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Vulnerable Pop. Safety G102

# Estimating Head Impact Time for Pedestrian Crashes through Finite Element Human Modeling

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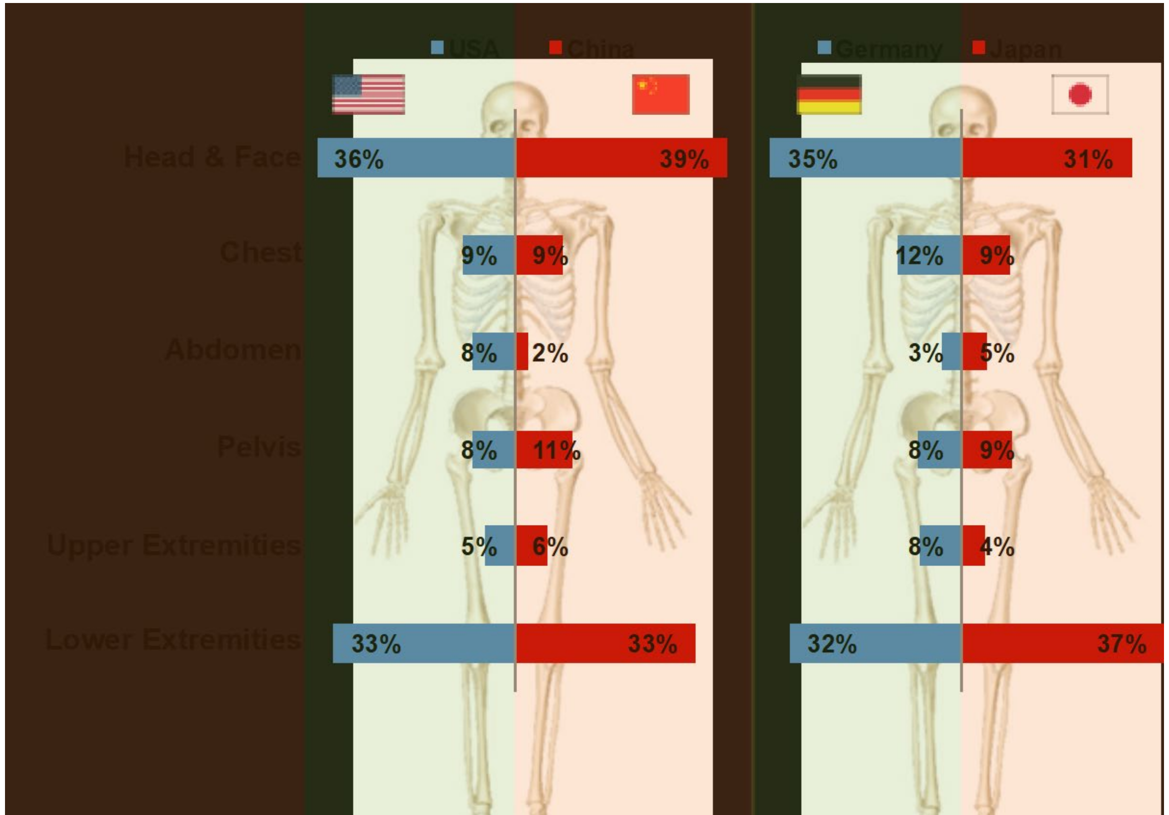
# Background

Head is the most commonly injured body region in pedestrian impacts.




Pedestrian injury distribution (Hu and Klinich 2015)

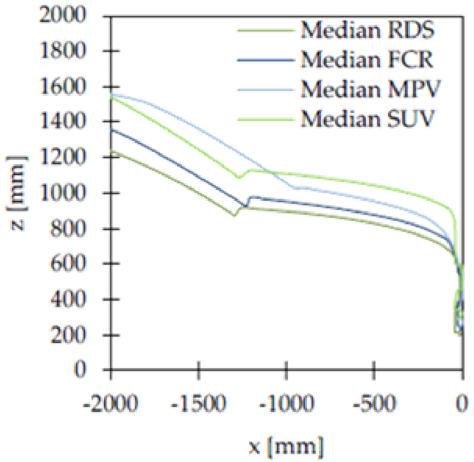
Pop-up hood can potentially reduce the pedestrian head injury risks.

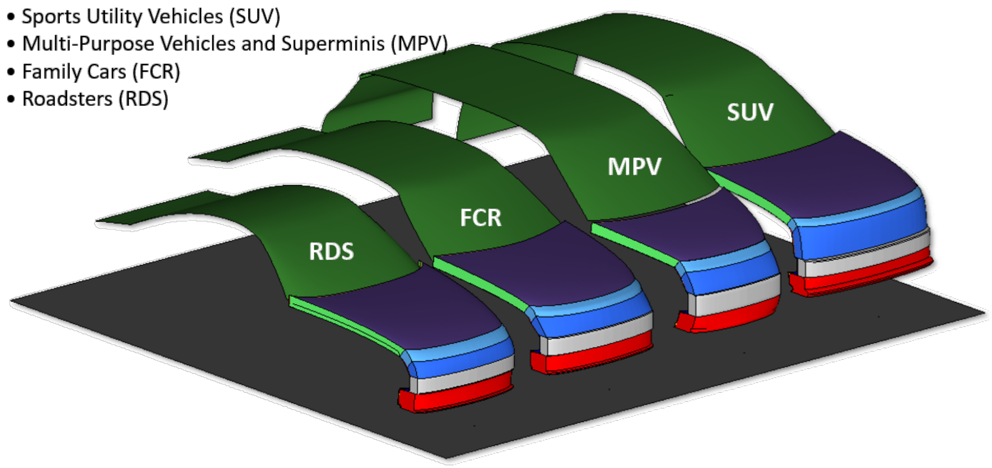
Pop-up hood (Inomata et al. 2009)

# Background

- Both UNECE and Euro NCAP used protocols including both testing and finite element (FE) simulations for assessing **pop-up hoods** for pedestrian protection, in which **Head Impact Time (HIT)** is important to evaluate the activation time of pop-up hood designs.
- **HIT** is determined using crash simulations between the manufacturer's own vehicle model and 6YO, F05, M50, and M95 human body models walking perpendicular to the vehicle with an impact along the hood centerline at a speed of 40 km/h.
- Pedestrian models must be certified through a standardized set of boundary conditions involving simulating the pedestrians through a series of impacts with four previously published **generic vehicle (GV)** models at three impact speeds (30, 40, and 50 km/h).

European vehicle front-end median midsections

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# Research Gap

- The GV models were specifically developed based on European vehicles.
- Vehicle sizes and shapes in the U.S. are significantly different from those in the Europe. In particular, larger SUVs and pickup trucks are much more popular in the U.S. than in Europe.
- Moreover, there is a lack of data and knowledge on how vehicle front-end geometries may affect HITs in pedestrian crashes and how pop-up hood design parameters may affect pedestrian injury risks.

# Objectives

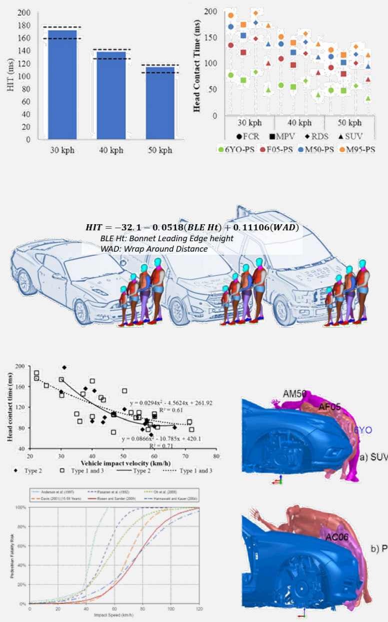
- Generate a virtual (FE-model simulated) database of HITs with a large number of US vehicle front-end characteristics, and develop prediction models to use vehicle front-end geometry, pedestrian size, and impact speed to predict HITs.

# Methods

## Literature Review

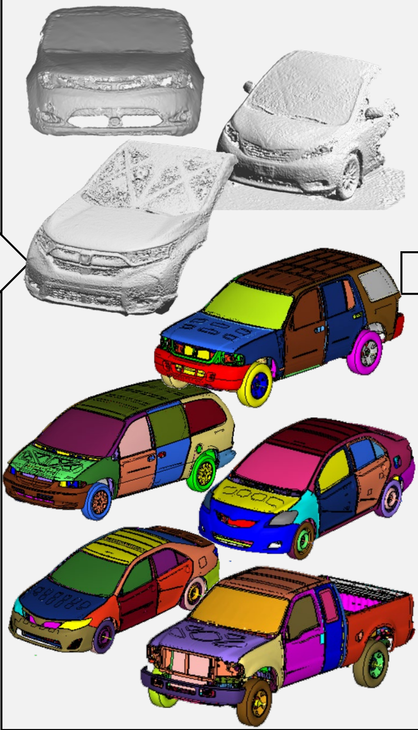
Variable identifications

- Impact speed
- Pedestrian height
- Vehicle geometry
- ….



