Does Unbelted Safety Requirement Affect Protection for Belted Occupants?

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GM

Background & Objective

- **Background:**
  - Seatbelt can reduce fatality risk by more than 50%
  - Seat belt use rate in the US is about 86%
  - Seatbelt interlock → ~100% seatbelt use rate
  - NHTSA belted and unbelted requirements
- **Objective:**
  - To compare the performance of restraint systems optimized for belted only occupants with those optimized for both belted and unbelted occupants through computational design optimizations

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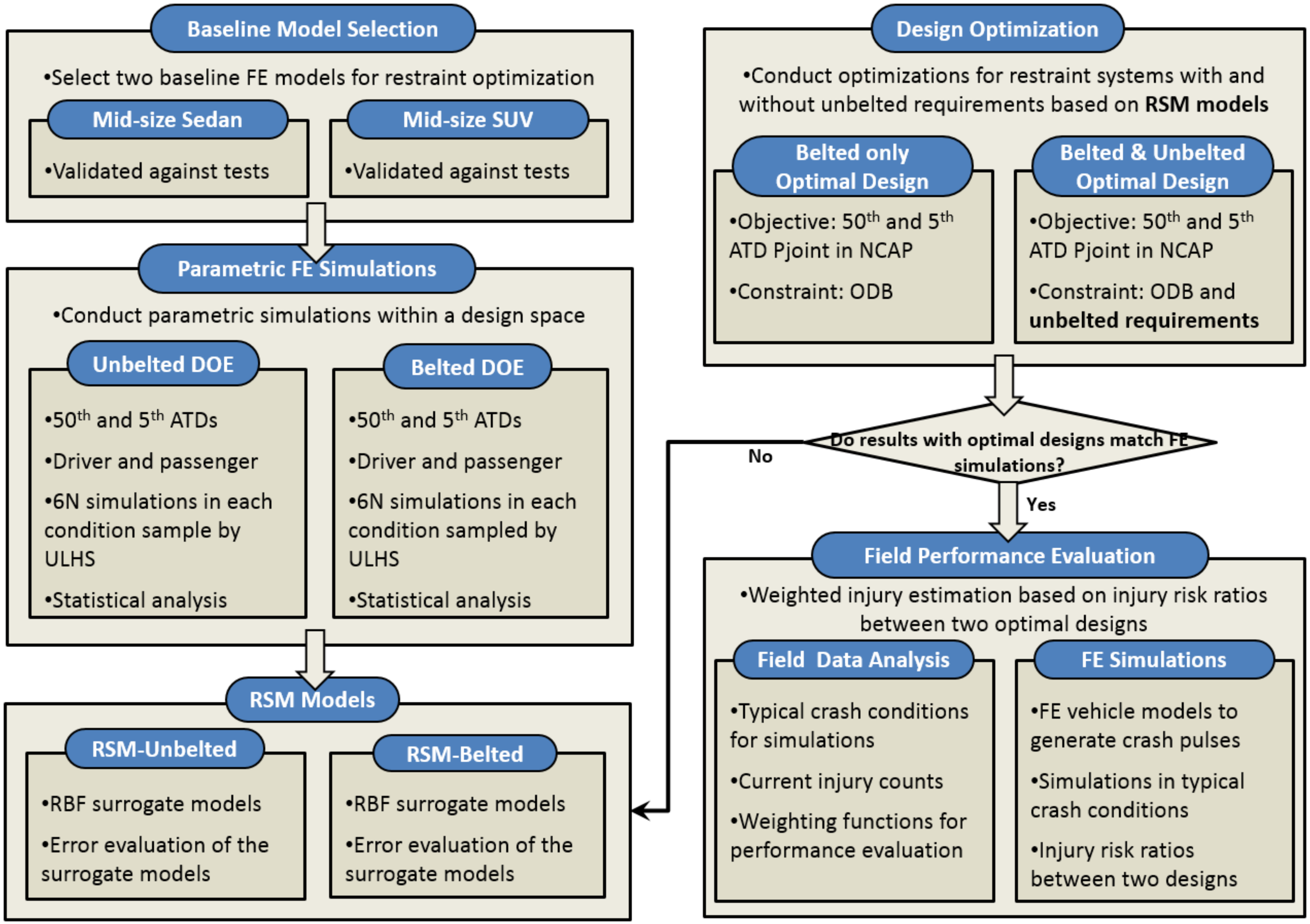
Technical Schematic



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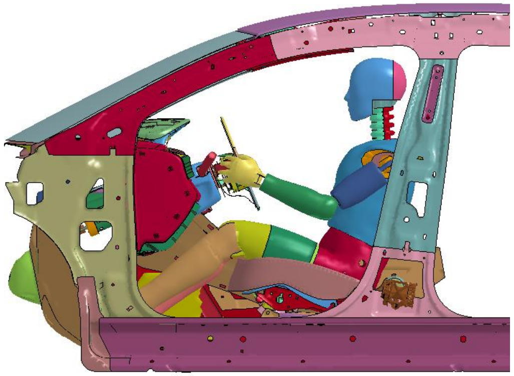
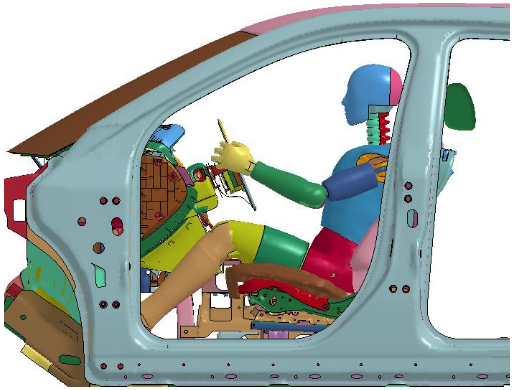
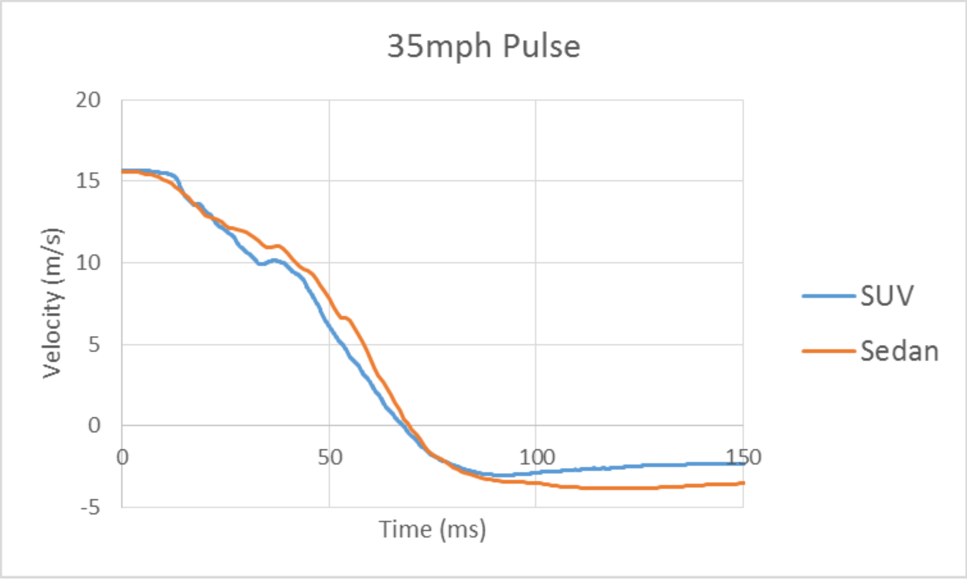
Baseline Model Selection

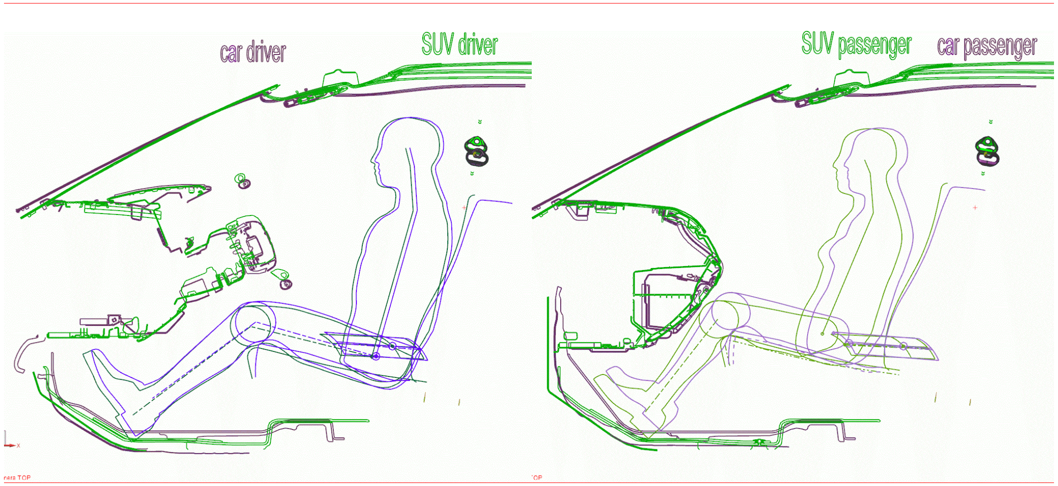
- Mid-size Sedan



- Mid-size SUV







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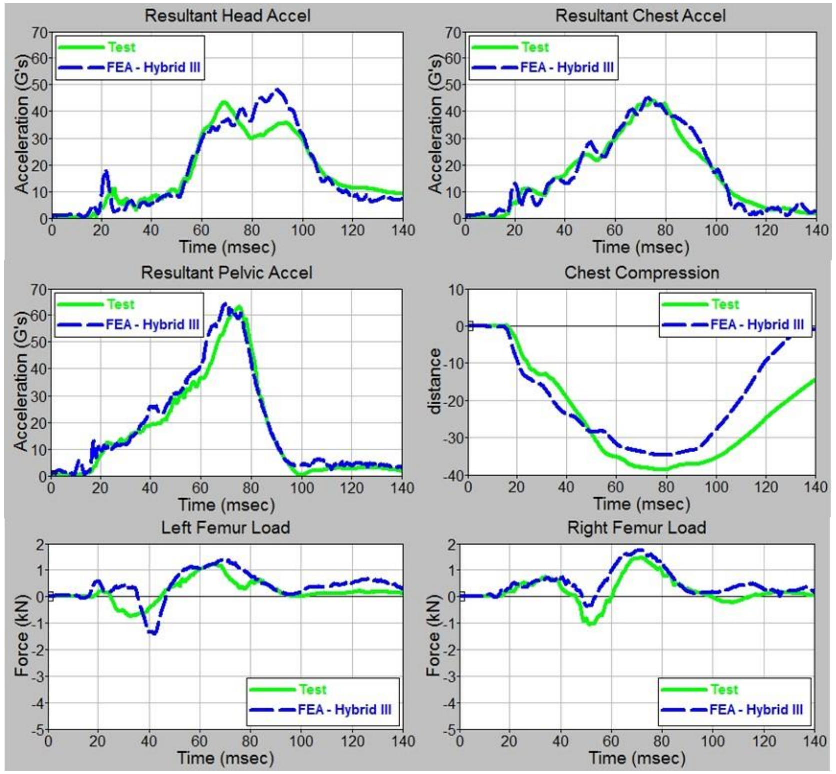
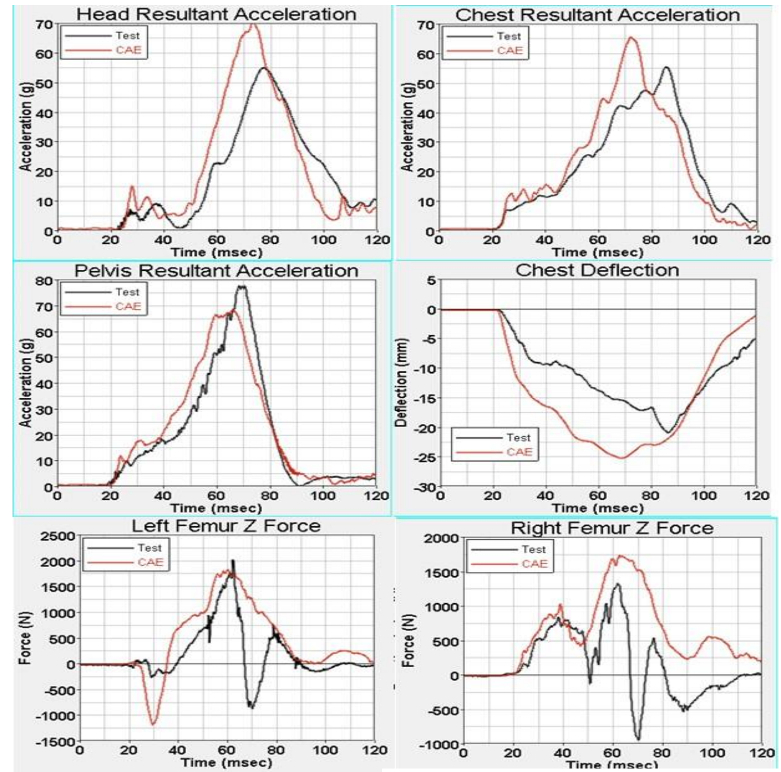
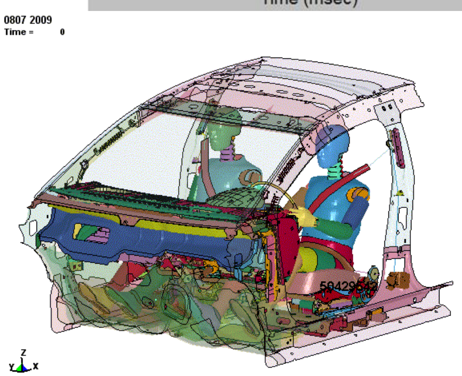
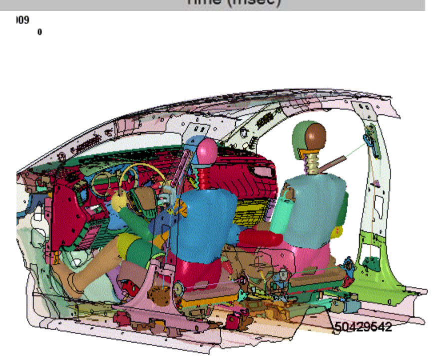
Vehicle Baseline Model Correlations

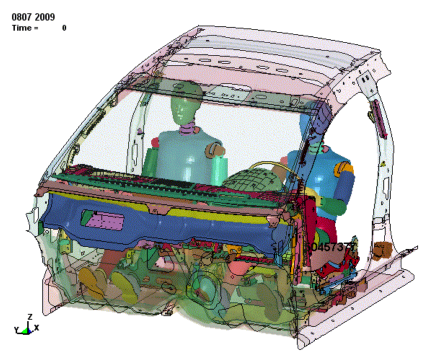
- Sedan Driver – 50th Male
- SUV Driver – 5th Female

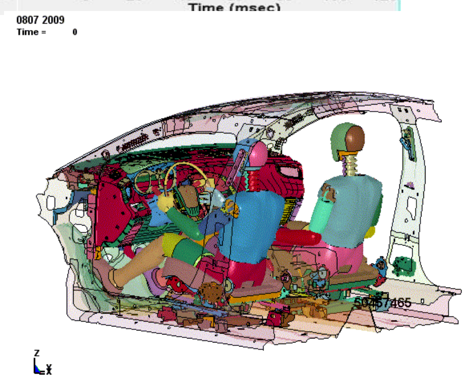












Objectives & Constraints

Belted Occupants

Test	Driver	Passenger
35 mph Rigid Barrier*	50th male	50th male
35 mph Rigid Barrier*	5th female	5th female

*Has to meet occupant safety regulatory requirements

Unbelted Occupants

Test	Angle in degrees	Driver	Passenger
25 mph Rigid Barrier	0	5th female	5th female
25 mph Rigid Barrier	0 (-30 to 30)*	50th male	50th male

* Zero-degree was the main condition for restraint optimization, but -30 and 30 degree crash conditions were checked after restraint optimization to make sure that they meet regulatory requirements.

Objectives **Constraints**

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Objectives

NCAP Injury Assessment

- Belted

	HIII 50M dummy	HIII 5F dummy
Head (HIC15)	$P_{head}(AIS3+) = \emptyset\left(\frac{ln(HIC15) - 7.45231}{0.73998}\right)$ Where Φ=cumulative normal distribution	
Neck (N_{ij} and tension / compression in kN)	$\begin{cases} P_{Nij}(AIS3+) = \frac{1}{1+e^{3.2269-1.9688Nij}} \\ P_T(AIS3+) = \frac{1}{1+e^{10.9745-2.375T}} \\ P_C(AIS3+) = \frac{1}{1+e^{10.9745-2.375C}} \\ P_{neck} = Max(P_{Nij}, P_T, P_C) \end{cases}$	$\begin{cases} P_{Nij}(AIS3+) = \frac{1}{1+e^{3.2269-1.9688Nij}} \\ P_T(AIS3+) = \frac{1}{1+e^{10.9745-3.770T}} \\ P_C(AIS3+) = \frac{1}{1+e^{10.9745-3.770C}} \\ P_{neck} = Max(P_{Nij}, P_T, P_C) \end{cases}$
Chest (deflection in mm)	$P_{ch}(AIS3+) = \frac{1}{1+e^{10.5456-1.568*D^{0.4612}}}$	$P_{ch}(AIS3+) = \frac{1}{1+e^{10.5456-1.7212*D^{0.4612}}}$
Femur (force in kN)	$P_{femur}(AIS2+) = \frac{1}{1+e^{5.795-0.5196F}}$	$P_{femur}(AIS2+) = \frac{1}{1+e^{5.7949-0.7619F}}$

$$P_{joint} = 1 - (1-P_{head}) \times (1-P_{neck}) \times (1-P_{chest}) \times (1-P_{femur})$$

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Constraints
FMVSS208 Injury Assessment

- Unbelted

Body Region	Parameter	50M dummy	5F dummy
Head	HIC-15	700	700
Neck	Nij	1.00	1.00
	Neck axial tension (kN)	4.17	2.62
	Neck compression (kN)	4.0	2.52
Chest	Chest acceleration (3ms, g)	60	60
	Sternum deflection (mm)	63	52
Leg	Femur axial force (kN)	10	6.805

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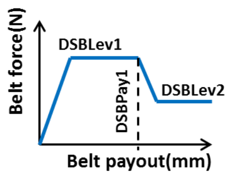
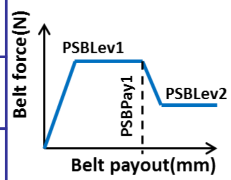
Design Parameters

	LS-DYNA parameter	Description	Baseline	Lower bound	Upper Bound
Driver	DCINCH	Cinching plate inactive/active	0	0	1
	DAPTTB	Anchor pretensioner no/yes	1	0	1
	DSBLev1 (N)		2850	2000	4000
	DSBLev2 (N)		2850	2000	4000
	DSBPay1 (mm)		150	100	200
	DVentD (mm)	Static vent diameters (two holes)	35	25	45
	DVentDD (mm)	Dynamic vent diameter (one hole)	0	0	50
	DVentDT (ms)	Dynamic vent time	30	30	60
	DtethA (mm)	Lower tether length	260	100	300
	DtethC (mm)	Upper tether length	290	200	300
	DMassR	Inflator flow factor	1	0.8	1.2
	CBL (N)	Steering column load	3000	2000	4000

	LS-DYNA parameter	Description	Baseline	Lower bound	Upper Bound
Passenger	PCINCH	Cinching plate inactive/active	0	0	1
	PAPTTB	Anchor pretensioner no/yes	1	0	1
	PSBLev1 (N)		2850	2000	4000
	PSBLev2 (N)		2850	2000	4000
	PSBPay1 (mm)		150	100	200
	PVentD (mm)	Static vent diameters (two holes)	60	30	90
	PVentDD (mm)	Dynamic vent diameter (one hole)	0	0	50
	PVentDT (ms)	Dynamic vent time	50	50	80
	PtethA (mm)	Upper tether length	460	360	560
	PMassR	Inflator flow factor	1	0.8	1.2

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Optimization Procedure

1. DOE runs (ULHS)
   - 72 runs for belted occupants in each condition
   - 42 runs for unbelted occupants in each condition
2. RSM (Radial Basis Function)
3. Virtual optimization (NSGA-II)
4. Optimal solution check with Ls-Dyna runs
   - If not satisfied, rerun items 2-4
   - If satisfied, done

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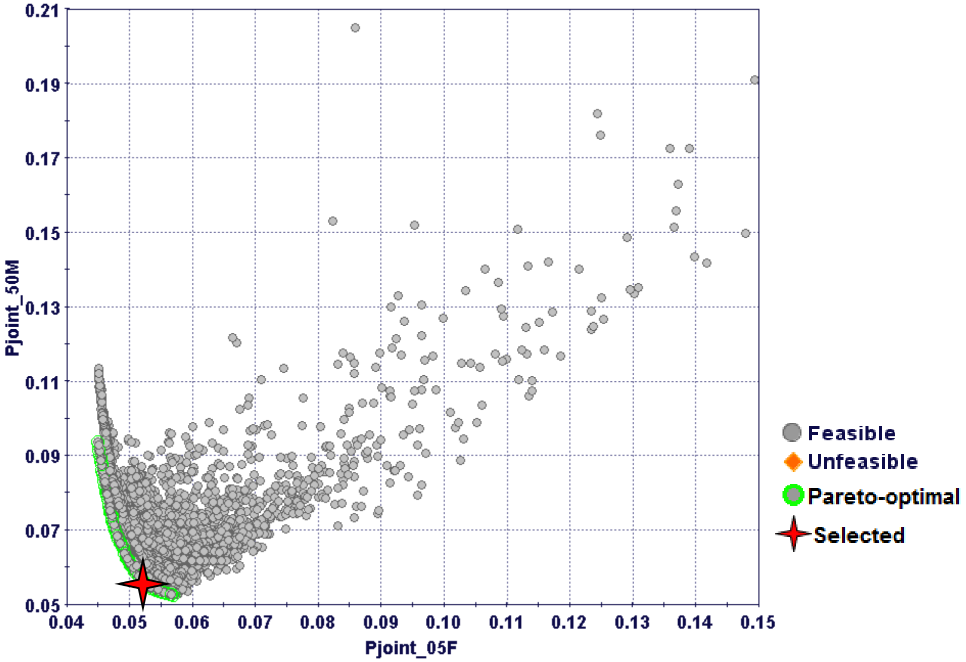
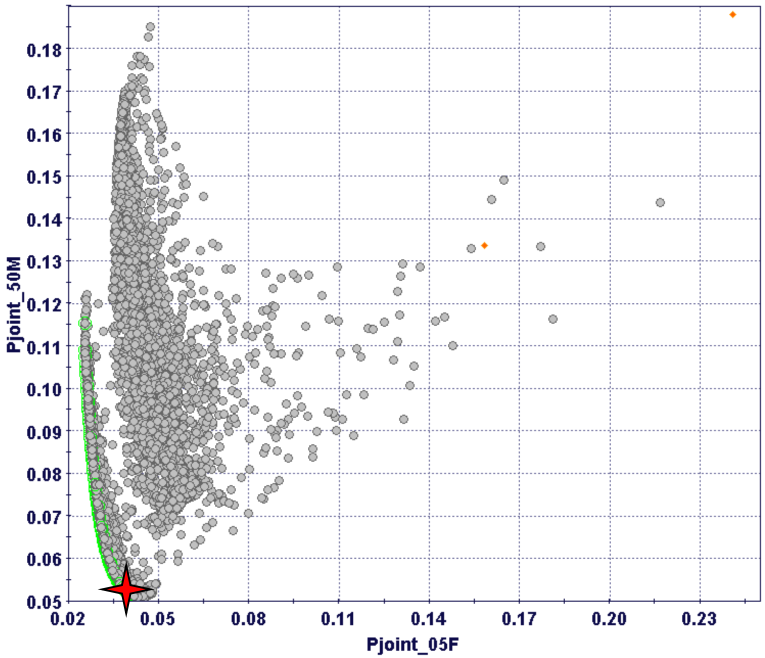
Sedan Optimum

