Thoracic Injury Assessment for Improved Vehicle Safety

Introduction and Status per April 2012
GRSP IG Frontal Impacts

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The trend of increasing performance of vehicles in consumer rating programs is in contradiction with observations from accident data.

This is due to several reasons among which the usage of Hybrid III dummies developed in the late 70ties.

HIII thorax was designed to assess injury risk related to localized hub type loading of an adult male.

State of the art restraints use load limiter belts in combination with multi stage bags which result in a different load case and sensitivity range.
The aim of the THORAX project is to develop numerical and experimental tools for the optimisation and assessment of frontal restraints for a wide variety of car occupants (age, gender, size)

- Identification of the two most relevant thoracic injury types from real world accident data
- Characterization of injury mechanisms and governing parameters for these injury types, quantifying effects of user diversities like age
  - Using PMHS test data and HBM simulations
- Development of hardware demonstrator consisting of a new thorax / shoulder design implemented in THOR NT dummy
- Development of injury risk functions
- Assessment of the sensitivity of the hardware demonstrator to modern vehicle safety systems and usability in safety system optimization
Project Structure

WP1: Accident Analysis
- Prioritisation of thoracic injuries
- Real world accident outcome versus crash test results
- Benefit estimation

WP2: Biomechanics
- Biomechanical requirements
- Volunteer testing
- Injury mechanisms & assessment crit.
- PMHS testing
- Injury risk curves

WP3: Demonstrator design
- Requirements
- Dummy concepts
- Design and prototype development
- Validation of biomechanical performance

WP4: Assessment for restraint optimization
- Load cases and evaluation criteria
  - Testing
  - Data analysis
WP1 Accident surveys

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WP1 Comparison accident cases / Euro NCAP test

**Collision / Accident Data**

- **Make:** Audi
- **Model:** A3
- **Collision speed (kph):** 34
- **Collision object hit:** Car
- **Component Intrusion:** None

**Driver (right side): Personal data**

- **Gender:** Male
- **Age:** 26

**Passenger (left side): Personal data**

- **Gender:** Female
- **Age:** 26

**Euro NCAP Test:**

- **Tested model:** Audi A3 1.6
- **Hand of drive:** RHD
- **Body type:** Small family car
- **Year of publication:** 2003

**Frontal Impact Test:**

The restraint system used a single stage tethered airbag with belts fitted with pretensioners and load limiters. These worked well although loads on the occupants’ chests were a little high. Unfortunately, the driver risked knee injuries from hard points behind the fascia. The body proved very strong after the impact showing minimal distortion around the sill and screen pillar areas, while the footwell suffered only minor deformation.

**Summary:** Euro NCAP predicted adequate protection for the thorax for front seat passenger. This occupant sustained only one injury to this region; however, a clavicle fracture seems harsh given the age of the occupant and the low delta-v of the crash. The PSL load limiter was not activated and was possibly set too high for clavicle protection. The pretensioner activated.

