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.

Prof. Costin Untaroiu

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

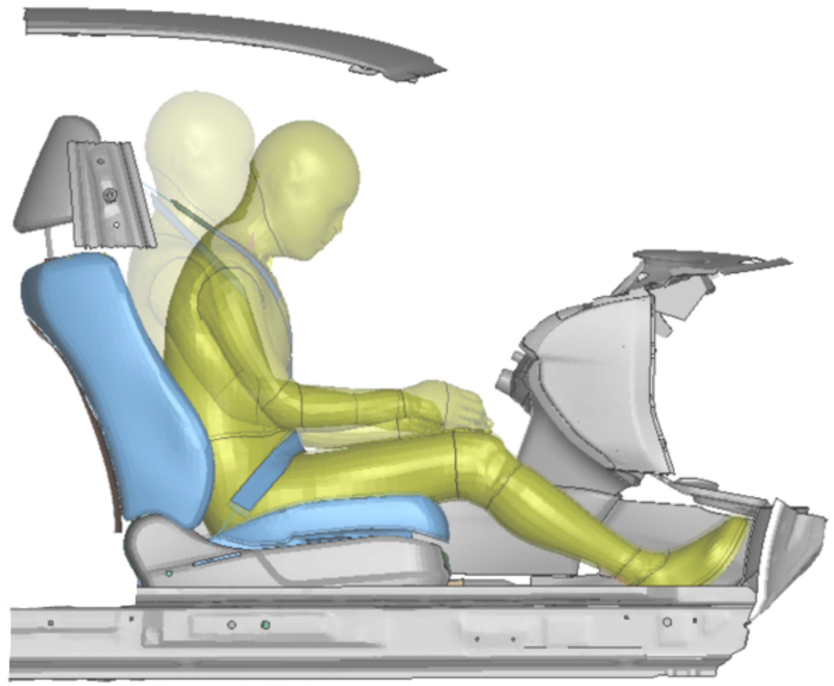
- Model Capability to Quantify Injury Risk for eVTOL Vehicles - NASA
- Assessment, Evaluation, and Approaches to Modifications of FMVSS that may Impact Compliance of Innovative New Vehicle Designs Associated with Automated Driving – NHTSA
- GHBMC Center of Expertise in Full Body Models Phase III - GHBMC
- Characterization and Modeling of Different Snow Attributes for Tire Performance Simulation- CenTiRE
- Characterization and Modeling of Deformable Soils for Tire Performance Simulation - CenTiRe

Introduction: Pre-Crash Occupant Maneuvers

- 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].

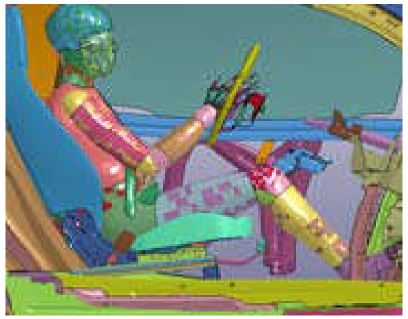


Occupant posture changes during braking.

[1] Carlsson & Davidsson 2011
[2] Ejima et al 2009
[3] Antona et al. 2011

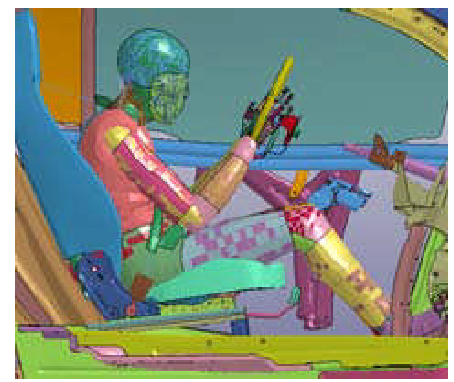
Introduction: Crash FE simulation

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



t= 0 ms (crash starts)

- New FE Crash simulation in the active and pre-triggered passive area (with pre-crash)[1,2]



$t < t_a$ (t_a ~-1500/-2000 ms)

t= 0 ms (crash starts)

[1] Ghosh et al 2015
[2] Öztürk et al 2019

Introduction: The Objective

- 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

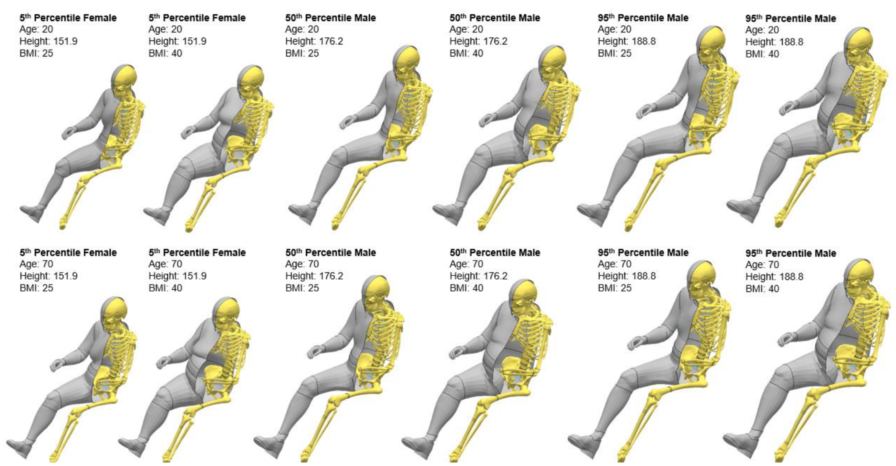
Methods: Design of Experiments (DOE)

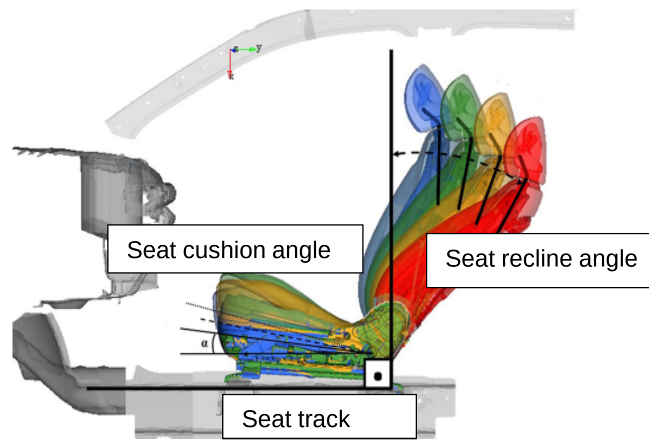
Design variables

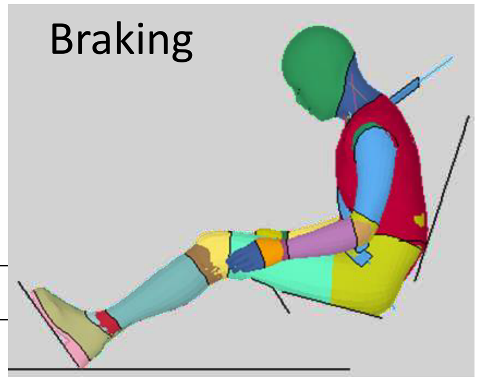
Occupant characteristics
1. Age
2. BMI
3. Stature
4. Sex

