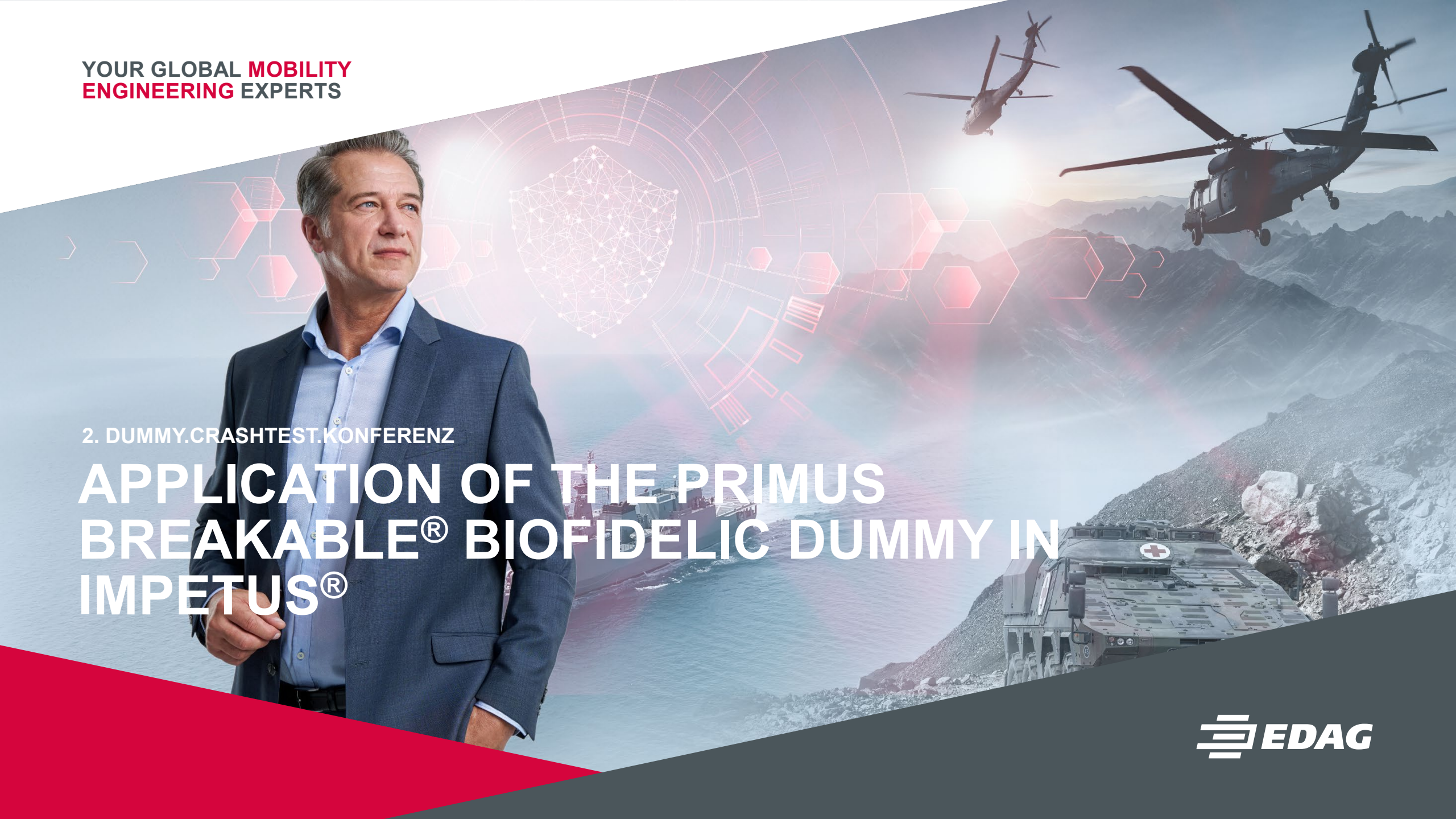
YOUR GLOBAL **MOBILITY**
ENGINEERING EXPERTS



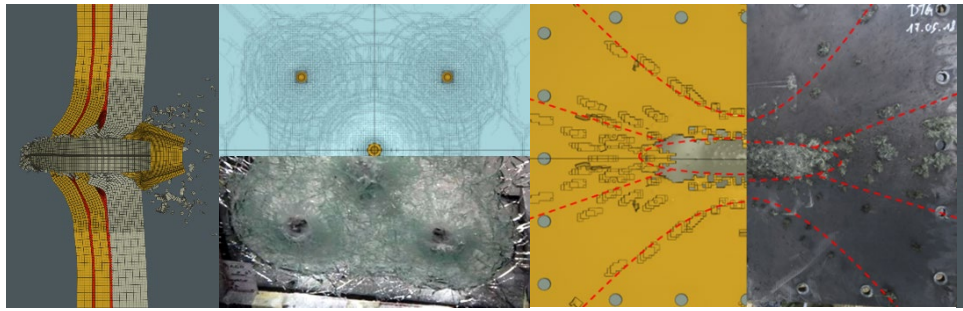
2. DUMMY.CRASHTEST.KONFERENZ

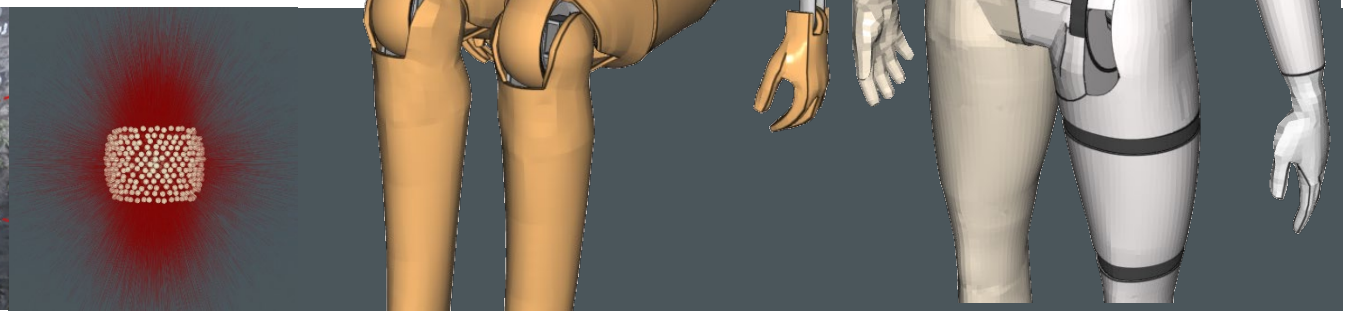
APPLICATION OF THE PRIMUS BREAKABLE® BIOFIDELIC DUMMY IN IMPETUS®

EDAG

AGENDA
2. DUMMY.CRASHTEST.KONFERENZ

1. **Introduction in armoured vehicle development**
   a. Development process and occuring injury mechanisms
   b. Certification approach according to VPAM ERV Ed. 3 and STANAG 4569
2. **Development of the PRIMUS Breakable® model for IMPETUS®**
3. **Use case comparison of the PRIMUS Breakable® and Hybrid III®**
   a. Vertical loading condition after a mine detonation underneath a structure
   b. Secondary projectile impact after an IED detonation
   c. Forensic reconstruction of an accident with a „Panzerfaust 3“ at the WTD 91
4. **Conclusion**





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DEVELOPMENT OF ARMOURED VEHICLES
OBJECTIVE AND INJURY

Protection of human life

Civil: Withstand the attack and initiate the escape!

http://news.bbc.co.uk/nol/shared/spl/hi/pop_ups/03/uk_enl_1069160874/img/1.jpg

https://media1.faz.net/ppmedia/aktuell/3768422299/1.6504913/format_top1_breit/1989-polizeibeamte-stehen-in.jpg

https://www.rbc.ua/static/ref/img/mercedes432.jpg

https://noticias.coches.com/wp-content/uploads/2015/08/Blindado.jpg

Military: Take countermeasures and fulfill the mission!

https://img.apmcdn.org/61dbcf54e60788d210c87e94a09281066ec67d2c/uncropped/bcc01f-20060315-humvee.jpg

https://www.theguardian.com/world/2007/aug/23/iraq-us-military

https://media0.faz.net/ppmedia/aktuell/politik/204102126/1.1073832/mmobject-still_full/verlust-der-bundeswehr-in.jpg

https://augengeradeaus.net/wp-content/uploads/2020/01/20200101_Mali_BEL_Dingo_3.jpg

Damages / Injuries	Primary injuries Shockwaves	Secondary injuries Fragments	Tertiary injuries Accelerations
	• **Traumatic amputation**, large deformation of soft tissue • **Splinter fractures** due to the explosiveness of the explosive • **Injuries to air-filled organs** (lungs, abdomen) • **Eardrum injuries**	• **Penetrating wounds**, which occur mainly on the lower extremities and the face • **Splinter fractures on the extremities** due to the impact of fragments	• **Injuries to the lower extremities** by vertical loading • **Thigh injuries or femural fracture** by hitting other parts • **Blunt injuries** by contact with the vehicle structure • **Fractures of the extremities and skull** through contact with the vehicle structure

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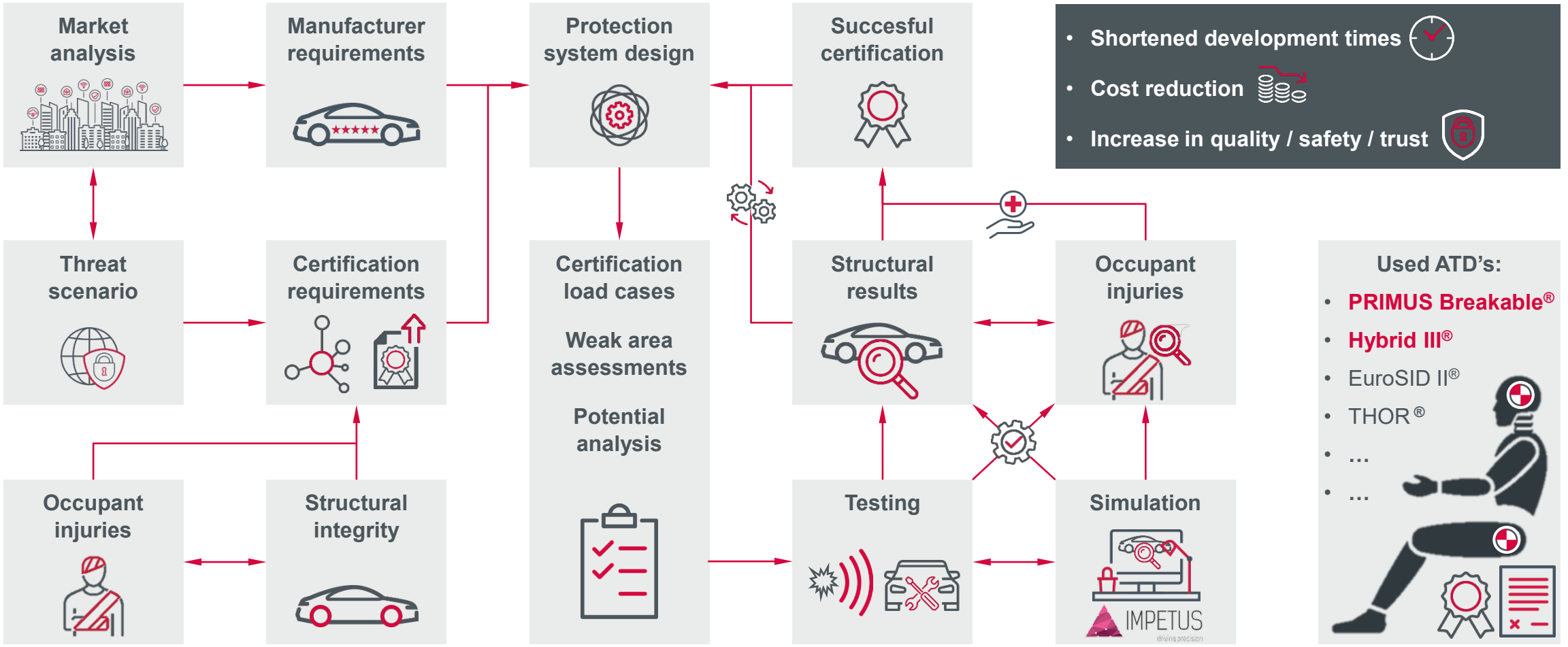
CHANGES IN ARMOURED VEHICLE DEVELOPMENT **PROCESS**



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VALUATION APPROACHES OF INJURIES
ADMISSIBILITY & EVALUATION

Civil VPAM ERV Ed. 3

Continuous evaluation spectrum!

Mandatory use of the CTS Primus Breakable® biofidelic dummy

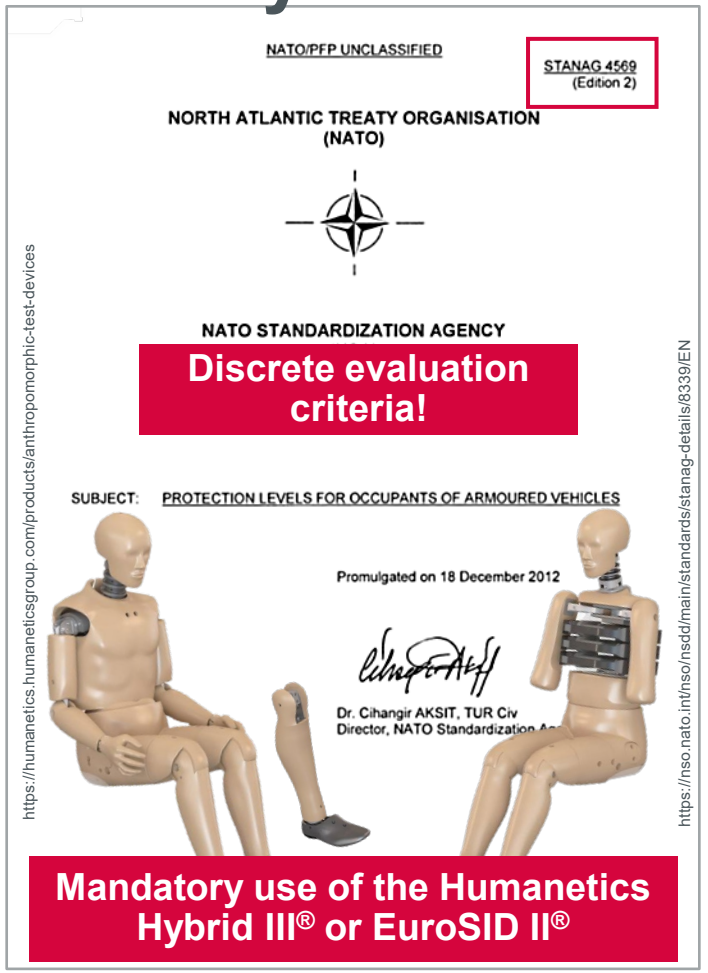
Comparison

Surviveability	**Permissible Injuries**	**Combat ability**
Biofidelic behavior	**Design of the dummy**	**Fatigue strength**
Flexible	**Application**	**Restricted to load case**
Mostly representable	**Relevant injuries**	**Conditionally representable**
Detailed autopsy	**Evaluation**	**Discrete measurements**
~ 26.000€ (refurbishable)	**Buying costs per Dummy**	**> 250.000€** (multi time use)

Biofidelity:

The imaging quality of a model regarding the simulation of a biological system e.g., the human

Military STANAG 4569



Discrete evaluation criteria!

Mandatory use of the Humanetics Hybrid III® or EuroSID II®

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PRIMUS BREAKABLE®
IN IMPETUS AFEA SOLVER®

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

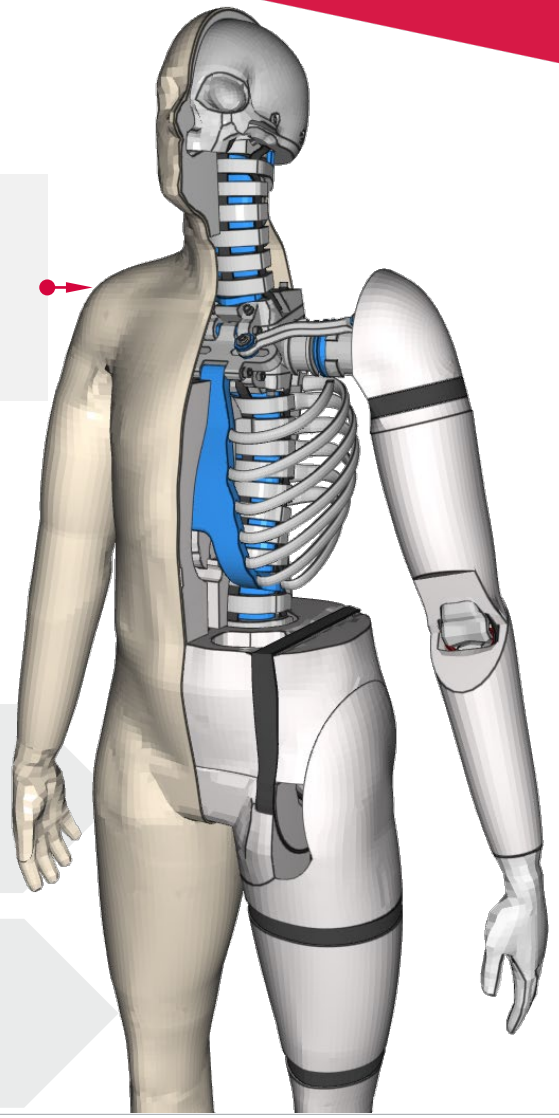
Structural results

Testing

Optimized design of protection systems!

Simulation

Damage / Injury mechanisms



Cooperation:

Hochschule für Technik und Wirtschaft Dresden
University of Applied Sciences

CTS crashtest-service

EDAG

CAD-Geometry preparation:

CATIA

Meshing & Pre-Processing:

ANSA PRE PROCESSOR

Solving & Post-Processing:

IMPETUS driving precision

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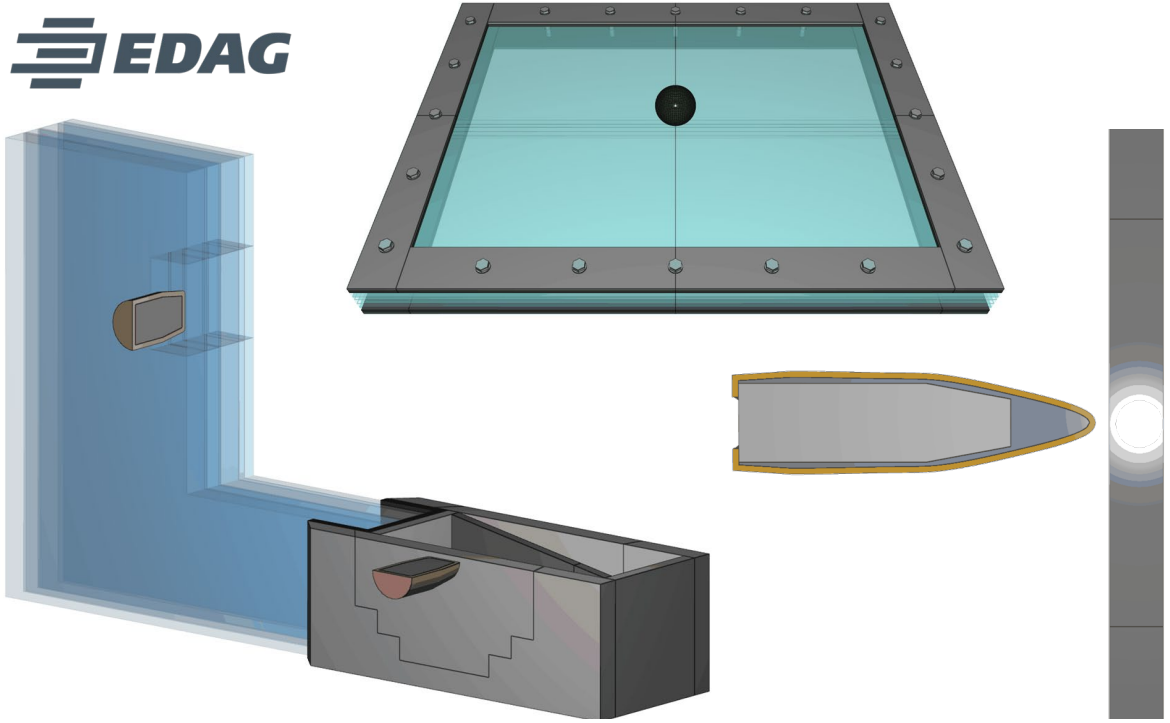
NUMERICAL SOLVER
IMPETUS AFEA SOLVER®

General fields of application:

- **Large deformations and high degrees of deformation**
  - Extreme speeds (explicit solver)
  - Particle conversion
- **Material behavior under extreme loading conditions**
  - Variety of detailed material and failure models
  - Node splitting algorithm to represent cracking
- **Structural interaction of pressure waves**
  - Discrete particle method DP (gases and granules)
  - Smoothed particle hydrodynamics SPH (liquids)

Simulation as a Development-Tool:

- **Understanding of the causal relationships**
  - Optimizations and structural improvements
- **Virtual evaluation of certification load cases**
  - Possibility to save several prototypes in the long term



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MODELING OF THE PRIMUS BREAKABLE®
SURROGATE MATERIALS

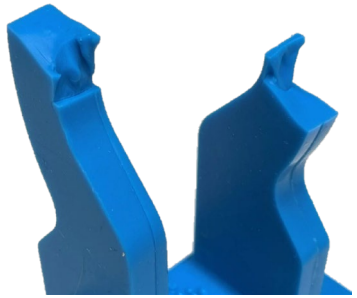
Surrogate Materials

- Validation of the material models based on material tests

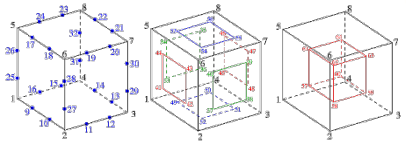
Fitting of the stress-strain curves under realistic damage behavior!

Further Materials

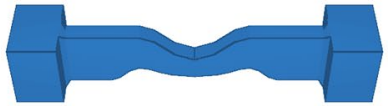
- Skin surrogate and elastic-band
- Wire-cable and steel screws



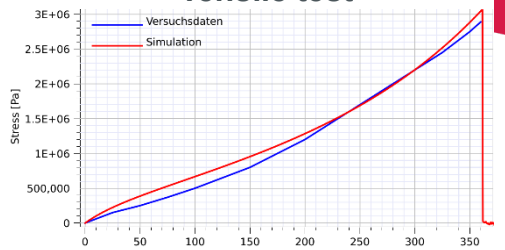
Soft-tissue surrogate



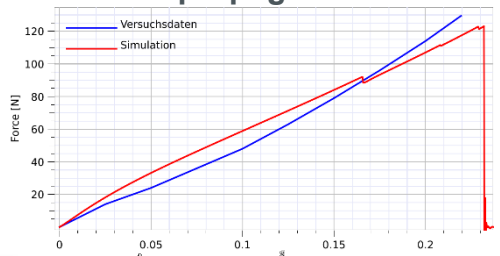
$\emptyset\ 8{,}0 - 10{,}0mm$
cubic



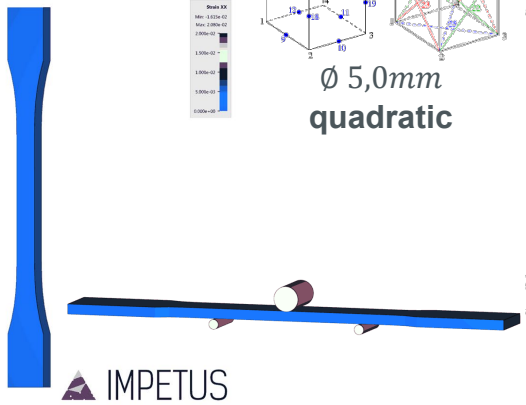
Tensile test



Tear propagation test

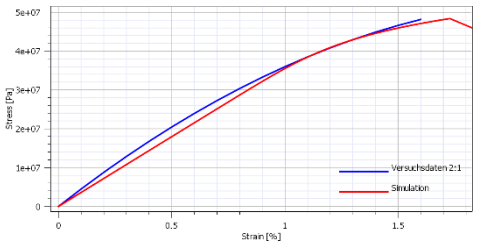


Bone surrogate

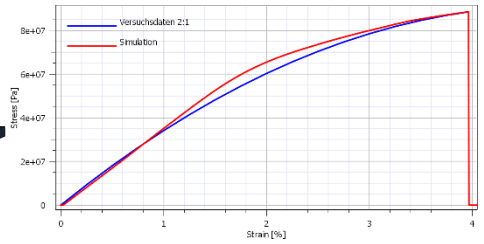


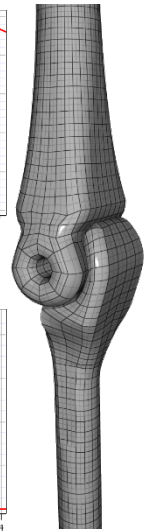
$\emptyset\ 5{,}0mm$
quadratic

Tensile test

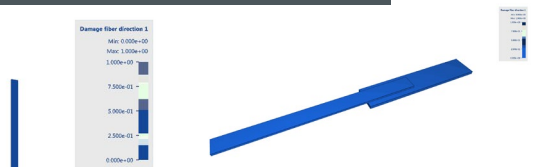


Bending test

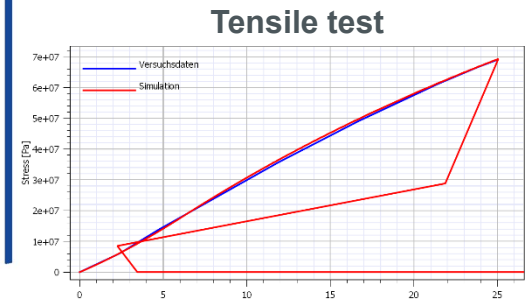


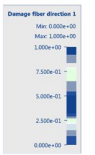


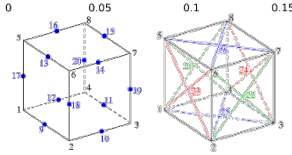
Ligament surrogate



Tensile test

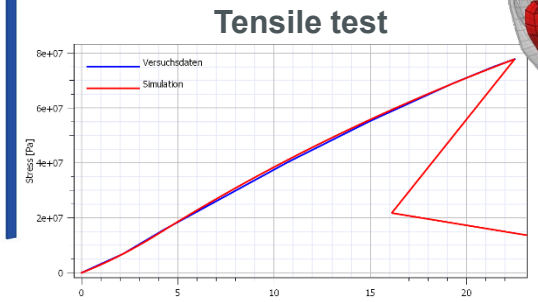


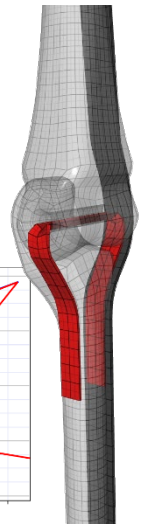




$\emptyset\ 5{,}0 - 10{,}0mm$
quadratic

Tensile test





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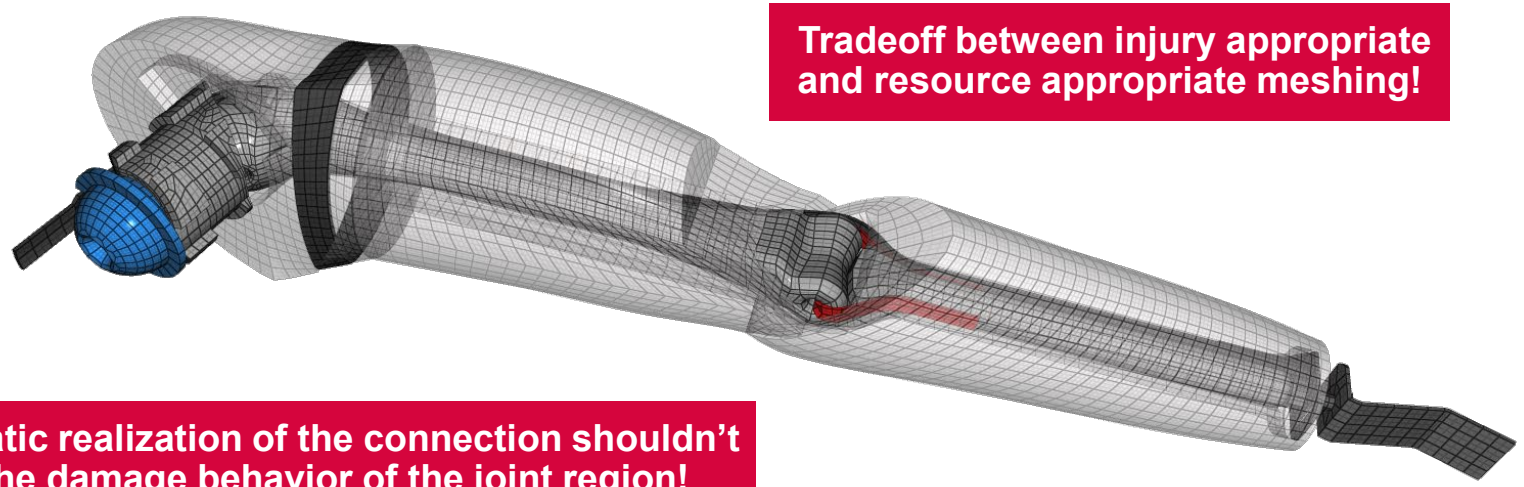
MODELING OF THE PRIMUS BREAKABLE®
MESHING AND CONNECTION TECHNIQUES

Meshing

- Visualisation of fractures, penetrating injuries and torn ligaments

vs.

- GPU memory, number of elements and polynomial order

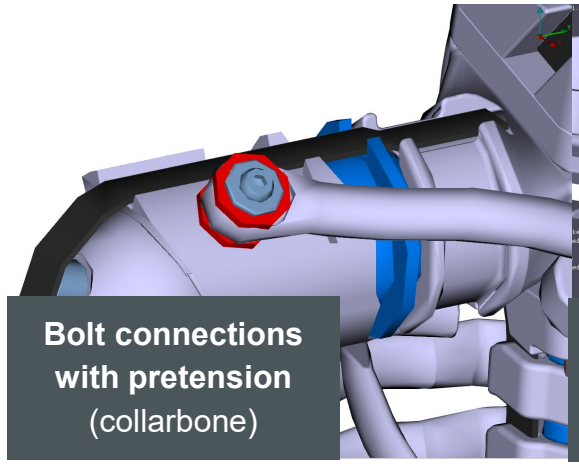


Tradeoff between injury appropriate and resource appropriate meshing!

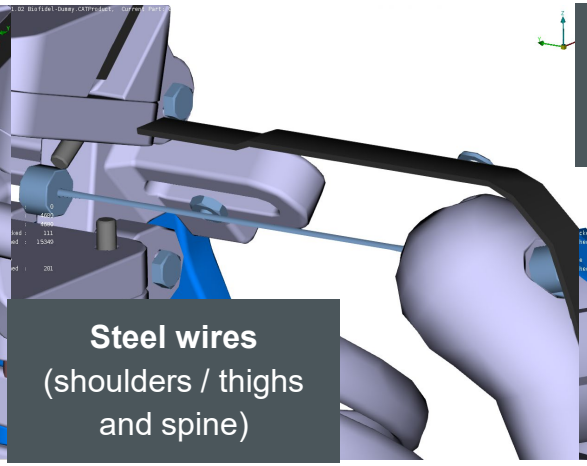
Connections

- Realization of the kinematic degrees of freedom

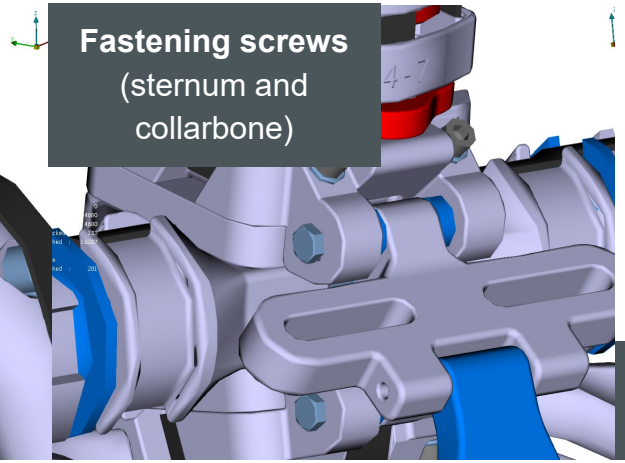
The kinematic realization of the connection shouldn't change the damage behavior of the joint region!



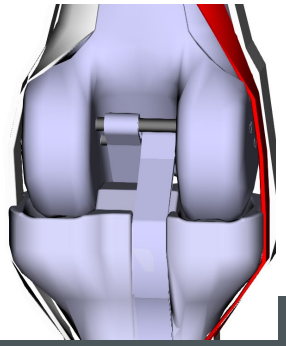
Bolt connections with pretension (collarbone)



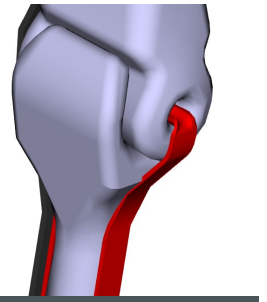
Steel wires (shoulders / thighs and spine)



Fastening screws (sternum and collarbone)



Pin connections (knee joint)



Adhesive (ligaments and tendons)

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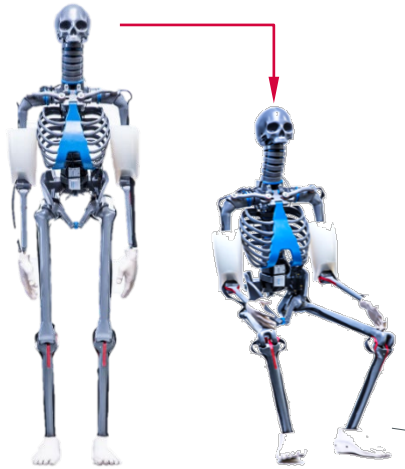
MODELING OF THE PRIMUS BREAKABLE®
POSITIONING & SENSOR SIMULATION

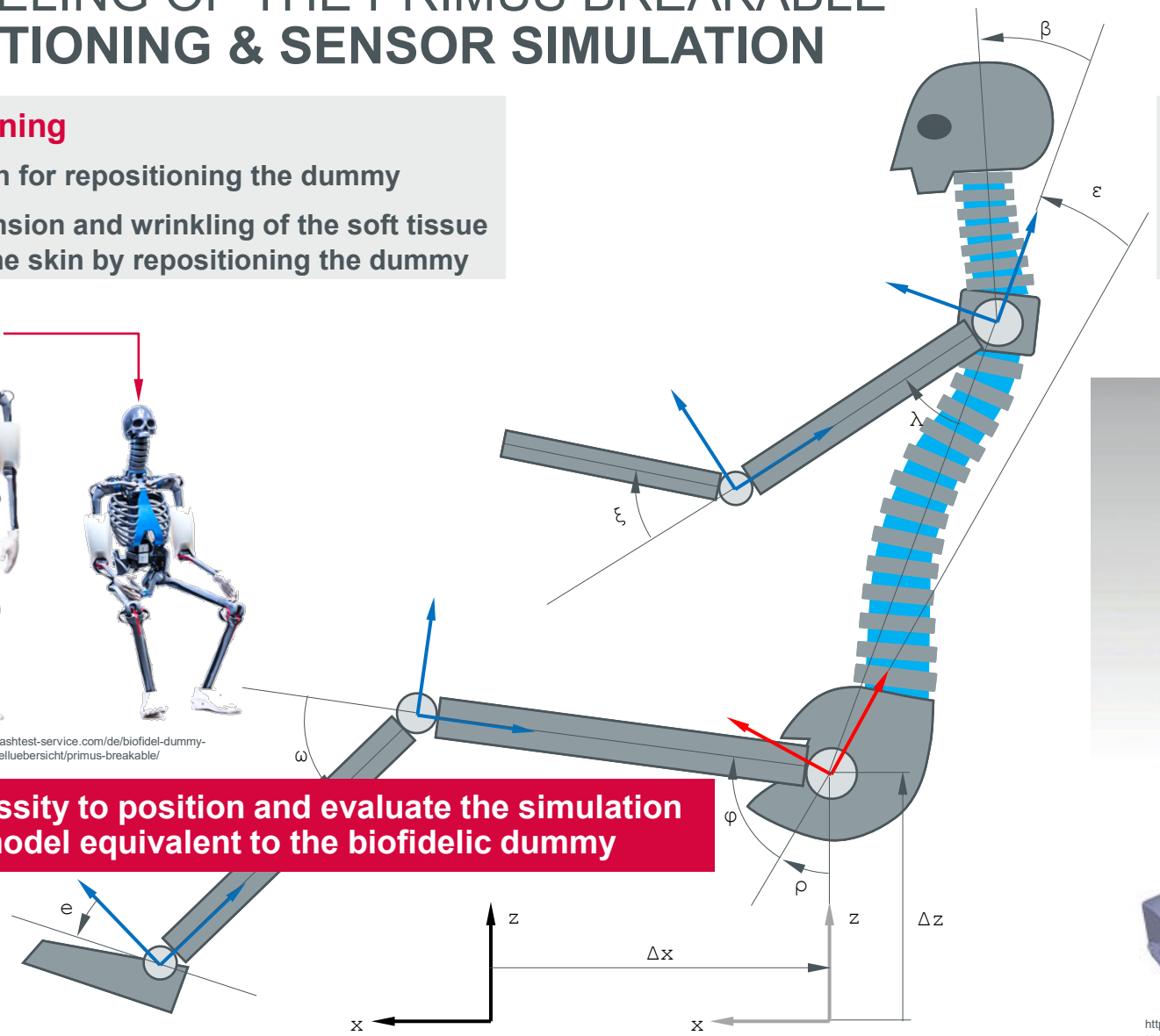
Positioning

- Option for repositioning the dummy
- Pretension and wrinkling of the soft tissue and the skin by repositioning the dummy



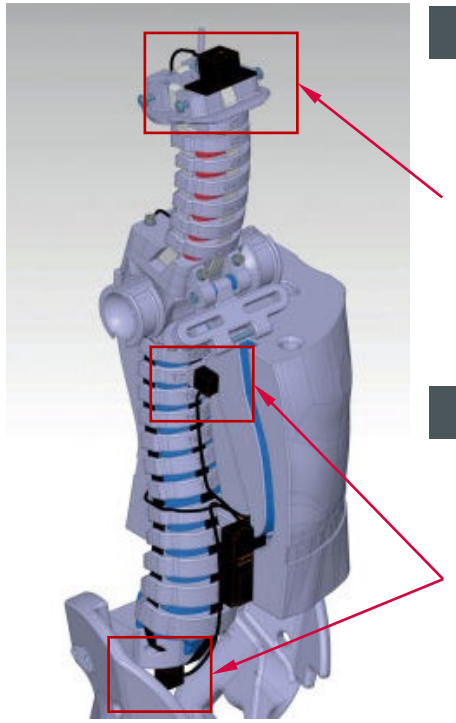
https://www.crashtest-service.com/de/biofidel-dummy-/modelluebersicht/primus-breakable/

Necessity to position and evaluate the simulation model equivalent to the biofidelic dummy



Output / Sensoring

- Representation of the measurement technology for the evaluation of acceleration induced injuries.



https://www.evuonline.org/index.php/publikationen?lang=de&option=com_content&view=article&id=3021

Kistler DTI5002A06

https://www.kistler.com/de/produkt/type-dti5002a06/

Kistler DTI-M60-3K

https://www.kistler.com/de/produkt/type-dti-m60-3k/

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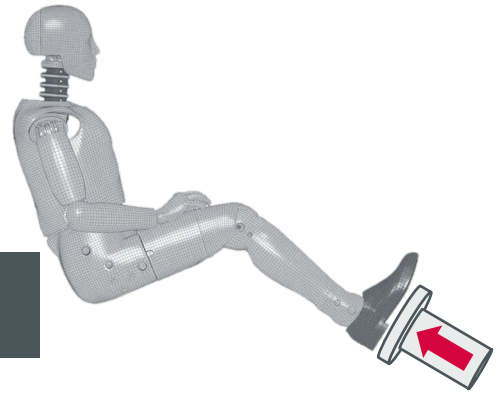
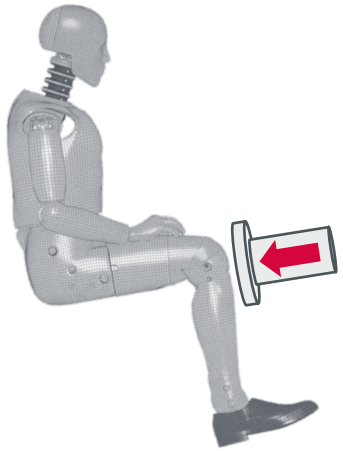
MODELING OF THE PRIMUS BREAKABLE®
SIMULATION MODEL VALIDATION

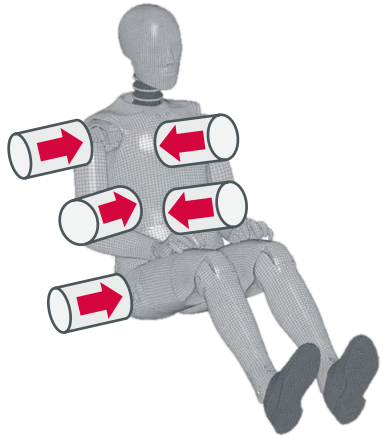
Movement validation

- Testing the kinetic movement and validation of the biofidelic dummy by pendulum tests

Impact mass:	$1.63\text{kg} - 64.0\text{kg}$
Impact velocity:	$4.4\,^{m}/_{s} - 14.3\,^{m}/_{s}$







Use of as many different validation options as possible

Damage validation

- Testing the damage behavior of the biofidelic dummy by ballistic and blast tests

Impact mass:	$0.1\text{kg} - 5.0\text{kg}$
Impact velocity:	$30.0\,^{m}/_{s} - 300.0\,^{m}/_{s}$

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USE CASE COMPARISON
PRIMUS BREAKABLE® & HYBRID III®

Civil VPAM ERV Ed. 3

VPAM | Prüfrichtlinie Sprengwirkungshemmung Sondergeschützte Fahrzeuge - Anforderungen und Prüfverfahren - | VPAM ERV Fassung 3 Stand: 01.03.2021

★★☆

PRÜFRICHTLINIE

Sprengwirkungshemmung
"Sondergeschützte Fahrzeuge"

VPAM-ERV
Fassung 3
Stand: 01.03.2021

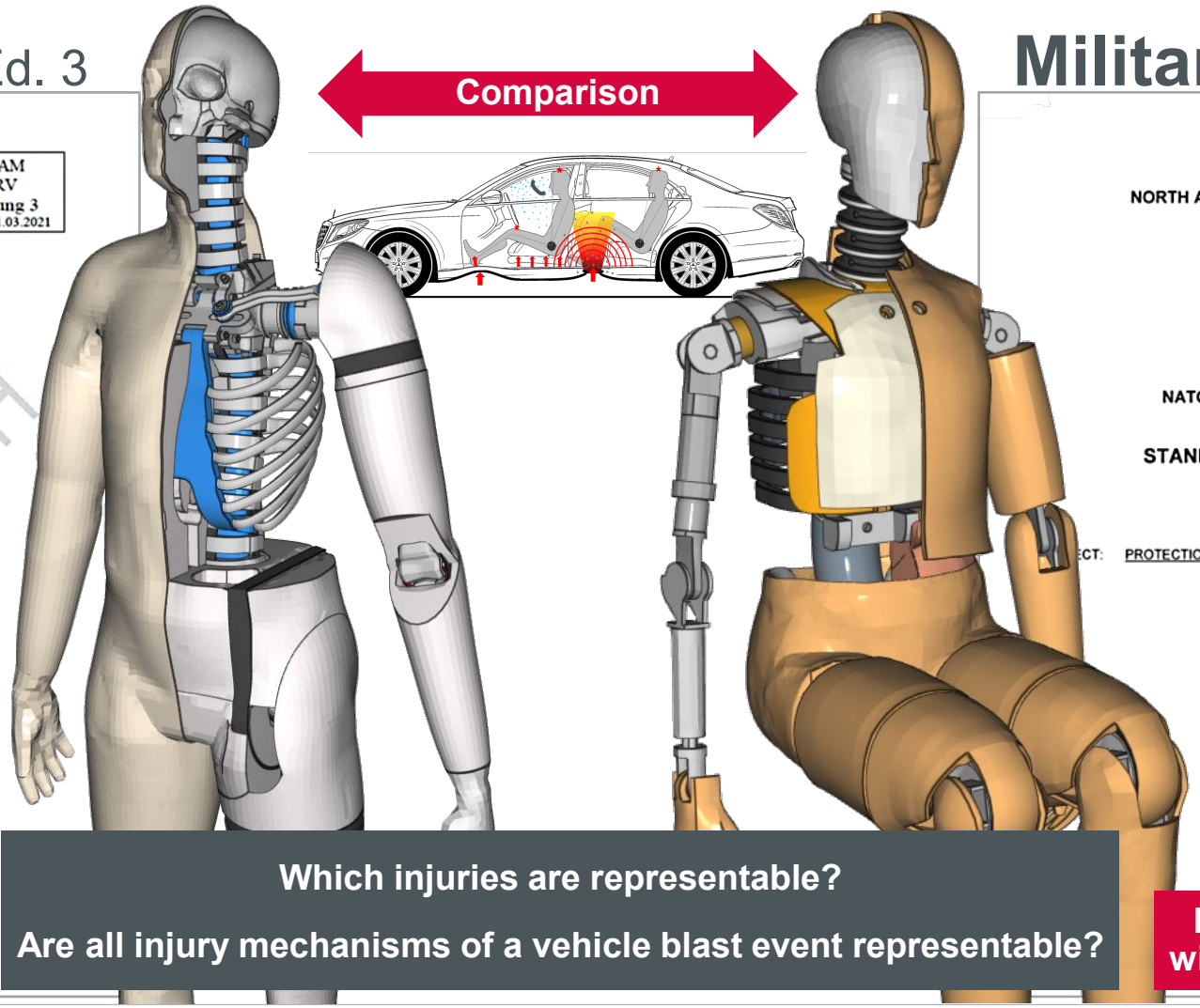
Ausfertigung für die Fahrzeughersteller

Bezugsquelle ist das PTI - Münster

VERTRAULICH

Herausgeber:
Vereinigung der Prüfstellen für angriffshemmende Materialien und Konstruktionen (VPAM)

CTS Primus Breakable® with biofidelic approach



Which injuries are representable?

Are all injury mechanisms of a vehicle blast event representable?

Military STANAG 4569

NATO/PFP UNCLASSIFIED

STANAG 4569
(Edition 2)

NORTH ATLANTIC TREATY ORGANISATION
(NATO)

NATO STANDARDIZATION AGENCY
(NSA)

STANDARDIZATION AGREEMENT
(STANAG)

SUBJECT: PROTECTION LEVELS FOR OCCUPANTS OF ARMOURED VEHICLES

Promulgated on 18 December 2012

Dr. Cihangir AKSIT, TUR Civ
Director, NATO Standardization Agency

Humanetics Hybrid III® with measuring approach

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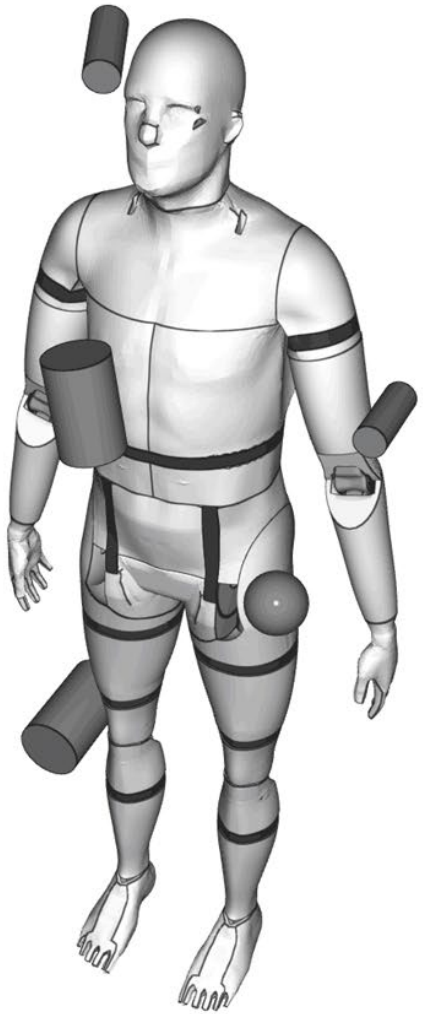
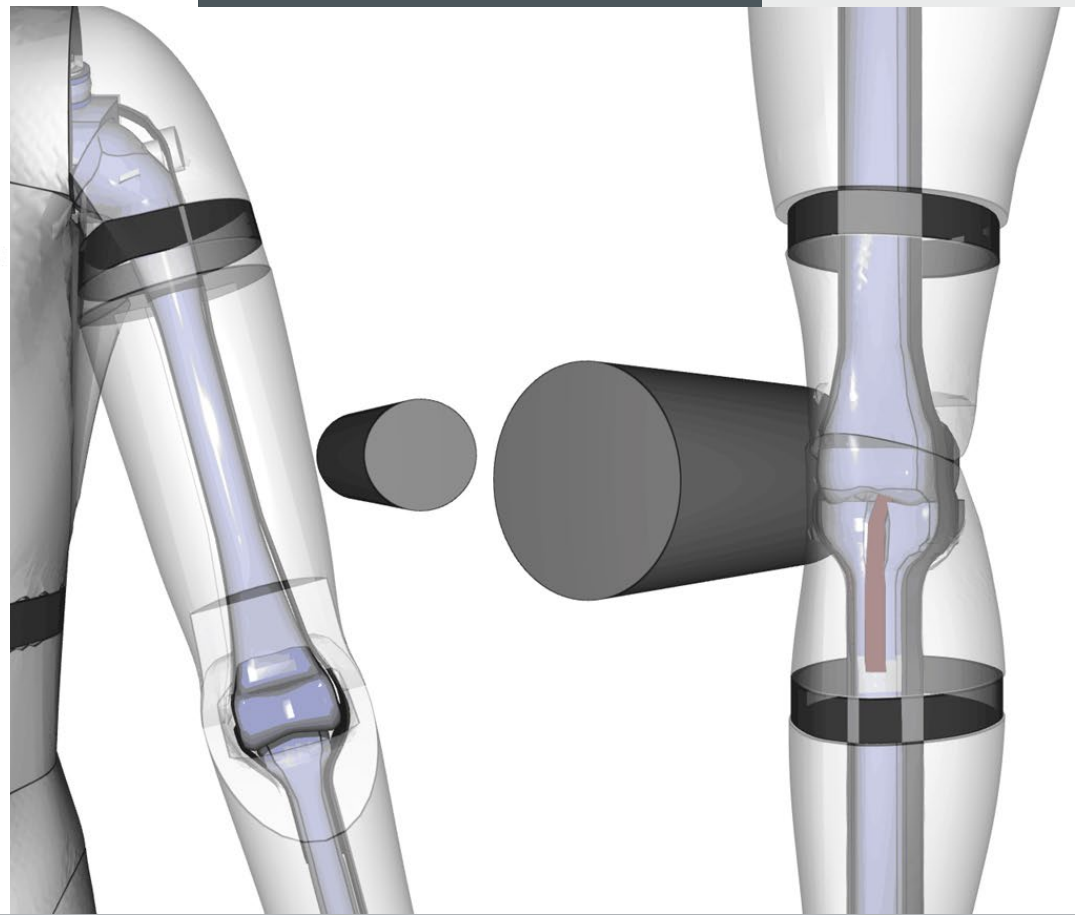
PRIMUS BREAKABLE®
BRUTE FORCE BEHAVIOR / TEST LOAD CASE

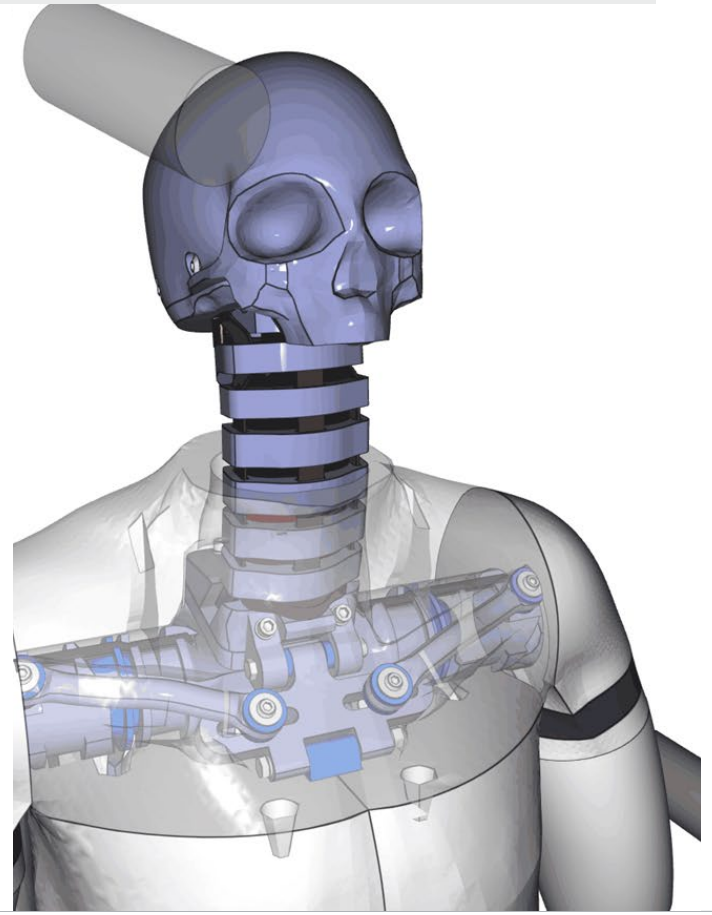
Visualization of the dummy behavior under different load directions

Brute force

- Fractures in dependency of energy transfer
- Torn ligaments (knee joint)







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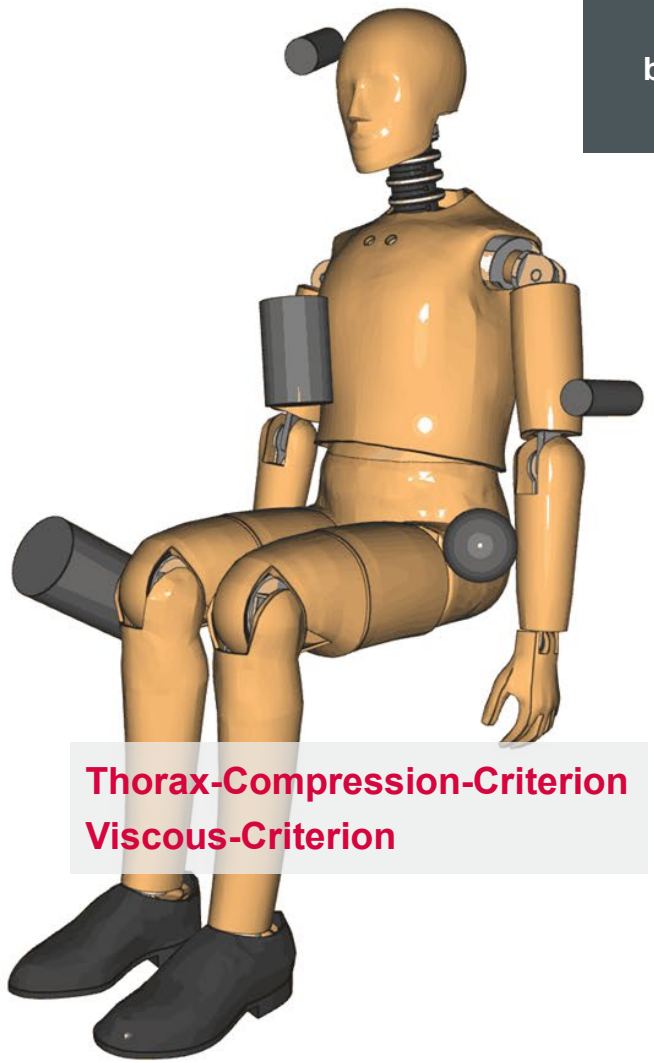
HYBRID III®
BRUTE FORCE BEHAVIOR / TEST LOAD CASE

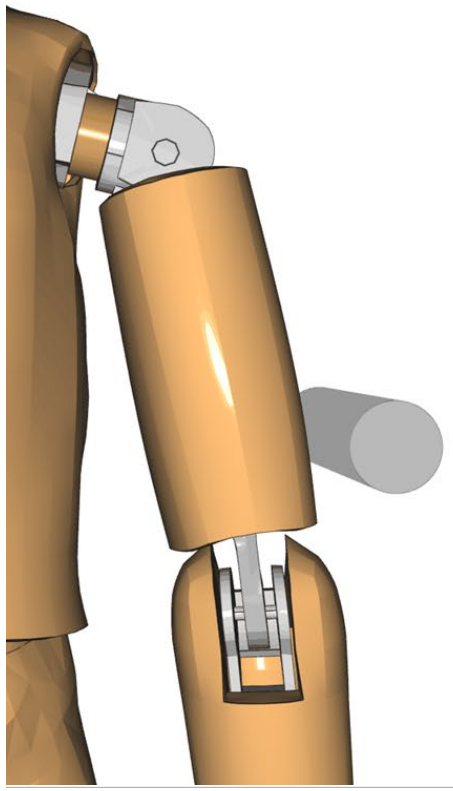
Visualization of the dummy behavior under different load directions

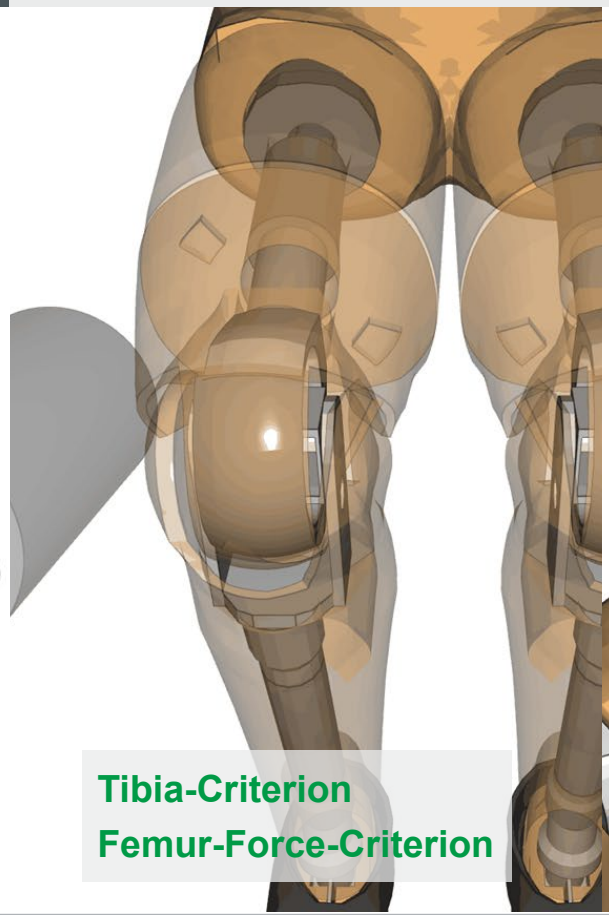
Brute force

- Often no damage indication caused by wrong loading direction
- Most of the built-in measuring devices are not triggered

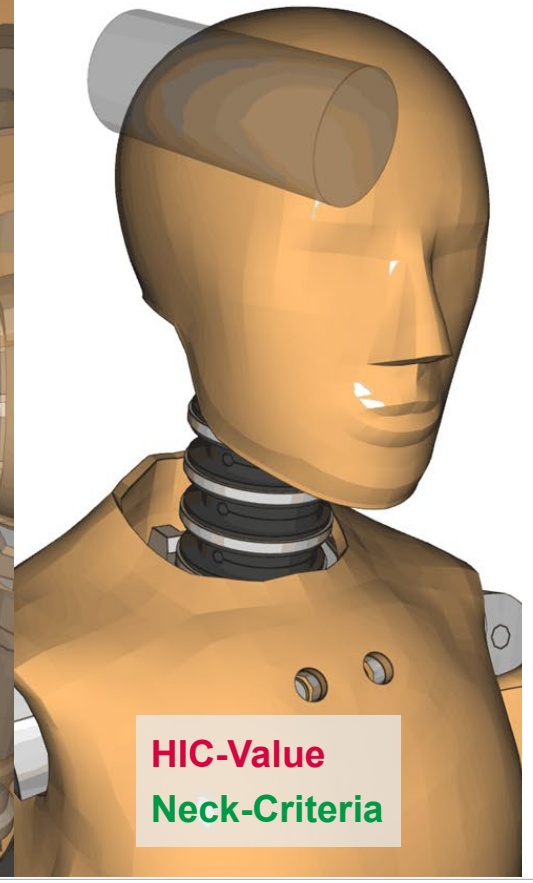


Thorax-Compression-Criterion
Viscous-Criterion





Tibia-Criterion
Femur-Force-Criterion



HIC-Value
Neck-Criteria

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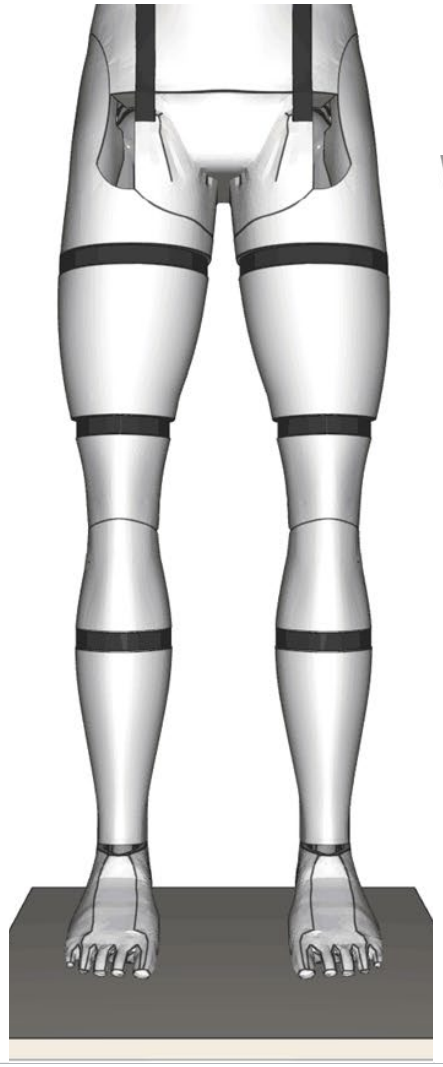
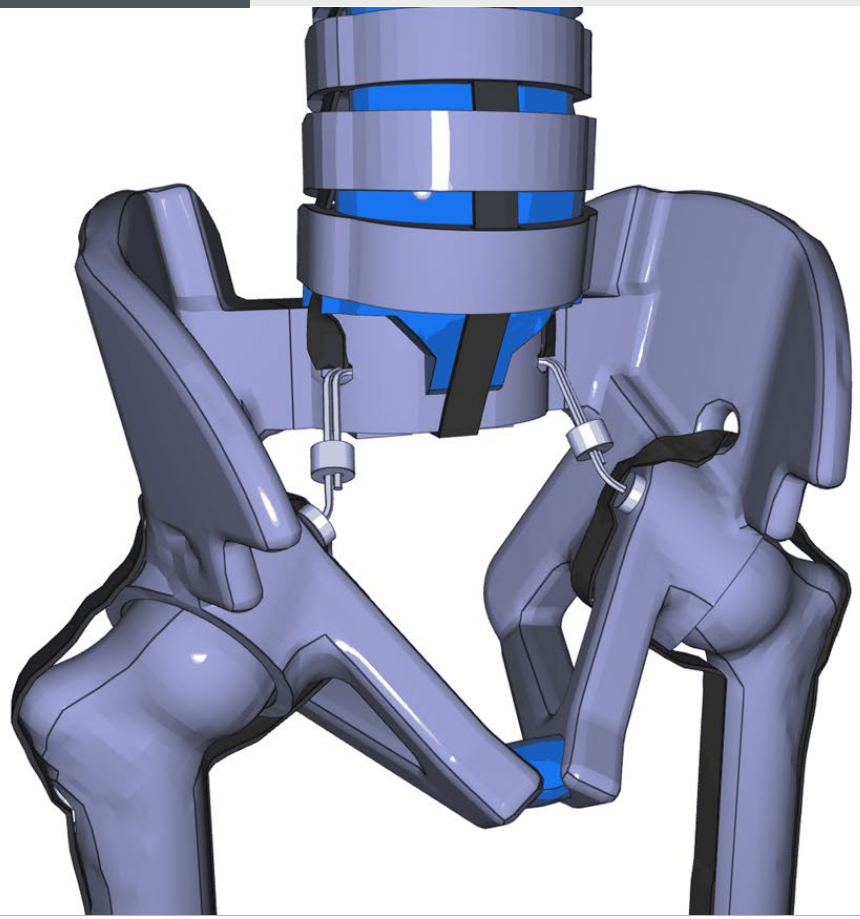
PRIMUS BREAKABLE®
VERTICAL LOADING CONDITION

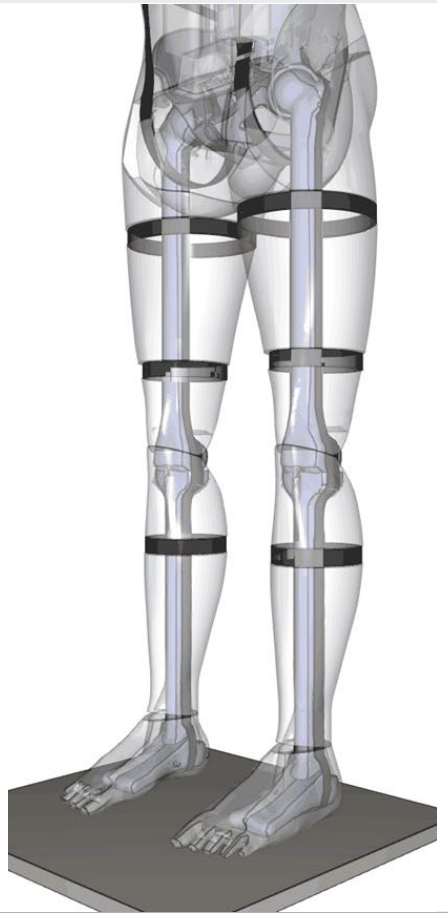


Reaction to a vertical loading condition from a mine explosion for example

Vertical loading condition

- Splintering fractures (ankle, knee joint and femur neck)
- Soft tissue damage





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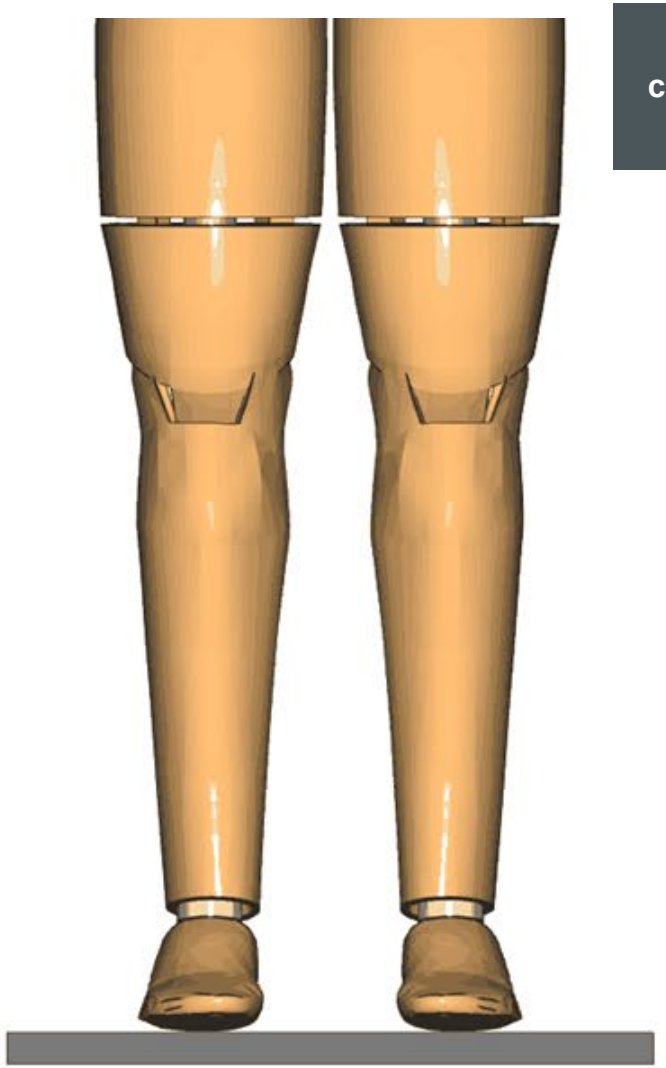
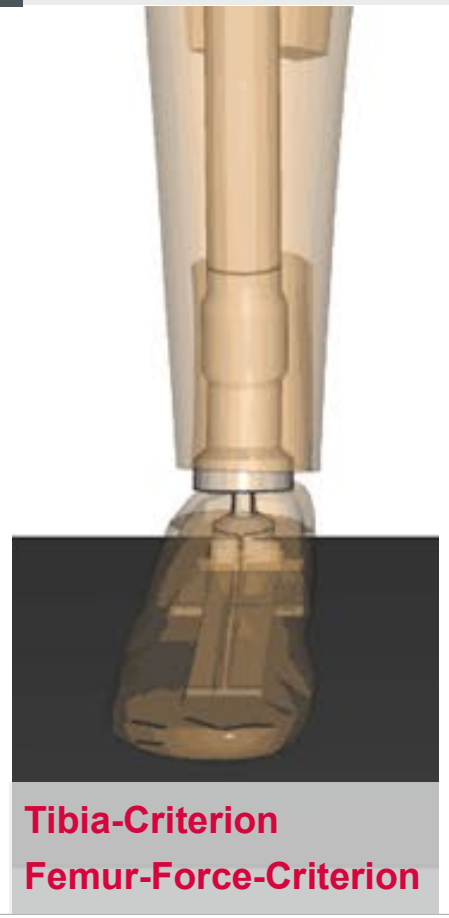
HYBRID III®
VERTICAL LOADING CONDITION



Reaction to a vertical loading condition from a mine explosion for example

Vertical loading condition

- Meaningful measured values, caused by the intended loading direction
- Massively exceeding the permissible limit values



Tibia-Criterion

Femur-Force-Criterion

Dynamic-Response-Index

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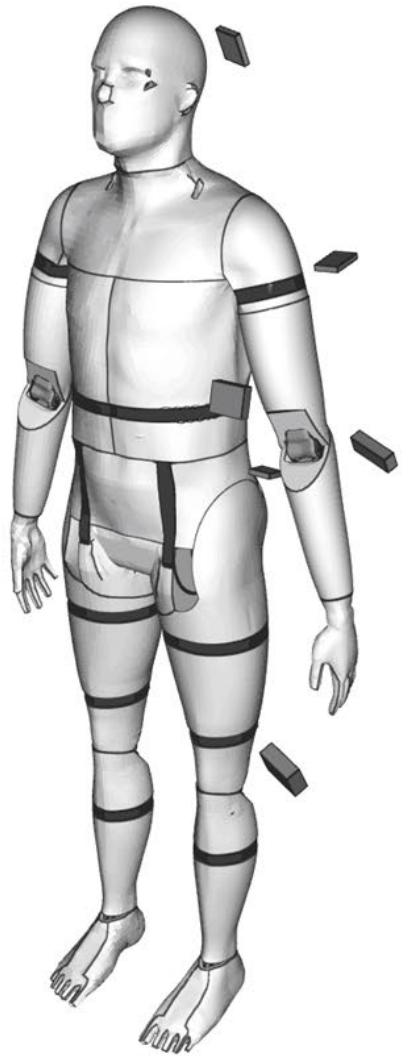
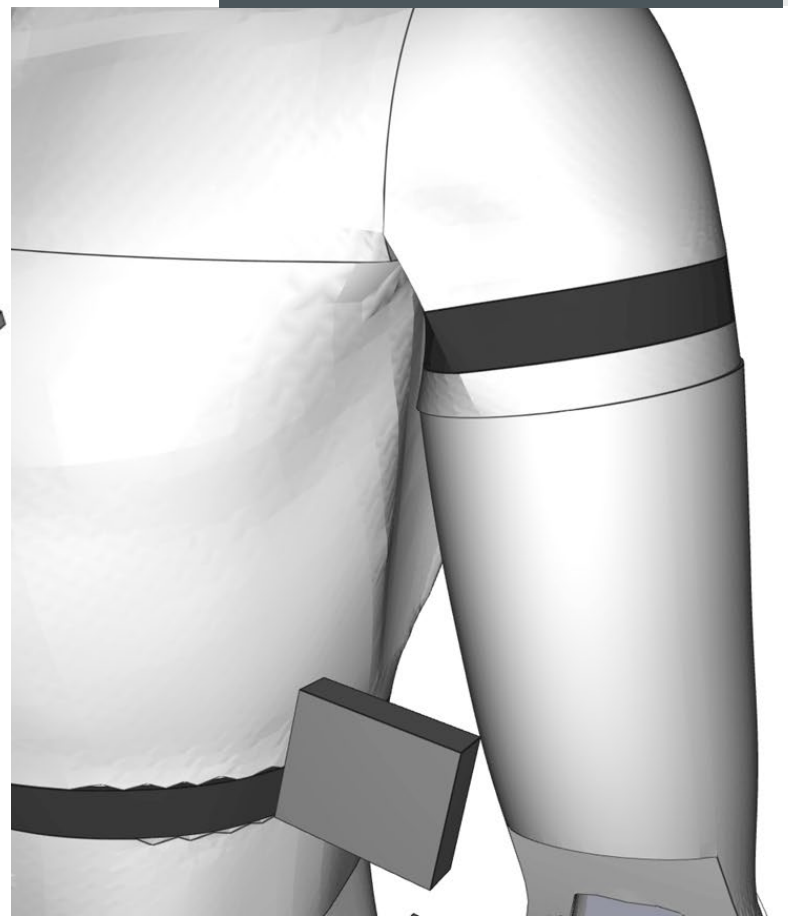
PRIMUS BREAKABLE®
SECONDARY PROJECTILE IMPACT

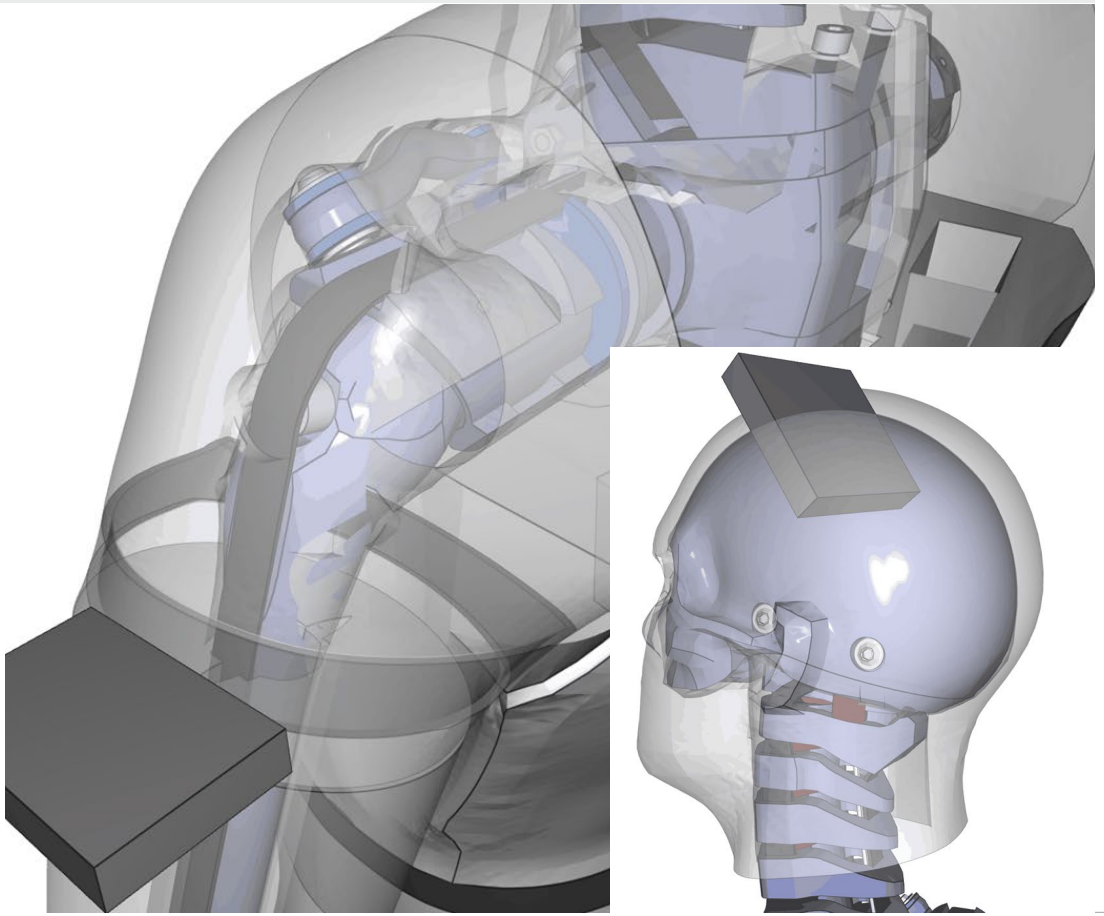


Impact of secondary projectiles after an IED side blast to a vehicle



Secondary projectiles

- Fractures in dependency of energy transfer (Head)
- Large soft tissue damage



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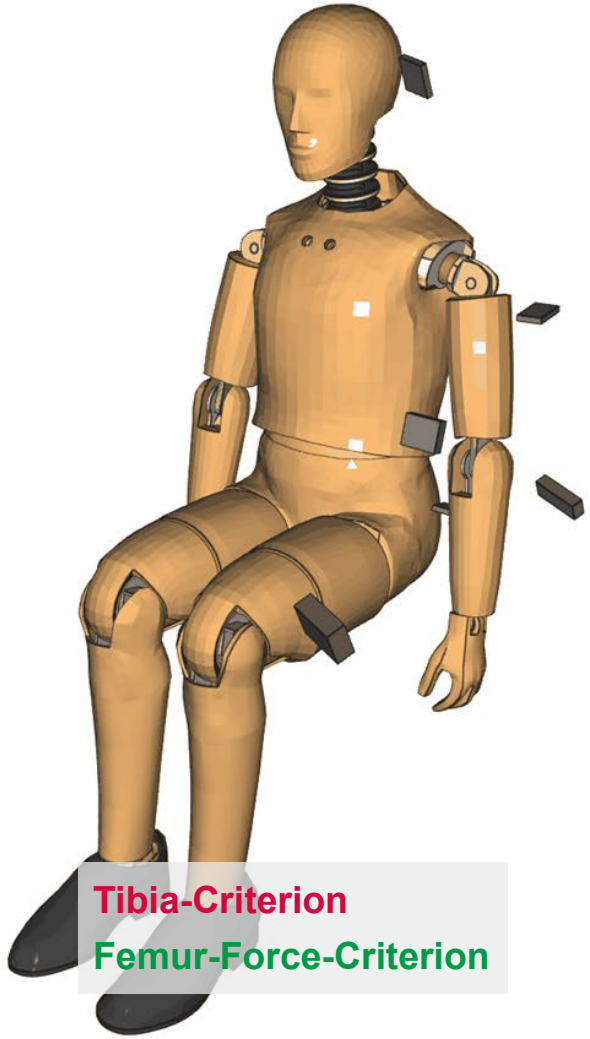
HYBRID III®
SECONDARY PROJECTILE IMPACT

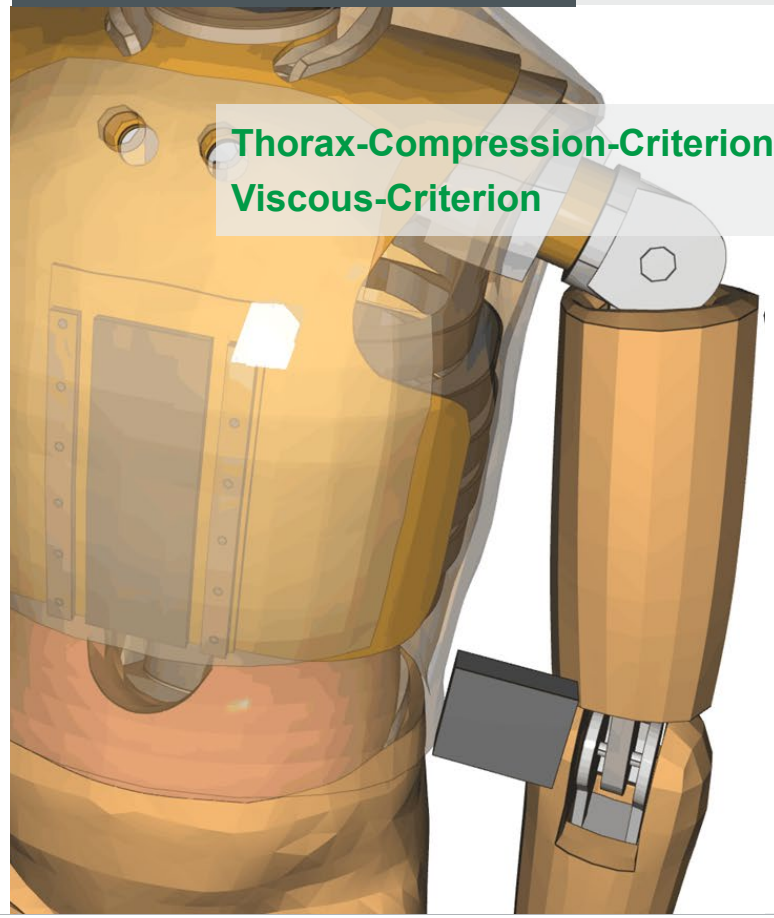


Tibia-Criterion
Femur-Force-Criterion

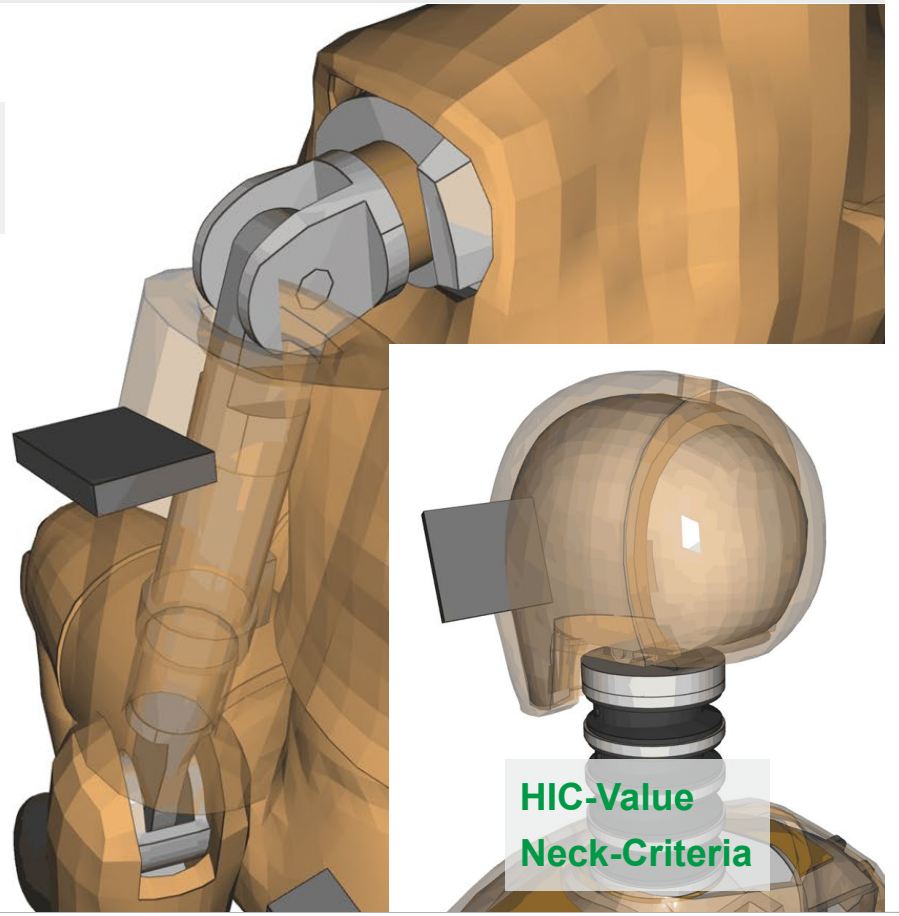
Impact of secondary projectiles after an IED side blast to a vehicle

Secondary projectiles

- Either no damage indication or massive damage and reparation cost
- Most of the built-in measuring devices are not triggered



Thorax-Compression-Criterion
Viscous-Criterion



HIC-Value
Neck-Criteria

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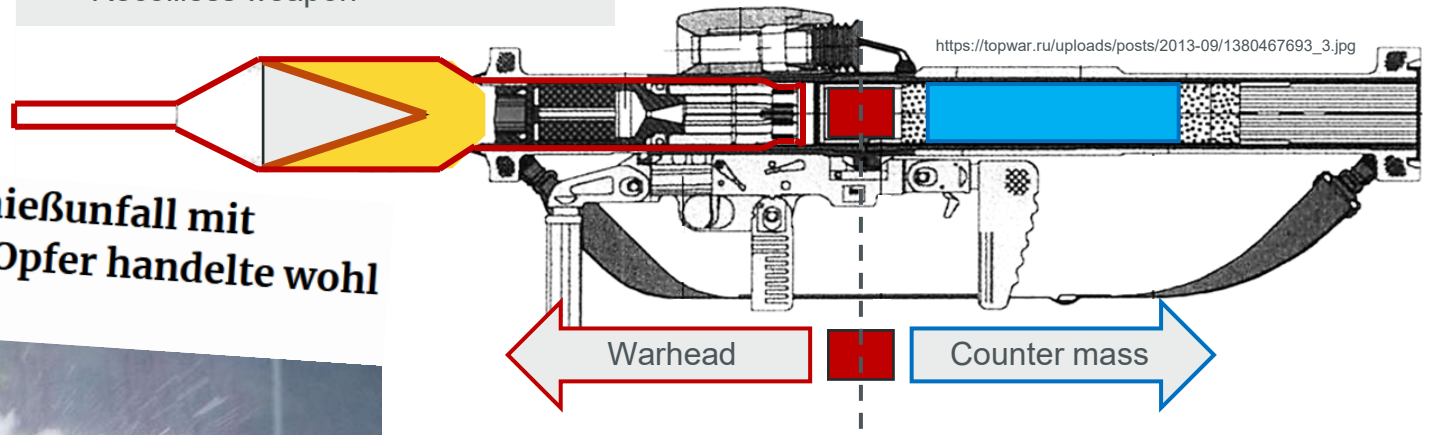
FORENSIC RESEARCH
ACCIDENT RECONSTRUCTION

Panzerfaust 3 (PzFst 3)

- Rocket-propelled grenade RPG
- Recoilless weapon

Dynamit Nobel



Unfall mit Panzerfaust

Soldat bei Schießübung getötet

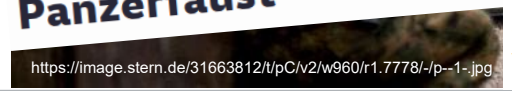
Bei einer Schießübung der Bundeswehr ist in Bayern ein Berufssoldat ums Leben gekommen. Der 29-Jährige stand hinter einer Panzerfaust, als ein Kollege den Abzug betätigte.

Tödlicher Schießunfall mit Panzerfaust: Opfer handelte wohl fahrlässig

Wildflecken

Soldat stirbt bei Übung mit Panzerfaust

Paderborner gerät in den Rückstrahl einer Panzerfaust – Unfallhergang rekonstruiert



Soldat stirbt bei Schießübung mit Panzerfaust: Verfahren eingestellt

Date: May 16th 2017

- Proving groud Wildflecken
- Combat shooting test with PzFst 3
- One soldier got killed by accident
- Possibly struck by the counter mass of the RPG

What exactly happened?

How to proof / disproof upcoming theories?

Who's fault is it and is it even somebodies fault?

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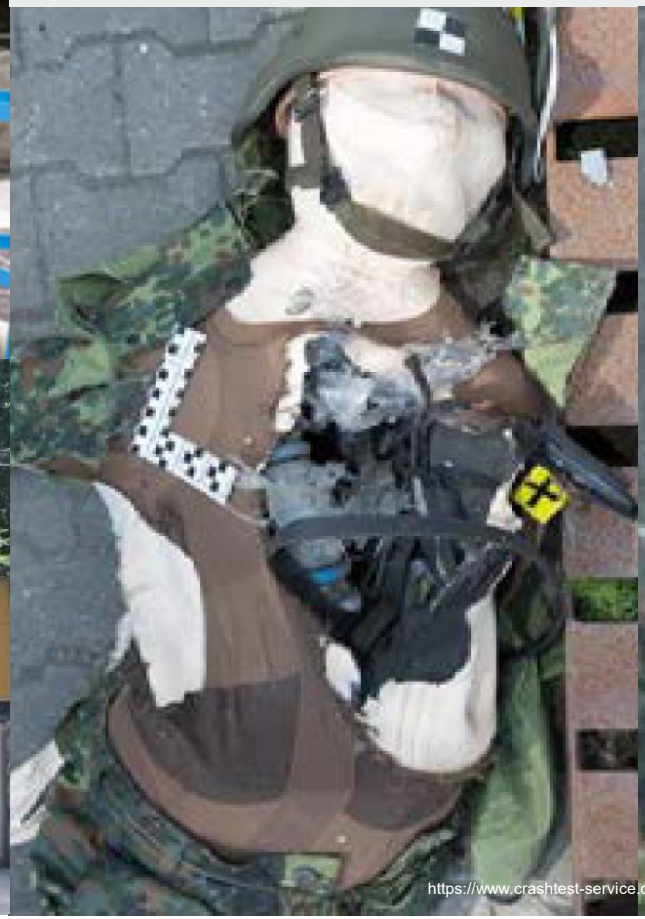
FORENSIC RESEARCH
ACCIDENT RECONSTRUCTION

PzFst 3 accident reconstruction at the WTD 91

- Massive destruction of thorax and torso with and without ballistic protective vest
- Comparable damage and displacement on the biofidelic Primus Breakable® dummy



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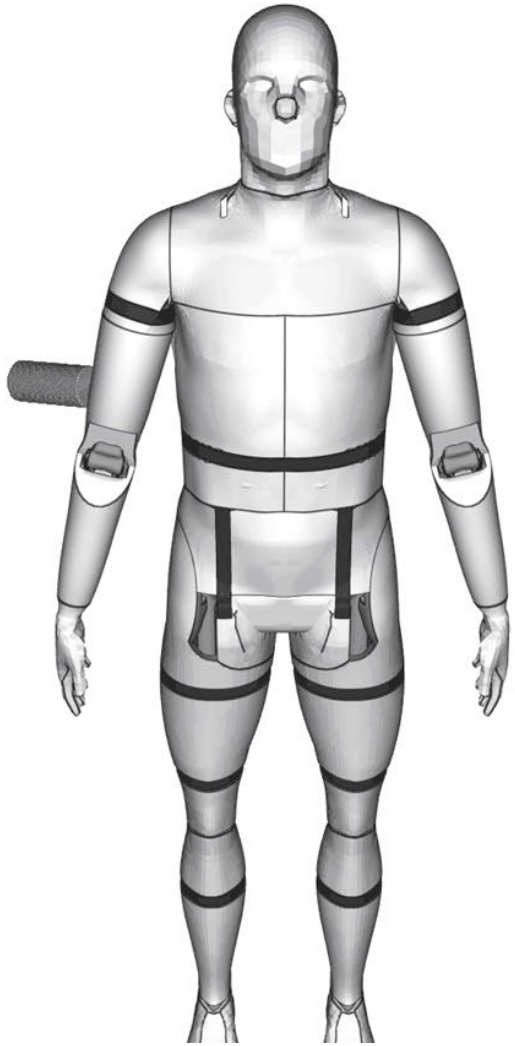
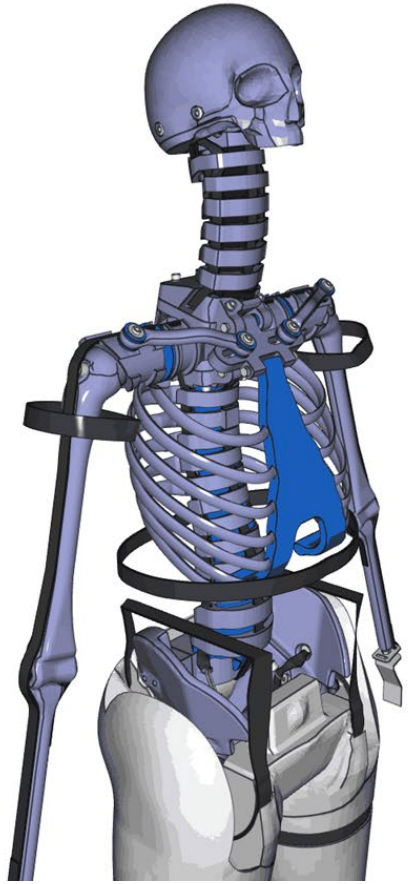
PRIMUS BREAKABLE® FORENSIC RESEARCH
ACCIDENT RECONSTRUCTION

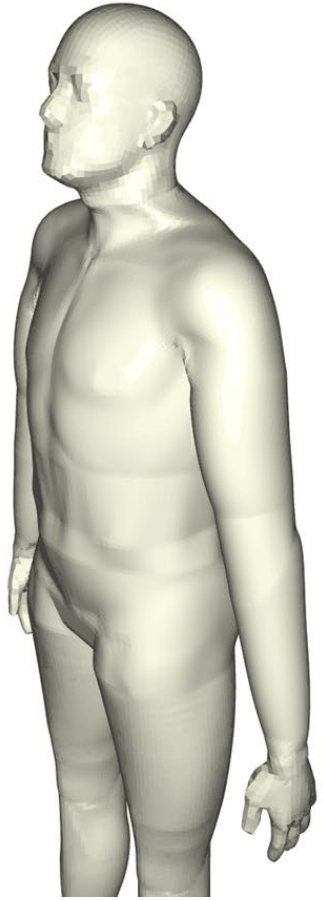


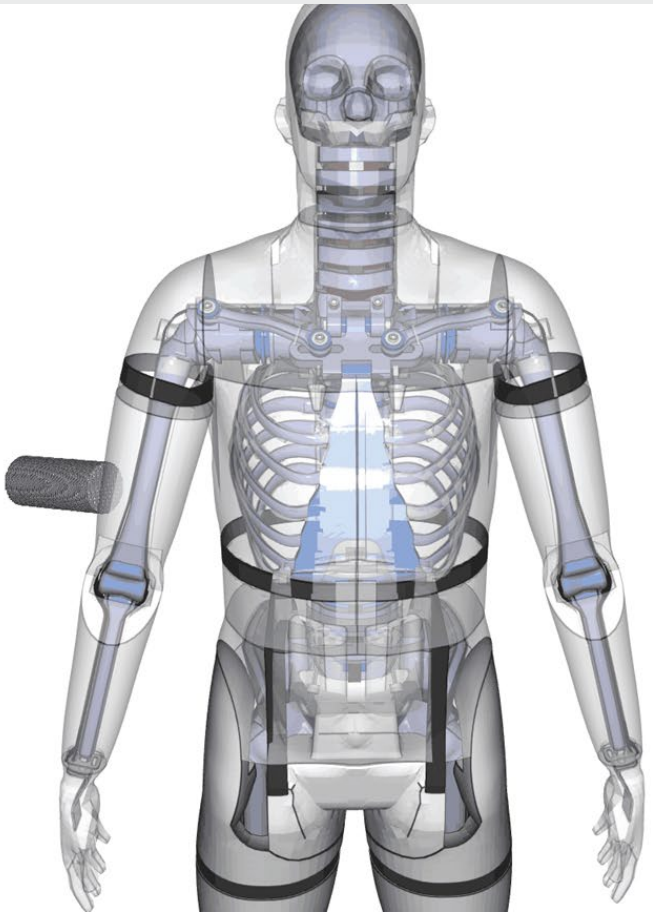
Forensic research and accident reconstruction

PzFst 3 accident reconstruction

- Massive destruction of the torso with no chance of survival
- Huge impulse transfer to the body







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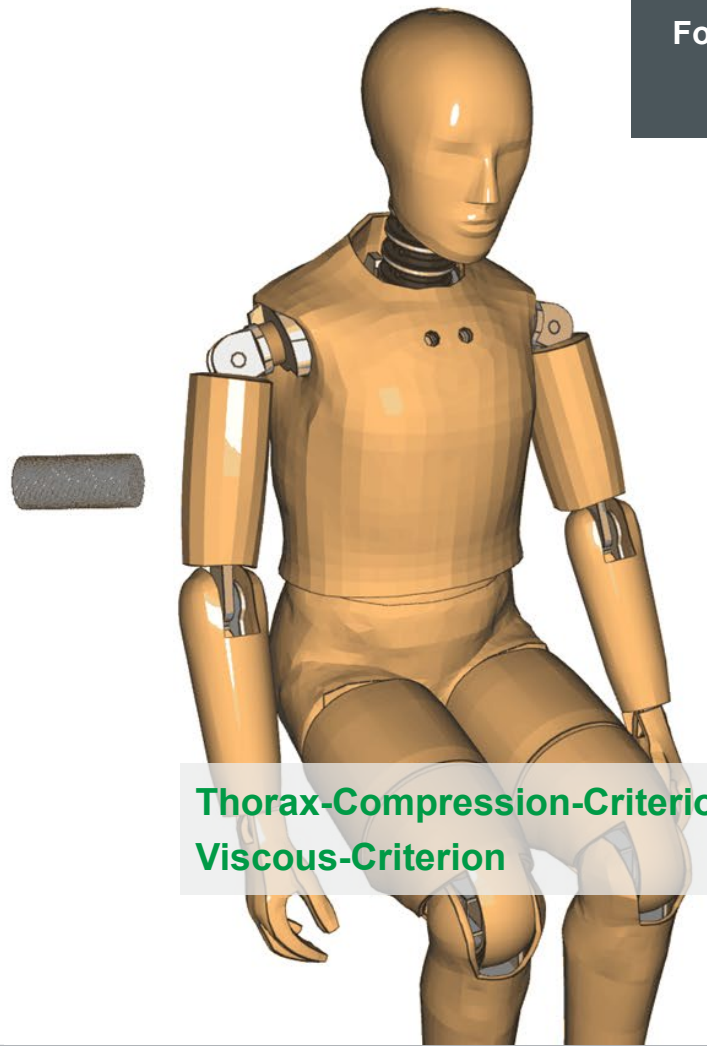
HYBRID III® FORENSIC RESEARCH
ACCIDENT RECONSTRUCTION

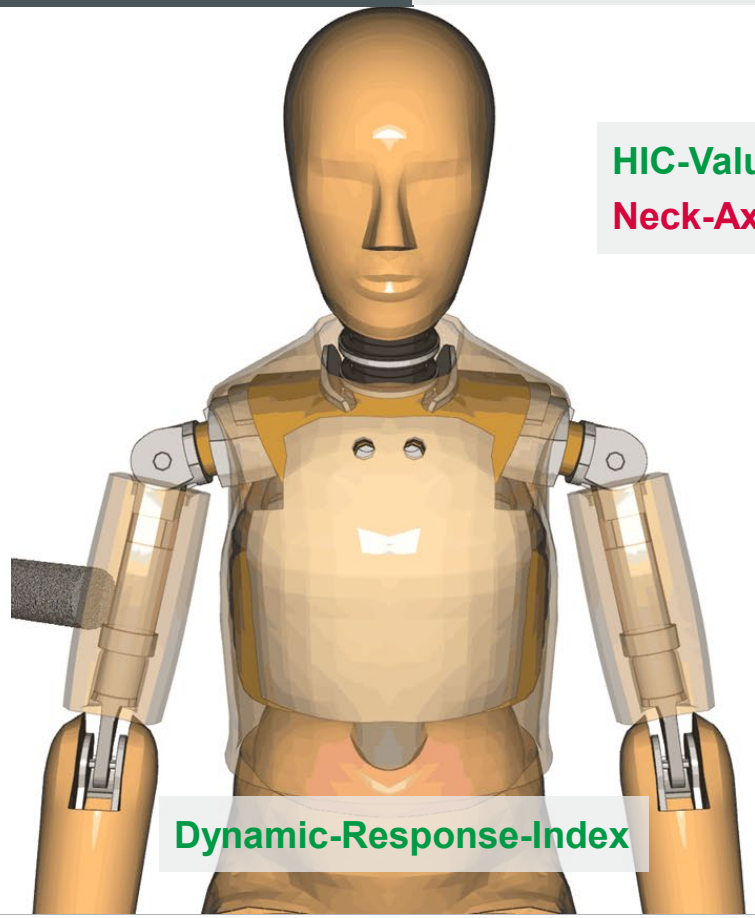
Forensic research and accident reconstruction

PzFst 3 accident reconstruction

- Massive destruction, but no indication by the measuring devices
- Destruction is comparable to the reality (loss of the Dummy)

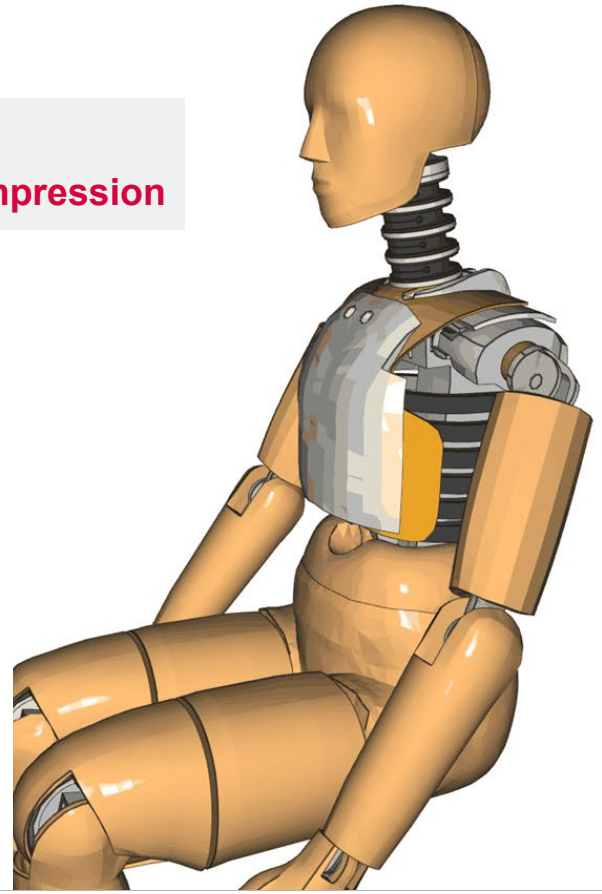


Thorax-Compression-Criterion
Viscous-Criterion



Dynamic-Response-Index

HIC-Value
Neck-Axial-Compression



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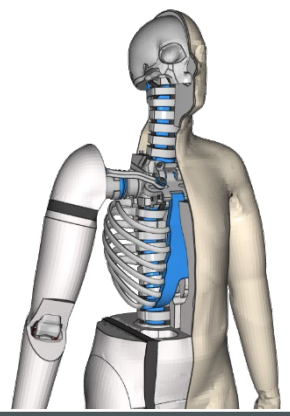
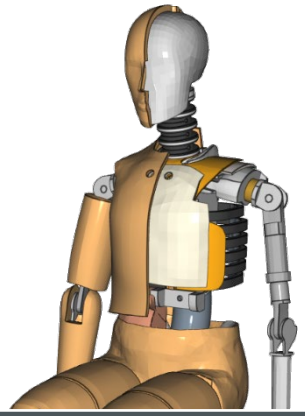
CONCLUSION
PRIMUS BREAKABLE® & HYBRID III®

- The **PRIMUS Breakable®** offers a continuous evaluation spectrum (direction independent damage) → **Developed for accident research**
- The **Hybrid III®** offers discrete evaluation criteria (directional measured values) → **Developed for front crash applications**





Loading condition / Injury mechanism	Primus Breakable®	Hybrid III®
Secondary explosive injury mechanism (Fragments)	**Yes**	**Conditional**, dummy loss / repair
Tertiary explosive injury mechanism (Accelerations)	**Yes**, advantage due to kinematics	**Yes**, loading ~ measuring direction
Undefined loading conditions (Accident reconstruction)	**Yes**	**Conditional**, dummy loss / repair

- In previous trials on protected vehicles the **PRIMUS Breakable®** showed very meaningful results → Part of the **VPAM ERV Ed. 3**
- Design and evaluation of the **PRIMUS Breakable®** and the **Hybrid III®** follows totally different approaches → Trade-off regarding **cost, risk** and **required level of detail**

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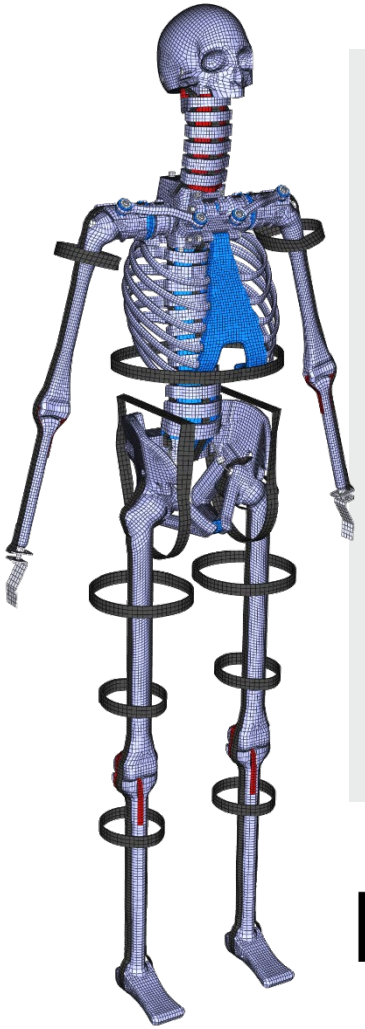
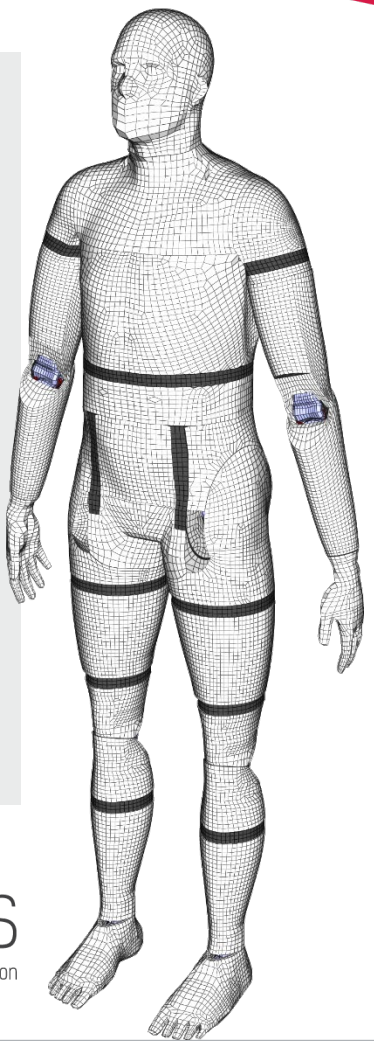
CONCLUSION
THE PRIMUS BREAKABLE® MODEL IN IMPETUS®



- The **PRIMUS Breakable®** model building process for **IMPETUS®** is completed (meshing, materials, connections, contacts, etc.)
- The realistic kinematics of the **PRIMUS Breakable®** are given on the **IMPETUS®** model as well and the positioning simulation of the model is currently being worked on
- In previous simulations we achieved to re-enact different types of fractures, torn ligaments and soft-tissue penetrations with the simulation model of the **PRIMUS Breakable®**
- The today's model size in **IMPETUS®** is ~ 20GB, therefore the numerical performance has to be further improved.
- The **PRIMUS Breakable®** model is in validation phase at the moment to get it ready for the **IMPETUS® Market** as soon as possible
- The **IMPETUS®** model of the **PRIMUS Breakable®** is already of exceptional quality and we are very proud to have been part of this project



Hochschule für Technik und Wirtschaft Dresden
University of Applied Sciences

CTS crashtest-service

EDAG

IMPETUS driving precision

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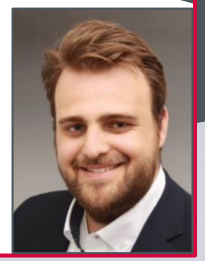
CAE - Engineer
Blast & Ballistic Simulation



THANK YOU.

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