**Typical case for younger occupants**
WP2 Biomechanical requirements

<table>
<thead>
<tr>
<th>Body region</th>
<th>Type</th>
<th>Absolute / Relative</th>
<th>EEVC (ESV 2003)</th>
<th>NHTSA (GESAC 2005)</th>
<th>ACEA/ISO (Draft June 2010)</th>
<th>THORAX (Draft October 2010)</th>
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<tbody>
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<tr>
<td>Shoulder</td>
<td>Sled</td>
<td>Absolute</td>
<td>Vezin (2002)</td>
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<td></td>
<td></td>
<td></td>
<td>Two restraint conditions; two speeds</td>
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<tr>
<td></td>
<td>Quasi-static</td>
<td>Absolute</td>
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<td>None defined</td>
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<td></td>
<td>Table-top</td>
<td>Relative</td>
<td>Schneider (1992)</td>
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<td></td>
<td></td>
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<td>Quasi-static thorax regional coupling</td>
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<td>Cesari and Bouquet (1990) Belt loading – relative regional compression</td>
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<td>Thoracic spine</td>
<td>Sled</td>
<td>Absolute</td>
<td>Vezin (2002) - NB: more tests required</td>
<td>None defined</td>
<td>None defined</td>
<td>Shah (2009) - 3 pt seat-belt, 40 kph</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Sled: see shoulder</td>
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<tr>
<td></td>
<td>Quasi-static component</td>
<td>-</td>
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<td>Several tentative proposals (mostly embalmed PMHS)</td>
<td>None defined</td>
<td>None defined</td>
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<tr>
<td></td>
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<td></td>
<td>FrONTAL RIGID IMPACTOR: 23.4 kg; 4.3 and 6.7 m/s</td>
<td>Based on Kroell (1971),</td>
<td>Based on Kroell (1971),</td>
<td>Based on Kroell (1971),</td>
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<td></td>
<td></td>
<td></td>
<td>Neathery (1974)</td>
<td>INRETS, and CEESAR</td>
<td>INRETS, and CEESAR</td>
<td>INRETS, and CEESAR</td>
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<tr>
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<td>Frontal Rigid Impactor: 4.3 m/s</td>
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<td>data</td>
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<td>Lebarbè (2010)</td>
<td>Pendulum Impactor tests based on Kroell (1971),</td>
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<td>FrONTAL Rigid Impactor: 23.4 kg; 4.3 m/s</td>
<td>INRETS, and CEESAR</td>
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<td>INRETS, and CEESAR</td>
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<td></td>
<td>Oblique padded Impactor: 23.4 kg; 4.3 m/s</td>
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WP2 Injury mechanism and assessment criteria

Combined deflection $D_c$:

$$D_c = D_s + c_f \left(\Delta D - L_c\right) + |\Delta D - L_c|$$

- $D_s$ = Mid sternal deflection
- $\Delta D$ = Lower thorax differential deflection
- $L_c$ = Characteristic length
- $c_f$ = correction factor

Will be analysed further in future THORAX activities with HBM’s and hardware demo and included in risk curve development.
WP2 Influence of rib cage geometry

Influence of rib initial angle on the deflection mechanism (adapted from Kent et al. 2005a)

- Vertical rib cage: More joint rotation, less bone strain
- Horizontal rib cage: Less joint rotation, more bone strain

Approach will be used to support further studies into the injury assessment criteria and development of risk curves.
Base design 2010 THOR NT with updated pelvis, femur, knee, neck installed
Include instrumentation to study proposed & existing assessment criteria
Minor updates in chest stiffness
Using updated SD2 shoulder and adjusted arms
In dummy DAS
Dummy updates

- Upper arm redesign matching UMTRI data
- WorldSID arm load cell
- In dummy DAS
- Modified SD2
- Clavicle load cell
- Strain gages
- Biofidelity response tuning
SD2 changes

- Coracoid and scapula parts now combined into one
- Clavicle same profile as SD2
  Durable ball and clevis joint
- Revised humerus joint based on THOR adjustable friction and stable position
- Corrected Sterno-Clavicular joint position to match UMTRI
- Simplified shapes for machining
SD2 changes

- Improved bearing material on all shafts
- Shoulder pivot, spring housing, rib shelf integrated
- Threaded hole for position measurement and film target mount
- PTFE pad removed metal parts to have low friction coating
- Rib 2 Interference removed
- Adjustable joint friction with Belleville washers
Based on NHTSA 2005 Biofidelity 4.3m/s pendulum test corridor without muscle tension

Changes include

- Reduction of damping material thickness
- Ensolite foam ¼” inside jacket
- Mean upper CRUX X displacement
- 3 repeats on 3 rib sets
- Lebarbe frontal Biofidelity corridors 4.3m/s pendulum test corridor without muscle tension, based on external chest deflection
  - (includes soft tissue compression outside the ribs)
- Summation of CRUX X displacement and calculated jacket compression
- 3 repeats on 3 rib sets
Harmonization NHTSA / FP7 THORAX