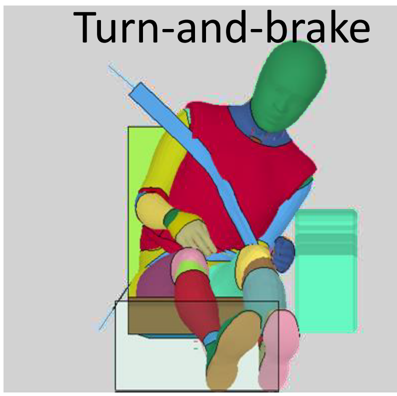
Seat positioning
1. Seat track
2. Seat Recline Angle
3. Seat Cushion Angle

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

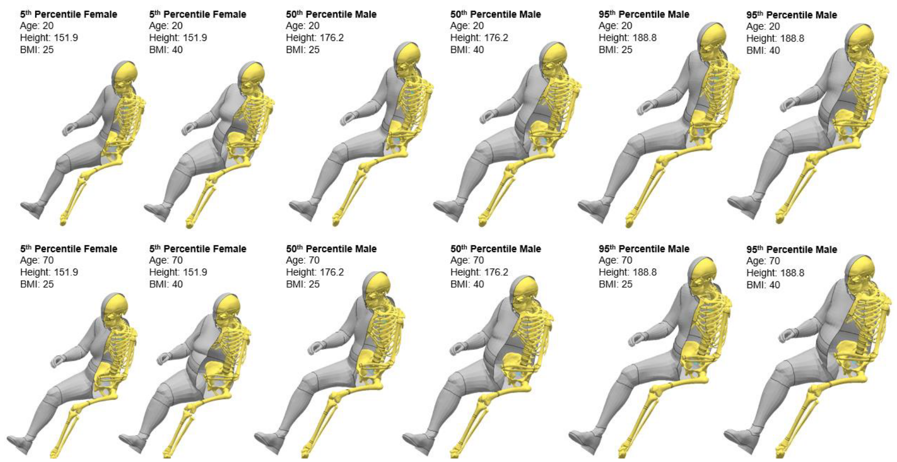


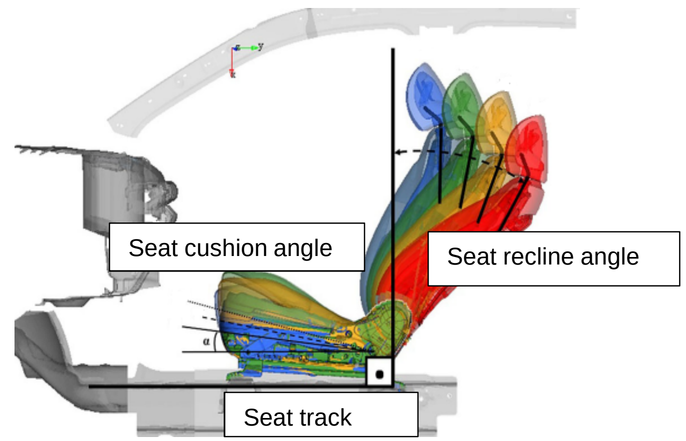


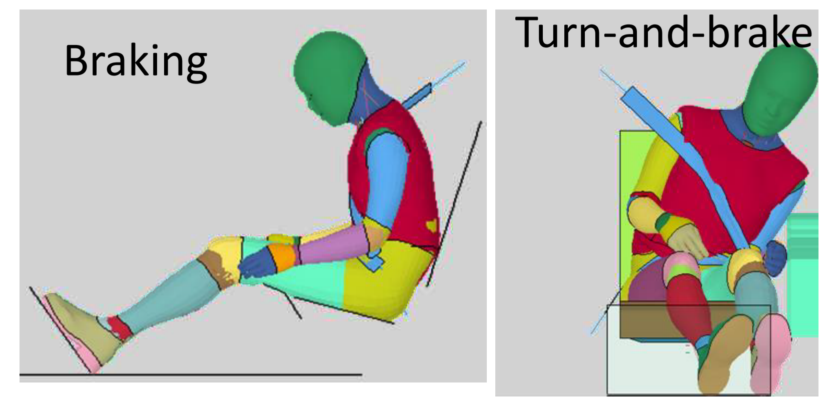




Methods: Design of Experiments (DOE)







Occupant characteristics[1] (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[2]

- Breaking/ Turn-and-brake:2 levels

Full-Factorial DOE: 12 x 2 x 2 x2 x 2 = 196 simulations

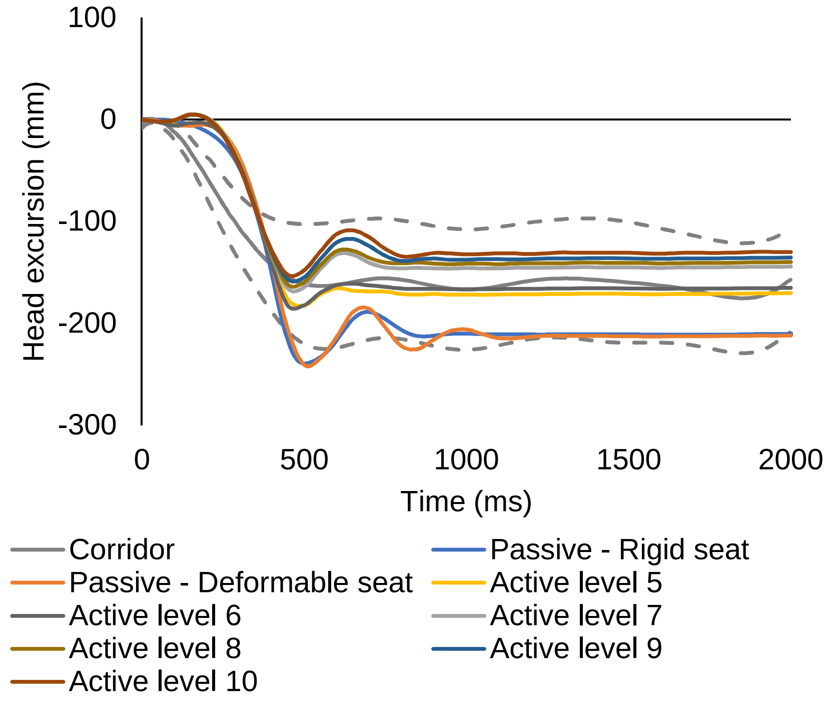
Reduced Factorial DOE (Latin Hypercube sampling: 56 simulations

