Parametric Study of Pre-Crash Vehicle Maneuvers and Occupant Safety Performance Response

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Education
PhD, Mech. & Aero. Engineering, Univ. of Virginia  May 2005
Diploma (BS & MSc) Applied Mathematics: Solid Mechanics May 1996
University of Bucharest, Romania
Diploma (BS & MSc) Mechanical Engineering May 1990
“Politehnica” University of Bucharest, Romania

Professional Experience
Associate Professor of Biomedical Engineering 2015-present
Research Associate Professor 2011-2015
Virginia Tech and Wake Forest University
Research Assistant Professor 2008-2011, Univ. of Virginia

Dr. Costin Untaroiu is currently an Associate Professor of Biomedical Engineering & Mechanics at Virginia Tech. Dr. Untaroiu has a vast experience in the field of Computational Mechanics and Biomechanics. He is co-author of more than 80 peer reviewed journal papers and more than 100 conference papers. Dr. Untaroiu has extensive experience in rigid-body and finite-element modeling, including probabilistic models. He is also a Fellow of ASME.
Research Interests
Finite Element Optimization/Probabilistic Design
Applications of Pattern recognition techniques
Crashworthiness simulations
RestRAINT performance and optimization for impact mitigation
Injury biomechanics esp. lower limb trauma

Current Projects

• Model Capability to Quantify Injury Risk for eVTOL Vehicles - NASA
• Assessment, Evaluation, and Approaches to Modifications of FMVSS that may Impact Compliance of Innovative New Vehicle Designs Associated with Automated Driving – NHTSA
• GHBMC Center of Expertise in Full Body Models Phase III - GHBMC
• Characterization and Modeling of Different Snow Attributes for Tire Performance Simulation - CenTiRE
• Characterization and Modeling of Deformable Soils for Tire Performance Simulation - CenTiRe
During an autonomous emergency braking (AEB) maneuver, the occupants change their posture, position, and velocity relative to the car interior and restraint systems.\(^1\)

The level of muscle contraction has been identified as a significant factor to determine the forward displacement of volunteers subjected to braking pulses.\(^2\)

**occupant kinematics during pre-crash influences the occupant interaction with restraint systems and the resulting injury measures.**\(^3\)

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1. Carlsson & Davidsson 2011
2. Ejima et al 2009
3. Antona et al. 2011
Introduction: Crash FE simulation

- Classical FE Crash simulation – in the passive safety area (without pre-crash)

$$t = 0 \text{ ms (crash starts)}$$

- New FE Crash simulation in the active and pre-triggered passive area (with pre-crash)$^{1,2}$

$$t < t_a \quad (t_a \sim 1500/-2000 \text{ ms})$$

$$t = 0 \text{ ms (crash starts)}$$

• Develop a tool to reduce the computational effort of simulating both pre-crash and in-crash FE simulations.

• Investigate the influence of passengers’ pre-crash maneuvers on injury response in a frontal crash scenario.

• Perform a parametric study to study the influence of Seat characteristics and Occupant Anthropometry/Age
Methods: Design of Experiments (DOE)

Design variables

Occupant characteristics
1. Age
2. BMI
3. Stature
4. Sex

Seat positioning
1. Seat track
2. Seat Recline Angle
3. Seat Cushion Angle

Pre-crash maneuvers
1. Braking
2. Turn-and-brake

Braking

Turn-and-brake
Methods: Design of Experiments (DOE)

Occupant characteristics (12 models)
- Age: 2 levels (20 year-old and 70 year-old)
- BMI: 2 levels (25 and 40)
- Stature & Sex: 3 levels (F05, M50, M95)

Seat Characteristics
- Seat Track: 2 levels
- Seat recline angle: 2 levels
- Seat cushion angle: 2 levels

Pre-Crash Maneuvers
- Breaking/Turn-and-brake: 2 levels

Full-Factorial DOE: $12 \times 2 \times 2 \times 2 = 196$ simulations

Reduced Factorial DOE (Latin Hypercube sampling): 56 simulations

Methods: Pre-Crash Simulations - Challenges

- Computational cost of running long pre-crash simulations
  - use separate FE models for pre-crash (simplified) and in-crash (detailed)
- Introduce muscle activation during pre-crash
  - An active rigid human model (GHBMCsi-pre\textsuperscript{1}) was calibrated to volunteer sled test kinematic
- Integrate the output of pre-cash human model with in-crash human model
  - Develop a switch algorithm: a segmentation approach for transferring pre-crash kinematics.


