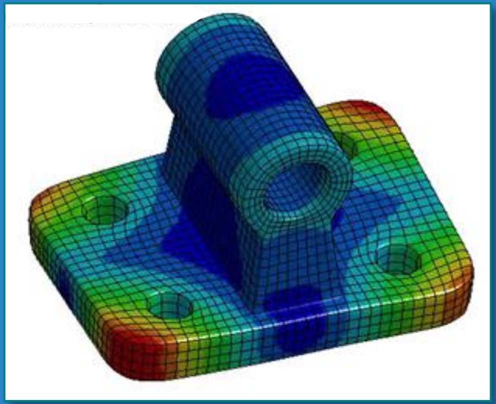
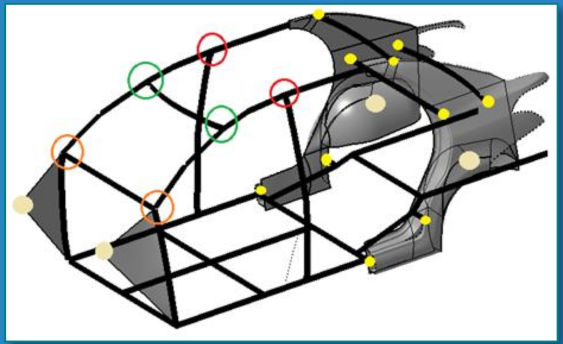
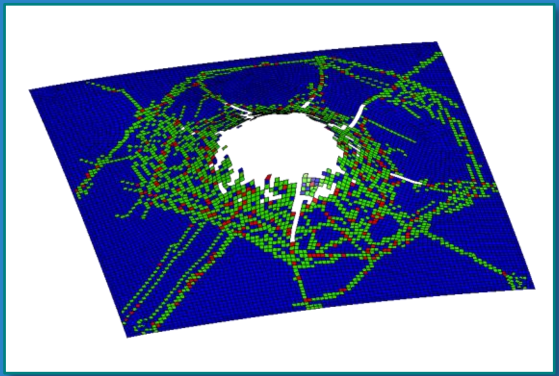
New Features in LS-DYNA

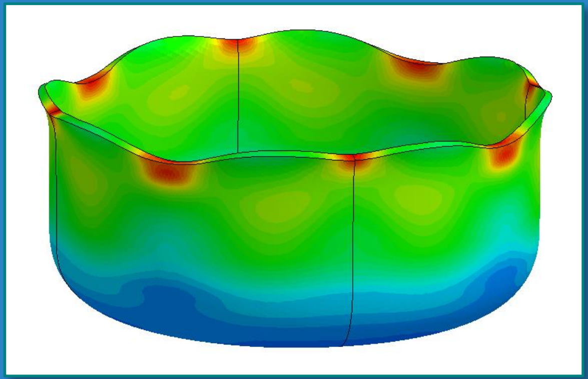
contributions from various developers
(LSTC, DYNAmore, NTNU)

