The Safety of Occupants in Rotated Seating Scenarios

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- Probing Questions
- Methodology
- Human corridors
- Choice of Human model
- Human Model validation
- Human Kinematics in Rotated Seating
- Human injuries in Rotated Seating
- Conclusions

Reference Papers

In your publications, please refer to these 3 references, which are used in this presentation.

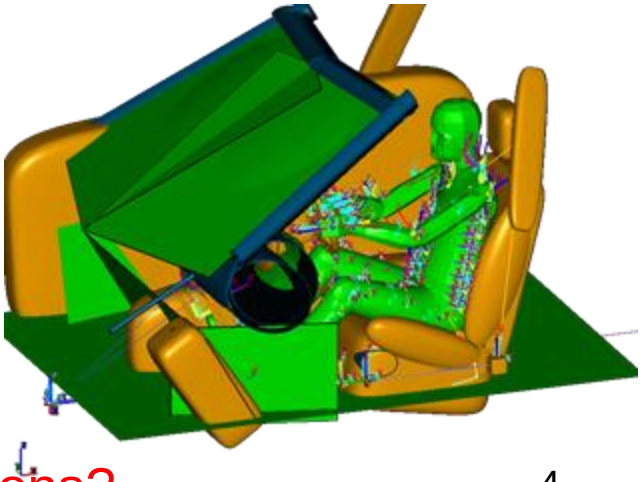
- **Occupant pre-crash kinematics in rotated seat arrangements** https://journals.sagepub.com/doi/abs/10.1177/09544070211004504?journalCode=pidb

- **The prediction of autonomous vehicle occupants' pre-crash motion during emergency braking scenarios** https://journals.sagepub.com/doi/10.1177/09544070231153262

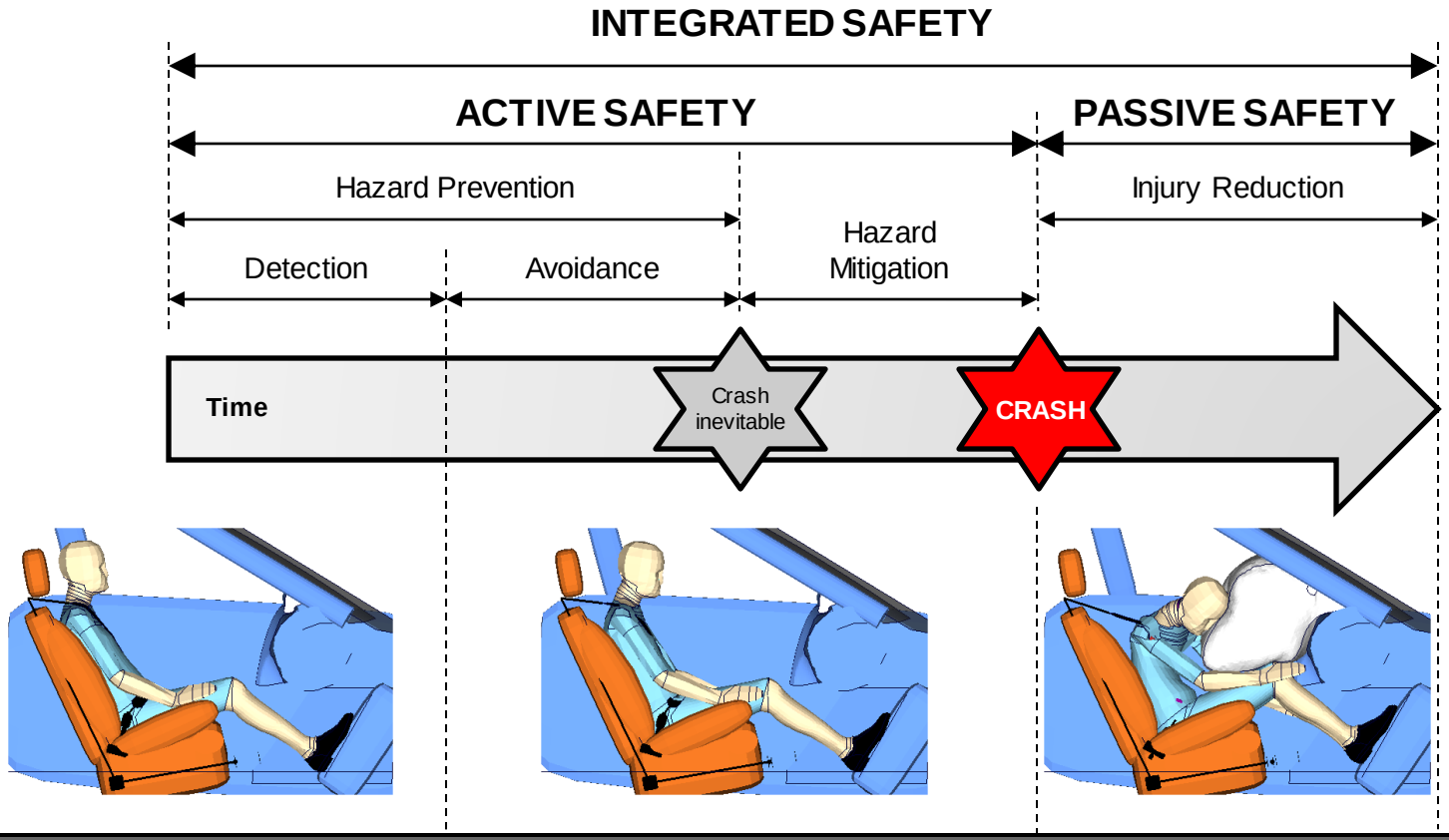
- **A Framework to Prediction Occupant Injuries in Rotated Seating Arrangements** https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4412592

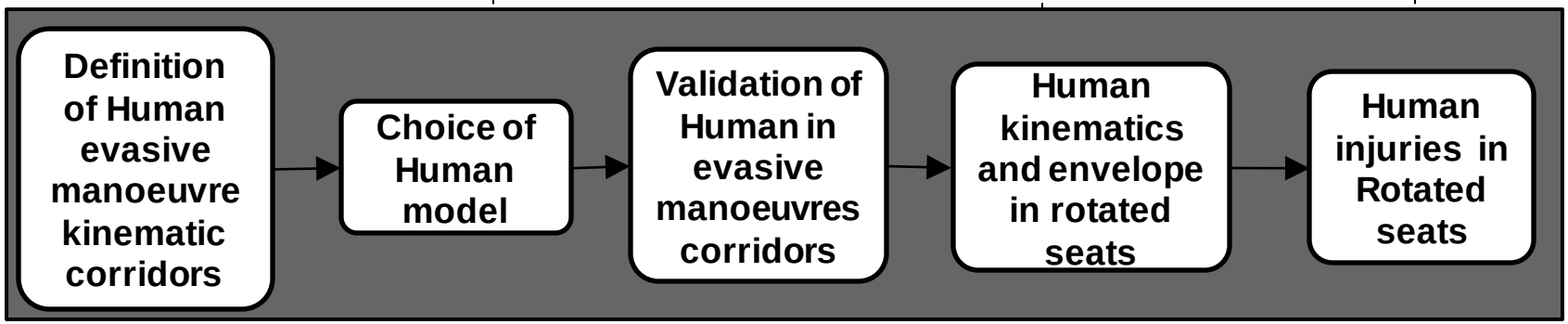
Probing Questions

- Forces acting upon occupants in emergency manoeuvre can be large.
- Current active safety technologies reduced collisions and are designed with occupants seating facing forward.
- How safe will autonomous vehicles be if occupants are not facing forward or in reclined positions during:
  - Pre-braking phase?
  - Pre-braking + crash phase?
- Questions:
  - How are people moving in the vehicle under extreme braking ?
  - How can injuries be calculated?
  - Can we prevent dangerous seating positions?

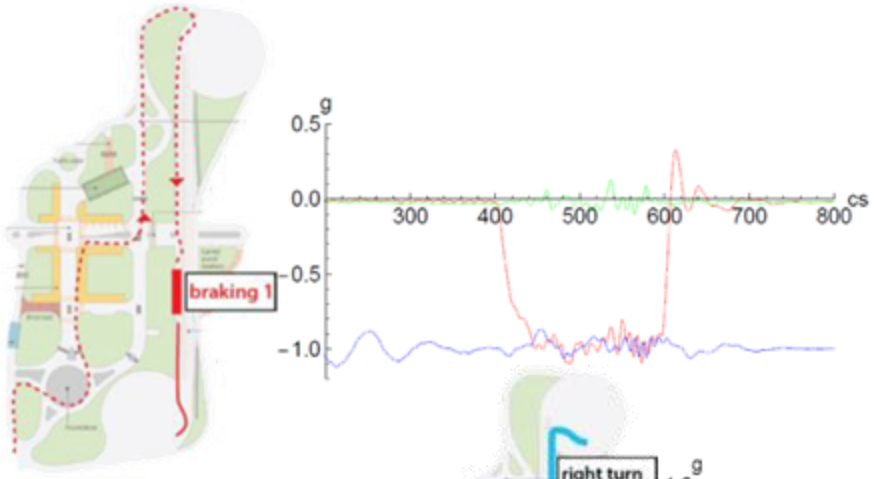


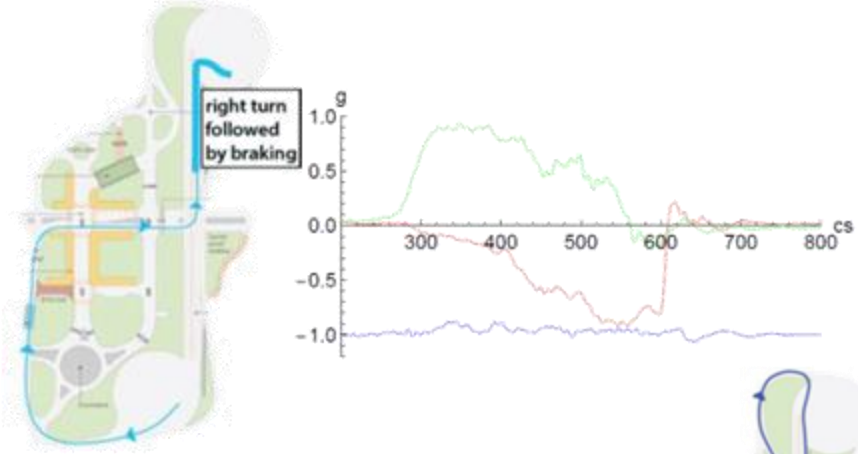
Methodology





Tests to Validate AHBM Kinematics



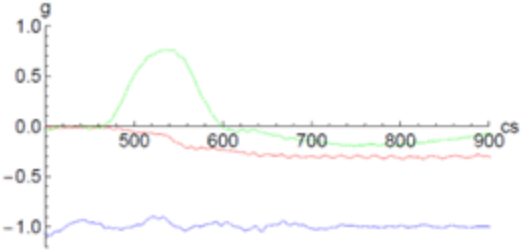


- **UMTRI Tests:**

50th percentile male/ female – 3-point belt

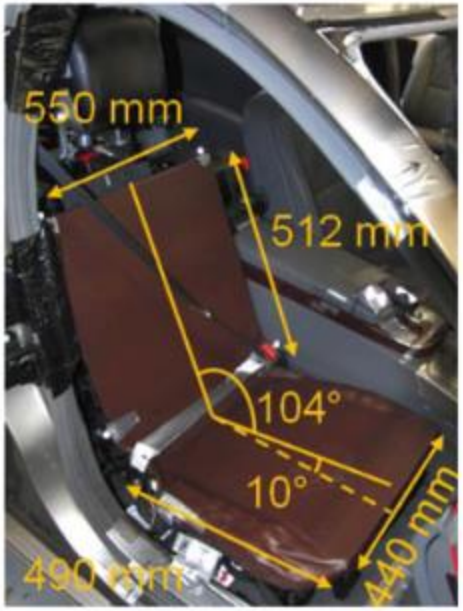
- **OM4IS Tests:**

50th percentile male (frontal / swerving) with lap belt



Tests to Validate AHBM Kinematics

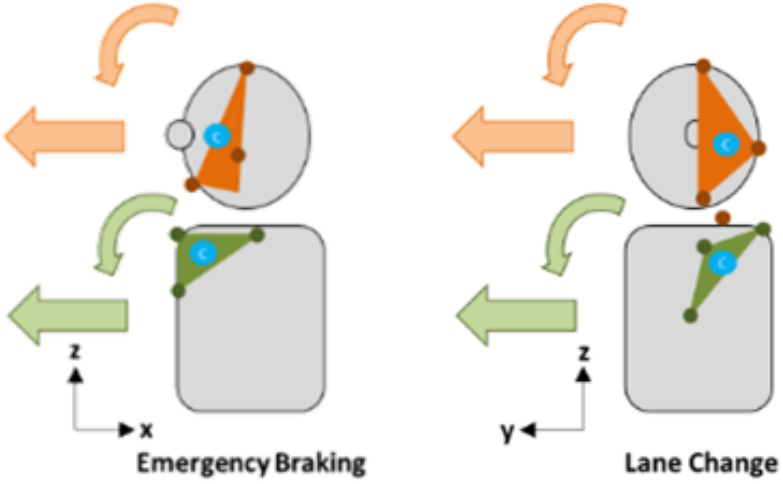
UMTRI Tests: 2016 Toyota Avalon



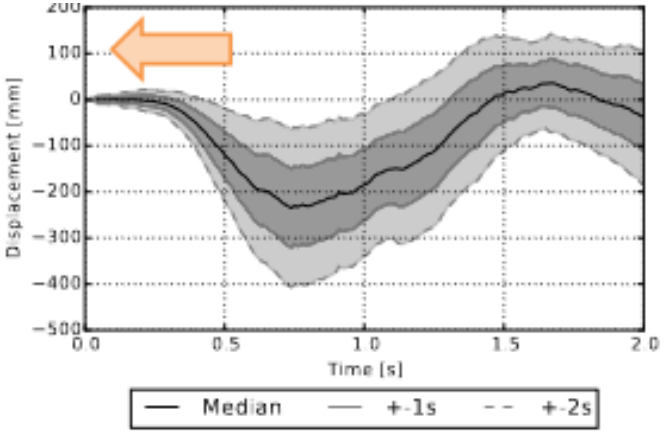
OM4IS Tests: Seat used to reduce influencing factors made of wooden plates mounted on the seat frame and covered with artificial leather

- **UMTRI Tests:** 50th percentile male/ female – 3-point belt
- **OM4IS Tests:** 50th percentile male (frontal / swerving) with lap belt

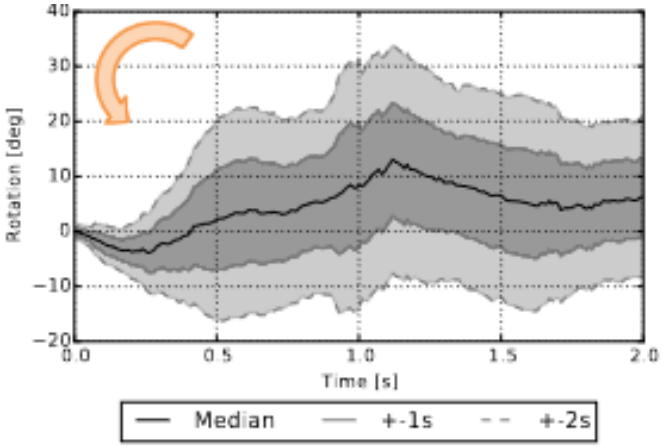
Occupants' Motion Extraction



Typical markers' location



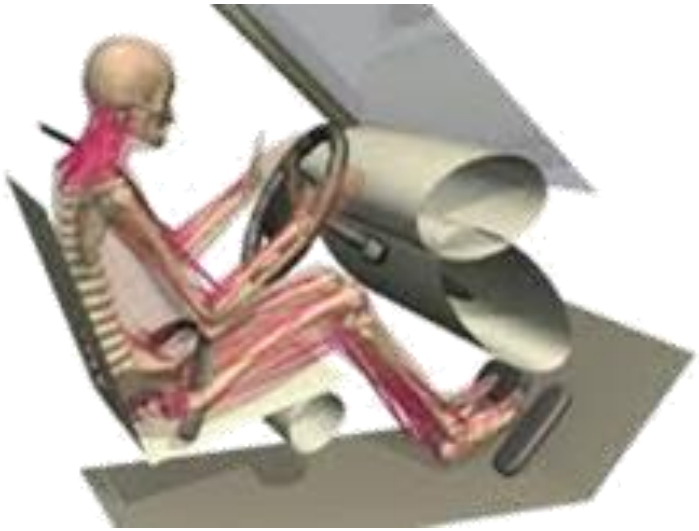
OM4IS: Head lateral displacement (mm) (Lane Change)



OM4IS: Head lateral rotation - x (deg.) (Lane Change)

Active Human Selection (AHBM)

Finite Element Models: 24 hours, 160 processors



Multibody: 2 hours, 1 processor

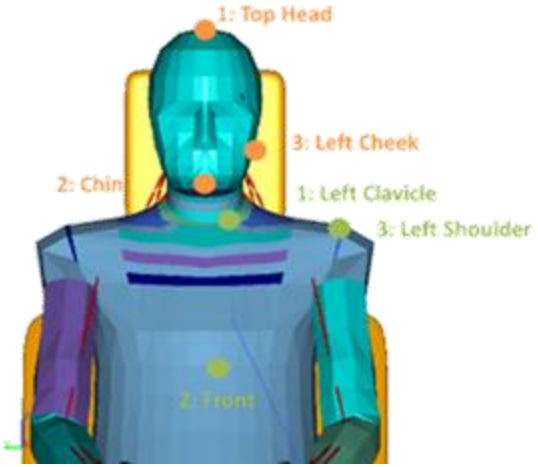
Key Aspects	Finite Element	Multibody
Solution speed	Slow, high numerical effort	Fast, Low numerical effort
Kinematics Prediction	Good	Good
Injury Risk Assessment	On tissue level depending on material properties and their limits	Comparable to crash test dummies
Performs Design of Experiment (DOE)	Limited due to high numerical effort	Method of choice

Computer Modelling of Tests

Left: Standard 2026 Toyota Avalon as in UMTRI.
Right: Standard Simcenter Madymo seat model used

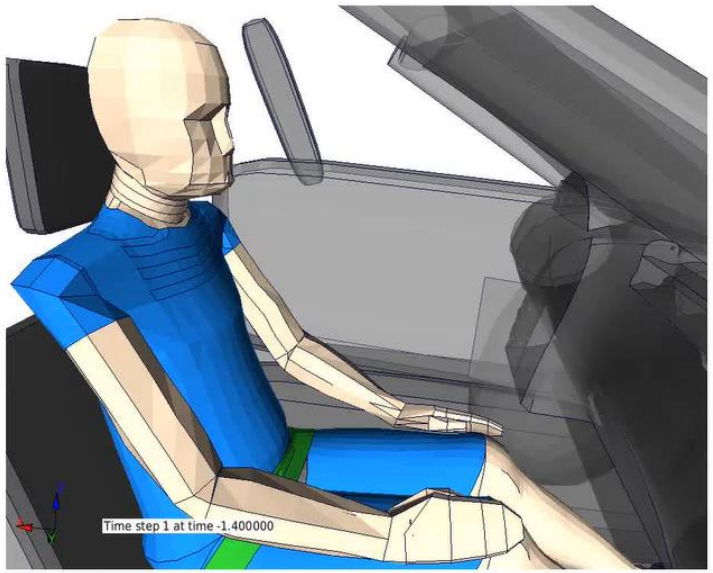
Left: 50th Percentile volunteer (OM4IS)
Right: Standard Simcenter Madymo AHM positioned on rigid seat

