehicle tests with NHTSA THORs
  - ~15 OEM-sponsored sled test representations of Oblique vehicle test with NHTSA THORs

- Occasional lost channels, but no significant damage

- One SOI test resulted in damage to femur, but there were other contributing factors
  - Significant intrusion, manufacturing defect and/or drawing deficiency (which has since been rectified)
Provisional Injury Criteria

- **Head**
  - HIC15 (FMVSS No. 208, NCAP)
  - BrIC (Takhounts, 2013)

- **Neck**
  - Nij, neck tension (Dibb, 2006)

- **Thorax**
  - Multipoint thoracic injury criterion (In review, 2015)

- **Abdomen**
  - Peak deflection (Kent, 2008)

- **Knee/thigh/hip**
  - Acetabulum peak resultant force (Rupp, 2010; Martin, 2011)
  - Femur axial load (Kuppa, 2001)

- **Lower Extremity**
  - Tibia axial force, revised tibia index, ankle rotation and/or moment (Kuppa 2001)
Multipoint Injury Criteria Development
Current NHTSA Research Applications

- Frontal Oblique Test Program

- Advanced Adaptive Restraints
  - Takata
  - THOR FE Model

- Advanced Rear Seat Restraints
  - UMTRI/TRW
  - THOR MADYMO model
See University of Virginia presentation

Will be released through NHTSA website once Certification Suite is run and User’s Manual is complete
<table>
<thead>
<tr>
<th>Bio or Vehicle</th>
<th>Test Numbers</th>
<th>Test Performer</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Bio</td>
<td>10965-10970</td>
<td>VRTC</td>
<td>Neck qualification tests</td>
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<tr>
<td>Bio</td>
<td>10996-11013</td>
<td>JARI</td>
<td>Neck biofidelity and qualification tests</td>
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<tr>
<td>Bio</td>
<td>11017-11022</td>
<td>UVA</td>
<td>SD-2 Shoulder evaluation</td>
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<tr>
<td>Bio</td>
<td>11070-11114</td>
<td>NASA</td>
<td>Evaluate the THOR ATD in spaceflight specific orientations and accelerations</td>
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<tr>
<td>Bio</td>
<td>11117-11145</td>
<td>UVA</td>
<td>Injury criteria development sled test series</td>
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<tr>
<td>Bio</td>
<td>11146-11205</td>
<td>JARI</td>
<td>Qualification tests, sled tests, vehicle tests</td>
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<tr>
<td>Bio</td>
<td>11342-11455</td>
<td>VRTC</td>
<td>Qualification tests</td>
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<tr>
<td>Bio</td>
<td>11456-11501</td>
<td>UVA</td>
<td>2 years worth of THOR data</td>
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<tr>
<td>Vehicle</td>
<td>Various</td>
<td>Calspan</td>
<td>NHTSA Oblique RMDB tests</td>
</tr>
</tbody>
</table>

Pending (not yet released to public database)
Questions?