Webinar presented by Tobias Erhart - 13 September 2019

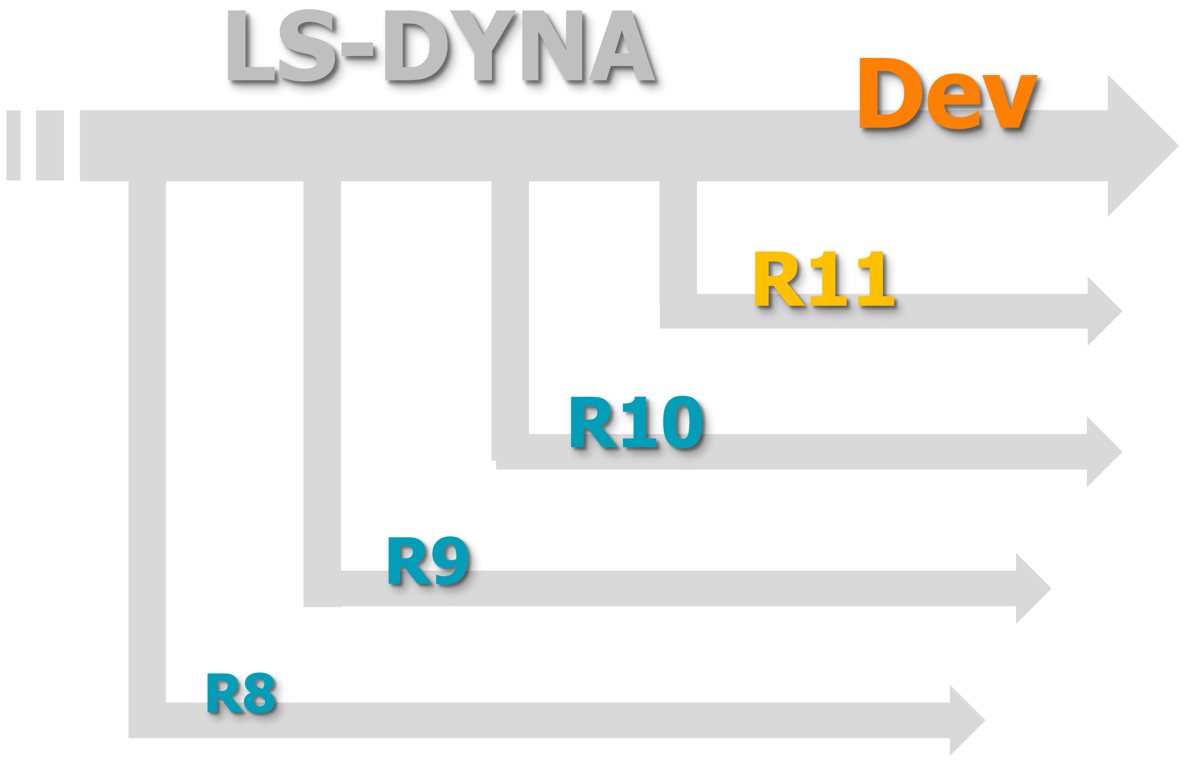








LS-DYNA versions

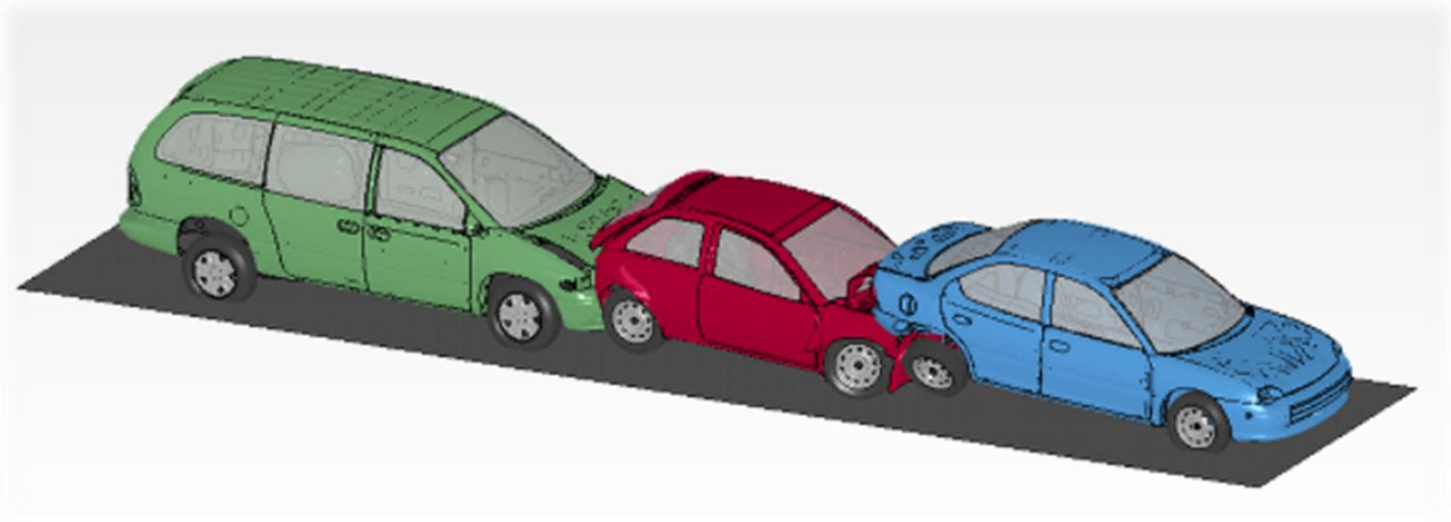


- Version numbering scheme
  - Major branches called R8, R9, R10, …
  - Official releases such as R9.3.0, R10.2.0, R11.1.0, …
- Most robust releases
  - Releases R7.1.3, R9.3.0, (R9.3.1*)
  - Recommended production versions
- Latest official versions
  - Release R9.3.0 from May 2018
  - Release R10.2.0 from February 2019
  - Release R11.1.0 from August 2019

*available soon

Latest developments: Outline

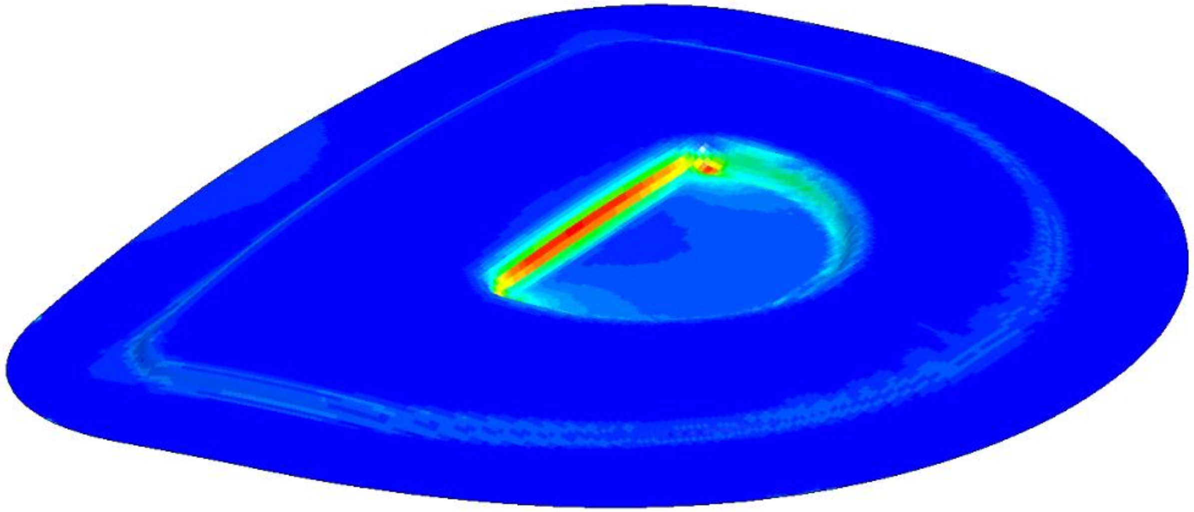
- Isogeometric Analysis (IGA)
- Element Technology
- Implicit
- Contact
- Connections
- Airbags (CPM)
- Material Models
- Forming Applications
- Thermal Analysis
- Miscellaneous