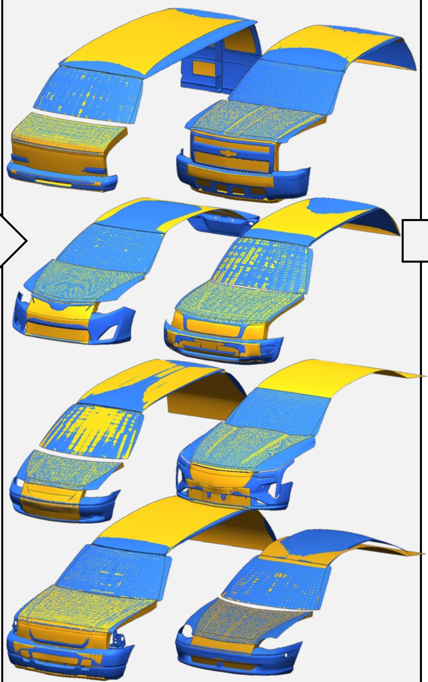

## Vehicle Geometry

Vehicle scans or FE models for 20 US vehicles



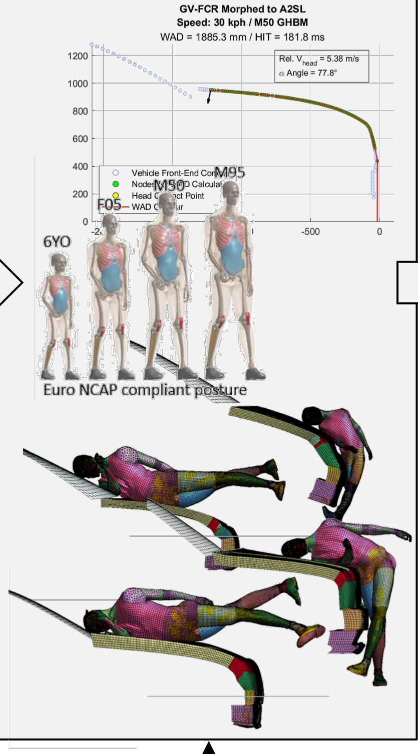
## US GV Models

Morph GV models into US vehicle geometries



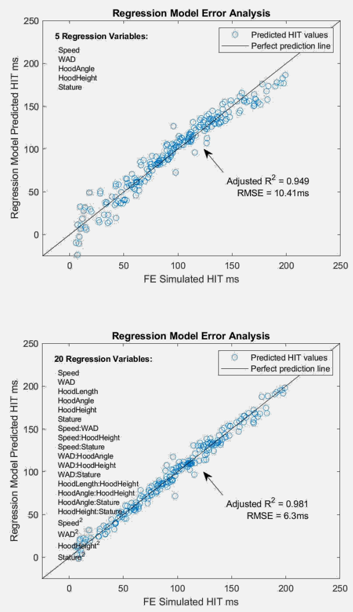
## Simulation Database

240 Simulations with varied input variables




## Prediction Models

Multiple regression models for HIT, head impact velocity and angle




Variables for parametric simulations and HIT prediction

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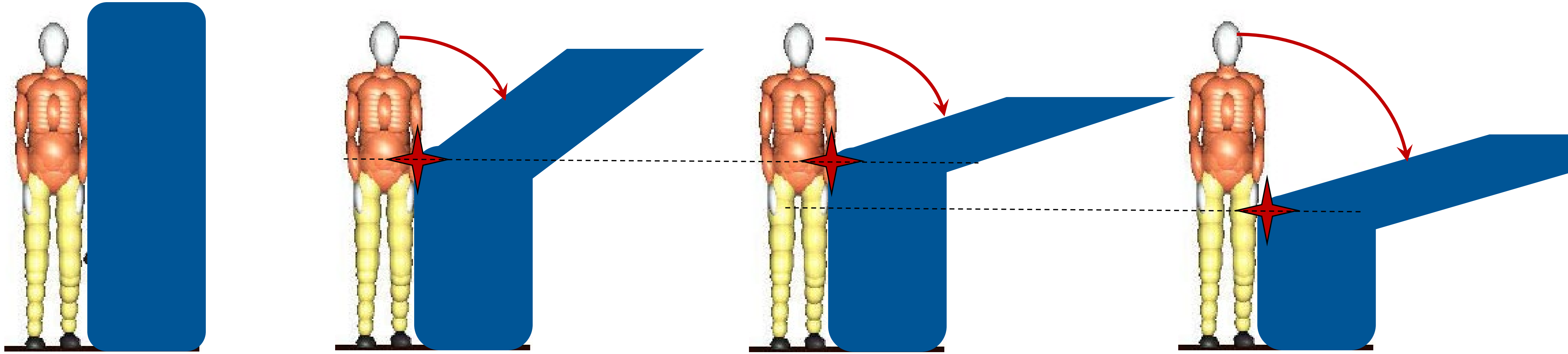
# Literature Review

- >100 articles about pedestrian safety and designs, and ~20 articles related to HIT or WAD
- Two comprehensive reviews + 10 most relevant studies

| Variables | Effects on HIT | References |
|---|---|---|
| **Impact speed** | **Strong, negatively correlated** | (Decker et al., 2019; Peng et al., 2013; Peng et al., 2012; Watanabe et al., 2012) |
| **Vehicle type / front-end geometry** | **Strong, shorter in SUVs and pick-ups** | (Bhattacharjee et al., 2017; Decker et al., 2019; Elliott et al., 2012; Kerrigan et al., 2012; Kerrigan et al., 2009; Klug et al., 2017; Pal et al., 2014; Peng et al., 2012; Song et al., 2017; Watanabe et al., 2012) |
| **Pedestrian size** | **Strong, positively correlated** | (Bhattacharjee et al., 2017; Decker et al., 2019; Pal et al., 2014; Watanabe et al., 2012) |
| **Wrap around distance (WAD)** | **Strong, positively correlated** | (Bhattacharjee et al., 2017; Kerrigan et al., 2012) |
| **Vehicle impact location** | Weak, mixed trends | (Peng et al., 2013; Watanabe et al., 2012) |
| **Vehicle-to-pedestrian friction** | Weak, mixed trends | (Elliott et al., 2012; Klug et al., 2017) |
| **Pedestrian age** | Weak, no trends | (Pal et al., 2014) |
| **Pedestrian posture (gait and arm)** | Weak, mixed trends | (Chen et al., 2015; Elliott et al., 2012; Klug et al., 2017; Peng et al., 2012) |
| **Pedestrian impact angle** | Weak, no trends | (Chen et al., 2015) |

# Simplistic Theory Behind HIT



**Main factors:**
- Height of the pedestrian
- Vehicle type / front-geometry
- Impact speed

**Secondary factors:**
- Friction
- Contact characteristics
  - Posture, age, stiffness, etc.

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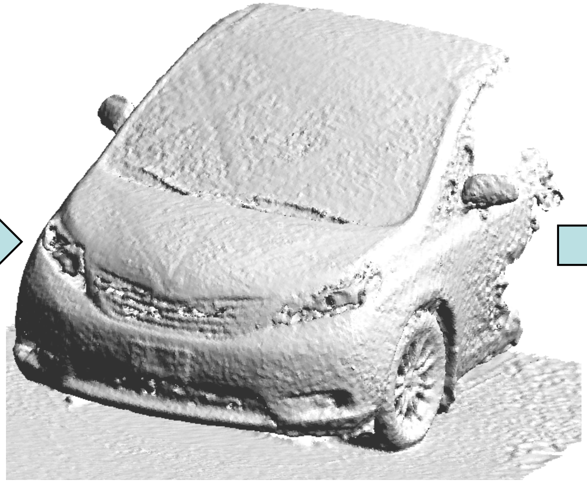
*Using Scanned Sienna as example