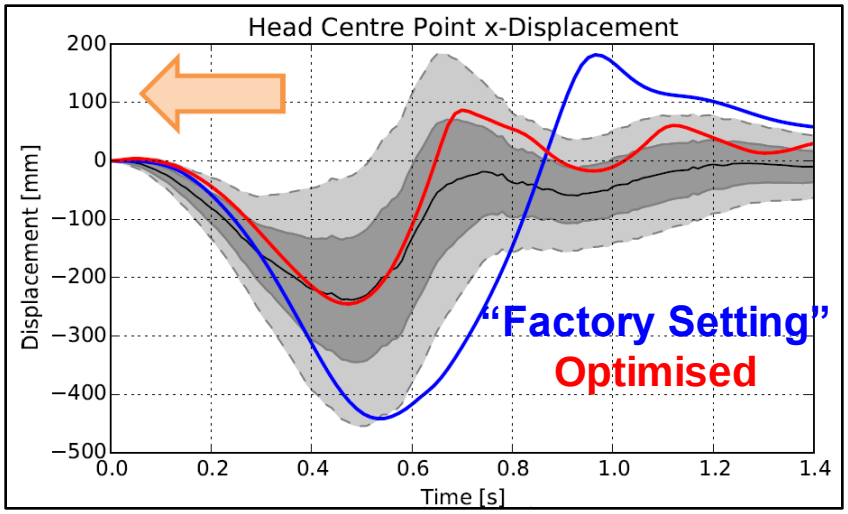
Left: 50th Percentile volunteer (UMTRI)
Right: Standard Simcenter Madymo AHM positioned on Avalon seat



Some marker locations to track the body motion

Madymo AHBM Validation





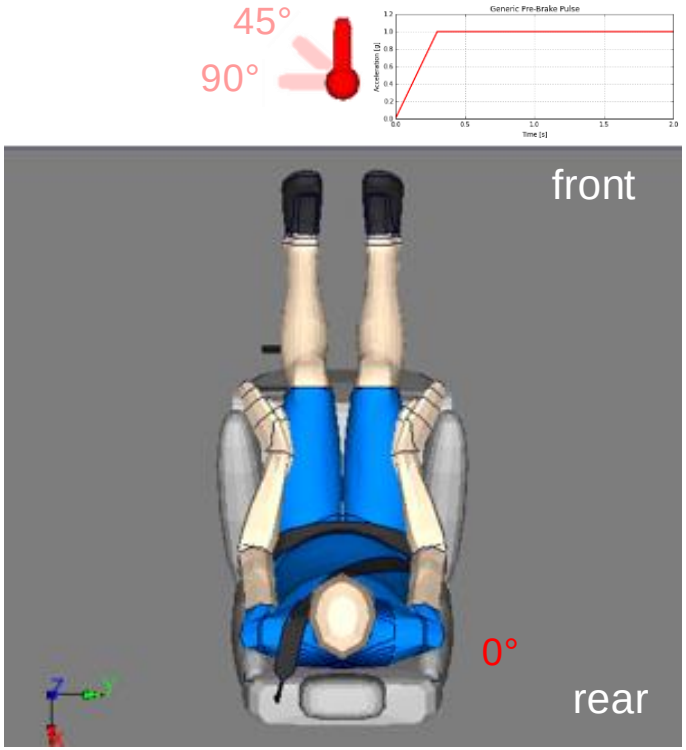
Kinematics validation performed:

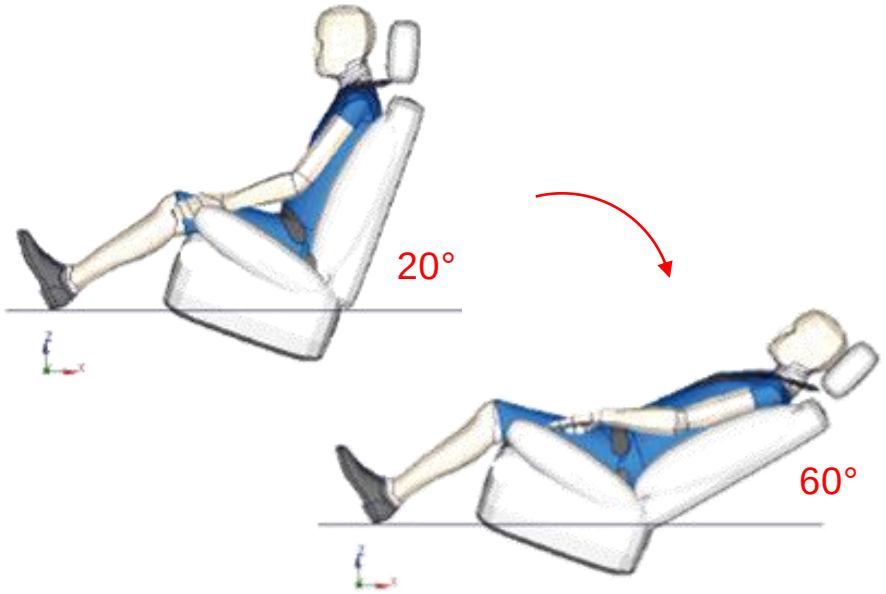
- UMTRI 50th percentile male/ female – 3-point belt
- OM4IS 50th percentile male (frontal / swerving) with lap belt

CORA: 0.64 → 0.84

Kinematics Envelope Definition

- A **Design of Experiment ("look & see") is performed** considering different seat rotation and seat back angles under extreme braking, **to explore the Madymo human kinematic response**.



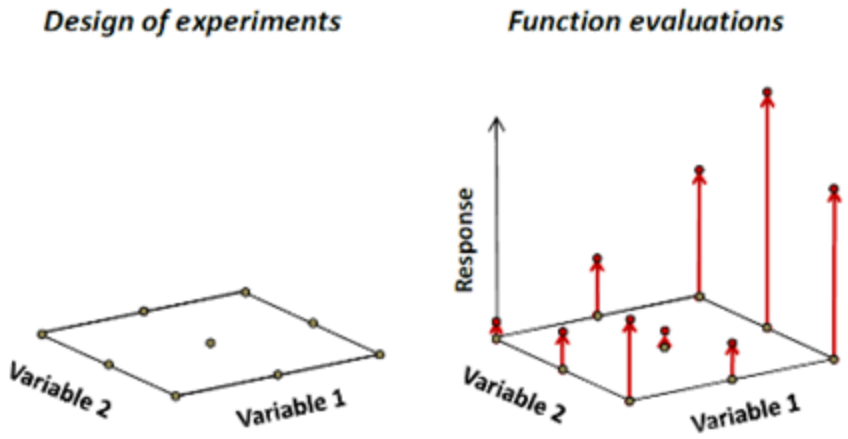


Acceleration Angle: 0° .. 360° in steps of 22.5°

Seat Back Angle: 20° .. 60° in steps of 8°

Head Kinematics Training Data

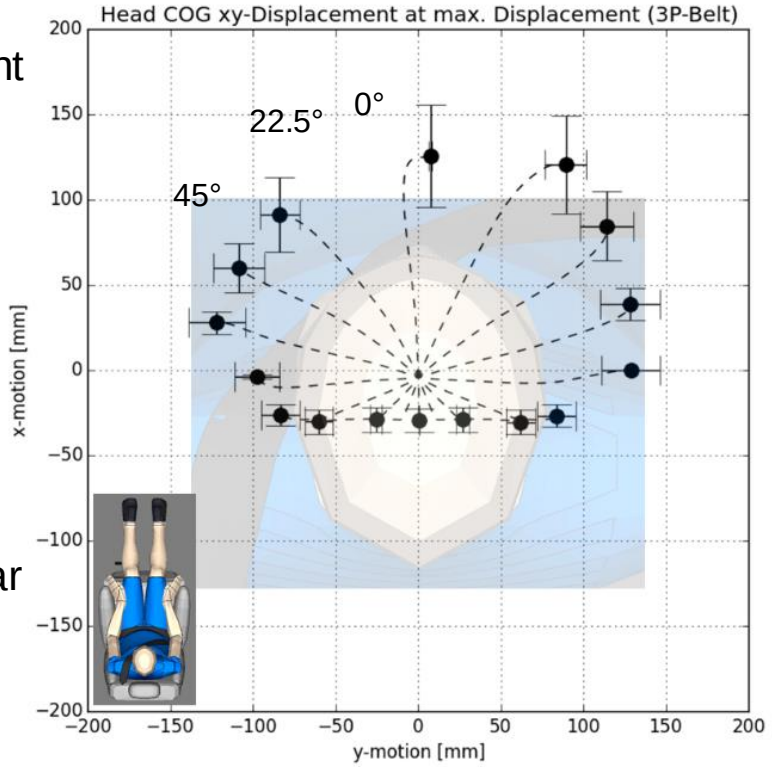
The head kinematic exploration responses are plotted (top view).



Head COG Kinematics at max. Excursion (x/y)

front

rear



Can we use this exploratory analysis to predict ALL the head motions ?

Head Kinematics Validation (1/4)

The head kinematic responses are then used to train a Machine Learning (ML) routine to predict ALL the head kinematics.

Two steps are undertaken:

Validation Cases 1-6

- Seat back angle values as per DOE (look and see)
- Variation of Acceleration Angle (1 variable only)

Case	Seat Back Angle	Accel. Angle
1	20	10
2	28	280
3	36	50
4	45	280
5	52	100
6	60	190

Validation Cases 7-12

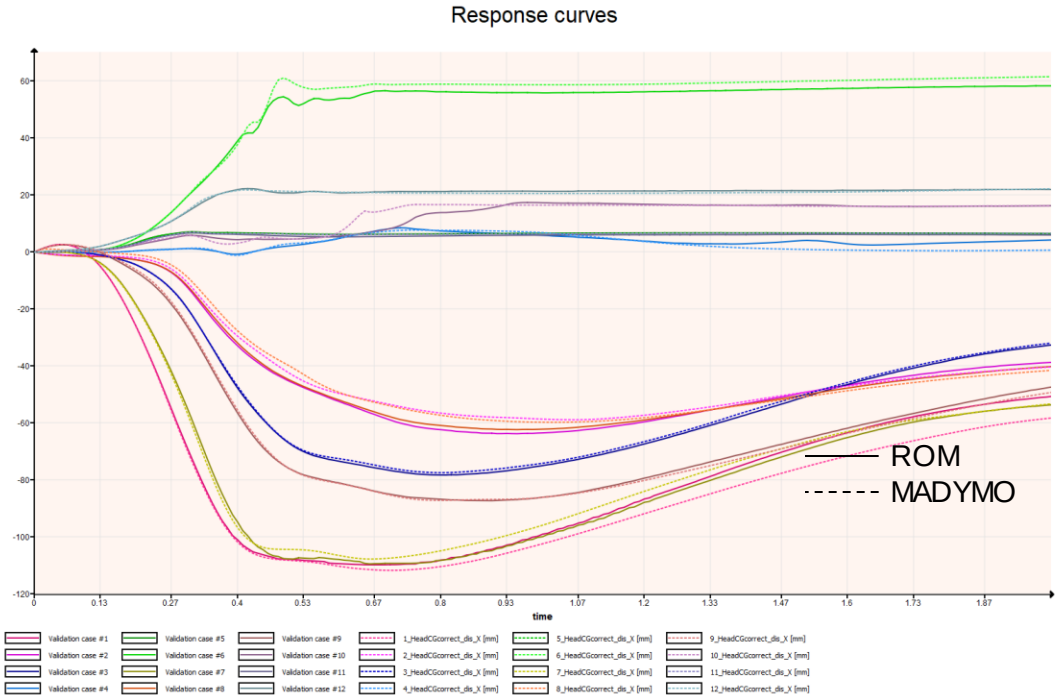
- Variation of Acceleration Angle
- **AND** Variation of Seat Back Angle (2 variables)

Case	Seat Back Angle	Accel. Angle
7	25	10
8	30	280
9	40	50
10	50	280
11	50	100
12	55	190

Head Kinematics Validation (2/4)

A ML "**Reduced Order Model" (ROM)**, based on the Proper Orthogonal Decomposition (POD) method was created from the training data.

The ROM model was compared to scenarios NOT in the training data.



Head X Motion over Time

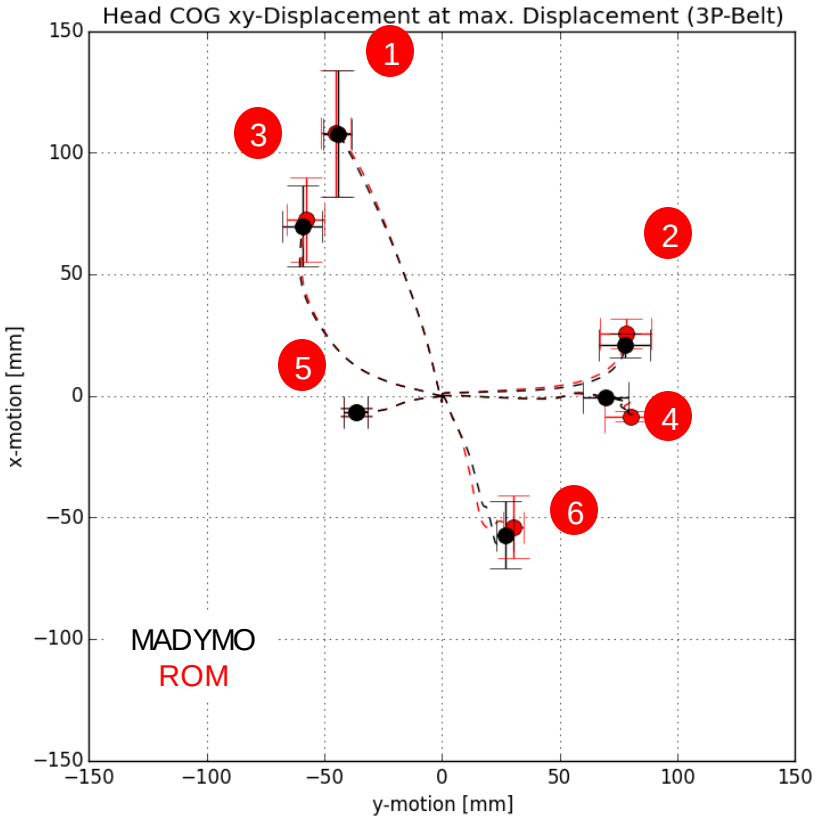
- Visual comparison of the ROM results to those obtained by Madymo simulation → visually close match
- Computation time ROM:
  - Kinematics: < 1s vs 2h
  - 3D Animation: < 1min

Head Kinematics Validation (3/4)

ROM Validation Results for Validation Cases 1-6, Variation of Acceleration Angle (1 variable) using CORA (quality check method).

Run	Seat Back Angle	Accel. Angle	CORA	ISO/TR 9790
1	20	10	0.99	excellent
2	28	280	0.98	excellent
3	36	50	0.97	excellent
4	45	280	0.91	excellent
5	52	100	1.00	excellent
6	60	190	0.93	excellent

Total obtained CORA score: 0.96 (excellent)

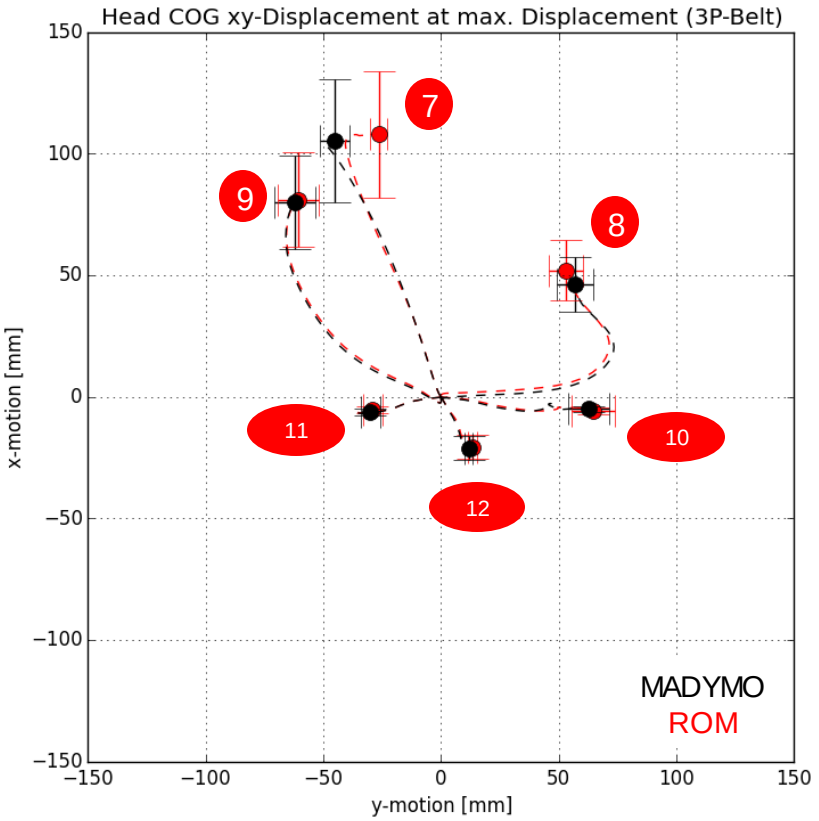


Head Kinematics Validation (4/4)

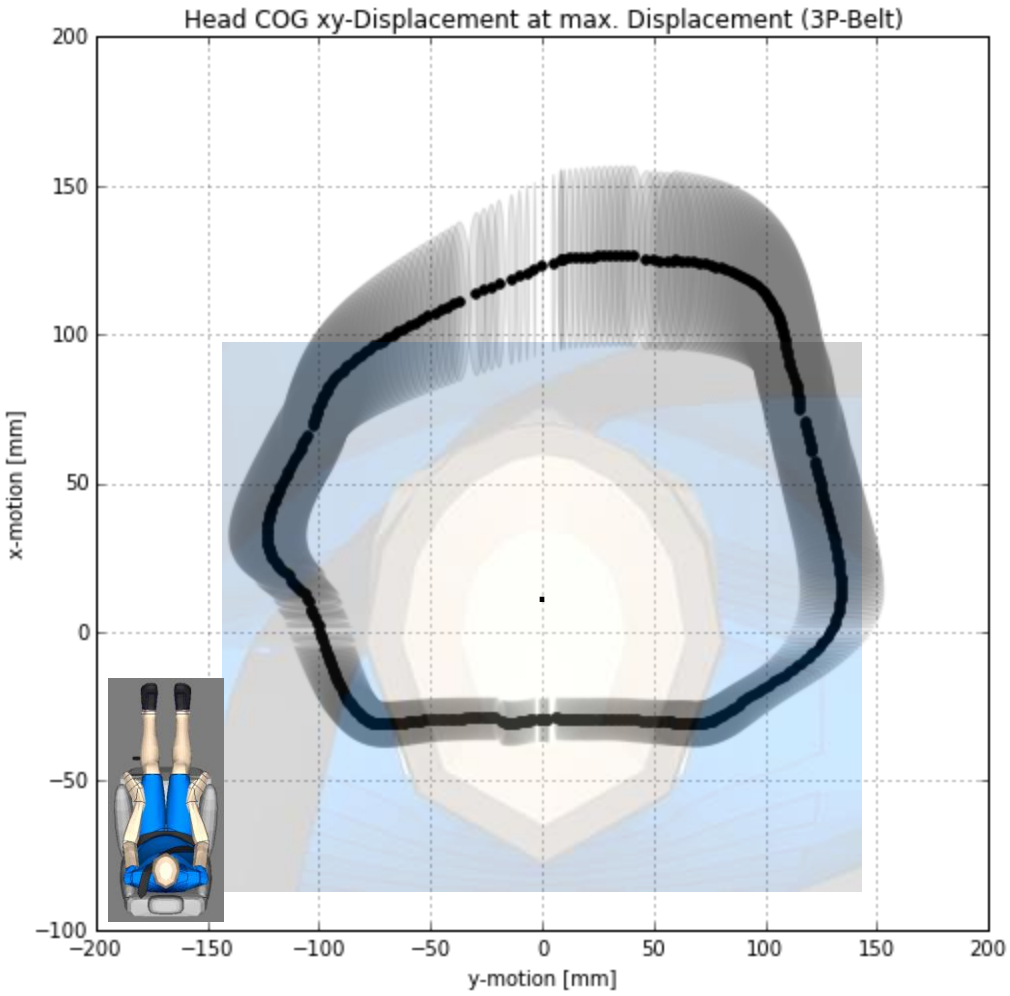
ROM Validation Results for Validation Cases 7-12, Variation of Acceleration Angle and Seat Back Angle (2 variables) using CORA.

Run	Seat Back Angle	Accel Angle	CORA	ISO/TR 9790
7	25	10	0.68	good
8	30	280	0.98	excellent
9	40	50	1.00	excellent
10	50	280	0.95	excellent
11	50	100	0.97	excellent
12	55	190	0.95	excellent

Total obtained CORA score: 0.91 (excellent)



Extraction of Head Envelope



Head Kinematics Envelope (max. over time)

- Occupants do not contact any cabin pillar trims.
- No head contact between occupants.
- Occupants' head is far from the range of a deploying airbag

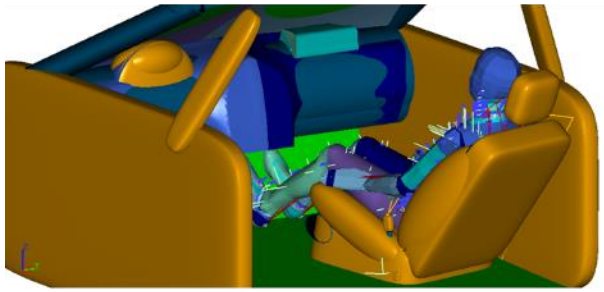
Risks of concussion in rotated seating reduced

What if a Collision was to Occur?

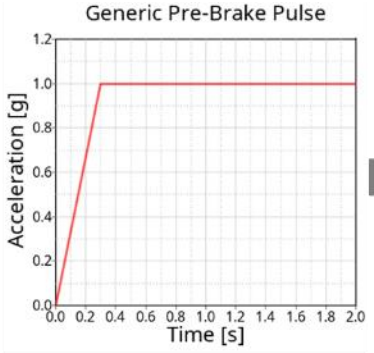
Honda Accord | 2012 | Frontal Crash Test | NHTSA High Speed Camera | CrashNet1

- **Video:** www.youtube.com/watch?v=kc63Zp_0Uz0

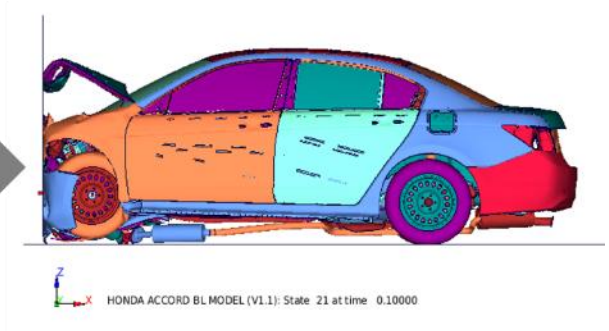
Breaking Followed by Collision



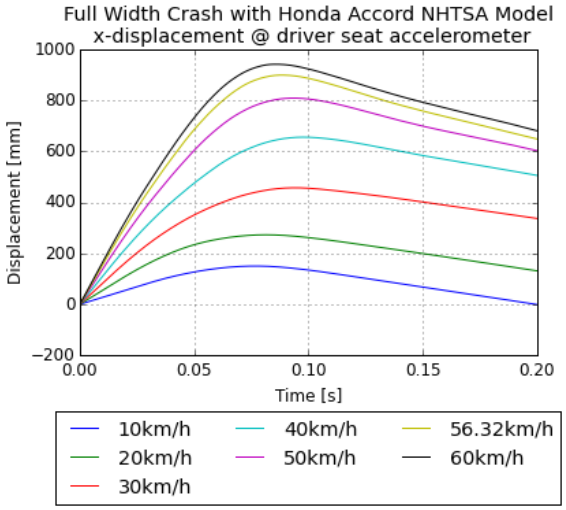
Occupant Extreme OoP in CAV
Due to rotated seating arrangements

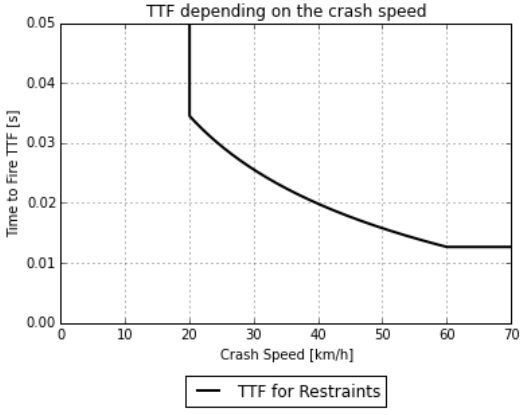


Extreme Braking



Followed by Crash

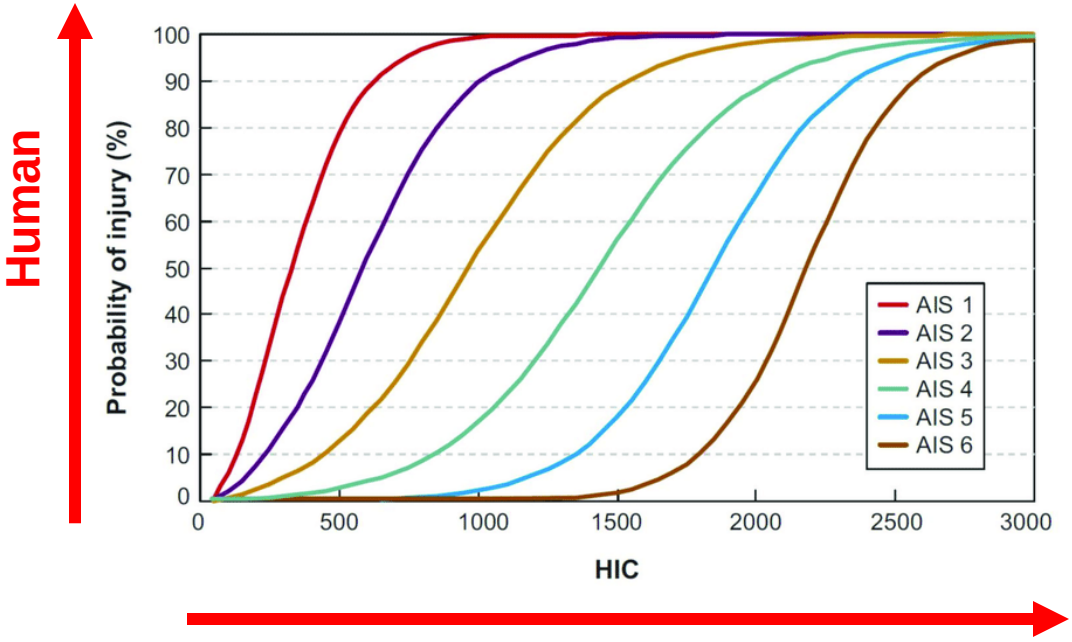




- Adjustments for crash speed (pulse, pre-tensioner firing etc…)
- Training data is generated
- A ML model is created to investigate full Design domain

How are Injuries Calculated?

- The **Injury Severity Code** – *Abbreviated Injury Scale (AIS)* describes the type of injury location and severity at the A&E department.



- 1 Minor (superficial laceration)
- 2 Moderate (fractured sternum)
- 3 Serious (open fracture of humerus)
- 4 Severe (perforated trachea)
- 5 Critical (ruptured liver & tissue loss)
- 6 Maximum (total severance of aorta)

- **The human model used in this study computes "injury criteria".**
- **"Injury criteria" relate to the PROBABILITY of an INJURY and NOT organ TRAUMA.**

Injuries Recorded

Body Region	Criteria	Equation	IARV
Head	HIC15	$HIC = max\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\ dt\right]^{-2.5}(t_2 - t_1)$	< 500
	BrIC	$BrIC = \sqrt{\left(\frac{\omega_x}{\omega_{xC}}\right)^2 + \left(\frac{\omega_y}{\omega_{yC}}\right)^2 + \left(\frac{\omega_z}{\omega_{zC}}\right)^2}$	< 0.89
Neck	Nij	$Nij = \frac{F_z}{F_{zc}} + \frac{M_{ocy}}{M_{yc}}$	< 1
Thorax	Deflection	Direct ATD Measurement	60mm
	Acceleration	Direct ATD Measurement	60g
	Combined Thoracic Index (CTI)	$CTI = \frac{A_{max}}{A_{int}} + \frac{D_{max}}{D_{int}}$	$A_{max} < A_{int}$ $D_{max} < D_{int}$
Lower Extremities	Knee-Thigh-Hip (KTH)	Direct ATD Measurement	10kN

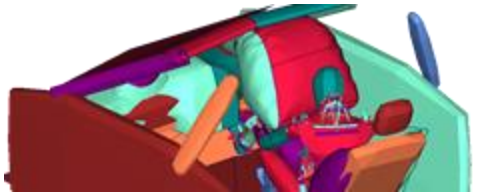
AIS 3+ Injury Probability

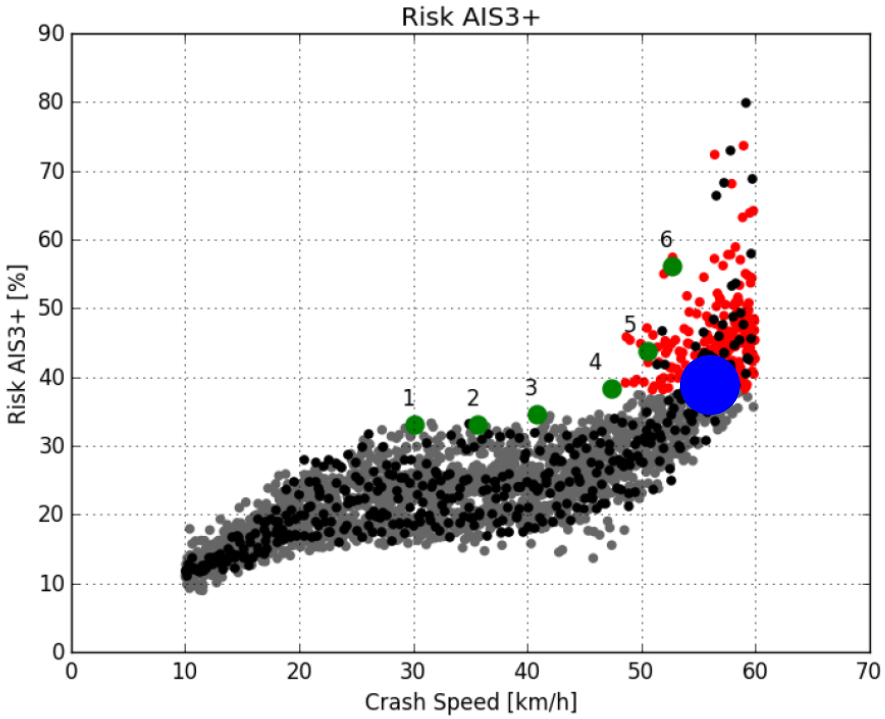
Body Region	Criteria	AIS 3+ Risk Function
Head	HIC15	$p_{HIC15}(AIS3+) = \Phi\left(\frac{ln(HIC15) - 7.45231}{0.73998}\right)$
	BrIC	$p_{BrIC}(AIS3+) = 1 - e^{\left(\frac{BrIC}{0.987}\right)^{2.84}}$
Neck	Nij	$p_{Neck}(AIS3+) = \frac{1}{1 + e^{3.227 - 1.969 \cdot Nij}}$
Thorax	Deflection	$p_{Chest-Deflection}(AIS3+) = \frac{1}{1 + e^{3.7424 - 0.0475 \cdot D_{max}}}$
	Acceleration	$p_{Chest-Acceleration}(AIS3+) = \frac{1}{1 + e^{3.1493 - 0.0630 \cdot A_{max}}}$
	Combined Thoracic Index (CTI)	$p_{Chest-CTI}(AIS3+) = \frac{1}{1 + e^{8.224 - 7.125 \cdot CTI}}$
Lower Extremities	Knee-Thigh-Hip (KTH)	$p_{KTH}(AIS3+) = \frac{1}{1 + e^{4.9795 - 0.326 \cdot F}}$

$$p_{joint}(AIS3+) = 1 - \left(1 - p_{Head}(AIS3+) \times \left(1 - p_{Neck}(AIS3+) \times \left(1 - p_{Chest}(AIS3+) \times \left(1 - p_{KTH}(AIS3+)\right)\right)\right)\right)$$

Rotated Seating Injury Predictions

- same ML method, but coupling pre-braking and crash
- Injury Risks for AIS2+ and AIS3+ can be predicted in before they happen..
- Predictions are within 10% of the Madymo crash model.





- Blue dot is the USNCAP Full Width crash test AIS3+ risk (reference)
- Black dots are from the initial DOE
- Grey dots are just below the reference, from the ML model
- Red dots are just higher that the reference, from the ML model
- The green dots are the highest point in the respective crash speed range, not necessarily higher than the blue reference., having “the same risk as” Blue dot.

Conclusions

- Active Human Computer models are necessary to assess occupant safety in rotated seating arrangements
- The research validated human kinematics.
- **Based on computer simulations, rotated seated configurations are of concern for comfort and safety, due to excessive kinematics and extreme Out-of-Position (OoP) with airbag deployment.**
- **Machine learning can be used to compute human kinematic envelopes** at the beginning of the vehicle cabin design to present any injuries caused in the CAV emergency pre-braking phase.
- **Machine learning can extract the dangerous seating positions**, before the start of the journey, in case of CAV pre-braking followed by a collision.

Thank you !

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