200-series Breakout: FMVSS No. 208 - Rear Seat Testing

Moderator: Warren Hardy, VT-CIB

Presenters:

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Crashworthiness and Occupant Protection Rear Seat Testing and Seating Location Selection

FMVSS 208 Rear Seat Testing Overview

Andrew R. Kemper

Part 1: Problem Scoping

1.3 Select Late-Model Vehicles Spanning a Range of Potential Rear-Seat Safety Performance

NCAP Report, NCAP-MGA-2012-027, 2011

1.3.1 Survey NCAP boneyard inventories

Surveyed 2018 NCAP boneyard inventories to determine which vehicles were available for inspection

1.3.2 Select sedans, SUV/crossovers, and Minivans for inspection

Screened the available vehicles and selected a more-limited set for further examination

Emphasis of this work was passenger vehicles - **Sedans, SUV/Crossovers, and Minivans**

- More rear-seat occupants are in Minivans (based on vehicle miles driven), but the majority of AIS3+ injuries for rear-seat occupants occur in sedans followed by SUVs for all ages. (Bose et al., 2017)

1.3 Select Late-Model Vehicles Spanning a Range of Potential Rear-Seat Safety Performance (from 23)

2018	Chevrolet	Equinox
2018	Audi	Q5
2018	Jeep	Compass
2018	Mercedes	GLC-Class
2018	Nissan	Rogue Sport
2018	Nissan	Maxima
2018	Subaru	Legacy
2018	BMW	X1
2018	Chevrolet	Bolt
2018	Honda	Accord Sedan
2018	Hyundai	Santa Fe
2018	Toyota	Camry

2017	Buick	Envision
2018	Cadillac	Cadillac XT5
2017	Chrysler	Pacifica
2018	Honda	Honda Odyssey
2017	Hyundai	Elantra
~~2017~~	~~Kia~~	~~Kia Niro~~
2018	Lincoln	Lincoln Continental
2017	Mazda	CX-3
2018	Subaru	Impreza
2017	Toyota	Prius
~~2018~~	~~Chevrolet~~	~~Traverse~~

Test Lab
TRC
Karco
MGA
208/MGA
Calspan

1.3 Select Late-Model Vehicles Spanning a Range of Potential Rear-Seat Safety Performance

1.3.3 Examine vehicles' package characteristics, restraint geometry, and seatbelt routing

Placed a representative ~50th percentile occupant in the second row of actual vehicles

Documented restraint and seat characteristics

Restraint Characteristics

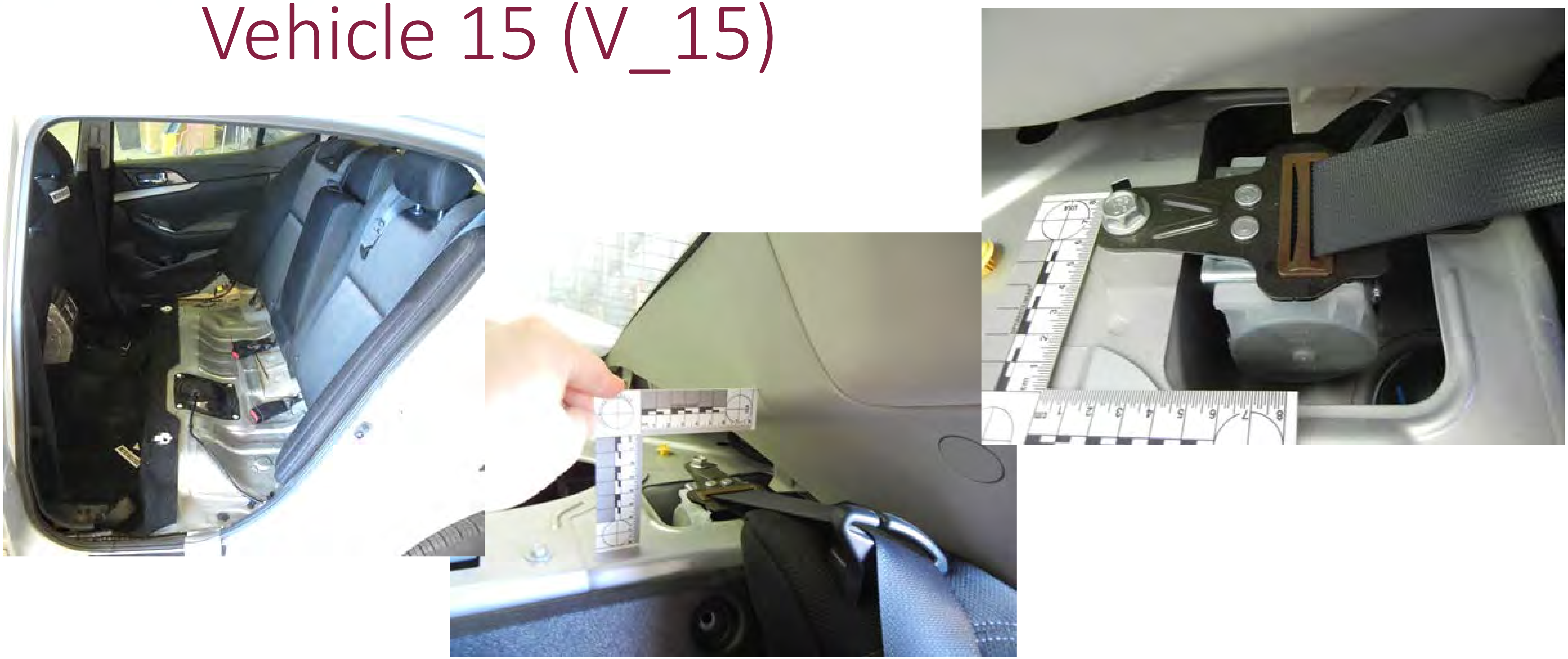
- Belt anchor point locations, including D-rings and retractors
- Presence of load limiters, pretensioners, or inflatable seatbelts
- Seatbelt routing

Seat Characteristics

- Seatback angle
- Seat bottom angle and length
- Seat pan geometry, including riser height
- Seat cushion stiffness
- Relative headrest position

Vehicle 15 (V_15)

Vehicle 15 (V_15)

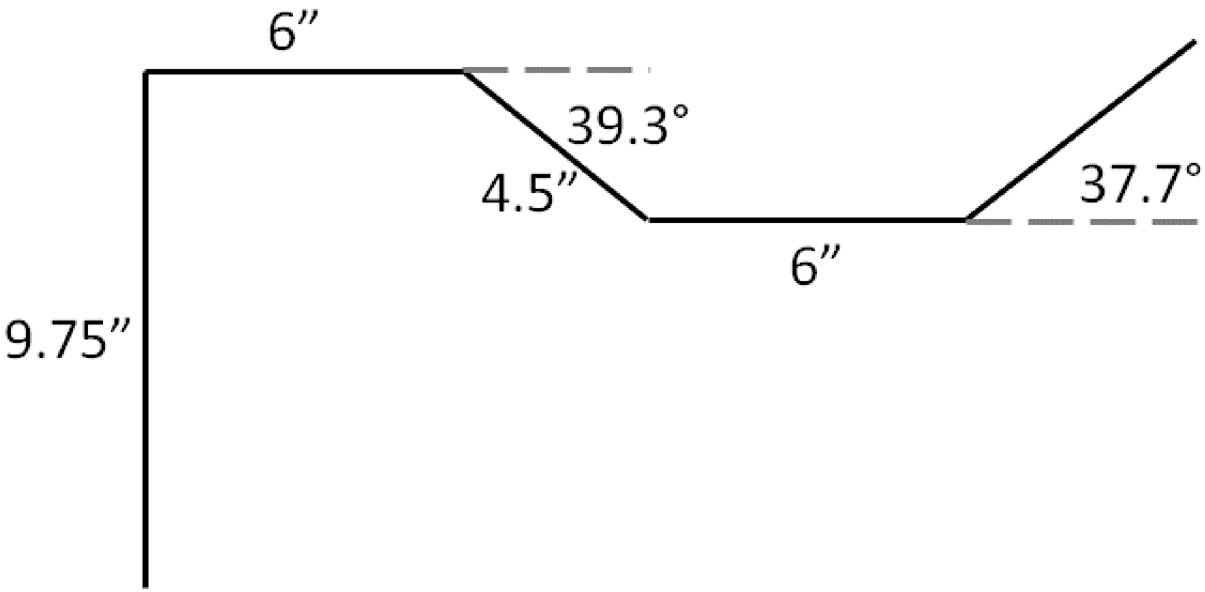


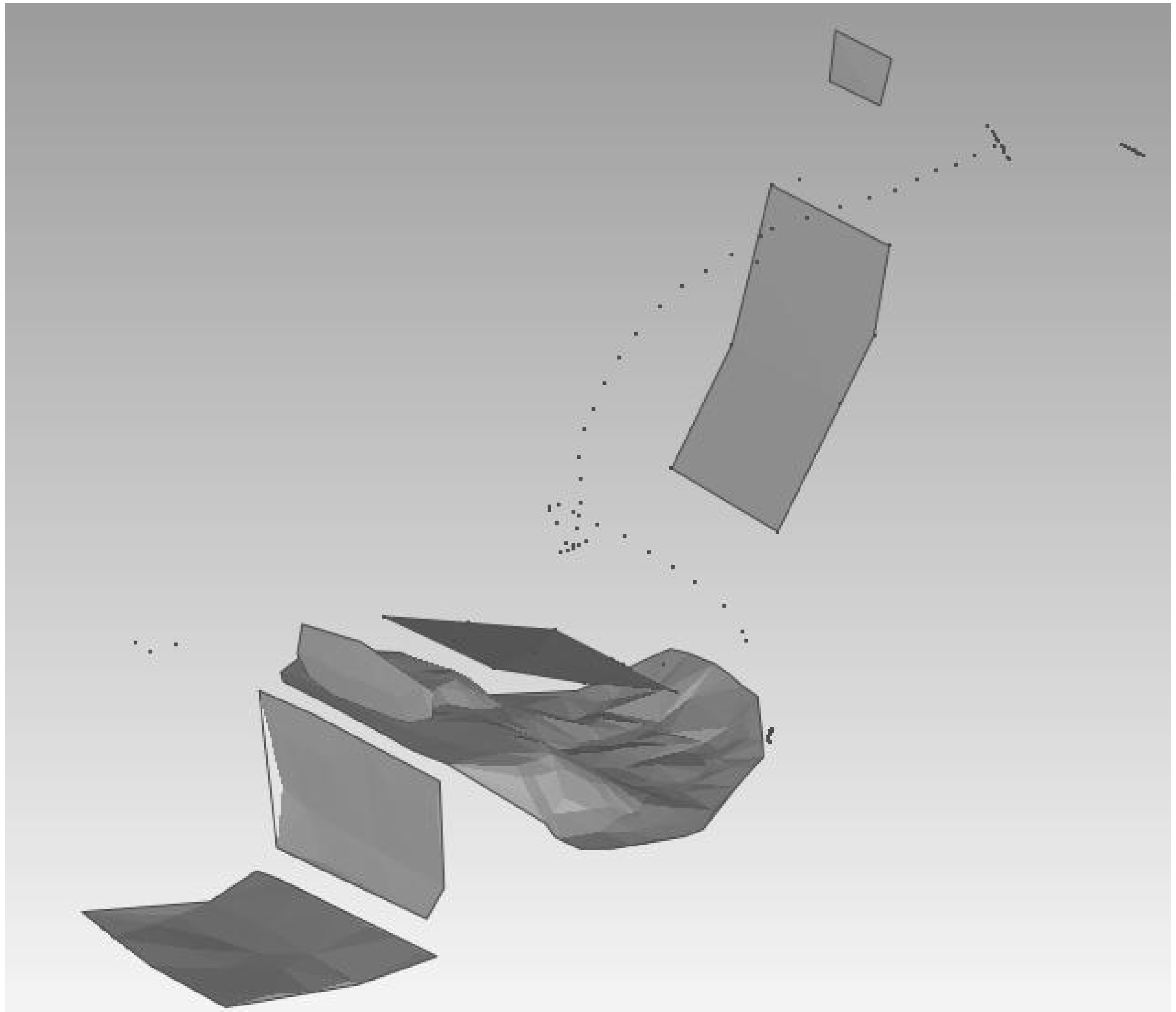
1.3 Select Late-Model Vehicles Spanning a Range of Potential Rear-Seat Safety Performance

Faro Arm Data Collection:

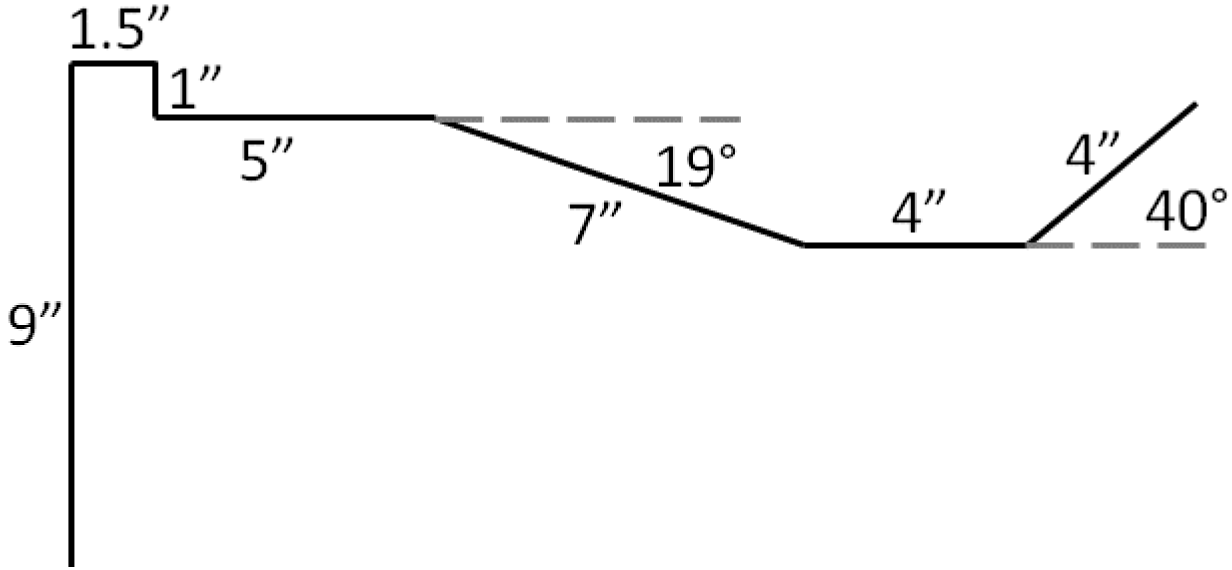
- Vehicle origin and coordinate system established
- FARO point clouds taken for floor pan, riser, and seat pan
- FARO point clouds taken for seat bottom and back cushions
- FARO point clouds taken for the headrest
- Specific points taken for anchor points and retractors
- Points taken for belts, buckles and anatomical landmarks with 50th-percentile subject positioned in left second-row seat
- Point clouds turned into surfaces (IGES files) for model generation

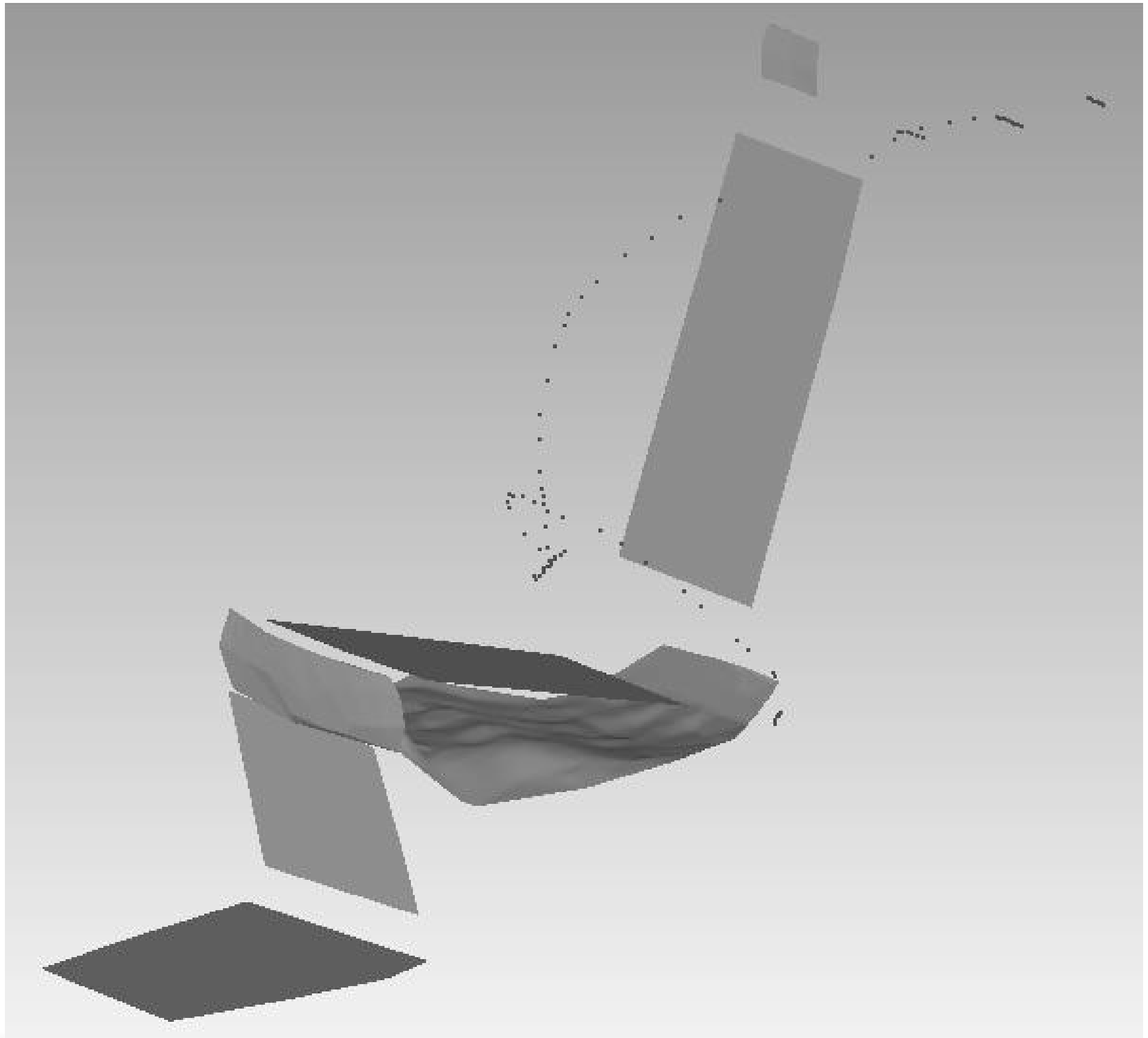
Vehicle 15 (V_15)



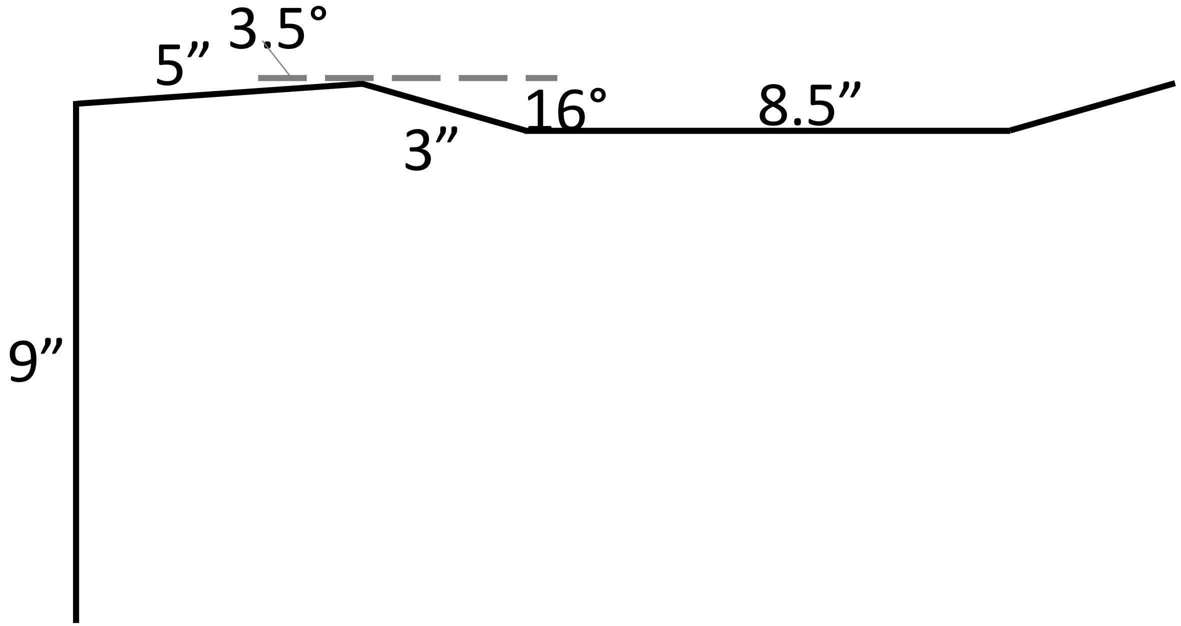


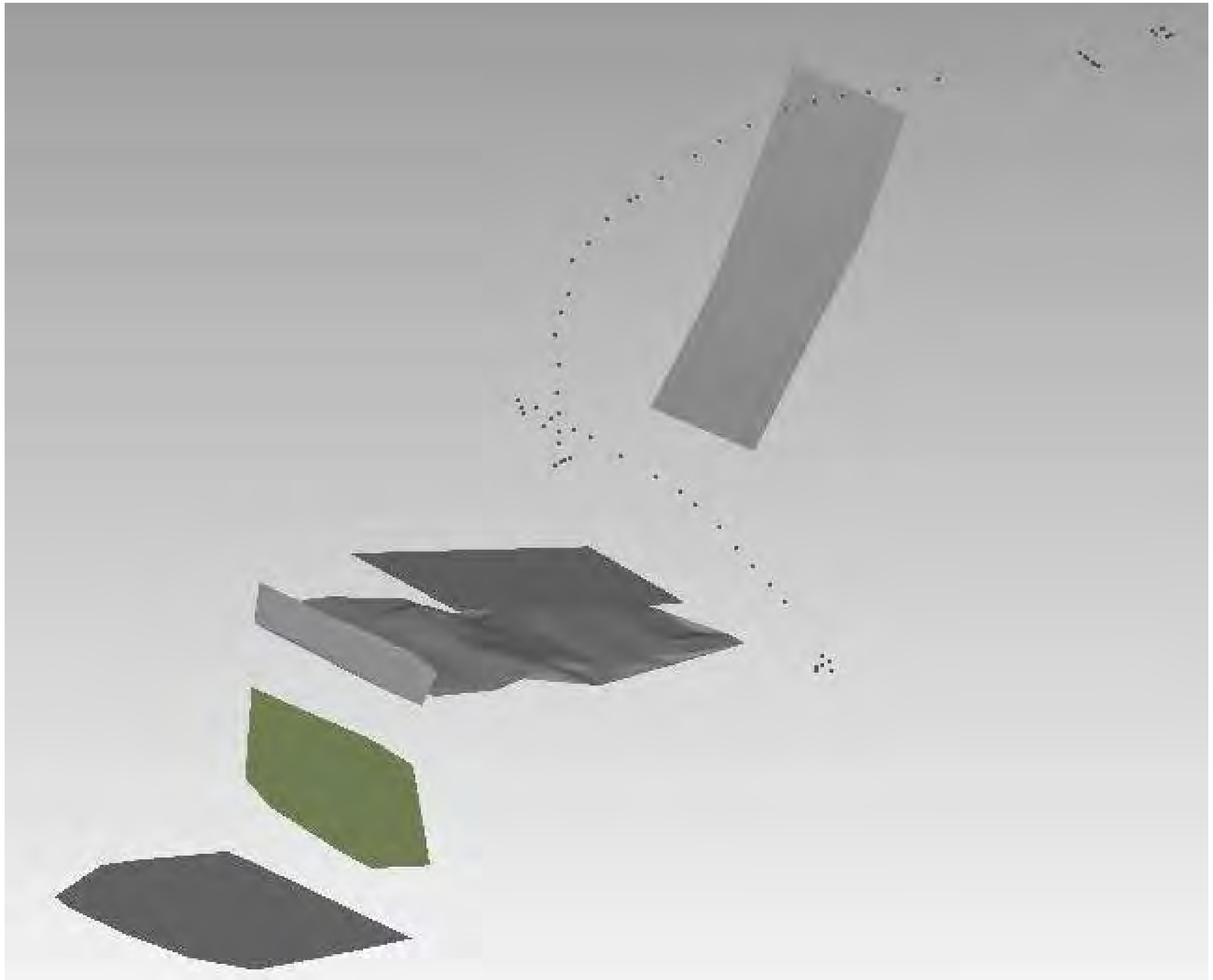
Vehicle 9 (V_9)



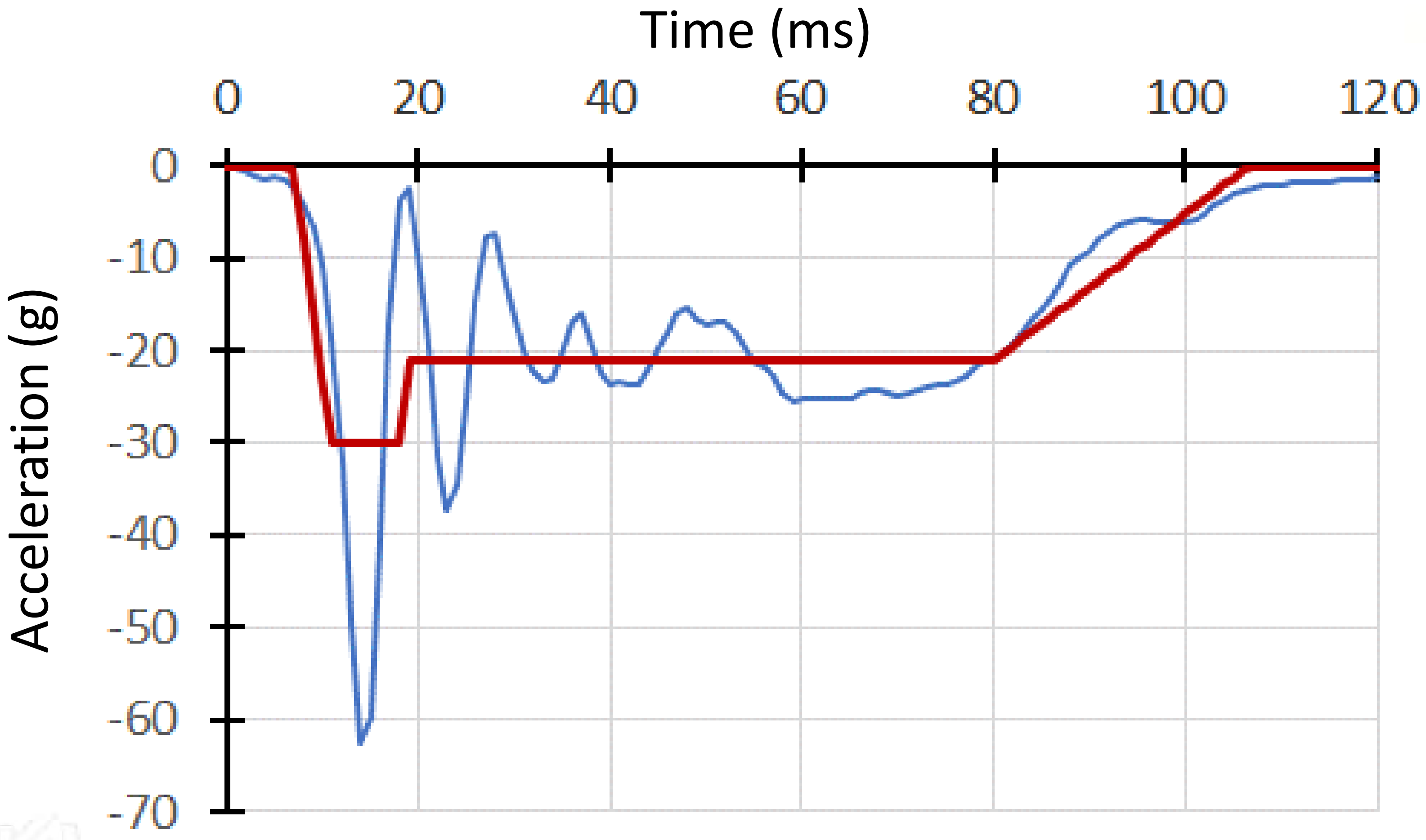


Vehicle 16 (V_16)



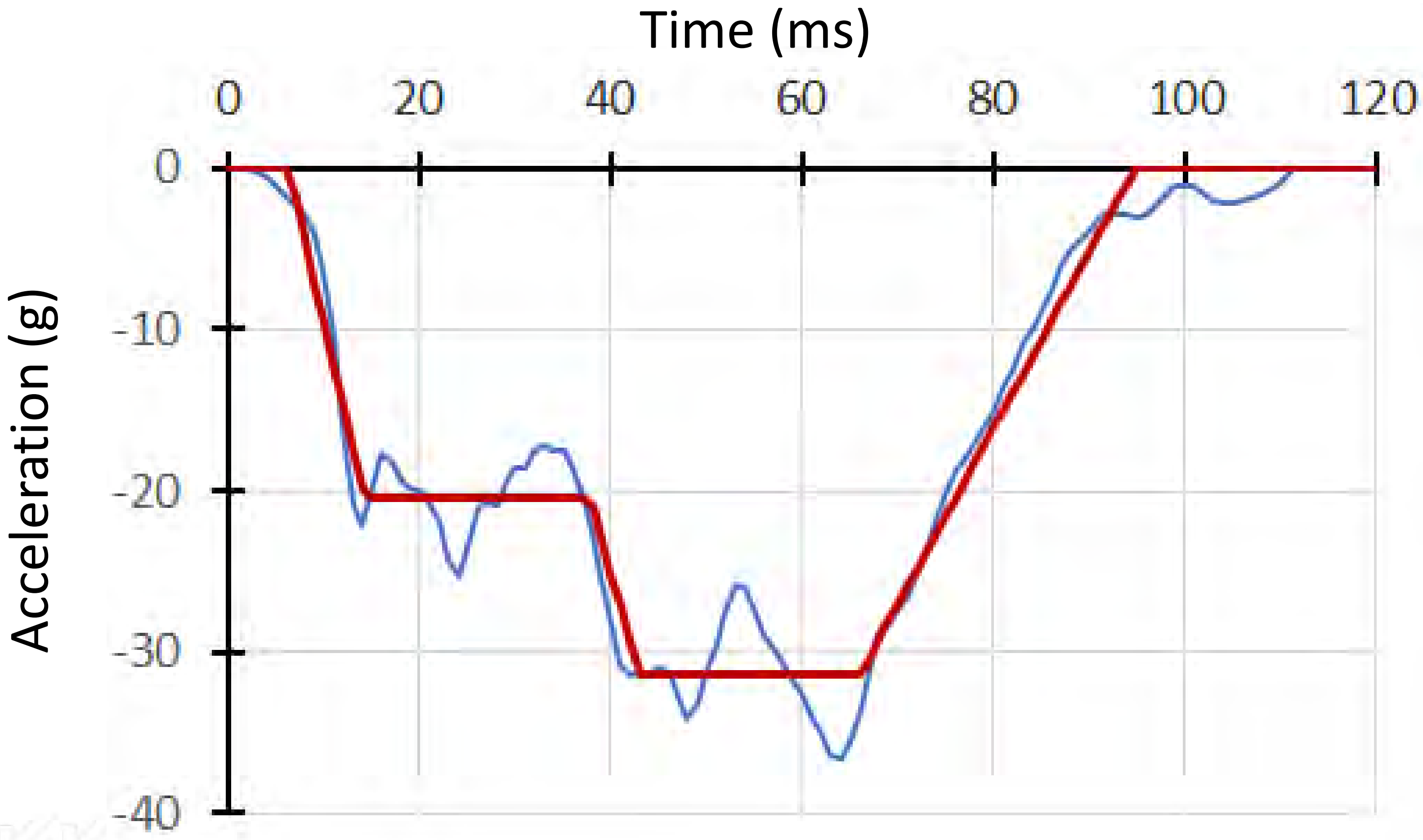


Vehicle 5 (V_5) Crash pulse shape/magnitude



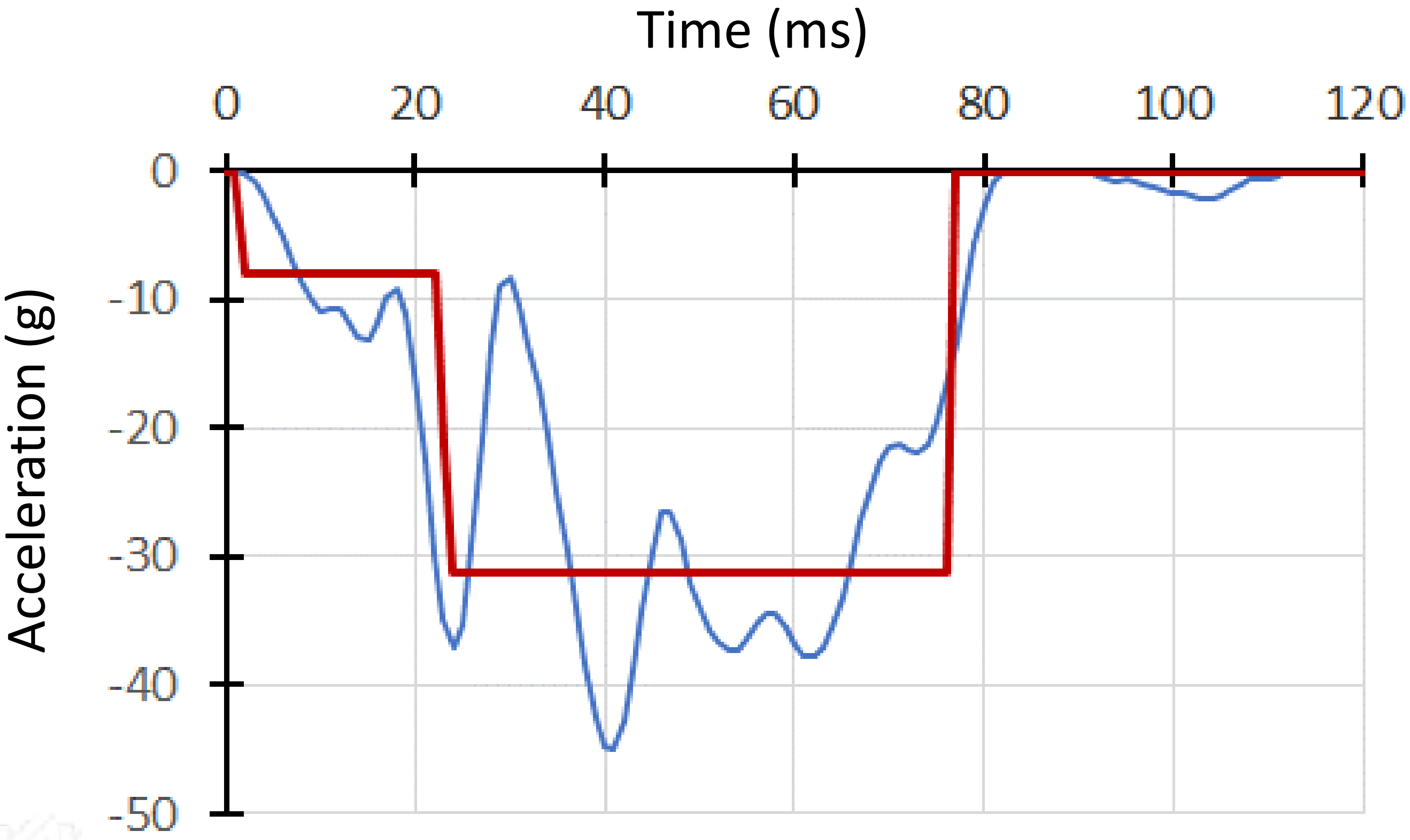
Two-step Fit	
t (s)	A (g)
0	0
0.006963	0
0.011	-30.02
0.018469	-30.02
0.018469	-21.16
0.080005	-21.16
0.106443	0
0.12	0

Vehicle 3 (V_3) Crash pulse shape/magnitude



Two-step Fit	
t (s)	A (g)
0	0
0.006272	0
0.014202	-20.40
0.037707	-20.40
0.042994	-31.37
0.065994	-31.37
0.094725	0
0.12	0

Vehicle 16 (V_16) Crash pulse shape/magnitude



Two-step Fit	
t (s)	A (g)
0	0
0.001	0
0.0015	-8.00
0.022899	-8.00
0.023075	-31.25
0.076931	-31.25
0.076931	0
0.12	0

Down selection to approximately ~10 vehicles for FE modeling

Crash Performance Parameters

- Shoulder Belt Location on Clavicle
- Retractor (P/T, CFR + P/T)
- Seat Pan Ramp, Sub Bar, or Box at End of Ramp
- Box at end of Ramp
- Drop off at end of Ramp
- Lap Belt Angles
- Seat Foam Stiffness
- Sub Bar
- Foam Stiffness + Sub bar
- NCAP Crash Pulse (shape/magnitude)

Crash Performance

Neck Loads
Chest Deflection
Lumbar Loads
Pelvis Acceleration
Overall

Score: 0 to 200 (larger=better)

Down selection to approximately ~10 vehicles for FE modeling

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- NCAP Crash Pulse (shape/magnitude)

Crash Performance

Neck Loads
Chest Deflection
Lumbar Loads
Pelvis Acceleration
Overall

Score: 0 to 200 (larger=better)

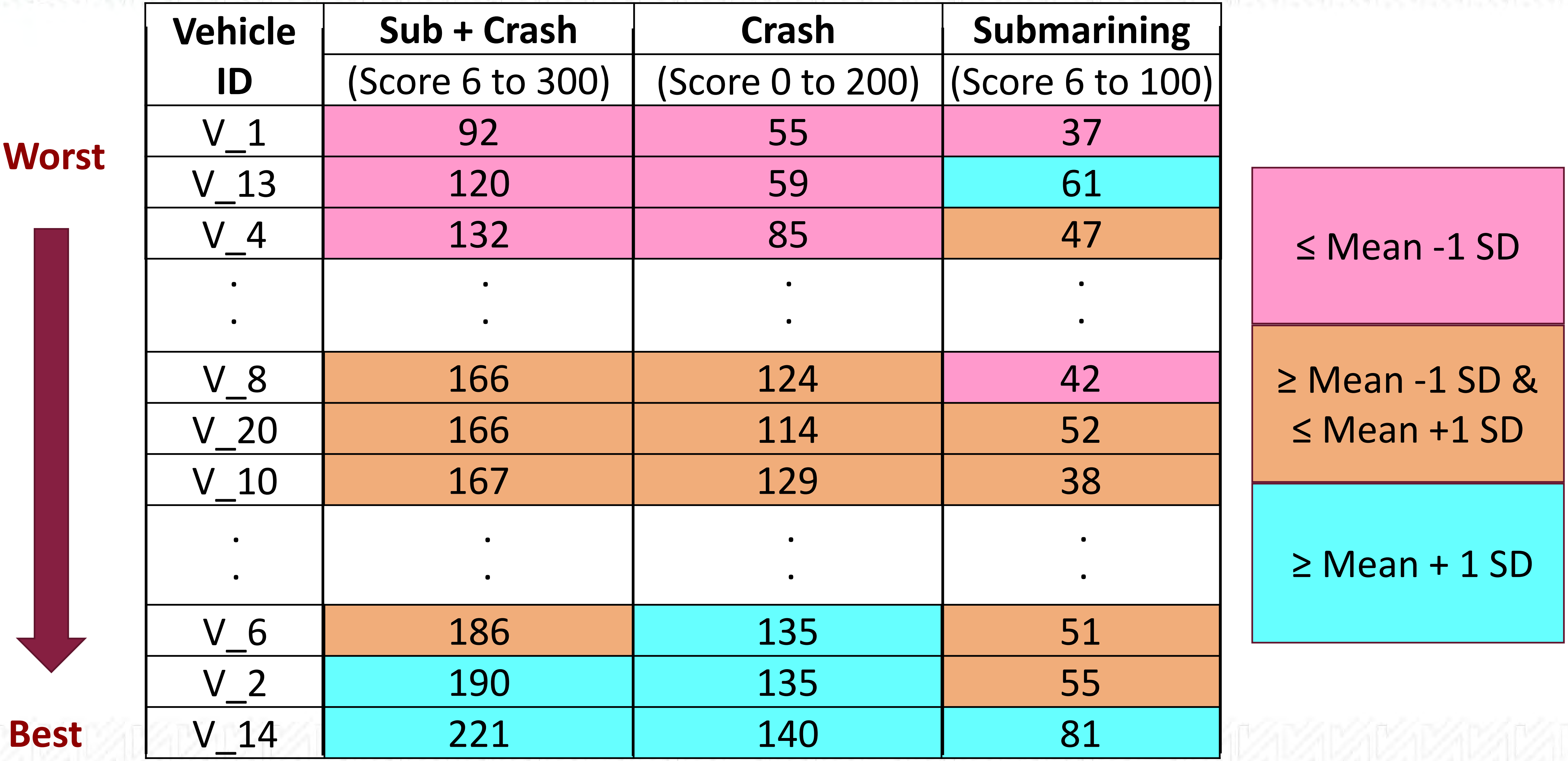
Down selection to approximately ~10 vehicles for FE modeling

Submarining Parameters

- Seat or Floor Pan Ramp Angle
- Anti-Submarining Bar
- Seat A-Surface Pocket
- Seat Surface to Floor Height
- Seat Foam Stiffness and Structure Interaction
- Shoulder Belt Retractor (P/T, CFR, Combo)
- Lap Belt Angle
- Lap Belt P/T
- Lap/ Shoulder Belt Junction

Submarining Performance

Score: 6 to 100 (larger=better)



Worst

Best

Vehicle ID	Sub + Crash (Score 6 to 300)	Crash (Score 0 to 200)	Submarining (Score 6 to 100)
V_1	92	55	37
V_13	120	59	61
V_4	132	85	47
⋮	⋮	⋮	⋮
V_8	166	124	42
V_20	166	114	52
V_10	167	129	38
⋮	⋮	⋮	⋮
V_6	186	135	51
V_2	190	135	55
V_14	221	140	81

≤ Mean -1 SD

≥ Mean -1 SD & ≤ Mean +1 SD

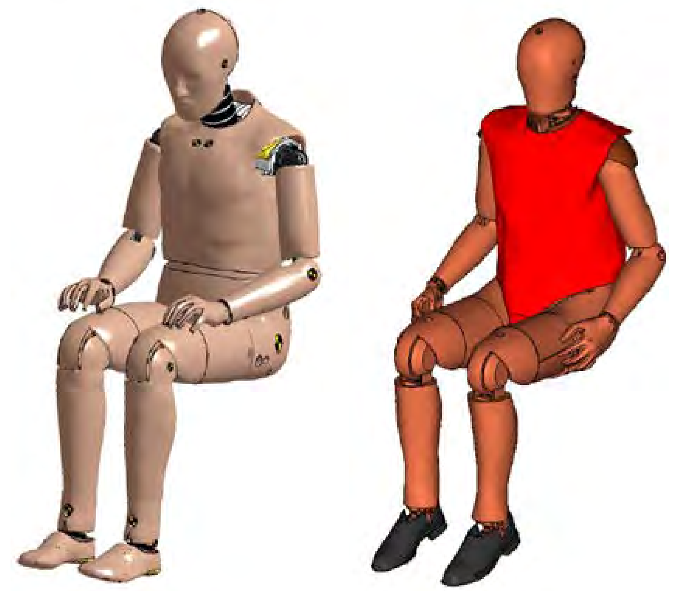
≥ Mean + 1 SD

PART 2: Platform and ATD Modeling, and Vehicle Selection

2.2 Simulation of Vehicle-Specific Frontal NCAP and Reduced-Energy Tests using ATD FEMs

Simplified models developed as part of this research component will be used to simulate two crash pulses using two ATD FEMs

- Two Crash Pulses
  - NCAP pulse (56 kph) for the specific vehicles
  - Scaled down pulse (32 kph) for each model
- Two ATD FEMs
  - Humanetics THOR-M 50th LS Dyna model
  - Humanetics Hybrid III 50th LS Dyna model



Shah et al. (2014)/ Humanetics

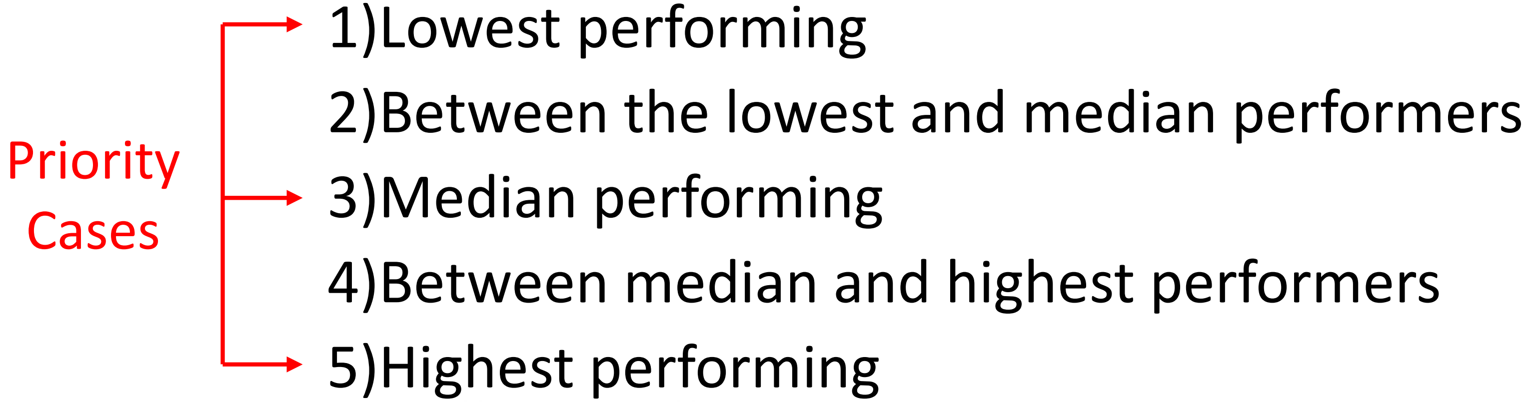
Output: *Results of up to 40 simulations (10x2x2)*

PART 2: Platform and ATD Modeling, and Vehicle Selection

2.4 Selection of Vehicles to be used in Sled Testing

Select **5 to 7 vehicles** for subsequent physical testing based upon the initial down selection and modeling results

Platforms will be selected from the master list based on performance rankings:



Priority Cases

1)Lowest performing
2)Between the lowest and median performers
3)Median performing
4)Between median and highest performers
5)Highest performing

Part 3: Test Buck Preparation

https://www.wingsmagazine.com/innovations/road-test-to-flight-test-10266

Acquire **5 to 7 vehicles**

- Vehicles will be retrieved from either NCAP boneyards, with NHTSA approval, or salvage operations

Test bucks will be fabricated from each acquired vehicle

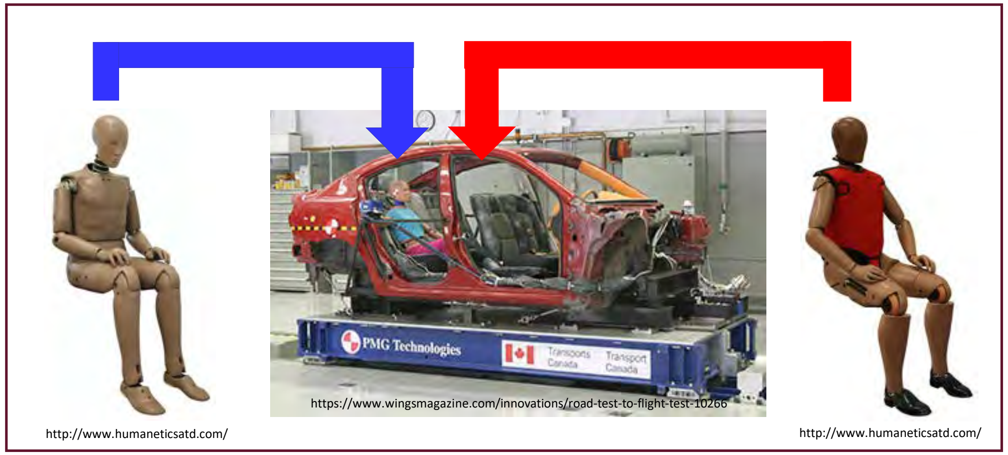
- Only the passenger compartments, including the front-row seats but minus the doors and glass, will be retained
    - Seat and restraint system characteristics will be preserved
    - Passenger compartments will be reinforced so that they can be tested repeatedly
    - Roof structures will be modified to provide an overhead camera perspective
- Bucks will be made to interface to the deck of the CIB ServoSled

Part 4: ATD Testing

4.3 Conduct Paired ATD Sled Tests using up to Five Vehicle Bucks and Two Speeds

CIB ServoSled will be used to simulate frontal crashes using the previously fabricated vehicle bucks

- Two Crash Pulses
    - NCAP pulse (56 kph) for specific vehicles
    - Scaled down pulse (32 kph) for each model
- Two ATDs (right and left outboard positions)
    - THOR-M 50th
    - Hybrid III 50th



https://www.wingsmagazine.com/innovations/road-test-to-flight-test-10266

http://www.humaneticsatd.com/

http://www.humaneticsatd.com/

Output: *Responses from Hybrid III and THOR for 10-14 sled tests using 5-7 bucks and 2 speeds*

Part 4: ATD Testing

4.1 Determine ATD Positioning Procedures for Seating behind the First Row

Available documentation has been obtained and reviewed

- NHTSA Memorandum Reports
  - THOR-50th Percentile Male Metric Driver Dummy Seating Positioning Procedures
  - Hybrid-III 5th Percentile Female Rear Seat Seating and Positioning Procedures
- THOR Frontal Passenger Seating Procedure Draft July 22 2015
- IIHS- Dummy Seating Procedure for Rear Outboard Positions

Positioning Procedure will be an iterative process involving VT, MGA, and NHTSA

- Procedures reconciled with dummy capabilities and the anticipated conformation a PMHS might assume in a similar seat
- Procedures will be applied using different vehicles to verify their efficacy

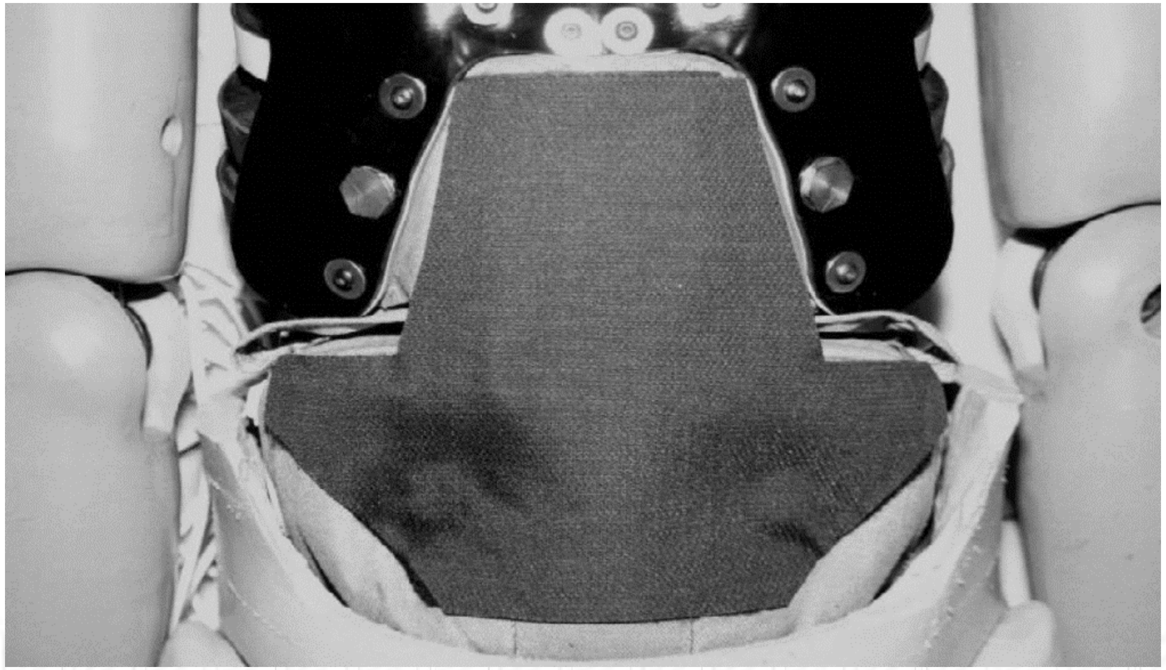
Part 4: ATD Testing

4.2 Establish Methods to Assess Submarining in the ATDs

THOR has an instrumented abdomen and bilateral dual-axis ASIS load cells

- Modest abdomen biofidelity
- Interpretation of instrumentation is not straightforward

THOR Abdomen



Part 4: ATD Testing

4.2 Establish Methods to Assess Submarining in the ATDs

Hybrid III has a simple foam abdominal that is not biofidelic

- No abdomen or pelvis instrumentation

Hybrid III Abdomen and Pelvis

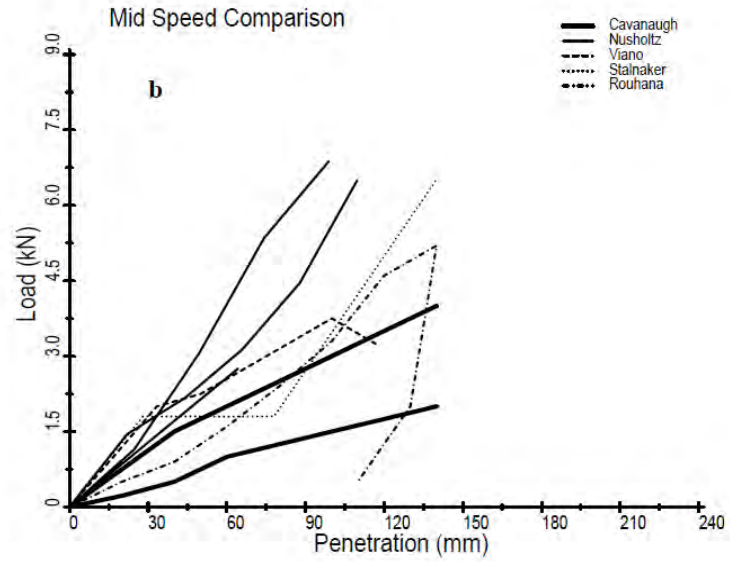
Part 4: ATD Testing

4.2 Establish Methods to Assess Submarining in the ATDs

Dr. Hardy and students are exploring:

- ASIS load cells
- Electronic contact strips to indicate seatbelt pelvis interaction
- Frangible Abdomen for the Hybrid III

Hybrid III Frangible Abdomen



Part 4: ATD Testing

4.4 Assess Relative Vehicle Platform Safety Performance for Rear Seats

4.4.1 Evaluate metrics

Existing FMVSS 208 requirements

Additional Variables will also be assessed:

- Lower neck loads and moments
- Lumbar or T12 loads and moments
- Lap belt submarining & shoulder belt escape by the shoulder and/or torso
- Provisional IARVs for the abdomen will be computed
  - Fmax (kN), Cmax (%), Fmax*Cmax (kN), Peak Penetration (mm), Penetration Speed (m/s), Vmax*Cmax (m/s), and Peak V*C (m/s)

Part 4: ATD Testing

4.4 Assess Relative Vehicle Platform Safety Performance for Rear Seats

4.4.2 Compare ATDs to FE

Compare general kinematics as well as computed injury metrics between ATDs and FE

Output: *Summary comparison between test and model outcomes with examination of the nature of, and reasons for, observed differences*

4.4.3 Summarize findings

Generate a report summarizing the findings of the Phase One work. The ATD tests will inform a series of PMHS sled tests that will be used to evaluate the dummy findings

Output: *Summary of findings from both dummies from ten sled tests*

Questions

JNCAP
YAMASAKI
and UESAKA, 2011

Contact: Andrew R. Kemper (akemper@vt.edu)

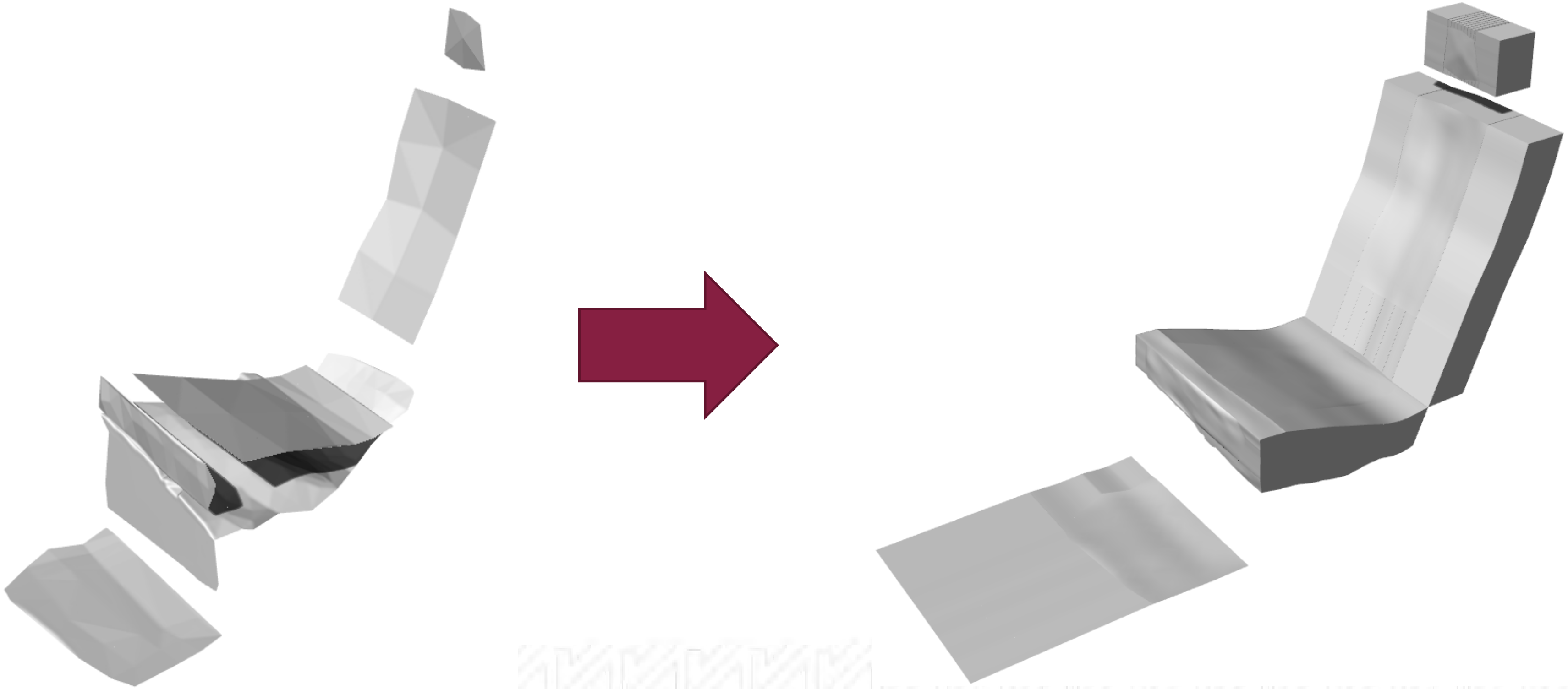
Crashworthiness and Occupant Protection Rear Seat Testing and Seating Location Selection

FMVSS 208 Rear Seat Modeling Overview

Costin D. Untaroiu

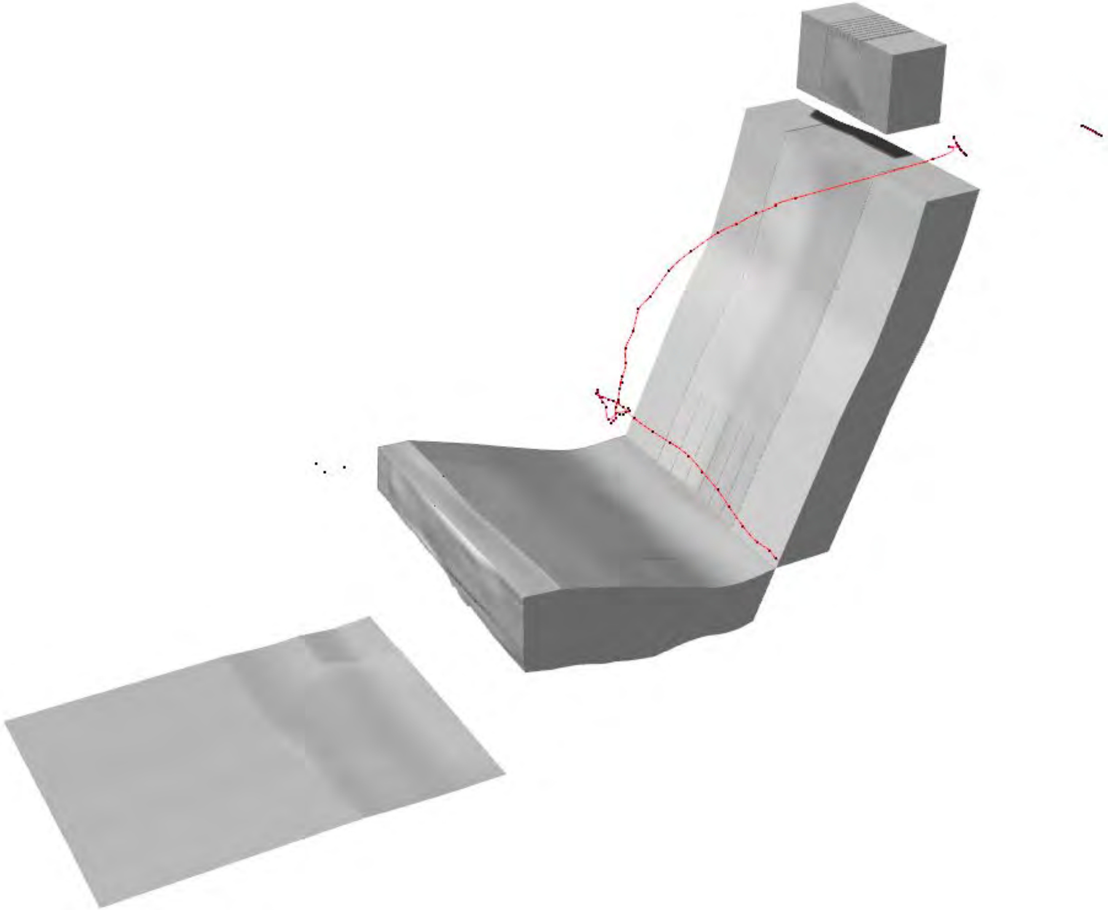
Rear Seat Geometry Reconstruction

Seats reconstructed from FARO scans with careful attention to seat pan geometry



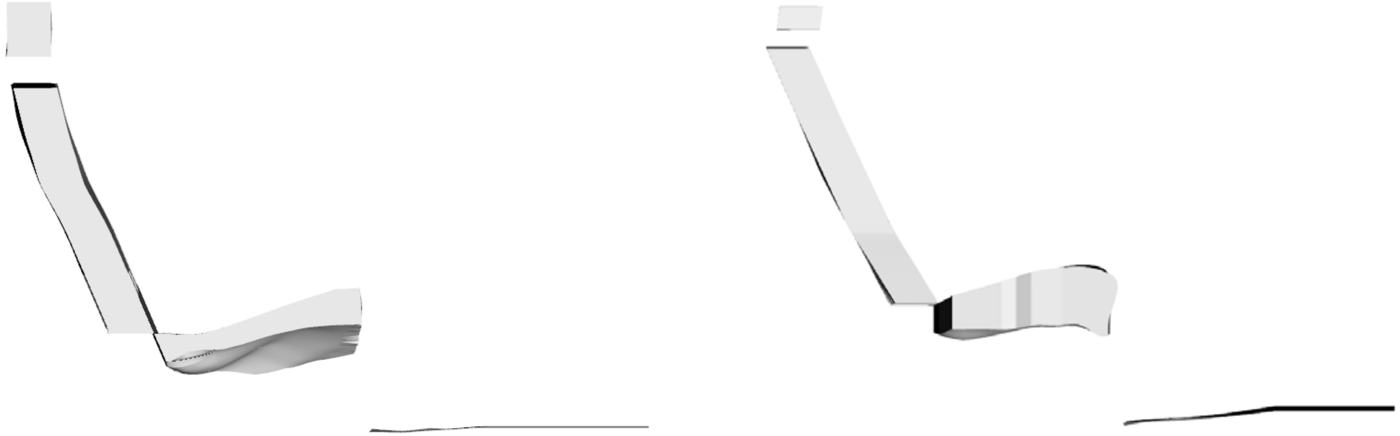
Rear Seat Geometry Reconstruction

- Seat belt anchor points, D-ring, and retractor location noted
- Path of seat belt noted



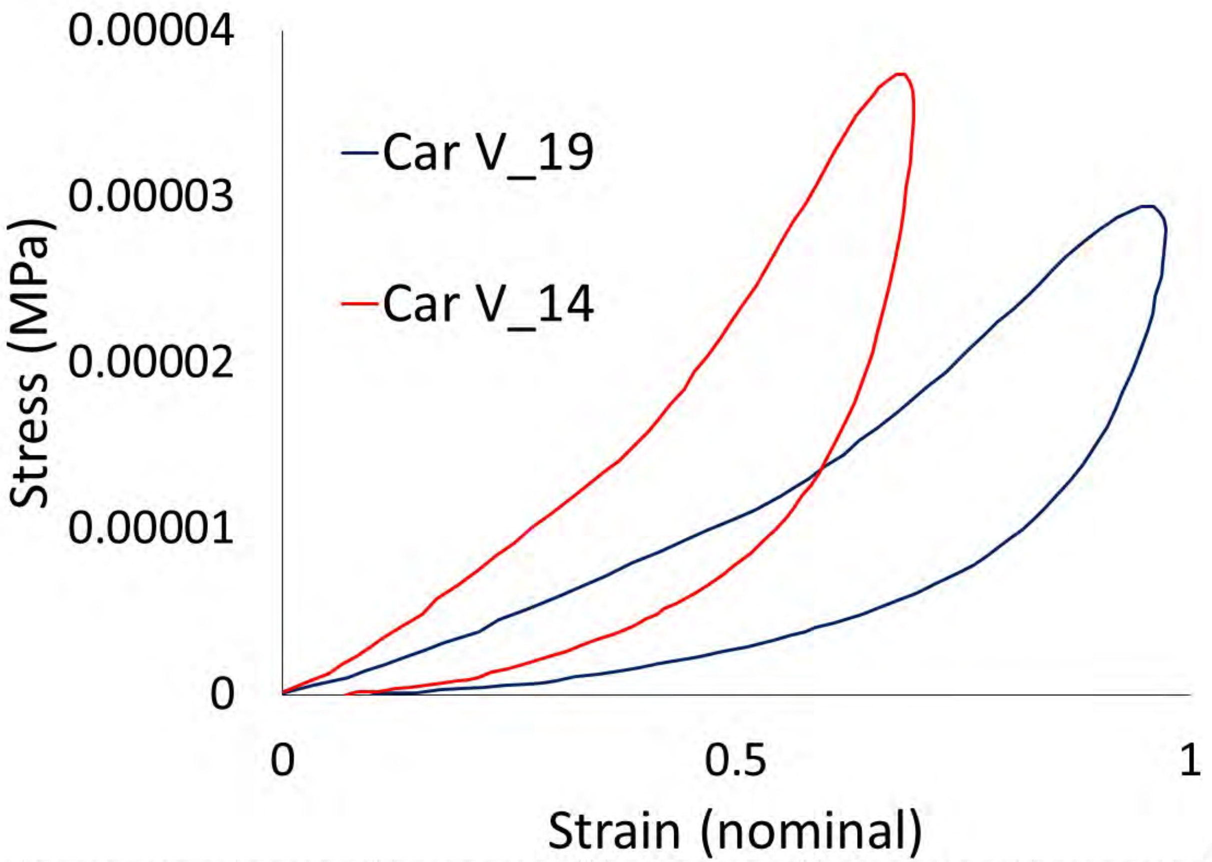
Cars Modeled

	Car V_19	Car V_14
Seat Angle (deg)	12.6	18.8
Stiffness (N/mm)	9.8	12.2
Pretensioner	No	Yes



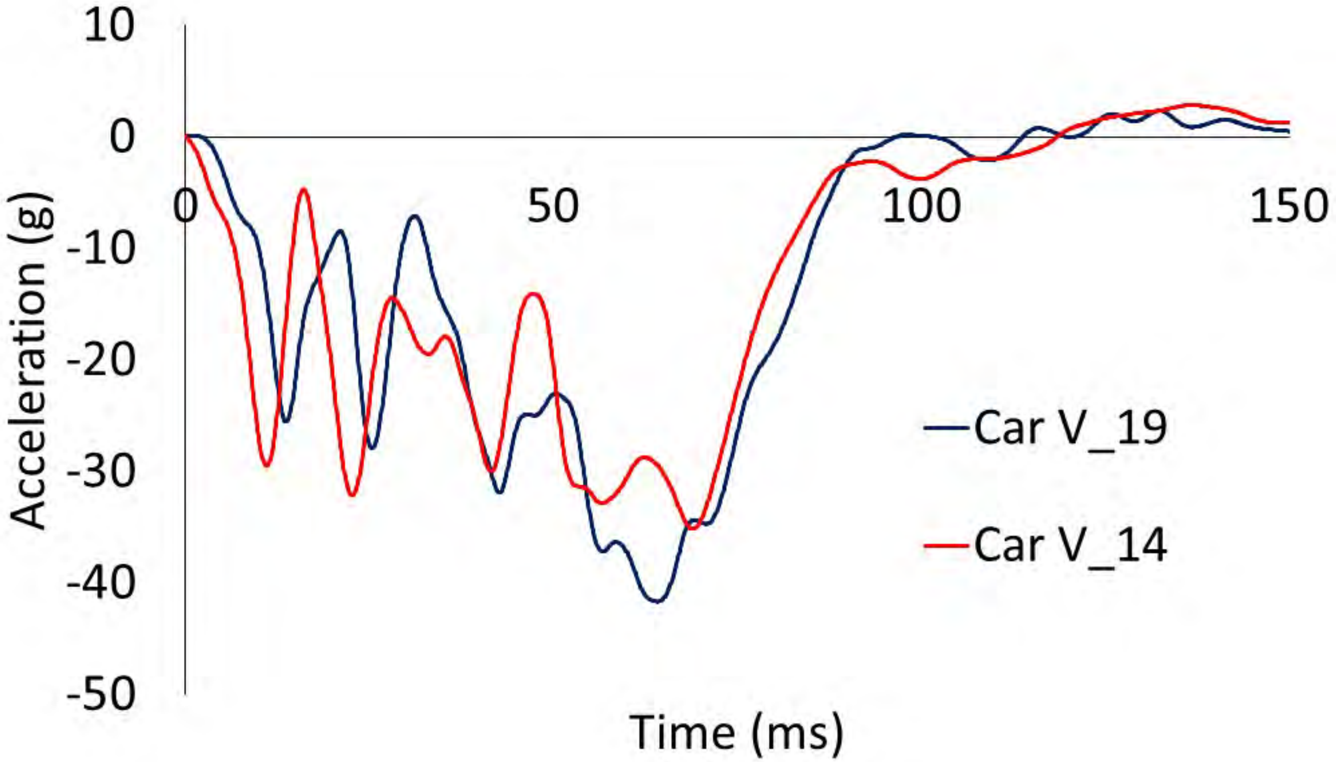
Material Properties: Seat Cushion

- Properties measured by quasi-static test for each seat
- Data fit to load curve of an average seat
- Stress-Strain curve approximated with average seat thickness



Boundary Conditions: Vehicle Crash Pulses

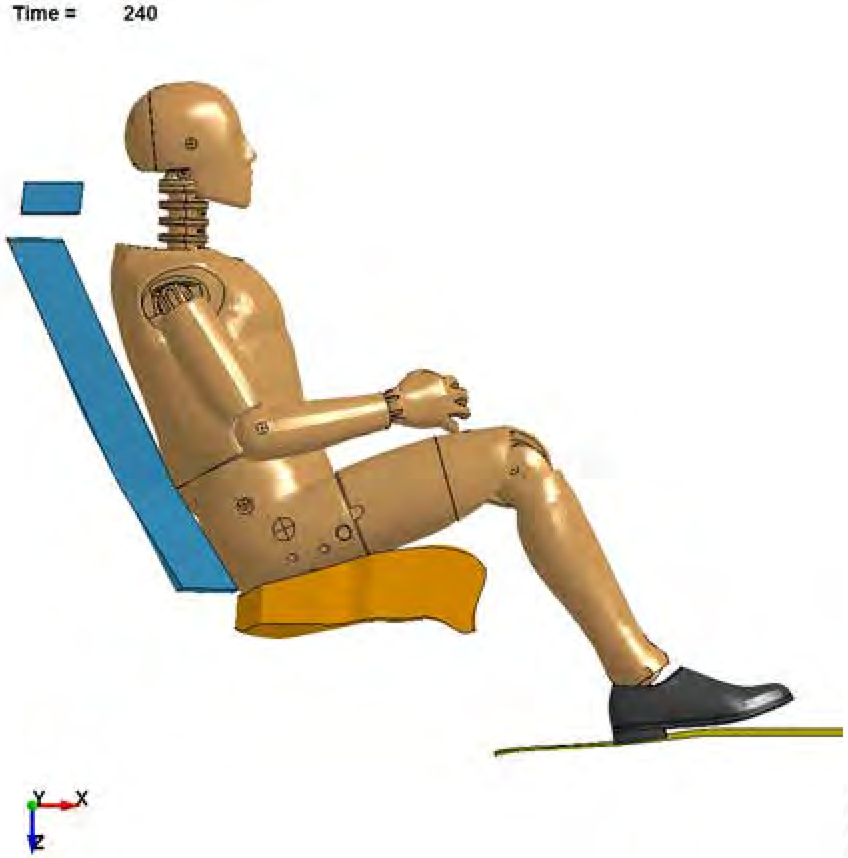
- Seatpan, seatback, belt anchors, and floor modeled as rigid and coupled
- NCAP full crash pulses applied as well as scaled down to V_0=30mph



Dummy Positioning

Step 1. Dummy limbs positioned with Marionette method

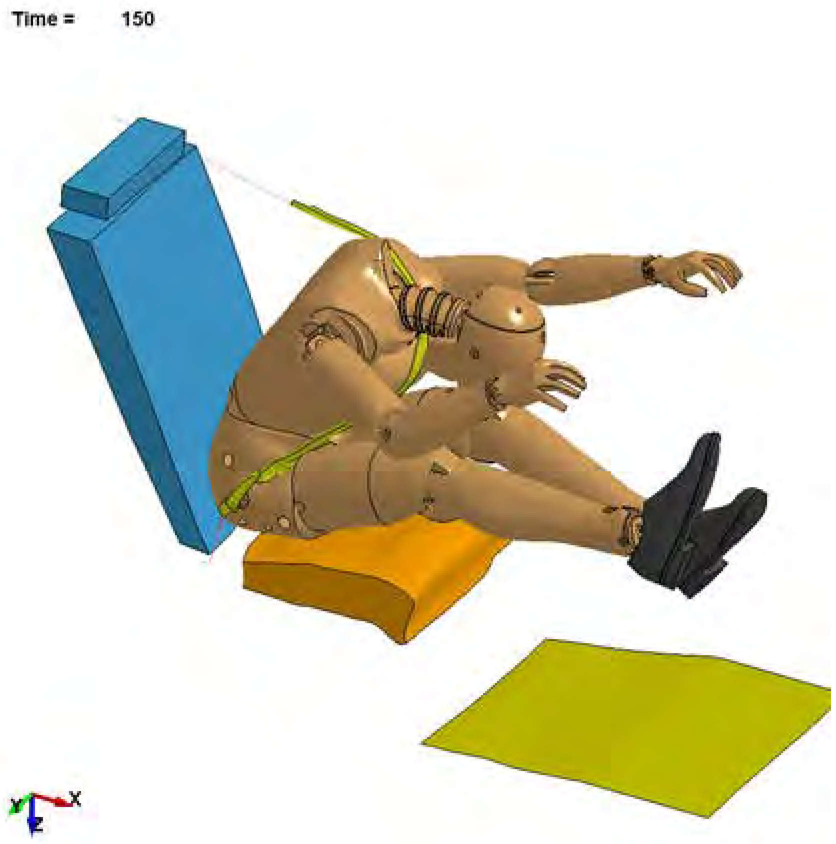
Step 2. Dummy settled with gravity



Car-to-Car Variation

Car V_19

Car V_14



Dummy/Pulse Variation (Car V_19)

Hybrid III NCAP

Hybrid III scaled down

THOR NCAP

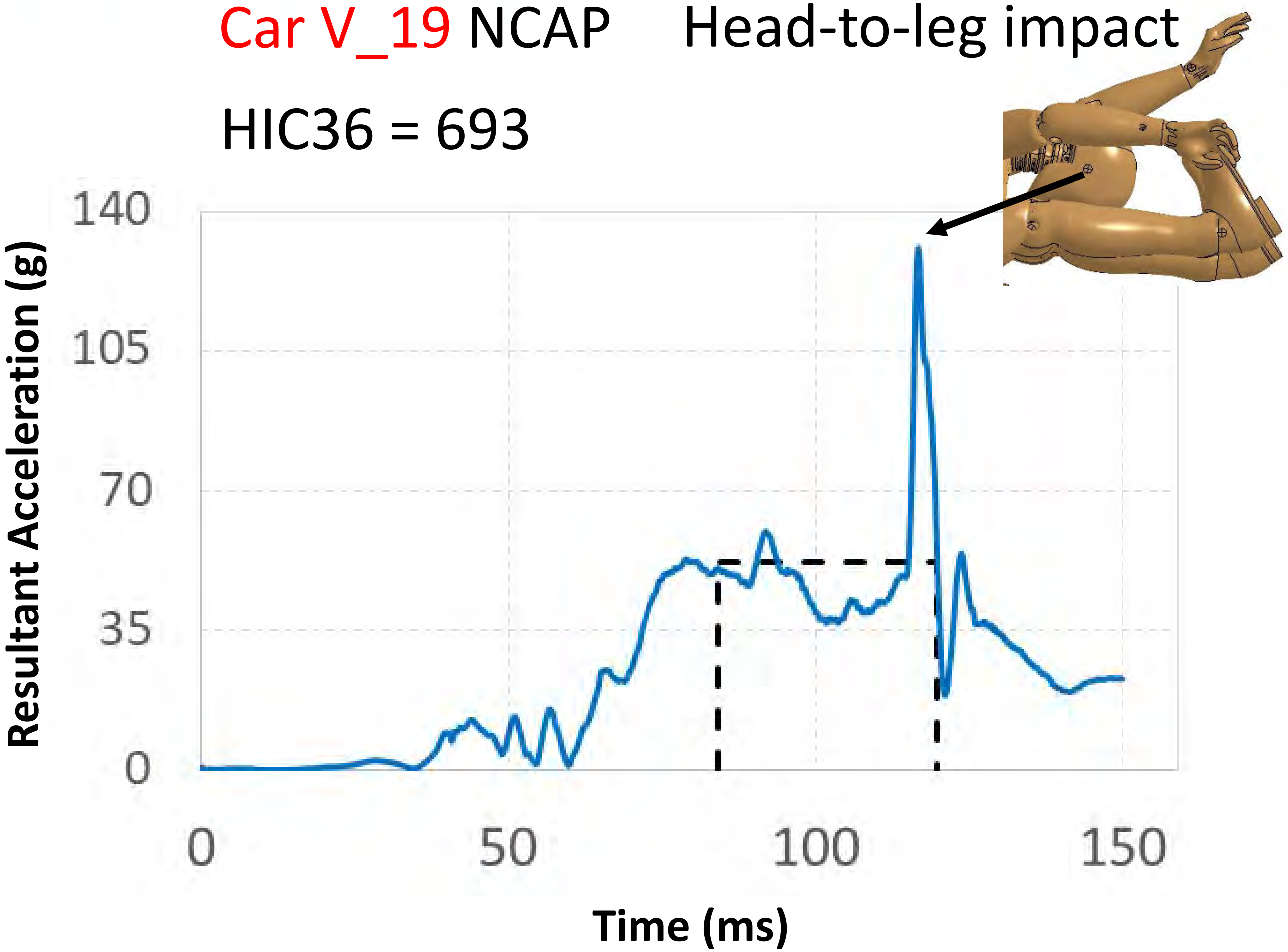
THOR scaled down

HIC – HIII Predictions

$$\mathrm{HIC} = \max\left[\left(\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a(t)\,\mathrm{d}t\right)^{2.5}(t_2-t_1)\right]$$

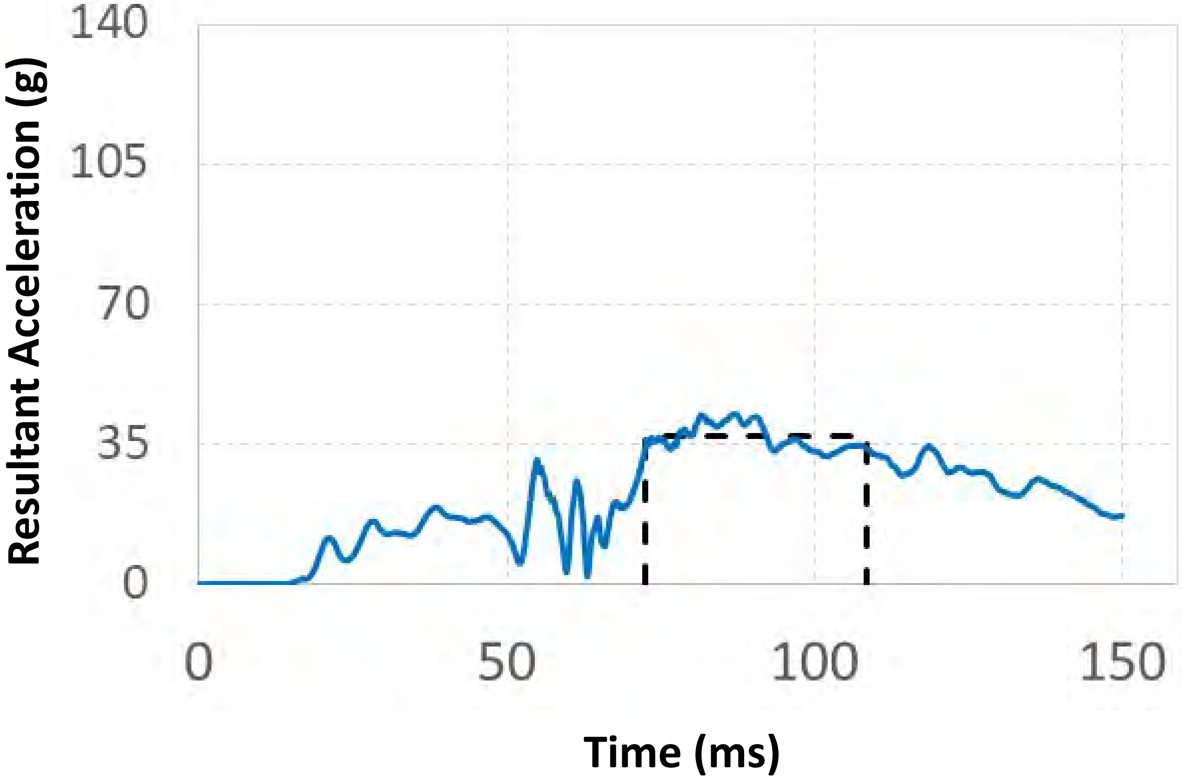
Car V_19 NCAP

HIC36 = 693



Car V_14 NCAP

HIC36 = 389



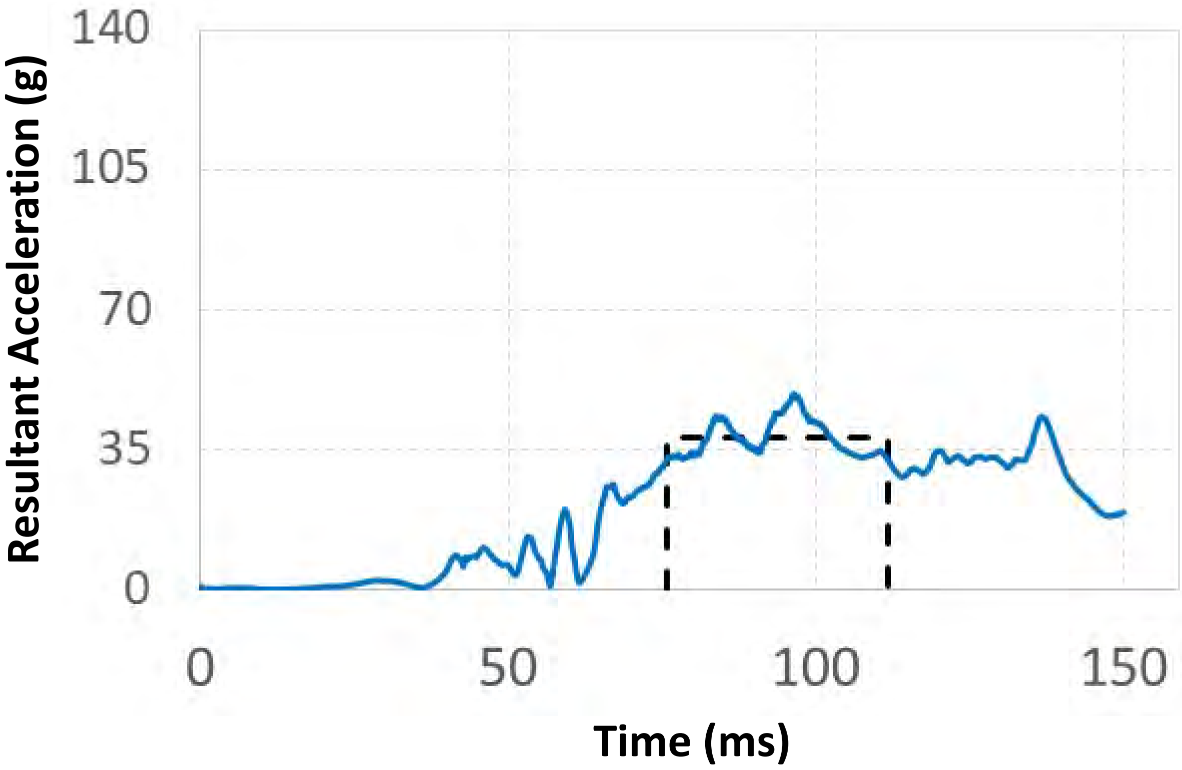
Car V_14 shows better performance than Car V_19 (in terms of HIC)

HIC – HIII Predictions

$$\mathrm{HIC} = \max\left[\left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\mathrm{d}t\right)^{2.5}(t_2 - t_1)\right]$$

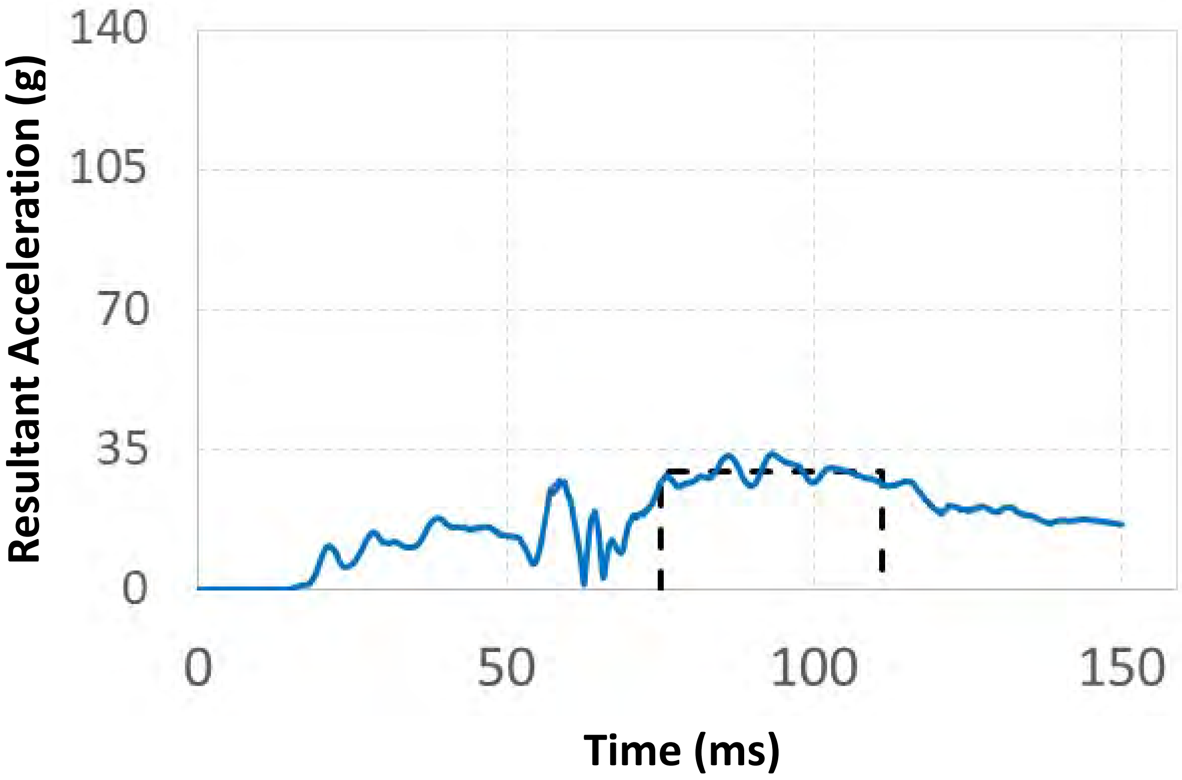
Car V_19 Scaled NCAP

HIC36 = 407



Car V_14 Scaled NCAP

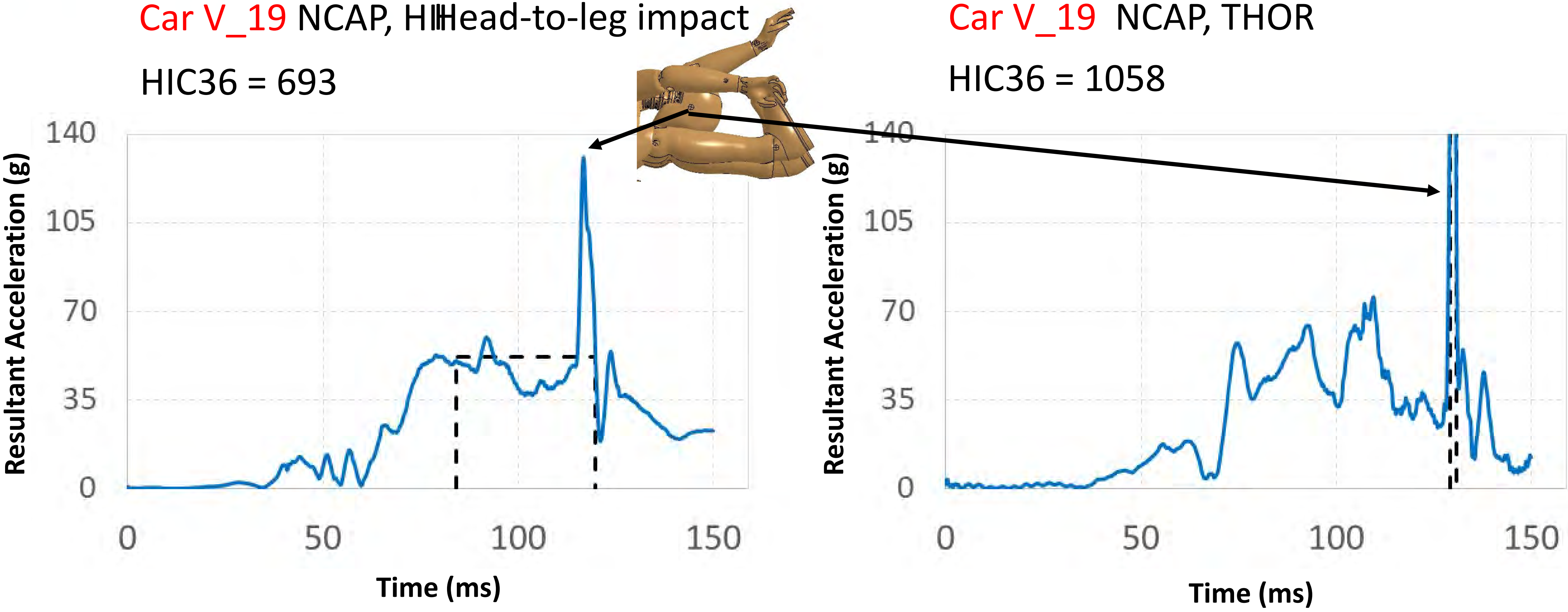
HIC36 = 294



Car V_14 shows better performance than Car V_19 (in terms of HIC)

HIC – HIII vs. THOR

$$\mathrm{HIC} = \max\left[\left(\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a(t)\mathrm{d}t\right)^{2.5}(t_2-t_1)\right]$$



Car V_19 NCAP, HIII

Head-to-leg impact

HIC36 = 693

Car V_19 NCAP, THOR

HIC36 = 1058

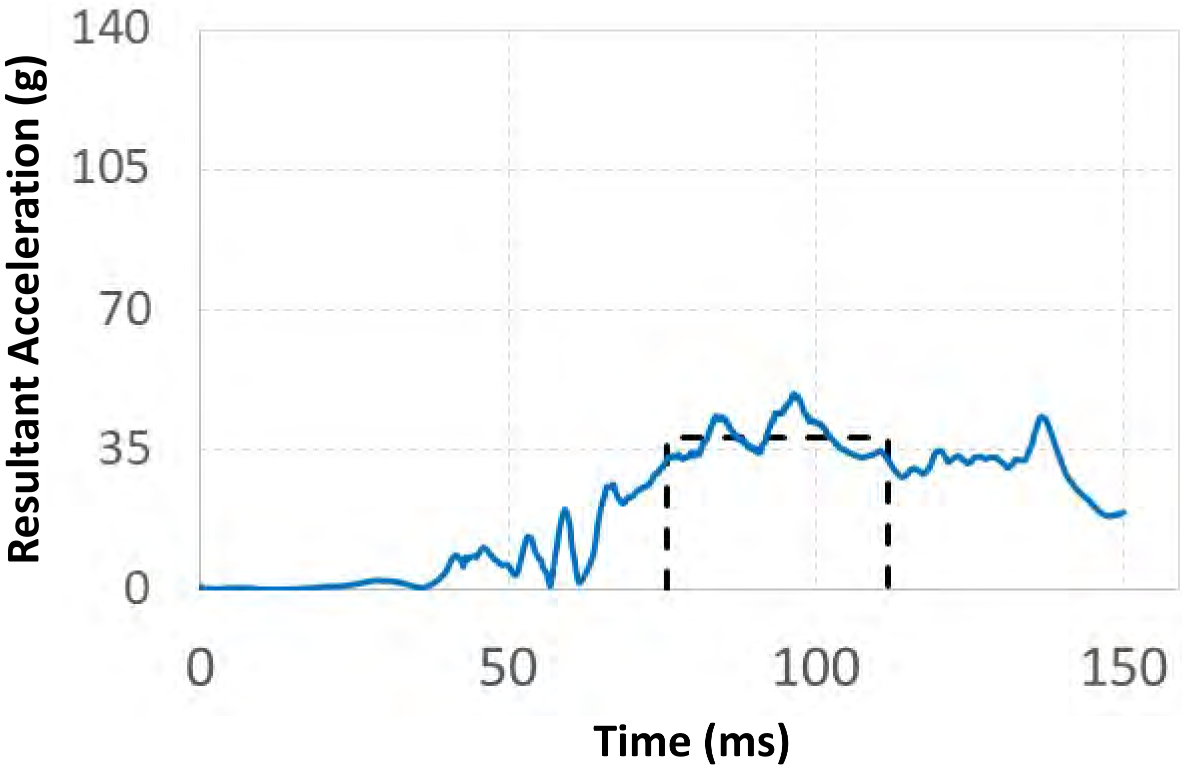
THOR shows higher HIC values than HIII

HIC – HIII vs. THOR

$$HIC = \max\left[\left(\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a(t)\mathrm{d}t\right)^{2.5}(t_2-t_1)\right]$$

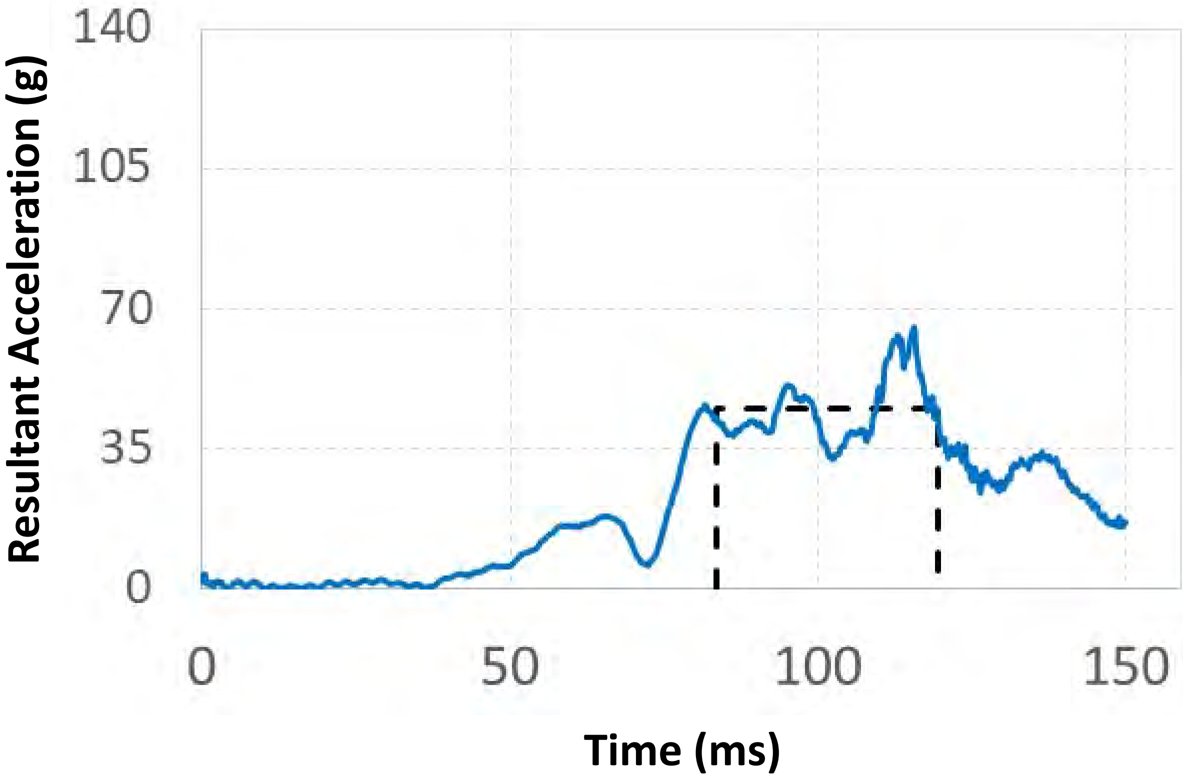
Car V_19 Scaled NCAP, HIII

HIC36 = 407



Car V_19 Scaled NCAP, THOR

HIC36 = 533



THOR shows higher HIC values than HIII

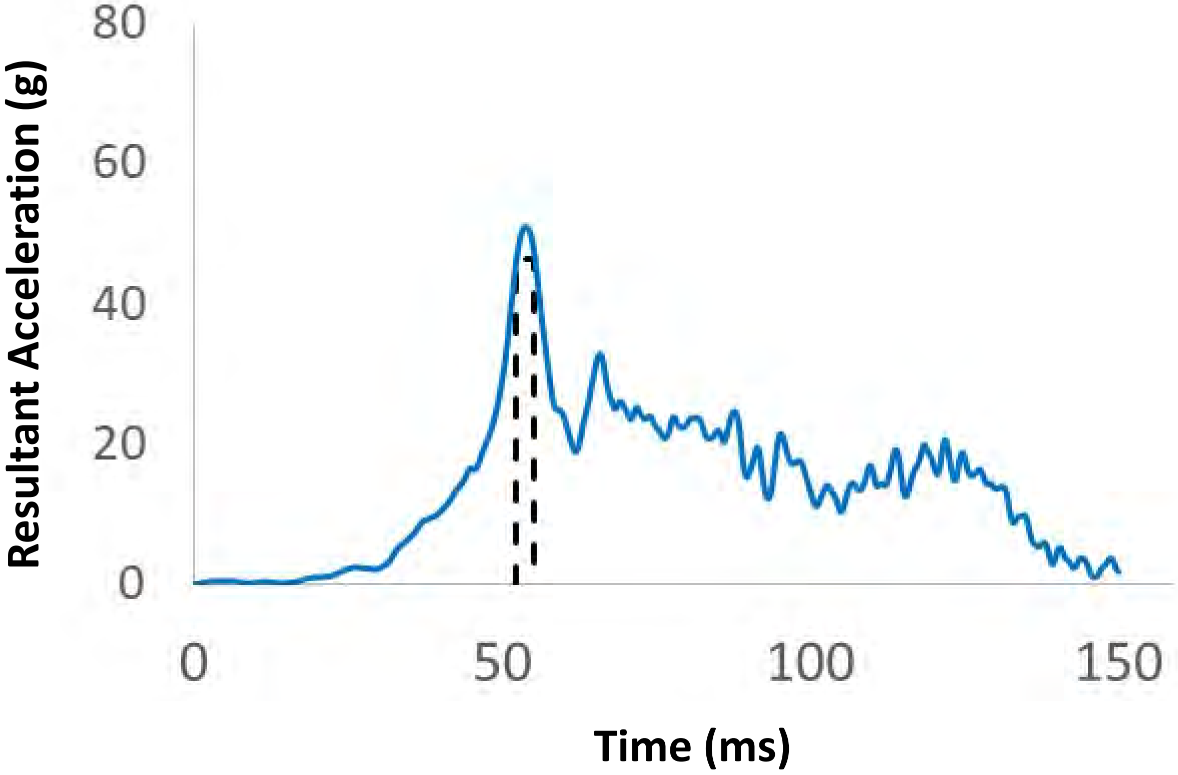
Nij

		Car V_19	Car V_14
NCAP	Hybrid III	0.54083	0.54984
	Thor	0.52958	0.42779
Scaled	Hybrid III	0.48736	0.4145
	Thor	0.45769	0.28443

CIS – HIII Predictions

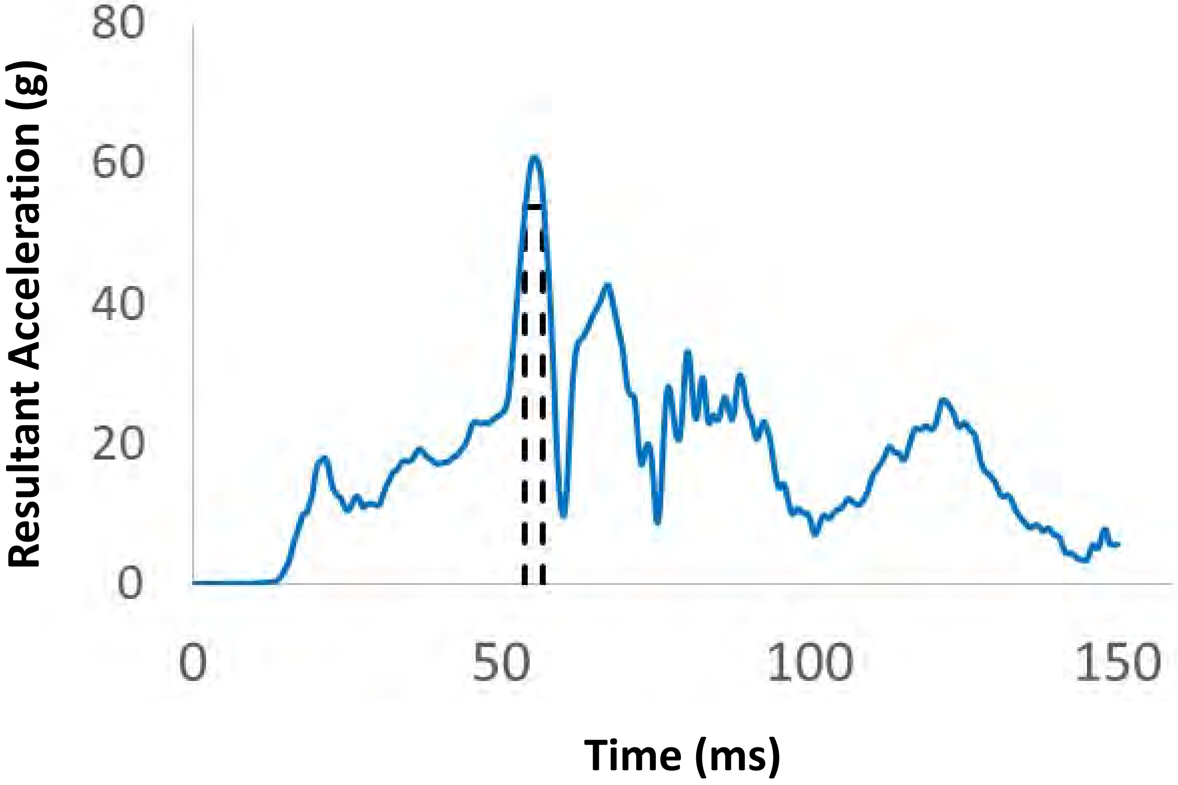
Car V_19 NCAP

CIS = 405



Car V_14 NCAP

CIS = 376

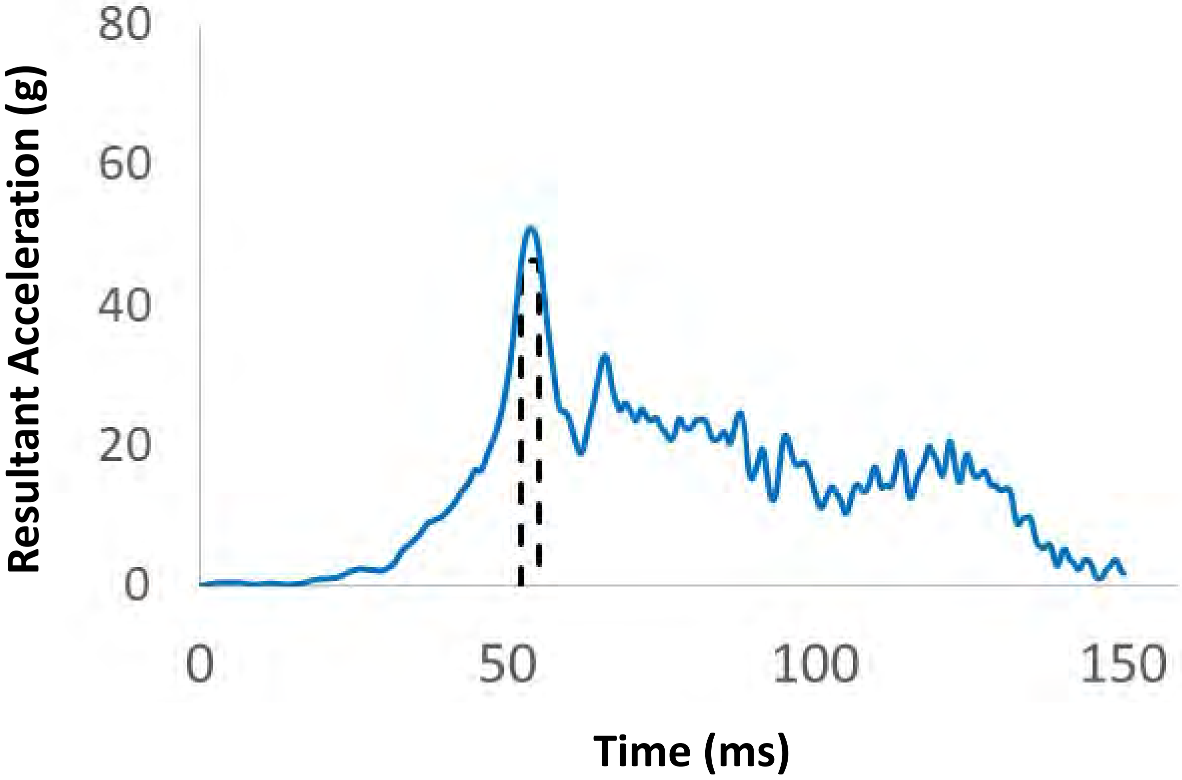


Car V_14 shows slightly better performance than Car V_19 (in terms of CIS)

CIS – HIII Predictions

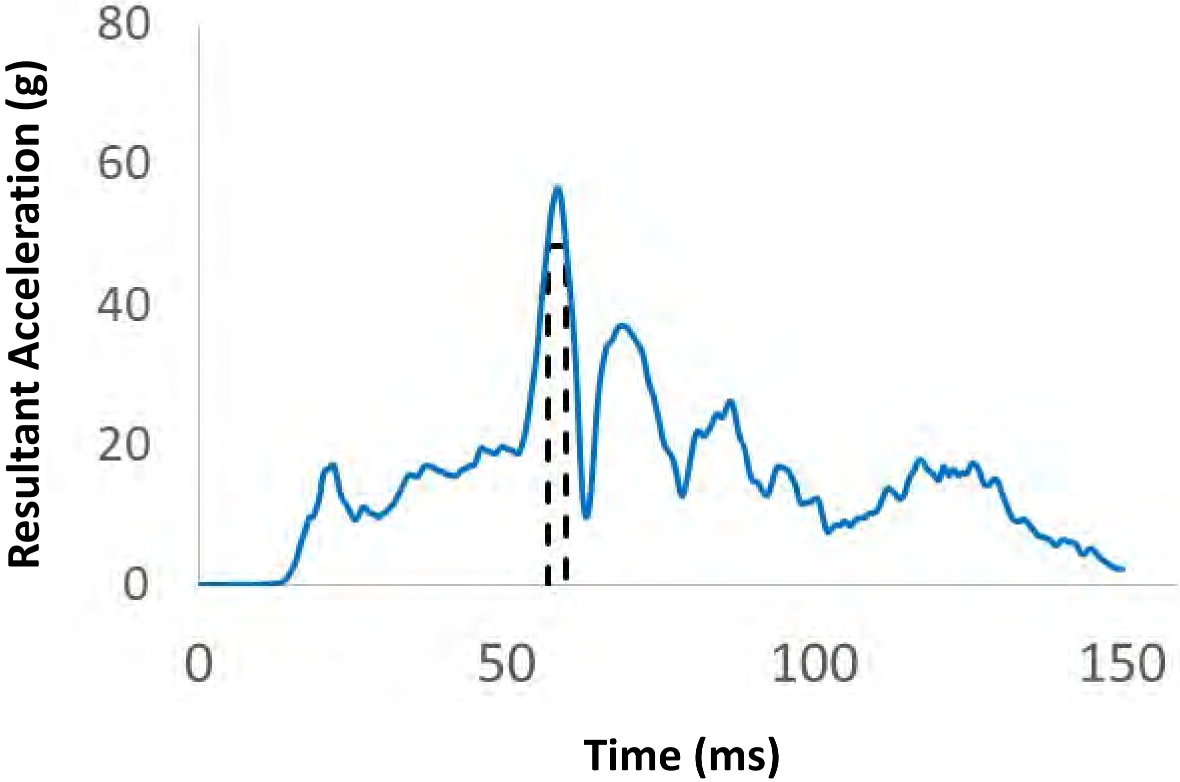
Car V_19 Scaled NCAP

CIS = 246



Car V_14 Scaled NCAP

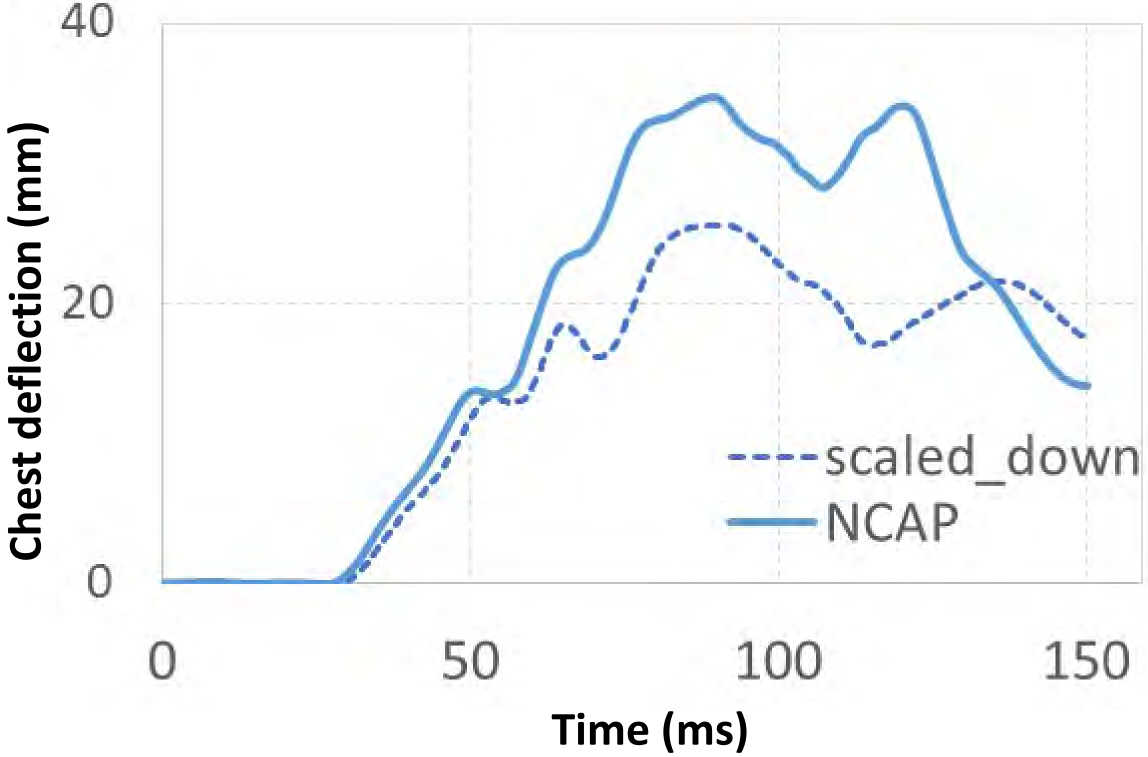
CIS = 273



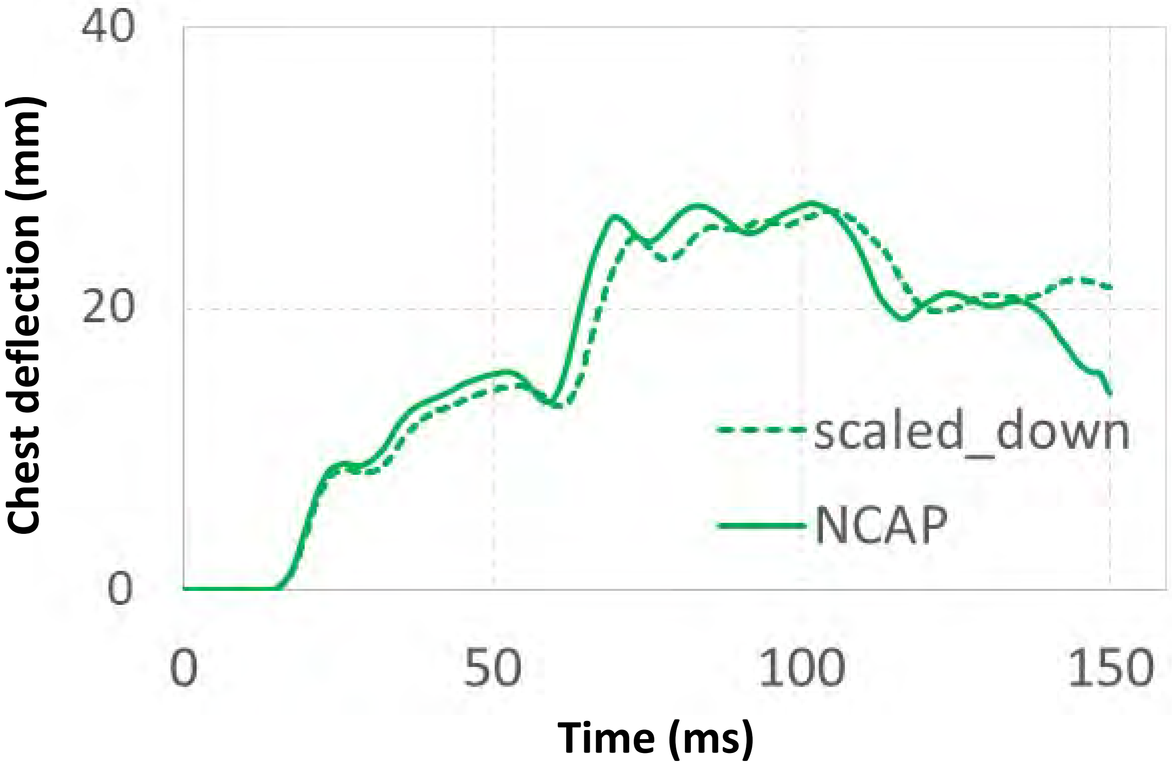
Car V_19 shows slightly better performance than Car V_14 (in terms of CIS)

Chest Deflection – HIII Predictions

Car V_19 HIII



Car V_14 HIII

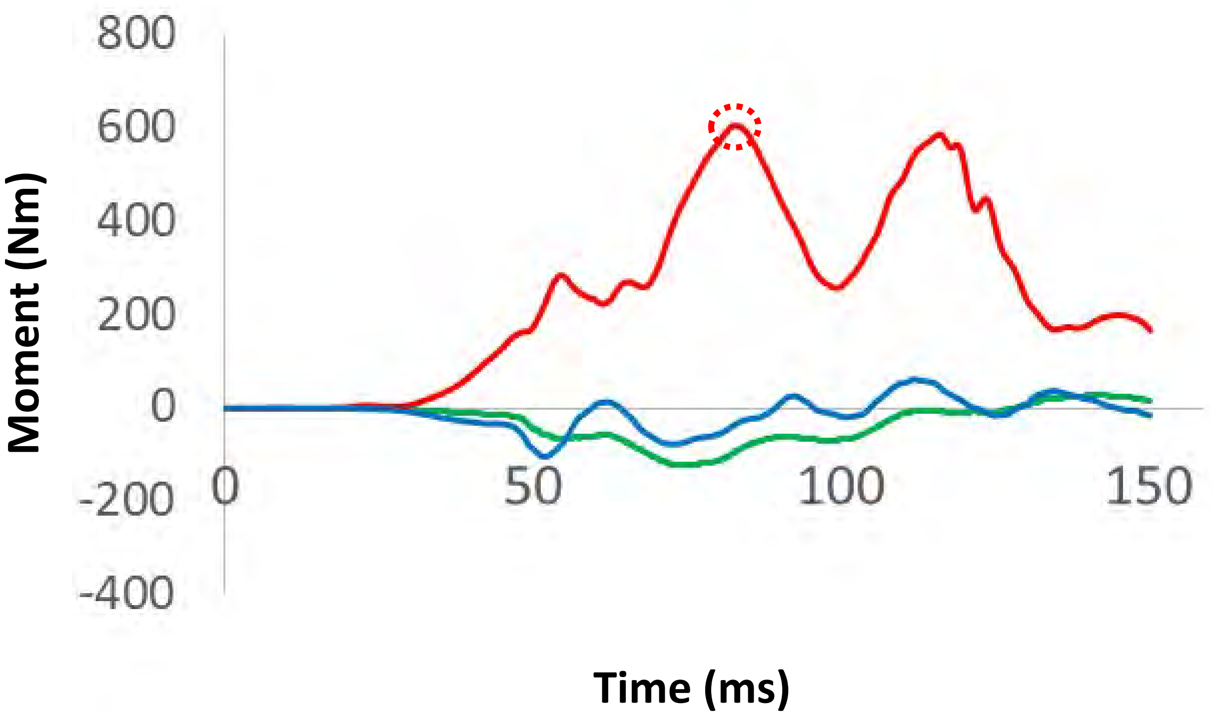


Higher Chest Deflection in Car V_19 than Car V_14 in NCAP simulation

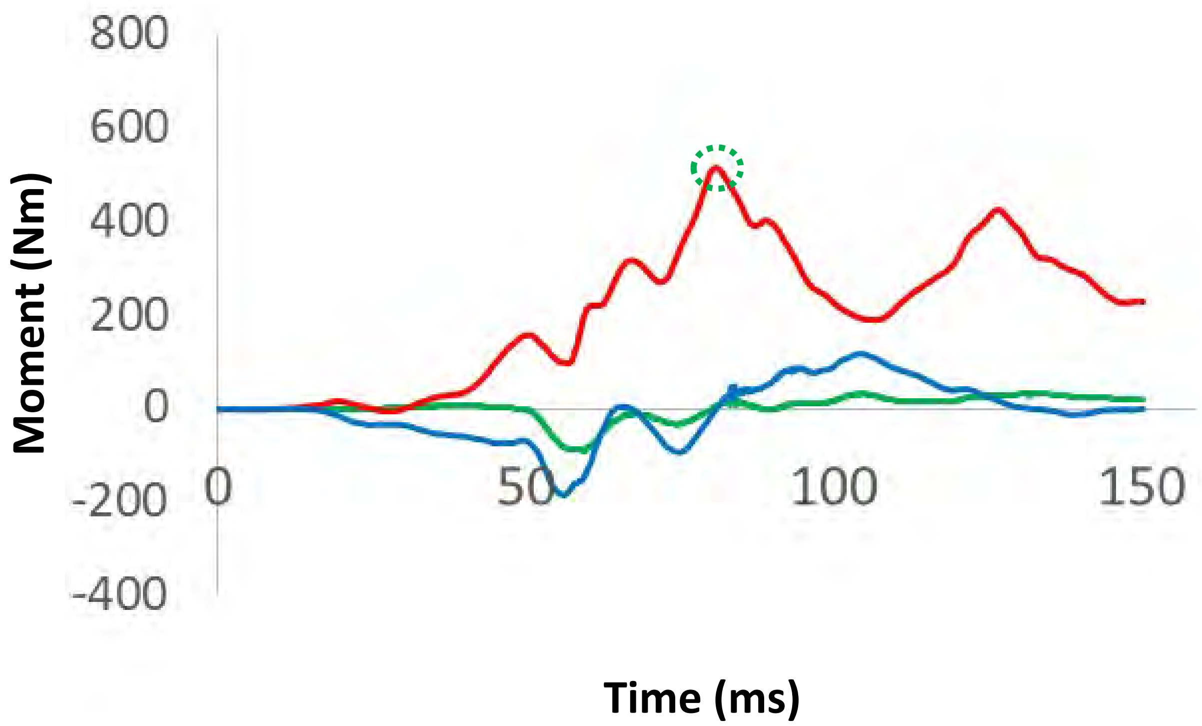
Not much sensitivity in Car V_14 relative to pulse is caused probably due to the presence of the pretensioner

Lumbar Load: HIII Predictions

Car V_19 NCAP



Car V_14 NCAP

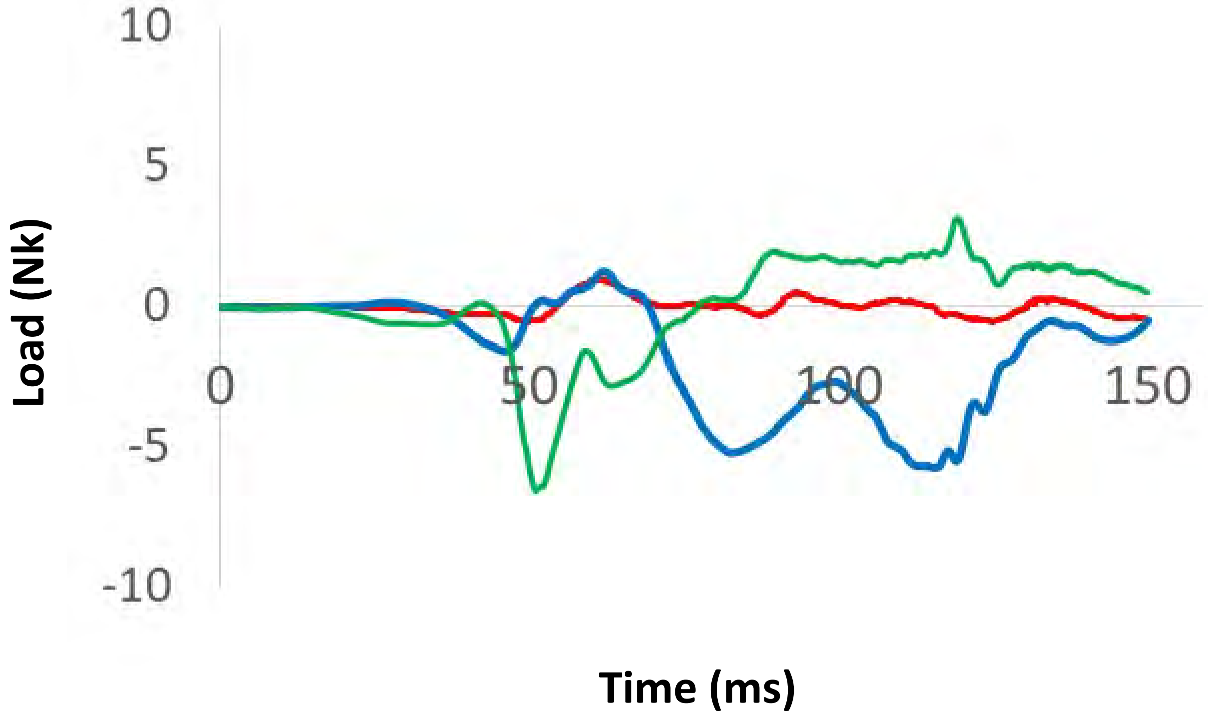


Car V_14 shows lower peak of moment, but ……

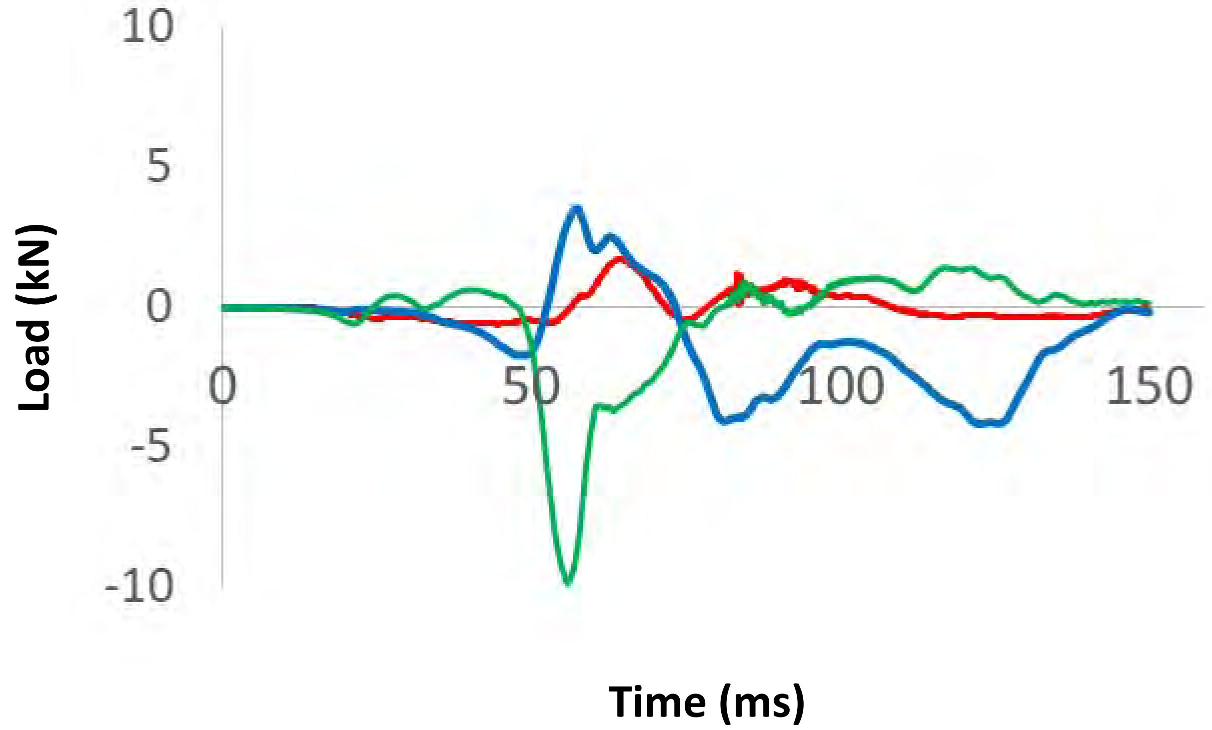
🟥 S-moment Resultant
🟩 T-moment Resultant
🟦 Torsional Resultant

Lumbar Load: HIII Predictions

Car V_19 NCAP



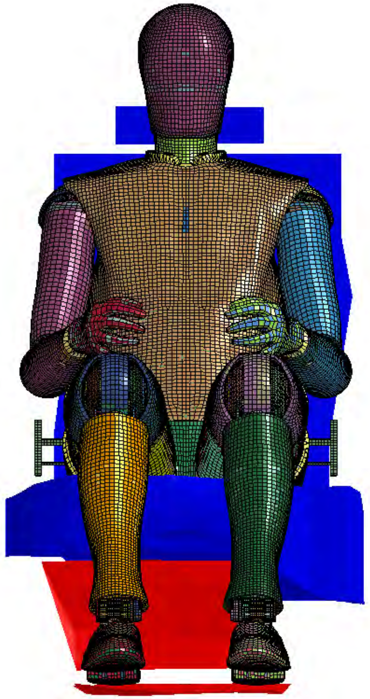
Car V_14 NCAP



……, but higher peak of axial force than Car V_19

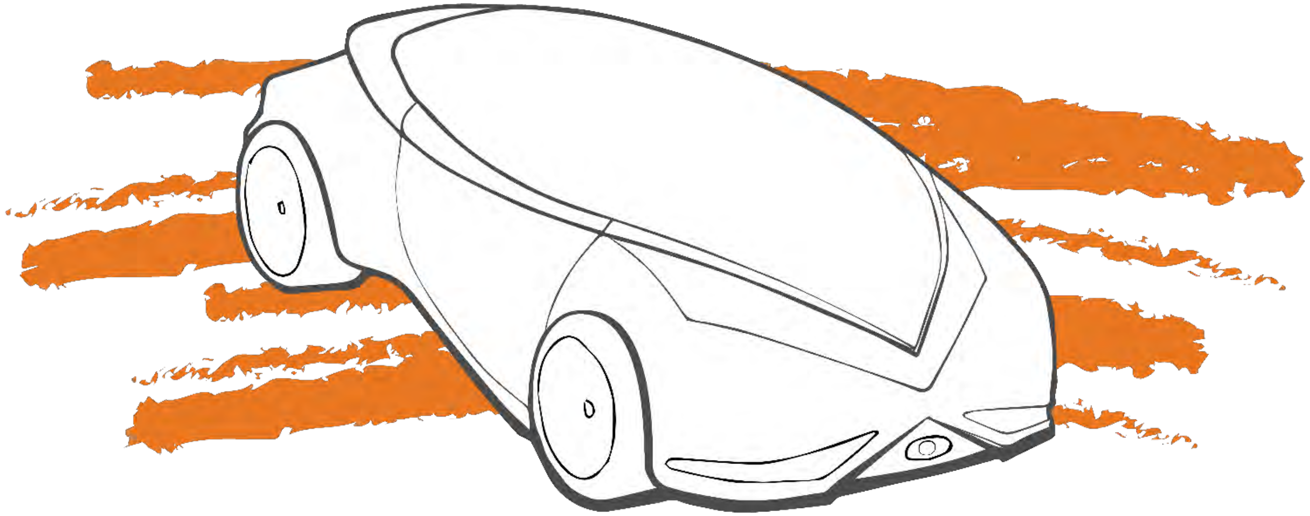
Axial Force Resultant
S-shear Resultant **(kN)**
T-shear Resultant

Questions



Contact: Costin D. Untaroiu (costin@vt.edu)

Thank You



200-series Breakout:
FMVSS No. 208 - Rear Seat Testing

Crashworthiness and Occupant Protection Rear-Seat Testing and Seating Location Selection

Seating Location Discussion

Warren N. Hardy

Current Rear-Seat Experience

- FMVSS No. 208 and NCAP do not include the evaluation of rear-seat occupant safety.

- Traditionally, there has been a lower percentage of rear-seat occupants compared to front-seat occupants on US roadways.

- 12.9% of person-trips had rear-seat occupants. (Trowbridge and Kent, 2009)

- 34.5 billion trips annually and 399 billion vehicle miles traveled with a rear-seat passenger indicates that the national at-risk exposure is high. (Bose et al., 2017)

- Rear-seat occupants account for 23% of occupants with injuries and 9% of fatalities. (NCSA, 2008)

Future Rear-Seat Experience

The percentage of rear seat passengers might increase dramatically.

When occupants have no driving involvement in certain or all conditions, passengers may elect to sit in the rear seat because of:

- Increased comfort
- Perceived safety
- Peace of mind
- Psychological predisposition (prior taxi experience)
- Desire to face the direction of travel

Rear-seat occupant protection can vary drastically between vehicles.

Rear-Seat Safety

Kuppa et al. (2005)

- 48 kph and 56 kph, front- and rear-seat frontal barrier tests
- 5th female and 50th male Hybrid III ATDs
- <u>ATDs in the rear seat had considerably higher head, neck, and chest injury risks, and the percentage of tests that had injury measures that exceeded threshold levels was substantially higher for rear-seat occupants</u>

Hu et al. (2015, 2017)

- 48 km/h, rear-seat frontal sled tests using two crash pulses: ‘soft’ and ‘severe’
- 6 yo, 5th female, and , 95th male Hybrid III, and 50th male THOR-NT
- Three-point belt, four-point belt, retractor/buckle pretensioners, load limiters, inflatable three-point belt, bag in roof (BiR), and bag in front seat (SCsRAB)
- <u>Severe crash pulse: Both advanced restraint systems reduced nearly all IARVs for all ATDs but THOR</u>

Rear Seat Safety, PMHS

Michaelson et al. (2008)

- 48 km/h, rear seat frontal sled tests
- 3, ~50th male PMHS
- Standard three-point belt
- Vehicle seat representative of a 2004 mid-sized sedan
- <u>All PMHS had severe chest injuries (AIS 4), cervical spine injuries (AIS 1-5), thoracic or lumbar spine injuries (AIS 1-3), and submarining</u>

Sundararajan et al. (2011)

- 56 km/h rear seat frontal sled tests
- 4, ~50th male PMHS and 4 small female PMHS
- Compared rear-seat inflatable seatbelt relative to a standard three-point seatbelt
- <u>The inflatable belt resulted in reduced head excursion, chest deflection, rib Fx, and neck injuries</u>

Bilston, Du, and Brown, 2010

Sample

- NASS-CDS (1993-2007)
- All crash modes
- Model year 1990 and newer vehicles
- All restrained front and rear seat occupants, age 9+
- All injury levels

Analysis Method

- Matched-cohort

Conclusions

- "…rear seat occupant protection has not kept pace with front seat safety improvements."
- Adults (16 years and older) are better protected in the front seat
- **Adjusted rear to front risk ratios for AIS 3+ injury in adults range from 1.11-3.16 (α = 0.05)**

Durbin, Jermakian, Kallan, McCartt . . . 2015

Sample

- FARS and NASS-CDS (2007-2012)
- All crash modes
- Model year 2000 and newer vehicles
- All front and rear seat occupants
- No age restriction
- All injury levels

Analysis Method

- Logistic regression modeling

Conclusions

- "Findings of an elevated risk of death for rear row occupants . . . in the newest model year vehicles provides further evidence that rear seat safety is not keeping pace with advances in the front seat."
- Vehicle model years ≥ 2007 have a **relative risk of fatal injury for rear vs front seat occupants of 1.46 ($\alpha = 0.05$)**
- Older vehicle model years show no statistically significant difference

Mitchell, Bambach, and Toson, 2015

Sample

- Linked police-report, hospitalization, and emergency department presentation records in New South Wales, Australia (2001-2011)
- All crash modes
- No model year restriction
- All restrained front and rear seat occupants, age 9+
- All injury levels

Analysis Method

- Matched-cohort

Conclusions

- "Rear seat car passengers are sustaining injuries of a higher severity compared to front seat passengers travelling in the same vehicle, …"
- The **odds ratio of rear seat compared to front seat passengers measuring higher risk of injury severity is 1.10** (1.01-1.21, $\alpha = 0.05$)
- When considering only passengers 51+ years old, the odds ratio is significantly higher at 2.02 (1.68-2.43)

Mitchell, Bambach, and Toson, 2015

Sample

- Linked police-report, hospitalization, and emergency department presentation records in New South Wales, Australia (2001-2011)
- All crash modes
- No model year restriction
- All restrained front and rear seat occupants, age 9+
- All injury levels

Analysis Method

- Matched-cohort

Conclusions

- Adjusted risk ratio of rear seat compared to front seat passenger abdomen, lower back, lumbar spine, and pelvis injuries is 2.81 (1.82-4.34)

Bose, Crandall, Forman, Longhitano . . . 2017

Sample

- NASS-CDS (2001-2010)
- Frontal crashes
- Model year 1998 and newer vehicles
- All rear seat occupants, age 8+
- All injury levels

Analysis Method

- Descriptive epidemiology

Conclusions

- "…factors such as low rate of belt usage and unavailability of advanced safety features compromise the overall protections to [rear seat] victims involved in a crash."
- "The highest incidence of serious injuries observed in the thorax region may be attributed to the general lack of supplementary restraint features (e.g. belt load limiters, airbags, pretensioners) in the rear seat configurations."

Tatem and Gabler, in progress

Sample

- FARS and NASS-CDS (1997-2015)
- Frontal crashes
- Model year 1998 and newer vehicles
- All restrained front and rear seat occupants, age 8+
- All injury levels

Analysis Method

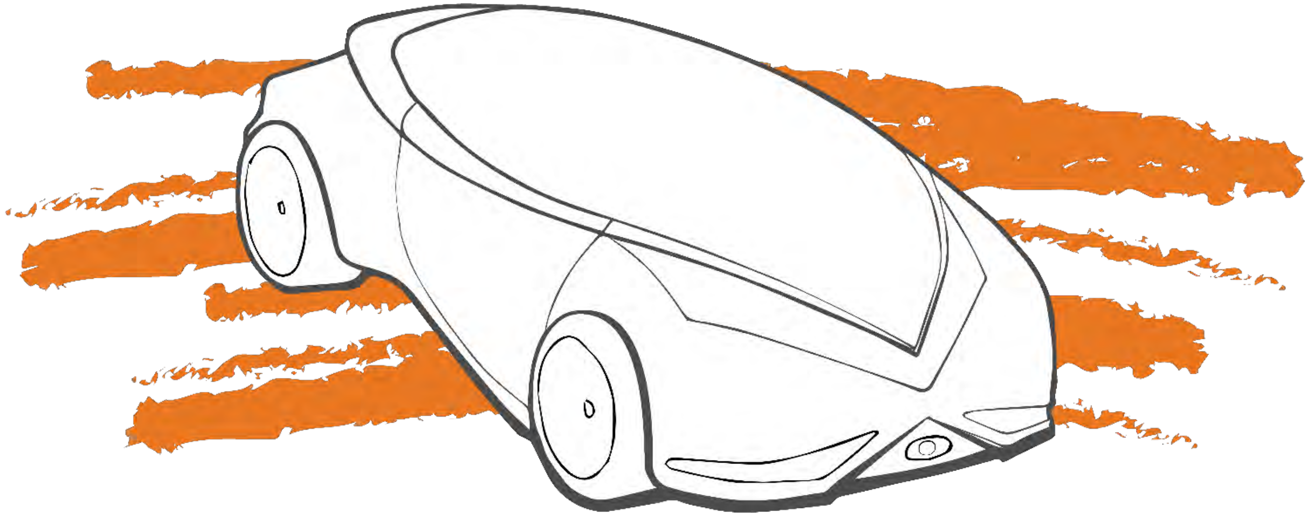
- Descriptive epidemiology - Comparisons between front- and rear-seat occupants, stratified across vehicle model years (1998-2007, 2008-2010, 2011+)

Questions

Overall, the fact that the risk of injury in frontal collision is higher for rear-seat occupants than for front-seat occupants, especially in newer vehicles and older occupants, illustrates that there is a need for improved rear-seat safety restraint performance and evaluation.

Contact: Warren N. Hardy (whardy@vt.edu)

Thank You



200-series Breakout:
Seating Location Selection

200-series Breakout:
Novel Seating Configuration

Moderator: Warren Hardy, VT-CIB

Panelists:

- **Joe Kanianthra,** Active Safety Engineering LLC
- **Priya Prasad,** Auto Alliance
- **Douglas Stein,** Autoliv Inc.
- **Kurt Driscoll,** Faurecia Automotive Seating
- **Amanda Prescott,** Zoox Inc.

Crashworthiness and Occupant Protection Rear-Seat Testing and Seating Location Selection

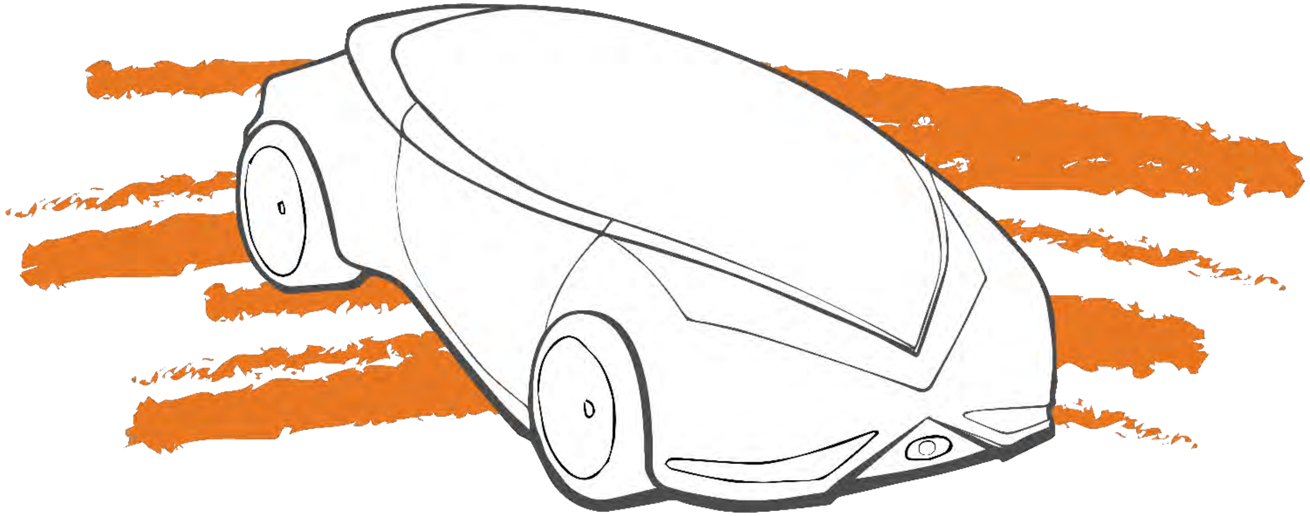
<u>Novel Seating Configurations Panel Discussion</u>

Scope

There will be significant considerations when translating current FMVSS to apply to the novel seating arrangements anticipated in the future in a meaningful way. FMVSS 208 and 214 are among the most concerning.

- What are the obstacles?
- What are the knowledge gaps?
- What are the enabling factors?
- What are the solutions?

Thank You



200-series Breakout:
Novel Seating Configuration