- Good exchange of info EU FP7 THORAX and NHTSA

- Thorax
  - Chest stiffness aligned
  - Both using 4 3-D IRTRACC’s for multiple point assessment criteria
  - EU FP7 THORAX also uses strain gages for local strain based assessment criterion

- Shoulder
  - EU FP7 THORAX has updated the SD2 shoulder to improve robustness etc.
  - Taking into account remarks from US
  - Updated shoulder will be provided to UVa for testing
  - First evaluation meeting UVa / NHTSA planned for July timeframe involving THORAX partners

- Other dummy parts
  - EU FP7 THORAX uses THOR dummies with upgrade kit for pelvis, femur and knee
  - Neck not included as this is minor detail only
  - Lower leg not included as this part is not influencing the thorax response

- Assessment criteria
  - Open dialogue between US and THORAX on criteria
  - French proposals: local NFR and global Dc (sternum deflection and left – right differential in lower thorax)
  - UVa studying extended version of Dc (using left – right differential in lower and upper thorax)
<table>
<thead>
<tr>
<th>Year</th>
<th>Activities</th>
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<tbody>
<tr>
<td>2009</td>
<td>Accident surveys, PMHS and Volunteer Testing</td>
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<tr>
<td>2010</td>
<td>Requirements shoulder / thorax complex, NHTSA Biom. Workshop, STAPP Car Crash Conference</td>
</tr>
<tr>
<td>2012</td>
<td>Certification procedures, Evaluation Restraint &amp; loading sensitivity, durability, R&amp;R, handling</td>
</tr>
<tr>
<td>2013</td>
<td>April 2013 end of project</td>
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</tbody>
</table>

**GRSP IG Frontal Impacts**
THOR Activities NHTSA

Upgraded dummies

Fully metric dummy

**Repeatability**
- Kinematics
- Kinetics

**Reproducibility**
- Dummy-to-dummy
- Lab-to-lab

**Biofidelity**
- vs. PMHS
- vs. Hybrid III

**Certification**

**Sled Testing**

**Vehicle Testing**

**Durability**
- Robustness
- Repair History

**Usability**
- Data quality
- User Feedback

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Timeline THOR Activities NHTSA

2010
JA SO ND JF MA MJ JA SO ND JF MA MJ JA SO ND JF MA MJ JA SO ND

HARDWARE
Completed Mod Kit THOR-NT (#1)
Repeatability Usability Durability
Injury Criteria Development
Biofidelity Evaluation

Task 1.3 Mod Kit upgrade of THOR-NT (#2)
Repeatability Reproducibility Usability Durability

Task 2.2 Fabrication of complete Mod Kit THOR-NT (#3)
Repeatability Reproducibility Usability Durability

Task 1.4 Draft Mod Kit TDP
Task 2.3 Draft Mod Kit TDP

Completed

Completed

Completed

2011

2012

2013
JF MA MJ JA SO ND

End of THORAX project

Round-Robin Testing

Injury Criteria Development

Evaluation and Documentation of Durability, Usability, Biofidelity

Finalization of Procedures: Certification, Seating, Data Processing

Milestone: THOR-NT TDP

Milestone: Final Mod Kit TDP

Milestone: NHTSA Agency Decision

KEY:
Completed
In Progress
Planned
Key work items for next period

- 3 prototype dummies shipping to partners next week for testing
  - Currently being tested at Humanetics
- Evaluation biomechanical performance May – July 2012
- Development of Injury Risk curves by Sept 2012
  - Including consideration of age
- Sled testing to assess dummy performance for restraint optimization Aug 2012 – Jan 2013
- 1 set of shoulders being provided to US for evaluation

Outlook

SAE 2012 Government/Industry Meeting
Please visit [www.thorax-project.eu](http://www.thorax-project.eu) for more information