- Driver
- Passenger





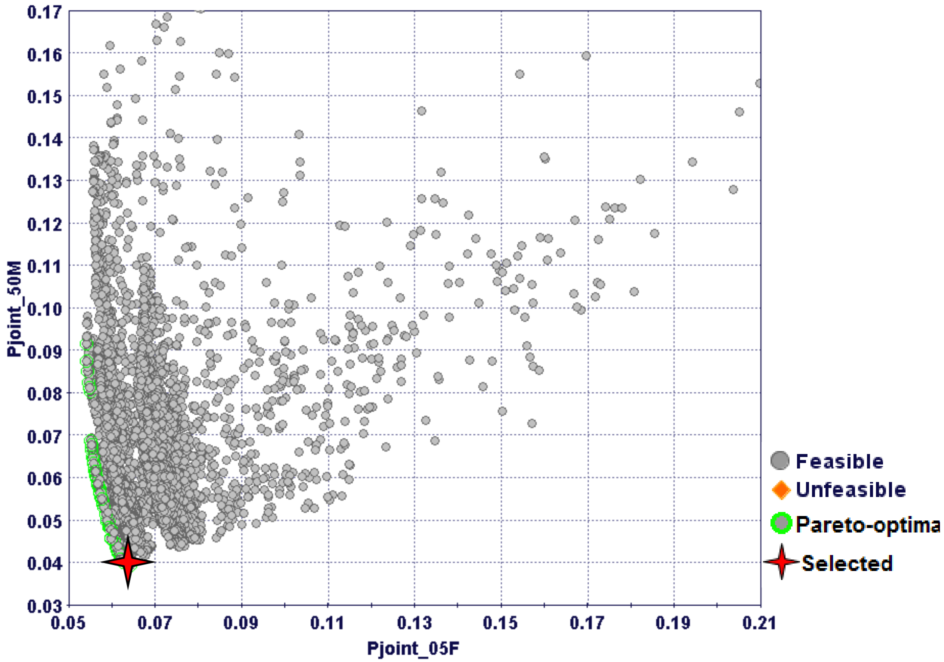
	DCINCHB	DAPTTB	DSBLev1	DSBLev2	DSBPay1	DVentD	DVentDD	DVentDT	DtethA	DtethC	DMassR	CBL	**Pjoint_50M**	**Pjoint_05F**
Driver	1	1	2010	2010	150.0	45.0	0.0	39.1	300	287	1.03	2044	**0.046**	**0.058**

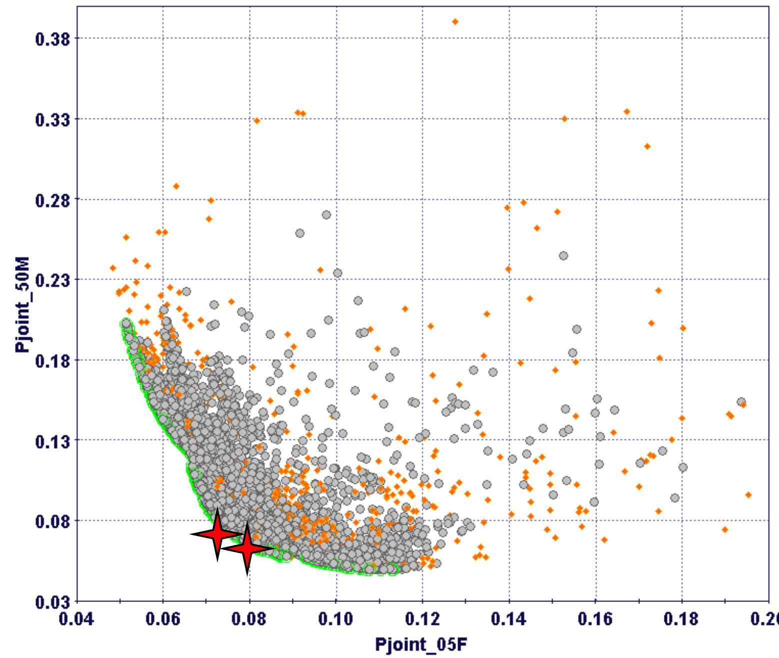
	PCINCHB	PAPTTB	PSBLev1	PSBLev2	PSBPay1	PVentD	PVentDD	PVentDT	PtethA	PMassR	**Pjoint_50M**	**Pjoint_05F**
Passenger	1	1	2892.4	2892.4	150.0	90.0	0.0	69.7	496.0	0.99	**0.0689**	**0.0461**

Results from Ls-dyna runs

SUV Optimum

- Driver
- Passenger





Orange dots indicate violations of unbelted requirements

	DCINCHB	DAPTTB	DSBLev1	DSBLev2	DSBPay1	DVentD	DVentDD	DVentDT	DtethA	DtethC	DMassR	CBL	**Pjoint_50M**	**Pjoint_05F**
Driver	1	1	2000	2000	150.0	45.0	0.0	60.0	299.6	233.1	0.80	1980	**0.058**	**0.033**

		PCINCHB	PAPTTB	PSBLev1	PSBLev2	PSBPay1	PVentD	PVentDD	PVentDT	PtethA	PMassR	**Pjoint_50M**	**Pjoint_05F**
Belted-only	Passenger	0	1	2328.1	2328.1	150.0	76.9	0.0	62.6	484.9	1.20	**0.050**	**0.058**
W Unbelted	Paseenger	0	0	2517.6	2517.6	150.0	67.6	0.0	59.1	478.0	1.12	**0.058**	**0.076**

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Results from Ls-dyna runs

Design Optimization Summary

- Optimizations significantly reduced Pjoint values for both 5th and 50th ATDs in NCAP crash conditions from the baseline model.
- Unbelted requirements do not affect the optimal designs in 3 out of 4 vehicle/side conditions, except for the SUV passenger side.
- Knee bolster design parameters were not included in the optimization, because the knee-to-bolster contacts are small for belted occupants.