# Vehicle Front-End 3D Scans and Mesh Morphed

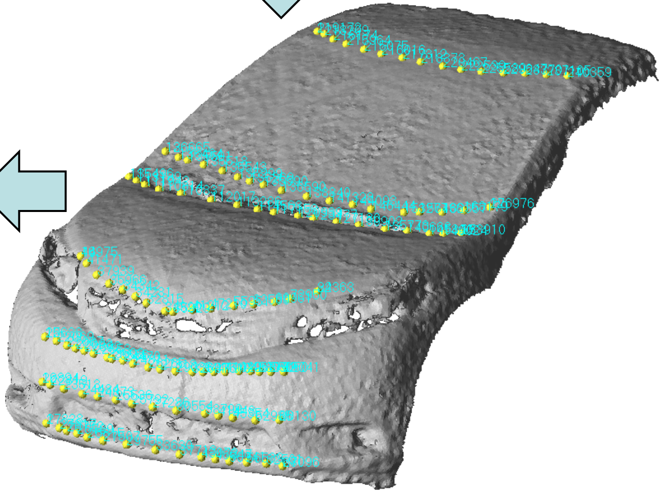
Scanning vehicle

Stitching point cloud

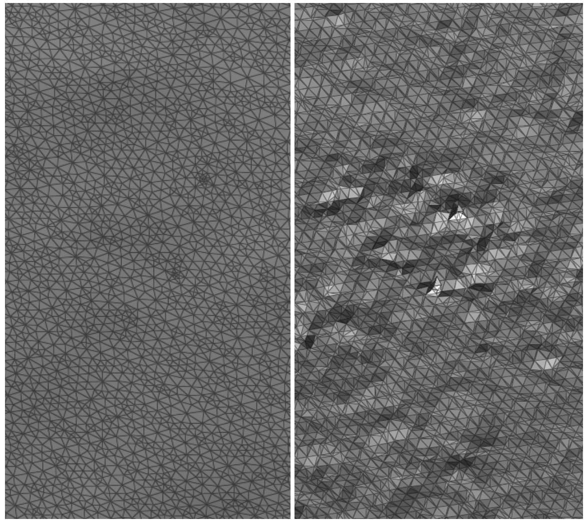


Reconstructed Mesh

Model cleanup & alignment

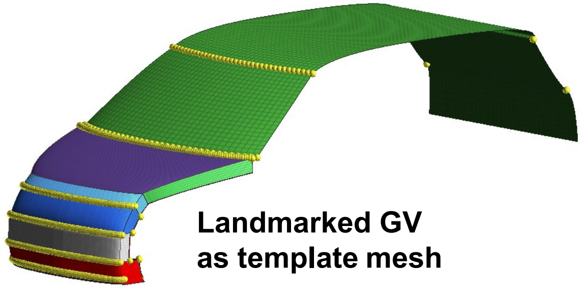


Landmarking

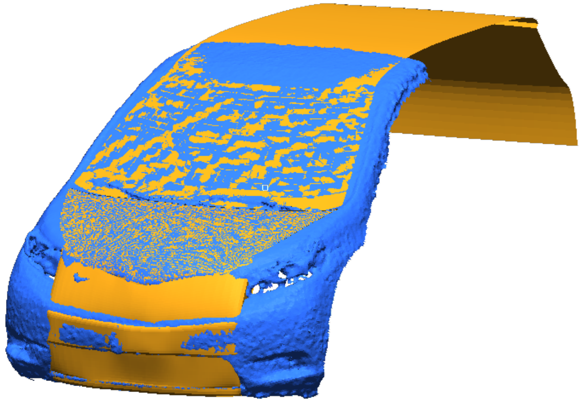


Smooth out windshield & hood mesh for projection

Mesh Morphing & Projection



Landmarked GV as template mesh



Morphed US GV Model

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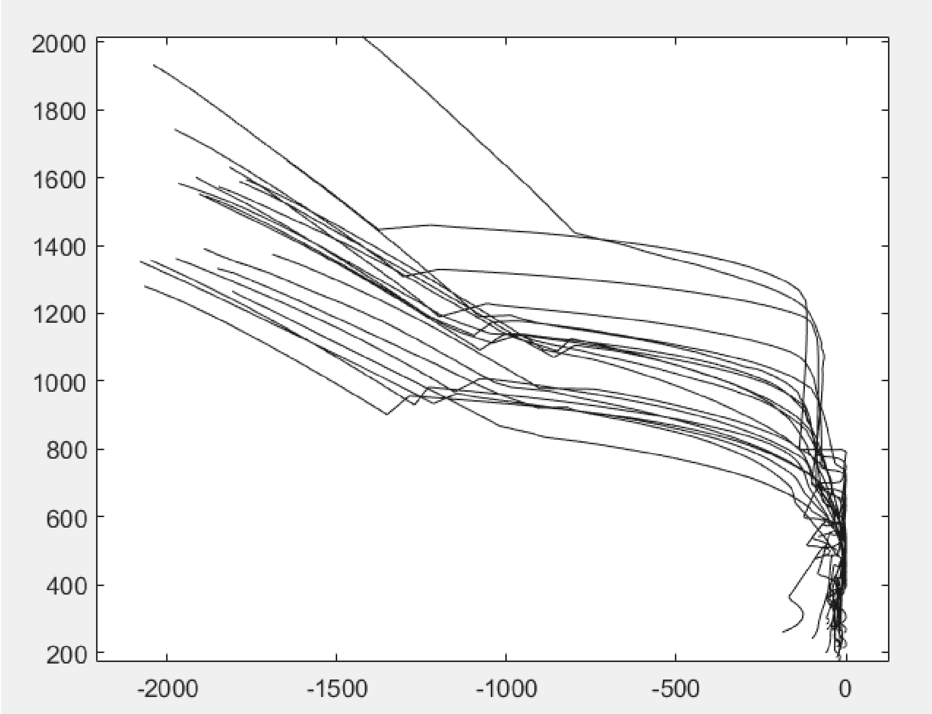
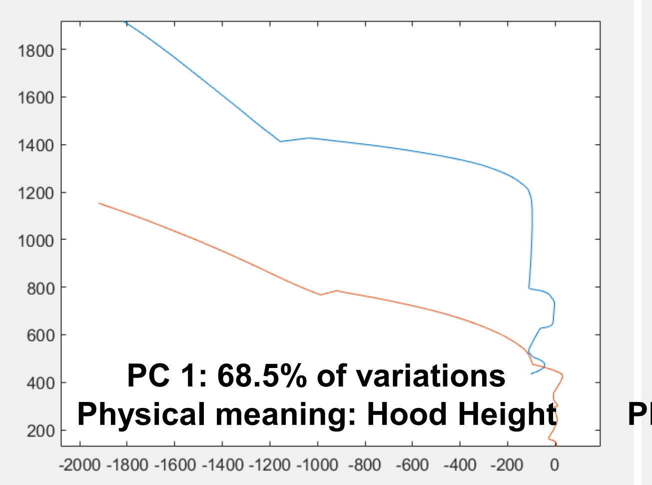
# Vehicle Front-End Geometry Analysis

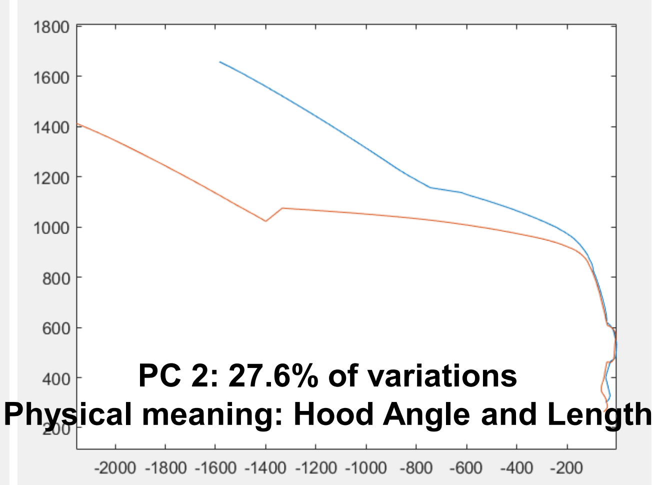
**Principal component analysis (PCA) using 20 morphed GV front-end centerline geometries**

- The first two PCs account for over 96% of the geometry variations
- PC 1 represents the hood height
- PC 2 represents the hood angle and length

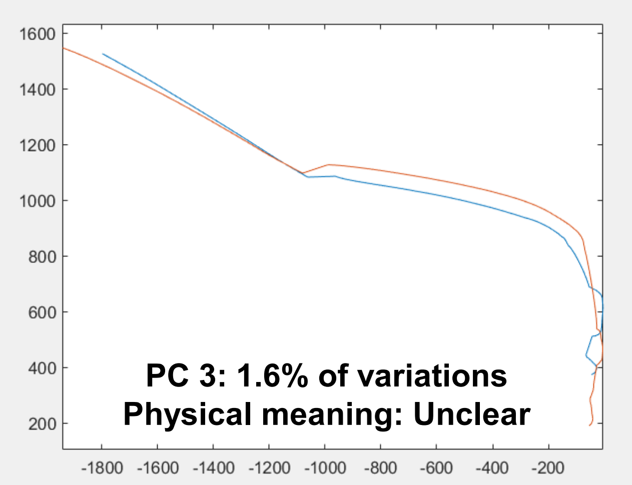


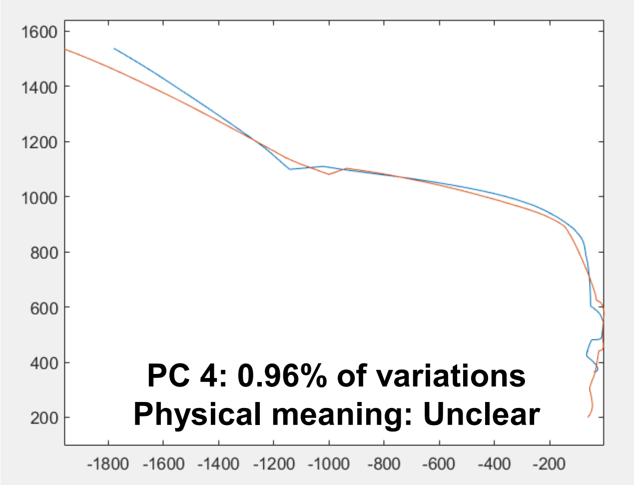
**PC 1: 68.5% of variations**
**Physical meaning: Hood Height**



**PC 2: 27.6% of variations**
**Physical meaning: Hood Angle and Length**



**PC 3: 1.6% of variations**
**Physical meaning: Unclear**



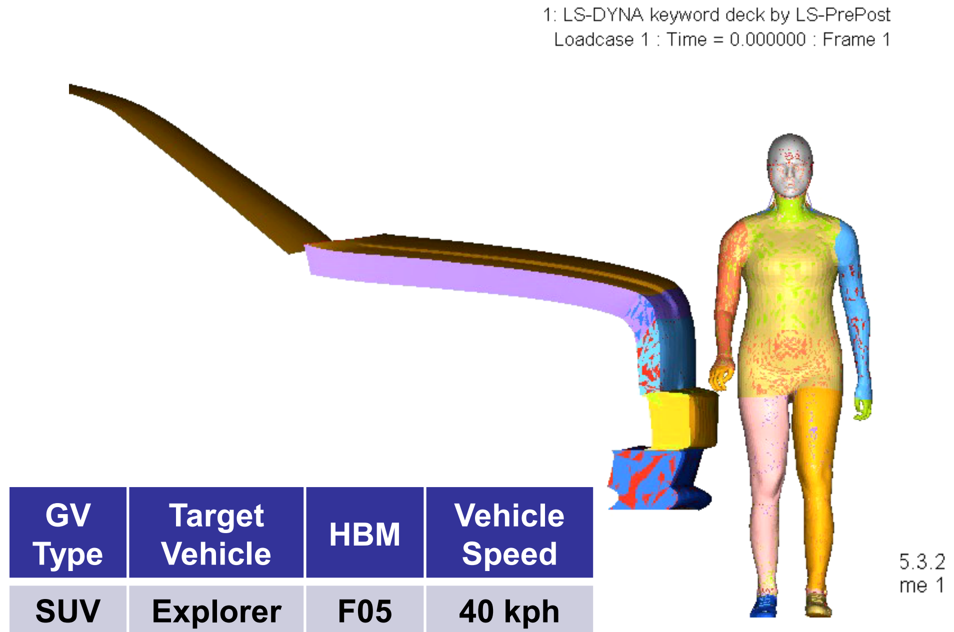
**PC 4: 0.96% of variations**
**Physical meaning: Unclear**

# Simulation Matrix

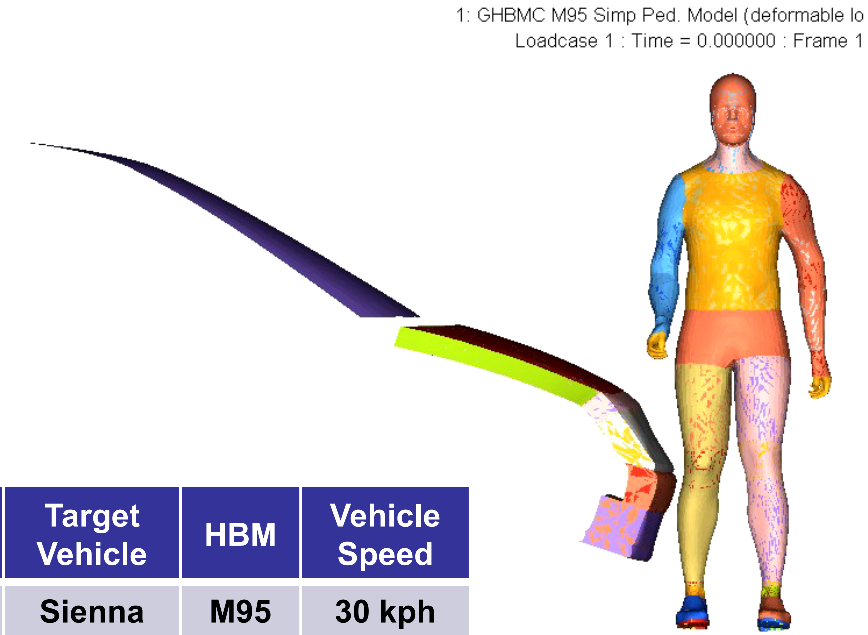
- **Input Variables**
  - 20 morphed US GV models with varied front-end geometry
  - Four GHBMC pedestrian models (6YO, F05, M50, M95)
  - Three impact speeds (30, 40, and 50 kph)
- **A total of 240 simulations**
  - 20 vehicles x 4 HBMs x 3 speeds
- **Output Variables**
  - HIT
  - WAD
  - Head impact velocity (HeadV)
  - Head velocity Angle (HeadV Ang)

| GV Category | U.S. Vehicle Category | FE Models available | Scanned Vehicles |
|---|---|---|---|
| - | Large SUV, Pickup, or Van | F-250, Silverado, Econoline | |
| SUV | Small to Midsize SUV | RAV4, Venza, Rogue | CR-V, Highlander |
| MPV | Mini-van | Caravan | Odyssey, Sienna, Pacifica |
| Family Car | Midsize to Full-size Sedan | Camry, Accord, Taurus, A2SL | |
| Roadster | Smaller Sedan | Neon, Yaris | Focus, Civic |