Head excursion of passive and active GHBMCsi-pre (M50) model in pre-crash simulations

- Corridor
- Passive - Rigid seat
- Passive - Deformable seat
- Active level 5
- Active level 6
- Active level 7
- Active level 8
- Active level 9
- Active level 10

Head excursion (mm)

Time (ms)
Methods: Switch algorithm: Data transfer from Pre-crash to In-crash

Run Pre-crash:
Optimize Active Level

Save posture and kinematics for optimal activation
(Segmentation Approach)

Reposition using UMTRI MATLAB tool

Morphing using Altair HyperWorks

Assign the pre-crash kinematics to GHBMC-si models
(Switch Algorithm)

Run In-crash:
Input ready in the desired posture

Methods: Switch algorithm: GHBMC In-crash Models

Methods: Pre-Crash Simulations with GHBMCSI-pre\textsuperscript{1,2}

Honda Accord 2013 FE Model (NHTSA database)

Pre-crash Pulse

\[ \sim 2000\text{-}3000 \text{ ms} \]

Pre-crash brake:
Drop in X - velocity $\sim 16.02$ m/s (57.67 km/h)
At the end of pre-crash brake: 56 km/h

Pre-crash Turn-and-brake:
Drop in X - velocity $\sim 15.4$ m/s (55.44 km/h)
Drop in Y - velocity $\sim 11.5$ m/s (41.4 km/h)
At the end of pre-crash brake: 56 km/h

Methods: In-Crash Simulations with integrated pre-crash dynamics

Crash Pulse

~150 ms

Acceleration pulse for in-crash simulations (56 km/h)
Results: Classical approach vs. New Approach with integrated pre-crash dynamics

Without Precrash
(Standard position)

With Precrash
(After braking)
Results: Classical approach vs. New Approach with integrated pre-crash dynamics

With Precrash (After braking)

<table>
<thead>
<tr>
<th>Crash Scenario</th>
<th>HIC15</th>
<th>BrIC</th>
<th>Nij</th>
<th>Chest Deflection (mm)</th>
<th>VC_max</th>
<th>Femur Force (N)</th>
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</thead>
<tbody>
<tr>
<td>Without Precrash</td>
<td>559</td>
<td>0.58</td>
<td>0.00043</td>
<td>58</td>
<td>0.00</td>
<td>2696</td>
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<td>With Precrash - Brake</td>
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<td>0.00</td>
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<tr>
<td>With Precrash - Turn and Brake</td>
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<td>0.52</td>
<td>0.00036</td>
<td>57</td>
<td>0.00</td>
<td>1947</td>
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</tbody>
</table>

Graph showing resultant head acceleration over time with different scenarios.

$t = 0$ ms  
$t = 45$ ms  
$t = 70$ ms  
$t = 100$ ms
**Male 50th Percentile**

<table>
<thead>
<tr>
<th>Crash Scenario</th>
<th>Injury Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$HIC_{15}$</td>
</tr>
<tr>
<td>Without Precrash</td>
<td>559</td>
</tr>
<tr>
<td>With Precrash - Brake</td>
<td>208</td>
</tr>
</tbody>
</table>

**Results: Injury Criteria**
Results: Our results vs. the literature

HIC

Without PCB  With PCB

Nij

Without PCB  With PCB

Chest Deflection

Without PCB  With PCB

Head injuries (HIC) are most sensitive to Seat Recline Angle and Seat Track position.

Both the seat characteristics change the position of head with respect to the airbag significantly.

This influences the interaction timing and duration of the head impact with the passenger airbag.
Results: DOE Preliminary results

- **Head** most sensitive to **Seat Track position** and **Seat Recline Angle**.
- **Brain** most sensitive to **Maneuver type**, **Human Size** and location of seat track.
- **Neck** highly sensitive to **Maneuver type** and **Seat Recline Angle**.
- **Thorax** significantly sensitive to **BMI** and **Seat Track position**.
- **Abdomen** risks were negligible but most sensitive to **Human Size**, **Seat Recline Angle** and **Maneuver types**.
- **Femur** was most sensitive to **Human Size**.

- Larger risks associated with **Seat Recline Angle**, **Seat Track position**, **Human Size**, and **Maneuver type**.
- **Seat Cushion Angle** and **Age** had smallest influence.

![Global sensitivity analysis](image)
• The pre-crash models were calibrated using optimization only in terms of the time histories of head excursion

• The developed switching algorithm does not transfer the stress/strain from pre-crash phase to in crash phase

• The “young” and “old” GHBMC have different geometries, but they shared the same material properties

• The statistical results depends on the chosen ranges of the variables (and DOE scheme)
Acknowledgements

• Thanks to the NHTSA for funding this study and ZF for help on debugging the airbag passenger airbag model.

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Thank You