[1] Hu et al 2019
[2] Hu et al 2020

Methods: Pre-Crash Simulations - Challenges

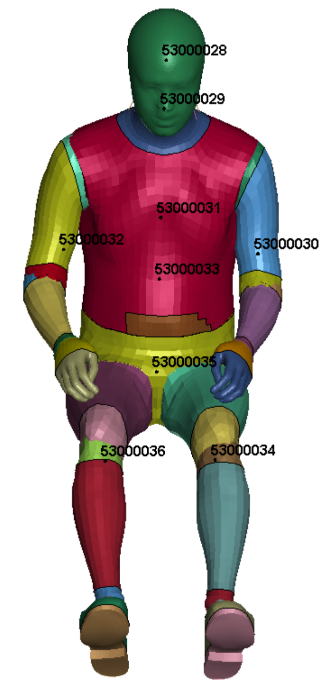
- Computational cost of running long pre-crash simulations
  - ➢ use separate FE models for pre-crash (simplified) and in-crash (detailed)
- Introduce muscle activation during pre-crash
  - ➢ An active rigid human model (GHBMCsi-pre[1]) was calibrated to volunteer sled test kinematic
- Integrate the 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



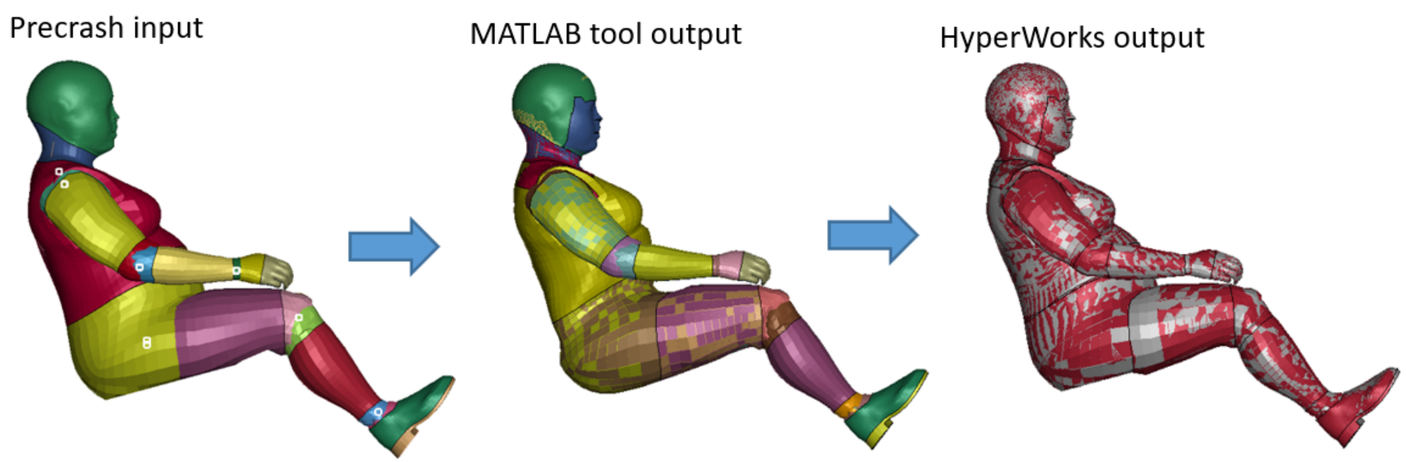
[1] Hu et al 2019

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**

Body regions/segments
Head
Neck
Upper extremity - Left
Thorax - Axial
Upper extremity - Right
Abdomen
Lower extremity - Left
Pelvis
Lower extremity - Right



[1] Hu et al 2019

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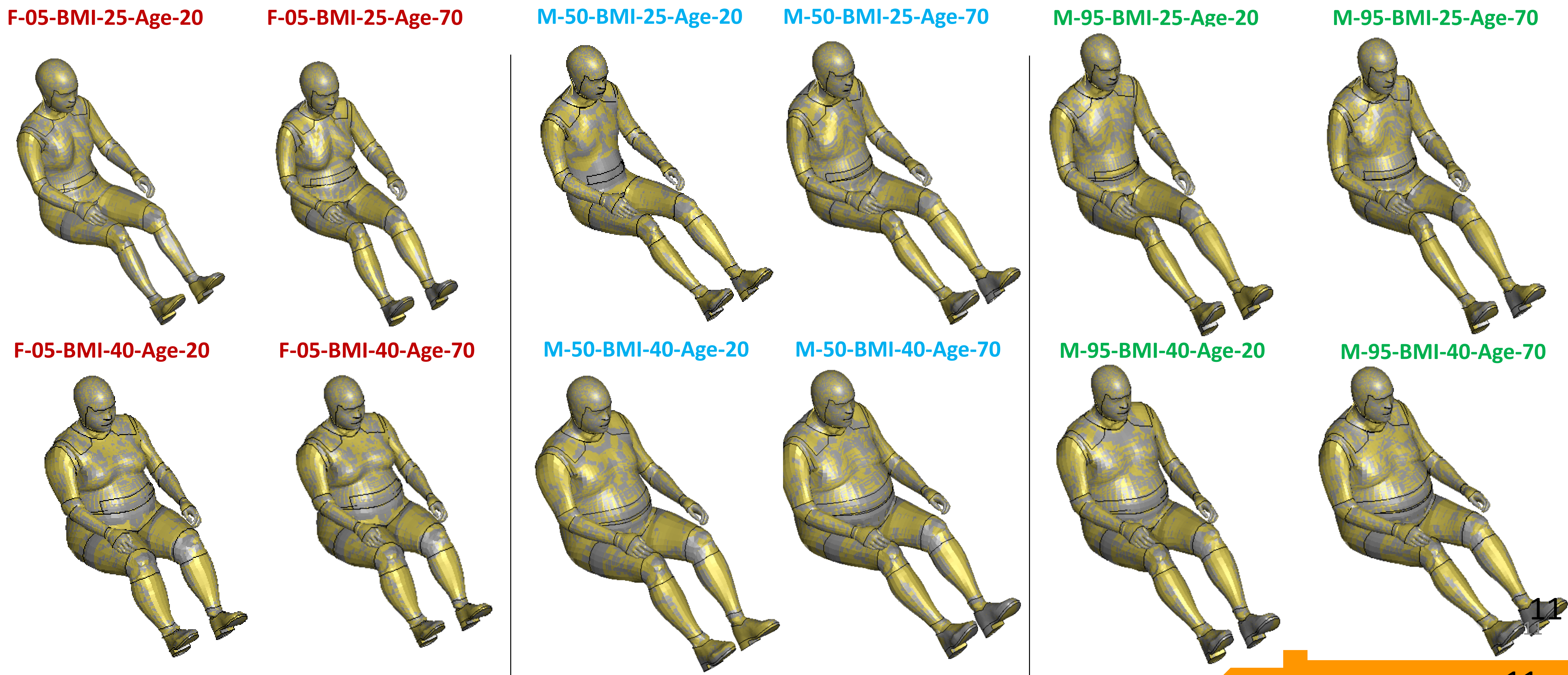
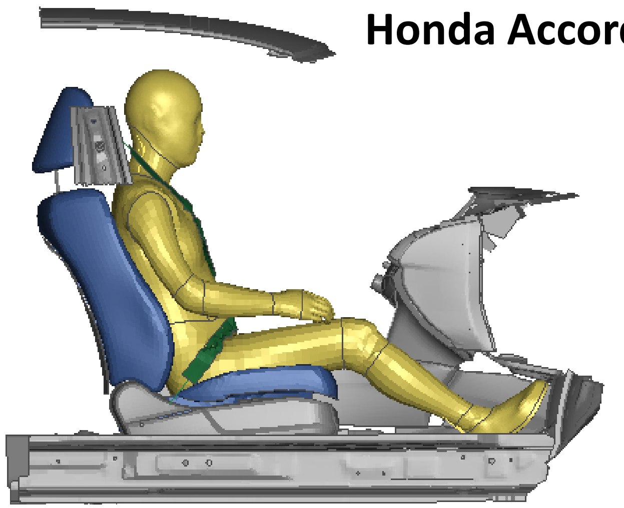
Methods: Switch algorithm: GHBMC In-crash Models