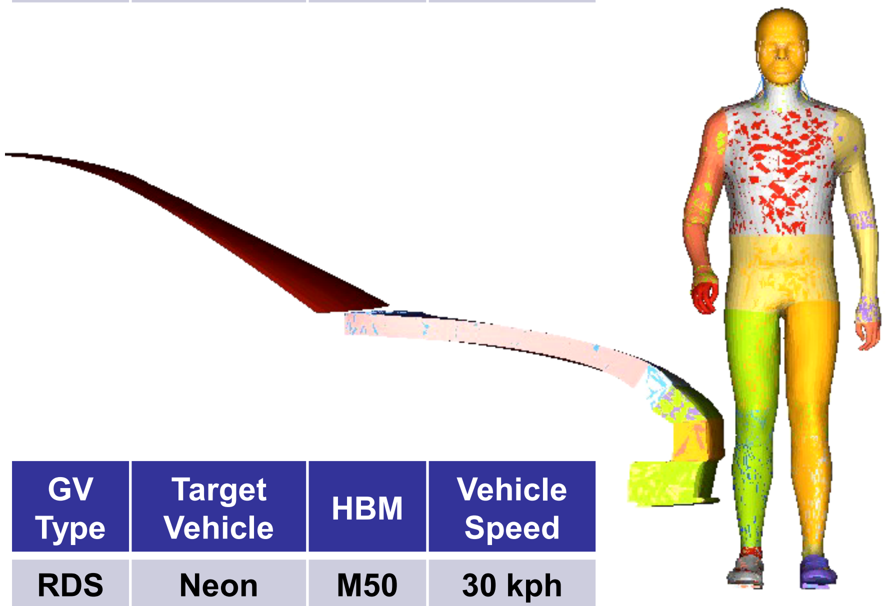
# Exemplary Simulations



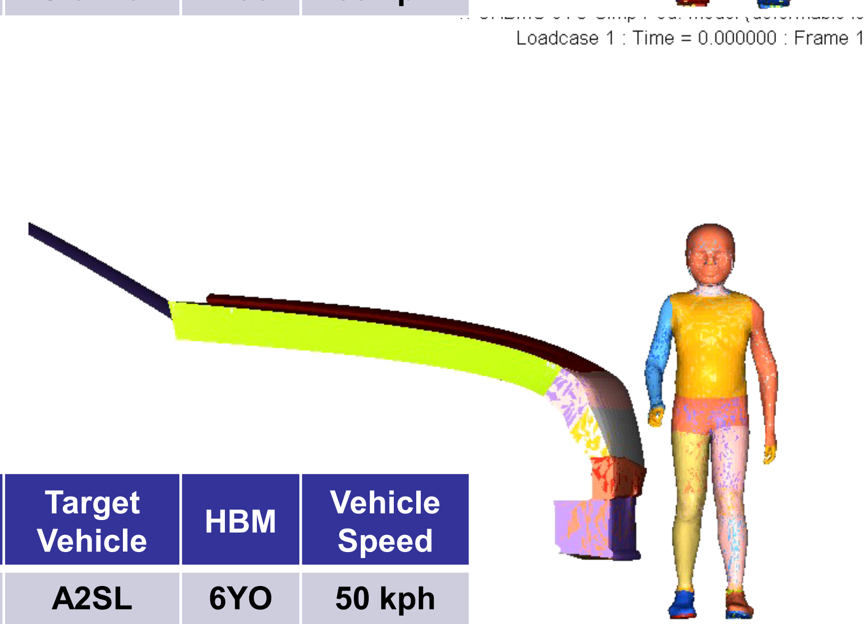

| GV Type | Target Vehicle | HBM | Vehicle Speed |
|---|---|---|---|
| SUV | Explorer | F05 | 40 kph |




| GV Type | Target Vehicle | HBM | Vehicle Speed |
|---|---|---|---|
| MPV | Sienna | M95 | 30 kph |



| GV Type | Target Vehicle | HBM | Vehicle Speed |
|---|---|---|---|
| RDS | Neon | M50 | 30 kph |

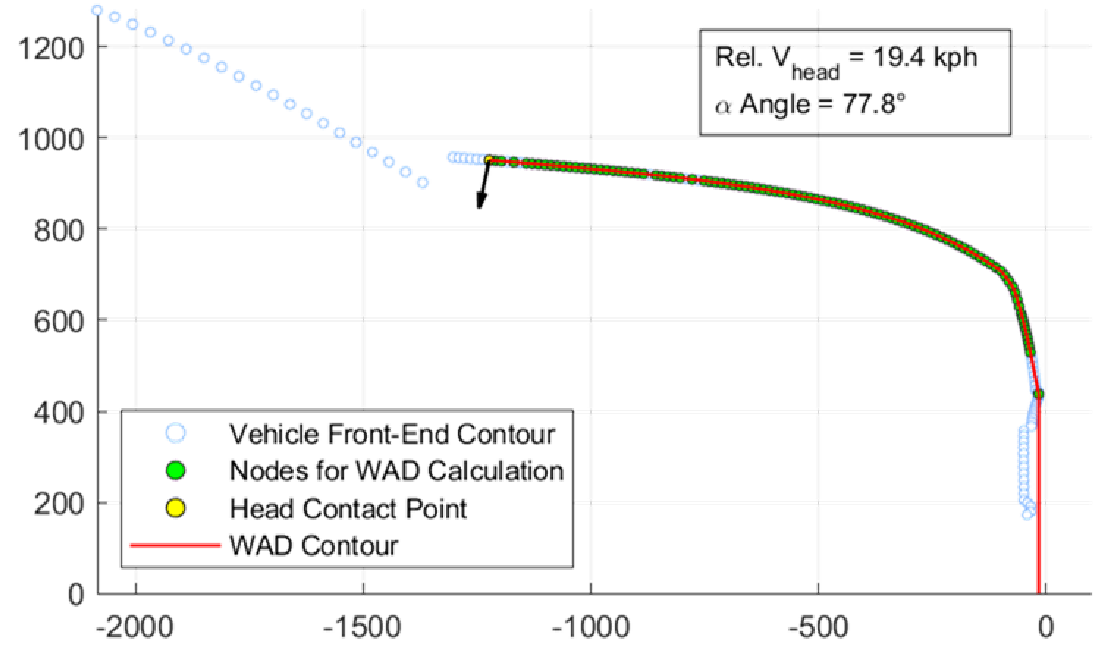


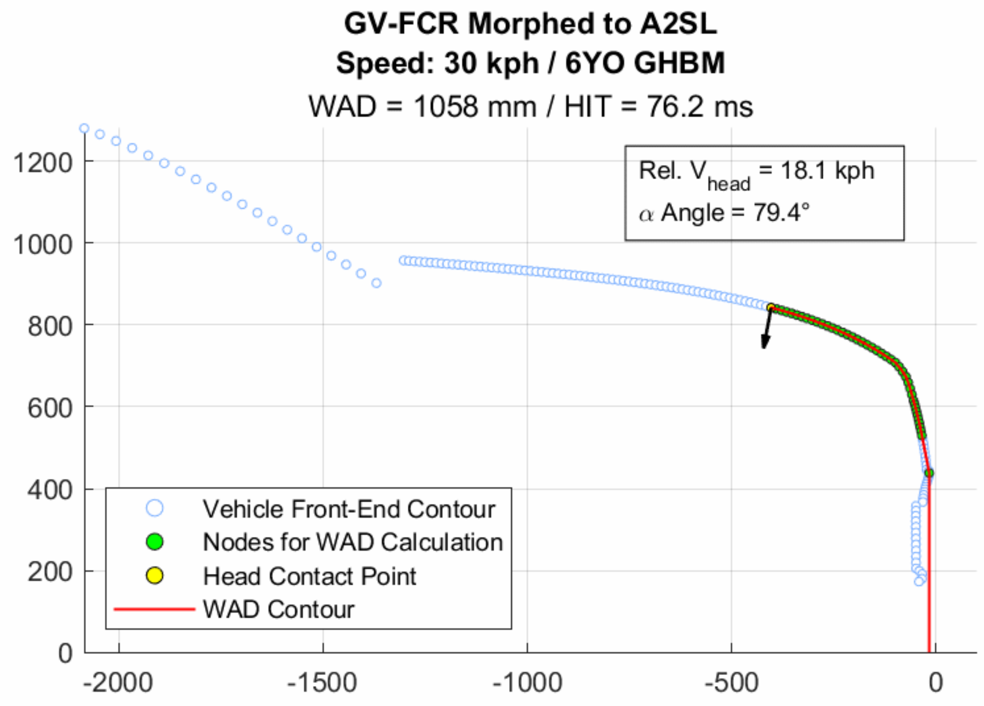

| GV Type | Target Vehicle | HBM | Vehicle Speed |
|---|---|---|---|
| FCR | A2SL | 6YO | 50 kph |

# Automated Data Collections (HIT / WAD / Impact V)

**GV-FCR Morphed to A2SL**
**Speed: 30 kph / M50 GHBM**

WAD = 1885.3 mm / HIT = 181.8 ms

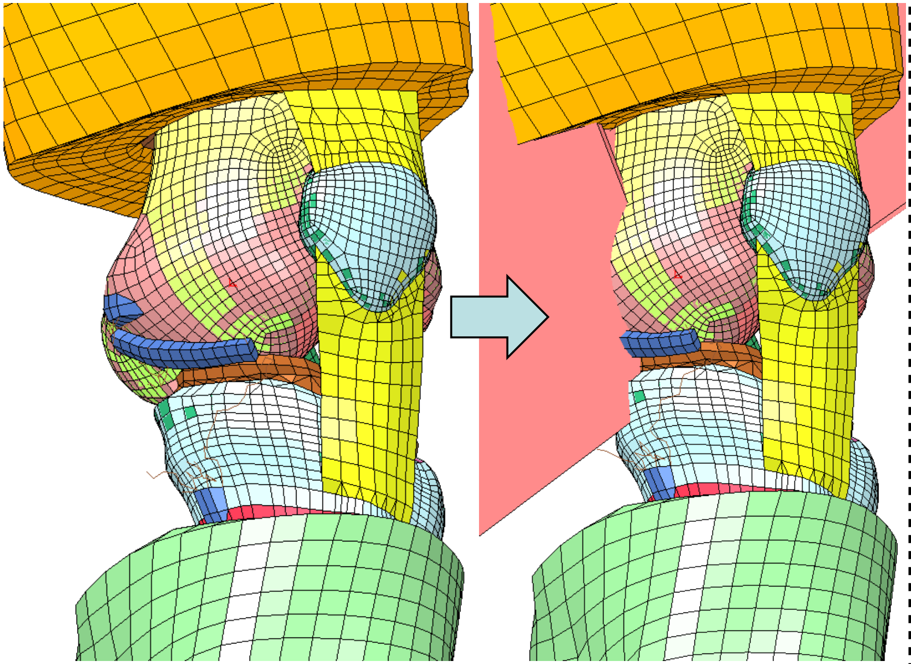



Rel. $V_{head}$ is the resultant head velocity relative to the vehicle
α Angle is the angle between $V_{head}$ and the horizontal line (X-direction)

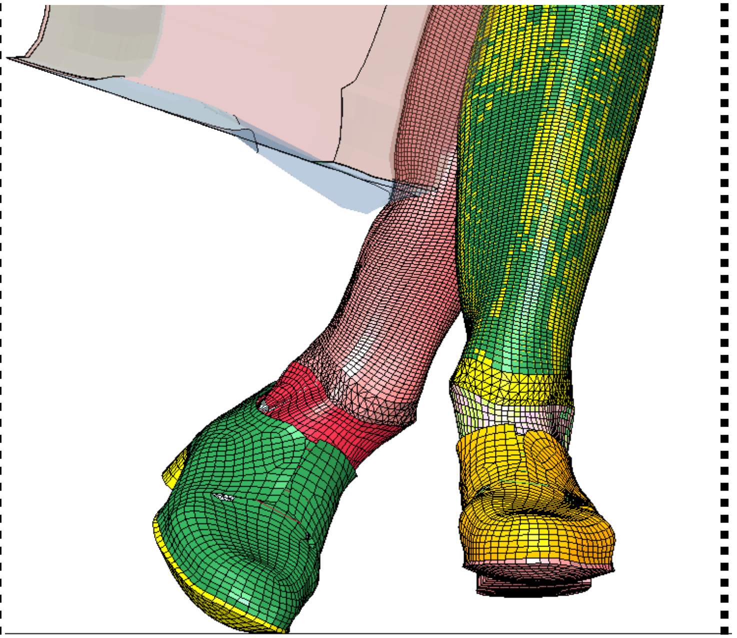
# Fixed Error Terminations

## Left femoral head out-of-range force
(Observed mainly on M95 HBM)



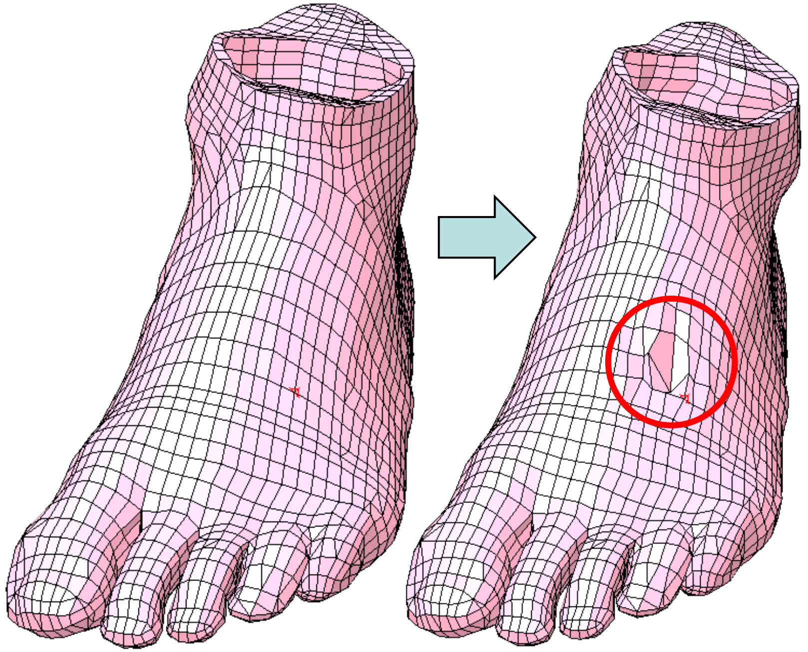
**Adjustment**
- Disable bone failure parameters

## Left leg flesh (near ankle) crushed by bumper
(Observed across all HBMs)



**Adjustments**
- Reduce timestep by 50%
- Add ankle & knee into internal contact part set

## Left foot flesh out-of-range force
(Observed mainly on M50 HBM)



**Adjustment**
- Reduce timestep by 50%

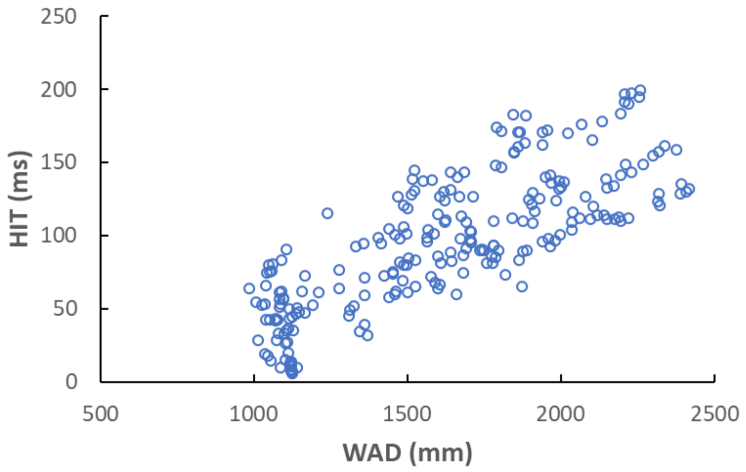
# Simulation Summary

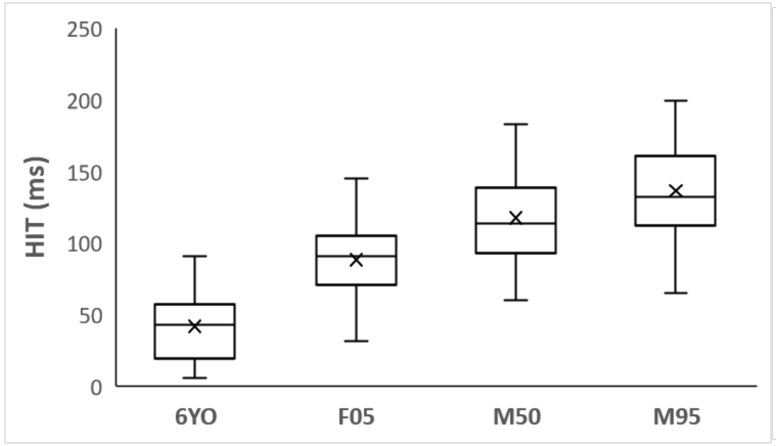
- Among 240 simulations
  - 234 simulations were finished with proper head contact and HIT values
  - 2 simulations were terminated with negative volume error
  - 4 simulations were terminated without any head contact

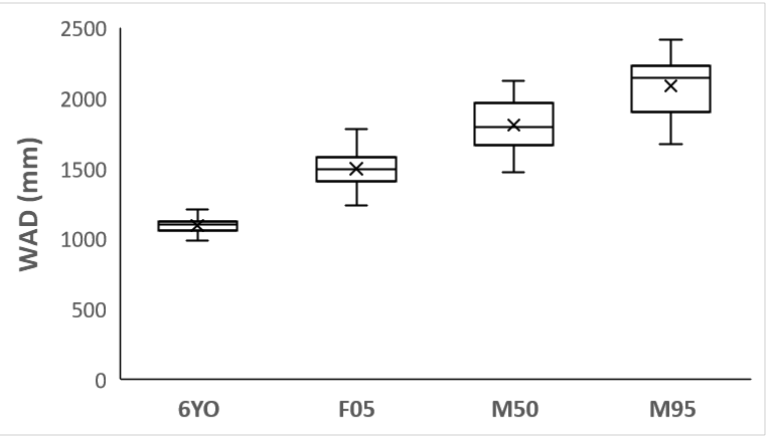
**List of 6 simulations with error termination or without head contact**

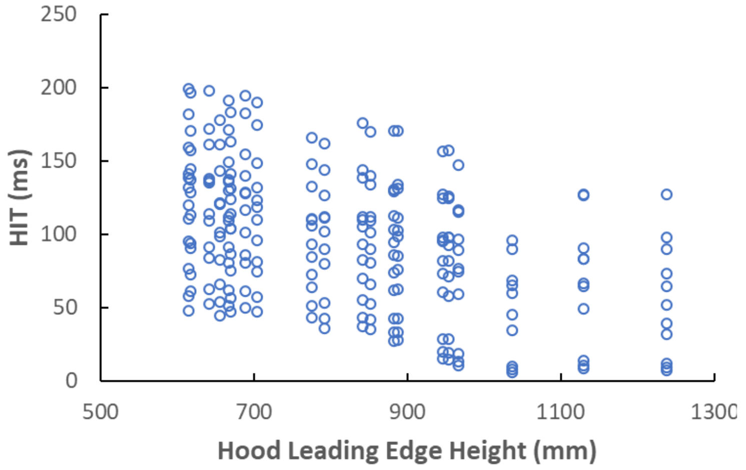
| Target Vehicle | HBM | Vehicle Speed | Cause of no HIT |
|---|---|---|---|
| Sienna | F05 | 50 kph | Lower leg flesh negative volume error |
| Neon | M50 | 50 kph | Armpit (L) flesh negative volume error |
| Silverado | F05 | 30 kph | Pedestrian knocked down without head contact |
| Econoline | F05 | 30 kph | Pedestrian knocked down without head contact |
| Econoline | M50 | 30 kph | Pedestrian knocked down without head contact |
| F250 | M50 | 30 kph | Pedestrian knocked down without head contact |

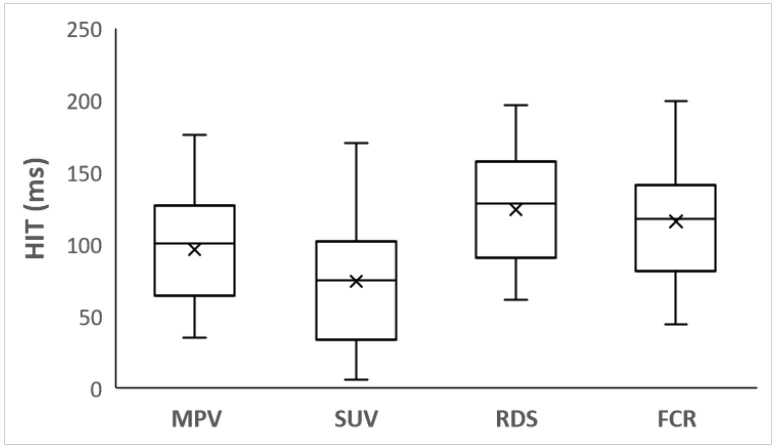
# Data Analysis – HIT

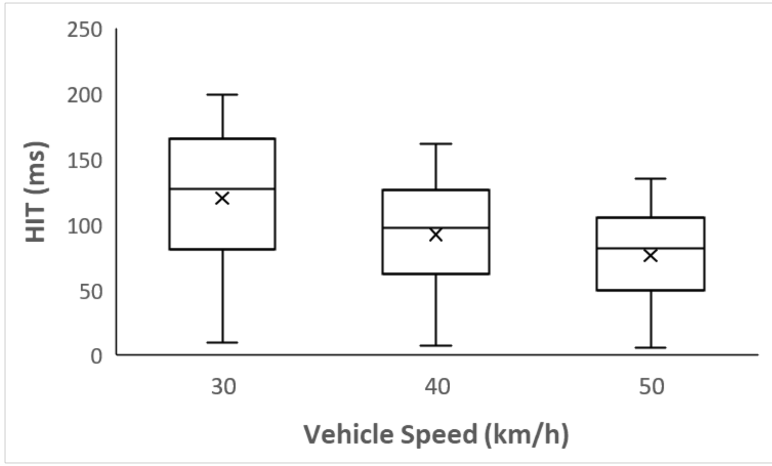


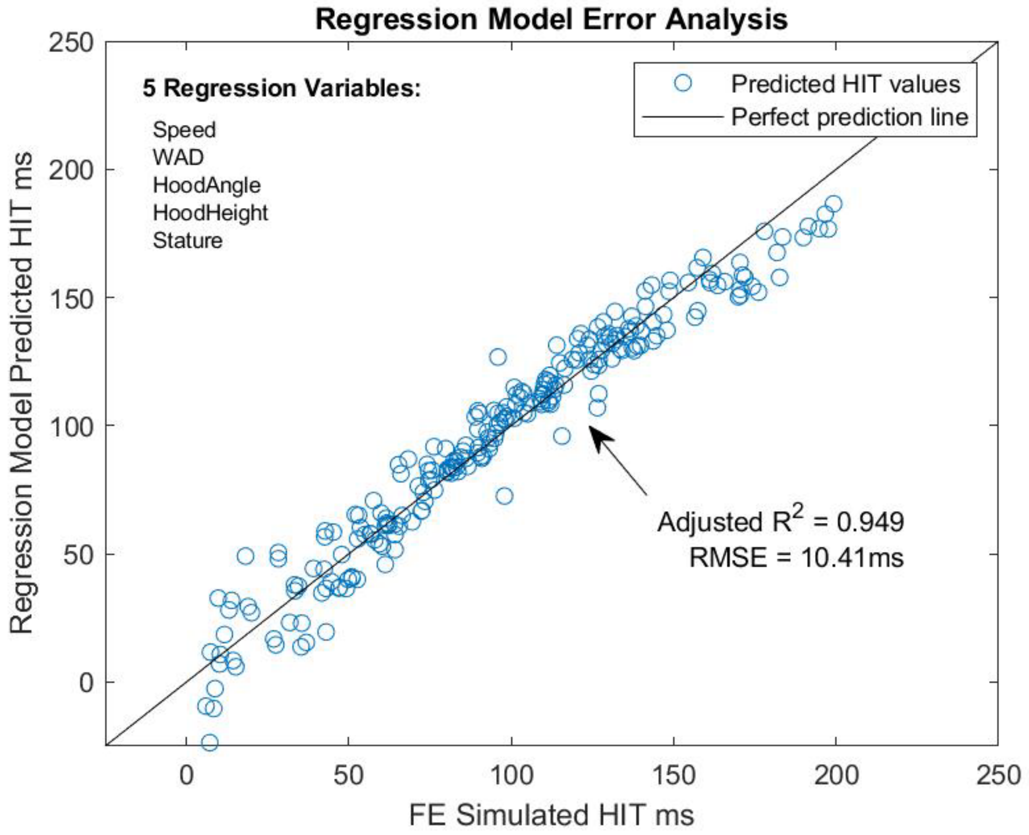



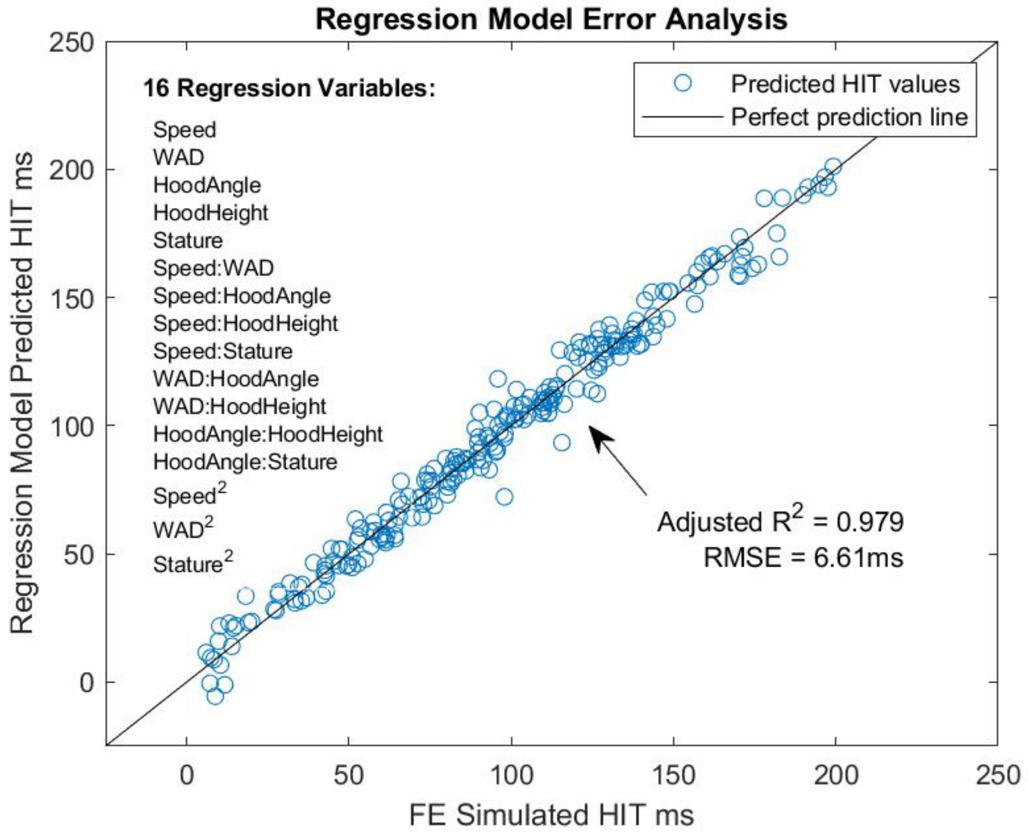



# Preliminary Data Analysis – HIT

- Stepwise linear regression

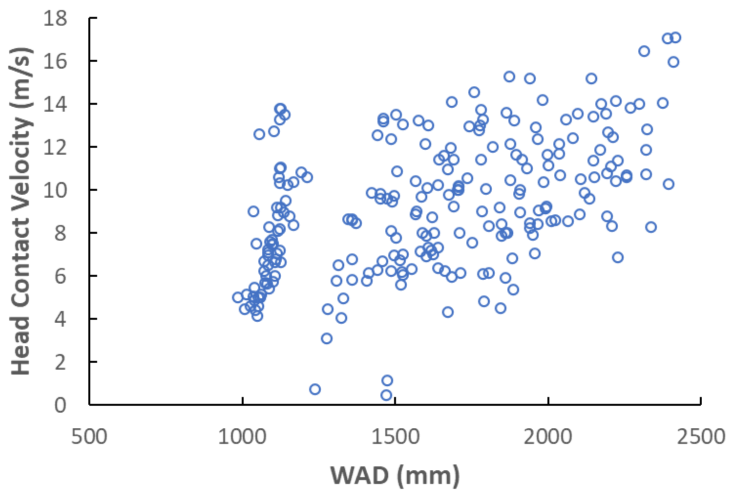


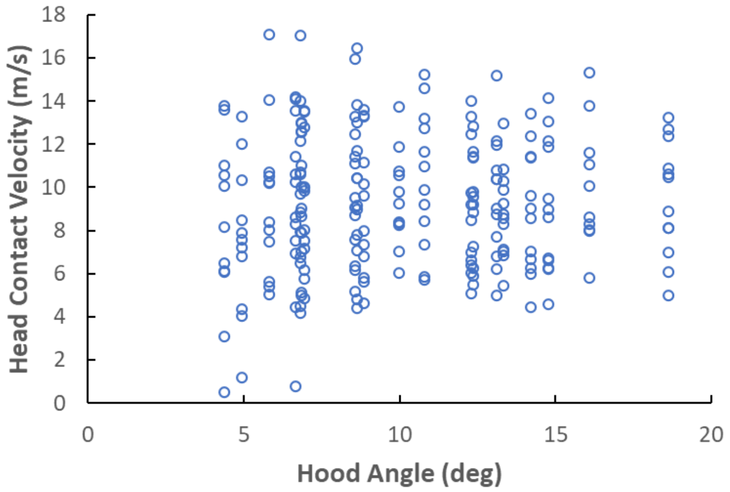

Variable Main Effects

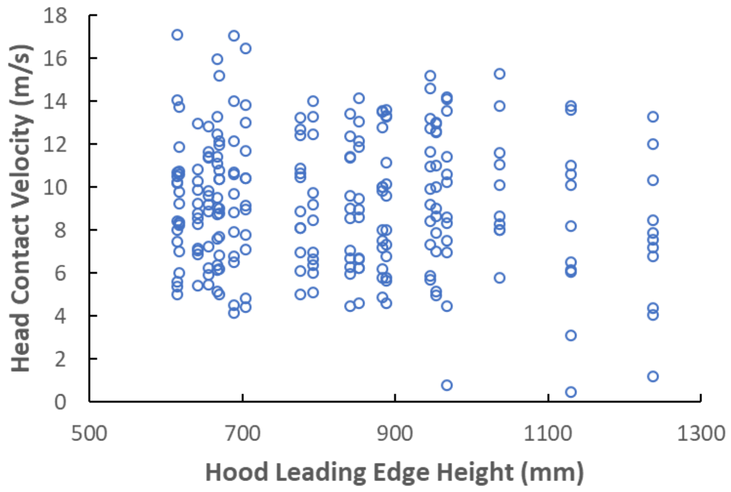


