Comparison of Submarining Behavior of THUMS Versions 4.02 and 5.02 in Seating Positions for Automated Driving Regarding Pelvic Kinematics and Anatomical Differences

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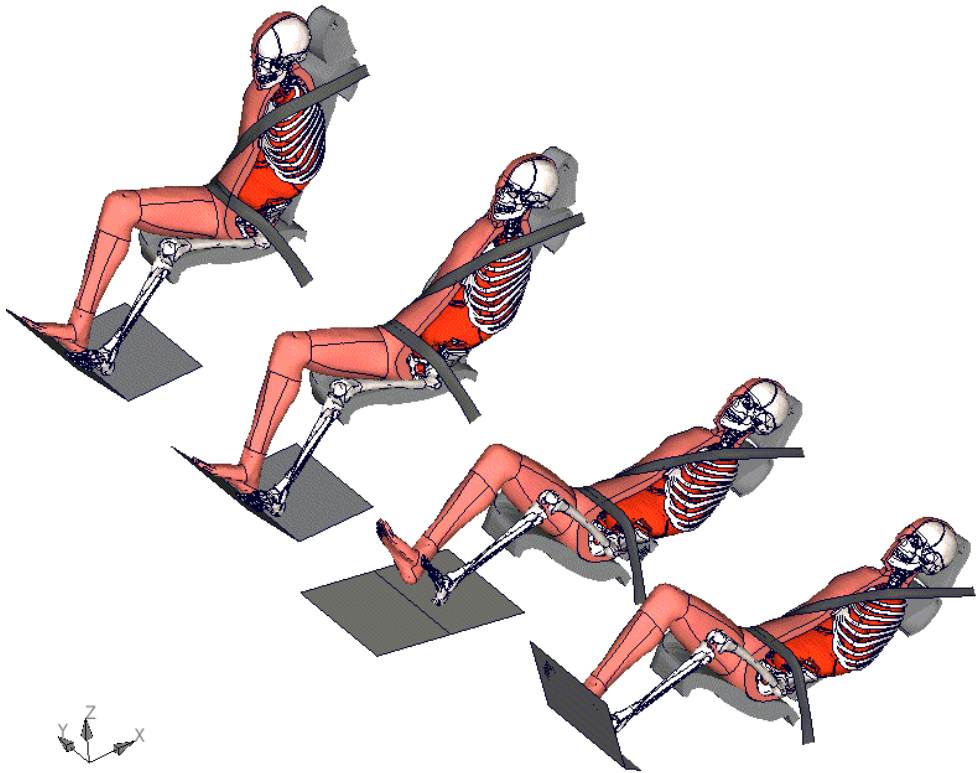
List of Contents

Seating Concepts and Restraint Systems

- Adjustments of 3 Point belting in comfort positions
- Alternative restraint systems for automated driving concepts
- A new era in restraint system development “Human Body Models“

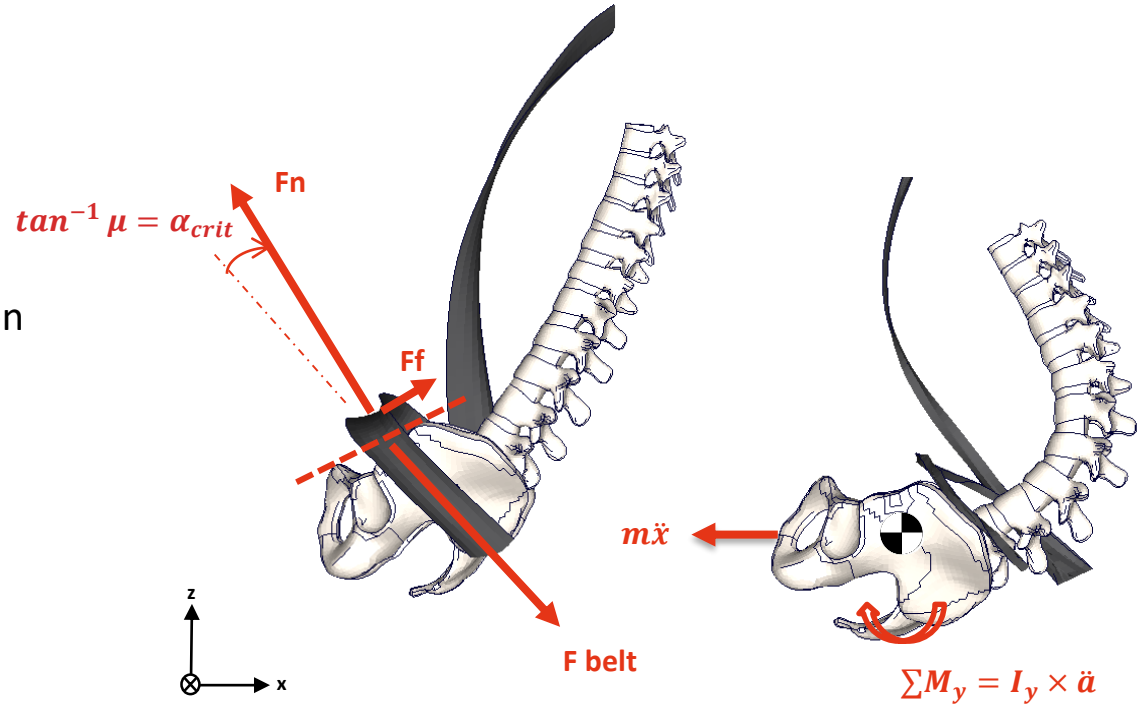


carhs. Empowering Engineers

Submarining in Details

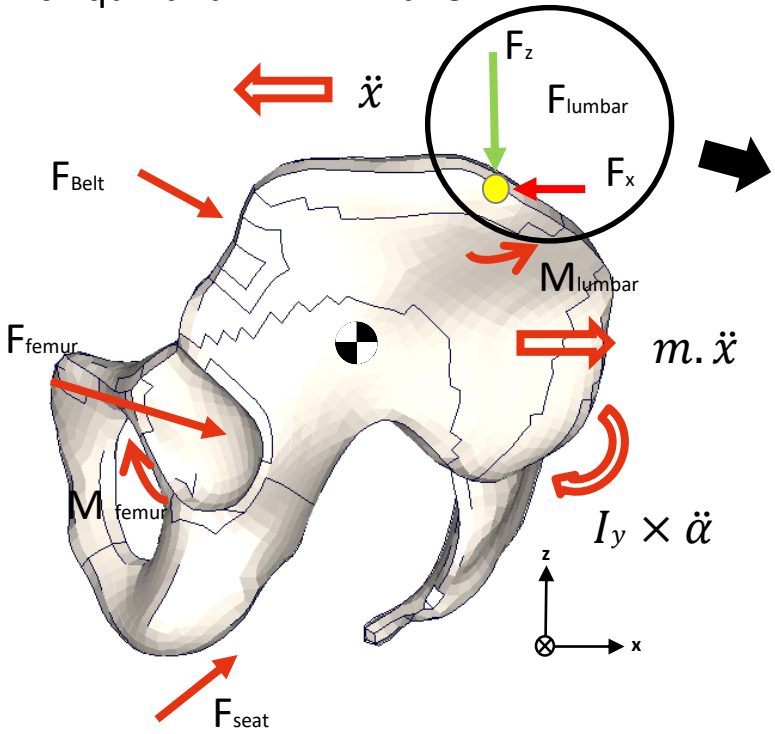
Aspects of Submarining

- Belt pelvis interaction (Hooking) (Horsch,1989)
- Relative angle and friction analogy (Nilson,1995)
- Pelvic restraint
- Pelvic rotation

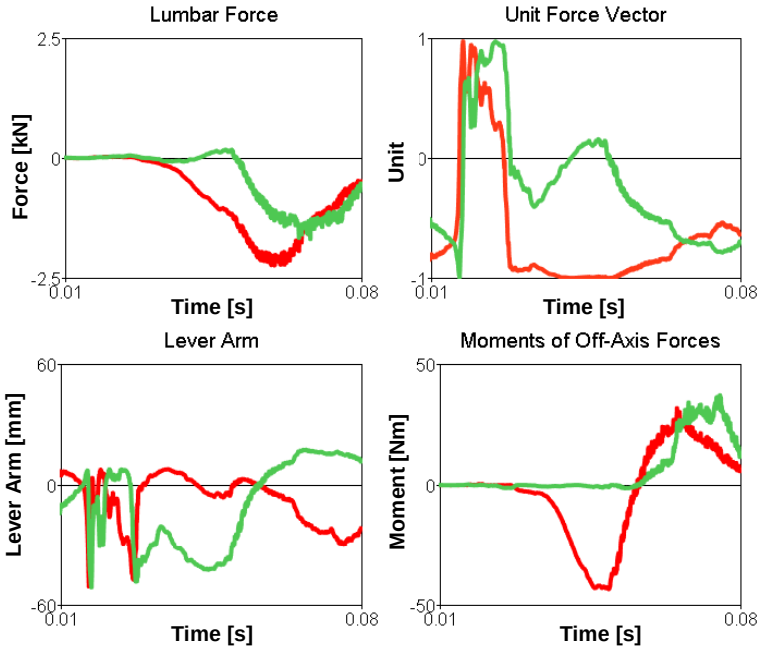


Development and Integration of Pelvic Equilibrium

Pelvic Equilibrium in XZ-Plane

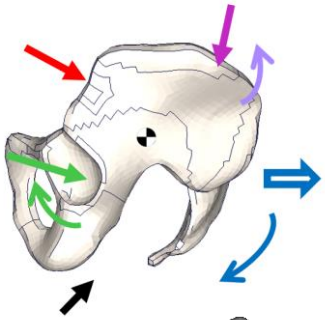


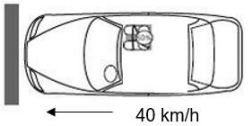
Moment Calculations in Y-Axis

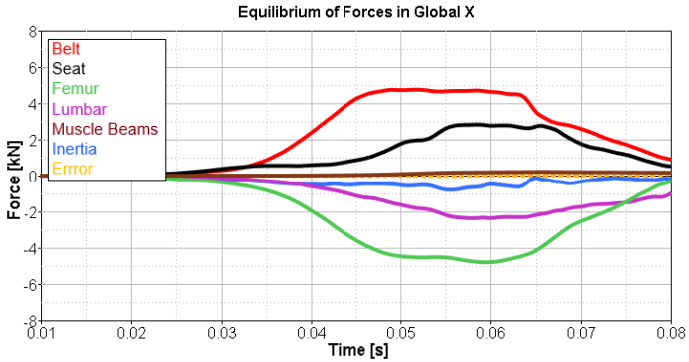


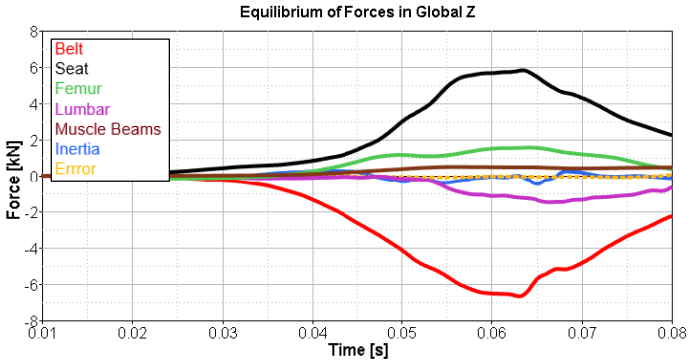
Development and Integration of Pelvic Equilibrium

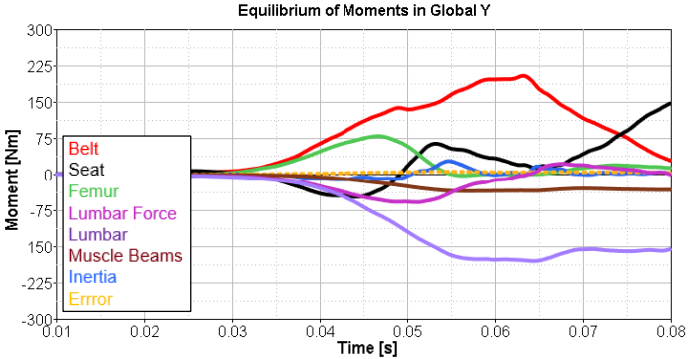
Evaluation of Pelvic Equilibrium in XZ-Plane

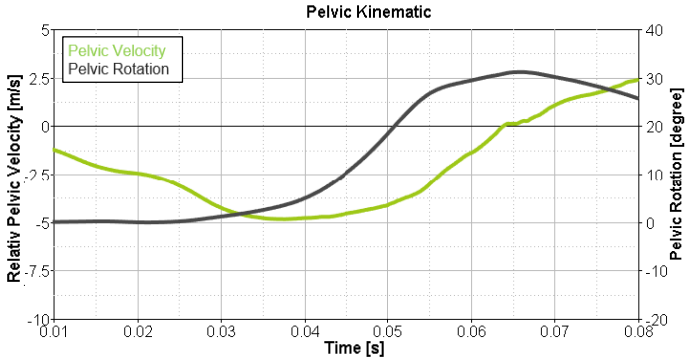












THUMS V4 vs THUMS V5 – Overview

Anthropomorphic Overview

THUMS V4

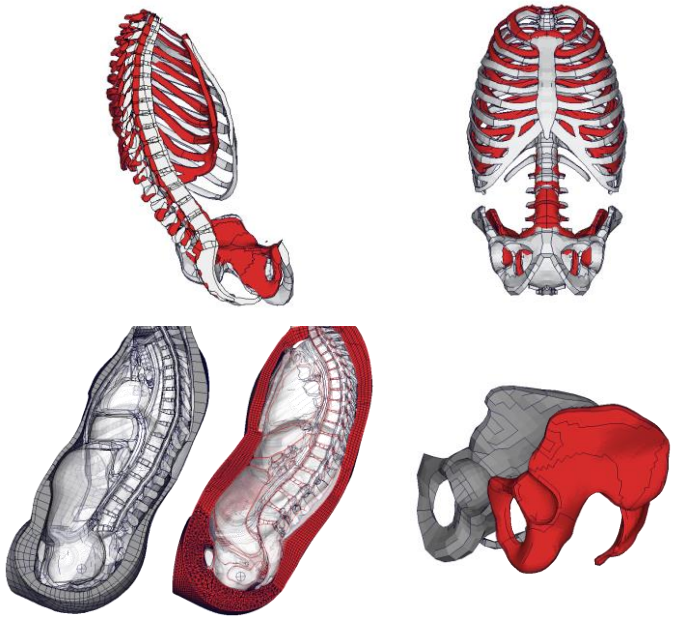
- **Ap.175 cm, 77.5 kg, BMI: 25.3**
- Ap. **2.000.000 elements**, detailed organs modelling

THUMS V5

- **Ap. 175 cm, 74 kg, BMI: 24.2**
- Ap. **280.000 elements** and active muscle elements

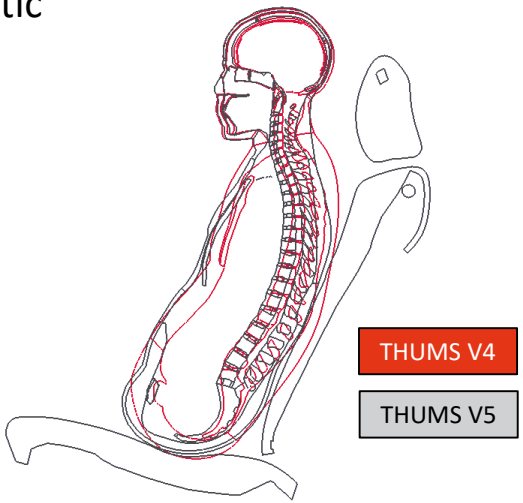
(Toyota Motor Corporation, 2015)

Anatomical Differences



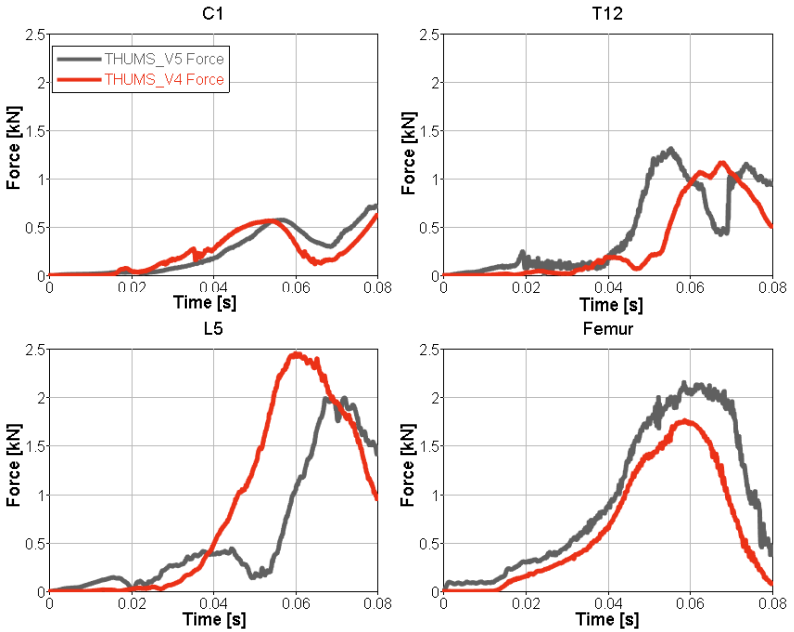
THUMS V4 vs THUMS V5 – Kinematic and Loading

Kinematic



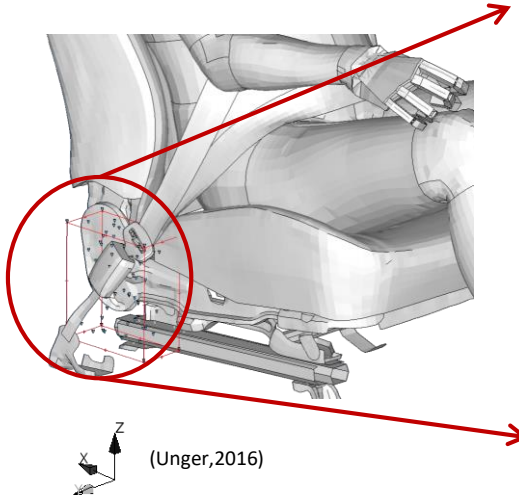
- Despite similar kinematic, models yield various loading response. In this given case, loading variations are mostly because of the geometrical deviations and different modelling strategies.

Loading

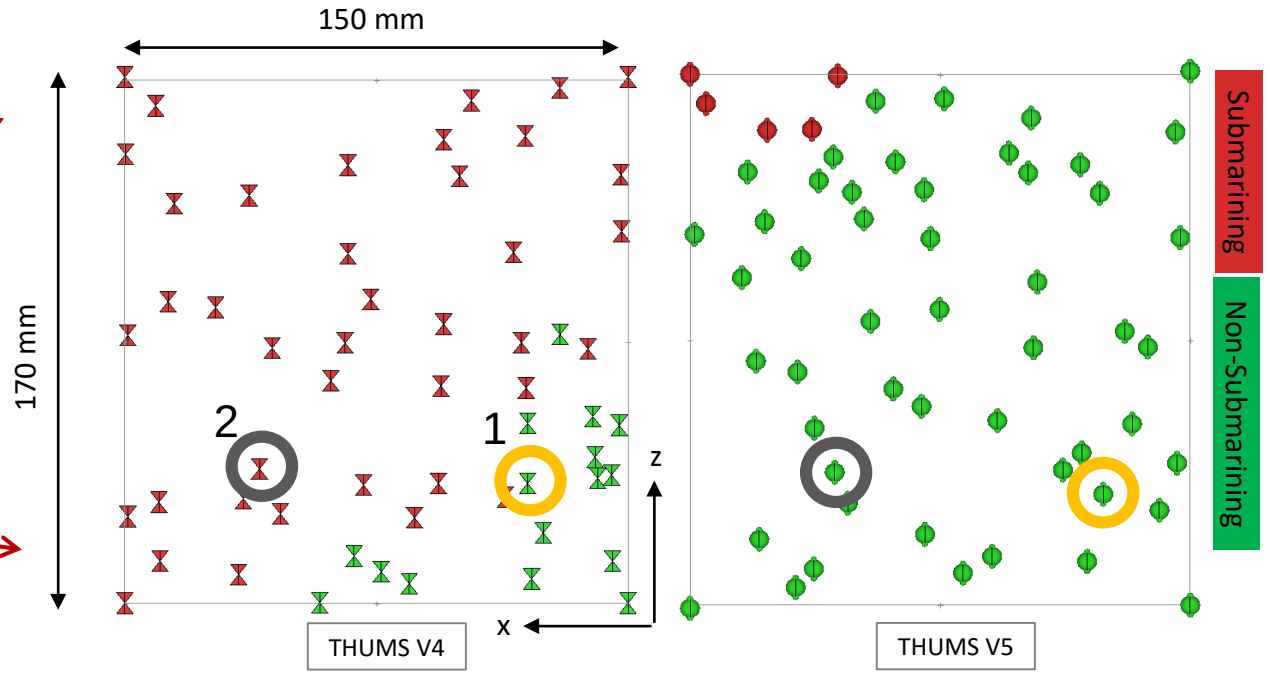


THUMS V4 vs THUMS V5 – Submarining

DOE over Buckle Position



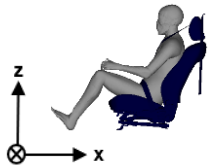
DOE Results



THUMS V4 vs THUMS V5 – Pelvic Equilibrium

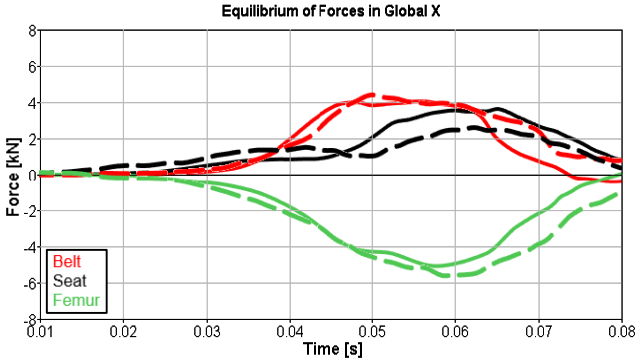
Both Non-Submarining

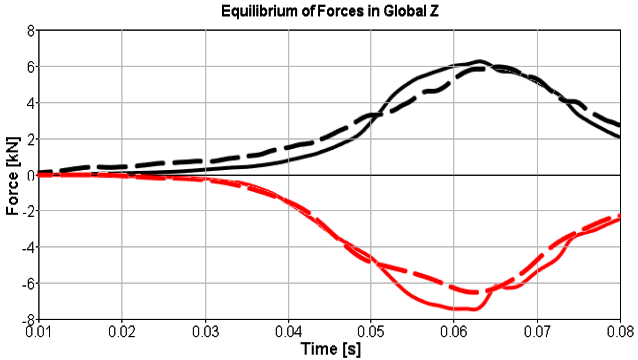
- Although results show comparable force response, pelvic moment distribution yields fundamental differences because of the muscle beam elements in THUMS v5.
- Higher pelvic rotation is observed in THUMS v5.

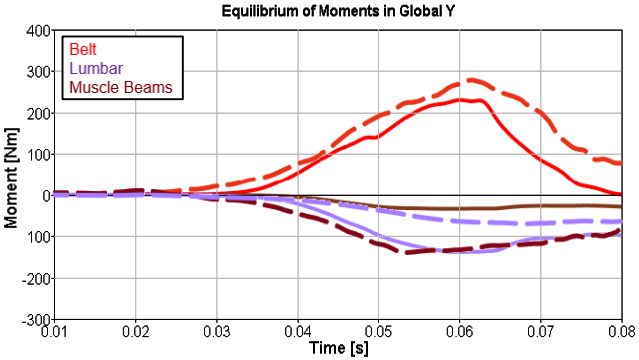


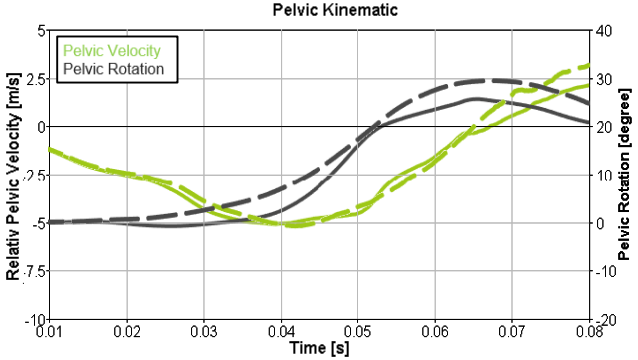
THUMS V4

THUMS V5





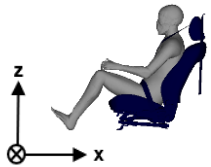




THUMS V4 vs THUMS V5 – Pelvic Equilibrium

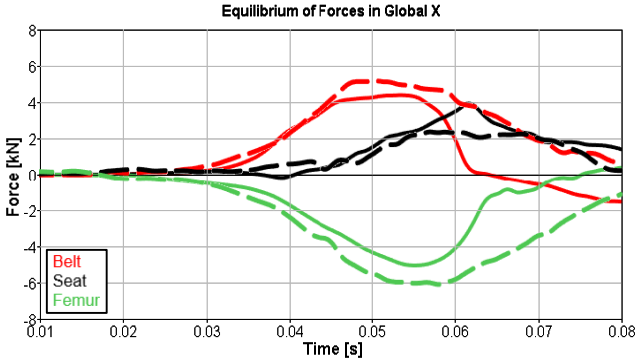
THUMS V4 Submarining, THUMS V5 no Submarining

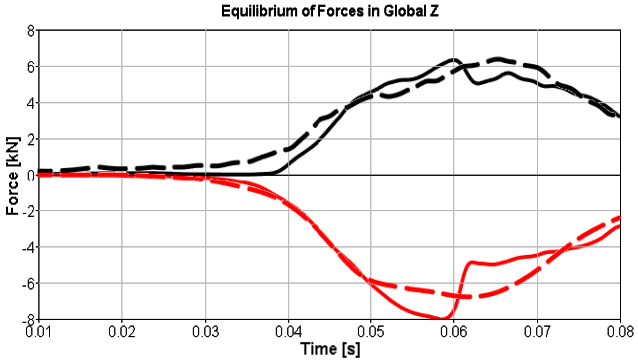
- Results show comparable force response until 50ms. Later a constant force drop is observed in THUMS v4.
- Force and pelvic velocity discontinuities at 55ms indicate submarining for THUMS v4.

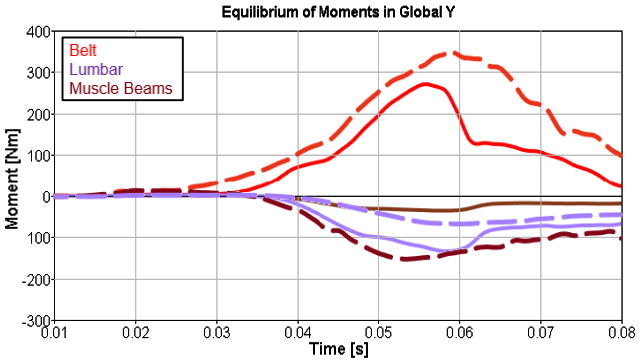


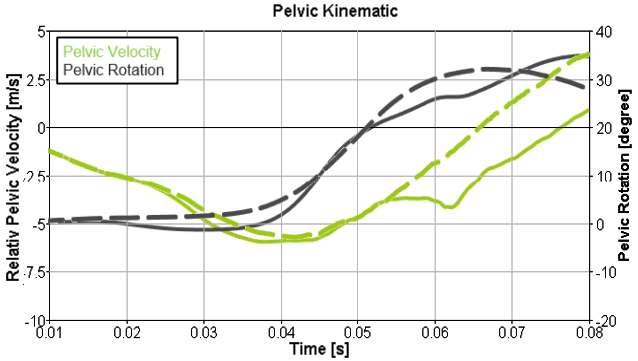
THUMS V4

THUMS V5





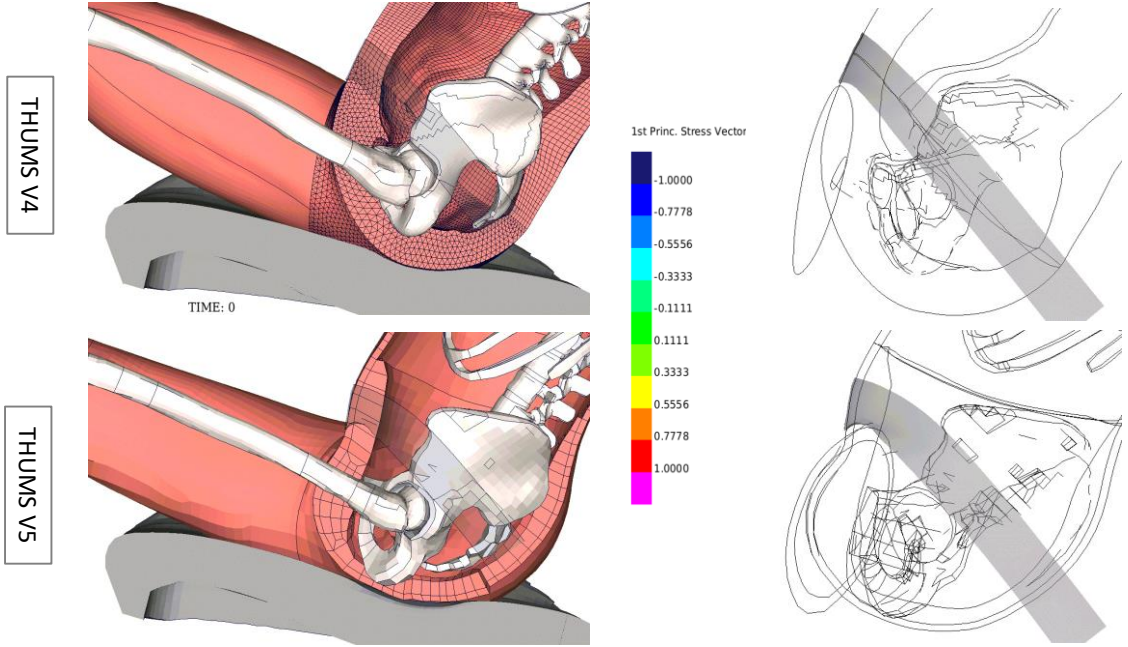




THUMS V4 vs THUMS V5 – Anatomy

Evaluation of Anatomical Differences

- In THUMS v4 lap belt is transferred into the abdomen by a viscoelastic deformation of the muscle/fat layer. A relative sliding between lap belt and skin is not observed
- In THUMS v5 unique form of the iliac crest leads an increased lap belt ilium hooking. Additionally ribcage ilium interaction obscures tangential lap belt sliding.



Comparison of 1st Principle Stress [+/-1MPa]

Restraint Systems in Various Seating Positions

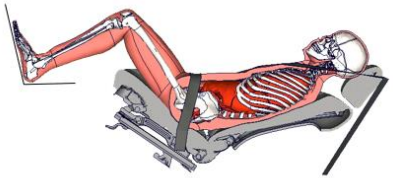
Further Investigation of Seating Concepts and Restraint Systems

- To investigate different seating concepts and understand the response of THUMS versions in various restraint systems, using THUMS v4 and THUMS v5, different load cases are studied.
- Load cases are selected based on the combinations of given seating concepts, pelvis/lap belt angle and restraint system variations.

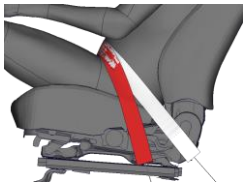
Upright Seating (Basis)

Backrest -20 ° (Comfort)

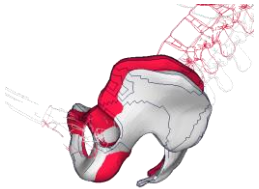
Seatpan -30 ° (Sleeping)



Lap belt angle +/- 25°



Pelvic angle +/- 15°



- Basis restraint system:
  - 6.0 kN Retractor load limiter
  - 2.5 kN Retractor pretensioner
  - Adjusted Yaris seat [10]
  - 11m/s front crash case [10]
- Buckle and anchor pretensioners (2.5 kN)
- Reduced seat stiffness (-15%)
- Reduced load limiter (-40%)

Restraint Systems in Various Seating Positions

Submarining Results of the Investigation and Remarks

			THUMS V4.02					THUMS V5.02			
		Pelvis Angle	Basis	Seat Pan Stiffnes - 15%	load limiter -40%	Anchor & Buckle PTS 2.5 kN		Basis	Seat Pan Stiffnes - 15%	load limiter -40%	Anchor & Buckle PTS 2.5 kN
Upright Sitting	Convetional lap belt angle	20°									
		35°									
	Belt angle +25°	20°									
Comfort Positions	Convetional lap belt angle	Comfort									
		Sleeping					**Without footrest**				
							With footrest				

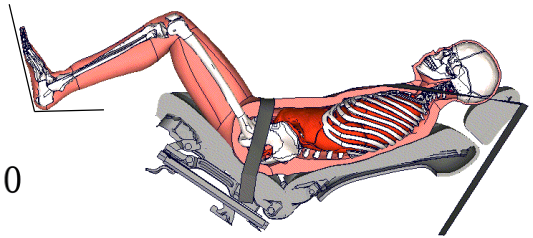
No Submarining
Submarining in one side
Submarining in both sides
Not applicable

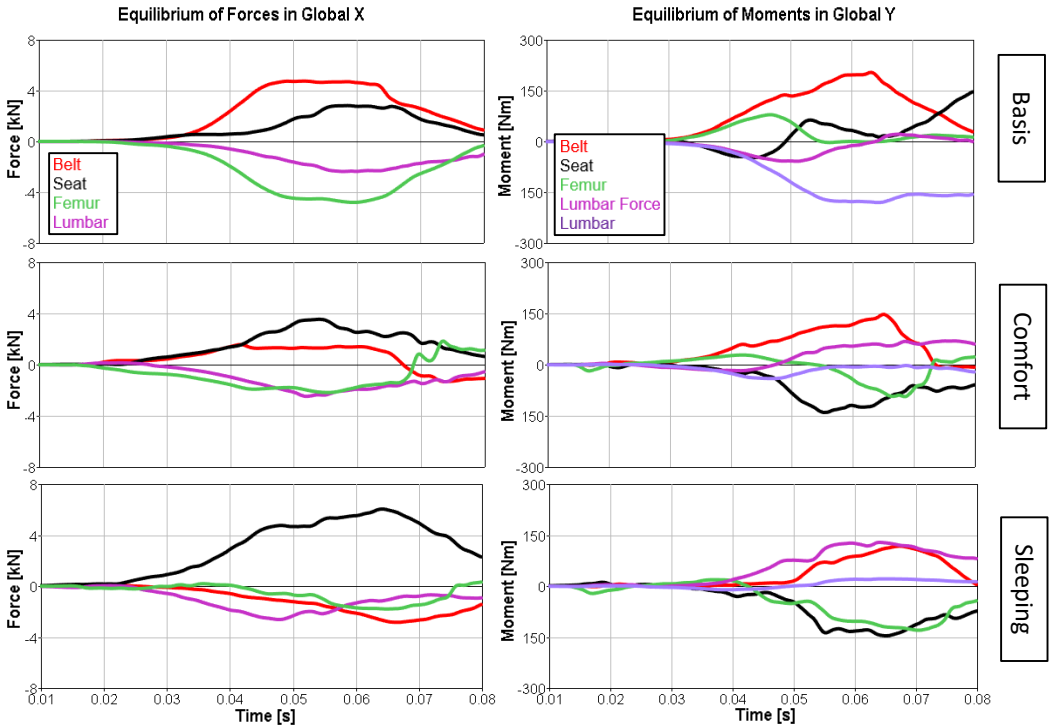
- Simulation results show diverse submarining response in upright and slouched sitting positions.
- Considering biomechanical consequences, enhanced comfort positions (so called sleeping positions) are not evaluated for submarining.

Evaluation of the Results Regarding Pelvic Equilibrium

Comparison of Seating Concepts Represented with THUMS V4

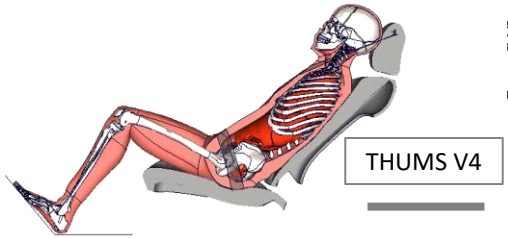
- Given pelvic equilibriums show how the loading response fundamentally changes based on the seating concepts.
- Results highlight the necessity of alternative restraint systems in sleeping positions.

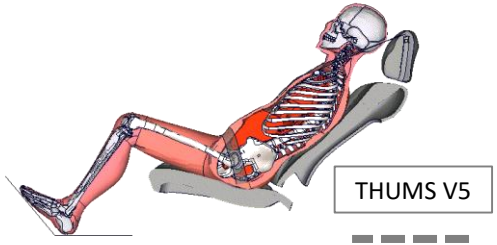




Evaluation of the Results Regarding Pelvic Equilibrium

Backrest -20 ° V4 vs. V5





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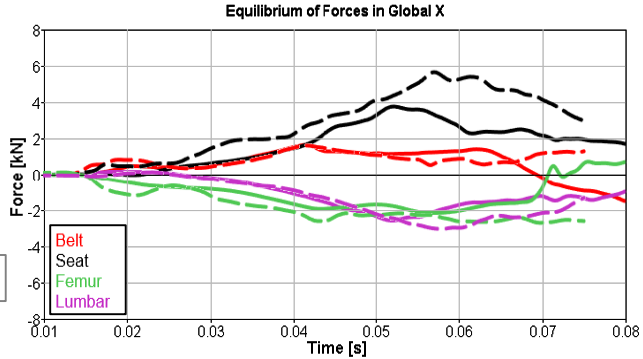
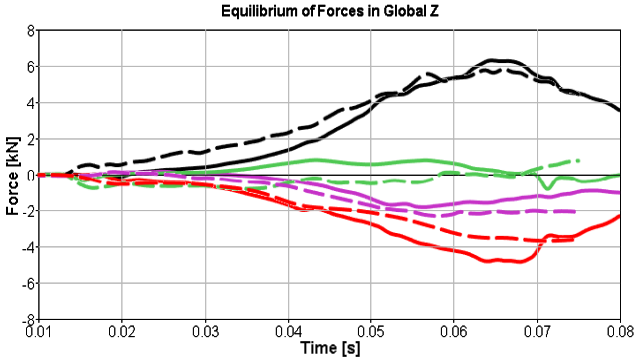
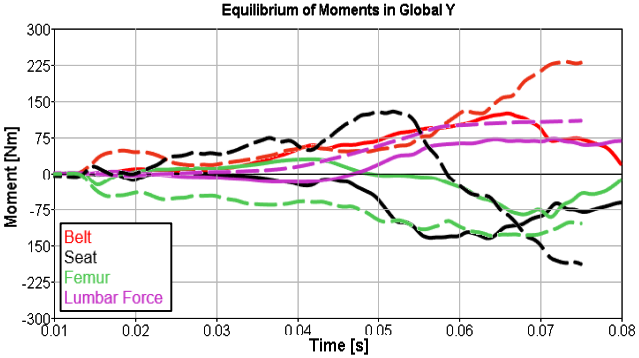
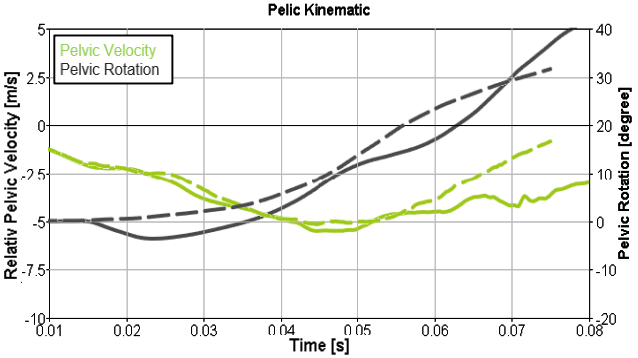


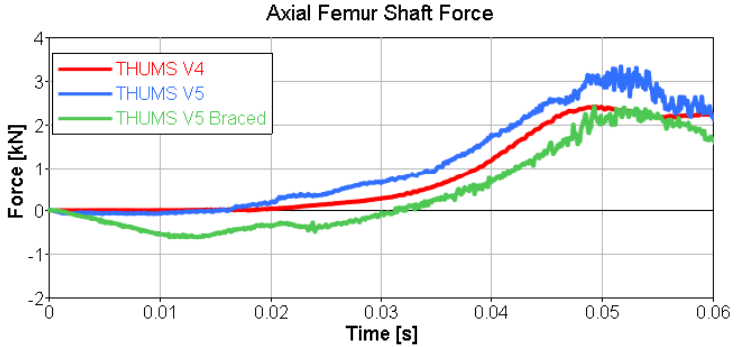




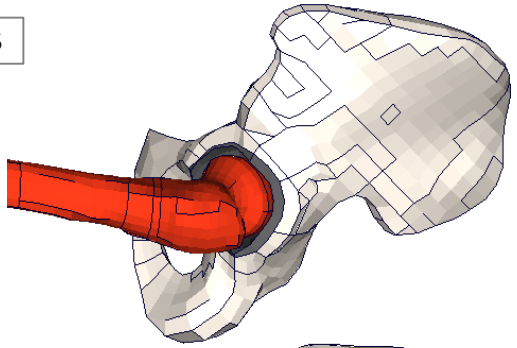


Remark Over Femur Pelvis Interaction

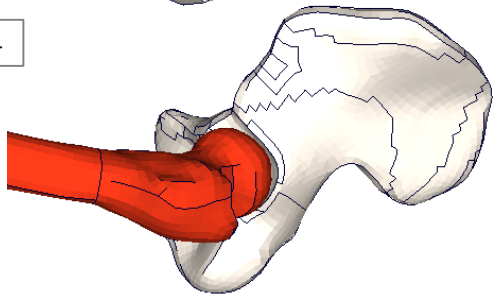
Acetabulum / Labrum Modelling and Effects of Muscles



THUMS V5



THUMS V4



Conclusion

- THUMS v4.02 THUMS v5.02 show diverse submarining responses because of the anatomical variations in pelvis, abdominal flesh and ribcage shape. Also considering the deformation modes, which lead to submarining, detailed abdominal mesh is observed as an important factor.

- Pelvic equilibrium analysis enables a comprehensive evaluation of restraint systems regarding the submarining beyond binary assessments.

- Detailed analysis of pelvic equilibrium shows fundamental differences in various seating concepts, which indicates the necessity of unique restraint measures in comfort seating concepts. The knowledge of pelvic force and moments can help to better understand the anatomical variations regarding restraint system passenger interaction and guide the restraint system modifications.

- Diverse submarining results should not be considered as an inconsistency between THUMS v4.02 and THUMS v5.02, it rather demonstrates that there exists no standard 50 percentile human body model, therefore they can be considered as unique individual models.

Further investigations

- Investigating anatomical variations in a single human body model to eliminate variations from different modelling strategies
- Similar studies for 5 and 95 percentile occupants
- Human body models with more individual variety and active muscle capabilities.
- Effects of individual material properties

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Thanks for your attention