Isogeometric Analysis | Multistage

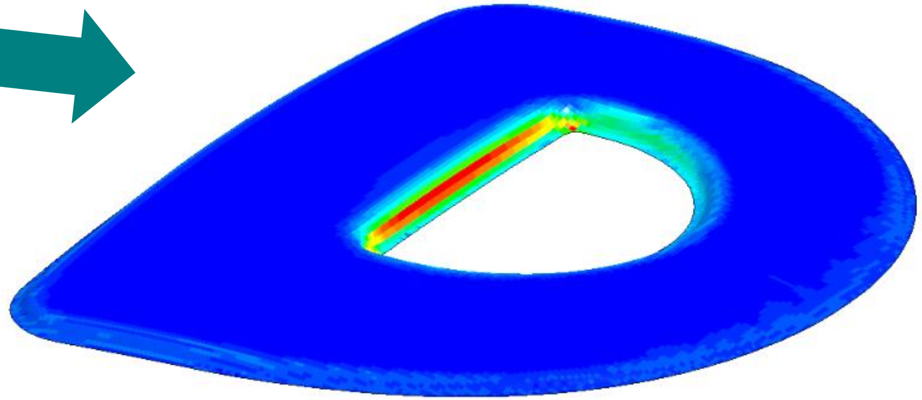
Benson, Hartmann, Li, Nagy

- Enable multistage analysis, e.g., forming processes
  - prepare for next step with *INTERFACE_SPRINGBACK_LSDYNA
  - start from last step with *INITIAL_STRESS/SHELL_NURBS_PATCH
    stresses, strains, thickness change, history variables
  - trimming step with *CONTROL_FORMING_TRIMMING