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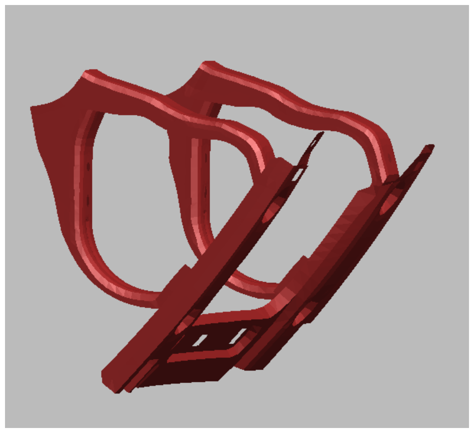
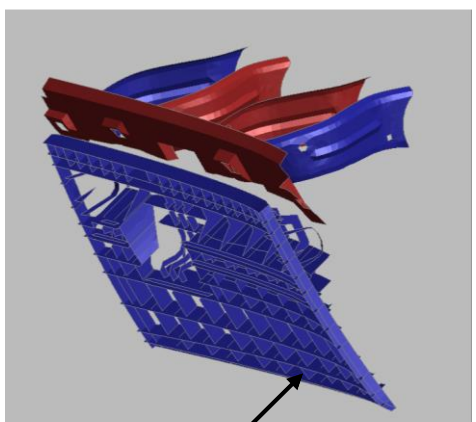
Final Optimal Designs - Sedan

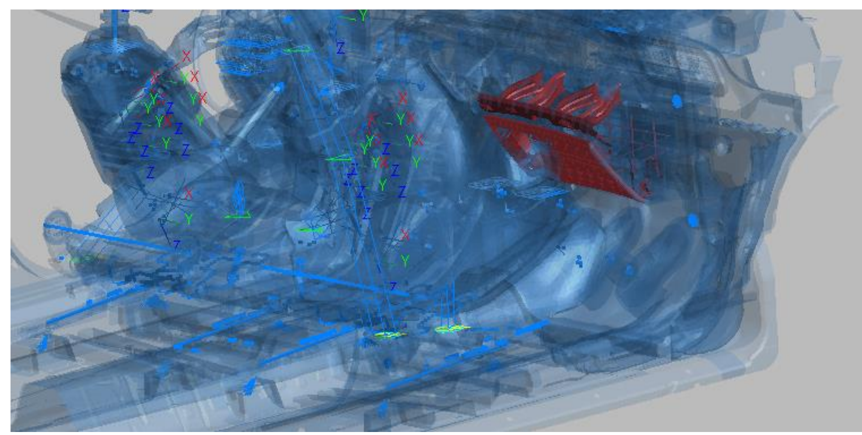
- Knee bolsters were removed for the “Belted-only” optimal designs

Driver



Passenger





Blue parts removed

Cost reduction: $2.92
Mass reduction: 1.27 kg

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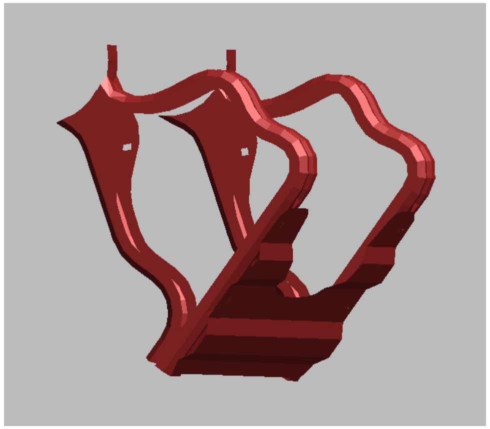
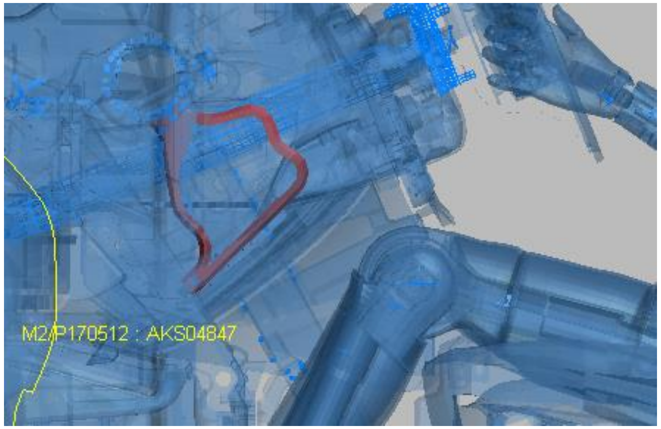
Final Optimal Designs - SUV

- Knee bolsters were removed for the “Belted-only” optimal designs

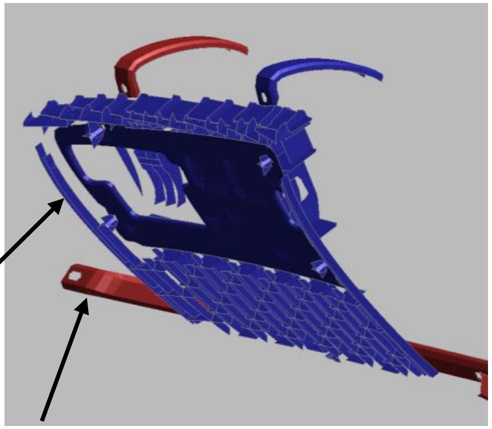
Driver

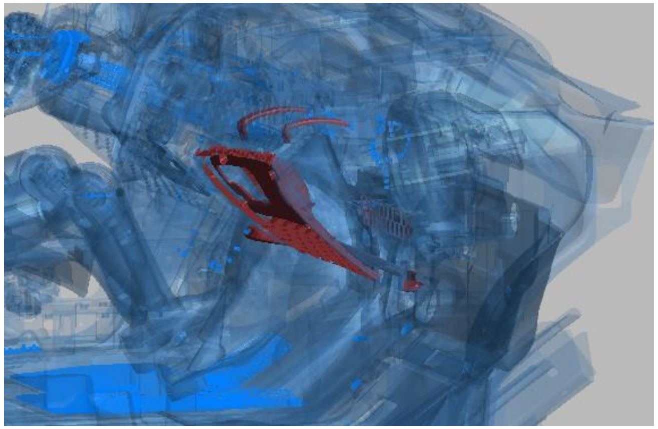




Passenger

Blue parts removed





Reduce gage from 1.5mm to 1.0mm

Cost reduction: $3.04
Mass reduction: 1.37 kg

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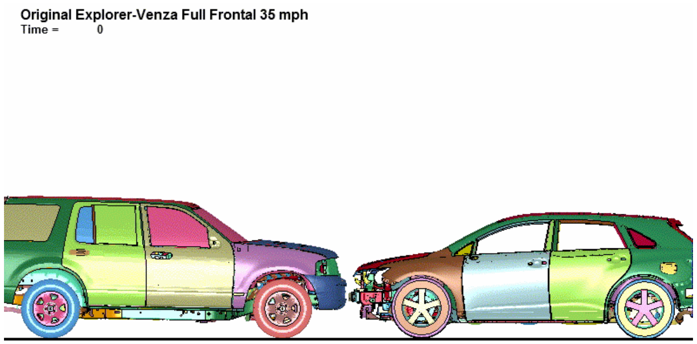
Field Performance - Simulation Matrix

- 11 crash scenarios (Venza full barrier, ODB, pole, frontal and offset crash to Yaris, Taurus, Explorer, and Silverado)
- 5 impact speeds for each crash scenarios (15, 20, 25, 30, 35mph)
- 2 vehicles (sedan vs. SUV)
- 2 ATDs (5^{th} vs. 50^{th})
- 2 sides (driver vs. passenger)
- 2 designs (belted only vs. belted&unbelted)
- 2 belt conditions (belted vs. unbelted)

1760 runs in total

Field Performance Example

35mph Full Frontal Venza-Explorer Belted Case



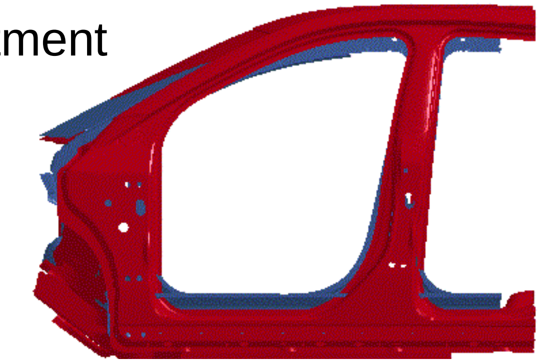
Vehicle crash simulation

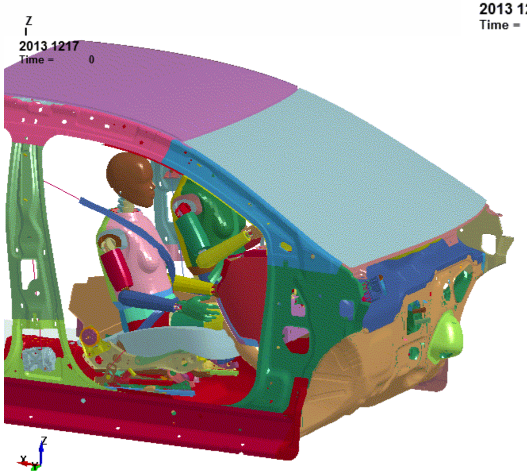
2013 1217
Time = 0

Prescribed motion to the occupant compartment

SUV model

sedan model





5th female passenger

5th female driver

50th male driver

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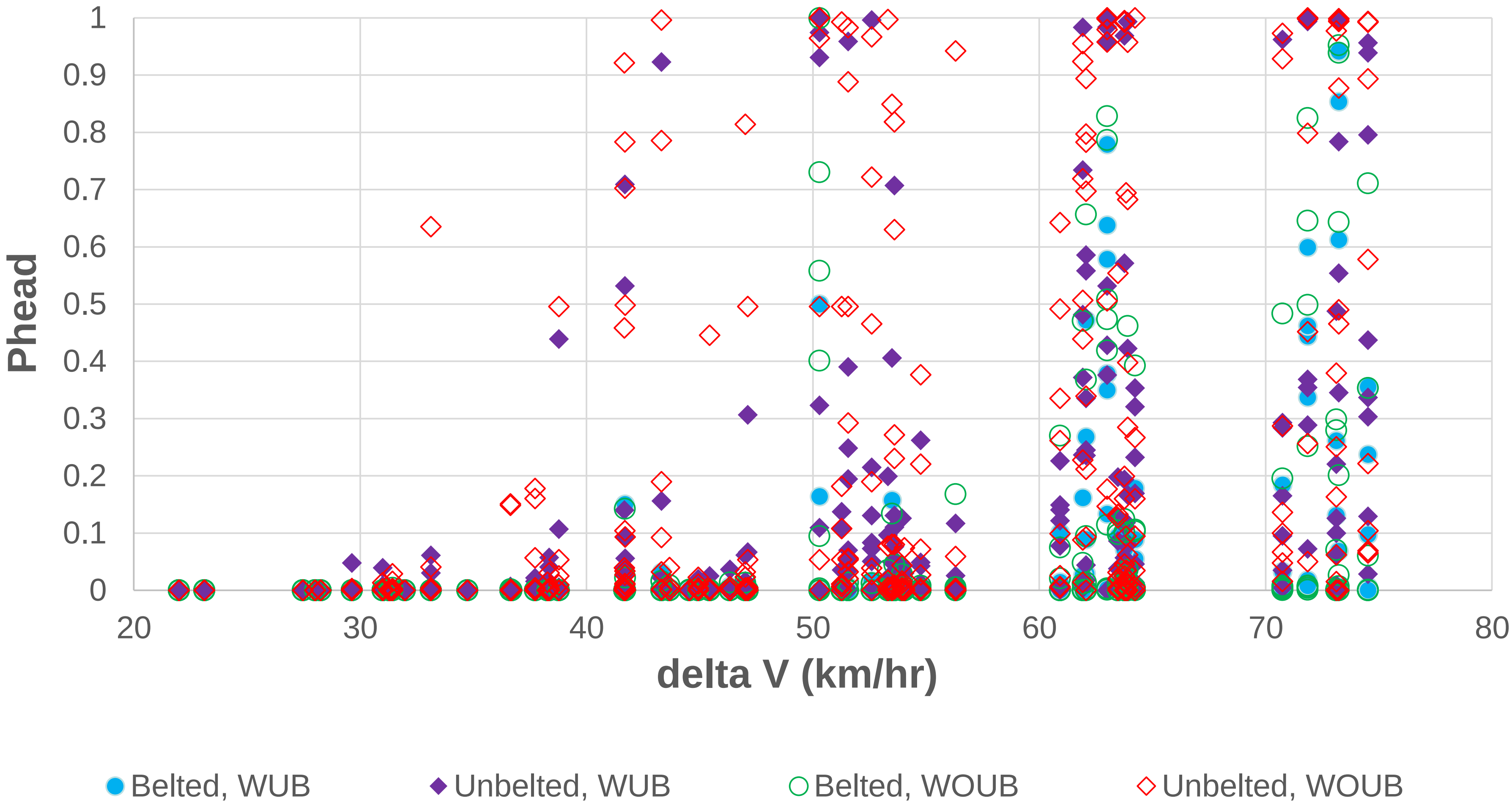
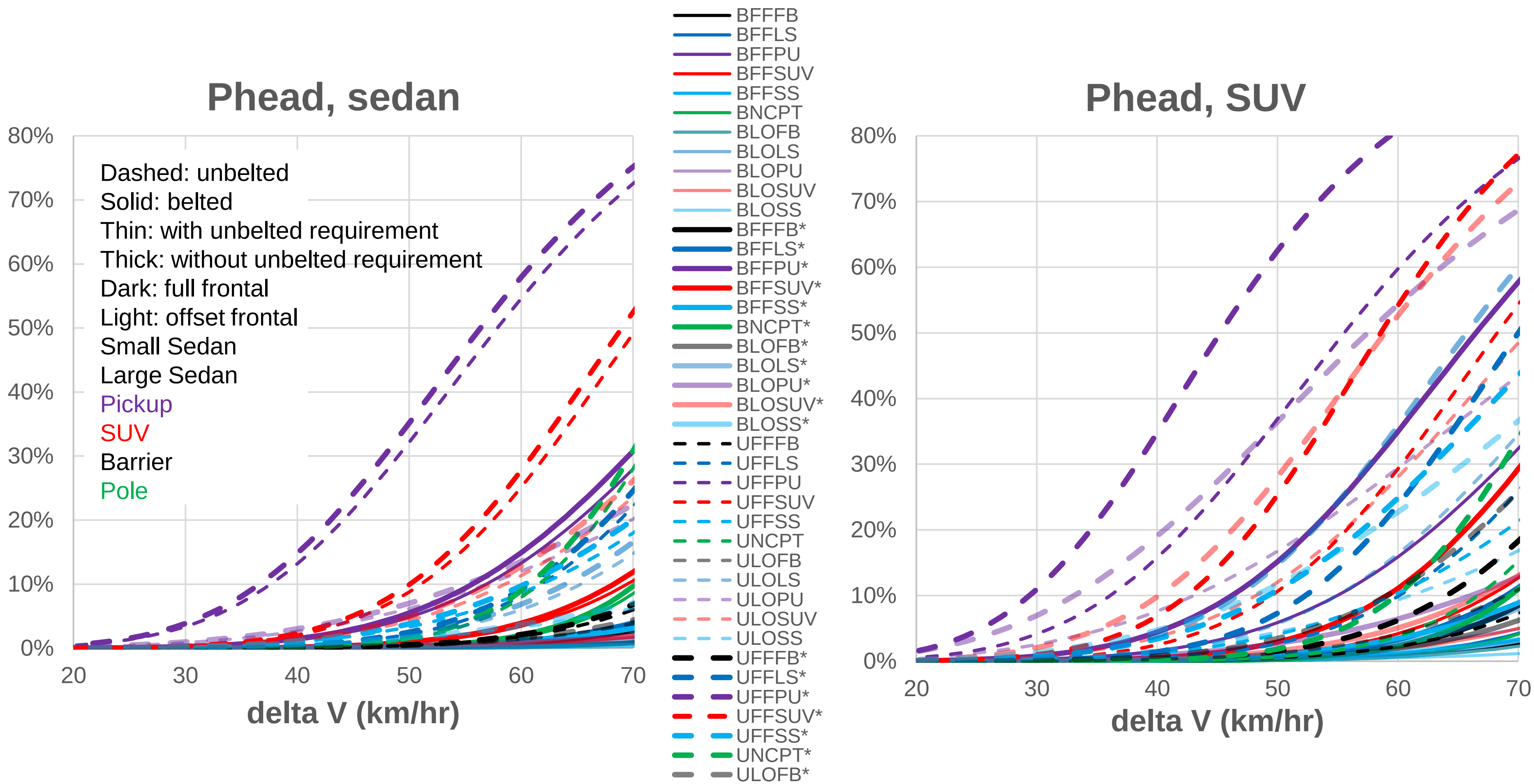
Simulation Results: Phead



Regression Curves for Simulated Phead



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Estimating Baseline Injury Risk

- Generate injury risk models for each body region as a function of ln(delta V), belt use, crash partner, crash type
- Use occupants in 2002-2012 CDS as the standard population
- P=1/{1+EXP[-(intercept+

  ln(dV) x (A + B_n x crash type + C_n x crash partner + D x belt use) + E_n x (crash partner) + F_n x (crash type) + G_n x (crash partner) x (crash type) + belt use x (H_n +J_n x crash type + K_n * crash partner))]}

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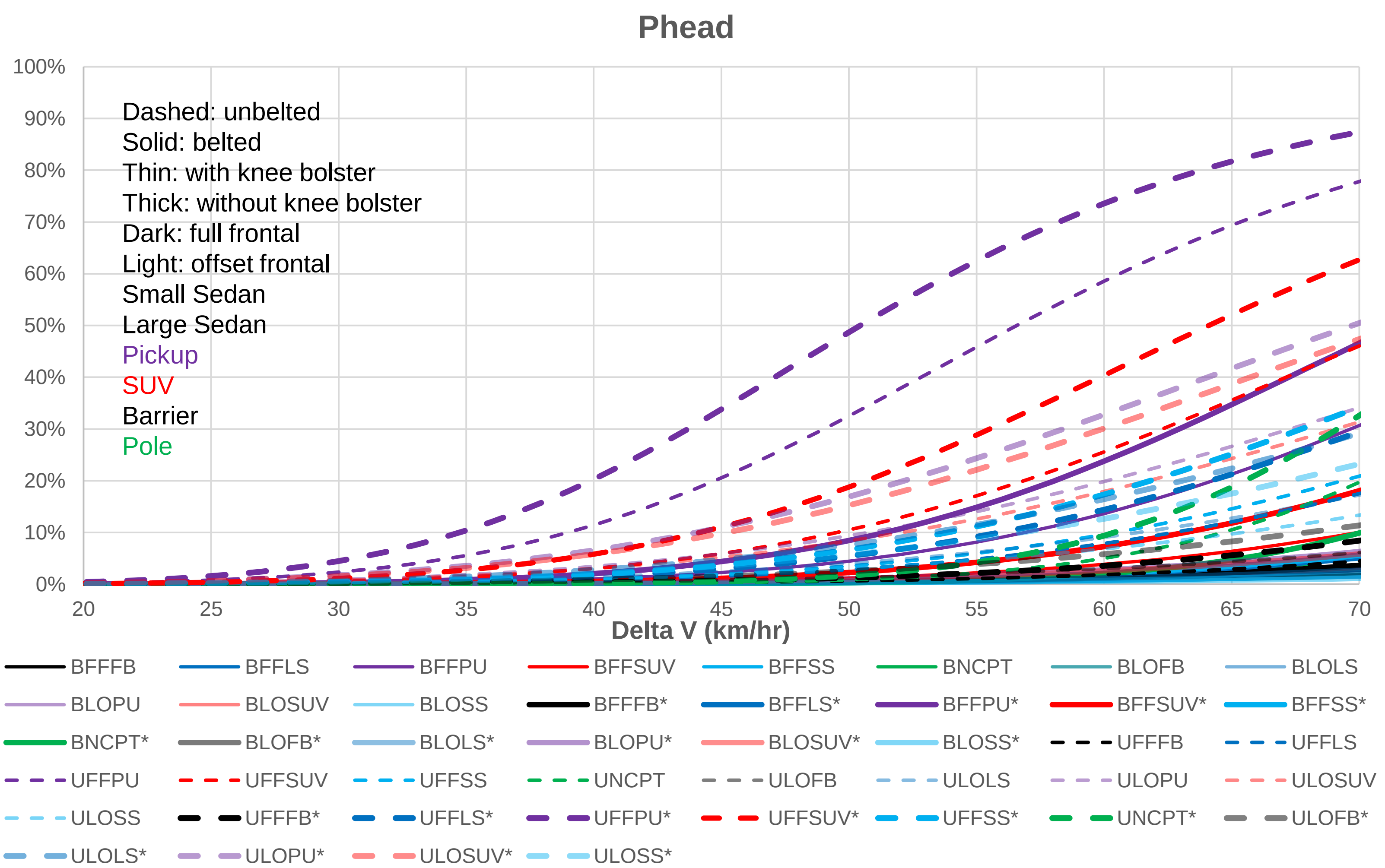
Head Injury Risk Model



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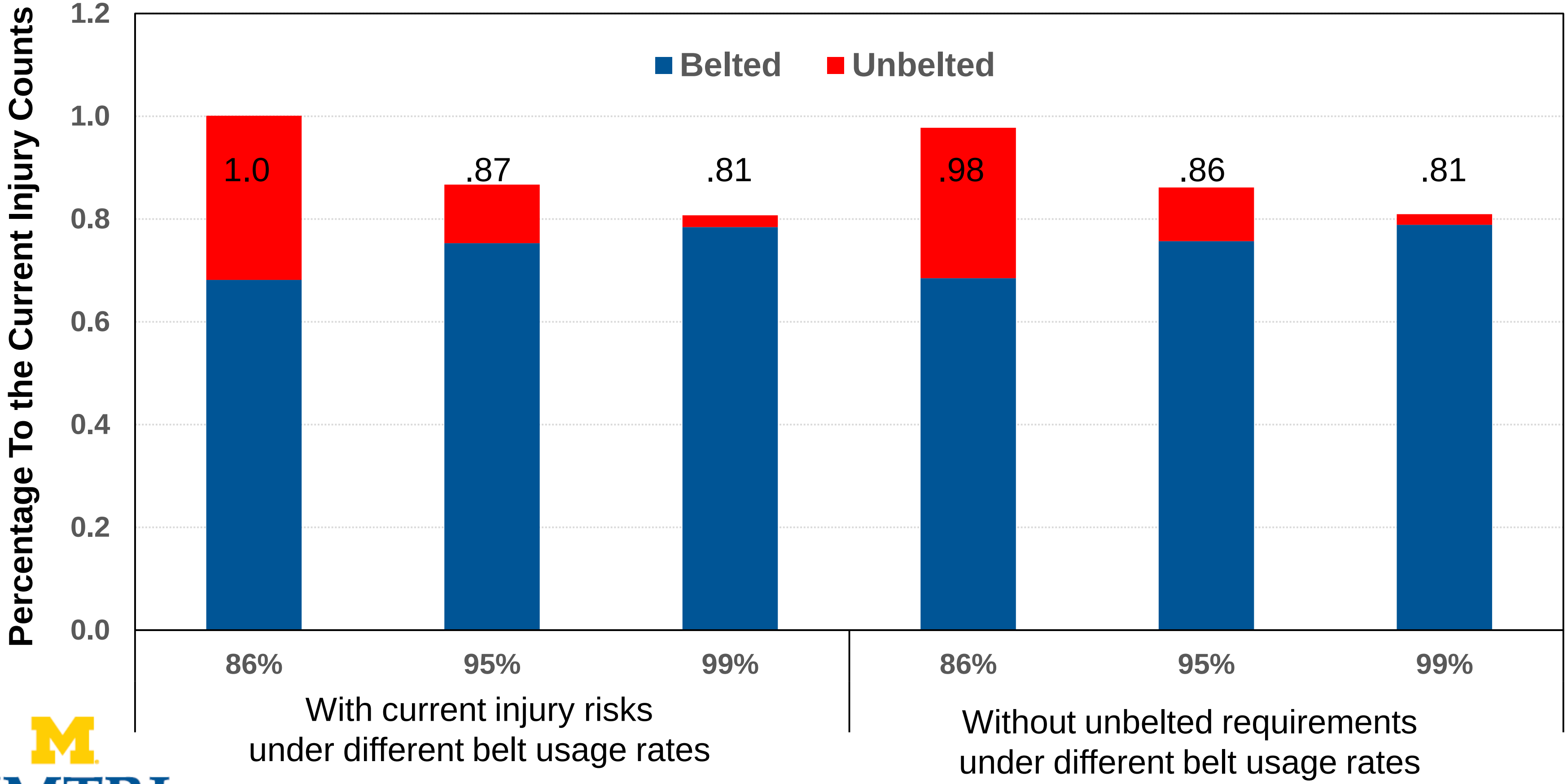
Estimated Total Injury Percentage to The Current Injury Counts

Combining head/face, neck/C-spine, chest, and KTH injuries

Based on the FE-mode-predicted injury risk differences between WOUB and WUB



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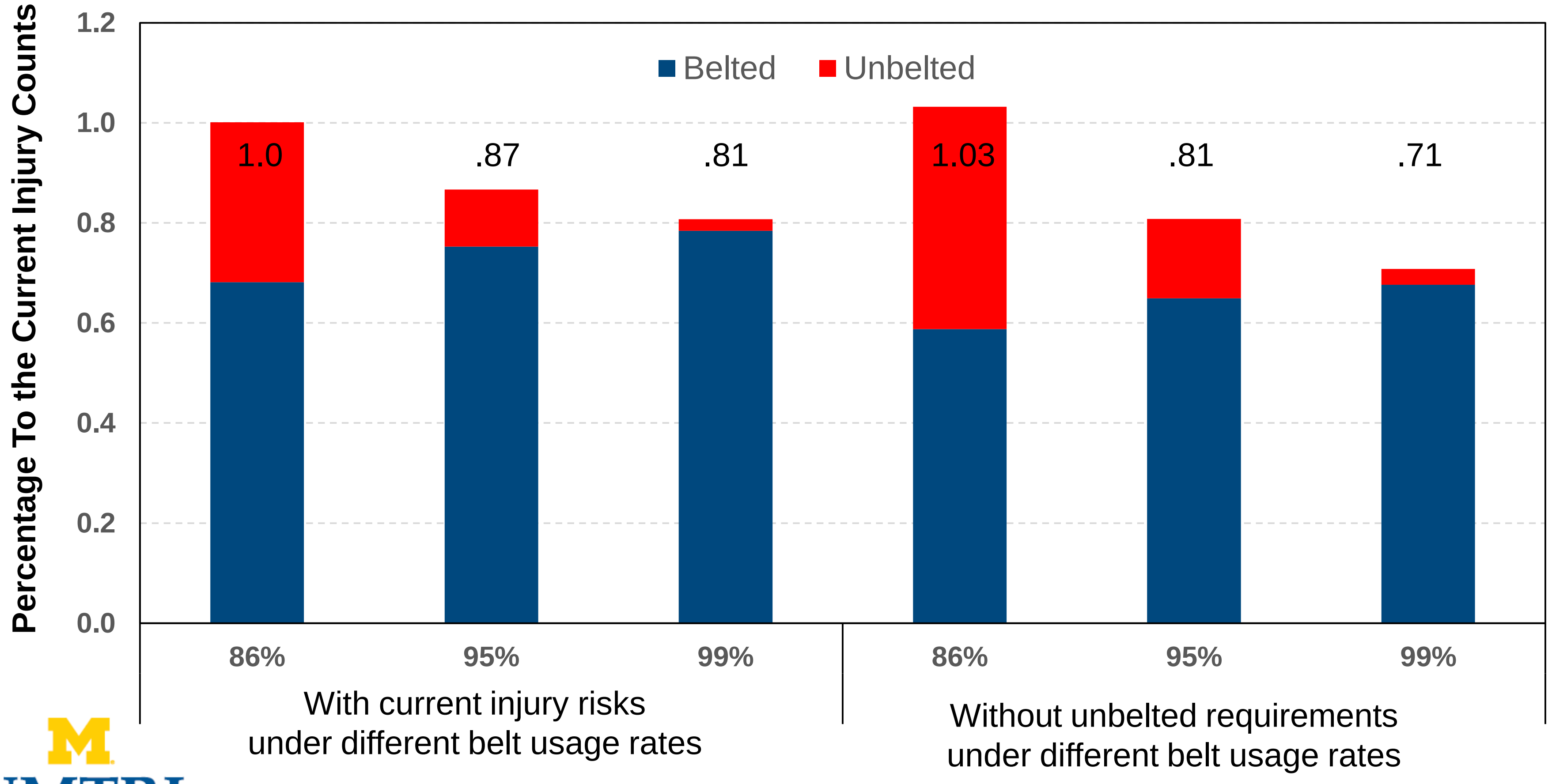
Estimated Total Injury Percentage to The Current Injury Counts

Combining head/face, neck/C-spine, chest, and KTH injuries

Based on the FE-mode-predicted injury risk ratios between WOUB and WUB



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Summary

- Optimizations significantly reduced Pjoint values for both 5th and 50th ATDs in NCAP crash conditions from the baseline model.
- Unbelted requirements do not affect the optimal designs in 3 out of 4 vehicle/side conditions, except for the SUV passenger side.
- Removing the unbelted requirements will likely reduce the total injury risks for belted occupants in the field, but may increase the injury risks for unbelted occupants.

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Limitations

- The crash pulses and vehicle kinematics used in the field performance evaluations are from a vehicle (Venza) that is different to and generally stiffer than the baseline sedan and SUV models.
- Different methods for calculating injury risk ratios will resulted in different trends in results for field performance evaluation. Further analysis is necessary.
- The design parameter ranges are relatively narrow, and further design changes focusing on belted occupants are needed.

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