OSCCAR

FUTURE OCCUPANT SAFETY FOR CRASHES IN CARS

OSCCAR-Virtual Pre-Ircobi workshop - Sept. 8th, 2020

Progress in Virtual Testing for automotive applications

Werner Leitgeb, Christian Mayer, Johan Iraeus, Lennart Nölle, Jason Fice, Andre Eggers
www.osccarproject.eu

OSCCAR has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768947.

Agenda

Update on OSCCAR 14:45 - 15:30

Results and future work incl. Q&A

- **Short intro + status** (Werner Leitgeb)
- Biomechanical alignment/ injury evaluation
  (Christian Mayer, Johan Iraeus, Lennart Nölle, Jason Fice)
- Virtual testing (Andre Eggers)

OSCCAR Project

OSCCAR
FUTURE OCCUPANT SAFETY FOR CRASHES IN CARS

PROJECT PARTNERS

AUSTRIA

- TECHNISCHE UNIVERSITÄT GRAZ
- VIRTUAL VEHICLE RESEARCH GMBH

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- SIEMENS INDUSTRY SOFTWARE NV
- TOYOTA MOTOR EUROPE

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- CHINA AUTOMOTIVE TECHNOLOGY AND RESEARCH CENTER

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PROJECT FACTS

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WEBSITE: WWW.OSCCARPROJECT.EU

START: JUNE 2018 **DURATION:** 36 months

PARTICIPATING ORGANISATIONS: 21

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OSCCAR – Main Objectives

The EU Horizon 2020 research project **“OSCCAR - Future Occupant Safety for Crashes in Cars”** - develops a novel, simulation-based approach to safeguard occupants involved in future vehicle accidents

- Understanding future accident scenarios involving passenger cars
- Demonstration of **new advanced occupant protection** principles and concepts addressing future desired sitting positions made possible by HAVs
- Contribution to the development of **diverse**, **omnidirectional**, **biofidelic** and **robust HBMs**
- Establishment of an integrated, virtual assessment framework for complex scenarios as needed for the development of advanced protection systems for all occupants
- Contribution to the **standardization of virtual testing procedures** and promotion of HBMs acceptance in order to pave the way for virtual testing-based homologation

Occupant protection principles – HBM application

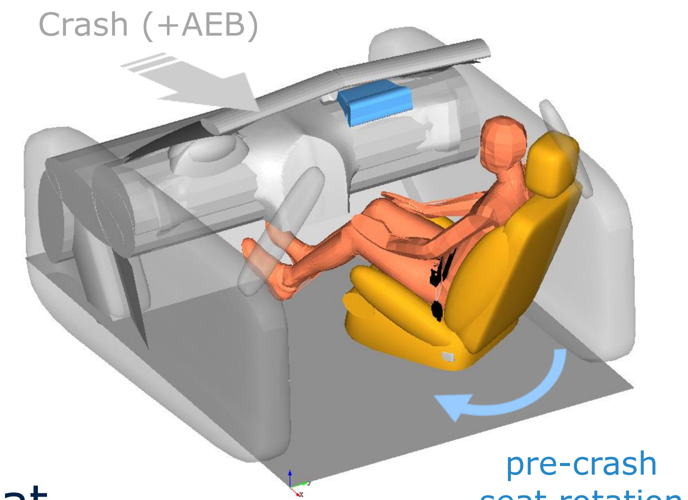
- Occupant protection principles:
  - Conception and investigation of advanced occupant protection principles for sitting positions and postures related to automated driving:
    - Restraints to be adapted towards new boundary conditions
    - Repositioning of the occupant into a conventional seating configuration prior to a crash
  - Considering aspects like occupant variety and omnidirectional occupant loading by use of HBMs
  - Virtual investigation of protection principles and hardware demonstration of selected cases

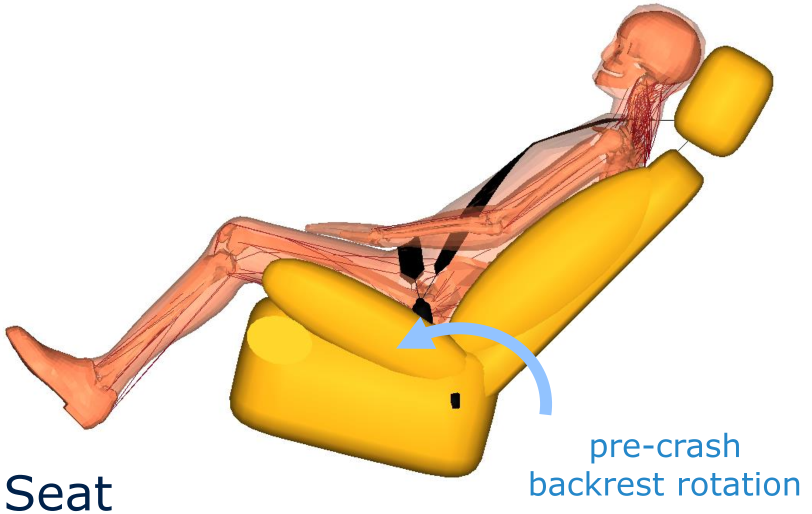
Protection Principles

#1	#2	#3	#4	#5	#6
Swivel Seat	Inertia Seat	Anti Submarining	Mushroom Airbag	Reclined Seat	Far Side

Occupant protection principles – HBM application

- Occupant protection principles - Repositioning of the occupant:





- <u>Swivel Seat</u>
  - Use Cases & Principle:
    - Occupant sitting slightly rotated, pointing away from the driving direction
    - The seat will be rotated around z-axis towards direction of crash during pre-crash phase
    - Active (defined rotation-time curve) and passive (inertia driven) rotations are considered

  Related publication: [Becker et al. IRCOBI 2020]

- <u>Reclined Seat</u>
  - Use Cases & Principle:
    - Occupant sitting in a relaxed seating position with a reclined backrest angle
    - Prior to the crash the backrest rotates to an upright angle to raise the occupant into a “normal” sitting posture

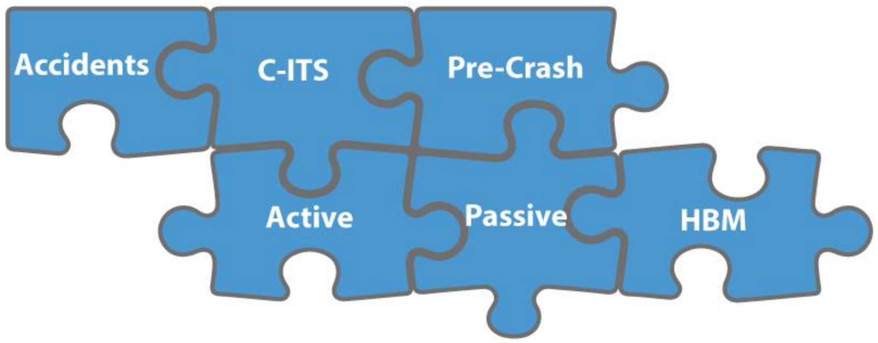
  Related publication: [Östh et al. IRCOBI 2020]

OSCCAR – Integrated and comparable assessment

Integrated, continuous and comparable assessment

- Common simulation "input" criteria that allow for comparing results
- Software tool for reproducible HBM seating procedure in development
- Comparable and common assessment using the OSCCAR enhanced open source software tool "DynaSaur"
- Enabling standardized solver output processing for different solvers used within OSCCAR

Fully Integrated Assessment Tool Chain



DYNASAUR https://gitlab.com/VSI-TUGraz/Dynasaur

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Virtual Testing requirements

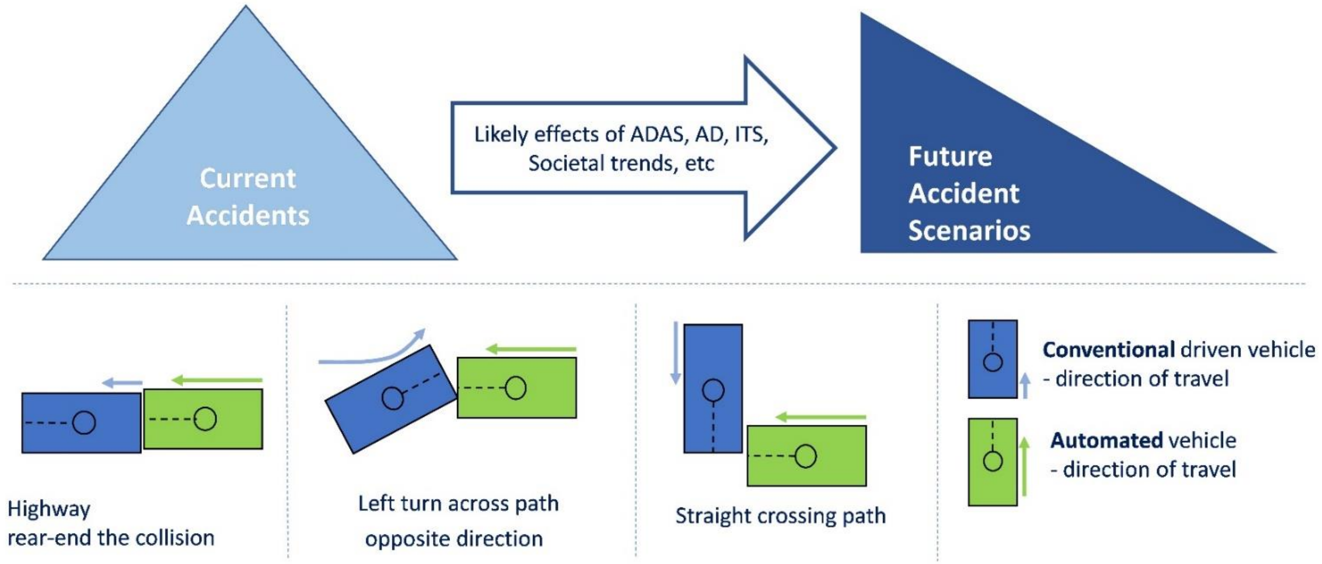
- Development of virtual testing and assessment procedures
- First proposal of a procedure for virtual environment validation published

  Eggers et al., Validation procedure for simulation models in a virtual testing and evaluation process of highly automated vehicles, VDI-Tagung Fahrzeugsicherheit 2019
- Harmonization efforts
- Homologation Test Case Demonstration

Harmonization of Virtual Testing

OSCCAR – Virtual Testing II

- Providing the bigger picture on complete story for virtual testing needs
  - Generic load-cases of future relevant accident scenarios
  - Methodology to estimate generic crash pulses for novel crash configurations, based on state-of-the-art FE vehicle crash models



OSCCAR – Virtual Testing III

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Harmonization of Virtual Testing

Harmonization of virtual testing
Virtual testing basic needs

Glossary and definition of relevant terms: “What is and what is needed for a valid model”

Verification:	Assessment of accuracy of computational model solving the mathematical problem.
Validation:	Assessment of the degree to which a computational model is an accurate representation of physics being modelled.
Calibration:	The process of modifying (parameters of) a model or tool to reach a performance target defined beforehand.
Certification:	The process of official approval that a model and its associated data are acceptable for a specific purpose. Purpose describes the use in an existing procedure, e.g. consumer rating or legislation with Virtual Testing.

developed in cooperation with Thumbs User Community TUC

OSCCAR – Virtual Testing IV

Homologation Test Case Demonstration

- OSCCAR demo case for an exemplary procedure for future virtual approval using HBMs
  - Extrapolation of hardware test based validity to new, “virtual only” Test Case
  - Focus on reclined, forward facing occupant position
- Demonstration of a method that delivers comparable results, the basis for credibility and acceptability
- Continuous virtual assessment of the pre- and in-crash phase

O_1

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Christian Mayer, Johan Iraeus, Lennart Nölle, Jason Fice

- Virtual testing (Andre Eggers)

Alignment of Rib Strain Injury Risk Assessment

Johan Iraeus (Chalmers University of Technology)

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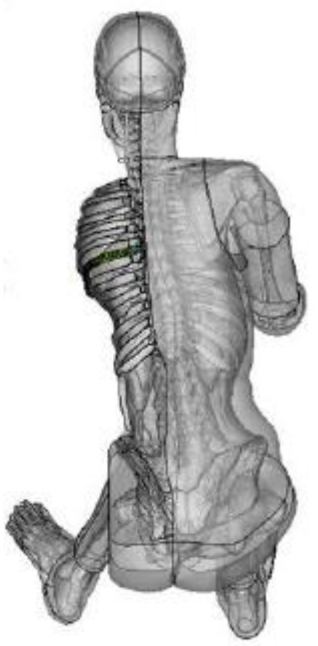
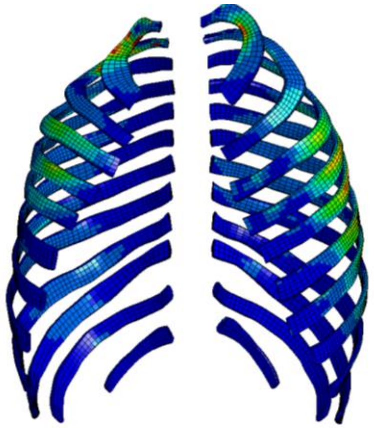
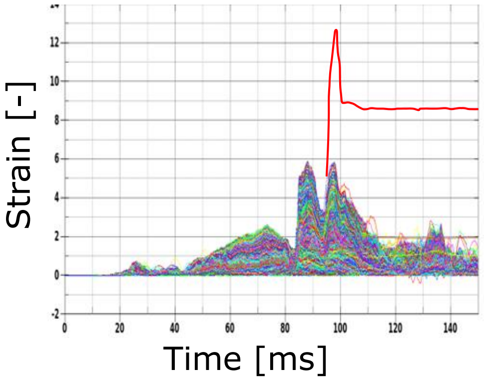
Alignment of Rib Strain Injury Risk Assessment

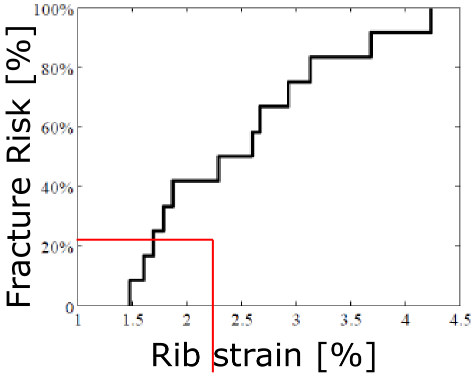
- Goal: Provide guidelines for robust strain based HBM rib injury risk assessment
- An overview of strain-based rib injury risk assessment

Use a robust HBM validated with respect to rib strain → Extract rib strains → Post process signals → Convert strain to fracture risk → Compute overall ribcage risk









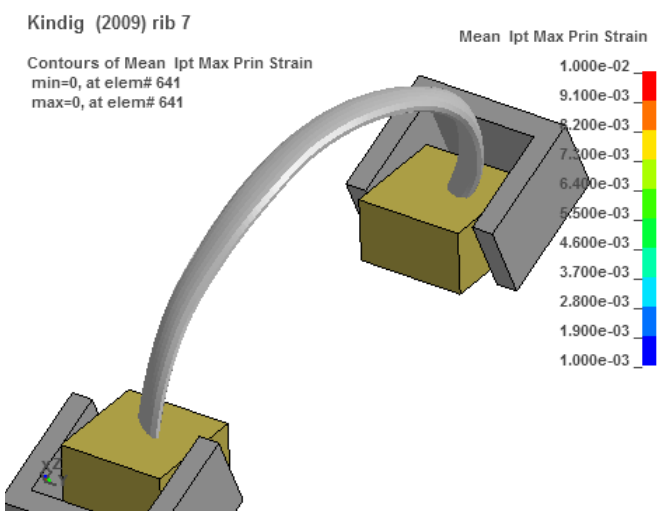
$$\Pr(X = k) = \sum_{A \in F_k} \prod_{i \in A} p_i \prod_{j \in A^c} (1 - p_j)$$

Forman, J. L., et al. (2012). Predicting rib fracture risk with whole-body finite element models: development and preliminary evaluation of a probabilistic analytical framework. the 56th annual AAAM Scientific Conference, Seattle, Washington, Association for the Advancement of Automotive Medicine.

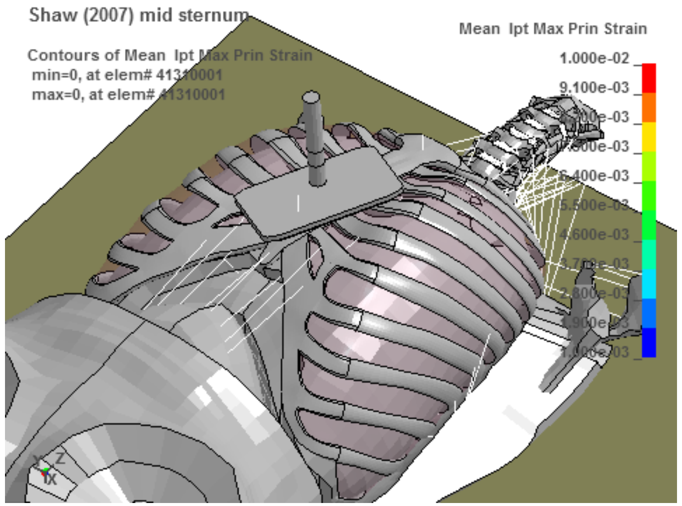
Alignment of Rib Strain Injury Risk Assessment

- Goal: Provide guidelines for robust strain based HBM rib injury risk assessment
- Method: Identified need for validation of HBMs on strain level + HBM modelling guidelines to reduce numerical noise (e.g. CPU dependency),

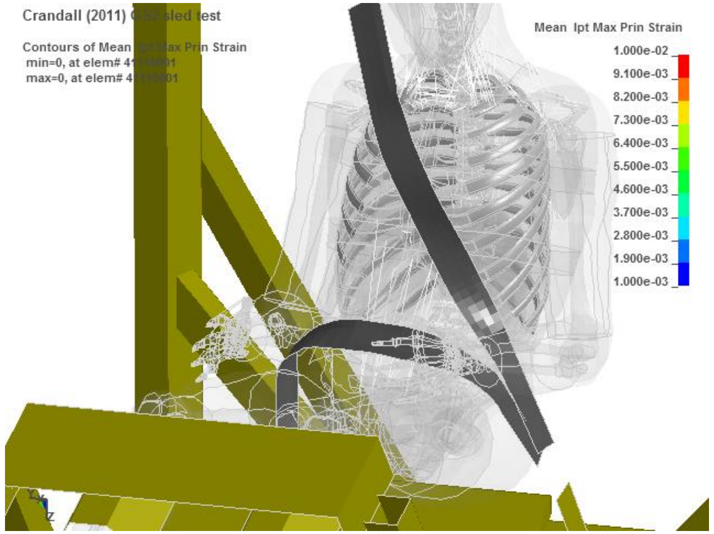
Single rib level (Kindig 2009)



Ribcage level (Shaw et al. 2007)



Full HBM level (Shaw et al. 2009)



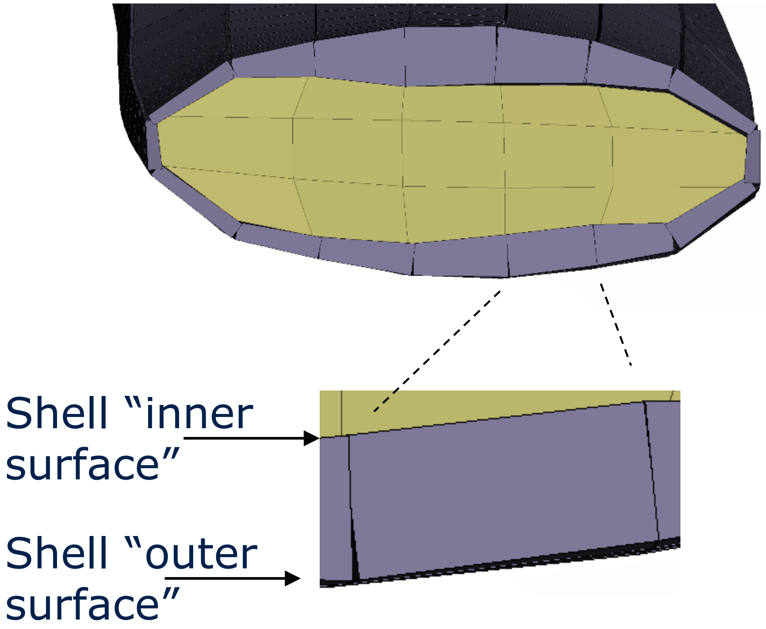
Iraeus, J. and B. Pipkorn (2019). Development and Validation of a Generic Finite Element Ribcage to be used for Strain-based Fracture Prediction. 2019 International IRCOBI Conference, Athens, Greece.

Alignment of Rib Strain Injury Risk Assessment

- Goal: Provide guidelines for robust strain based HBM rib injury risk assessment
- Method: Extract rib strains

Rib cortical bone considered to be brittle
> Use maximum principal strain evaluated at the shell "outer surface"

To be addressed:
- Exclude elements near unphysical stress concentrations in post-processing?



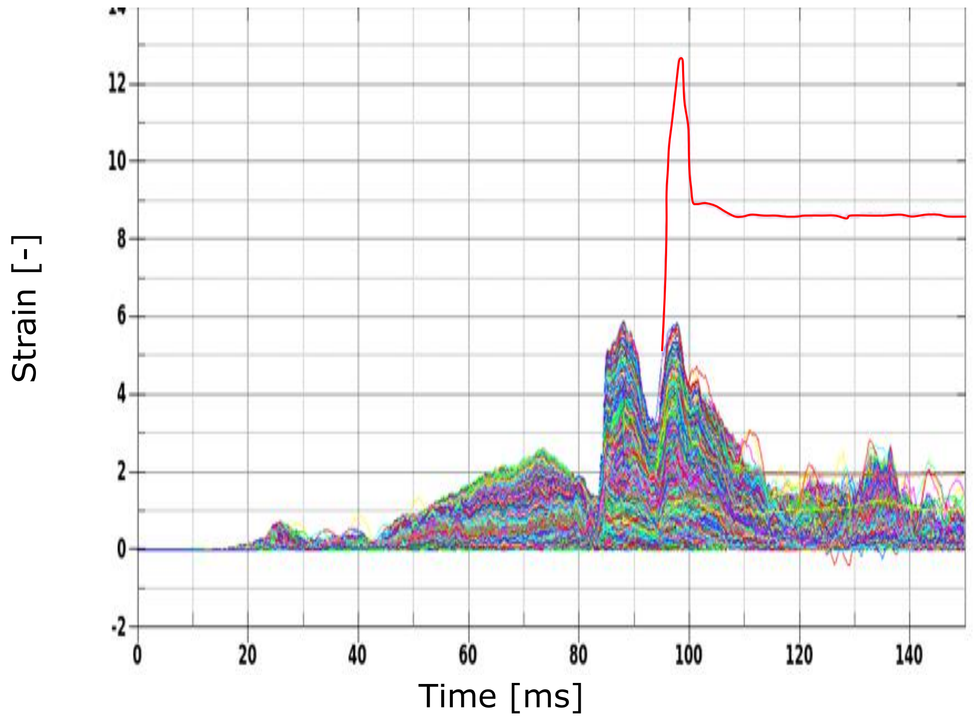
Isa et al., "Assessing Impact Direction in 3-point Bending of Human Femora: Incomplete Butterfly Fractures and Fracture Surfaces", J Forensic Sci, January 2018, Vol. 63, No. 1

Alignment of Rib Strain Injury Risk Assessment

- Goal: Provide guidelines for robust strain based HBM rib injury risk assessment
- Method: Propose result filtering to reduce effects of numerical noise

Tissue based injury criteria are sensitive to numerical noise!

To be addressed:
- (Time gradient) filtering of strain signals?
- Percentiles?



Alignment of Rib Strain Injury Risk Assessment

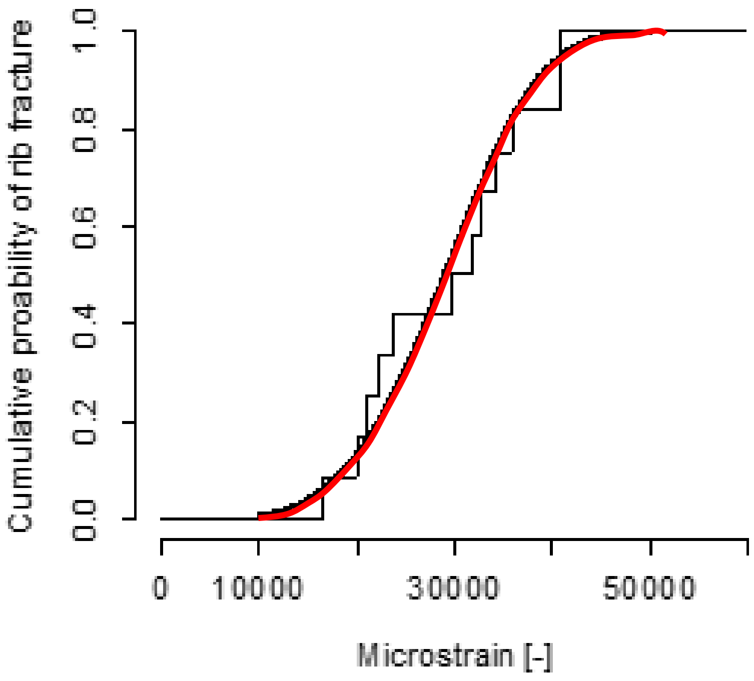
- Goal: Provide guidelines for robust strain based HBM rib injury risk assessment
- Method: Best-practice for model output and post-processing

Smooth Forman (2012) ECDF to remove unrealistic injury risk jumps

Cumulative Weibull distribution:

$$1 - e^{-(\frac{x}{\lambda})^k}, \quad x \geq 0$$

X=strain in microstrain
λ=(36578.7 – 165.5*AGE)
k=4.249542



Johan Iraeus & Mats Lindquist (2020) Analysis of minimum pulse shape information needed for accurate chest injury prediction in real life frontal crashes, International Journal of Crashworthiness, DOI: 10.1080/13588265.2020.1769004

Evaluating injury severity of the Muscle-Tendon-Unit (MTU)

Lennart V. Nölle, Oleksandr V. Martynenko, Syn Schmitt
(IMSB, University of Stuttgart)

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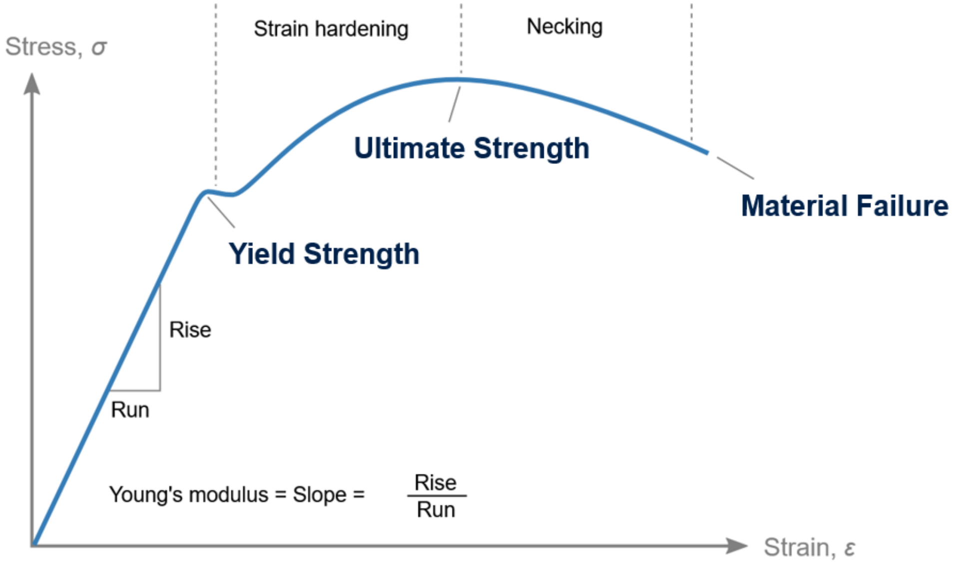
MTU Injury Criteria - **Introduction**

- **Motivation:** Developing a method to evaluate the risk of passengers sustaining minor injuries related to pre-crash safety system functions.
- **MTU** (Muscle-Tendon-Unit) **strain injuries** are the focus of this injury criteria definition because Hill-type muscle models, including the extended Hill-type material (EHTM) developed in USTUTT [1], are defined as 1D truss elements incapable of assessing other types of injury.
- The definition of **three injury thresholds** is done analogous to the generic material deformation stages of a standard engineering stress-strain-curve.

  - ☐ **Minor MTU Injury Threshold**
    Coincides with Yield Strength
  - ☐ **Major MTU Injury Threshold**
    Coincides with Ultimate Strength
  - ☐ **MTU Rupture Threshold**
    Coincides with Material Failure



Modified from: https://upload.wikimedia.org/wikipedia/commons/c/c1/Stress_strain_ductile.svg

MTU Injury Criteria – **Injury Thresholds**

- Injury thresholds for the **tendon**, the **passive** and the **active skeletal muscle** were determined from literature and are presented in the table below.

Type of Injury	Tendon	Passive Muscle	Active Muscle
Minor Injury	2% Strain	30% F_{tf}	70% F_{tf}
Major Injury	5% Strain	80% F_{tf}	90% F_{tf}
Rupture	10% Strain	100% F_{tf}	100% F_{tf}
References	[2]	[3,4]	[5]

where F_{tf} is the tensile force needed to pull the muscle to failure [N]

- Literature comparison indicates that the unknown F_{tf} can be estimated based on each muscle's maximum isometric force F_{max} given in anatomical literature sources:

$$\mathbf{F_{tf} = 3F_{max}}$$

MTU Injury Criteria – **Computational Modelling**

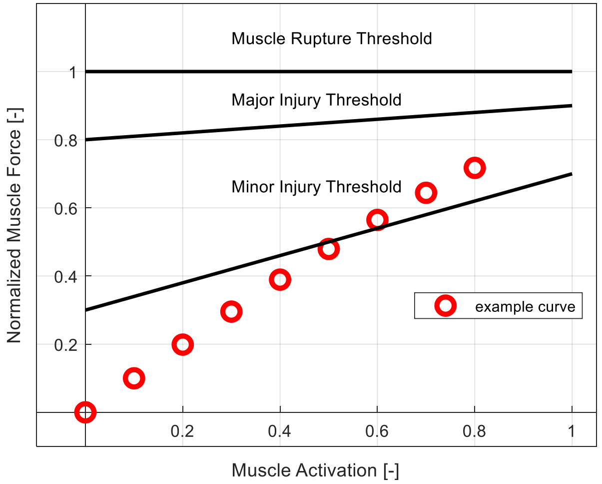
- Activation dependant injury thresholds for the muscle were calculated through linear interpolation between the passive and active threshold extreme values:

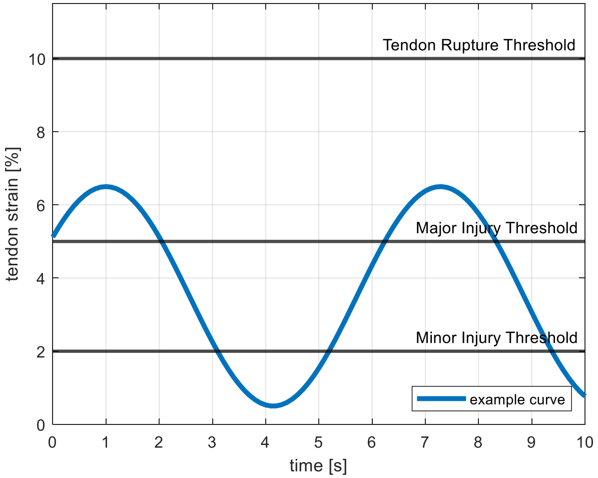
$$F_{thres}(a) = F_{thres,pa} + a\,(F_{thres,ac} - F_{thres,pa})$$

where F_{thres} is the muscle threshold force [N]
$F_{thres,ac}$ is the active muscle injury threshold [N]
$F_{thres,pa}$ is the passive muscle injury threshold [N]
a is the activity level of the muscle 0…1

- Assessment of injury severity is achieved through comparison of resulting muscle forces and tendon strains with the corresponding injury thresholds [6].

Muscle Injury Thresholds





Tendon Injury Thresholds

Injury Criteria - Muscles

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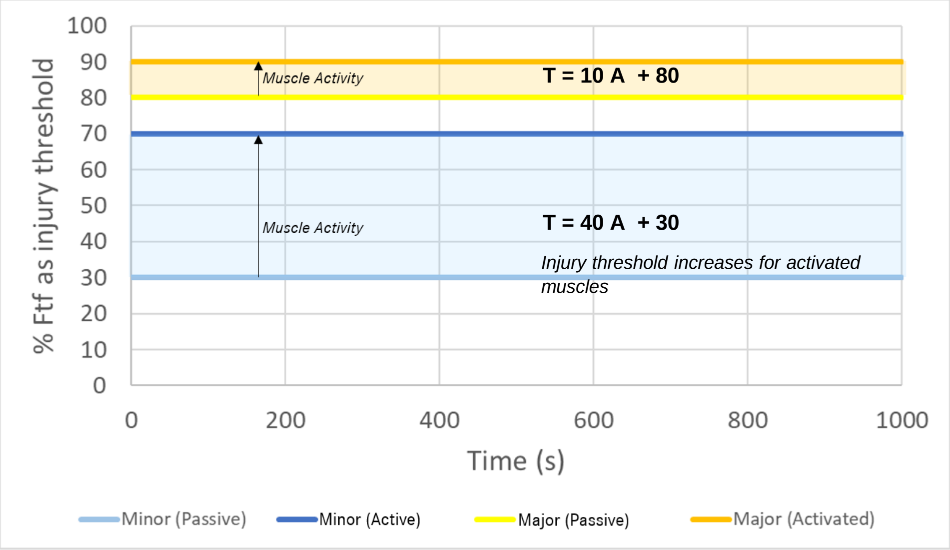
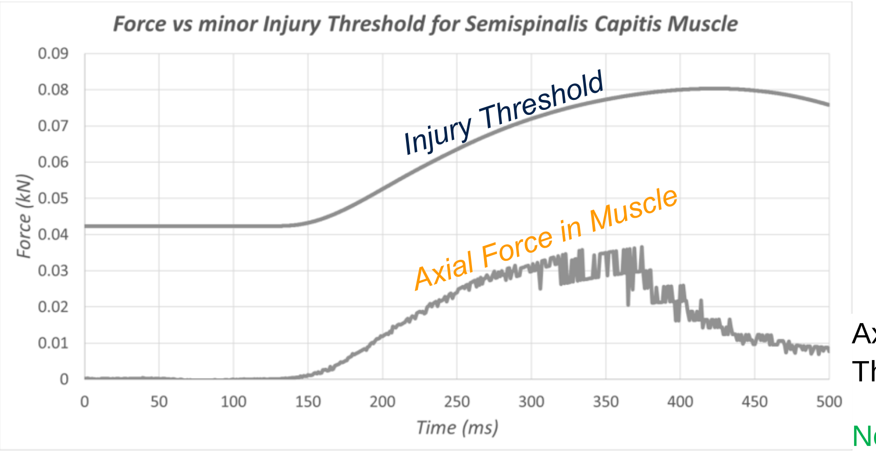
Criterion and Thresholds received from University of Stuttgart

Type of Injury	**Tendon**	**Passive Muscle**	**Active Muscle**
Minor Injury	2% Strain	30% F_{tf}	70% F_{tf}
Major Injury	5% Strain	80% F_{tf}	90% F_{tf}
Rupture	10% Strain	100% F_{tf}	100% F_{tf}
References	Stauber et al.	Noonan et al., Nikolaou et al.	Hasselman et al.

where F_{tf} is the tensile force needed to pull the muscle to failure [N] *(Values available)*

- *Strain based muscle injury in consideration*
- *Only stretching muscles can experience injury*

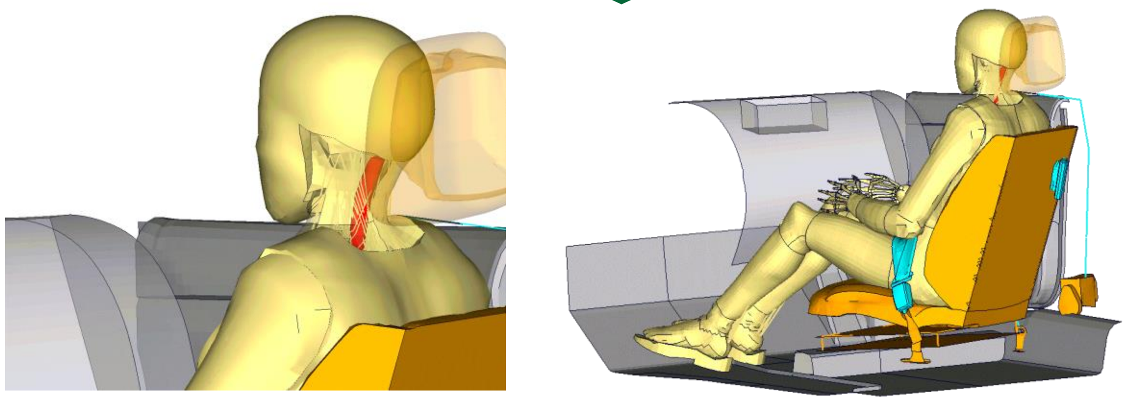




Both injury threshold and force increase with increase in activity level (A) after t=150ms

Axial force < Injury Threshold

No muscle injury!



OSCCAR PP1 Highway Pilot Pre-Crash Phase, with pre-rotated seat

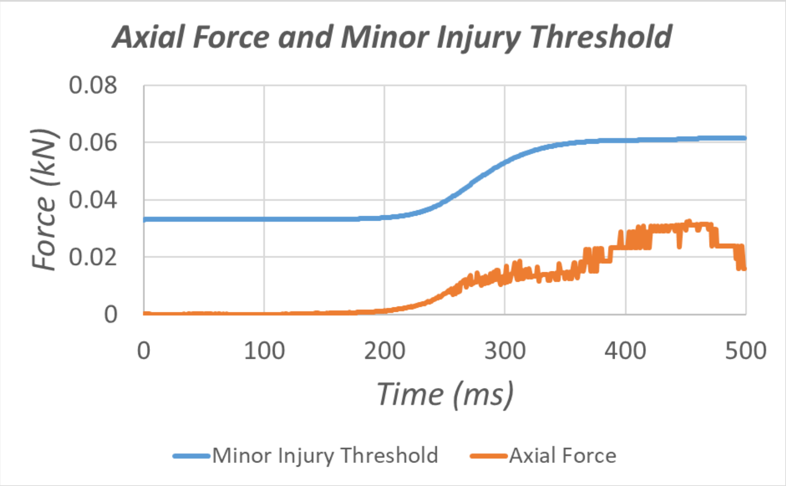
Semispinalis Capitis Muscle Highlighted in **RED**

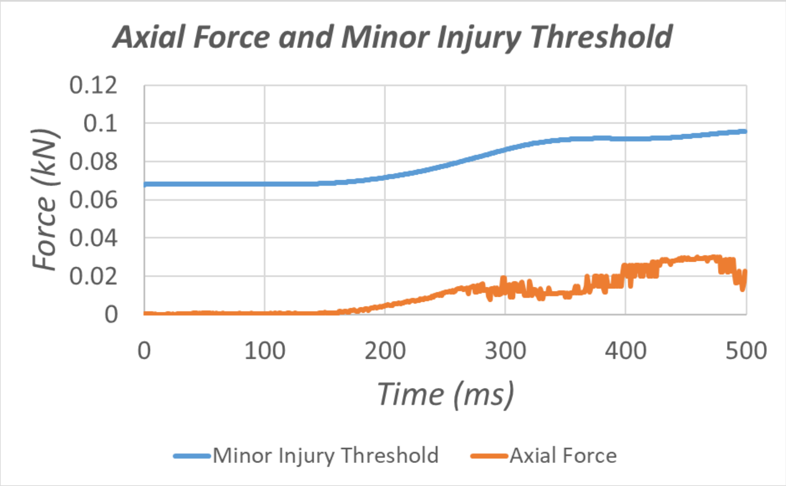
Results for Some Representative Neck Muscles

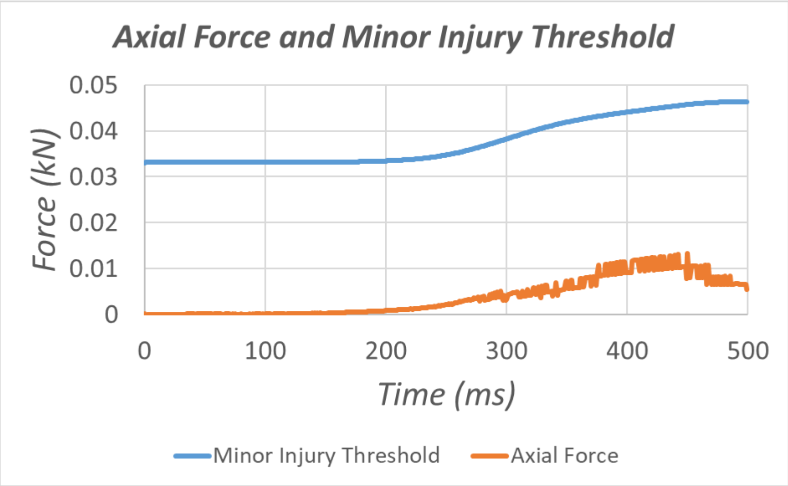
OSCCAR Protection Principle1 Highway Pilot load case with pre-rotated seat

Splenius Capitis | **Levator Scapulae** | **Splenius Cervicis**

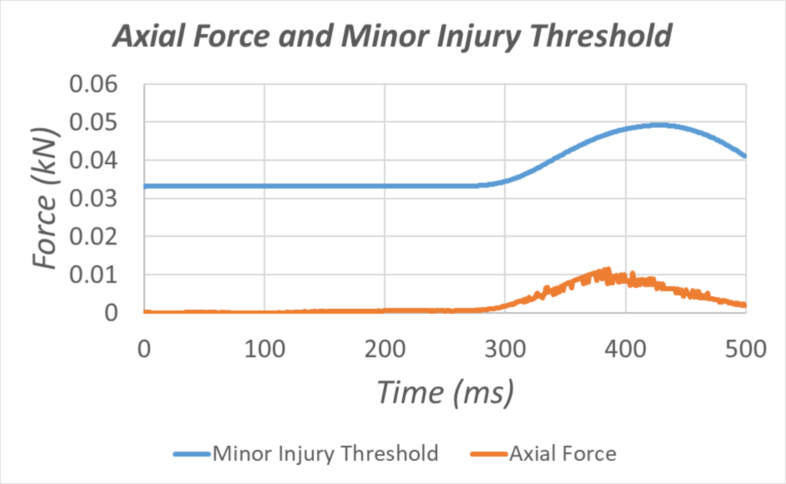
Seat Rotation in 200ms

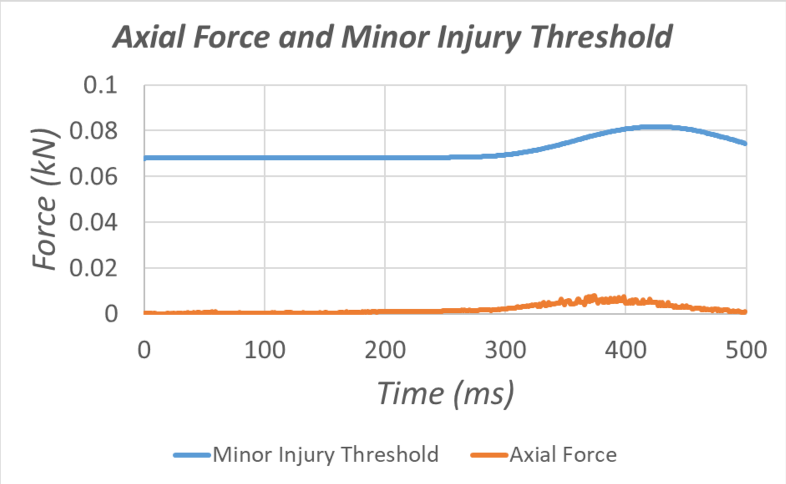


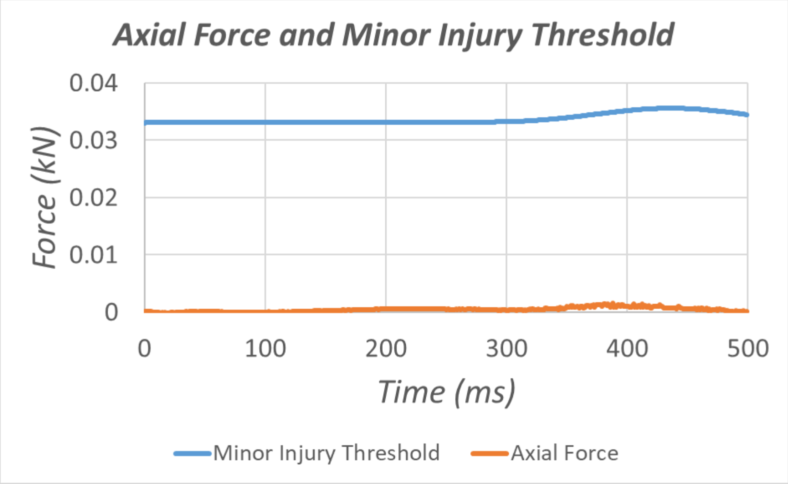




Seat Rotation in 350ms







Control algorithms for population diversity and mobility-impaired people

Lennart V. Nölle, Oleksandr V. Martynenko, Syn Schmitt
(IMSB, University of Stuttgart)

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Control algorithms for population diversity and mobility-impaired people

Development of control algorithms for three types of persons with reduced mobility:

- **Elderly occupants**
  - Can be characterised with an elongated reaction time, dependent on the age and gender.
  - *Approach:* Introduce a stimulation signal delay [7-9].

https://roadsafetygb.org.uk/wp-content/uploads/2018/01/Older-driver-GEM.jpg

- **Wheelchair-bound occupants**
  - *Approach:* Simulate reduced lower limb control by not stimulating the muscles in specified limbs [10].

- **Occupants** suffering from **neural diseases**
  - *Approach:* Introduce signal noise to the stimulation or modify reflex controller settings to model hyperexcitability of the peripheral motor nerve or a reduced inhibition of the stretch reflex [11,12].

https://i.pinimg.com/236x/53/e7/ce/53e7cec0962336db61fa4da17f48912b--small-cars-electric-cars.jpg

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Volunteer pre-crash validation catalogue

Jason Fice (Chalmers University of Technology)

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Volunteer pre-crash validation catalogue

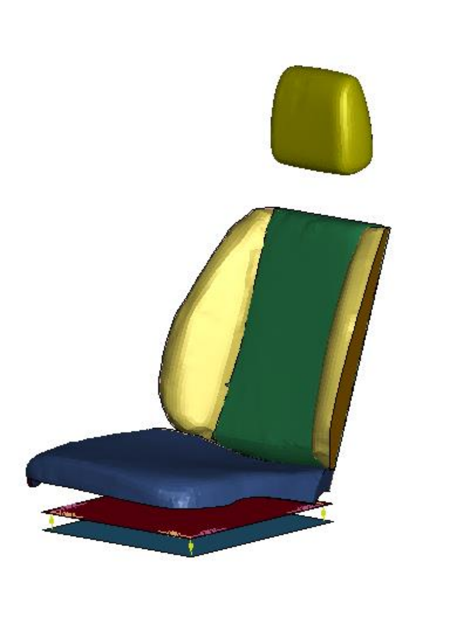
- Goal: Provide a set of volunteer data to validate HBMs for pre-crash manoeuvres
- Method: Identified 25 volunteer experiments. Choose reproducible datasets suitable for HBM validation.

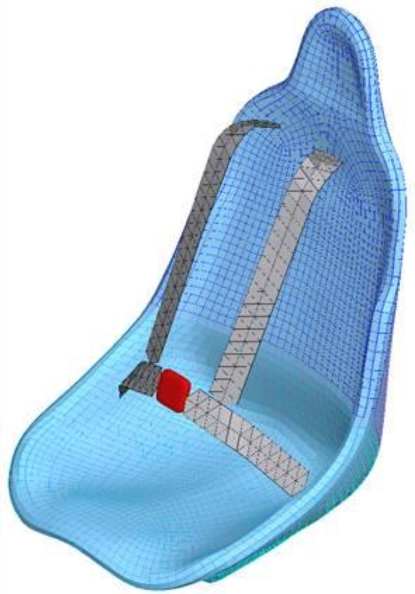
Frontal Acceleration (Braking)	**Lateral Acceleration (Lane-change)**	**Combination**
Chalmers Autobraking test series (Östh, J., et al., (2013). Stapp.; Ólafsdóttir, J. M., et al., (2013) IRCOBI) 	Siemens / TNO Robot test vehicle (Van Rooij, L., et al., (2013). Stapp) 	ViF / TU Graz OM4IS 2 
ViF / TU Graz Precooni (In preparation) 	Chalmers Lane-change test series (Ghaffari, G., et al., (2018), IRCOBI; Ghaffari, G., et al., (2019) Traffic Inj Prev.) 	Chalmers Lane-change test series 
ViF / TU Graz OM4IS 2 (Huber, P., et al., (2015). IRCOBI; Huber, P., et al., (2014) IRCOBI; Kirschbichler, S., et al., (2014), IRCOBI) 	ViF / TU Graz OM4IS 2 	

Volunteer pre-crash validation catalogue

- Seat and/or environment models are an important part of "well defined boundary conditions"

Chalmers	ViF / TU Graz	Siemens
• 2012/2016 Volvo V60 seat/belt model was developed.	• OM4IS II and Precooni use seat based on the structure of 2012 Mercedes-Benz S-Class.	• A rigid racing seat was used (RCI Poly Highback Seat 8000S).





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- Biomechanical alignment/ injury evaluation
  (Christian Mayer, Johan Iraeus, Lennart Nölle, Jason Fice)

- **Virtual testing** (Andre Eggers, BASt)

Full Virtual Testing approach with HBMs

Vehicle interior model certification procedure

Andre Eggers (BASt), Christian Mayer (Mercedes-Benz), Steffen Peldschus (LMU Munich)

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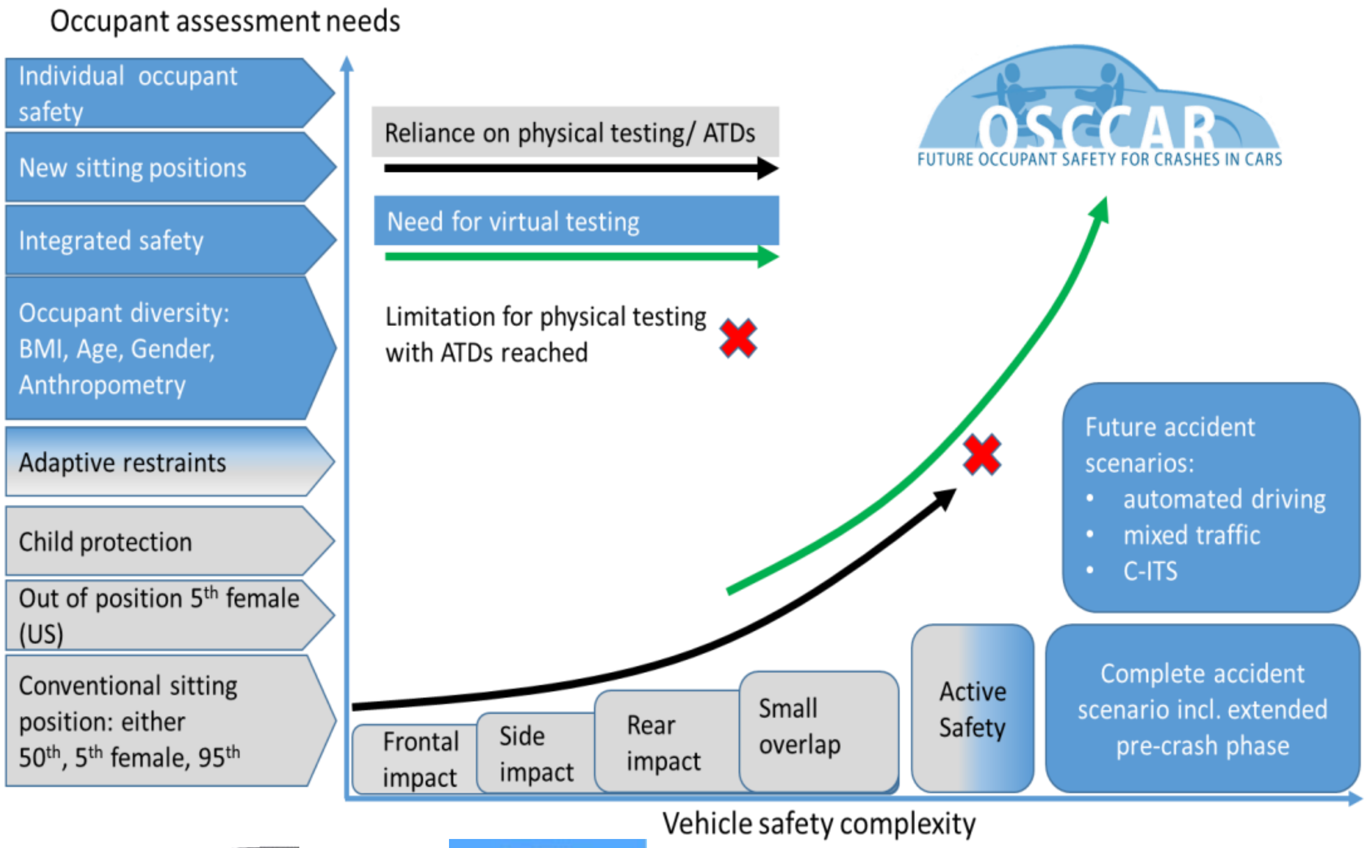
“Full Virtual Testing” approach with HBMs - no fallback option for RT

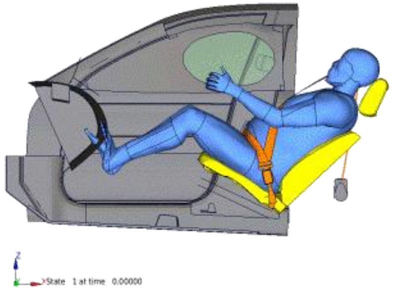
Motivation for Virtual Testing

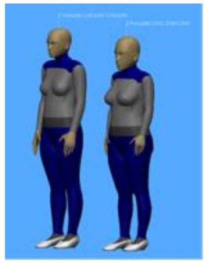
1.) **Replace existing RT** (real testing) based procedures **by VT** (virtual testing) → e.g. EU-Project IMVITER) with focus on **saving costs** (no new tests/requirements)

2.) **Extent the scope of protection** by adding test conditions using existing test tools (ATDs/impactors) by combined real and virtual testing (hybrid approach/grid approach)

3.) Use of **HBMs in a VT process** to address the limitation of ATDs → **OSCCAR**: HBMs to address new seating postures, user diversity (small vs. tall, male vs. female, Western vs. Asian), obesity,…





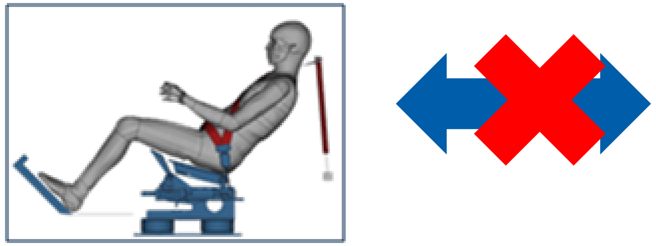


“Full Virtual Testing” approach with HBMs - no fallback option for RT

OSCCAR “Full Virtual Testing” approach with HBMs - vehicle interior model certification procedure

Why do we need vehicle interior certification procedure?

- ➢ No possibility to check validation of vehicle model by real tests in assessment/type approval test setup (No real test tool existing corresponding to HBM)



No corresponding real test for interior model validation

- ➢ No combined VT/RT hybrid approach
- ➢ No RT fall back option if validation fails

"Full Virtual Testing" approach with HBMs - no fallback option for RT

FUTURE OCCUPANT SAFETY FOR CRASHES IN CARS

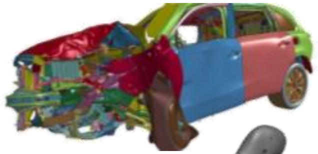
Phase 1: Vehicle Model Development

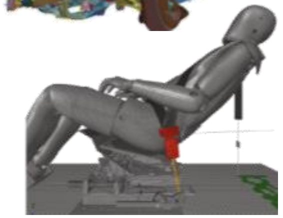
Vehicle (interior) model development

- Code-specific quality requirements
- Model validation based on internal experience, tests and data

Phase 2: Vehicle Model Certification

HBM Certification requirements for new load cases





Simulations (Carried out by OEM)

Simulation data

Objective correlation procedure

Real test data

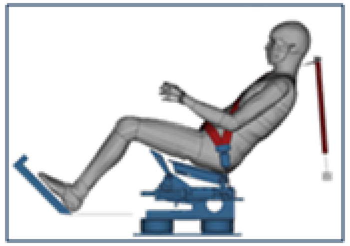
Validation Tests (by accredited lab)

Human Body Model (certifed for new loadcase)

Certified Vehicle Interior Model

Phase 3: Homologation / Assessment

Virtual Testing of new load case



- Test/Assessment Tool: HBM
- Standardized virtual test procedure
- HBM based assessment criteria

“Full Virtual Testing” approach with HBMs - no fallback option for RT

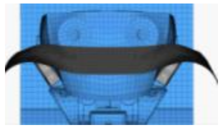
Phase 2: Model Certification

Vehicle interior model Simulations carried out by (OEM)

Simulation data

Objective correlation procedure

Test data



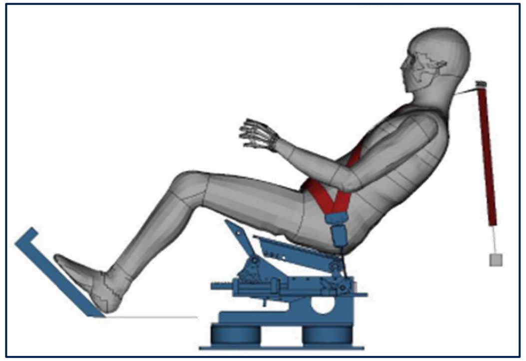
Validation Tests (carried out or witnessed by accredited lab)

Validation based vehicle interior model certification procedure:

- Defined set of **validation load cases** (crash test, sled test, impactor tests in representative of new loading condition) including suitable **validation tool** (standard ATD, modified/simplified ATD, impactor,..)
- Based on **objective correlation procedure** vehicle interior model is certified for use in Phase
- Selection of relevant validation measurements
- Definition of objective metrics threshold considering acceptable scatter in real test and vehicle components

Application to OSCCAR Homologation Test Case Demonstration

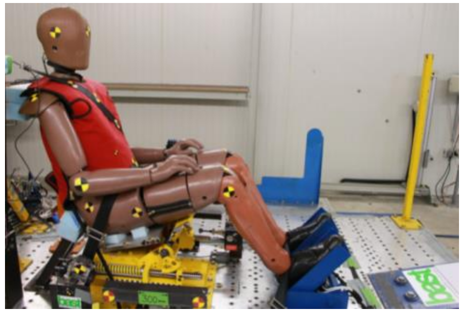
- Frontal impact
- Reclined seat (48° / 60°)
- Average occupant (50%ile) incl. soft tissue layer variation



Proposed **interior validation load cases** for the OSSCAR homologation scenario:

- **Sled tests** with 50 km/h full-frontal pulse
- **Validation tool: THOR-50M** (in upright and reclined seating position)

➢ Sled tests have been performed and used for interior model validation in different codes



Next steps / further work in OSCCAR:

- Comparison of THOR and HBM simulations in validation load cases
  - Discuss possible **limitations of sled validation load cases and THOR as validation tool**

- Evaluate objective metrics (e.g. Cora / ISO) and thresholds considering variation in dummy response, vehicle components and test scatter
  (More sled tests with THOR planned to evaluate load case specific **real test variation of relevant validation signals)**

- Evaluate validation procedure based on further THOR sled tests
  - Draft proposal procedure for vehicle interior certification

OSCCAR – downloads, results

OSCCAR public deliverables and downloads:

http://osccarproject.eu/media/

OSCCAR @ Ircobi 2020:

Östh et al.: Evaluation of Kinematics and Restraint Interaction when Repositioning a Driver from a Reclined to an Upright Position Prior to Frontal Impact using Active Human Body Model Simulations

Becker et al.: Occupant Safety in Highly Automated Vehicles Challenges of Rotating Seats in Future Crash Scenarios

Mroz et al.: Effect of Seat and Seat Belt characteristics on the Lumbar Spine and Pelvis Loading of the SAFER Human Body Model in reclined Postures

Nölle et al.: Defining Injury Criteria for the Muscle-Tendon-Unit

OSCCAR

FUTURE OCCUPANT SAFETY FOR CRASHES IN CARS

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