



NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Simulation Based Foot and Ankle Injury Comparison Between Females and Males

Tejas Ruparel, Crash Simulation Engineer, Bowhead Mission Solutions

Vikas Hasija, Mechanical Engineer, NHTSA

Erik Takhounts, Mechanical Engineer, NHTSA

January 2023

CONTENTS

3

Introduction

4

Methods

10

Results

14

Conclusion

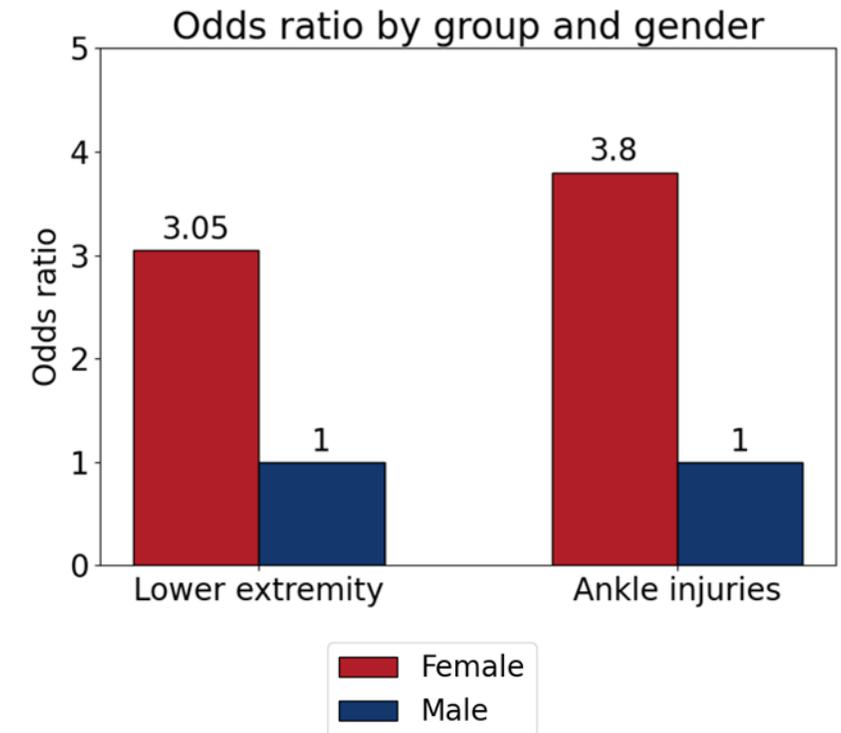
Introduction

Motivation:

- According to Forman et al (2019)*: Females are at greater risk of AIS 2+ and AIS 3+ injuries than males

Goal:

- Simulate foot & ankle injuries using biofidelic models
- Investigate injuries among different sexes
- Investigate different foot placements (brake pedal vs. toepan)
- Investigate injury mechanisms and contributing factors

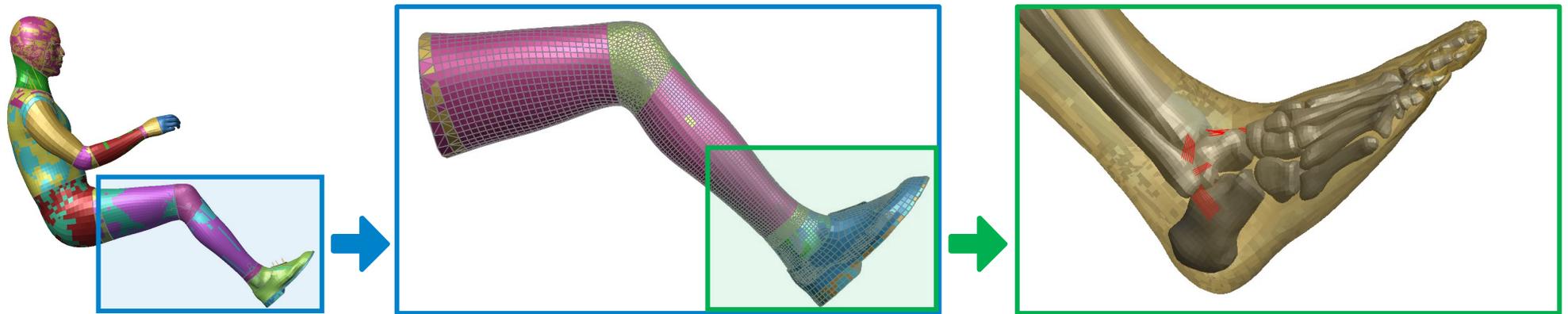


* Forman et al., "Automobile injury trends in the contemporary fleet: Belted occupants in frontal collisions", Traffic Injury Prevention (2019)

Methods

Human Body Models (HBM)

- *Analyzed HBM*: 5th female (5F), 50th female (50F) and 50th male (50M)
- Most recent and up-to-date *modular models* from GHBMC are being used in this study



Simplified upper body & pelvis

Detailed lower extremities

*Detailed ankle extremities
(deformable bones; ligament failure)*

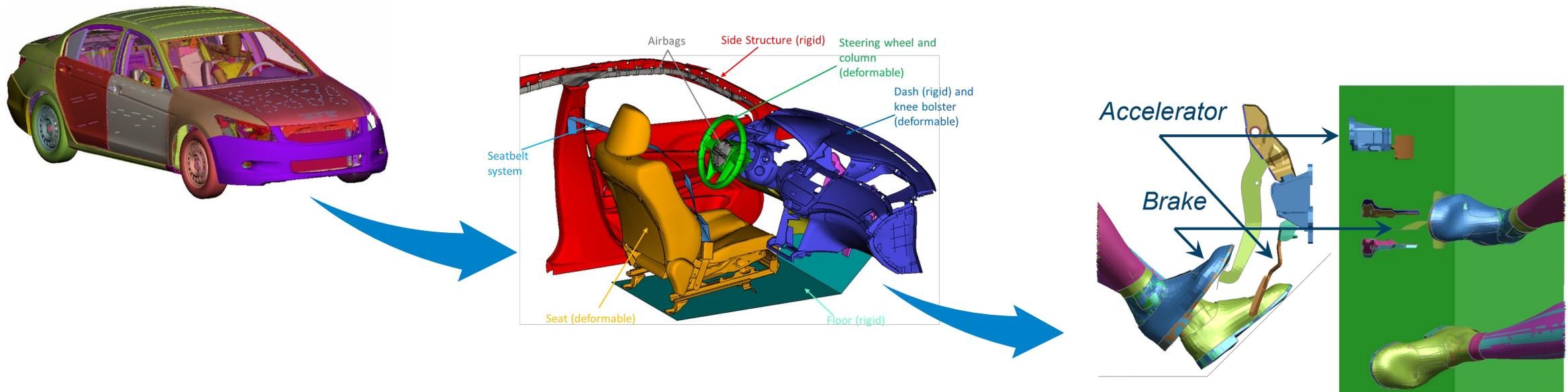
- 50F model was generated by *uniformly scaling up* the 5F model by a factor of 1.1 *

* Sitting height ratio between 50F and 5F; Anthropometric reference data for children and adults: United States, 1988–1994

Methods

Vehicle Model

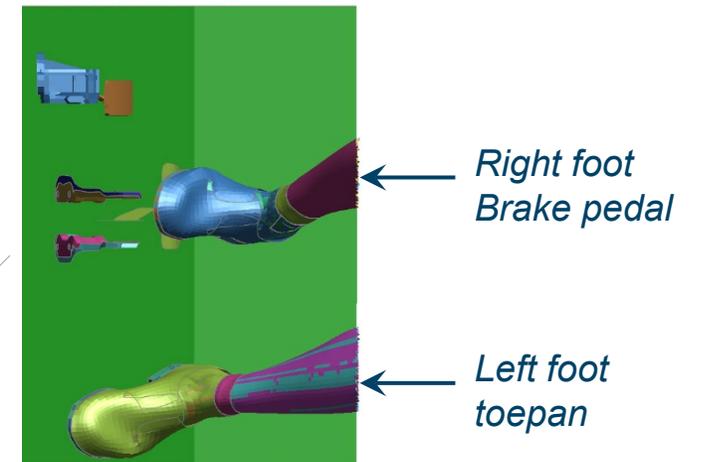
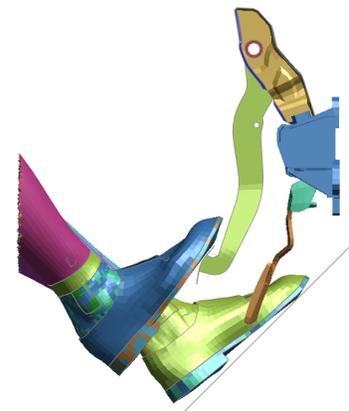
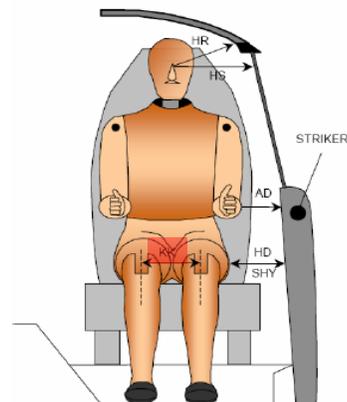
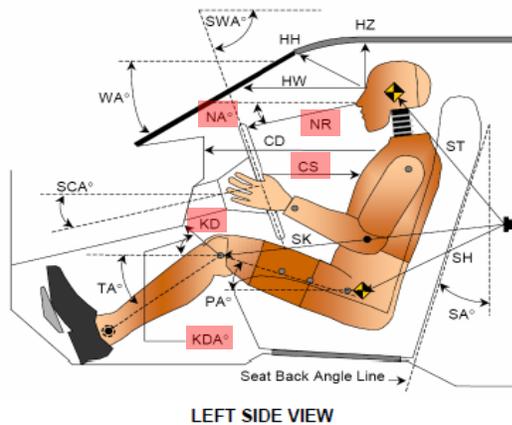
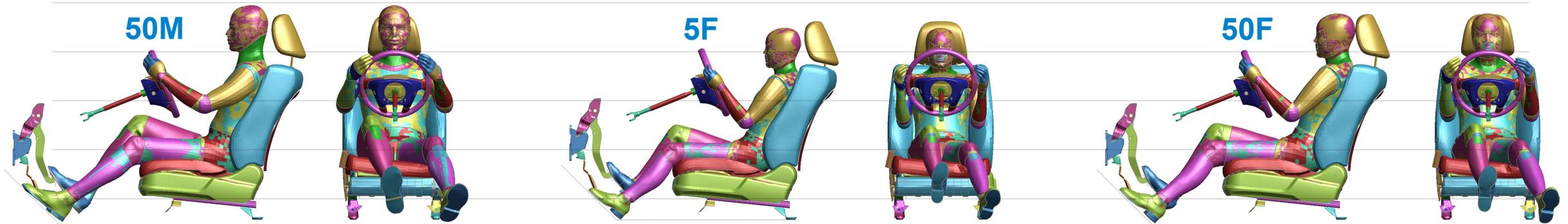
- *Simplified occupant compartment model*: 2014 Honda Accord FE model *
- Dash/door panel; seat & restraint systems; steering wheel; side & driver airbag; accelerator & brake pedals



* DOT HS 812 545 (2018)

Methods

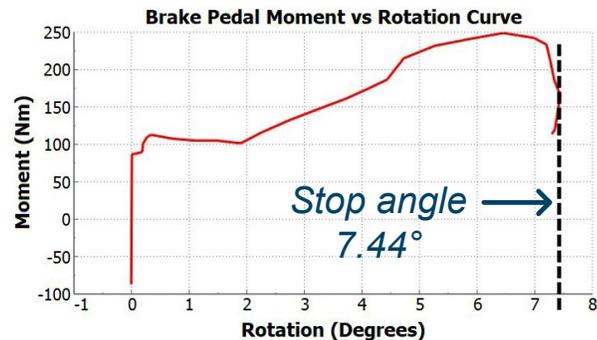
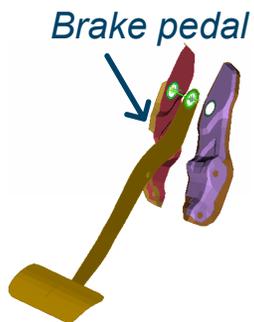
Occupant Positioning



Methods

DOE Input Variables

	Description	Nominal	Min.	Max.
Vehicle	Vehicle crash pulse (deltav)	35 mph	5 mph	35 mph
	Principal direction of force (pdf)	0 °	-30 °	30 °
	Brake pedal stop angle	7.44 °	3.44 °	11.44 °
	Brake pedal rotational stiffness	100%	50%	150%
	Seatbelt load limiting force	3000 N	1000 N	5000 N
Occupant	Seatbelt pretensioner limiting force	1000 N	1000 N	3000 N
	Normalized knee-to-dash distance	0	-1	1



Fitch et al., "Human Performance Evaluation of Light Vehicle Brake Assist Systems: Final Report", NHTSA (2010)

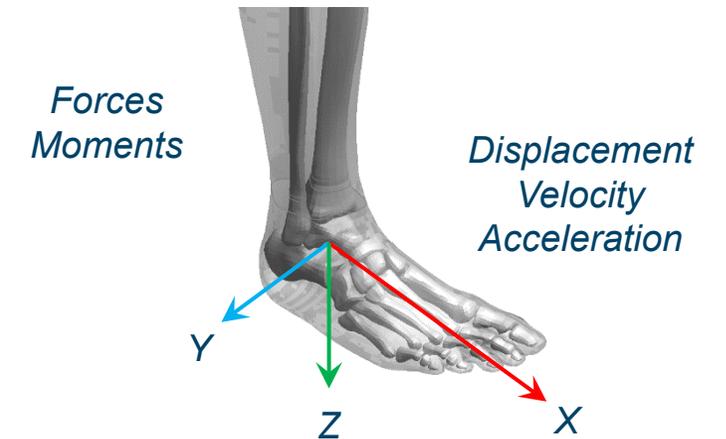
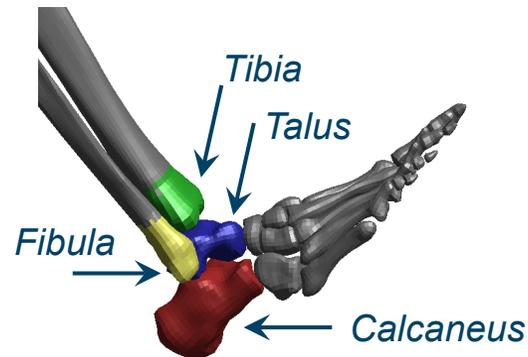
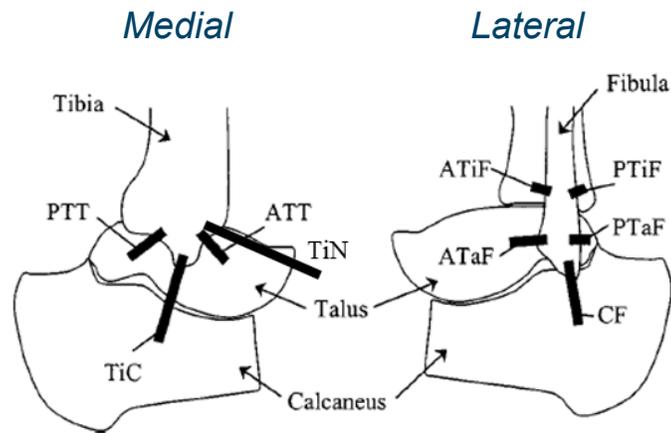
Total DOE runs: 302 per HBM

Methods

DOE Output Variables

	Response	Description
Injury (target variable)	Ligamentous injury Bone fracture	Strain based failure

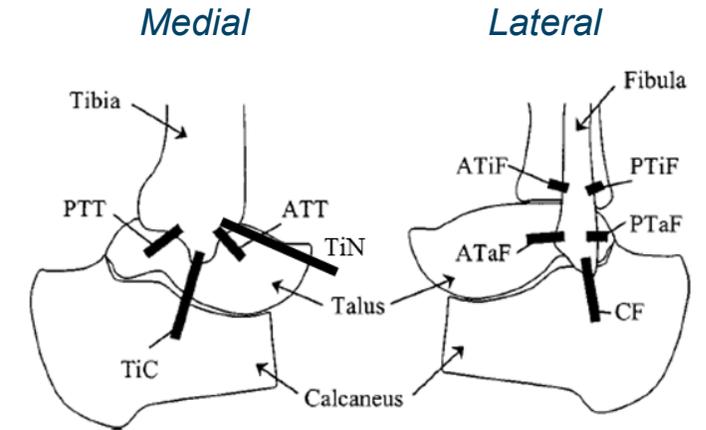
	Response	Description
Predictor (feature variable)	Foot kinematics Distal tibia loadcell	Principal components along x, y, and z



Methods

Ligamentous injuries

- Strain-based failure (GHBMC catalog)
- Injury is assumed to occur at first ligamentous failure
- Failure strain was adjusted based on post-positioning relaxed length (verified by comparing failure loads from Funk et. al *)
- Not accounted for due to lack of sufficient data



Ligament	Relaxed length (mm)	Unpreconditioned scale factor (USF)	Failure load (N)	Failure test sample size
ATaF	11.00 ± 3.61	1.75 ± .71	297.1 ± 80.3	n=2
ATiF	7.17 ± 2.56	1.44 ± .32	708.1	n=1
ATT	12.00 ± 2.00	1.40 ± .29	130.8 ± 2.00	n=2
CF	24.67 ± 5.51	1.96 ± .45	598.0 ± 52.7	n=2
PTaF	15.33 ± 4.04	1.65 ± .14	554.2 ± 94.6	n=2
PTiF	9.80 ± 1.10	1.38 ± .09	N/A	n=0
PTT	10.67 ± 3.79	1.72 ± .09	N/A	n=0
TiC	31.67 ± 3.51	1.62 ± .33	403.4	n=1

Funk et. Al (2000)

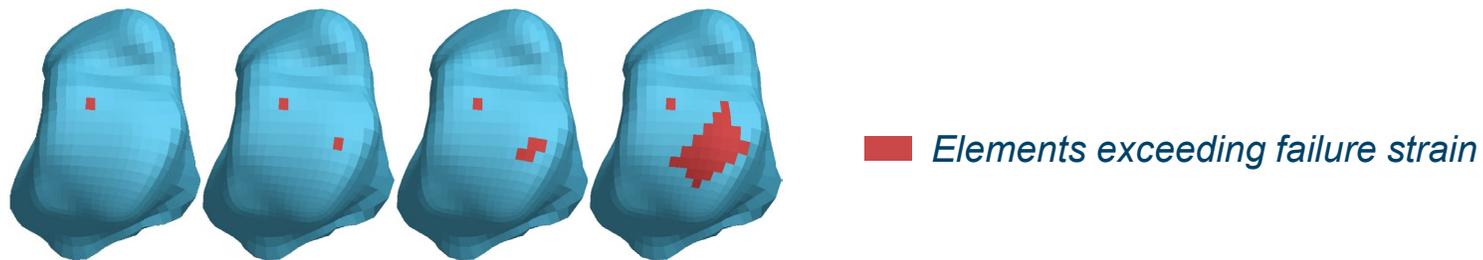
Ligament	Name	50M Failure strain
ATT	Anterior tibio talar	37%
PTT	Posterior tibio talar	22%
CT	Tibiocalcaneal	44%
TiN	Tibio Navicular	30%
ATaF	Anterior talo fibular	42%
PTaF	Posterior talo fibular	16%
CF	Calcaneo Fibular	52%
ATiF	Anterior tibio fibular	25%
PTiF	Posterior tibio fibular	119%

* Funk et. Al, Linear and Quasi-Linear Viscoelastic Characterization of Ankle Ligaments, 2000

Methods

Bone Fracture Criteria

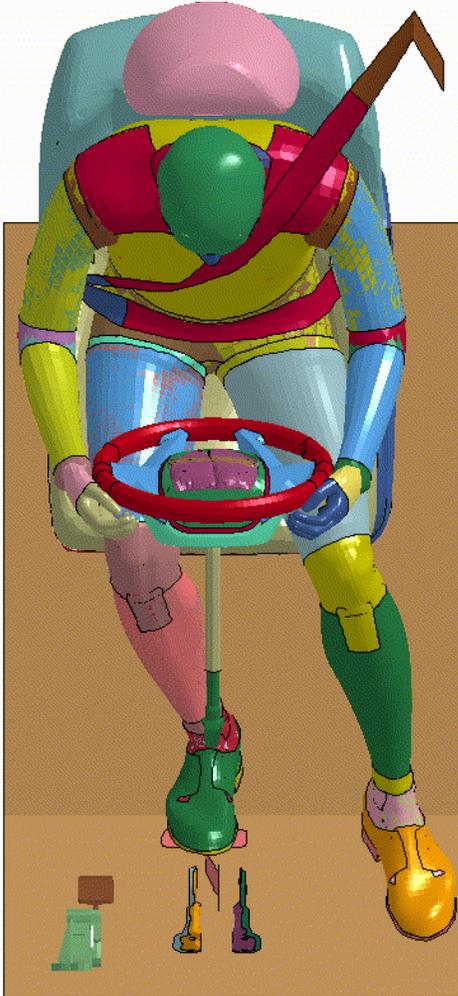
- *MPS (Maximum Principal Strain)*: Register fracture if any elements exceeds failure strain
- *MPS95 (95th percentile MPS)*: Register fracture only if 95th percentile element exceeds failure strain
- *NE2 (2 element neighbor)*: Register fracture only if 2 or more neighbor elements exceed failure strain
- *NET2 (time constrained 2 element neighbor)*: NE2 + initiation–propagation time constraint



Criteria/Case	1	2	3	4	Description
MPS	True	True	True	True	Captures the onset of fracture, but does not filter out spurious strains
MPS95	False	False	False	True	Does not capture the onset of fracture
NE2	False	False	True	True	Captures the onset of fracture and filters out spurious strains
NET2	False	False	False True	False True	Captures the onset of fracture and filters out spurious strains False: if initiation–propagation time window $> x$ ms True: if initiation–propagation time window $\leq x$ ms

Results: Full-Frontal Impact (pdof = 0°) at 30 mph

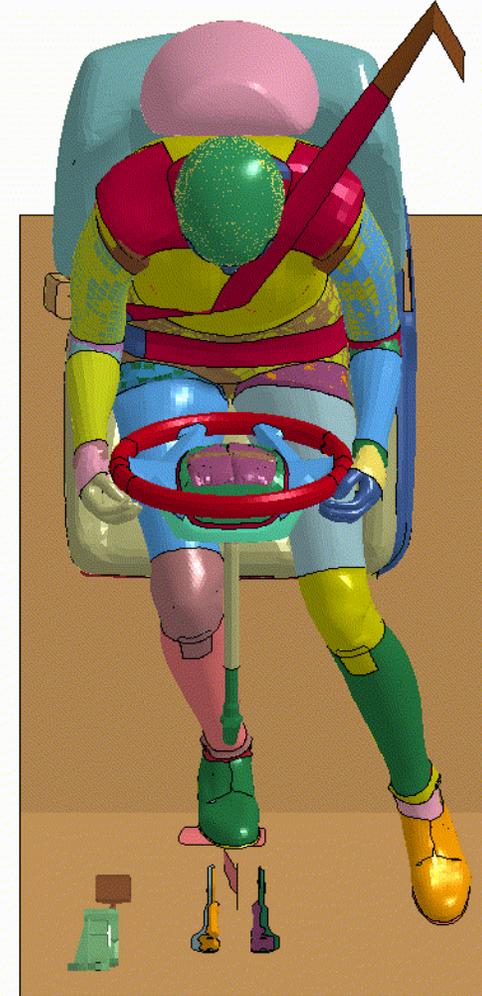
50M



5F

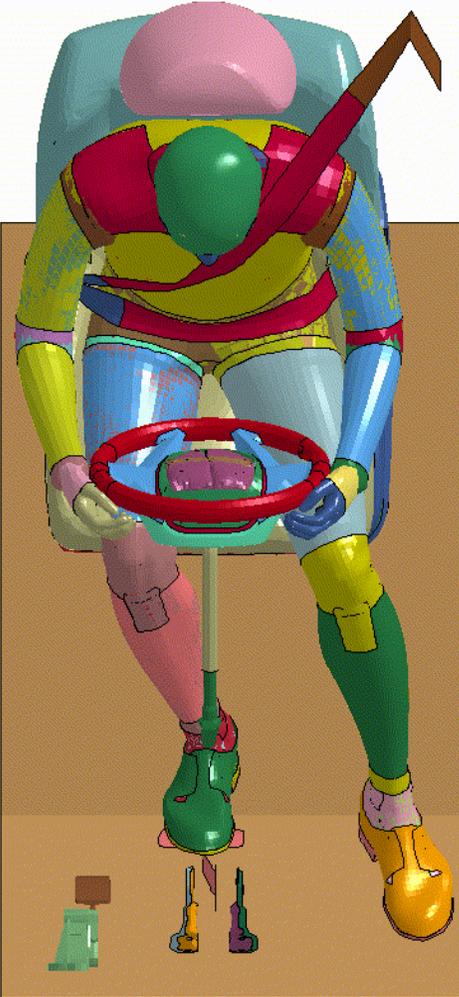


50F

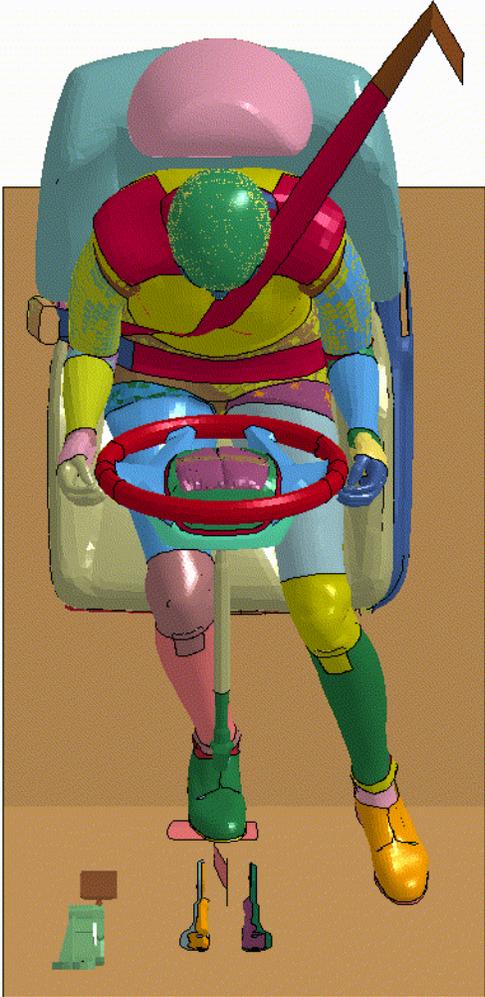


Results: Near-Side Impact (pdof = -30°) at 30 mph

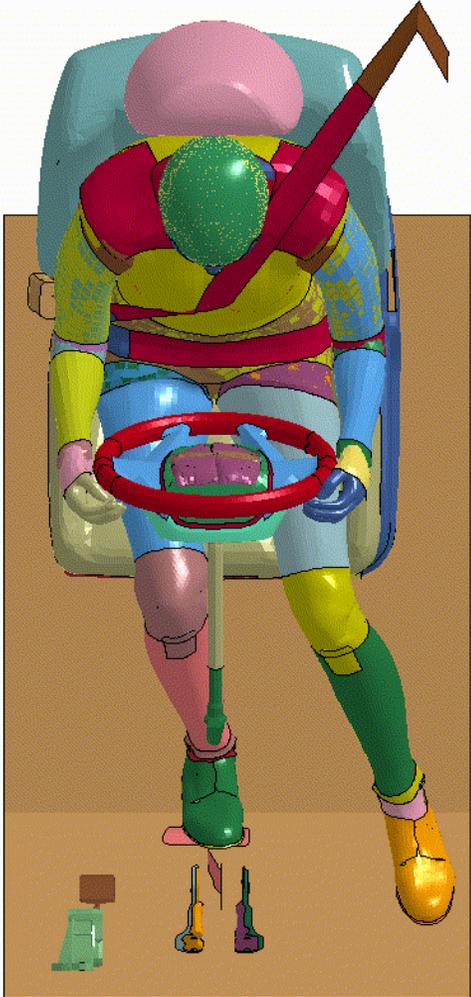
50M



5F

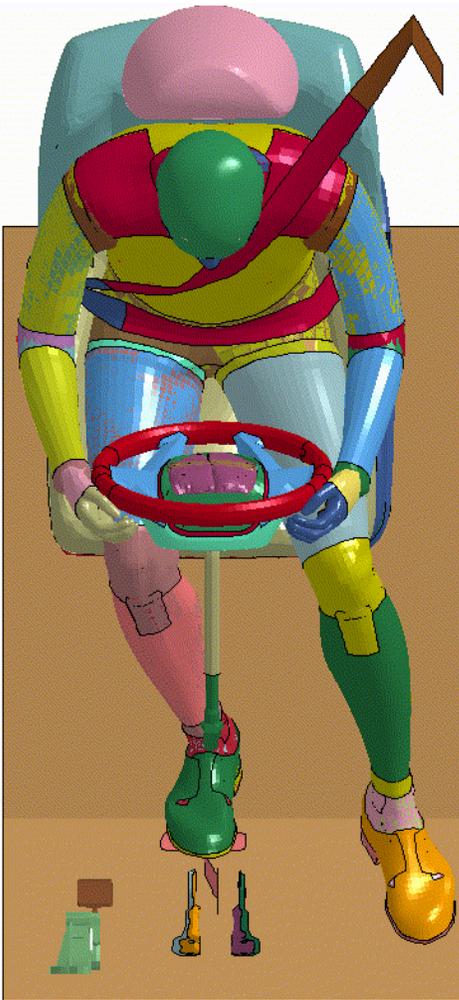


50F



Results: Far-Side Impact (pdof = +30°) at 30 mph

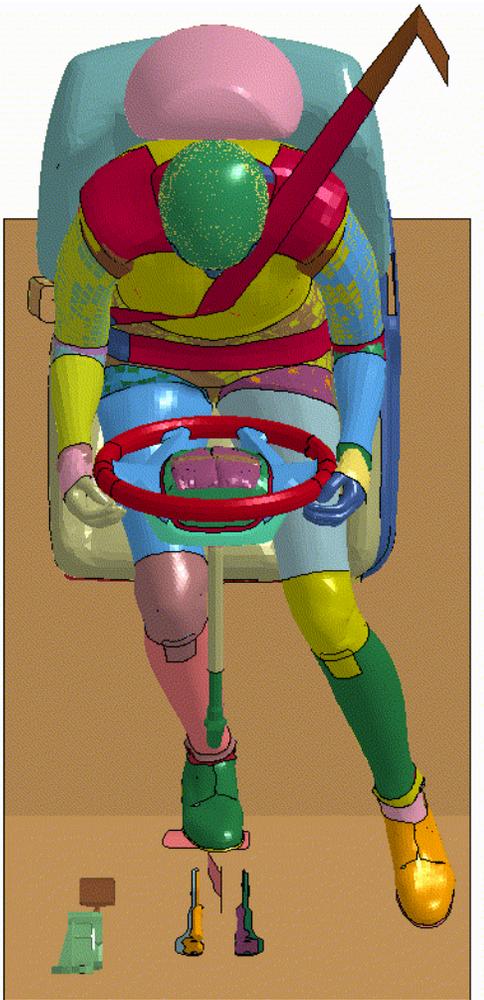
50M



5F

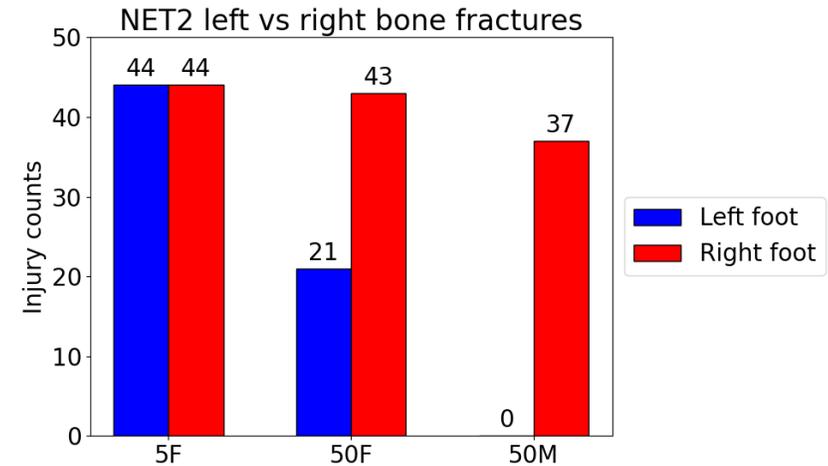
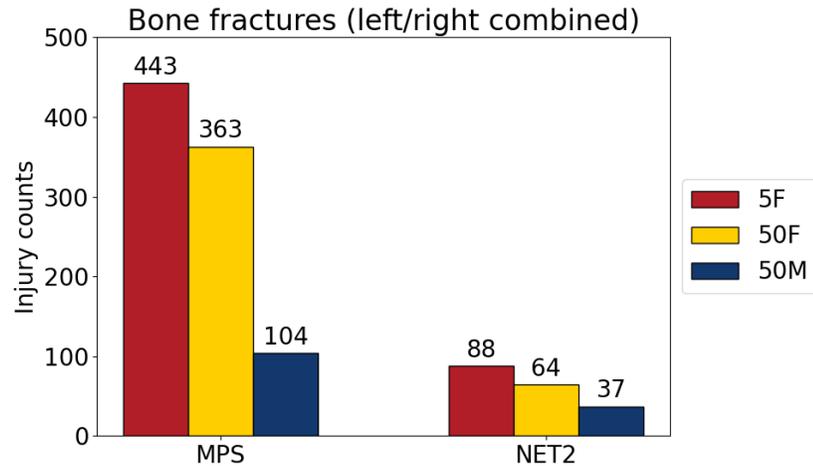


50F



Results

Injury Distribution: Bone Fracture



- MPS, due to its inability to filter out spurious strains, shows excessively high injury counts versus NET2
- Females show higher injuries than males, w/ 5F showing the highest number of injuries
- Right foot (positioned on brake pedal) shows higher injuries than left foot (positioned in the toepan)
- First bone to fail NET2 in most crash scenarios:
 - Females: Malleolar Tibia
 - Males: Talus

Conclusions

- New strain-based criterion, that takes into account both element cluster size and crack propagation time, was introduced (NET2)
- NET2 based odds ratio for foot & ankle injuries between females and males is 4.1, compared to 3.8 from the field data (Forman et. al. 2019)
- Females showed higher number of foot and ankle injuries than males, with 5F showing the highest number of injuries
- Right foot (positioned on brake pedal) showed higher injuries than left foot (positioned in the toepan) for all HBM, except for 5F which showed equal risk

THANK YOU!

✉ tejas.ruparel.ctr@dot.gov