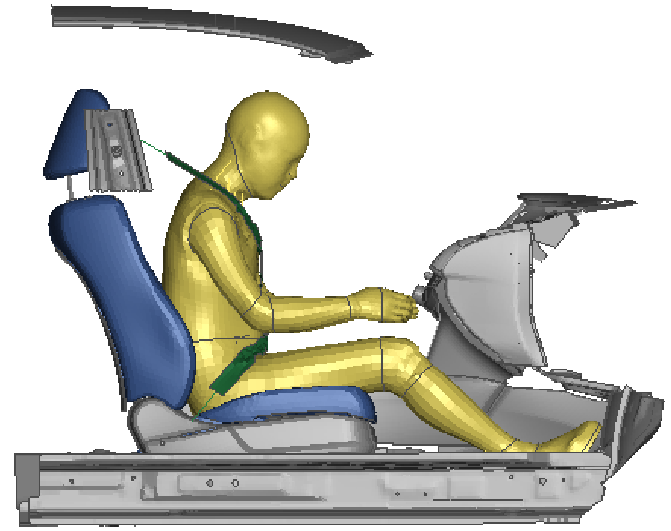
Methods: Pre-Crash Simulations with GHBMCsi-pre[1,2]

Honda Accord 2013 FE Model (NHTSA database)

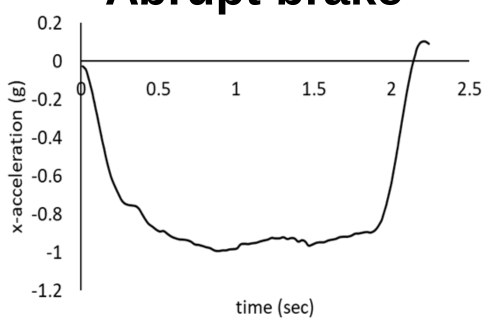


Pre-crash Pulse

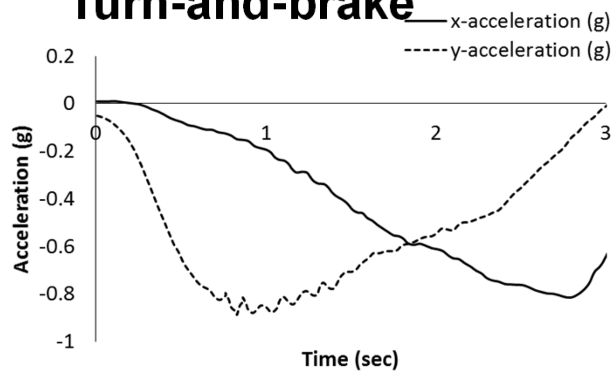
~2000-3000 ms



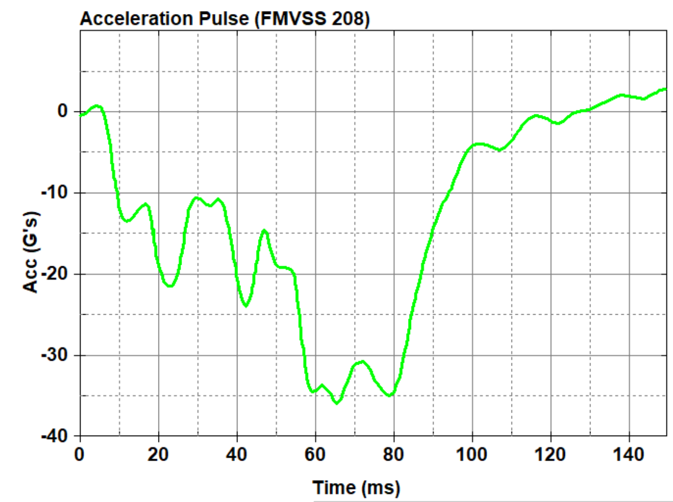
Abrupt brake



Turn-and-brake



Acceleration pulse for in-crash simulations (56 km/h)

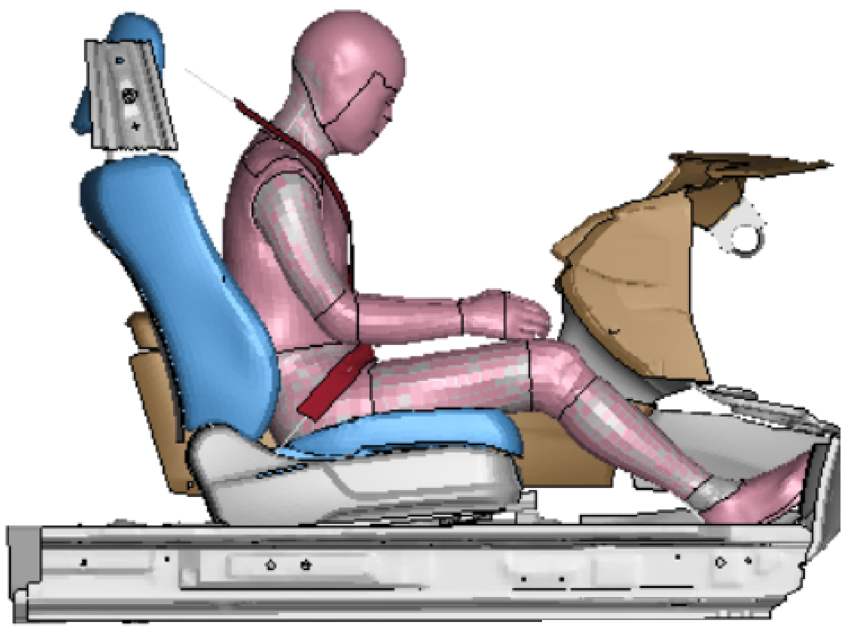


Pre-crash brake:
Drop in X - velocity ~ 16.02 m/s (57.67 km/h)
At the end of pre-crash brake: 56 km/h

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

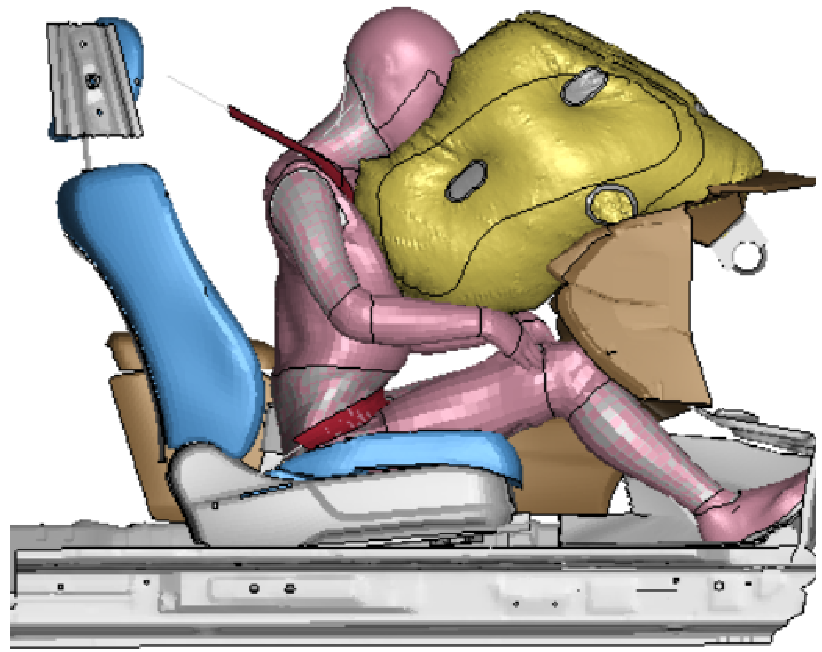
[1] Hu et al 2019
[2] Hu et al 2020

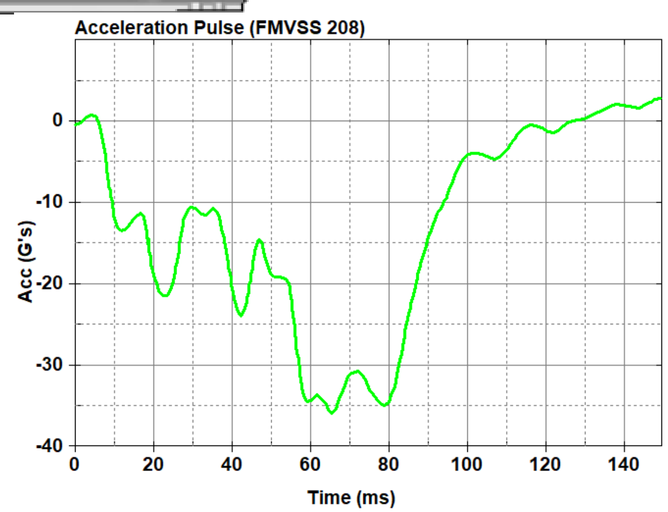
Methods: In-Crash Simulations with integrated pre-crash dynamics