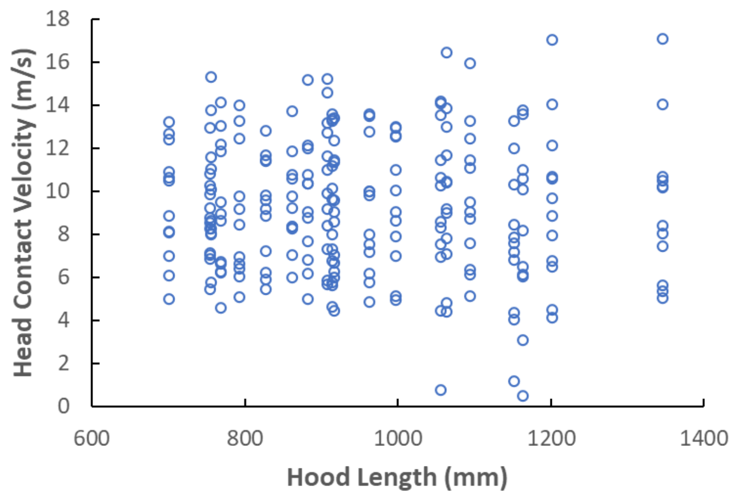

With interaction and quadratic terms

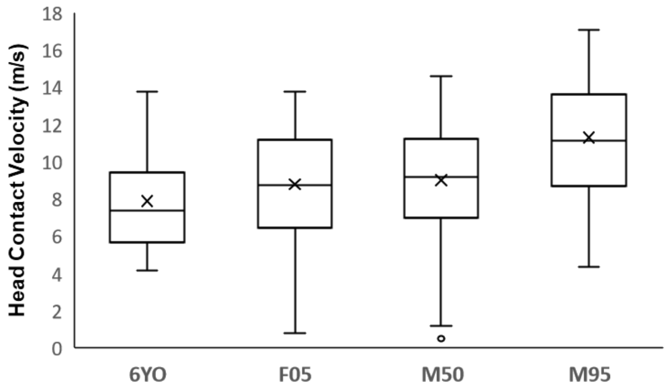
# Preliminary Data Analysis – Head Contact Velocity

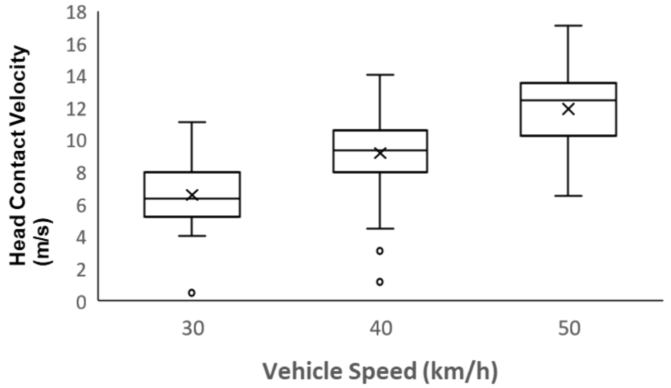


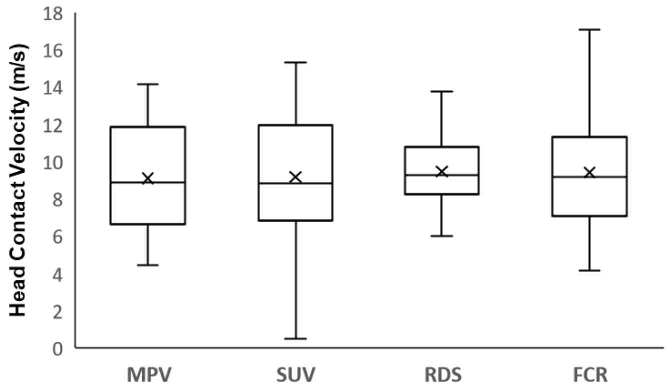

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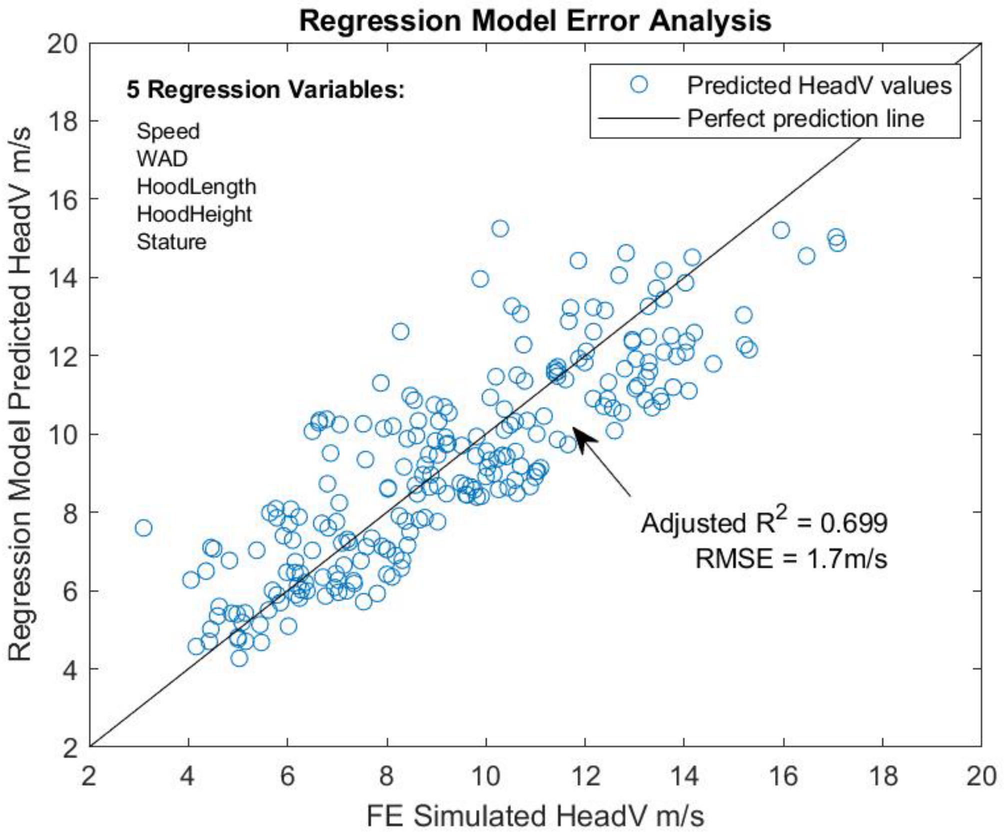
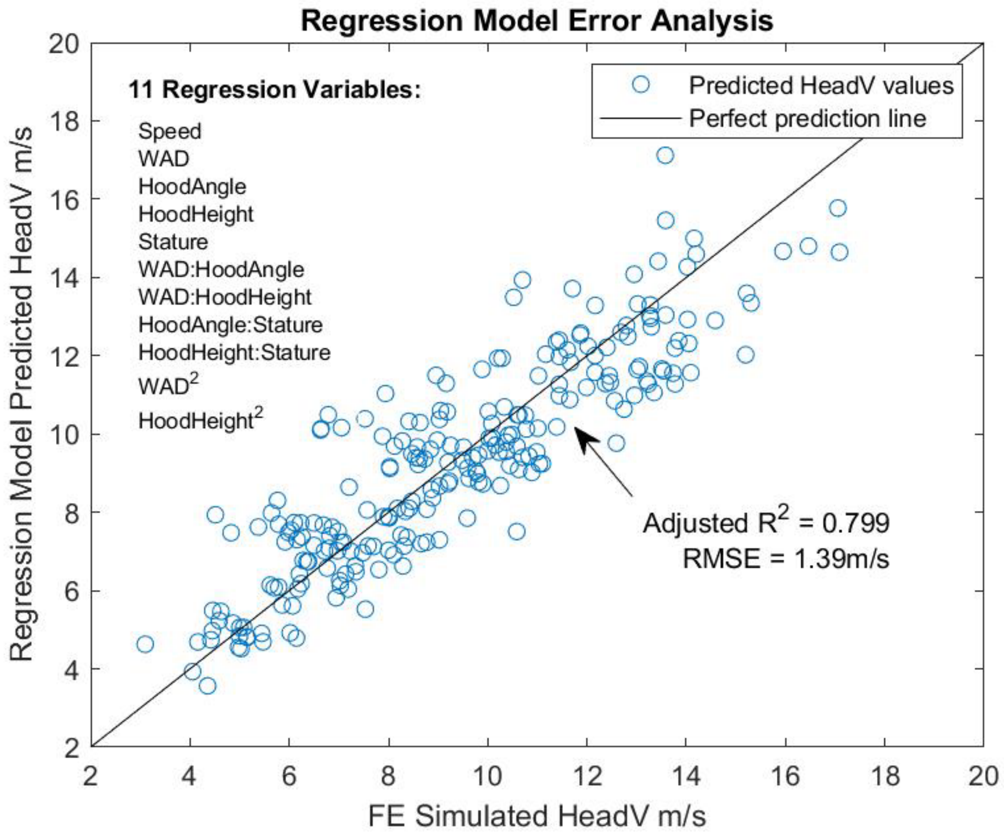
# Preliminary Data Analysis – HeadV

- Stepwise linear regression

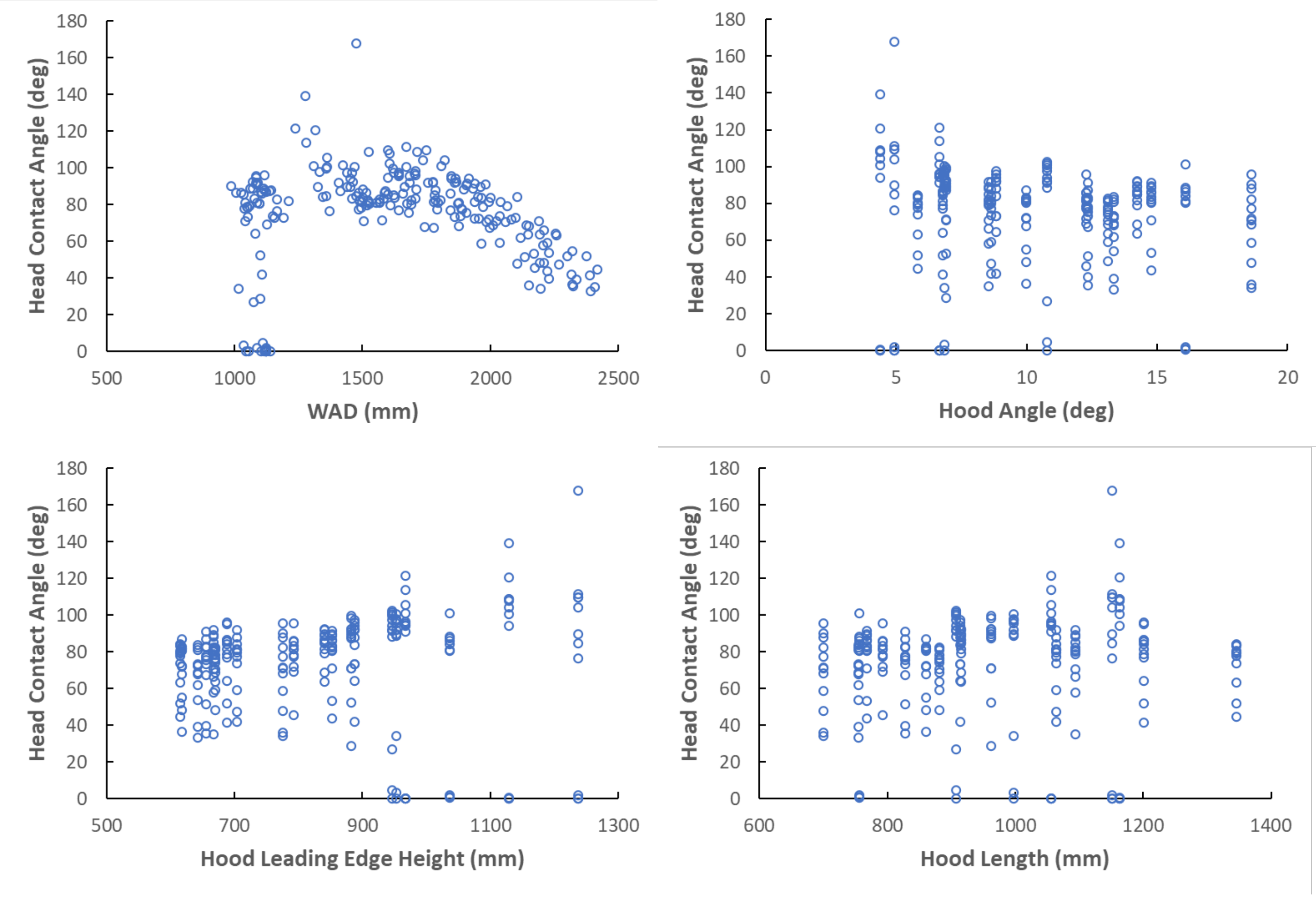


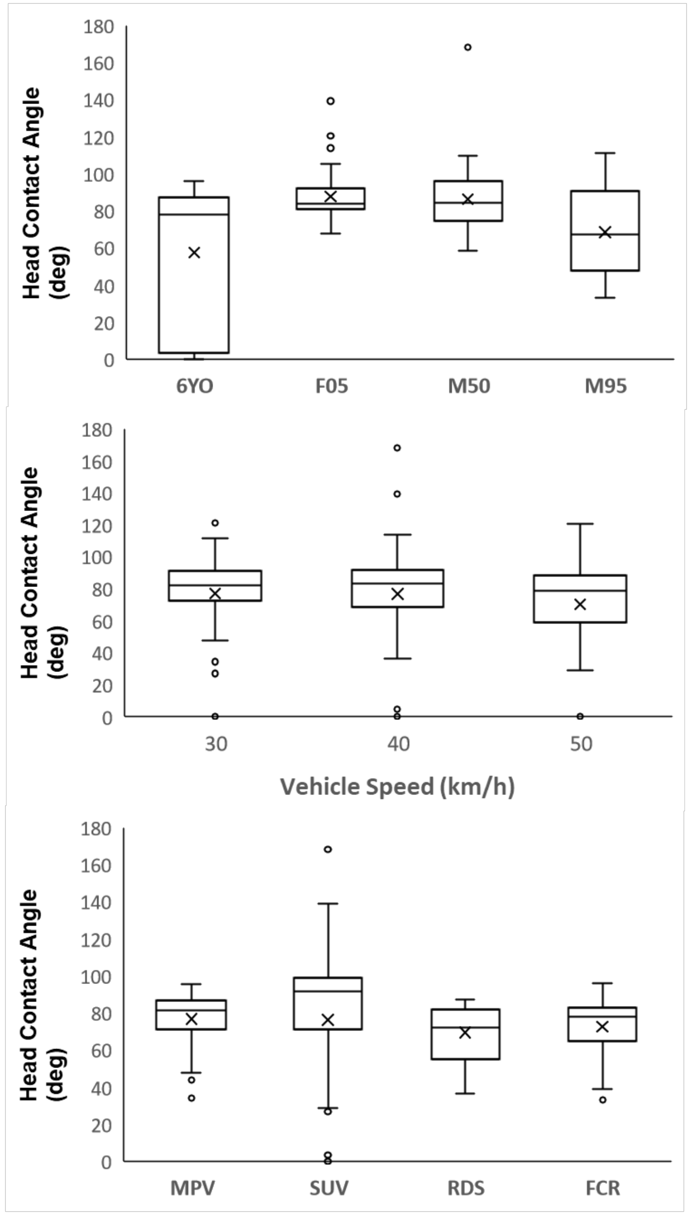

Variable Main Effects




With interaction and quadratic terms

# Preliminary Data Analysis – HeadV Angle

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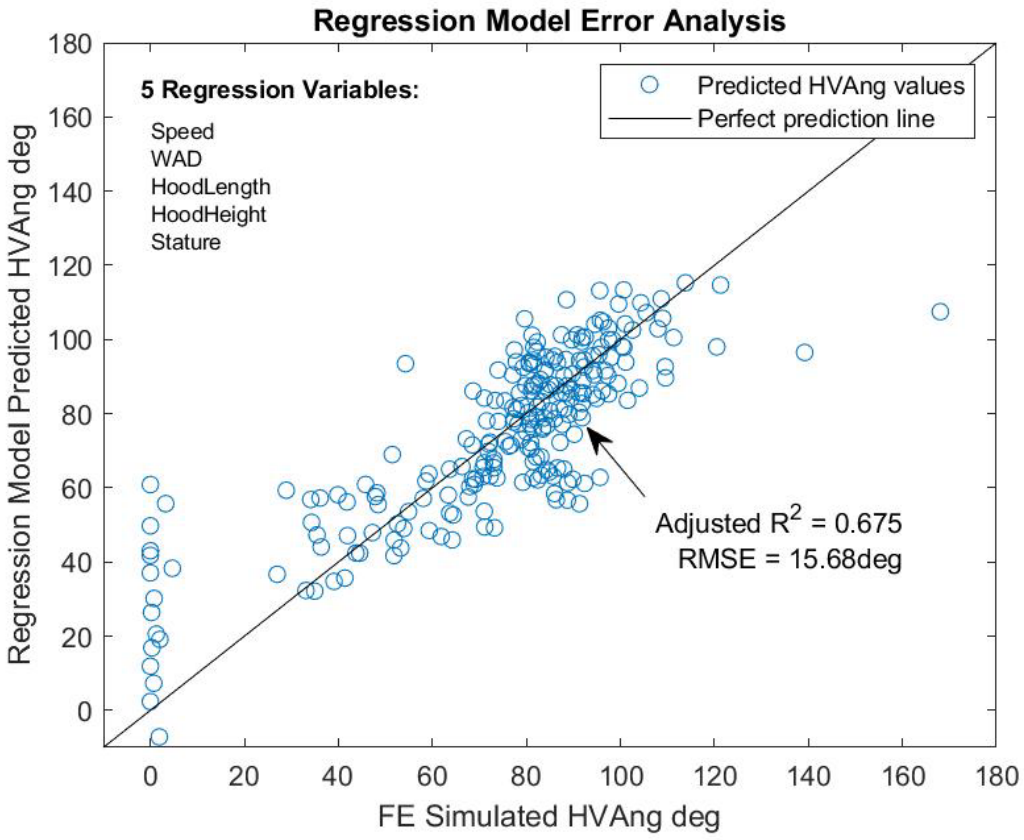
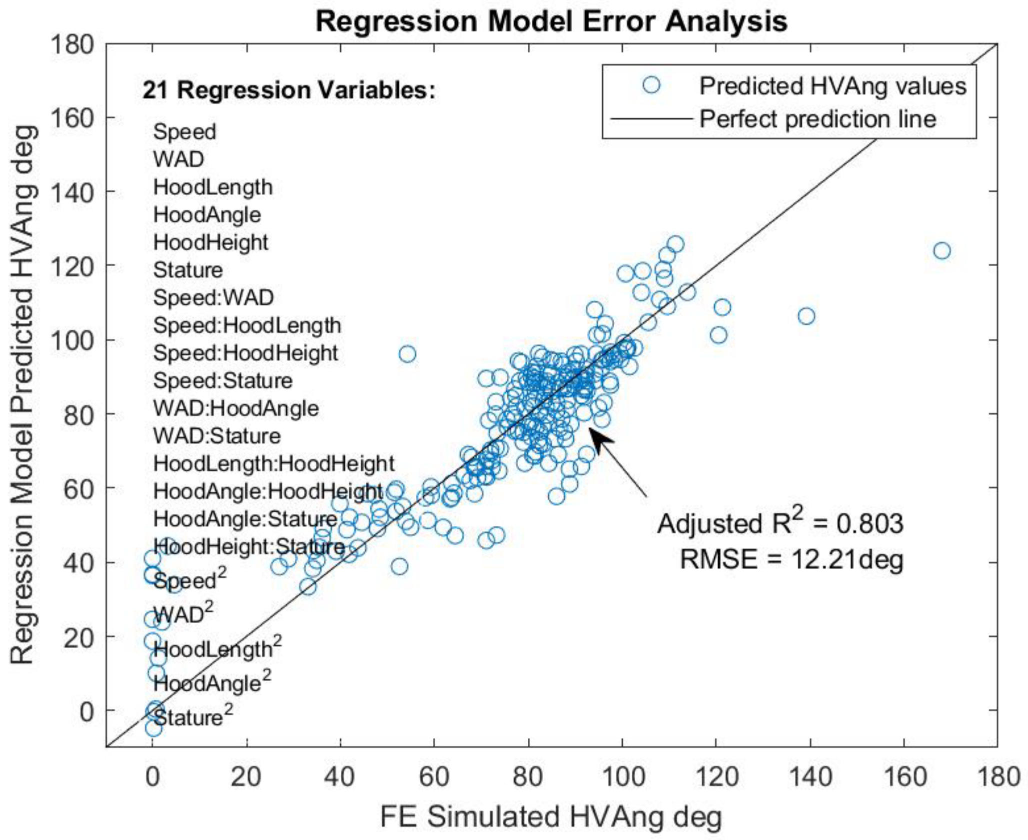
# Preliminary Data Analysis – HeadV Angle

- Stepwise linear regression




Variable Main Effects

With interaction and quadratic terms

# Summary

- GV models were morphed into 20 US vehicle geometries across a wide range of vehicle characteristics.
- 240 pedestrian simulations were conducted with 4 sizes of pedestrian human body models and 20 vehicle models at three speeds.
- In general, vehicle geometry variables, pedestrian height, and impact speed are able to predict HIT ($R^2$=0.979), head contact velocity ($R^2$=0.799) and angle ($R^2$=0.803) with good accuracy.

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# Acknowledgements

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## Questions?

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