Powering Innovation That Drives Human Advancement

LS-DYNA in Crash Safety

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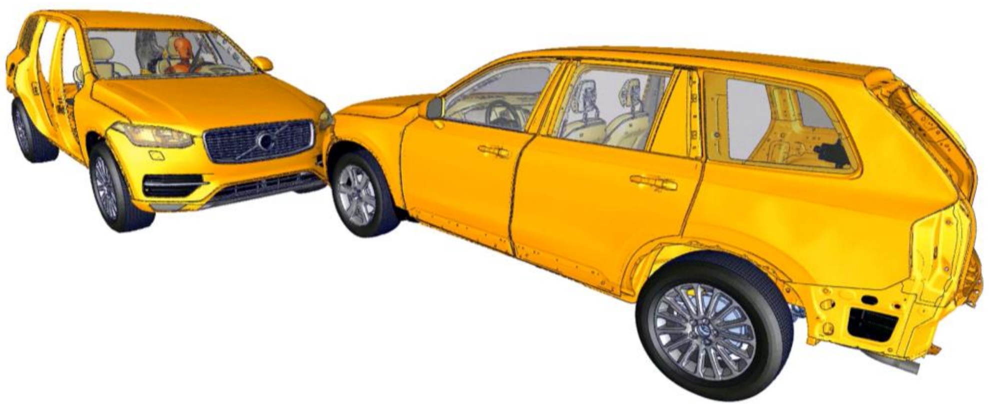
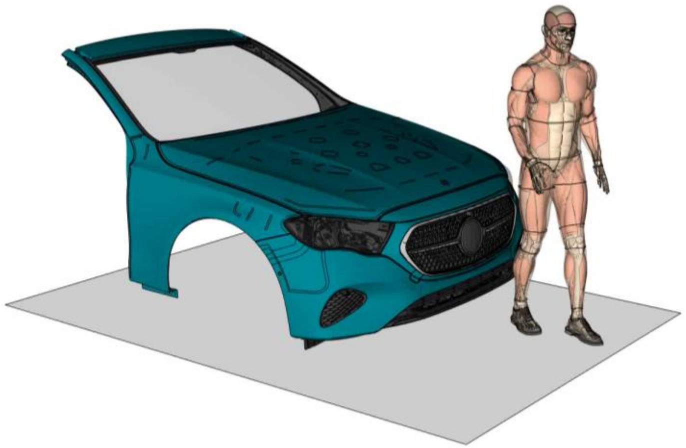
Ansys

Introduction to the Automotive Crash Safety Team

The Automotive Crash Safety Group (ACSG)

- ACSG emerged from **DYNAmore** acquisition in 2023
  that has been working with LSTC
  since day one of LSTC/LS-DYNA
- 77 people / 8 teams spanning the world
- **100% dedicated to LS-DYNA** and its workflow
- Focus on **automotive industry**
- Full service and software provider for LS-DYNA customer
- Dedicated teams for
  - Customer Success
  - ATDs and HBMs
  - Extended Customer Value
  - Method Development & Homologation





77	18	1000+
Employees (~1/3 PhDs)	Countries of origin of our employee base	Years LS-DYNA experience

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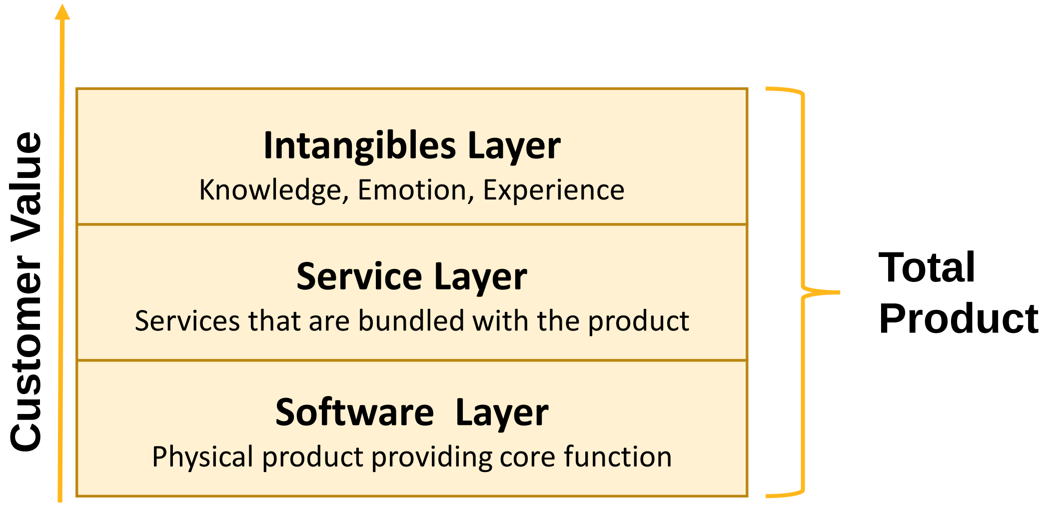
Extended Customer Value

- "The Extended customer value (ECV) model" by Robert R. Harmon:
- Highest benefit for the customer
  - Software is the **foundation**
  - **Service layer** to provide solutions for customer's challenges
  - Opportunity to gain and exchange knowledge and experience (trainings, conferences, …)

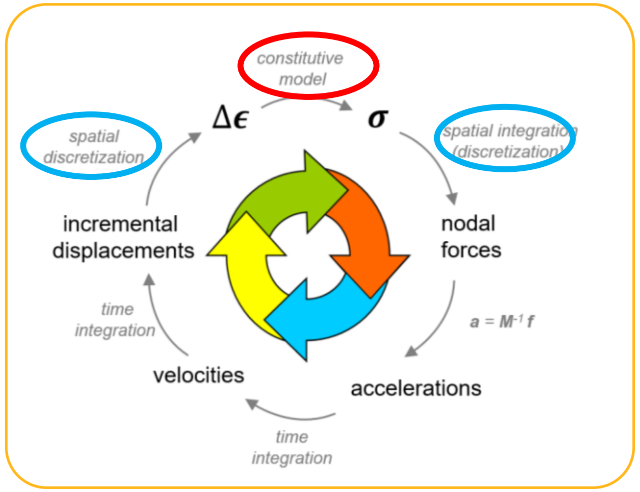


- Applied successfully for LS-DYNA in automotive industry, where LS-DYNA is the market leader today

ACSG Activities on Future Challenges

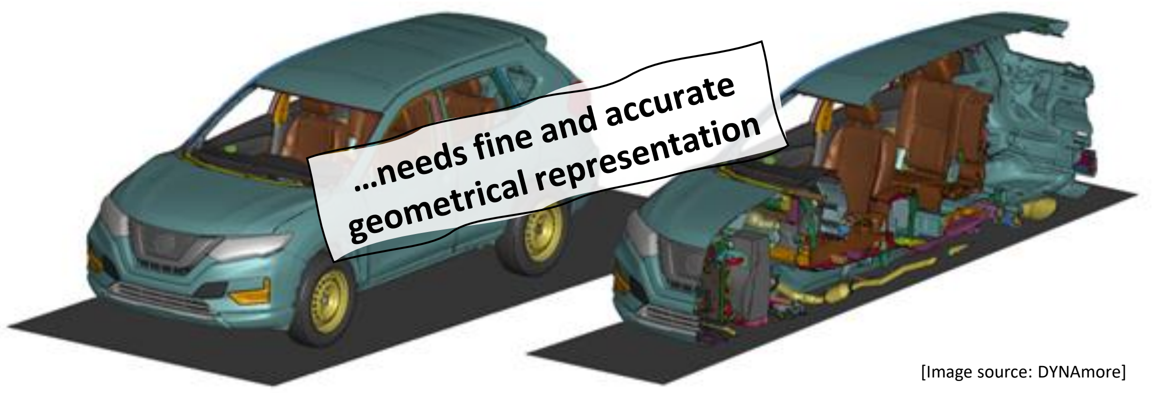
How to achieve Predictiveness in Crashworthiness?

Spatial discretization
(number/type of elements and model size)



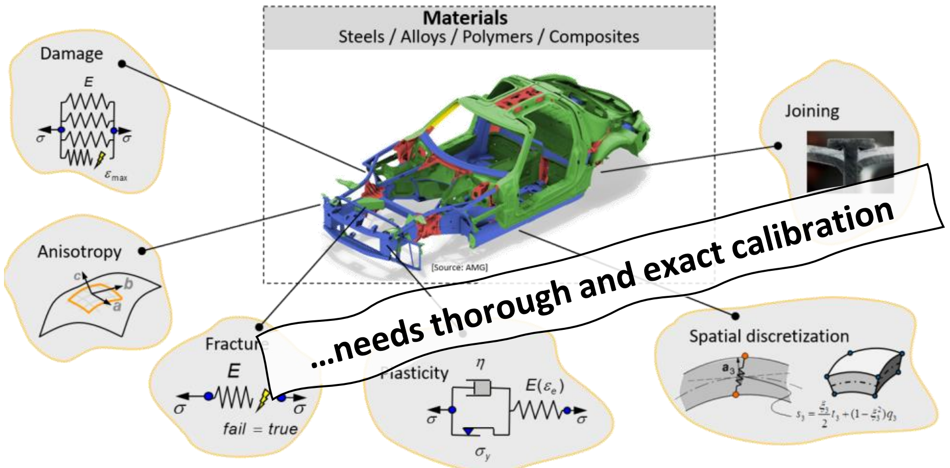
Constitutive & connection modelling
(complex models)

Spatial discretization



Public model of 2020 Nissan Rogue (3.2 Mio elements)

Constitutive & connection modelling



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Challenges in general Modelling

From ICE to BEV/PHEV – and still being predictive!

~70 % Steel
~25 % Alloy
~5 % 22MnB5

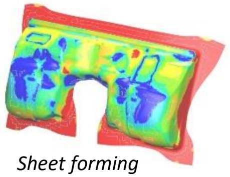
ICE

BEV/PHEV

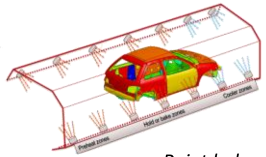
~30 % Steel sheet
~30 % 22MnB5
~20 % Alloy sheet
~20 % Cast & extruded alloy

[Czerwinski, F. Current, Trends in Automotive Lightweighting Strategies and Materials. Materials 2021, 14, 6631. https://doi.org/10.3390/ma14216631, CC BY 4.0:]

The manufacturing process chain

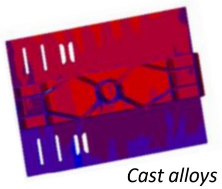


Sheet forming

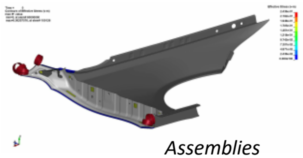


Paint bake

ENVYO

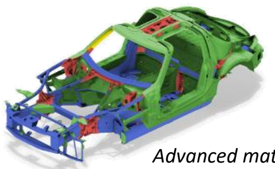


Cast alloys



Assemblies

Inhomogeneities in structures & materials

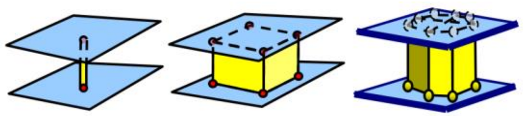


Advanced material mix

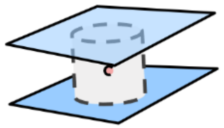
Batteries

H2 vessel

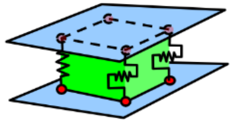
Connection modelling



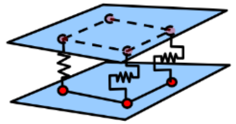
Beam/volume elements



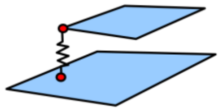
SPR



Cohesive element



Tiebreak contacts



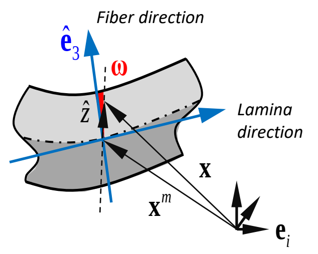
Discrete elements

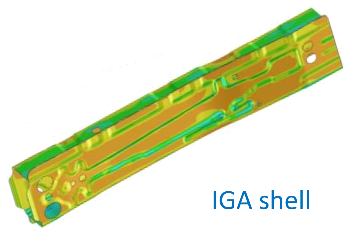
Challenges in general Modelling

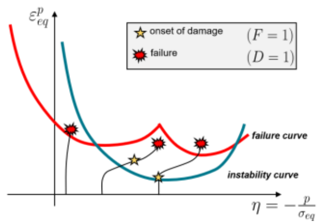
Spatial discretization and constitutive models

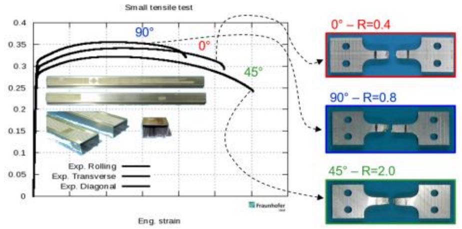
5-parameter shell model

(classical Reissner-Mindlin)

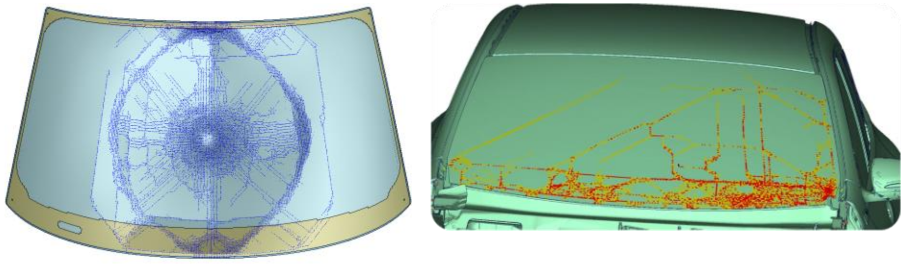






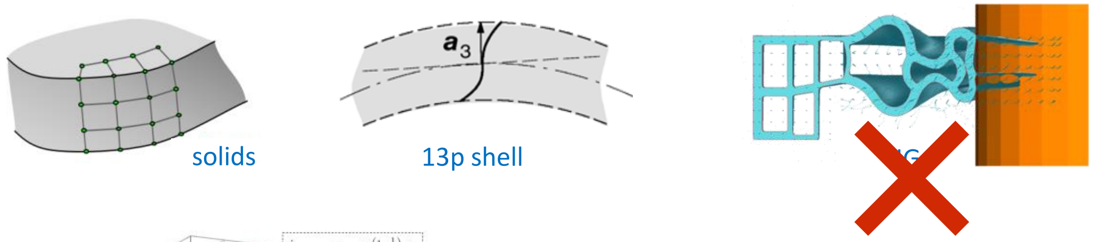


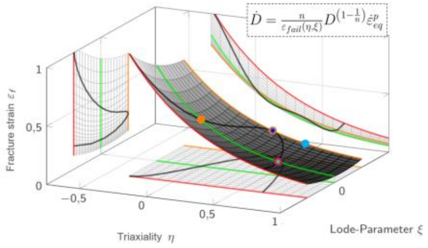
Stochastic glass modelling

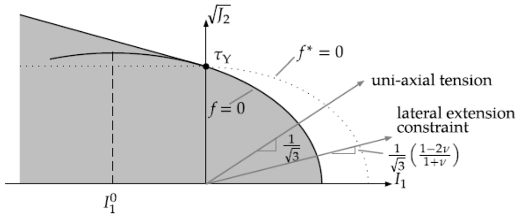


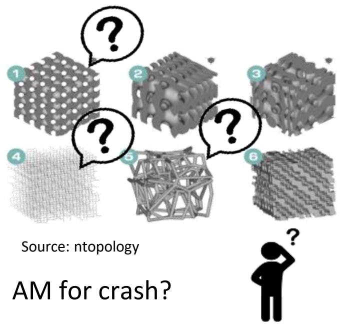
Solid discretization

(higher order hexahedrons, tetrahedrons or IGA as well as 13p shells)





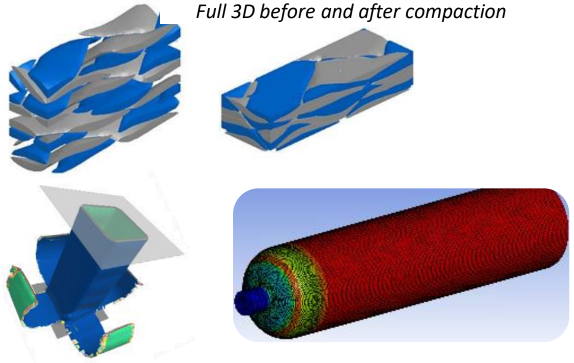




Source: ntopology

AM for crash?

Full 3D before and after compaction



Challenge: Process chain in Giga Casting

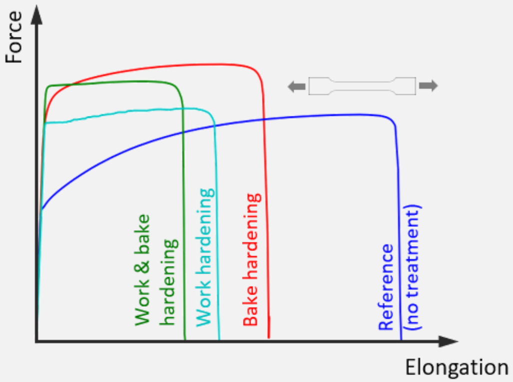
[Source: Tesla and S&P Global Mobility]

Tesla Model3 “old” BIW
(many parts + thousands of welds)

Tesla Model3 new BIW with Giga-Castings
(2 parts + 1,600 less spotwelds)

Technological challenges:

- Find the **optimal design** (classical optimization methods might be applied)
- Part design requires **enhanced spatial discretization** (T-intersections, thick walls)
- Varying **local properties** due to cast process
(yield length, cooling rates, porosity, boundary layers effects)
- Bake hardening effects of AlSi7CuMg or AlSi7MnMg
aloys due to **paint bake** (heat treatment) of BIW.



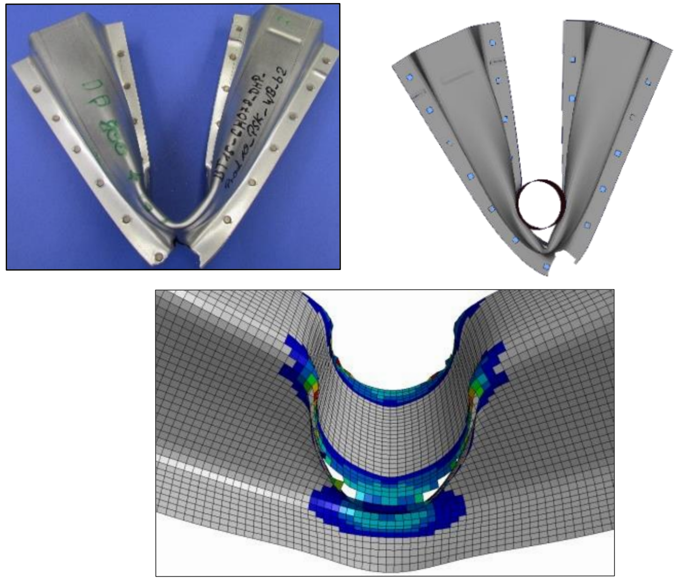
Traditionally supported by **Ansys/LS-DYNA** and Ansys/LS-OPT, LS-TaSC or OptiSLang

New and upcoming features in **Ansys/LS-DYNA** like **IGA**, higher order shell or solid elements

Closing the production process chain by advanced constitutive models (#187, #224, #251), sophisticated **mapping** procedures (**ENVYO**) and calibration services (**MCC**)

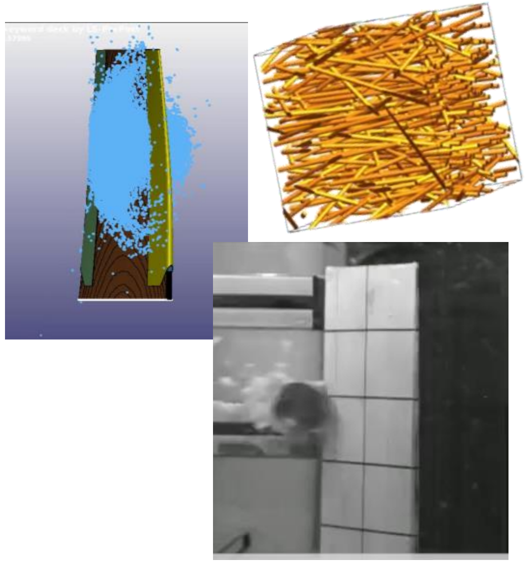
Calibration Services of the **Material Competence Center** (MCC)

Steel & Alloys



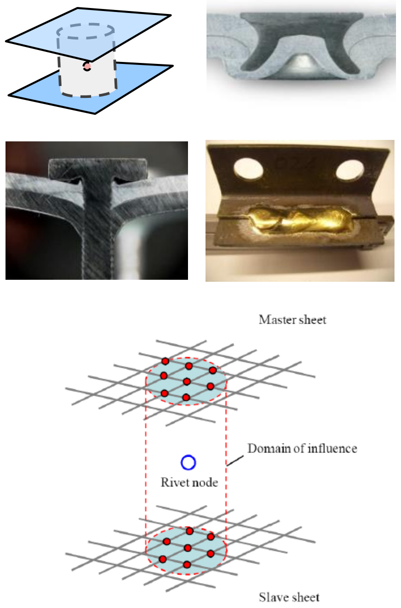
MAT24, MAT54, MAT36, MAT136, MAT187, GISSMO/eGISSMO, DIEM, …

Polymers & Composites



MAT157, MAT215, MAT249, …

Connection modelling

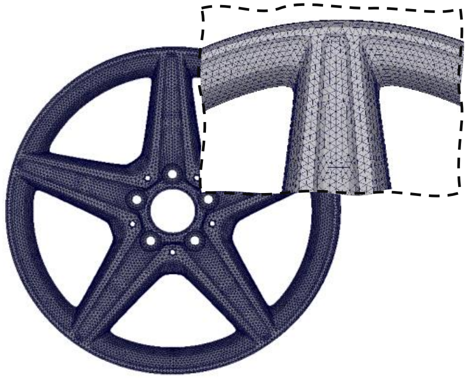


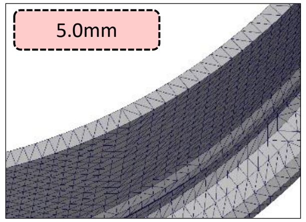
MAT100, SPR, cohesive, ...

- Many of the material models in LS-DYNA have been **developed** by **Ansys/DYNAmore researchers**
- Parameter identification and **calibration** of respective models is our **daily business**
- The MCC offers a **one-stop-shop** for testing and calibration services to ensure predictiveness of models

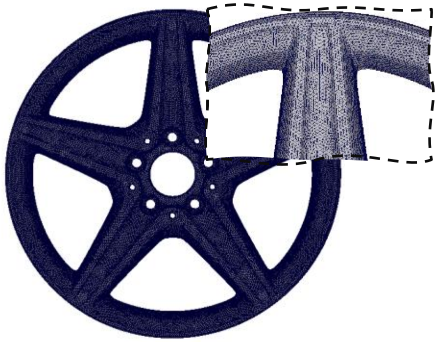
Example: Alloy Wheel in small Overlap Load Case

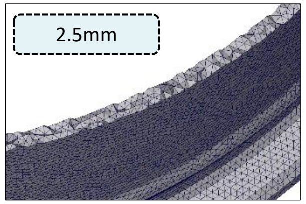
3D modeling including accurate damage and fracture prediction



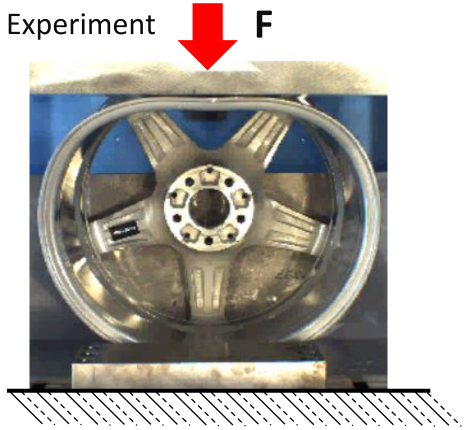


Coarse mesh

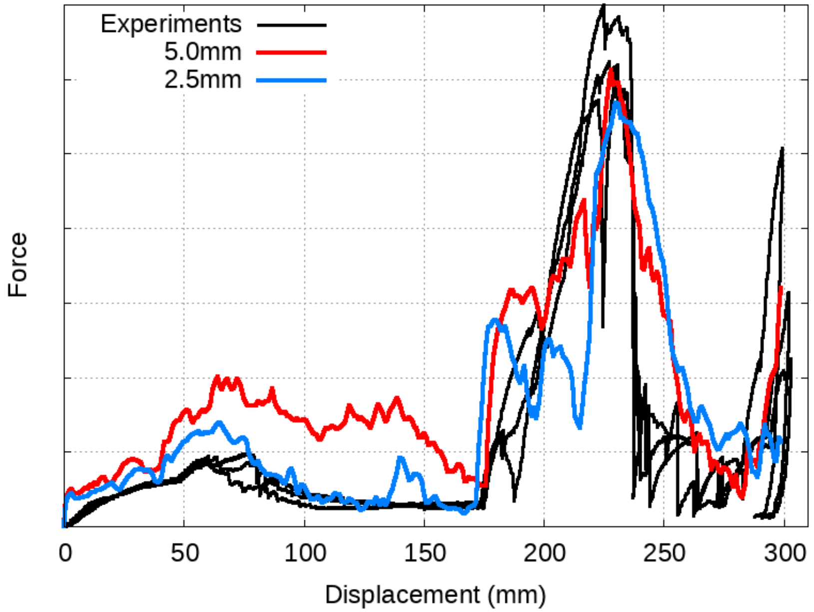


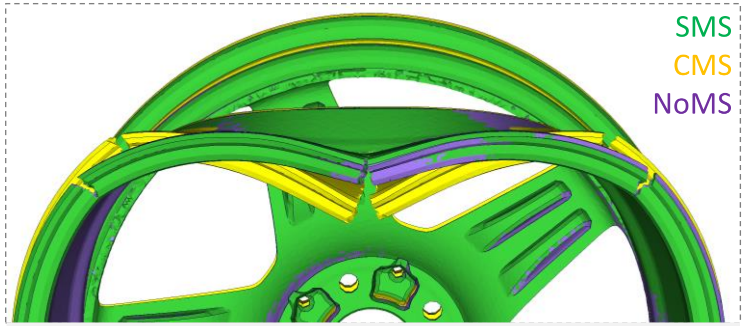


Fine mesh



Element size	Number of elements
~5.0 mm	~225,000
~2.5 mm	~1,600,000





Contrary to CMS, Selective Mass Scaling has only little impact on the solution using the fixed time step of 0.5ms

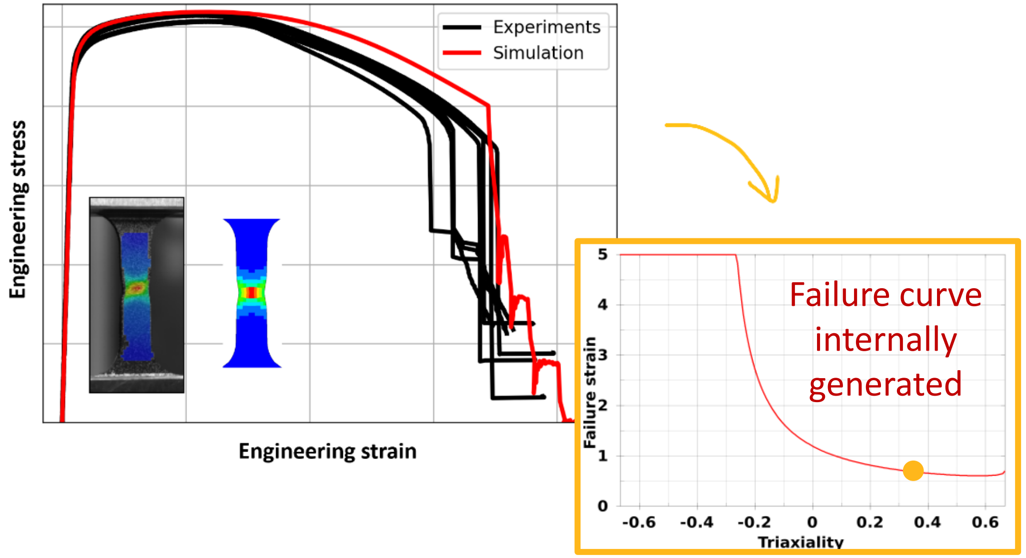
- Material model calibrated by MCC from real part
- Specimen milled from rim, tested and parameters for GISSMO calibrated

➡ **Fine mesh, small timestep and accurate constitutive model required!**

Materials
(only few examples)

Basic incremental Failure (BIF)

- Easy-to-use incremental failure model
  - Requiring only tensile test for calibration
  - Ideal to get good failure modeling when material data is scarce
  - It works for shell and solid elements (triaxiality and Lode parameter dependence)



True plastic strain at failure
for triaxiality = 1/3,
Lode parameter = 1

Cockcroft-Latham criterion

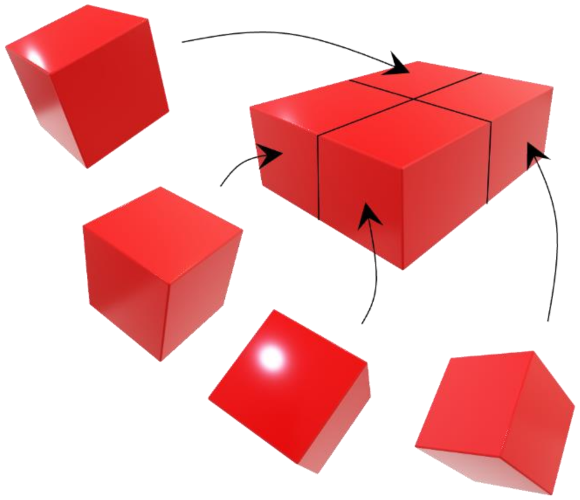
$$\int_0^{\varepsilon_f} \max(\sigma_1, 0)\, d\varepsilon^p \leq W_c$$

```
*MAT_ADD_BASIC_INCREMENTAL_FAILURE
$       MID                 NUMFIP   VOLFRAC     NEROD
          1                    -80
$      EPSF       LCSS      LCREGD     LCSRS    DMGEXP
        0.3                                          2
```

Example: Complex phase steel

Experiment　　FAIL (MAT24)　　BIF

Reference Configuration Treatment

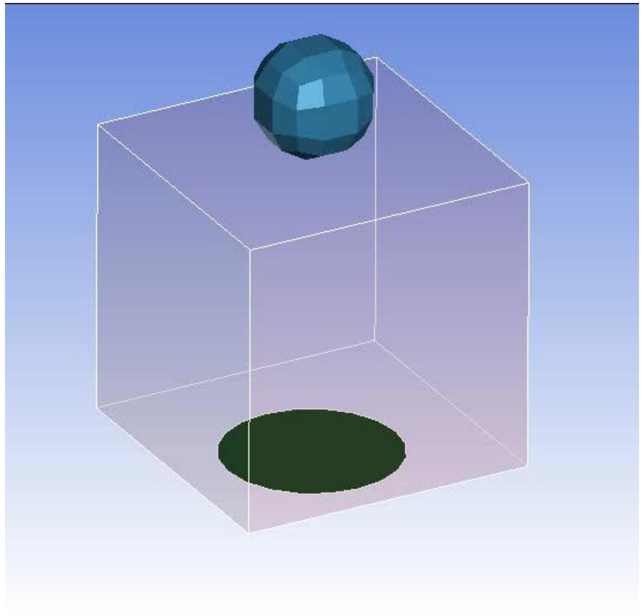


- *NODE_REFERENCE
  - Nodal coordinates in a reference configuration
- *ELEMENT_SOLID/SHELL_REFERENCE
  - Connectivities of elements “of interest”
    - The EID corresponds to the same EID in the *ELEMENT_... list of elements
    - The N1,… references nodes in the *NODE_REFERENCE list and *not* the ones in *NODE

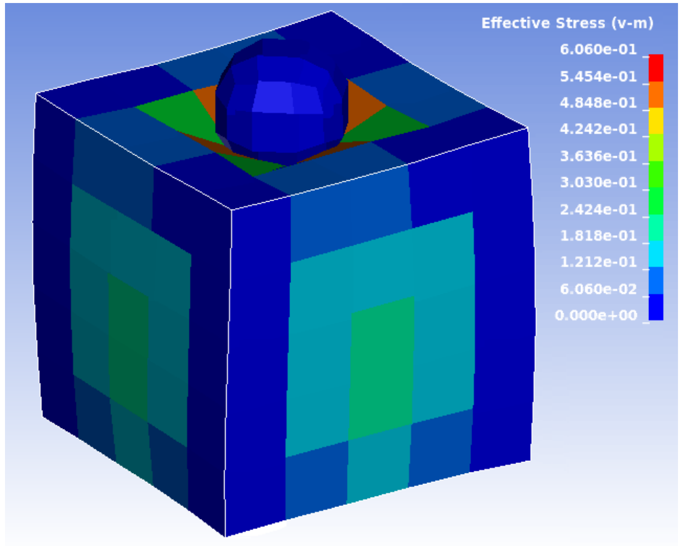
Generalization of
*INTIAL_FOAM_REFERENCE_GEOMETRY
*INITIAL_STRESS_SOLID/SHELL

- Whenever an *ELEMENT_SOLID/SHELL_REFERENCE is present in an input deck, this will be taken as the reference configuration of this element, overriding any other option
- Provides a seamless approach to dealing with hyperelasticity in a dynain context

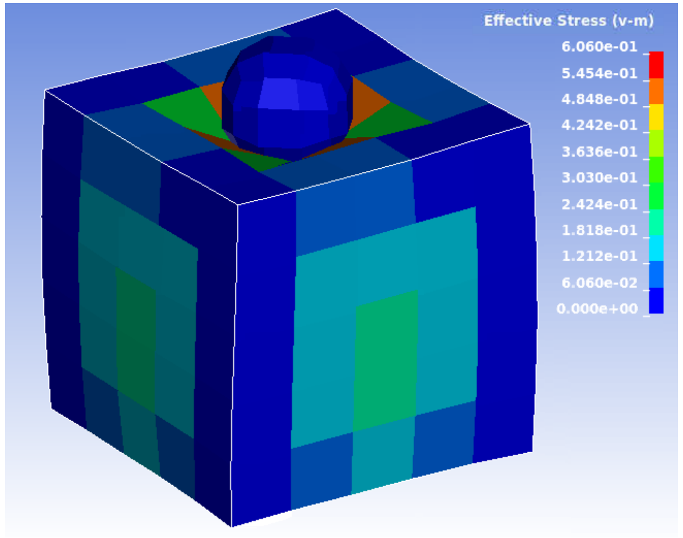
Example: Rubber Test



End of first simulation



Beginning of second simulation

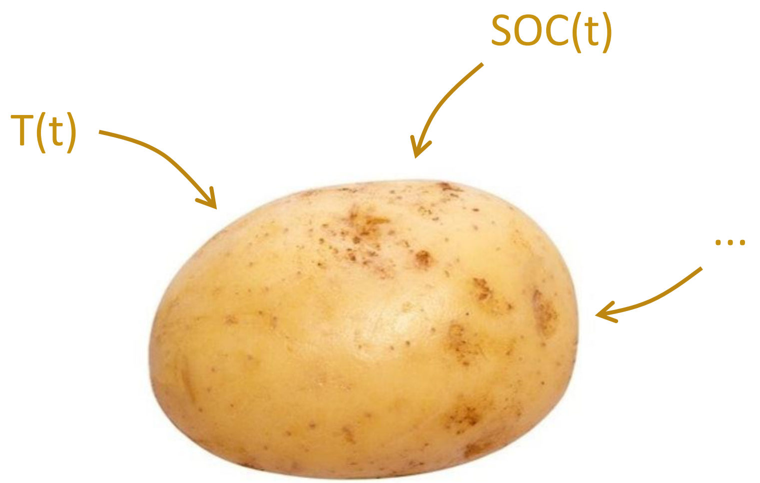


- A rubber cube with *MAT_BLATZ-KO is deformed according to above, after which a dynain file is written
- A second simulation just holds it in place
- “All” combinations of FMATRX, FTYPE, including second simulation running both explicit and implicit
  - A total of 32 cases
- All cases provide the correct stress state at the beginning of the second simulation

New Concept of external Variables

- New keyword *LOAD_EXTERNAL_VARIABLE defines temporally varying spatial distribution of an external variable field
  - e.g., moisture, state-of-charge, carbon content, absorbed hydrogen, …
  - Direct, tabular input per node or node set (curve)
  - Result data from a previous run interpreted as external variable (LSDA file)

- External variable distribution used to modify
  - Thermal material properties in *MAT_T08 and *MAT_T10
  - Structural material properties in *MAT_106 and *MAT_251
  - Phase change parameters in *MAT_254
  - Volume of a part with *MAT_ADD_EXTVAR_EXPANSION



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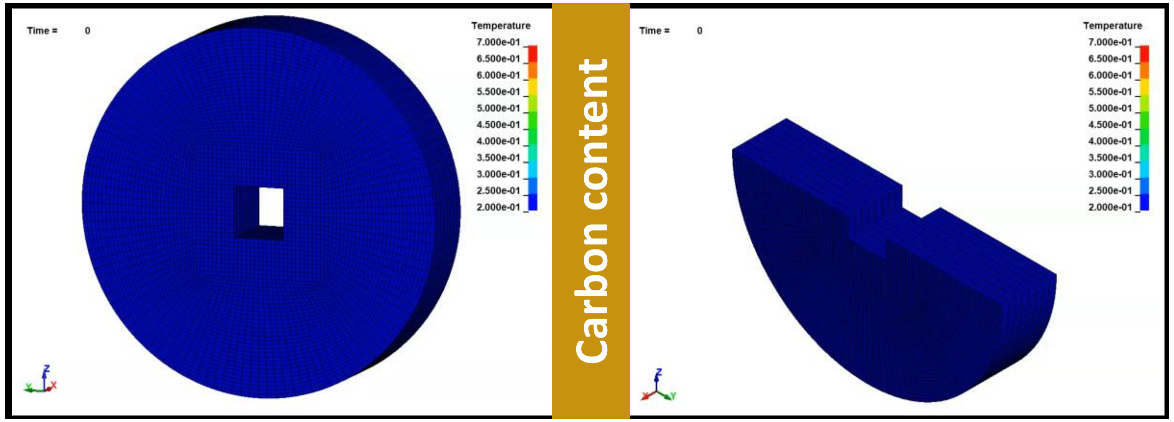
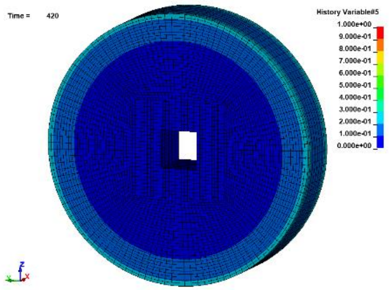
New Concept of external Variables – Case hardening Example

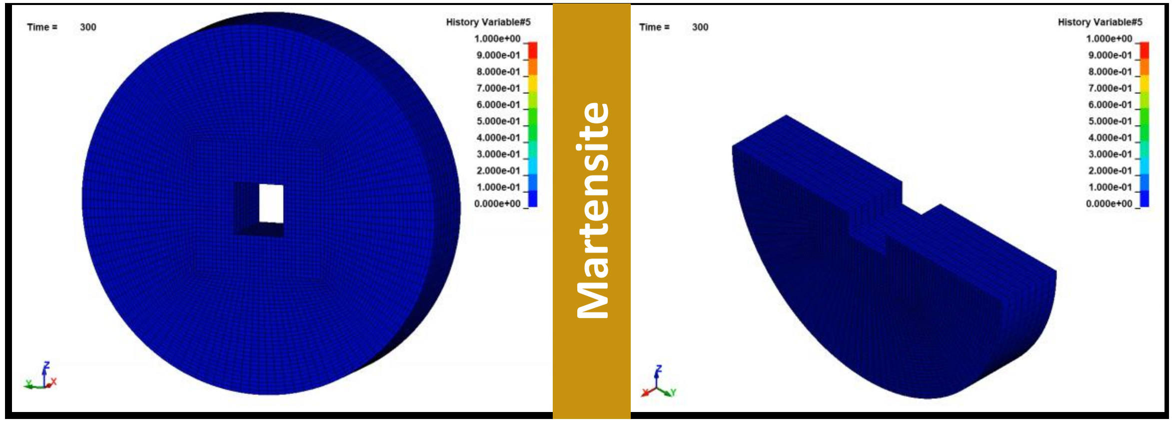
- Heating of a steel specimen in an oven with a carbonaceous environment
  - Austenitization in the material (due to heating)
  - Diffusion of carbon into the material (using temperature as external variable)



- Quenching of the specimen
  - Carbon concentration locally improves martensite formation

Result w/o carburization



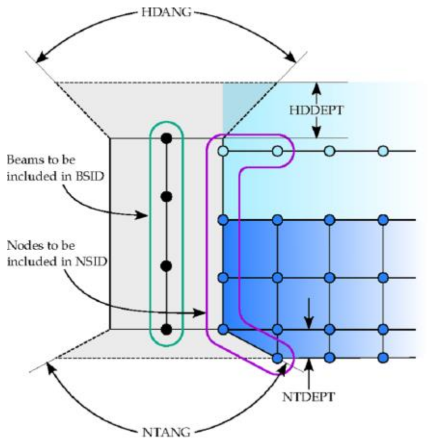


Connector Modelling

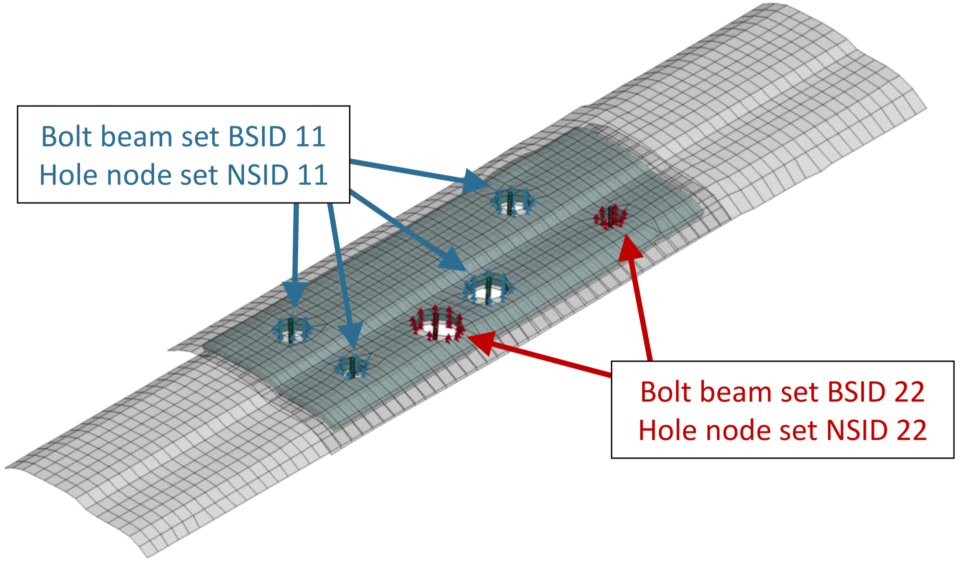
Simplified Modelling of Bolted Joints

- A new keyword *DEFINE_BOLTED_JOINTS for simplified modelling of structures containing a large number of bolts, e.g., airframes.
- Each bolt is modelled using beam elements, interacting with hole nodes through a penalty contact. The head and nut can be countersunk and are modelled as analytical contact surfaces.
- The bolt beams can be pretensioned using already existing functionality.
- The keyword is under development and will be available in future releases.

Boeing 787 cargo door. ©SAAB
https://www.saab.com/globalassets/cision/images/20230905-en-4620297-1.jpg




```
*DEFINE_BOLTED_JOINTS
$#    BJID  BJSLSFAC
         1       0.0
$#    BSID     HDANG     NTANG
        11       0.0       0.0
$#    NSID    HDDEPT    NTDEPT
        11       0.0       0.0
$#    BJID  BJSLSFAC
         2       0.0
$#    BSID     HDANG     NTANG
        22     100.0       0.0
$#    NSID    HDDEPT    NTDEPT
        22       3.0       0.0
```



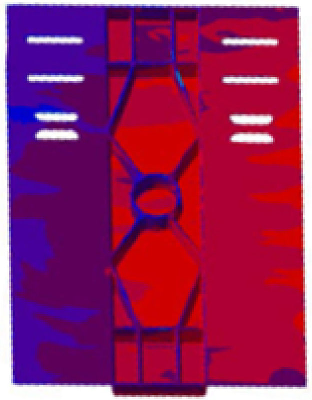
*https://www.saab.com/globalassets/cision/images/20230905-en-4620297-1.jpg

Process Chain

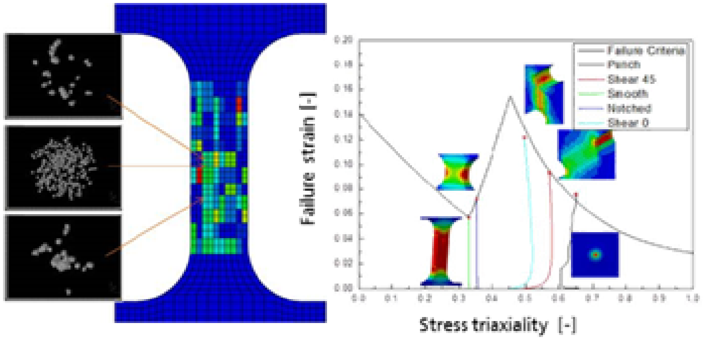
Closing the process Chain: Casting

Taking process chain into account

Aluminium cast part

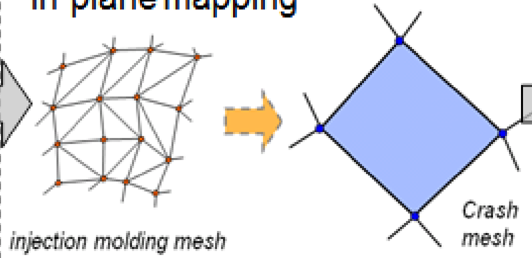


Locally varying constitutive Properties due to porosity etc.

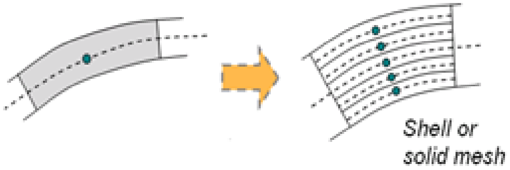


Mapping of local thickness, voids, derived damage from flow path length & Temp. or residual stresses

In plane mapping



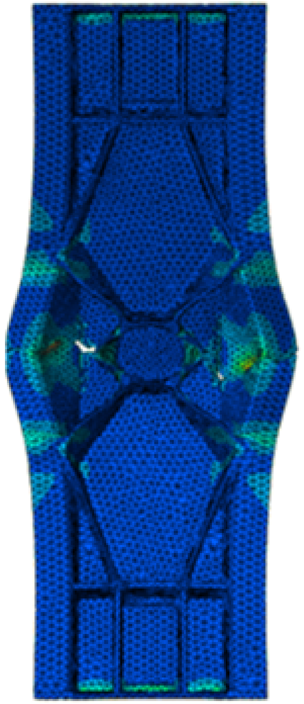
Mapping in thickness direction



Correction of history variables, & estimated damage, when discretization or constitutive model is changed!

Crash analysis

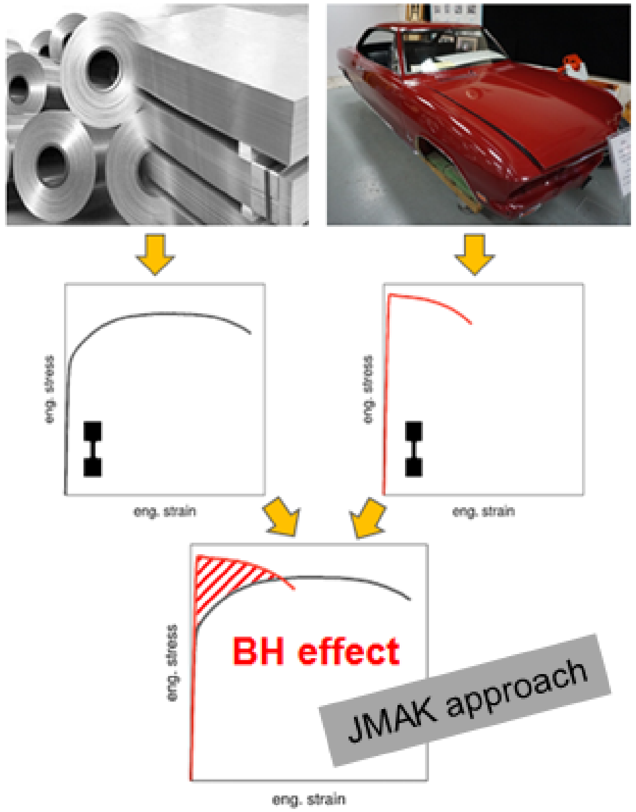
With calibrated anisotropic plasticity model including adjusted damage & failure.



Closing the process Chain: Bake Hardening

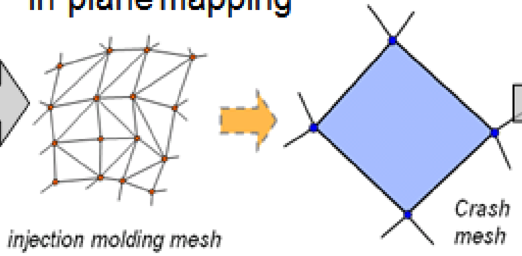
Taking process chain into account

Bake or precipitation hardening effect or dependent on temperature treatment and pre-straining!

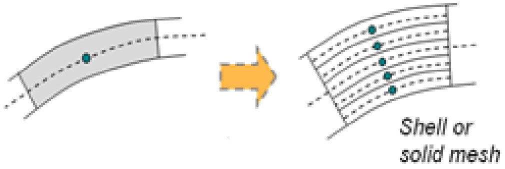


Mapping of local properties like thickness, pl. pre-strain and temp. treatment

In plane mapping



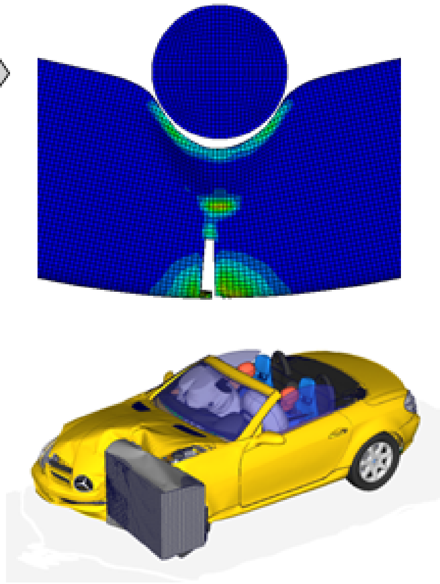
Mapping in thickness direction



Correction of history variables, yield curves when discretization or constitutive model is changed!

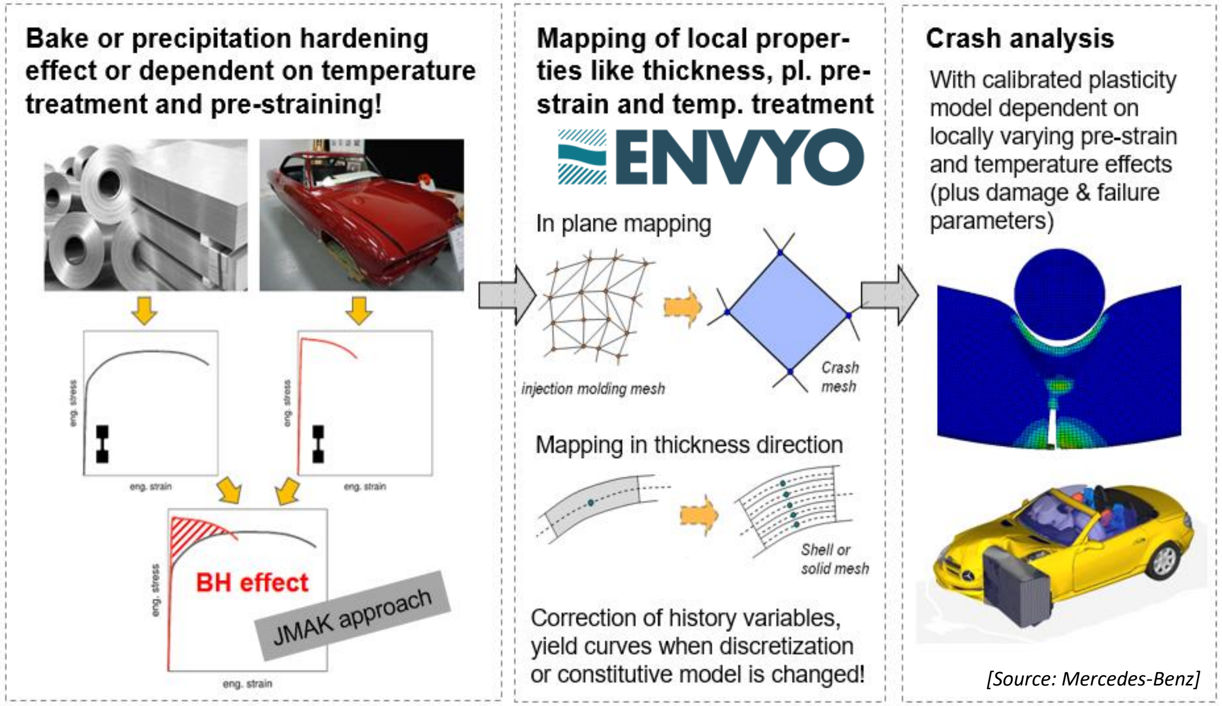
Crash analysis

With calibrated plasticity model dependent on locally varying pre-strain and temperature effects (plus damage & failure parameters)



Examples: The process Chain for Bake Hardening Effects

MCC calibrated process chain for bake hardening effects

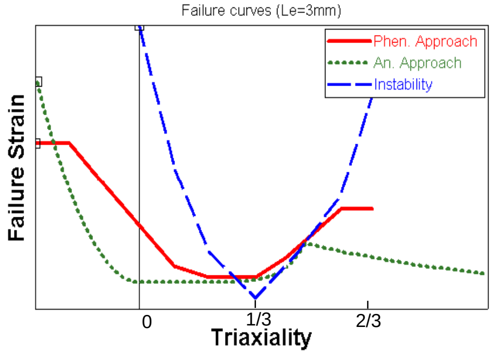


- Material coupons treated with varying pre-heating and pre-straining.
- Parameter identification and application to simulation process chain.

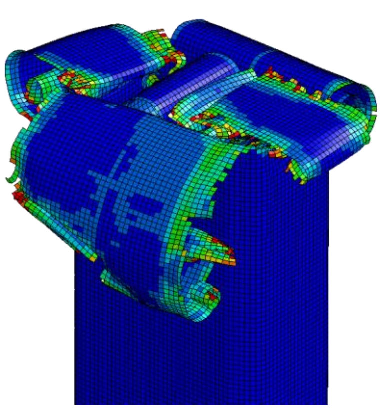
➡ **Predictive results only possible with completely calibrated process chain.**

MCC calibrated constitutive model of crash member

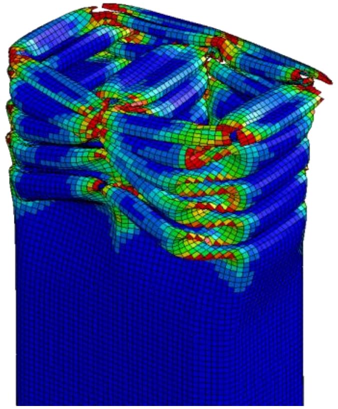
Experiment of alloy crash member



Various options in calibration



Inadequate model calibration



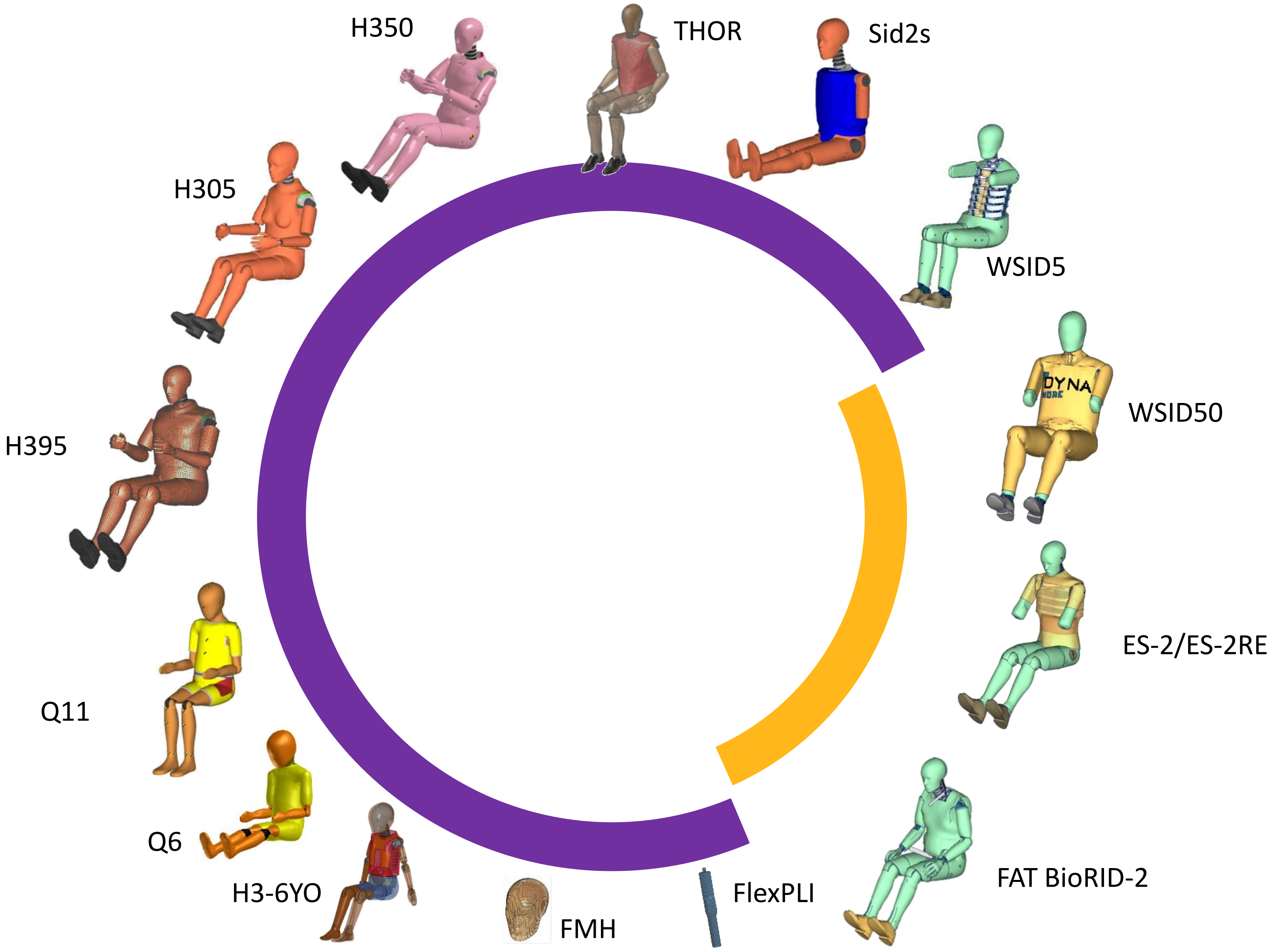
Accurate model calibration

ATDs and HBM

(i.e. dummies and Hans)

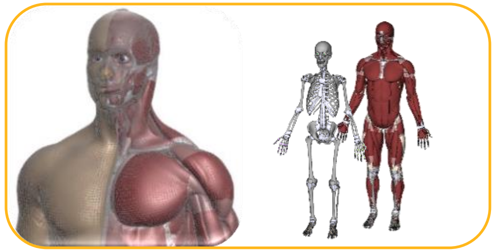
Dummy Models

- Side-impact dummies (SID)
- Rear-impact dummies (RID)
- Test device for Human Occupant Restraint (THOR)
- Forschungsvereinigung Automobiltechnik (FAT) BioRID
- Free-motion head (FMH)

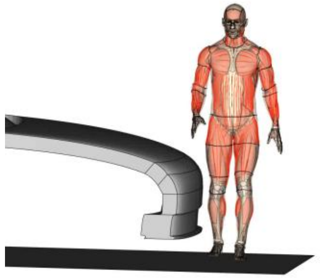


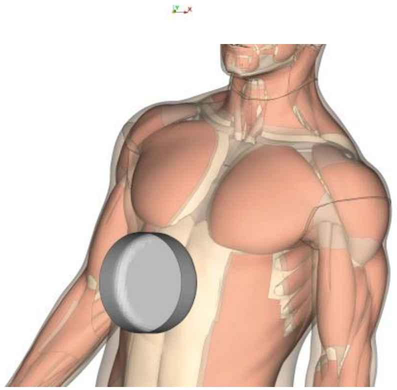
The Impact of Autonomous Driving

- Teleoperation of vehicles will reduce the number of crashes/fatalities (thorough validation and verification of AI based driving functions)
- Consequently, people will take on more relaxed seating positions
- For such load cases, classical ATDs are of limited use
- Human Body Models will play a significant role in virtual certification processes → HANS



Shaw et. al – Sled test

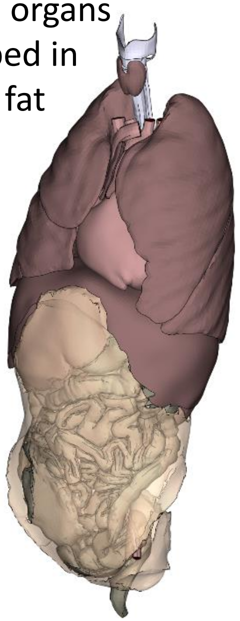


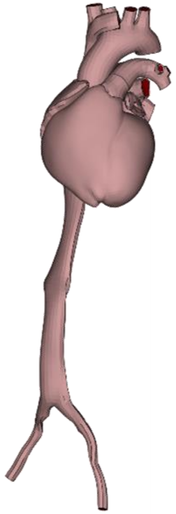


Hans – Some Details

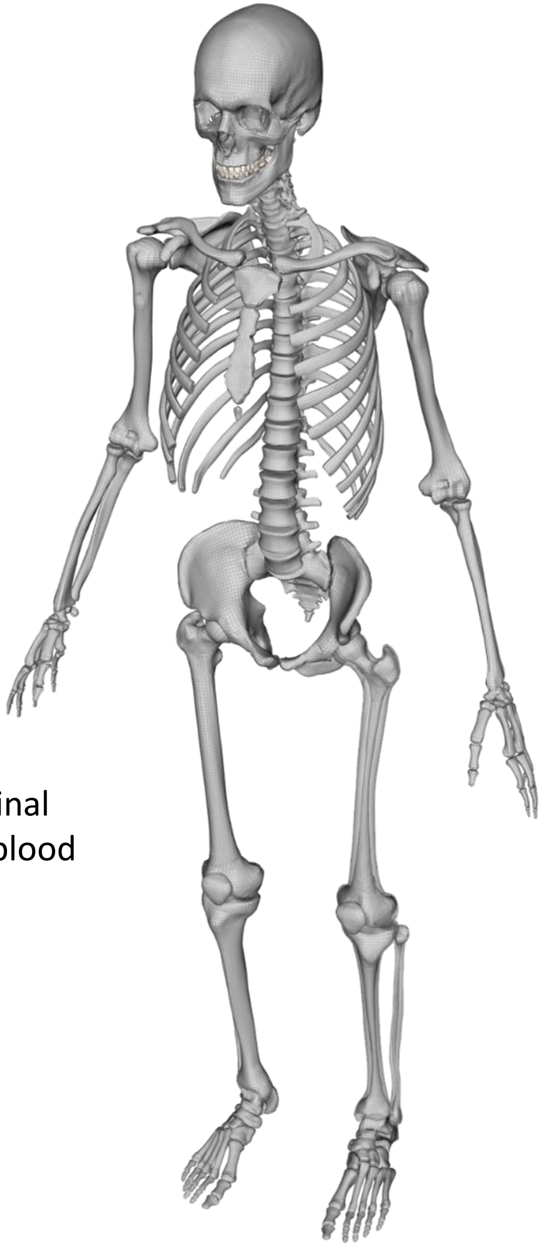
- Model, solver & services from one source
- Commercial model - licensed separately
- Hans represents an average male person – AM50
  - 78kg, 176cm, BMI 25, Age 30-40
- 2 million elements

Internal organs enveloped in visceral fat

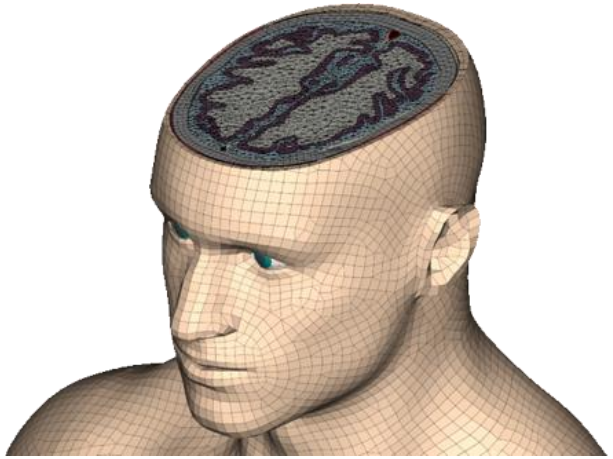


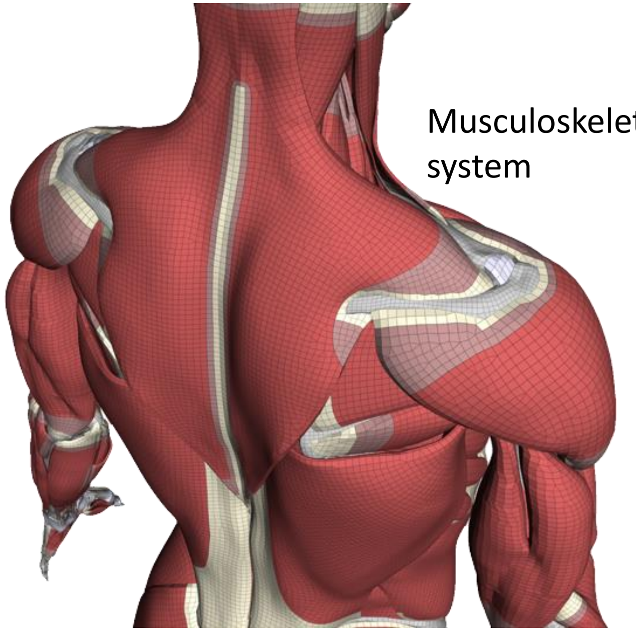


Heart and abdominal artery filled with blood



Brain model



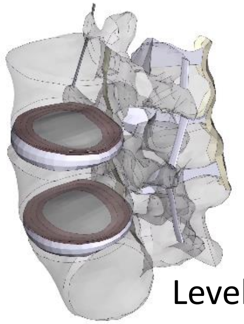


Musculoskeletal system

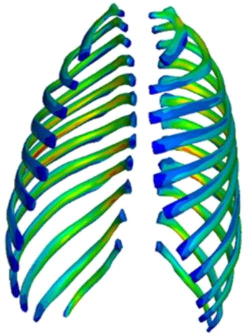
How is Hans calibrated?

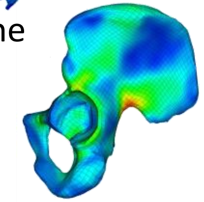
- Material properties of tissues, muscles, ligaments, … are known from **literature**
- The Hans model is calibrated against various datasets of **PMHS/cadaver tests**
- Data from funded **research projects**
- Frequent **exchange with Universities**

Soft tissue material calibration

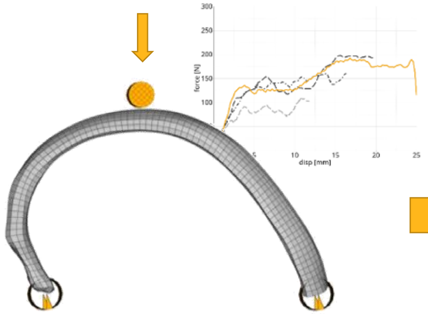


Level of detail

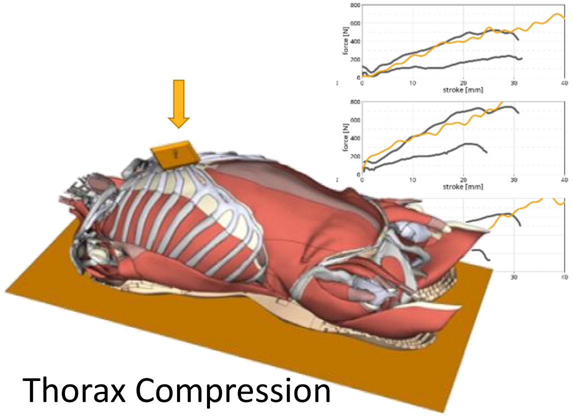




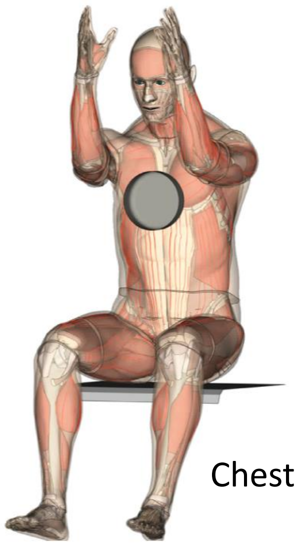
Cortical bone thickness



Single rib bending



Thorax Compression

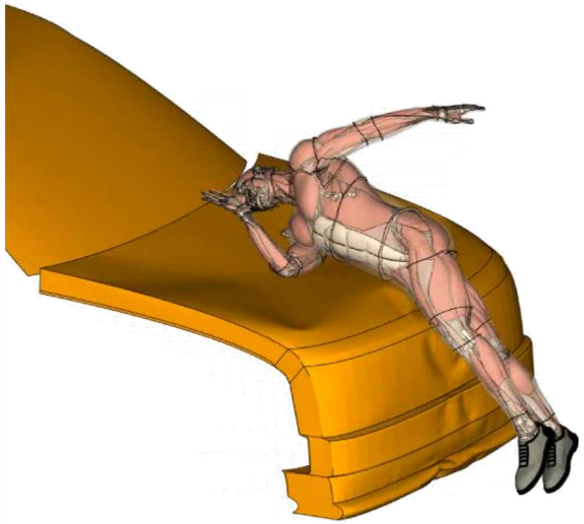


Chest impact

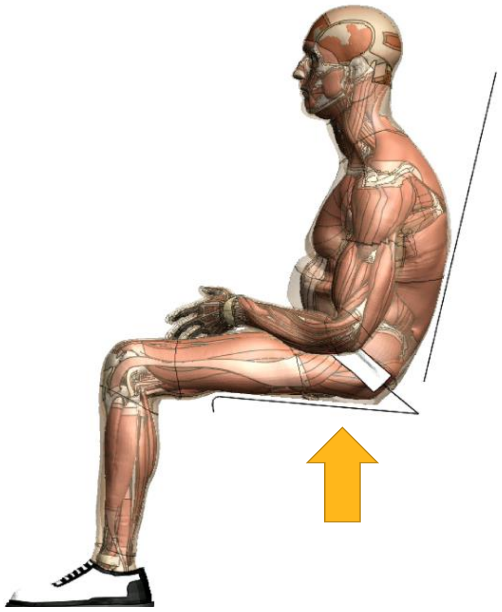
Example Applications

Occupant Analysis

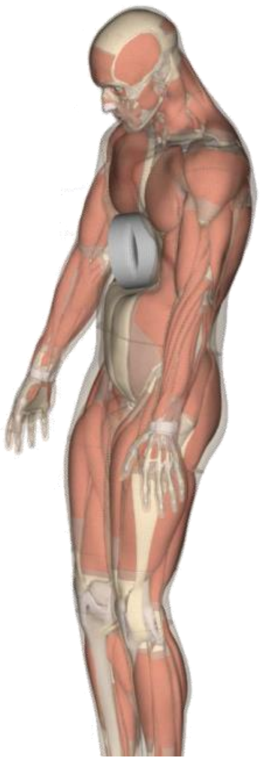
Pedestrian Analysis



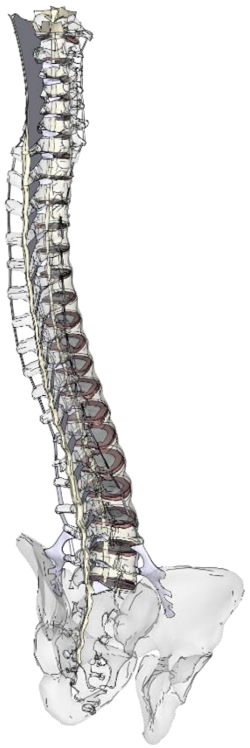
Vertical loads



Blunt impacts

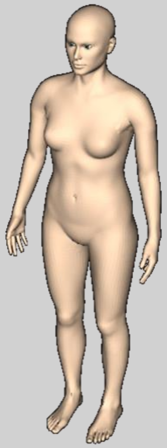


Biomechanics



Virtual Certification via HBM is targeted:

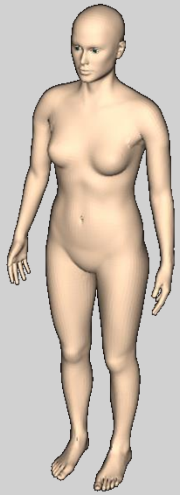
More Coverage of the Population



F5

150cm/5'0''

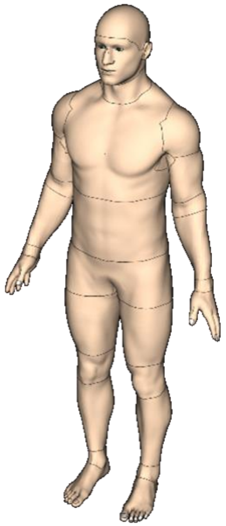
45kg/100lbs



F50

165cm/5'5''

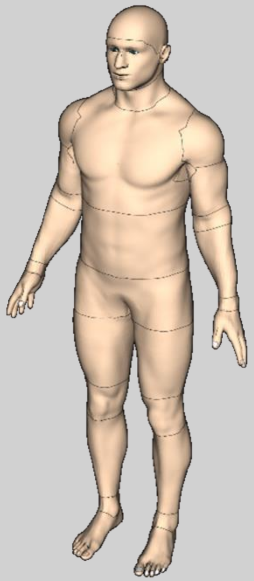
60kg/132lbs



Hans M50

178cm/5'10''

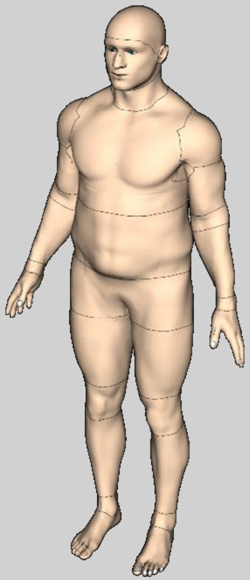
78kg/172lbs



Hans M95

192cm/6'3''

103kg/227lbs



Hans M95+

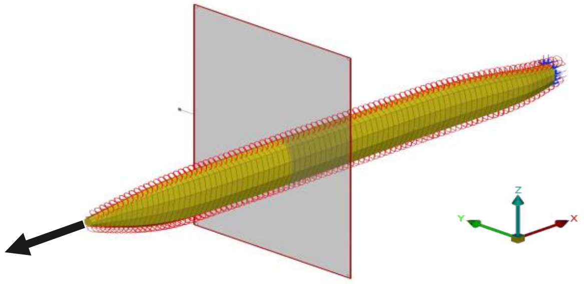
192cm/6'3''

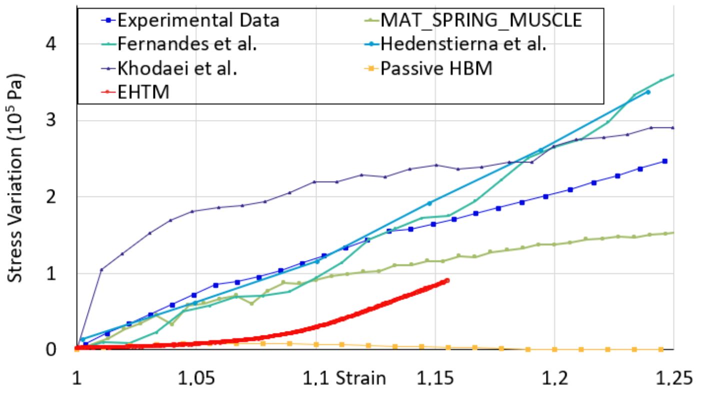
111kg/245lbs

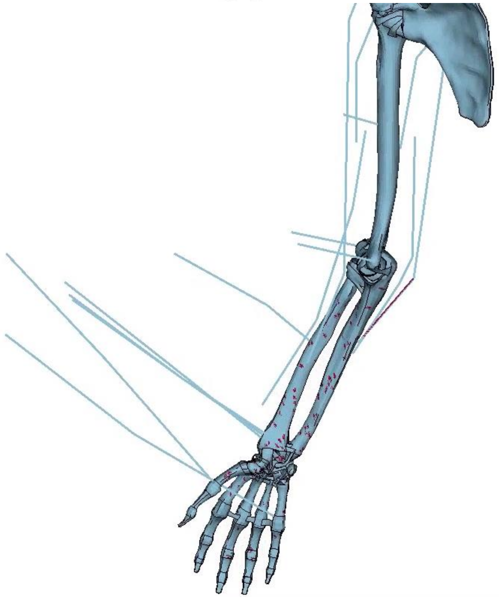
base models

Active Muscles for Hans – a hybrid Approach

- Active muscle modelling in HBMs traditionally performed using 1D Hill-type muscle elements.
- Muscles can be visualised as a composite material with fibres embedded in a 3D matrix.
- A strategy to control the motion generated through muscle driven actions is being developed:
  Activation scheme (alpha), **muscle length feedback** (lambda) and **hybrid controller** (alpha + lambda)







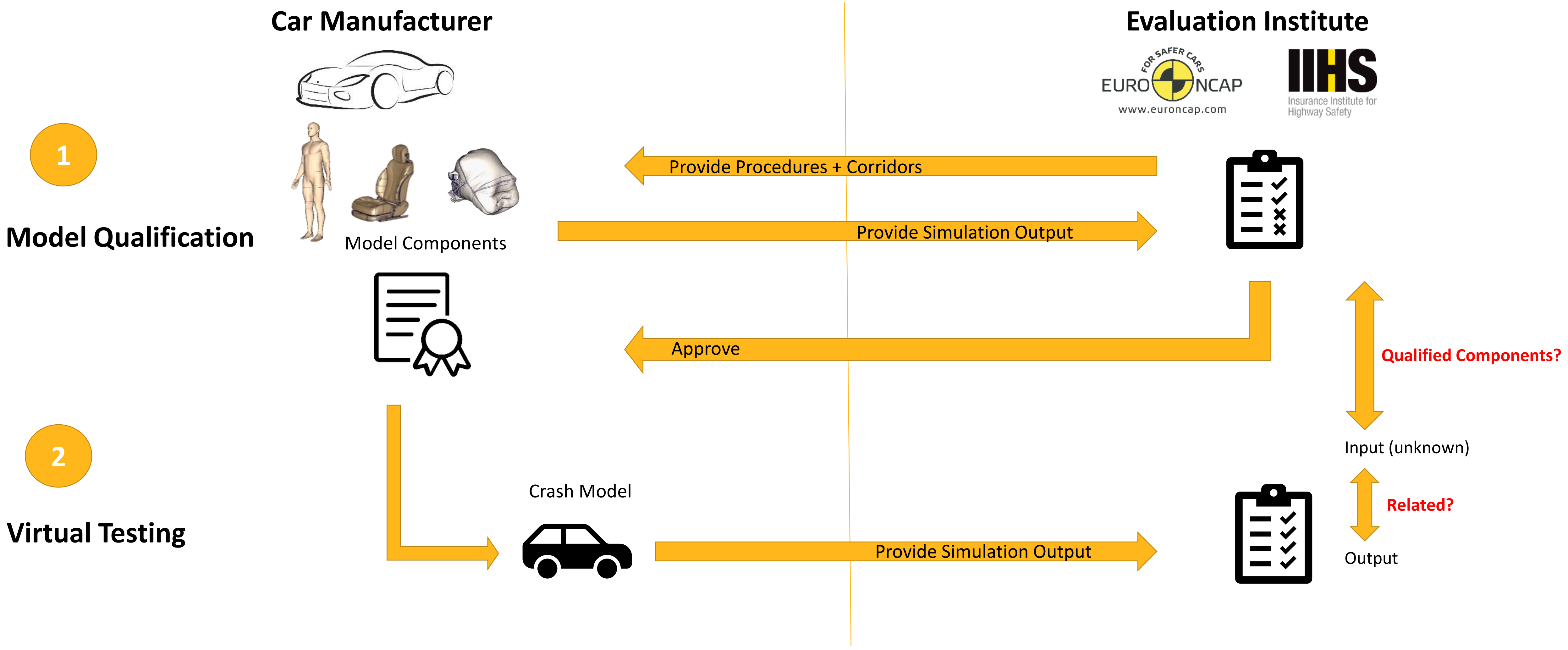
Ansys

Virtual Testing
(Fingerprinting)

Consumer ratings: Fingerprinting models

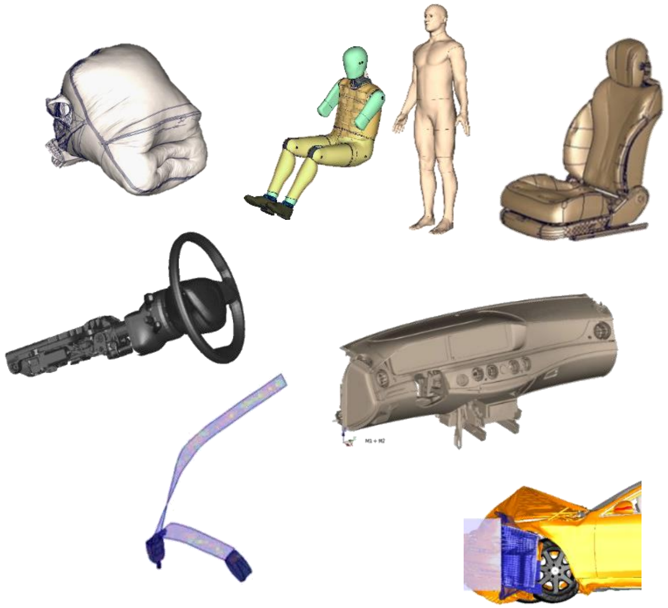
- In upcoming **Virtual Testing (VT)** protocols, car manufacturer are offered the opportunity to earn better ratings by **carrying out crash simulations** in addition to hardware tests
  - Today's car crash models hold **substantial IP;** hence OEMs are not willing to disclose their models to a 3rd party.
  - Sharing only parts of the output provides too little information for the evaluation institute
- **Model Qualification** in combination with **Fingerprinting** can resolve this deadlock issue
- LS-DYNA is now capable of hashing model data and adding a digital signature to enable fingerprinting for VT processes

EuroNCAP/IIHS: Concept of VT workflow



Model Qualification – a Closer Look

- Model components like **dummy models, Human Body models, restraint systems,** ... can be subject to model qualification.
  - Sled tests, impactor tests, …
  - Often developed in working groups with all parties involved
- Model qualification can also be applied to methodologies like **spotweld or material modeling**
- Ideally, **isolated non-IP protected load case** environments are chosen to qualify models.
- The evaluation institute provides result corridors based on available test data.
- The qualification simulations are carried out in the CAE environment of the OEMs or suppliers.
- As **only the output** is being shared → **fingerprinting is required.**



Fingerprinting – The Ingredients

- **Designation of essential model input** which is instrumental for the model response and **must not be changed** during the VT process. This includes for instance, part data, material data, connection definitions, … load case independent definitions.
- An open-source **hash technology built into the solver** to create unique identifiers of critical model input
  - LS-DYNA uses sha256 algorithms
- Technology to encrypt hashes → **digital signature**
  - LS-DYNA uses 2048bit gpg encryption
- The use of open-source algorithms enables 3rd parties to **independently verify** the hashes

Flow Chart Model Hashing

Car Manufacturer

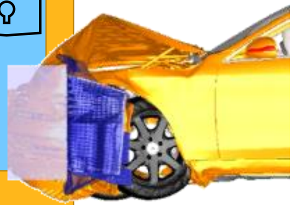
Model Input

Some keywords

Hash Block 1 e.g. HBM/Dummy

Some more keywords

Hash Block N e.g. Parts of structural car model



Ansys LS - DYNA

Hash Generation: **for individual input blocks**

SHA256

D3hsp general output

- Hash=Inp1
- Hash=RES1
- Hash=RES2

Hash Encryption With Private GPG Key
→ Digital signature d3hsp.sig

Hash Generation: **Outputs** SHA256

Model Outputs: Binout, D3plot, ...

Evaluation Institute

EURO NCAP FOR SAFER CARS www.euroncap.com

IIHS Insurance Institute for Highway Safety

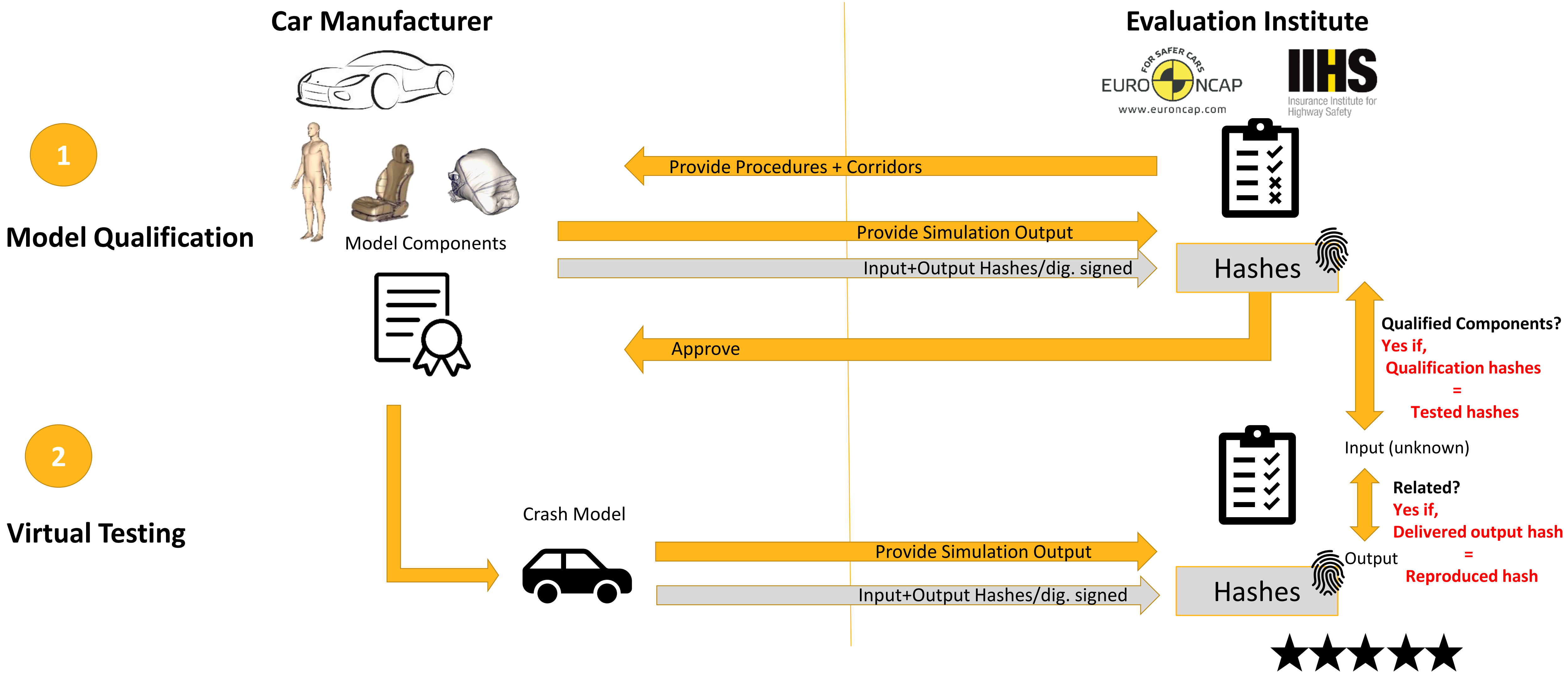
Ansys LS - DYNA

Public GPG key

Compare hash blocks of **VT model** vs **Qualified model**

Check if **input** and **output** are related

EuroNCAP/IIHS: Concept of VT Workflow **with Fingerprinting**



Summary

- LS-DYNA is a very powerful software solution for crash safety
- ANSYS continuously improves LS-DYNA
- Technology in automotive develops rapidly in classic structural mechanics
- Virtual homologation/testing will be a game changer for CAE
- Human modeling allows to design much safer cars
- The **Automotive Crash Safety Group** is available as partner for enhancing modeling fidelity and sophisticated method development
- We would be happy to engage more!

October 28th and 29th, 2025
@BMW Welt in Munich/Germany.

https://www.ansys.com/events/emea-transportation-summit

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