Crash Pulse

~150 ms



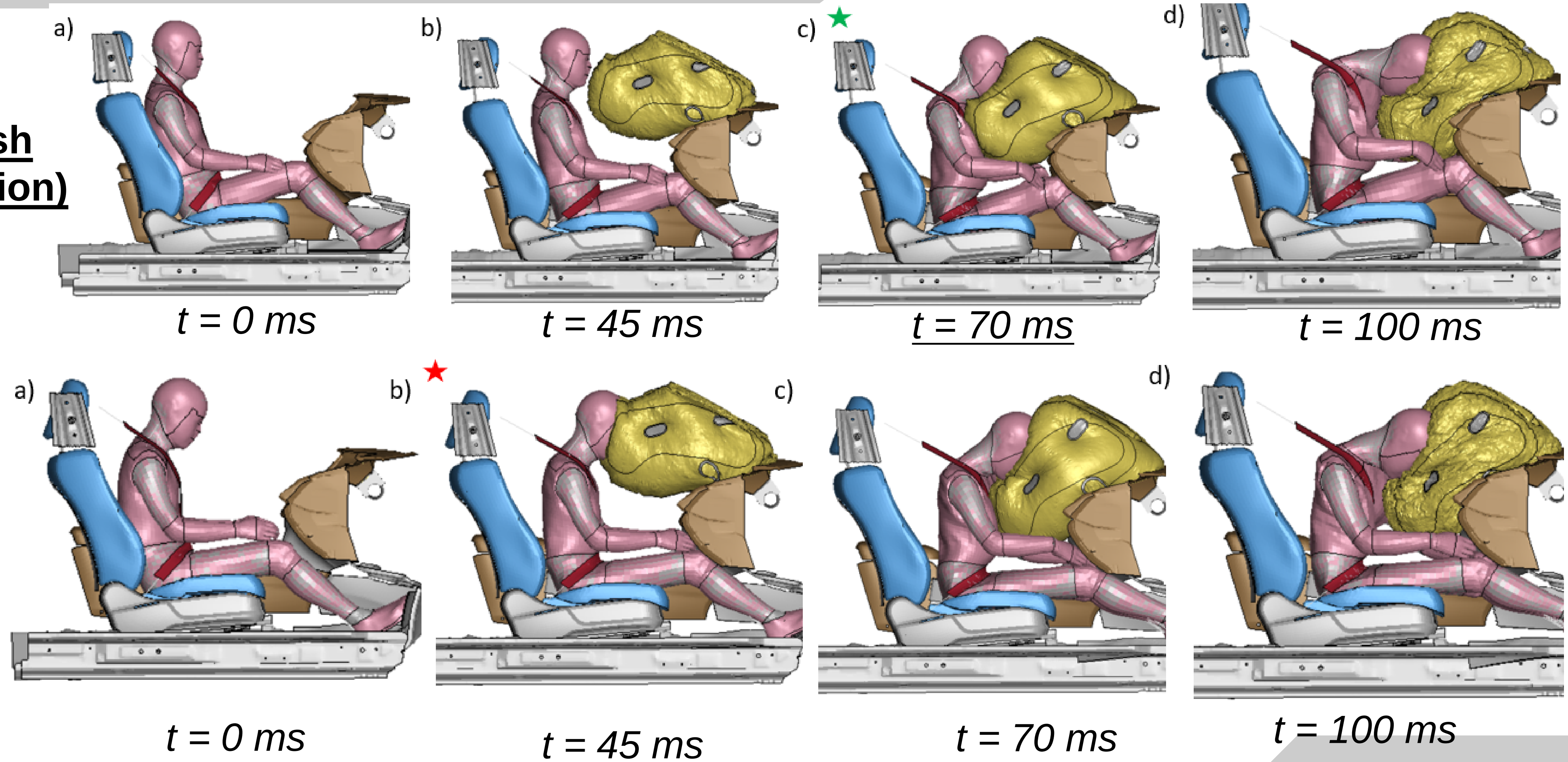


Acceleration pulse for in-crash simulations (56 km/h)

Results: Classical approach vs. New Approach with integrated pre-crash dynamics

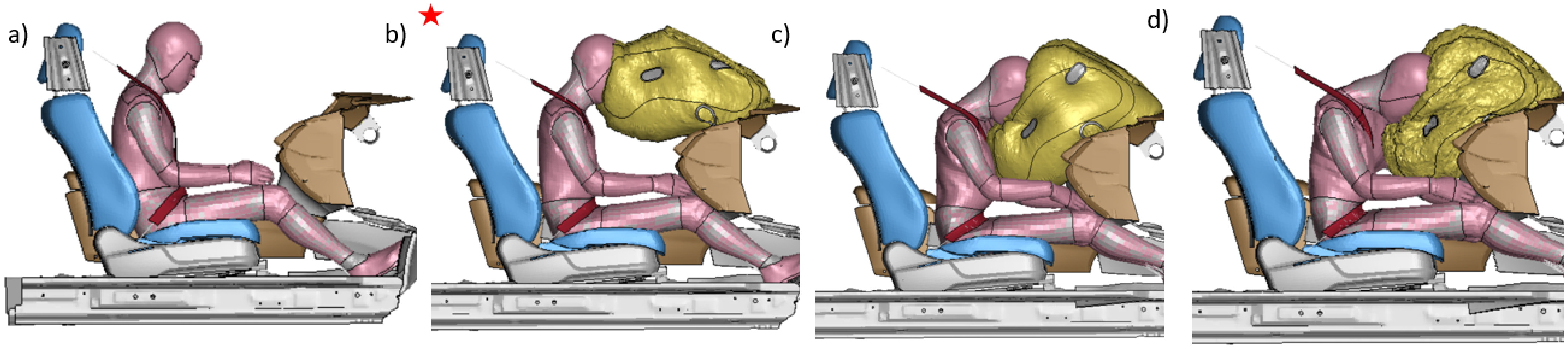
<u>Without Precrash (Standard position)</u>

<u>With Precrash (After braking)</u>

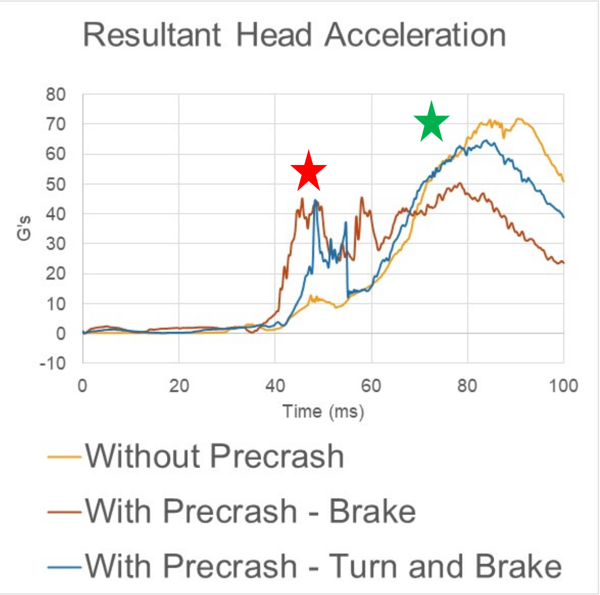


Results: Classical approach vs. New Approach with integrated pre-crash dynamics

With Precrash (After braking)

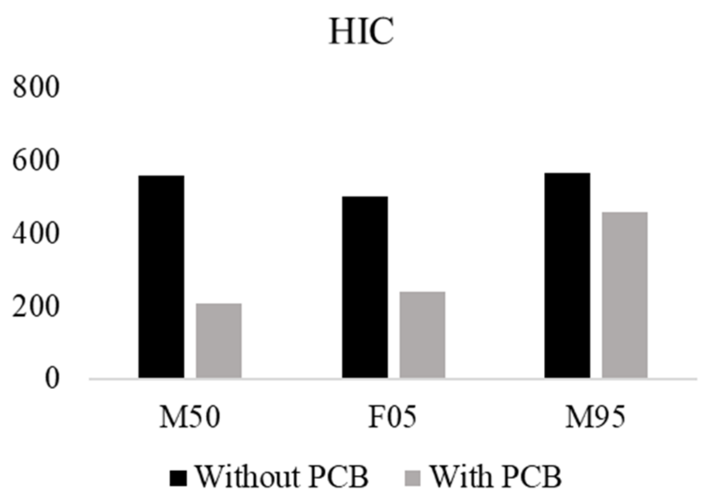


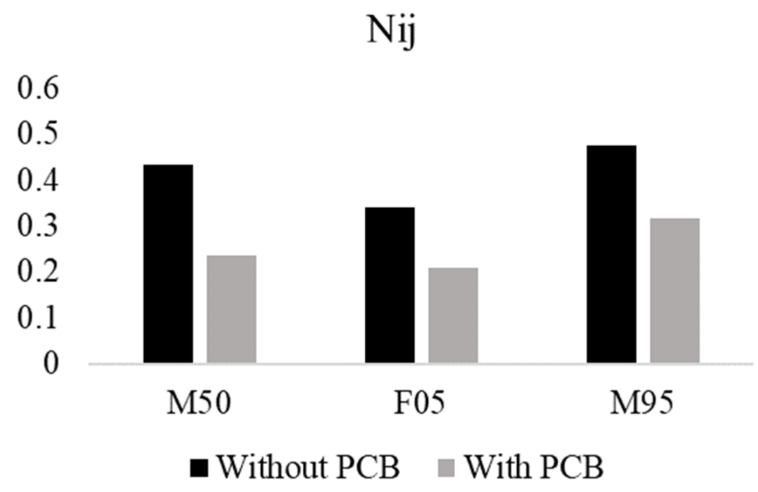
t = 0 ms *t = 45 ms* *t = 70 ms* *t = 100 ms*

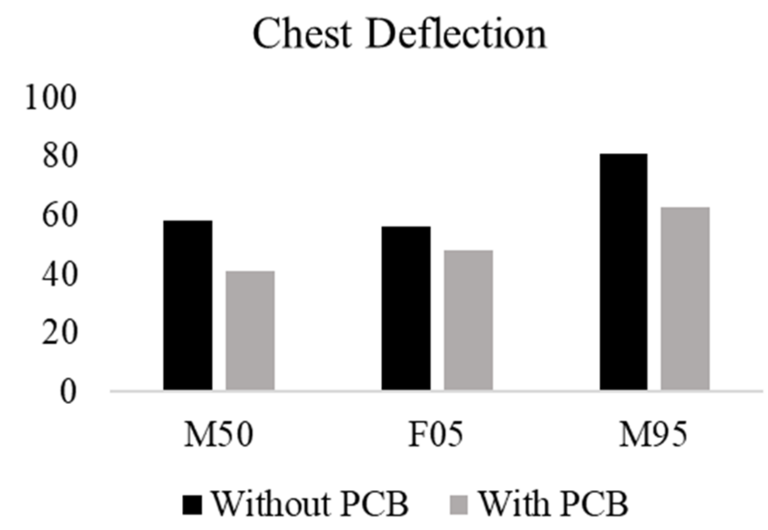


Crash Scenario	Injury Metrics					
	HIC15	BrIC	Nij	Chest Deflection (mm)	VC_max	Femur Force (N)
Without Precrash	559	0.58	0.00043	58	0.00	2696
With Precrash - Brake	208	0.52	0.00023	41	0.00	1724
With Precrash - Turn and Brake	431	0.52	0.00036	57	0.00	1947

Results: Injury Criteria



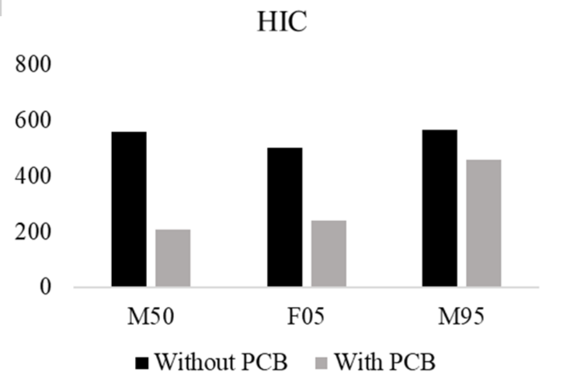


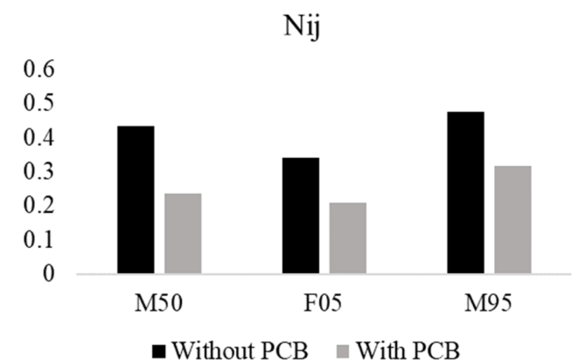


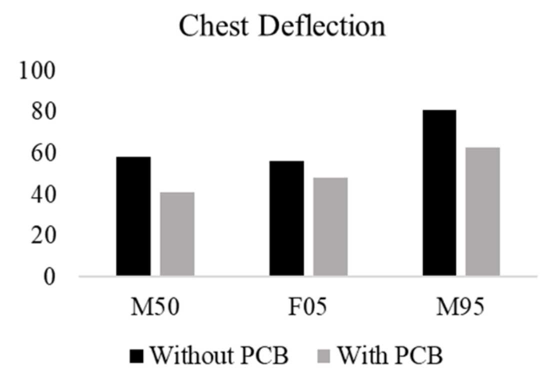
Male 50th Percentile

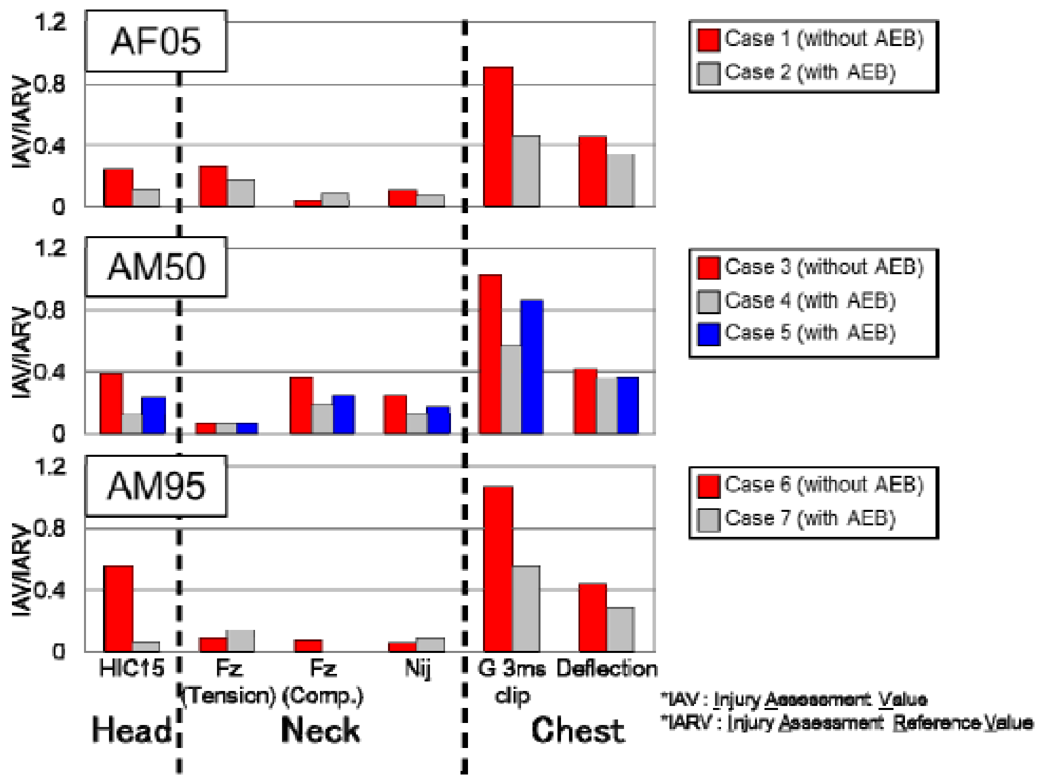
Crash Scenario	Injury Metrics					
	HIC_{15}	BrIC	N_{ij}	Chest Deflection (mm)	VC_{max}	Femur Force (N)
Without Precrash	559	0.58	0.43	58	0.00	2696
With Precrash - Brake	208	0.52	0.23	41	0.00	1724