deep drawing

mapping, e.g.,
plastic strains

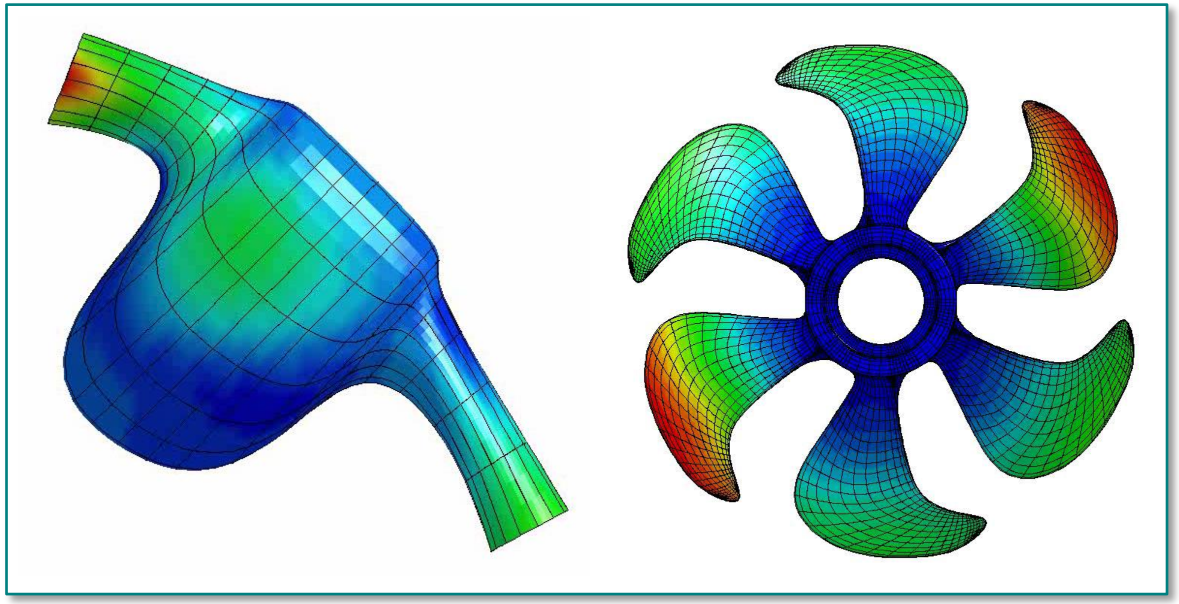


trimming

Isogeometric Analysis | Spline Techniques

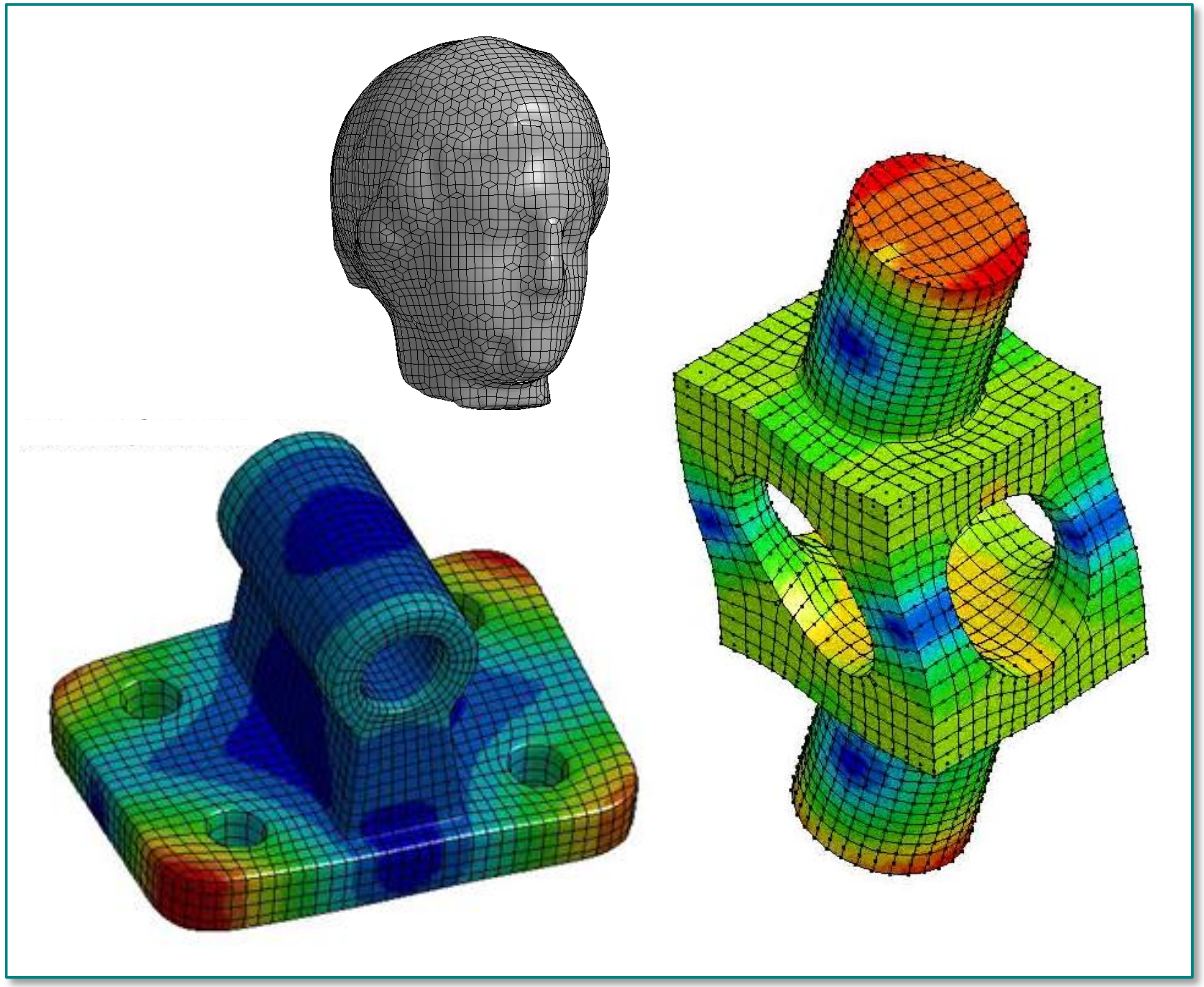
Benson, Hartmann, Li, Nagy

- Support ”Bezier-Extraction“-Format
  - allows study of different spline technologies
  - shell & solid NURBS



T-splines, U-splines

Coreform LLC · Ford Motor Co., Ltd.



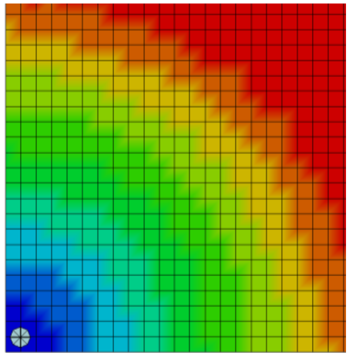
Truncated hierarchical T-spline

Carnegie Mellon University · Honda Motor Co., Ltd.

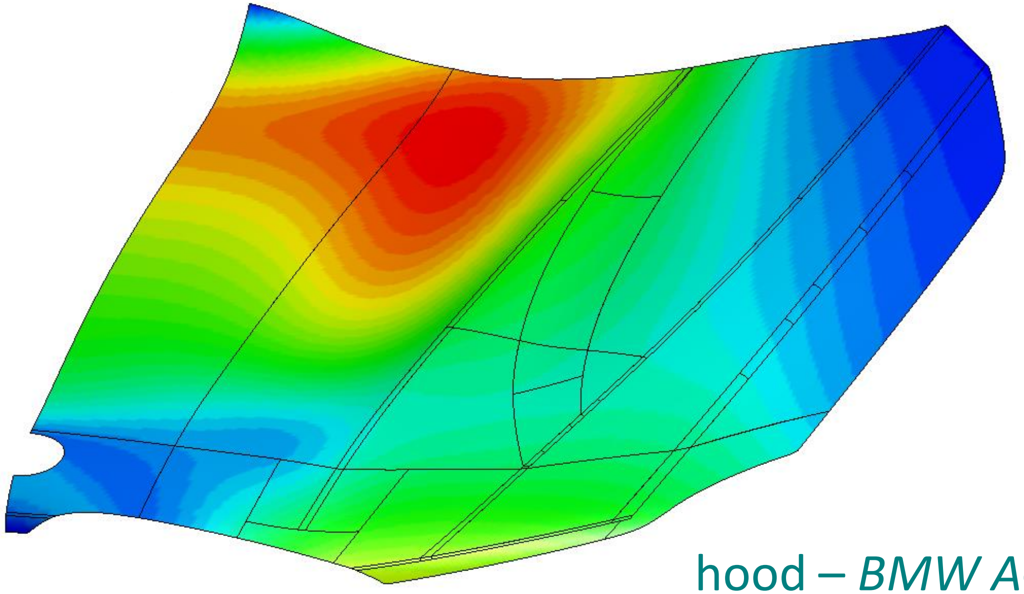
Isogeometric Analysis | Miscellaneous

Benson, Hartmann, Li, Nagy

- Support HAZ-option for NURBS shells
- *LOAD_NURBS_SHELL
  - line loads along curves
  - pressure loads on patch and areas
- *CONTACT_NURBS_TIED_EDGE_TO_EDGE
  - tying of (un-)trimmed NURBS patches
  - penalty formulation
  - explicit & implicit
  - currently only SMP (Dev-Version)
  - … work in progress



spotweld with heat affected zone

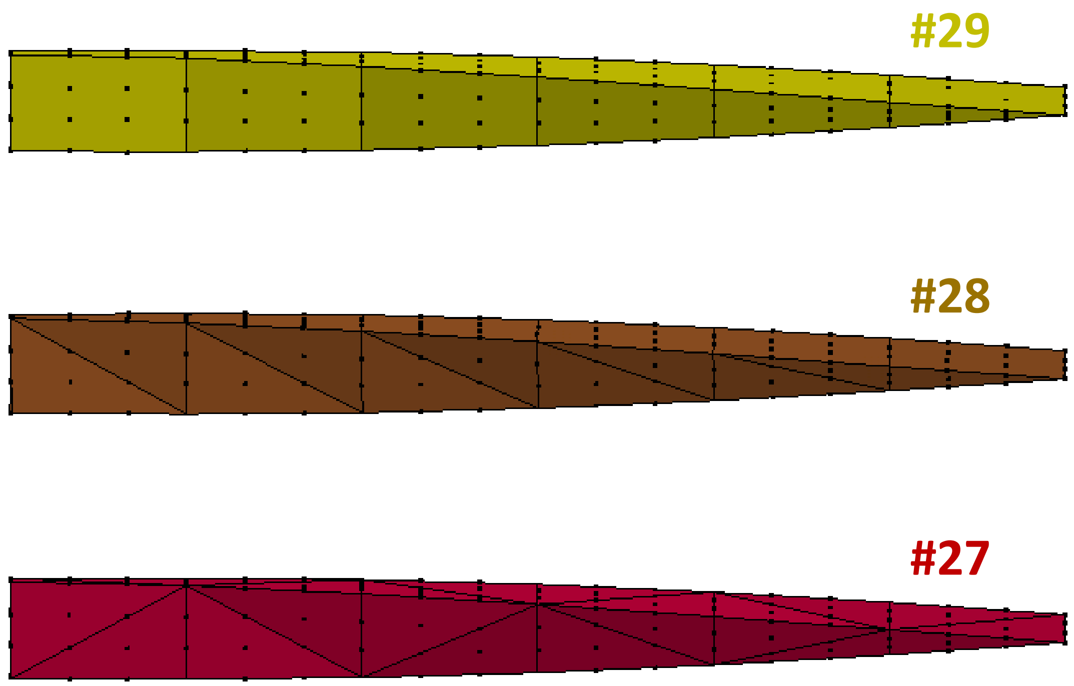


hood – *BMW AG*

Finite Elements | Cubic Solids

Benson, Teng

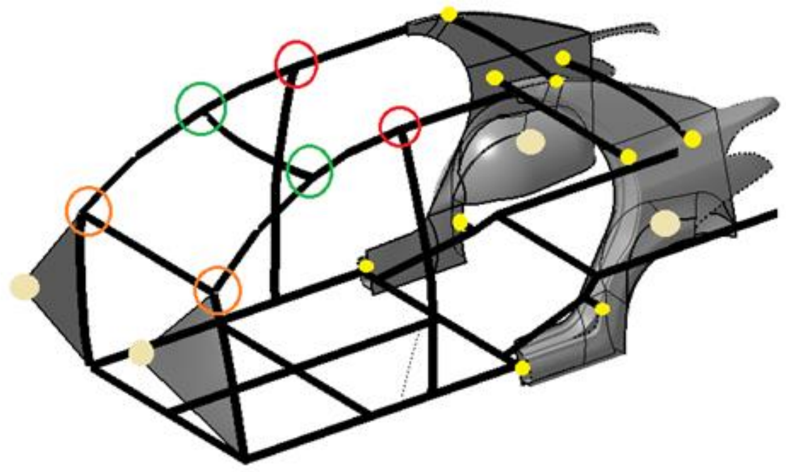
- New element formulations 27, 28, and 29
  - ELFORM=27 is a 20-node tetrahedron
  - ELFORM=28 is a 40-node pentahedron
  - ELFORM=29 is a 64-node hexahedron
- Element input
  - *ELEMENT_SOLID_T20
  - *ELEMENT_SOLID_P40
  - *ELEMENT_SOLID_H64
- Keyword to convert linear to cubic
  - *ELEMENT_SOLID_H8TOH64
- … work in progress

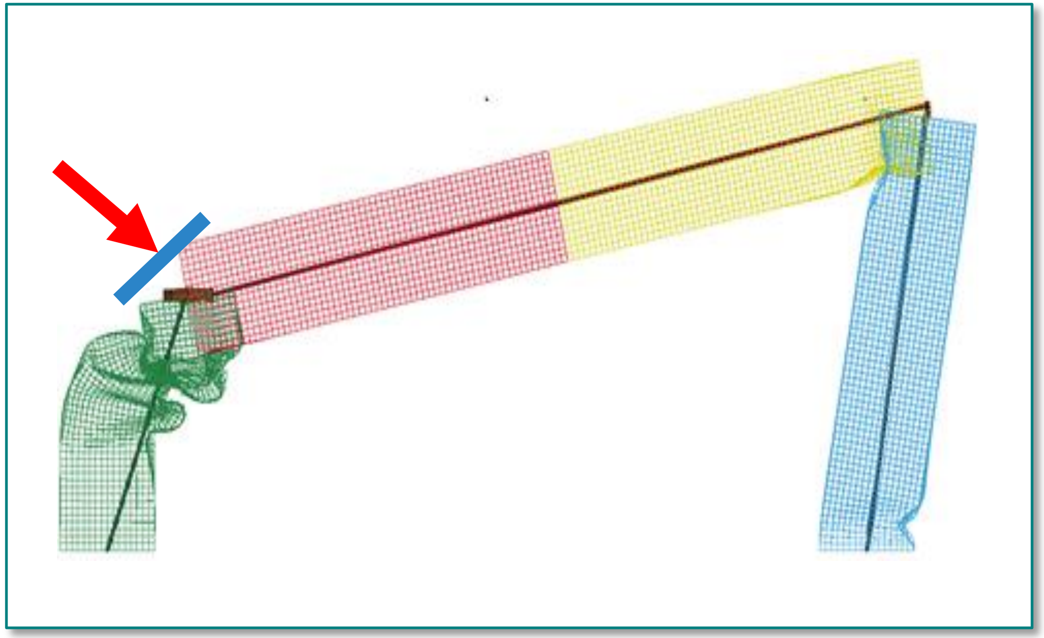


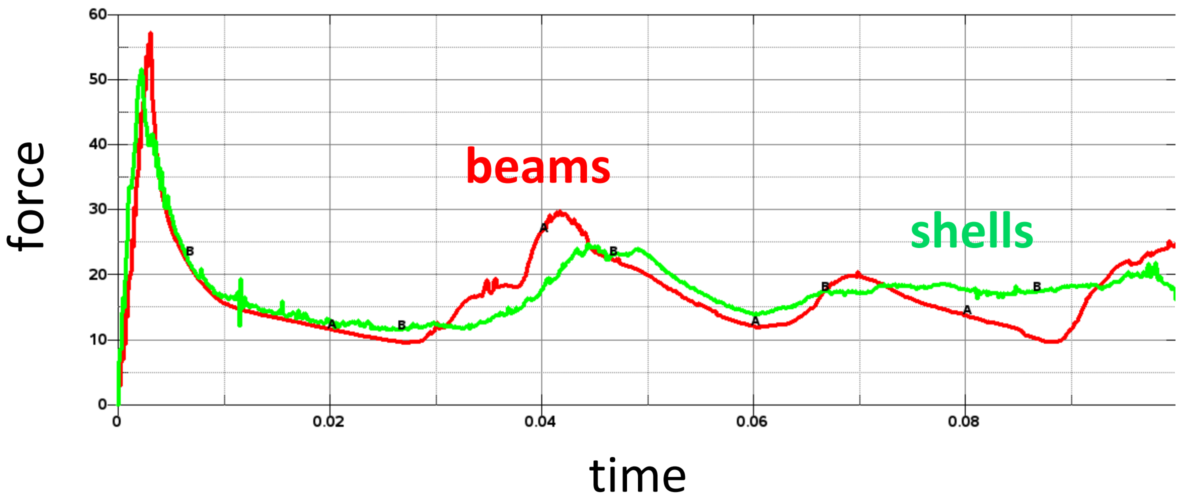
high accuracy in twisted beam problem
with only one solid over the thickness

Elements | Crushable Beam

- CAE models for concept design
- Replace detailed FE model (shells, solids) by simple beam frame structure
- Complex structural behavior embedded in material model: *MAT_119 enhanced (IFLAG=2)



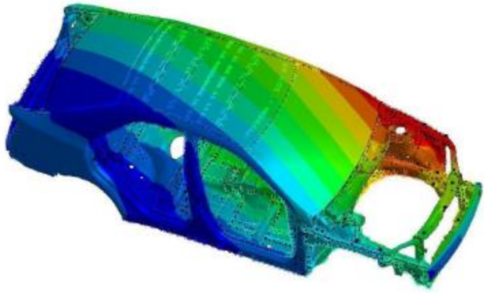


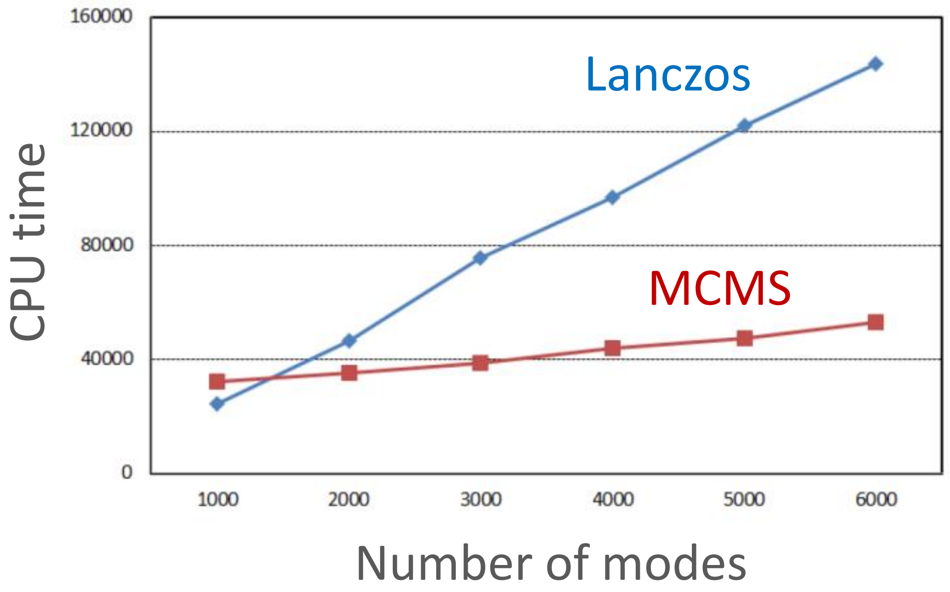


Linear Implicit (1)

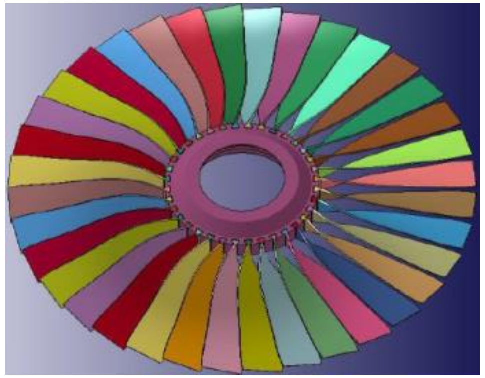
Grimes, Ashcraft, Lucas, Rouet, Wiesbecker, Vecharynski, Li

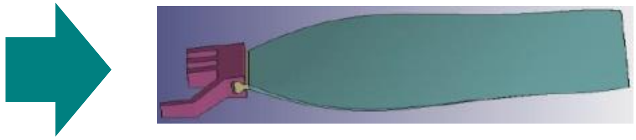
- New eigenvalue extraction method: MCMS
  - Multilevel Component Mode Synthesis
  - less accurate than Lanczos, but far less computer resources
  - useful for NVH applications that want thousands of modes





- Sectoral symmetry
  - for models with significant rotational symmetry: highly reduced eigenvalue problem





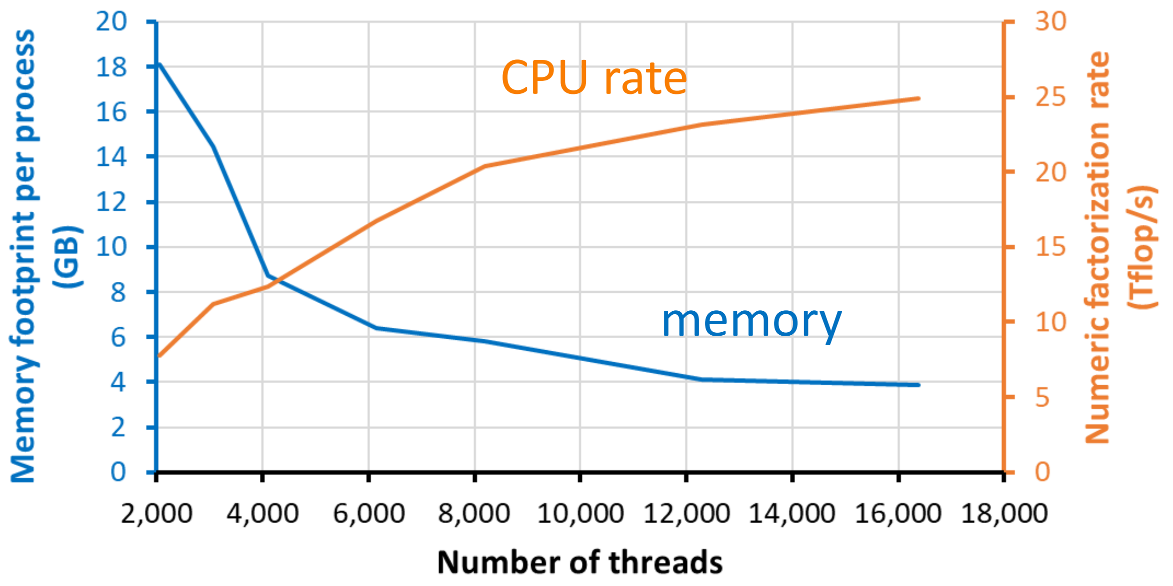
huge CPU/memory savings

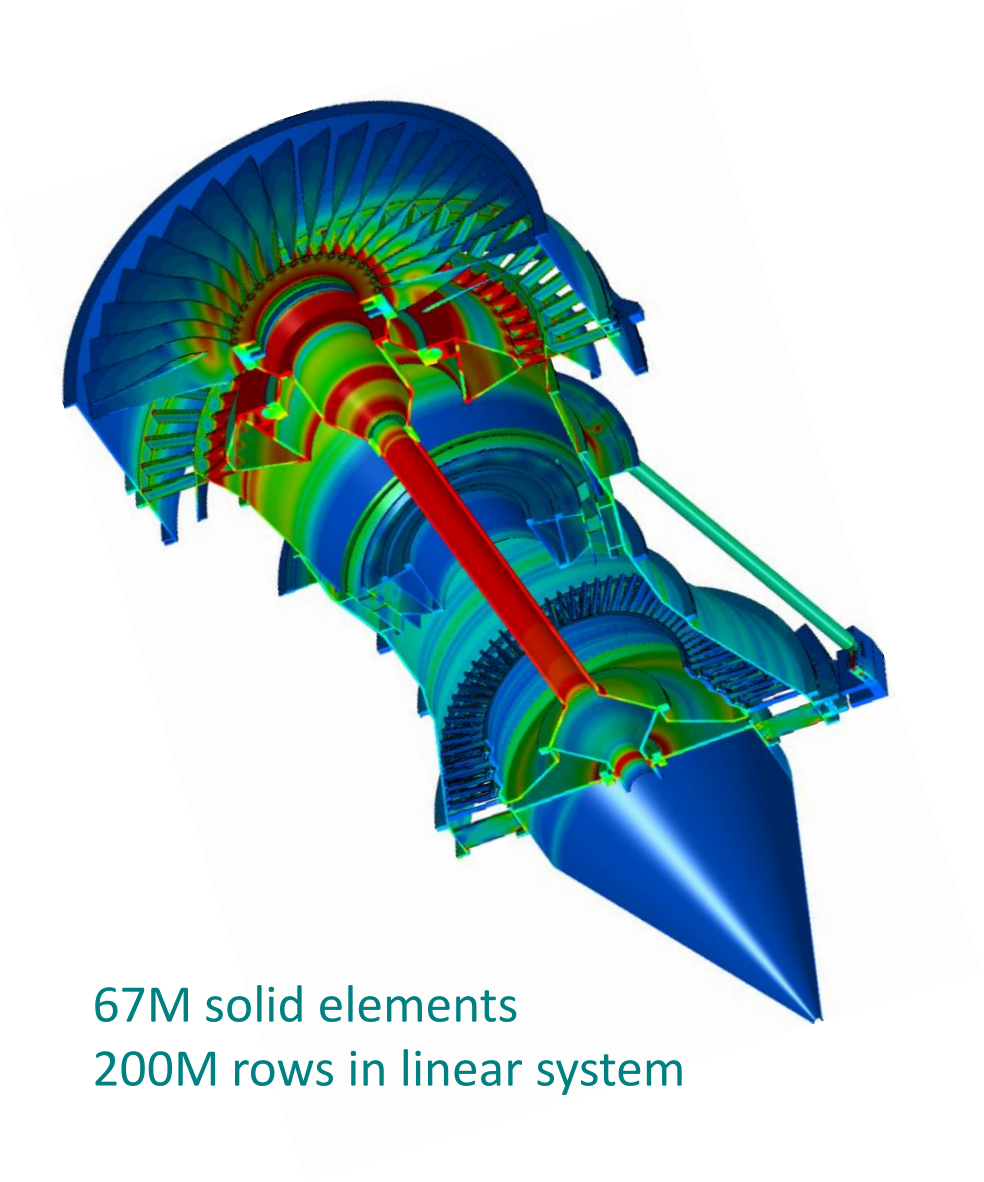
- And always…

Linear Implicit (2)

Grimes, Ashcraft, Lucas, Rouet, Wiesbecker, Vecharynski, Li

- …working on larger and larger models!
  - e.g. jet engine model from Rolly Royce
  - original attempt: 158 hours on 448 cores
  - current best: 12 hours on 2304 cores
  - continuing efforts to improve scalability



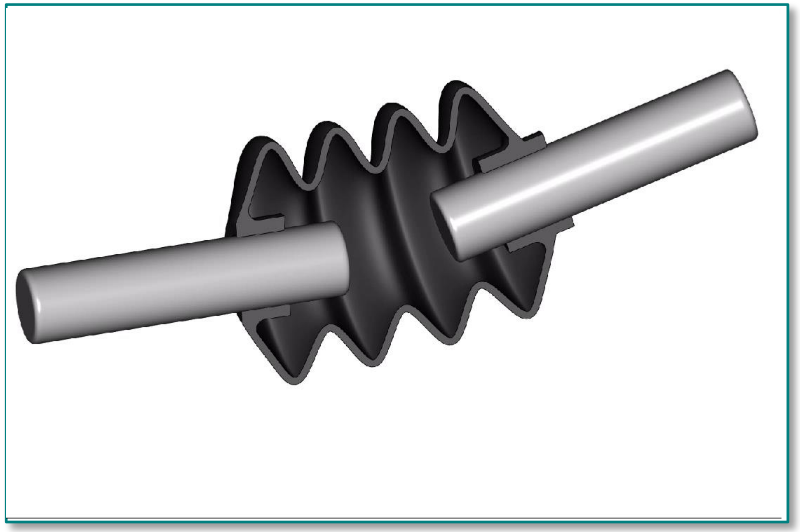


67M solid elements
200M rows in linear system

Nonlinear Implicit (1)

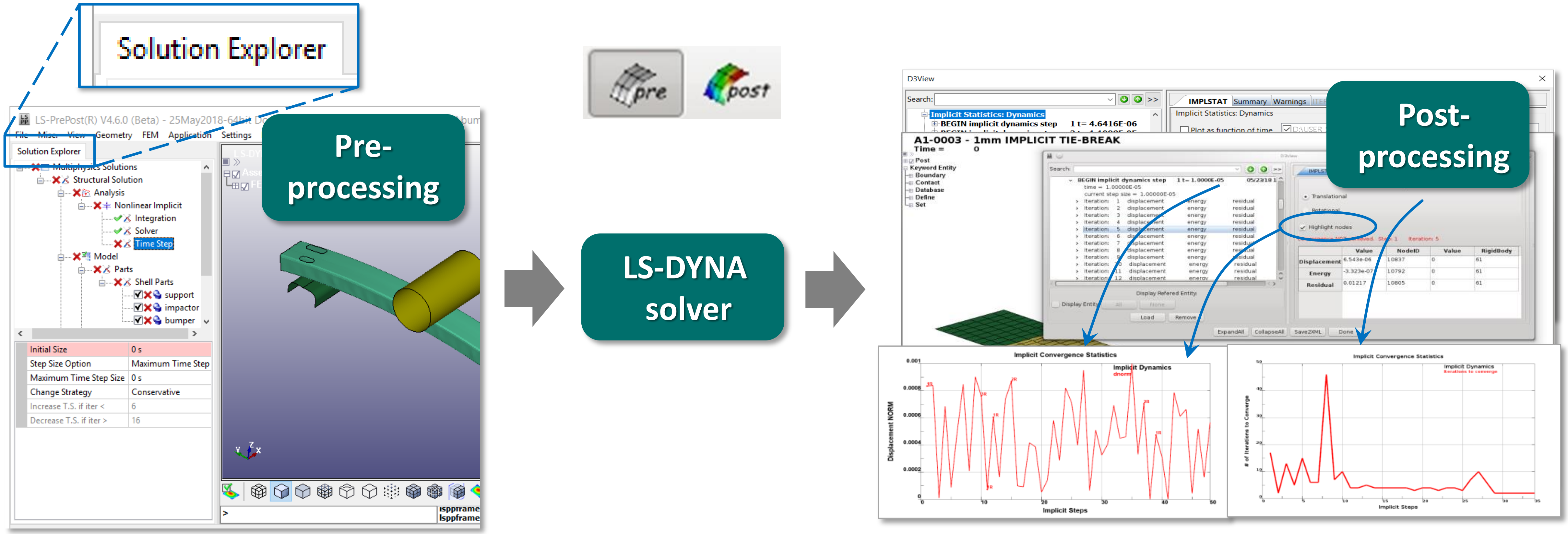
Borrvall, Bengzon

- Convergence tolerances
  - maximum values, consistent norms
- Time stepping
  - step change based on accuracy, automatic keypoints
- Process splitting by *CASE
  - ”complex” process divided into ”simple” steps
- