YOUR GLOBAL MOBILITY AND
INDUSTRY ENGINEERING EXPERTS

EDAG GROUP

IMPLEMENTATION OF THE PRIMUS BREAKABLE BIOFIDELIC DUMMY FE-MODEL IN LS-DYNA

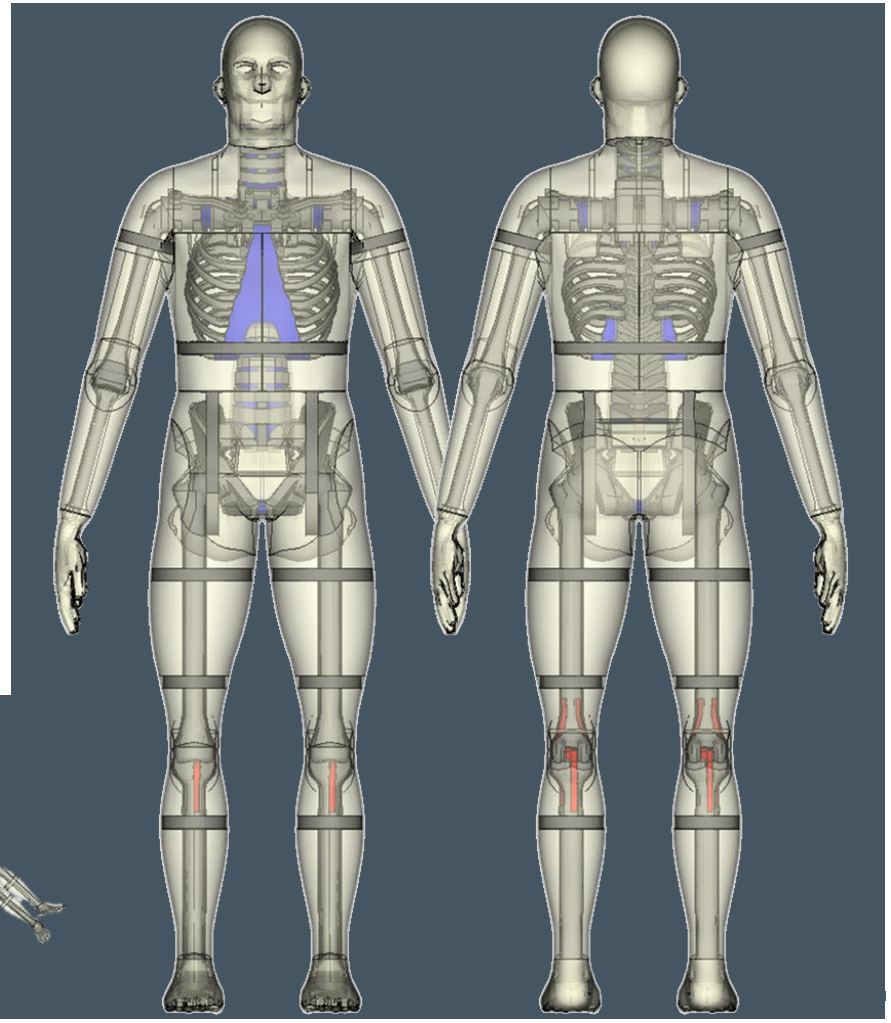
KRISHAA MADHIKARMI /
JAN BOHLEN

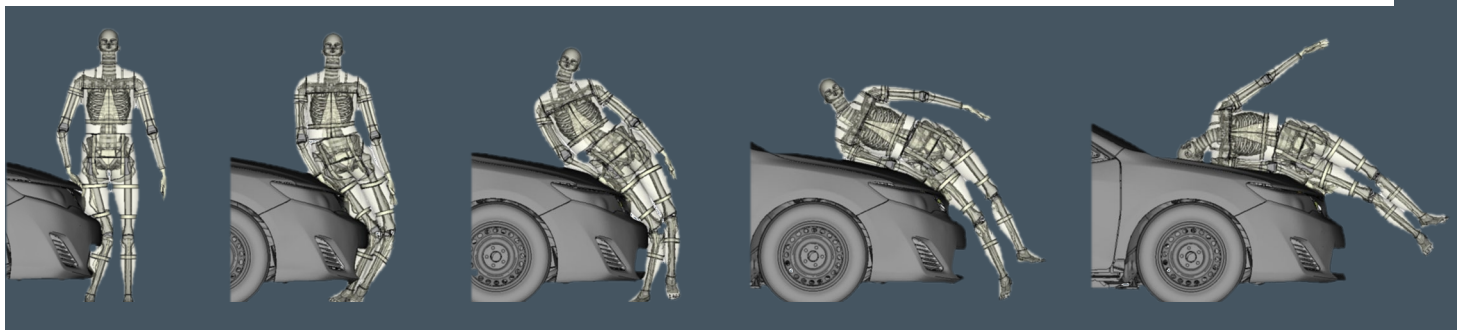
8/6/2024

EDAG

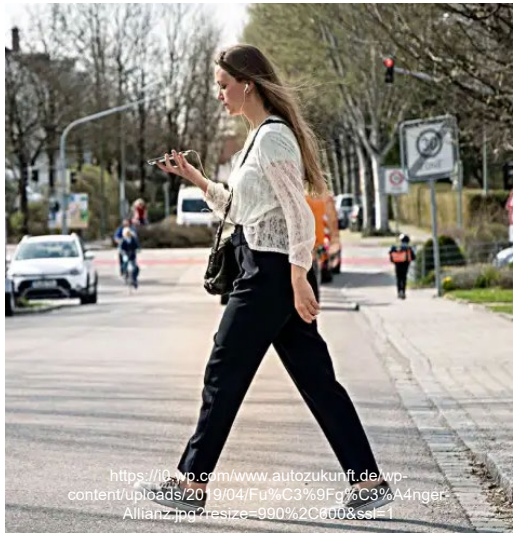
AGENDA
4. DUMMY.CRASHTEST.KONFERENZ

1. **Motivation**
2. **Development of the PRIMUS Breakable® model for LS-DYNA®**
3. **First test loadcases for pedestrian and occupant safety**
4. **Conclusion & Outlook**





MOTIVATION
PEDESTRIAN PROTECTION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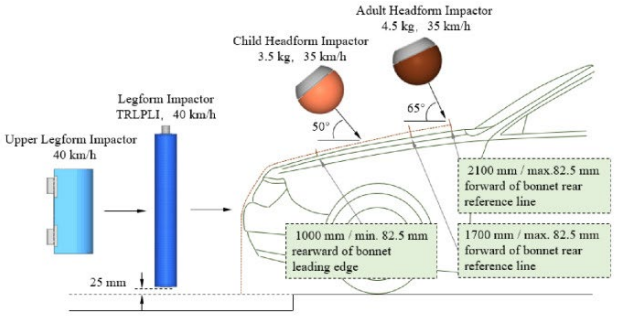
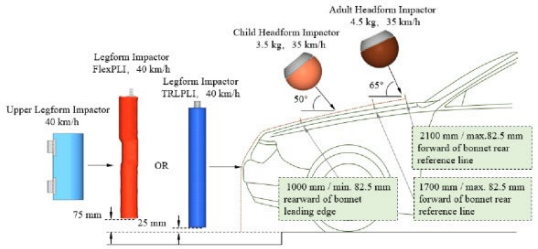
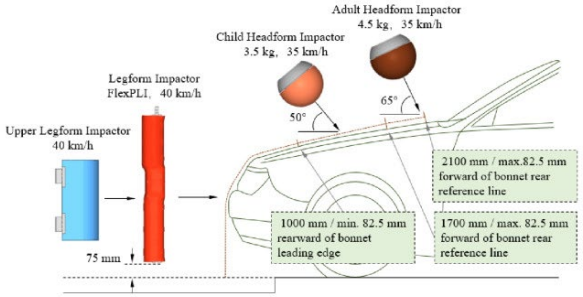
MOTIVATION
PEDESTRIAN PROTECTION



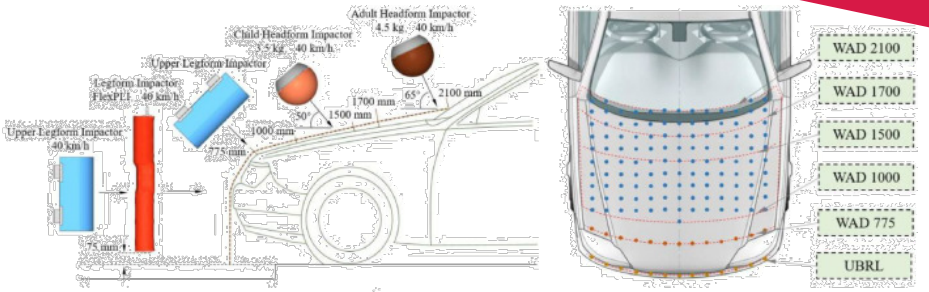
(a) GB/T 24550-2009



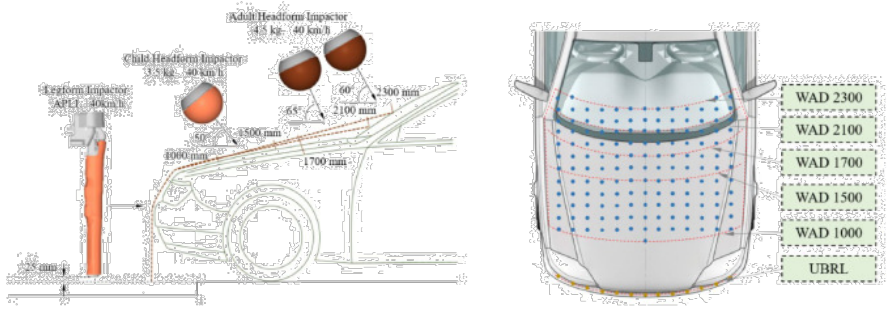
(b) TRIAS 18-J099(2)-1 / KMVSS 102-2 / AIS-100 Amendment No.2



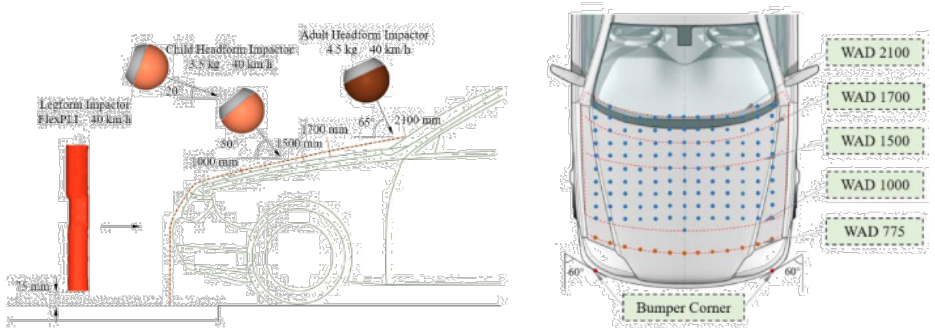
(c) GTR No.9 Amendment No.2 / ECE R127.2



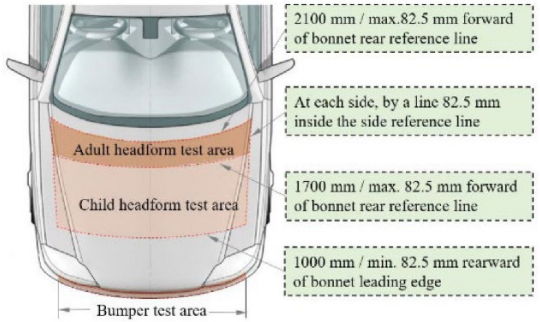
(a) Euro-NCAP V8.5



(b) C-NCAP V2021



(c) J-NCAP V2018



(d) Test area

On safety design of vehicle for protection of vulnerable road users: A review

MOTIVATION
PEDESTRIAN PROTECTION

MOTIVATION
OCCUPANT SAFETY

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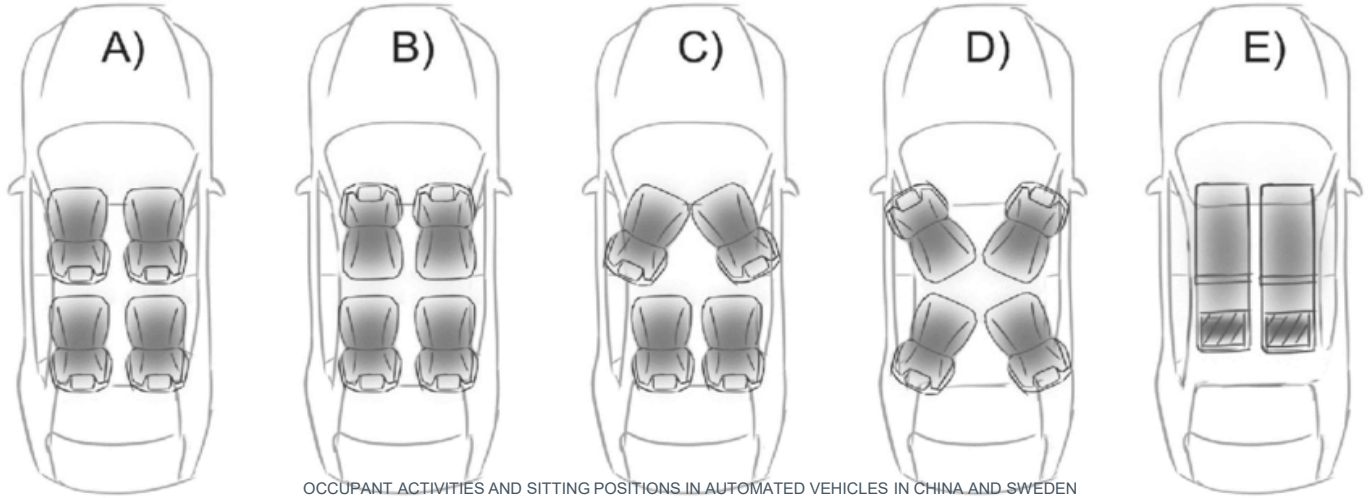
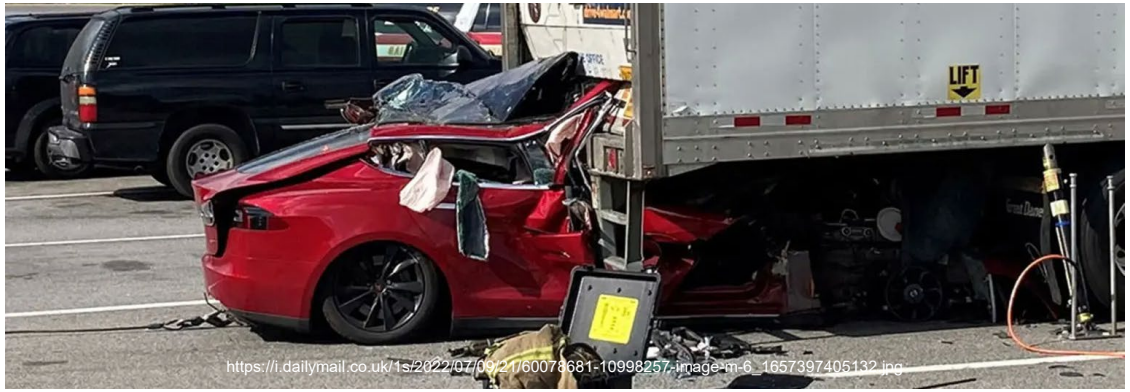


OCCUPANT ACTIVITIES AND SITTING POSITIONS IN AUTOMATED VEHICLES IN CHINA AND SWEDEN

MOTIVATION
OCCUPANT SAFETY



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MOTIVATION
OCCUPANT SAFETY

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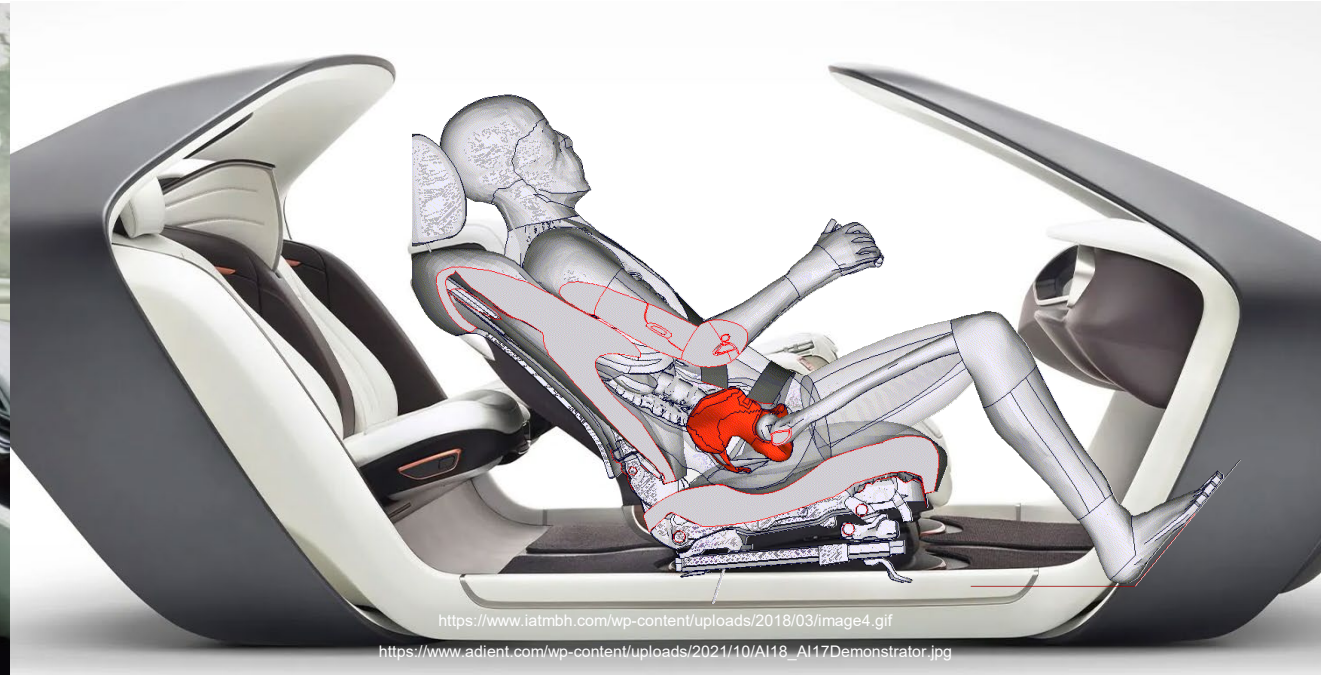

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https://www.adient.com/wp-content/uploads/2021/10/AI18_AI17Demonstrator.jpg

PRIMUS BREAKABLE® MODEL
IN LS-DYNA®

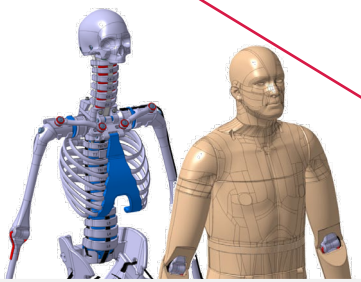
https://www.crashtest-service.com/de/biofidel-dummy-/modelluebersicht/primus-breakable/

Structural results

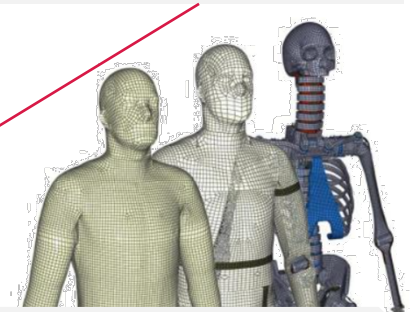
Testing

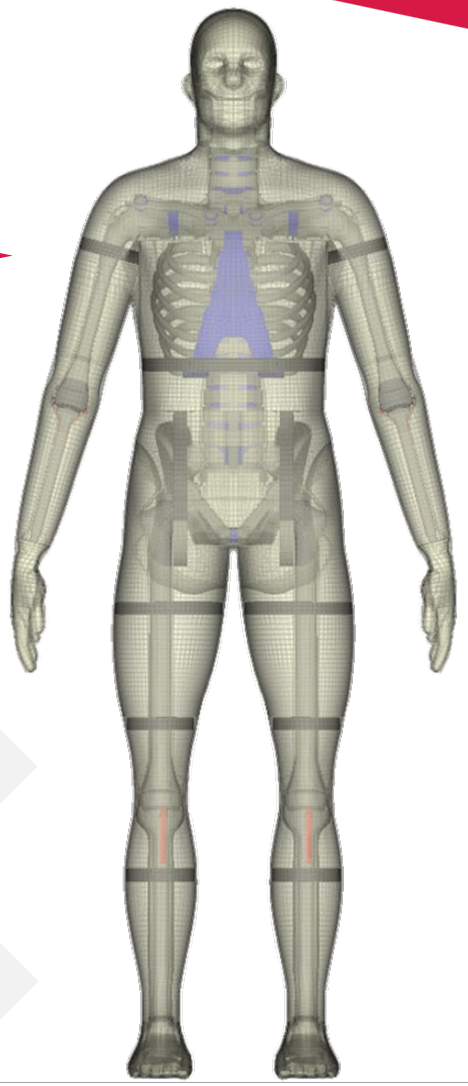
Optimized design of safety systems!

Simulation



Damage / Injury mechanisms





Cooperation:

HTW Hochschule für Technik und Wirtschaft Dresden University of Applied Sciences

CTS crashtest-service

EDAG

CAD-Geometry preparation:

DS CATIA

Meshing & Pre-Processing:

ANSA PRE PROCESSOR

Solving & Post-Processing:

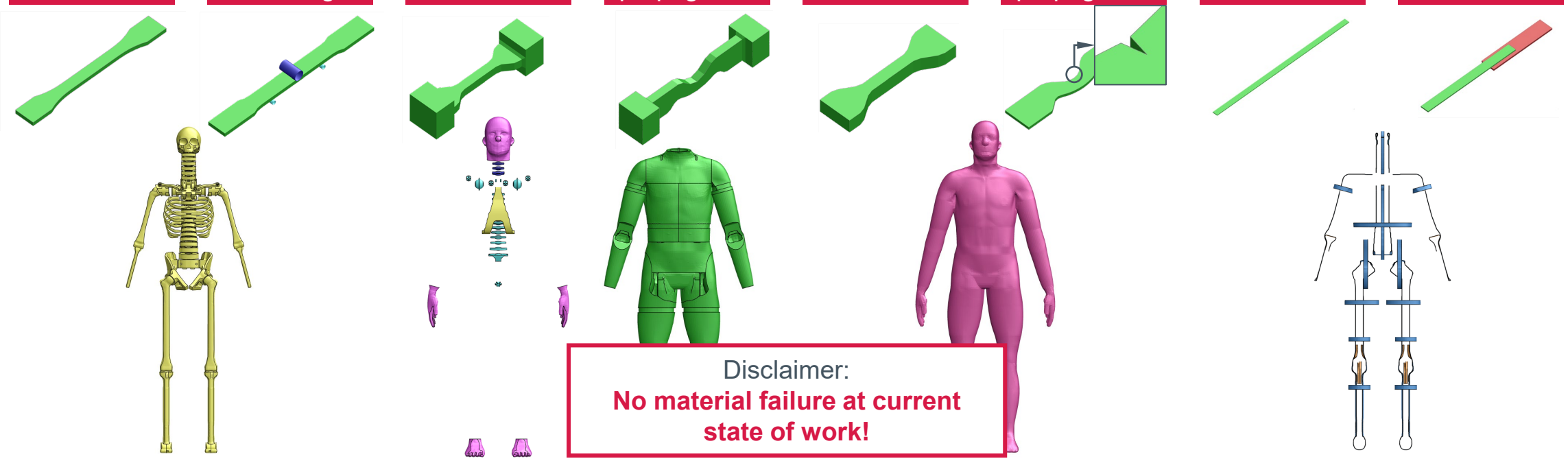
DYNA MORE

An Ansys Company

PRIMUS BREAKABLE® MODEL
MATERIAL MODELING

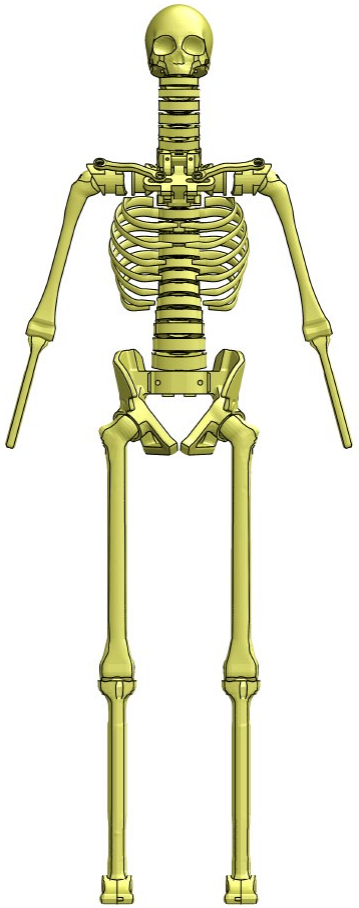
Reference: Physical material tests / IMPETUS material models

- **BONE SURROGATE**
  - Tensile
  - 3-point bending
- **SOFT TISSUE SURROGATES**
  - Tensile
  - Tear propagation
- **SKIN SURROGATE**
  - Tensile
  - Tear propagation
- **LIGAMANT SURROGATES**
  - Tensile
  - Tensile connection



Disclaimer:
No material failure at current state of work!

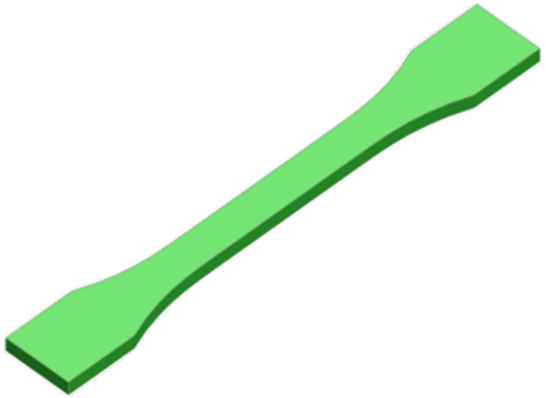
PRIMUS BREAKABLE® MODEL
BONE SURROGATE



BONE SUBSTITUTE

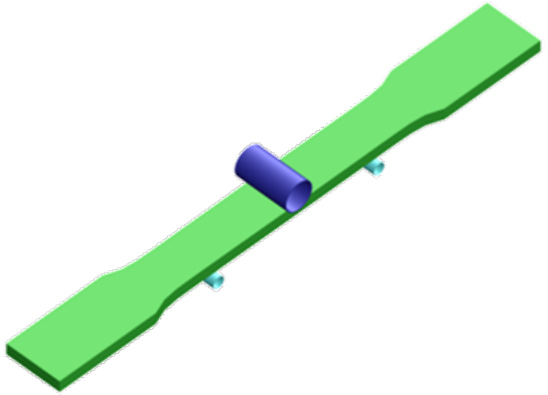
- Used as bone surrogate consisting of aluminiumpowder - epoxy resin composite
- Chosen LS-DYNA Material Model: **Modified Johnson-Cook (MAT 107) tested in 201-7**

Tensile

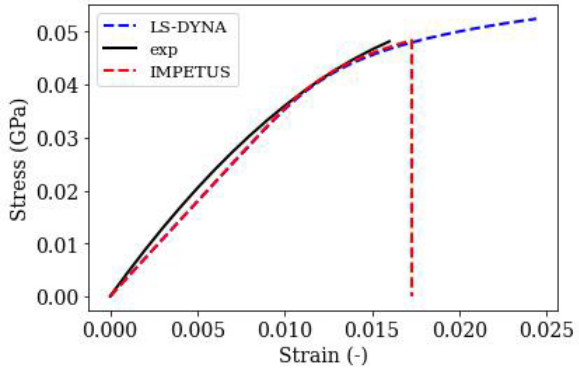


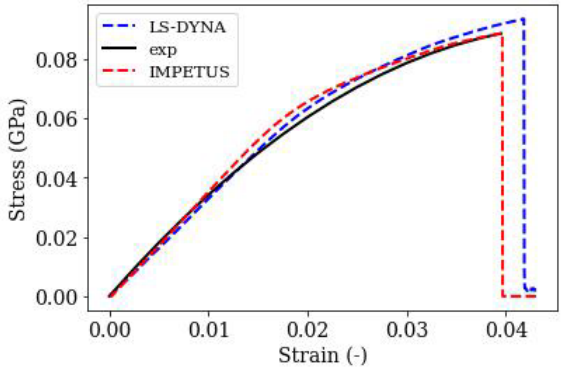
Tensile test specimen- Bone Surrogate

3-point bending



Bending test specimen- Bone Substitute (rigid cylinders in dark and light blue)





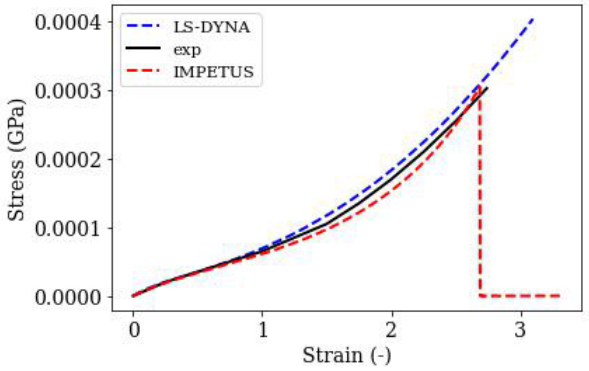
PRIMUS BREAKABLE® MODEL
SOFT TISSUE SURROGATE

ZHERMACK ZA00

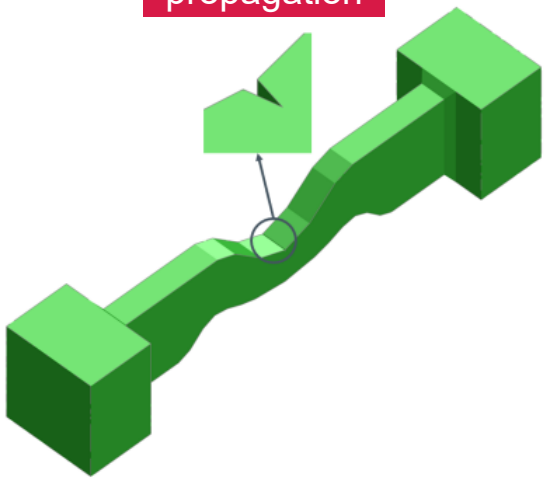
- Bulk of the soft tissue in the body
- Chosen LS-DYNA Material Model: **Ogden hyperelastic model (MAT 77O) as tested in 301-9**

Tensile

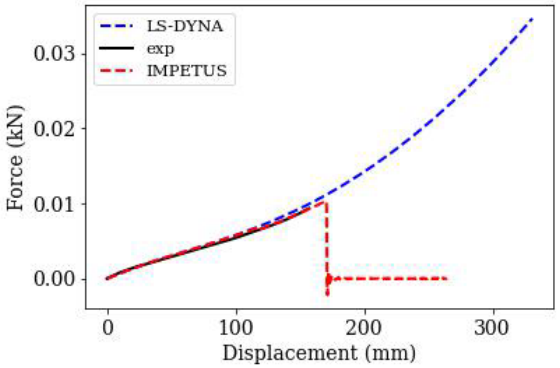
Tensile test specimen- Soft tissue Surrogate



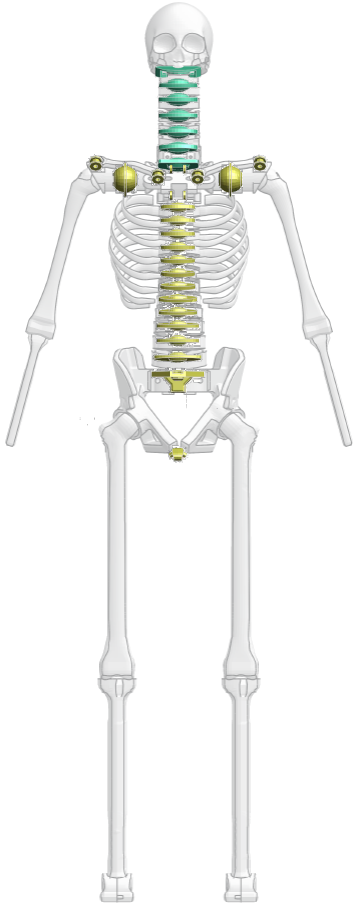
Tear propagation



Tear Propagation test specimen - Soft Tissue Surrogates



PRIMUS BREAKABLE® MODEL
SOFT TISSUE SURROGATE



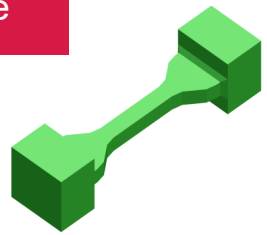
ZHERMACK ZA04

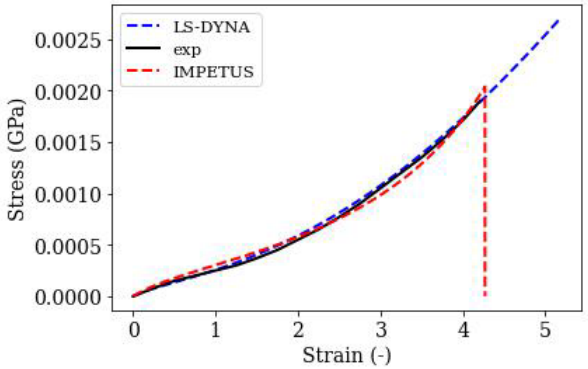
- Used as intervertebral disc material in the cervical spine

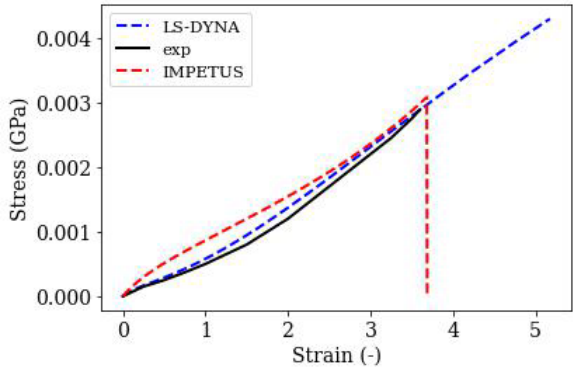
ZHERMACK ZA22

- Used as intervertebral disc material in the spine and as damping material in shoulder and pelvis region
- Chosen LS-DYNA Material Model: **Ogden hyperelastic model (MAT 77O) as tested in 303-9**

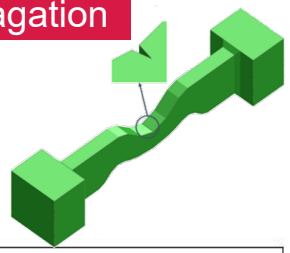
Tensile

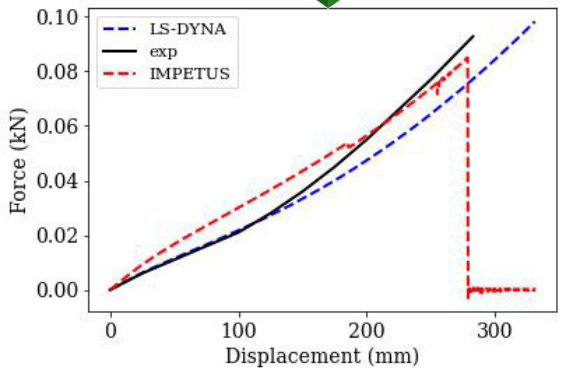


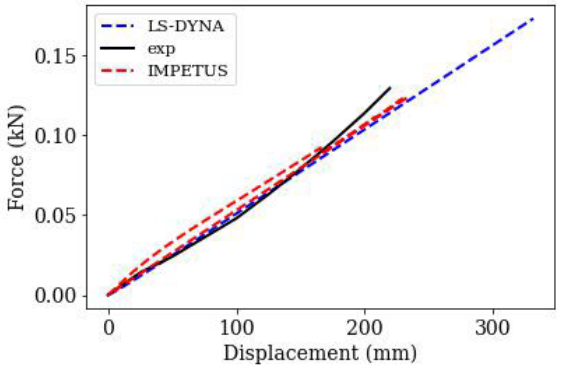




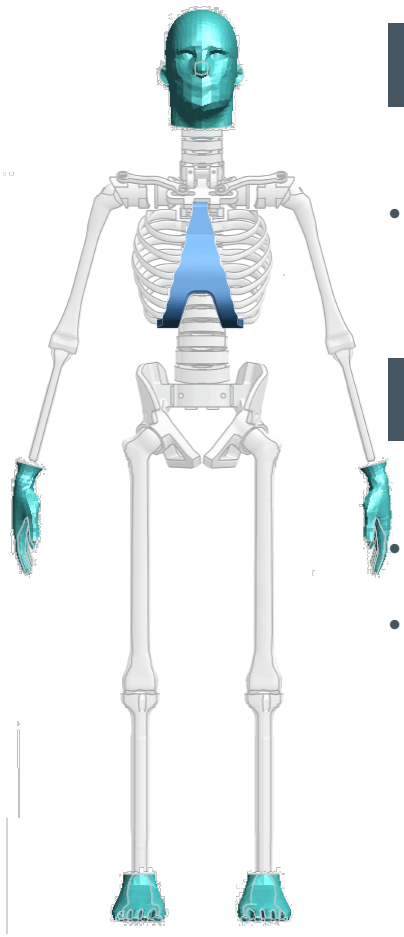
Tear propagation







PRIMUS BREAKABLE® MODEL
SOFT TISSUE SURROGATE



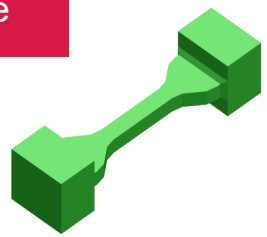
ZHERMACK ZA30

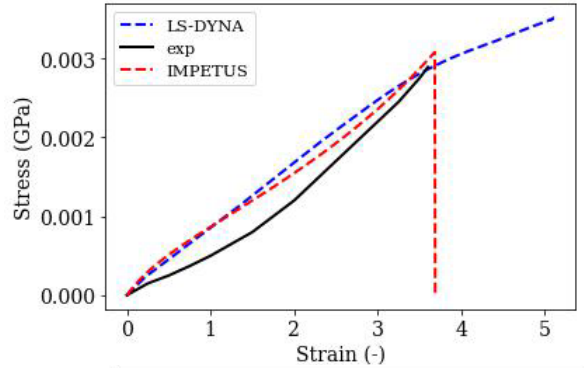
- Used for soft tissue in the hands, feet and face

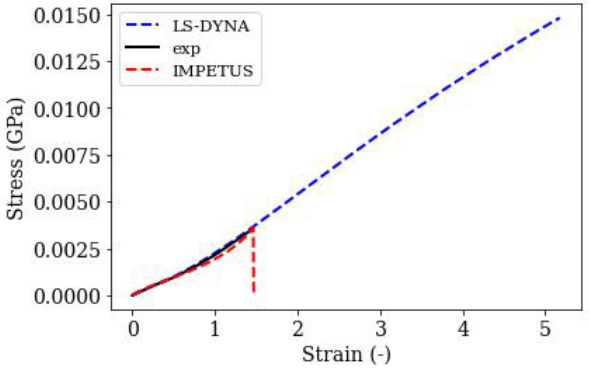
ZHERMACK ZA50

- Used in the sternum to connect ribs
- Chosen LS-DYNA Material Model: **Ogden hyperelastic model (MAT 77O) as tested in 305-9**

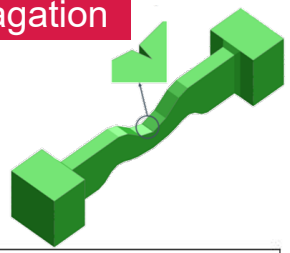
Tensile

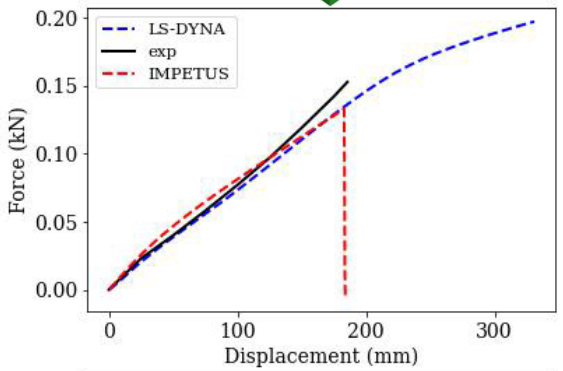


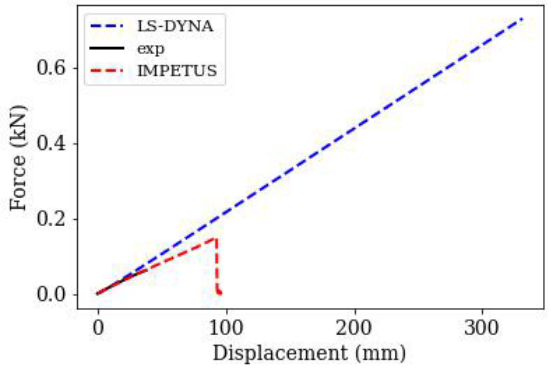




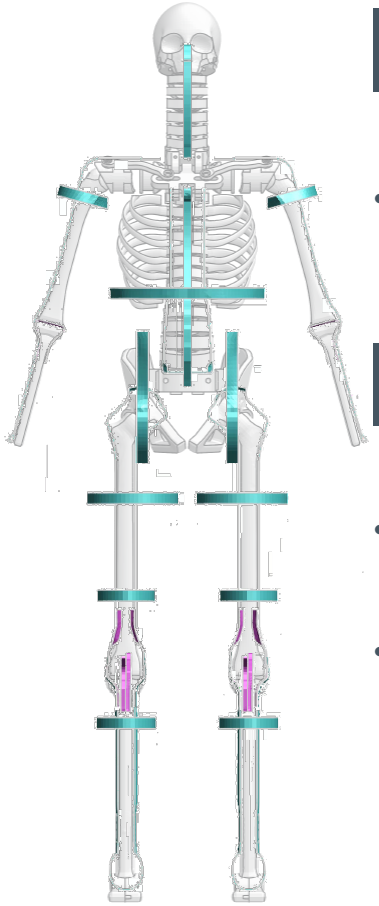
Tear propagation







PRIMUS BREAKABLE® MODEL
LIGAMENT SURROGATE



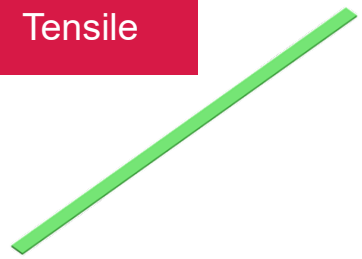
PP-BELT-BLACK

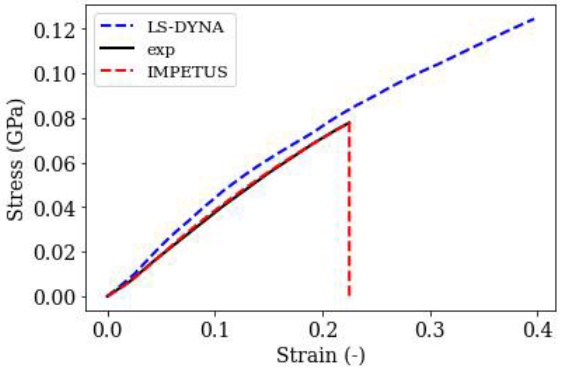
- Used in as strapping to provide structural integrity

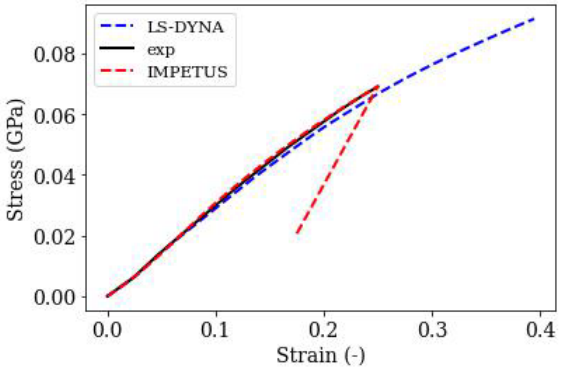
PP-BELT-RED

- Used in as ligaments in knee and arm joints
- Chosen LS-DYNA Material Model: **Simplified Rubber (MAT 181) as tested in 402-1**

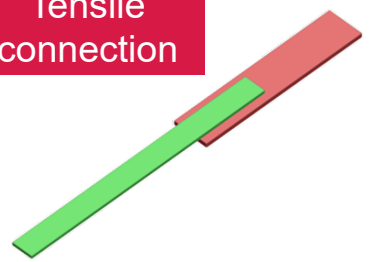
Tensile

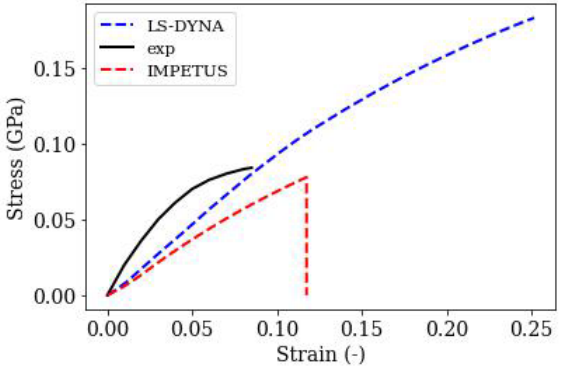


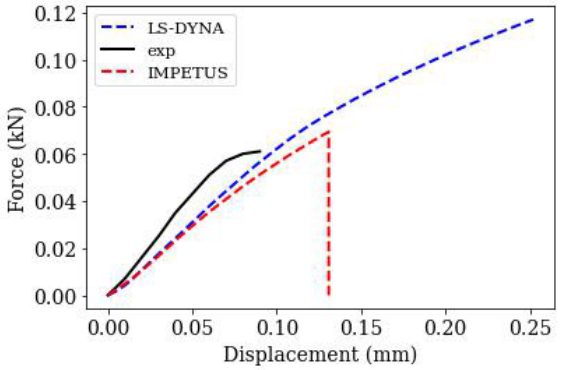




Tensile connection





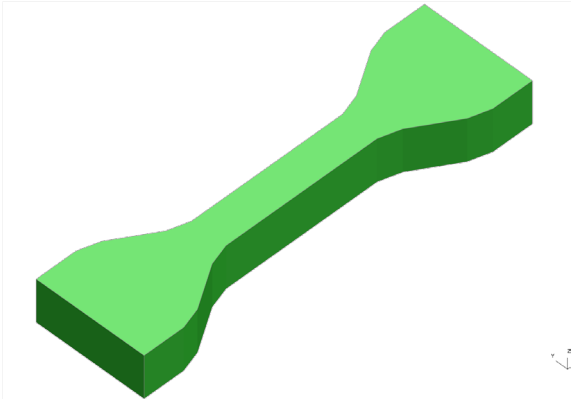


PRIMUS BREAKABLE® MODEL
SKIN SURROGATE

NEOPRENE SHARKSKIN

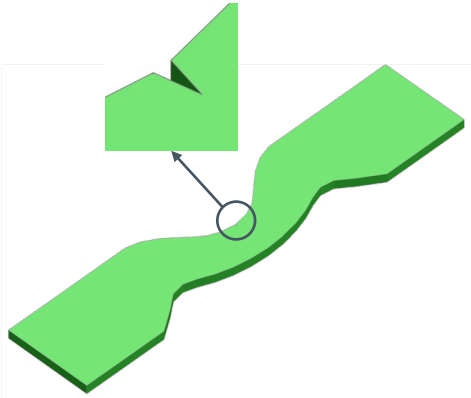
- Used for the skin surrogate
- Chosen LS-DYNA Material Model: **Simplified Rubber (MAT 181) as tested in 501-11**

Tensile

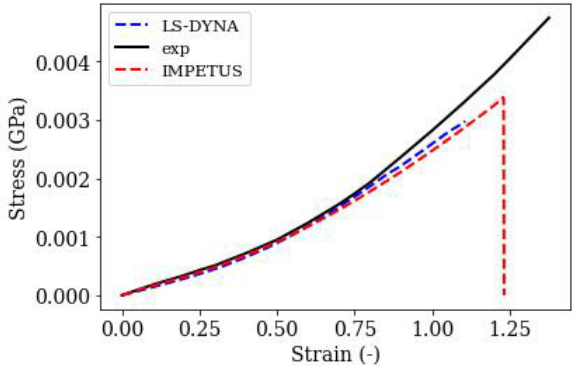


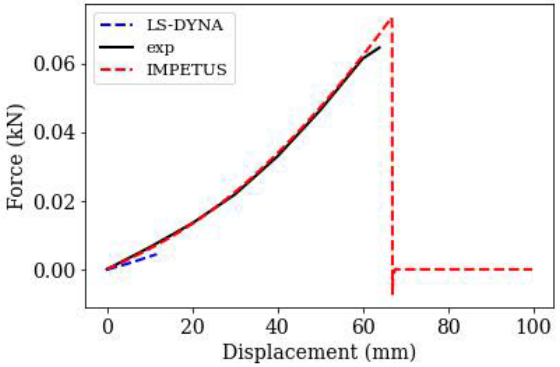
Tensile test specimen- Soft tissue Surrogate

Tear propagation

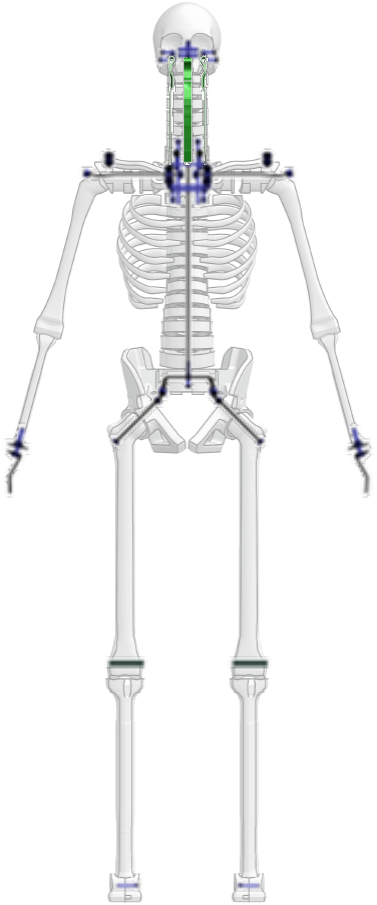


Tear Propagation test specimen - Soft Tissue Surrogates



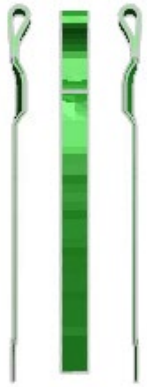


PRIMUS BREAKABLE® MODEL
OTHER MATERIAL MODELS



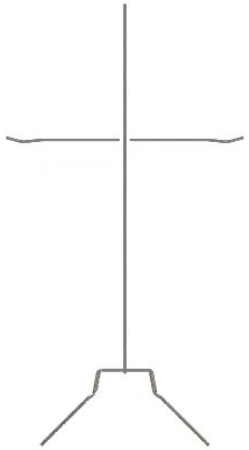
Elastic belt

- Used in the ligament surrogate parts in the neck area



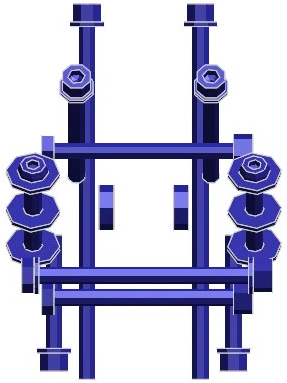
Steel cables

- Used in the spine and pelvis regions, they are significantly softer than standard steel.



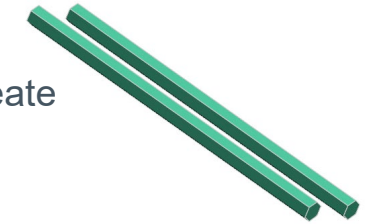
Steel parts

- Parts such as screws, washers are modelled using the properties of standard steel

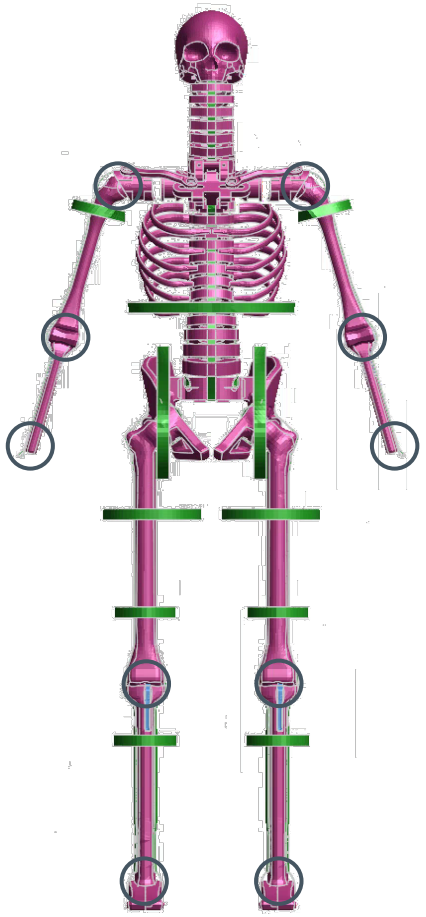


Rigid parts

- Rigid material is used to create embedded pins



PRIMUS BREAKABLE® MODEL
SUBSYSTEM COMPONENT ASSEMBLY



Exemplary cNRBs

Pure hexahedral CAD mesh (IMPETUS model)

↓

Creation of a null-shell layer for each part

↓

Creation of constrained nodal rigid bodies (cNRBs)

↓

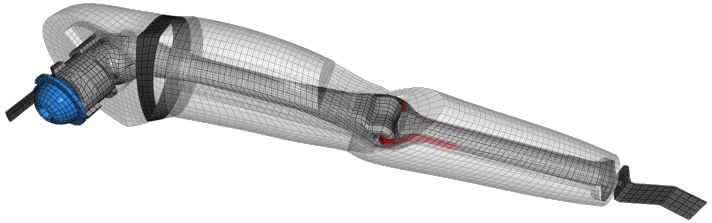
Creation of tied contacts

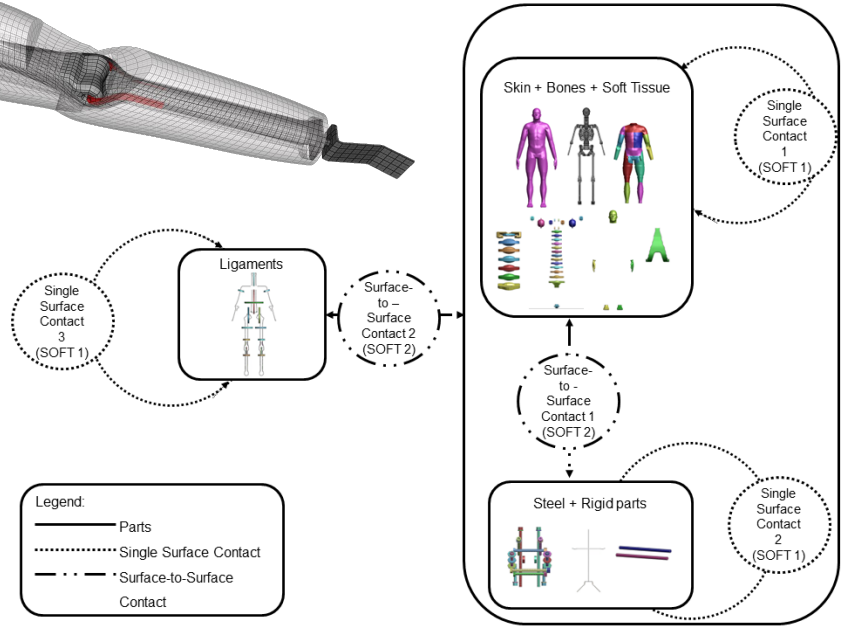
↓

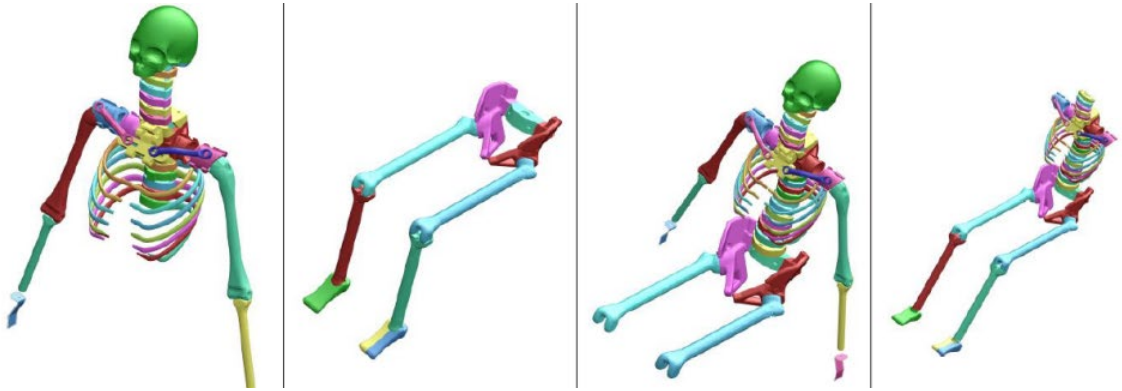
Creation of single surface and surface-to-surface contacts

↓

Joint implementation for positioning simulation

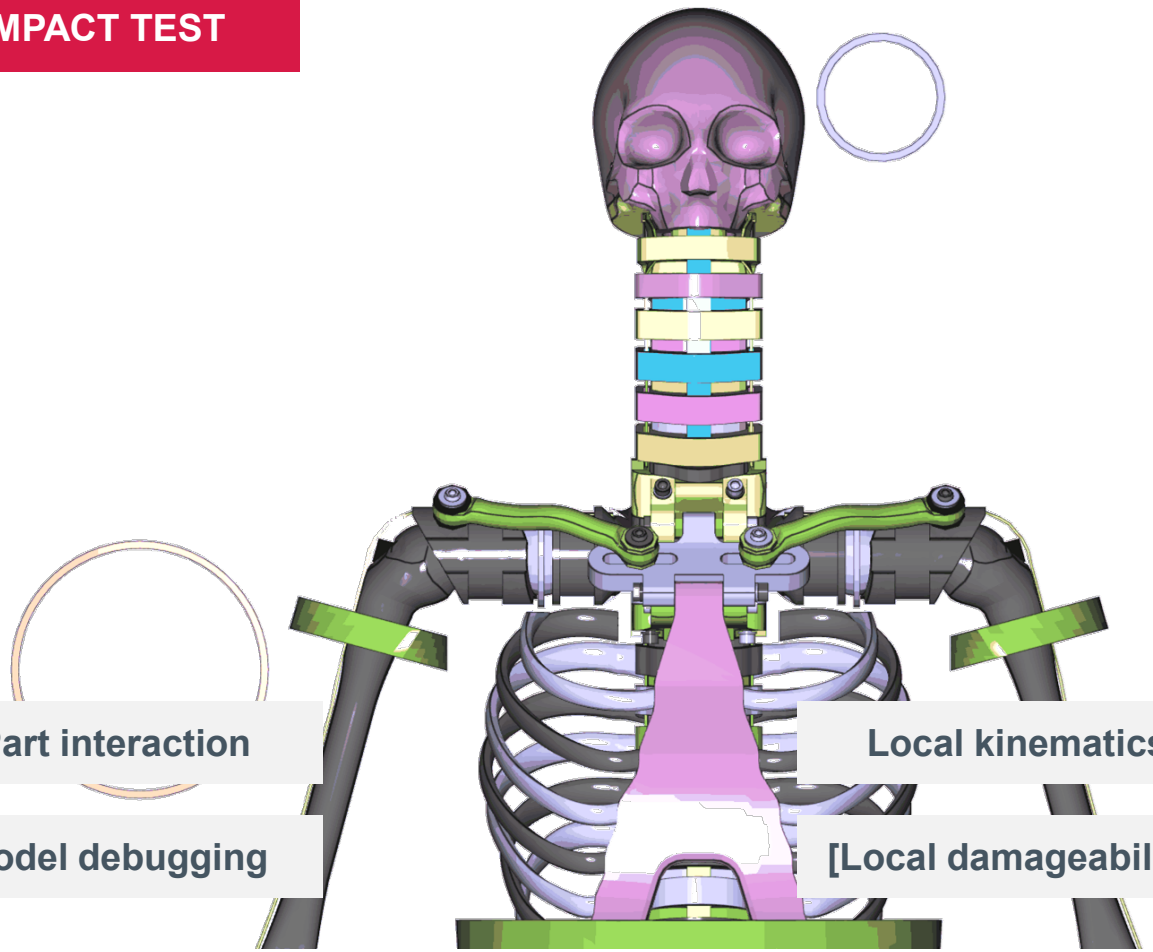






PRIMUS BREAKABLE® MODEL TEST
IMPACT LOAD CASE

IMPACT TEST



Part interaction

Local kinematics

Model debugging

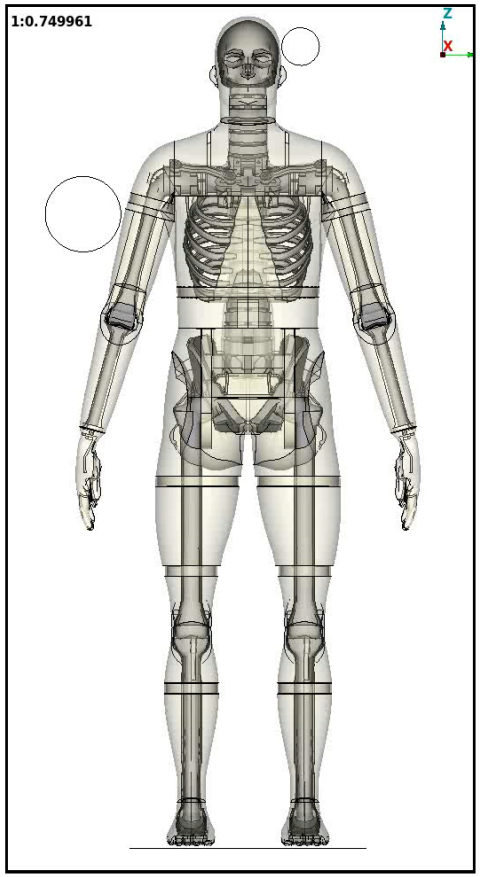
[Local damageability]

PRIMUS LS-DYNA

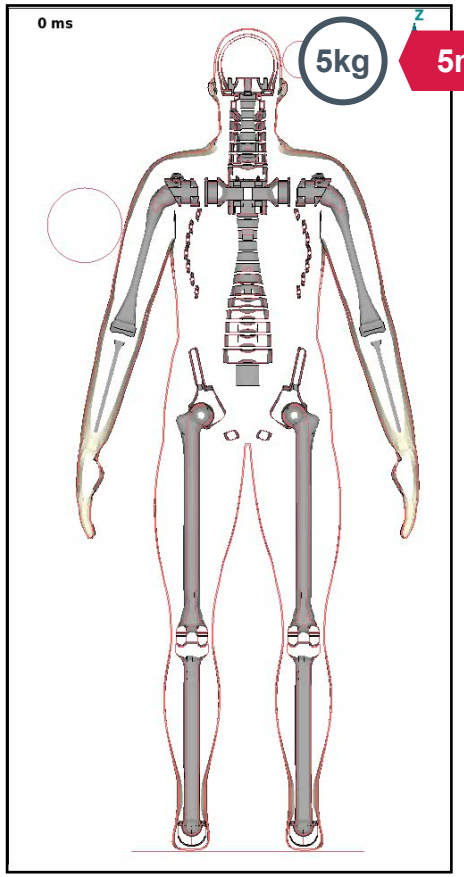
PRIMUS IMPETUS

PRIMUS BREAKABLE® MODEL TEST
HEAD IMPACT LOAD CASE

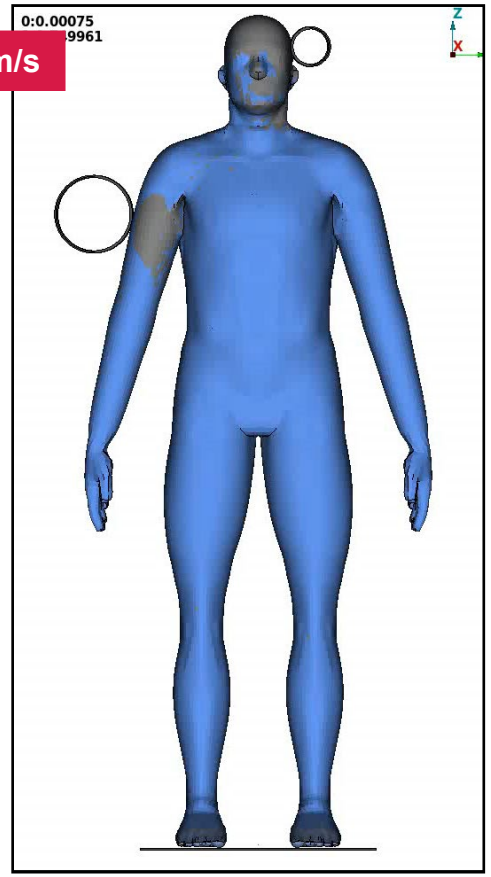
PRIMUS LS-DYNA



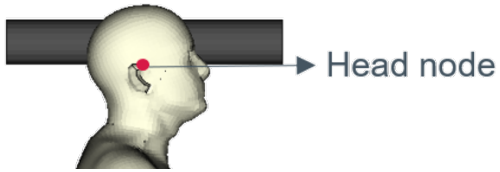
PRIMUS LS-DYNA SECTION

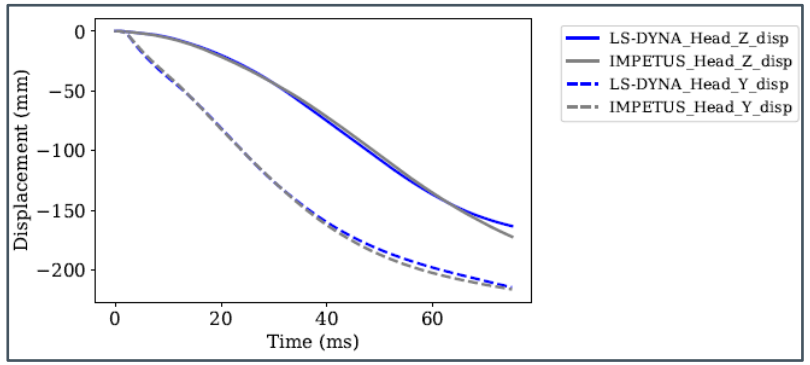


PRIMUS IMPETUS
PRIMUS LS-DYNA



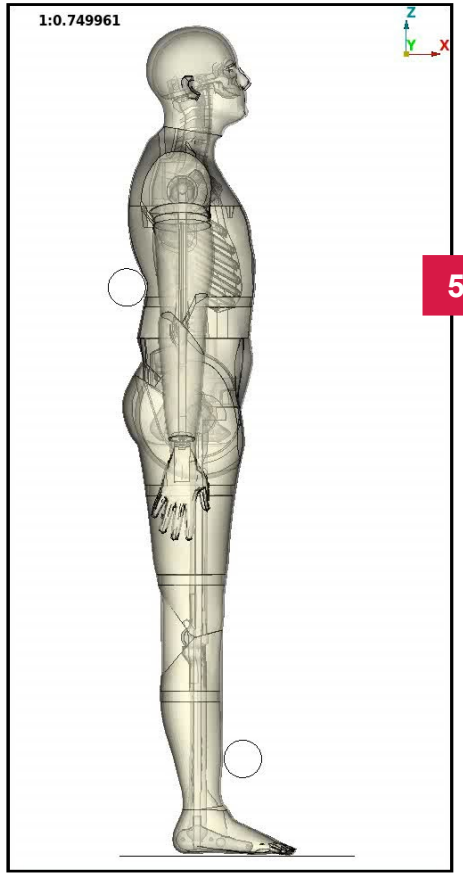
- Realistic neck movement- could be attributed to a vertebral system with distinct vertebrae
- Element distortion and instability in soft tissues seen in **PRIMUS LS-DYNA** version





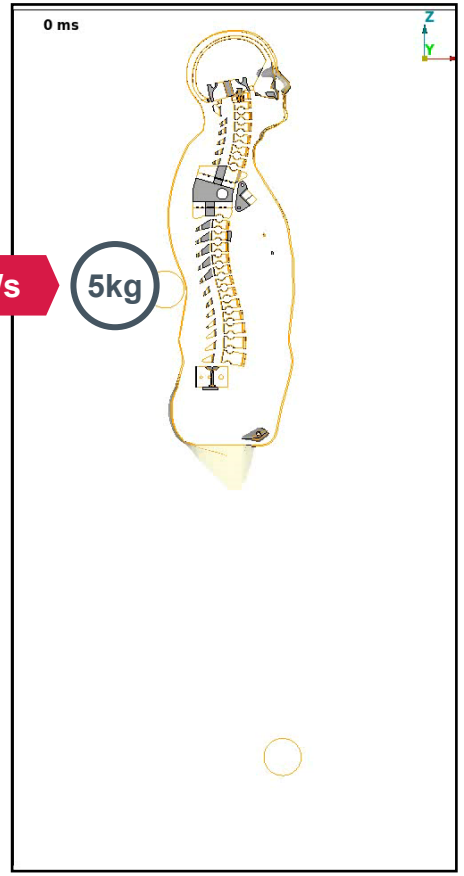
PRIMUS BREAKABLE® MODEL TEST
FULL BODY IMPACT LOAD CASE

PRIMUS LS-DYNA

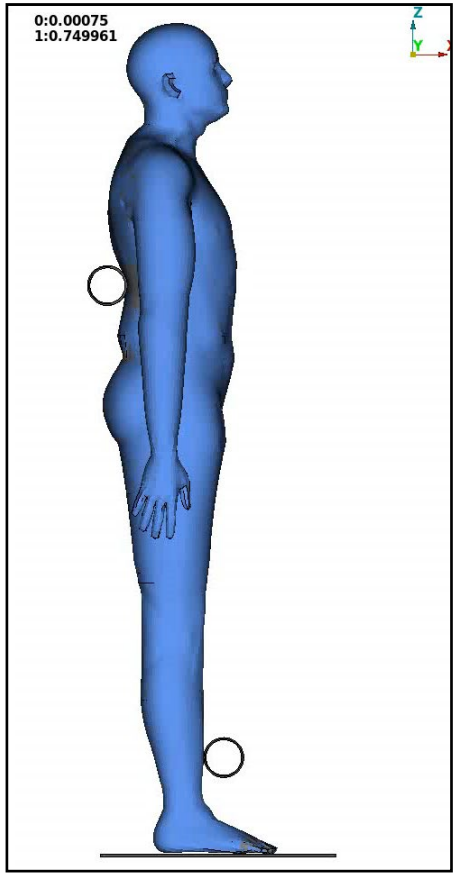


5m/s

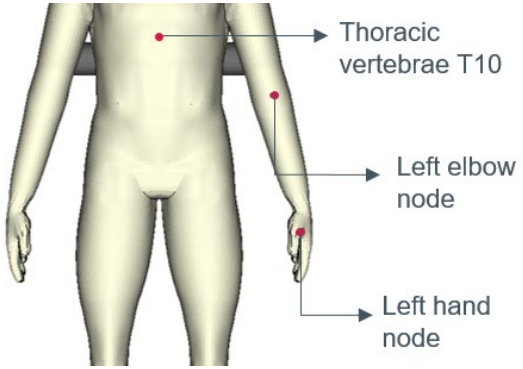
PRIMUS LS-DYNA SECTION

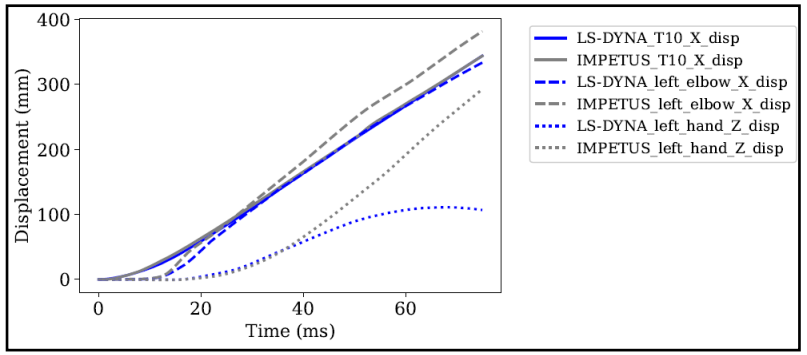


PRIMUS IMPETUS
PRIMUS LS-DYNA



- Complete destruction of the spine
- Element distortion and instability in soft tissues seen in **PRIMUS LS-DYNA** version



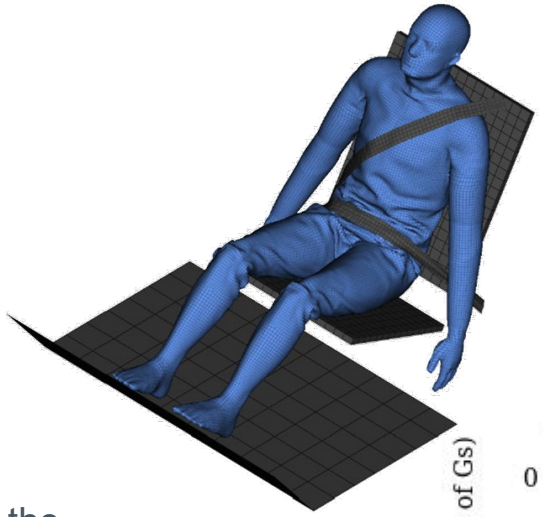


PRIMUS BREAKABLE® MODEL TEST
OCCUPANT SAFETY LOAD CASE

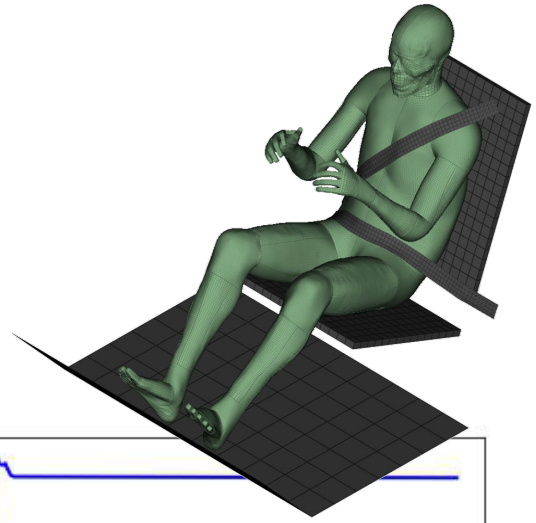
OCCUPANT SLED TEST

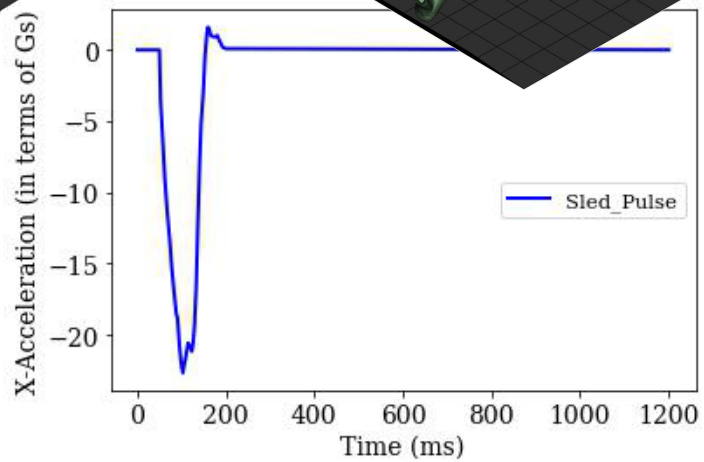
Global kinematics

PRIMUS LS-DYNA



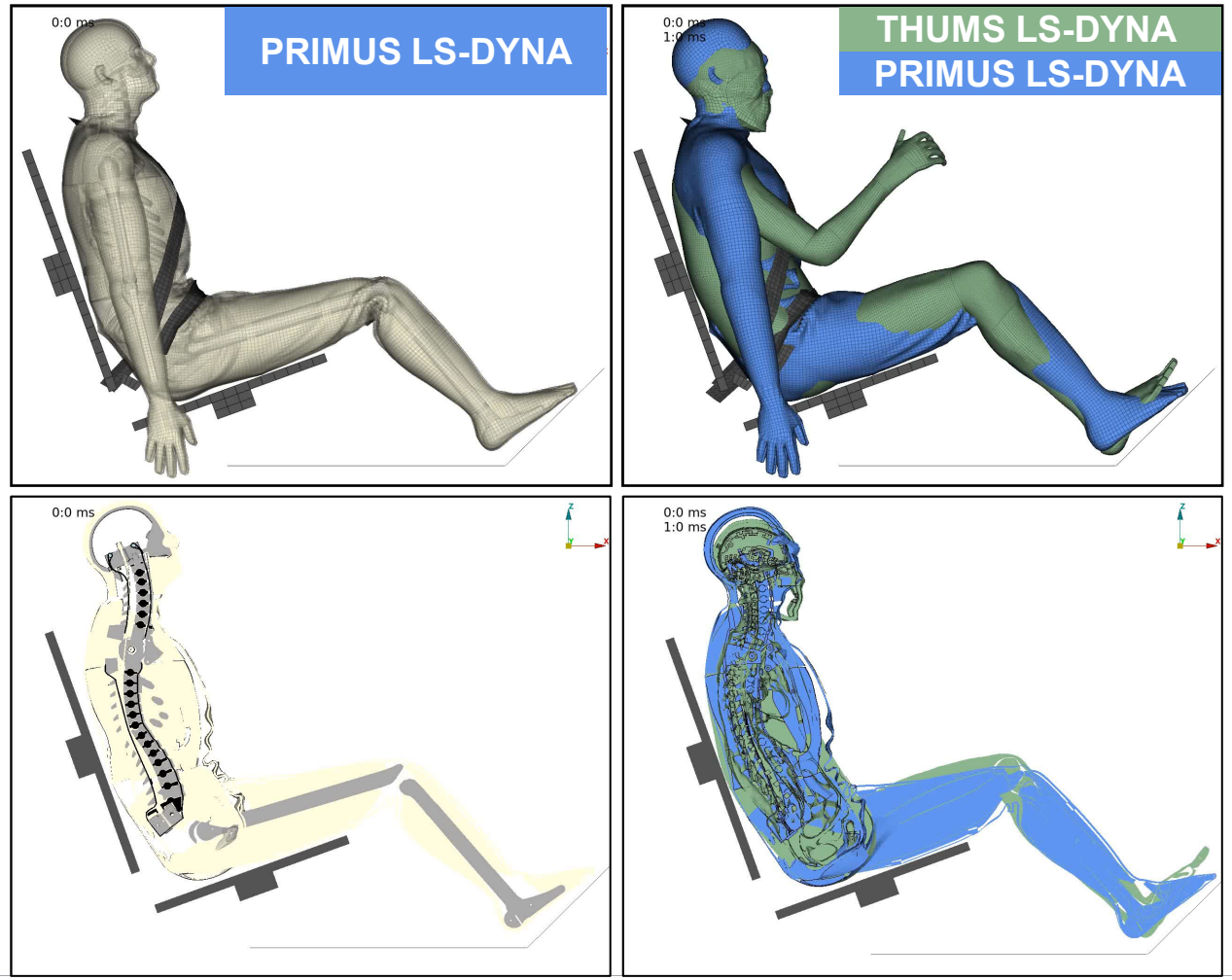
THUMS LS-DYNA

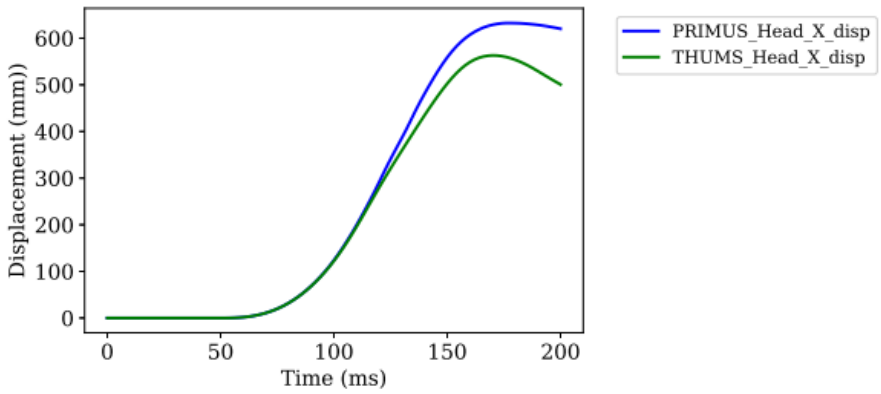




- Frontal sled load case setup to compare full-model response of the **PRIMUS LS-DYNA** with the **THUMS LS-DYNA** model (AM50 Version 7)
- Basic kinematic comparison (no injury comparison)
- Sled subjected to maximum deceleration of 22.79g (initial velocity 14m/s)
- Lap and shoulder belt to restrain the movement of the models with a force limiting system at 4kN

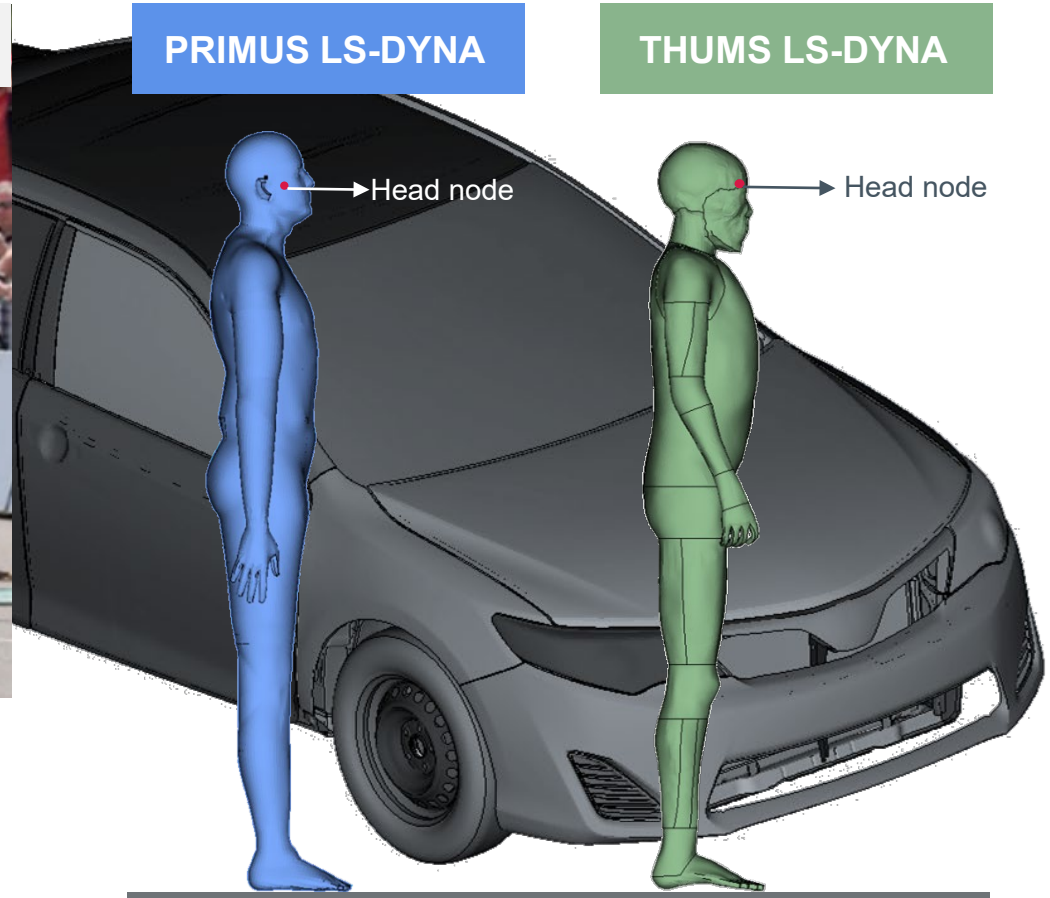
PRIMUS BREAKABLE® MODEL TEST
OCCUPANT SLED LOAD CASE





- Bulk of the soft tissue is stiffened compared to original calibrated material model in **PRIMUS LS-DYNA** due to errors / excessive deformation
- Different neck behavior of **Primus IMPETUS** compared to **PRIMUS LS-DYNA**
- High wrinkling in skin surrogate in **Primus IMPETUS** and **PRIMUS LS-DYNA** version
- Numerical instabilities (quite normal for HBMs) occuring faster than expected in **PRIMUS LS-DYNA** version

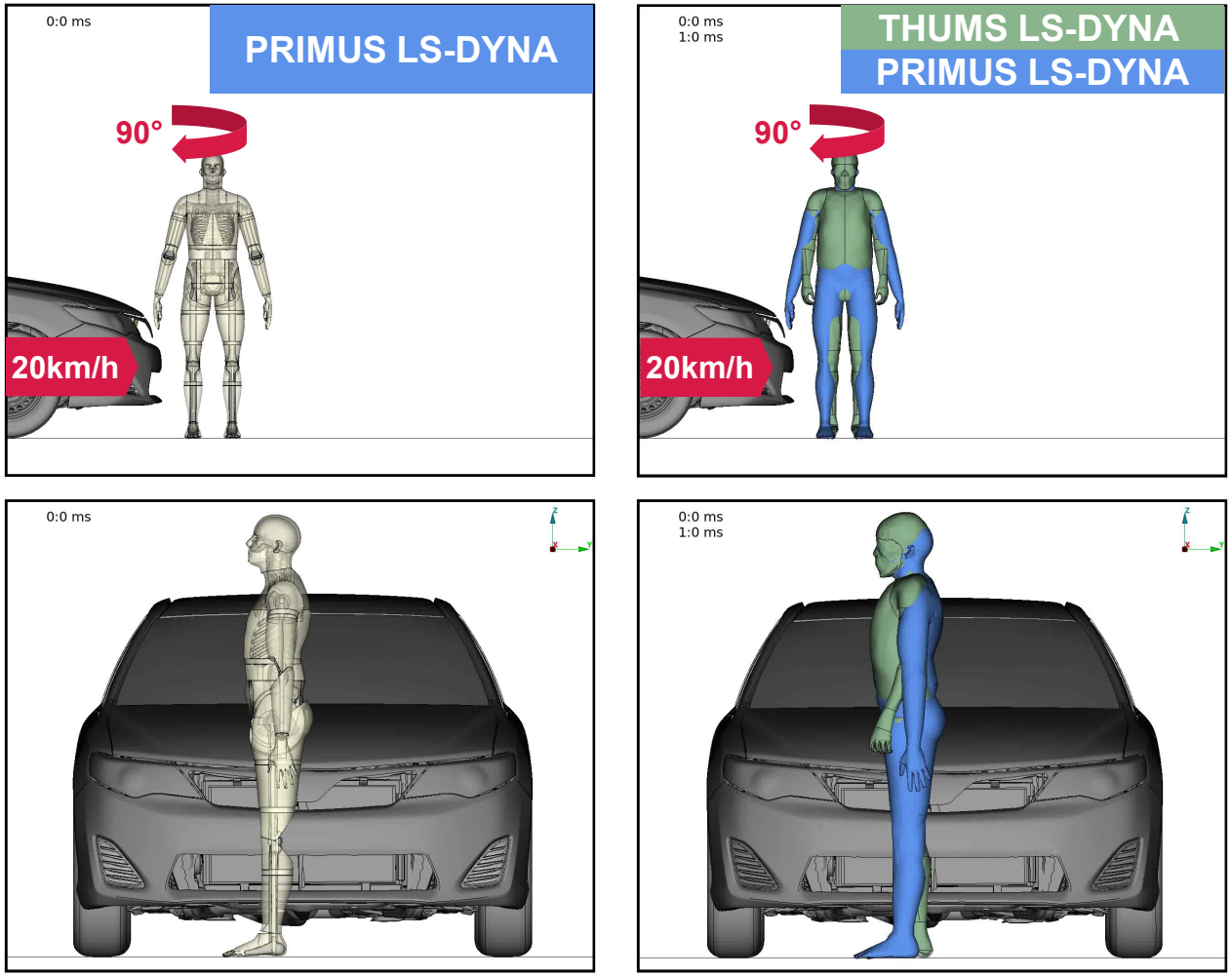
PRIMUS BREAKABLE® MODEL TEST
PEDESTRIAN PROTECTION LOAD CASE

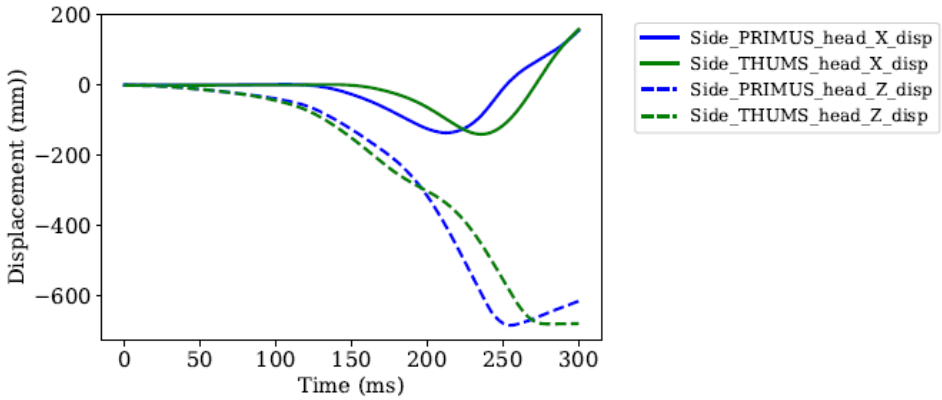


OPEN SOURCE TOYOTA CAMRY LS-DYNA

- Open source **TOYOTA CAMRY LS-DYNA** used as crash vehicle
- Basic global kinematic comparison of **PRIMUS LS-DYNA** and **THUMS LS-DYNA** (no injury comparison)
- Foreward, side and obique impact at 20km/h

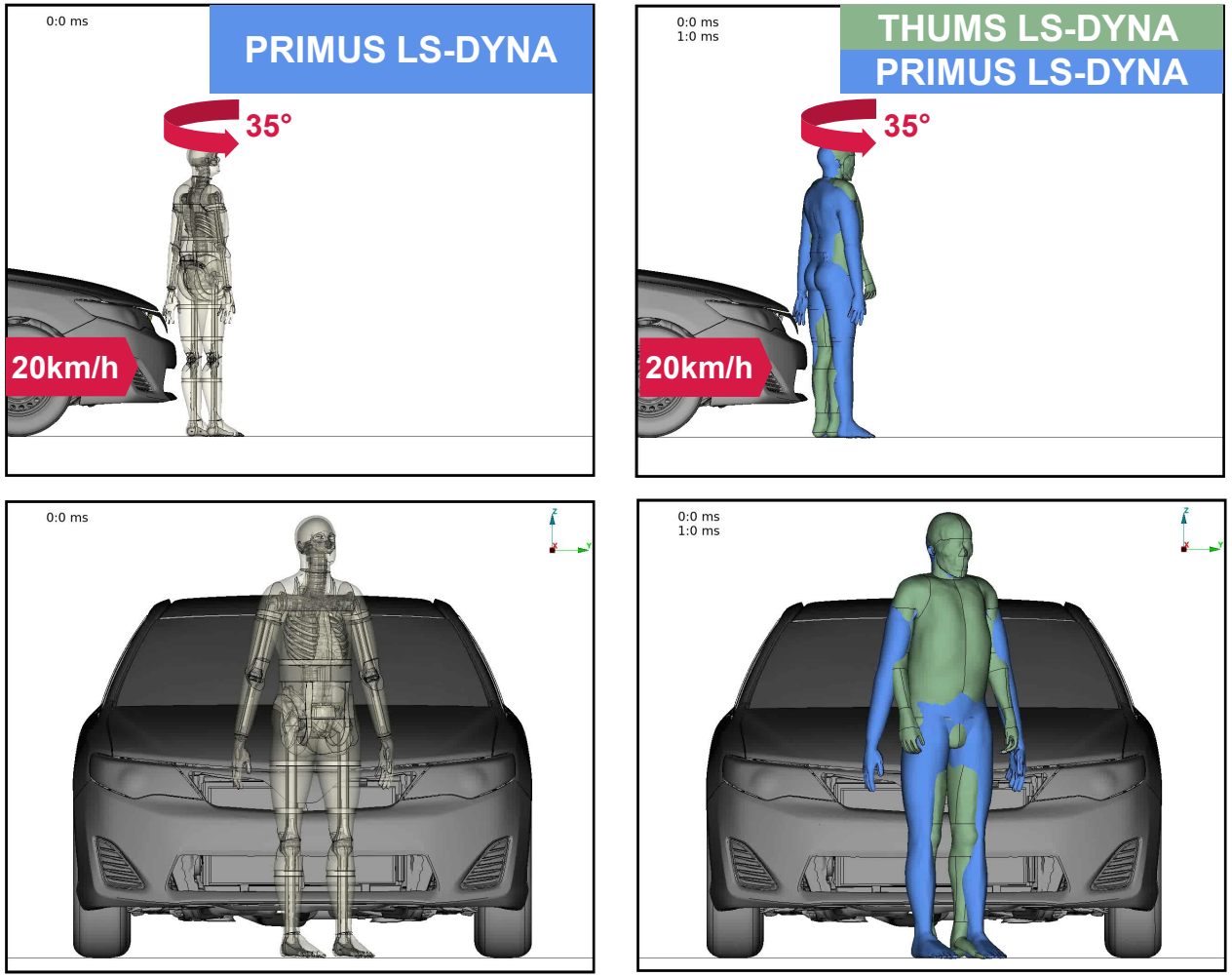
PRIMUS BREAKABLE® MODEL TEST
SIDE-FACING LOAD CASE

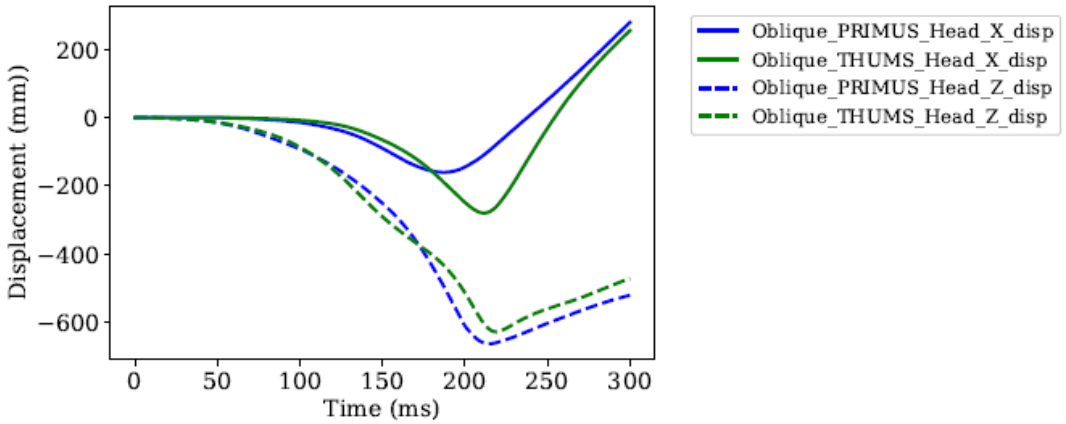




- Biofidelic leg movement of **PRIMUS LS-DYNA** model, **THUMS LS-DYNA** model seems to swing upwards much faster due to highter material stiffness
- The lower extremities of the **PRIMUS LS-DYNA** get caught under the vehicle for a few milliseconds
- Element distortion and instability in soft tissues seen in **PRIMUS LS-DYNA** version
- Magnitudes of head displacement is very similar in both models

PRIMUS BREAKABLE® MODEL TEST
OBLIQUE-FACING LOAD CASE





- Biofidelic leg movement of PRIMUS LS-DYNA model, THUMS LS-DYNA model seems to swing upwards much faster due to highter material stiffness
- Element distortion and instability in soft tissues seen in PRIMUS LS-DYNA version
- Increased head swing-back of THUMS LS-DYNA model compared to PRIMUS LS-DYNA model leading to a sharper head-displacement vs time curve

PRIMUS BREAKABLE® MODEL
CONCLUSION

EDAG

CONCLUSION

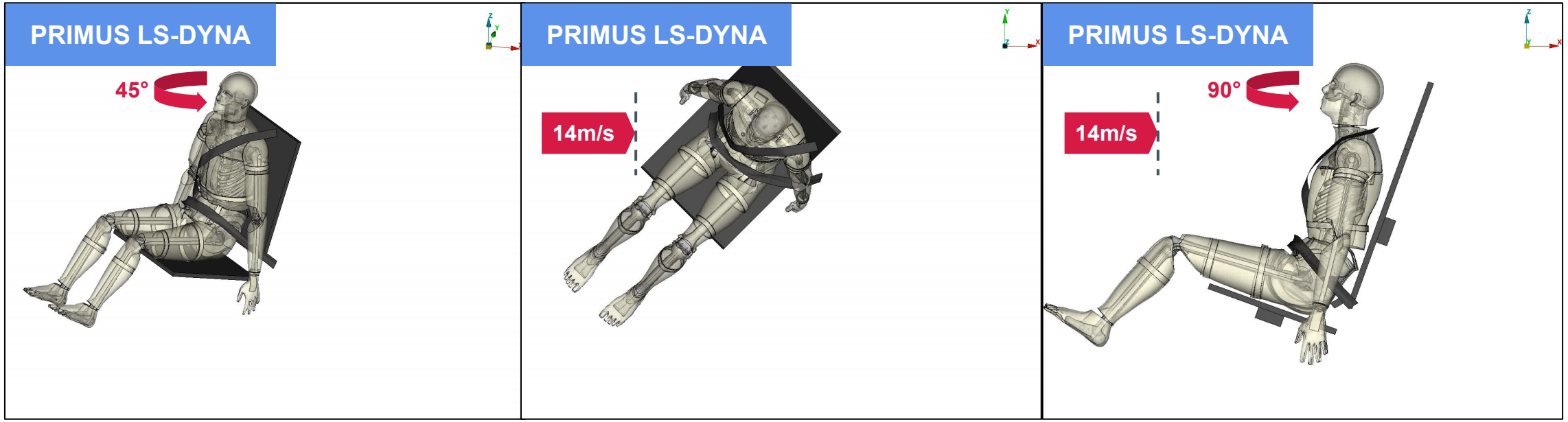
- The material models developed for use in the **PRIMUS LS-DYNA** are good representations of the available experimental test data
- The **PRIMUS LS-DYNA** model is comparable with the **Primus IMPETUS** model, but shows high element distortion and material instability in deformed areas.
- The **PRIMUS LS-DYNA** model shows similarities with the **THUMS LS-DYNA** model kinematics in impact and sled configurations
- Improvement of **material models** and **contact stability** is required.

FUTURE WORK

- Implementation of **material failure** will follow
- Further material modelling at **multiple strain rates** and **multiple loading conditions** needed
- Further studies on soft **tissue surrogate** material model **stability** planned
- A more efficient and streamlined **dummy positioning process** is necessary
- Dummy **component-based**, **subsystem level validation** and **full-dummy testing** required to increase accuracy of predictive capabilties of the model

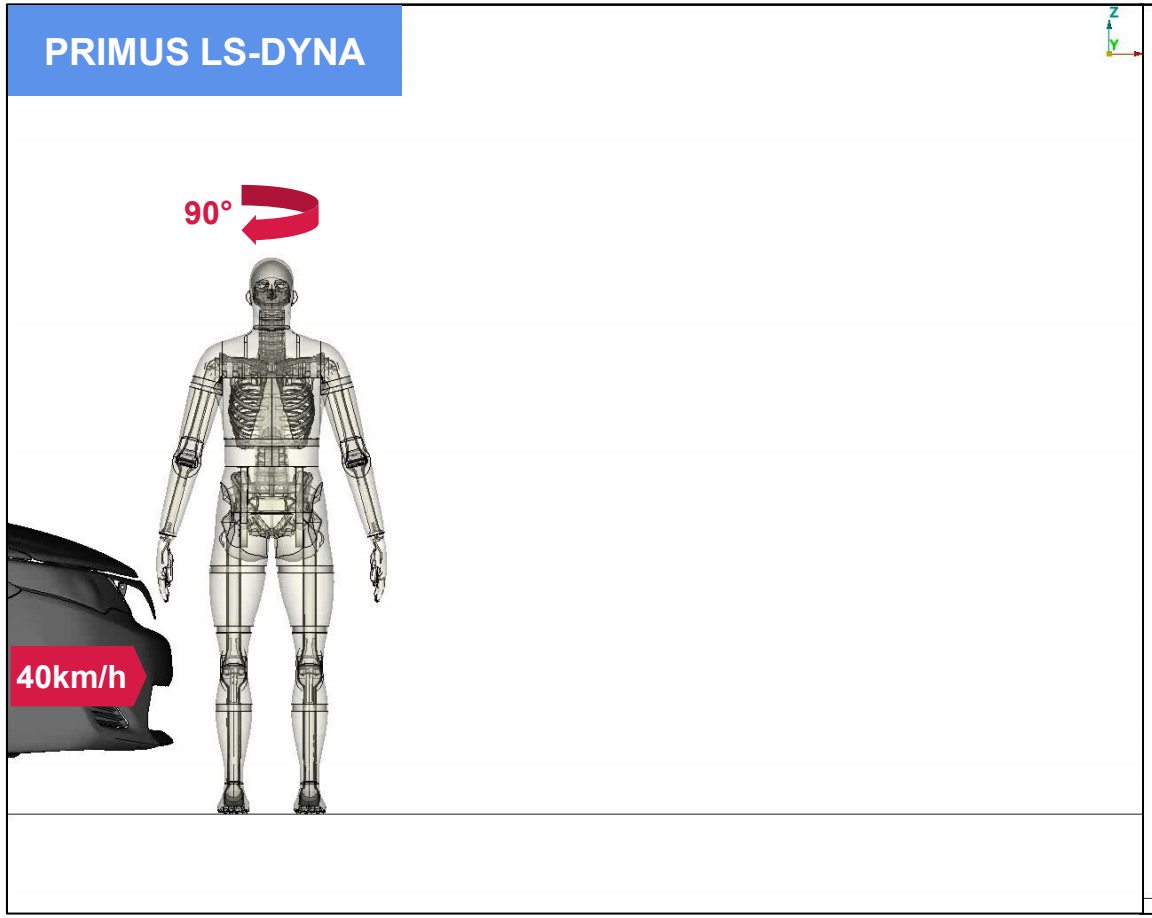
PRIMUS BREAKABLE® MODEL
OUTLOOK OCCUPANT SAFETY

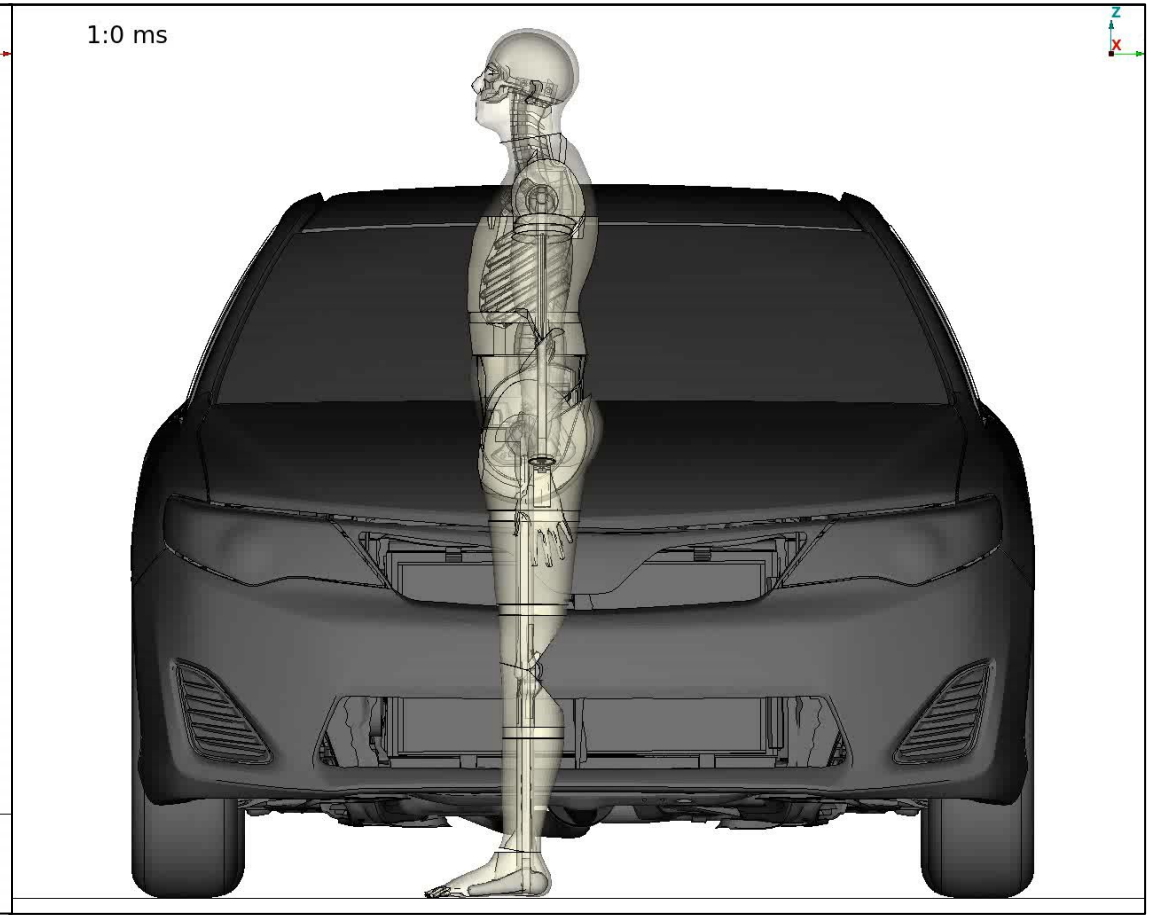
Occupant Safety



PRIMUS BREAKABLE® MODEL
OUTLOOK PEDESTRIAN PROTECTION

Pedestrian Protection





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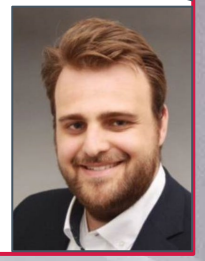
jan.bohlen@edag.com

Tel.: +49 841 9680 4898
Mobil: +49 151 1850 3556

Project Leader Defence
Blast & Ballistic Simulation



THANK YOU.