Results: Our results vs. the literature









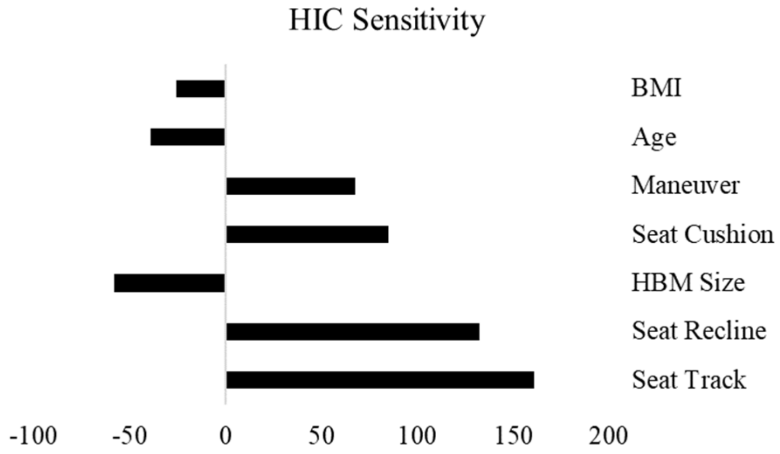
[1] Yamada et al. 2016

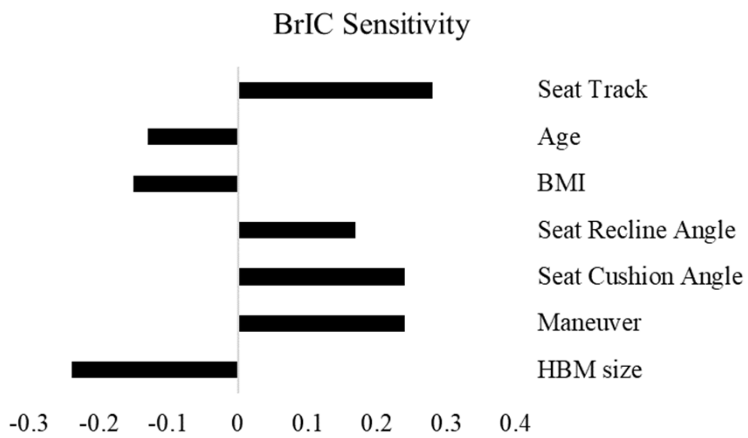
Results: DOE Preliminary results

- 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**.

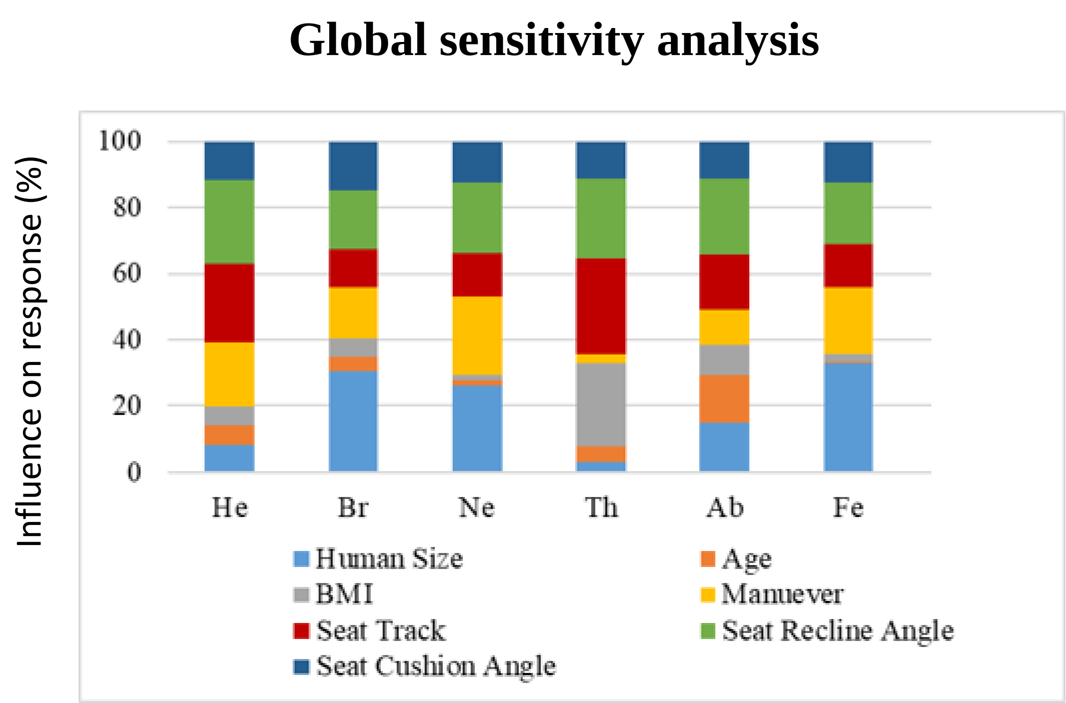




Sensitivities Plot for and HIC 15 and BrIC

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.

Results/Discussion: Limitations

- **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.

- My graduate students : Akshay Dahiya and Yunzhu Meng

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Thank You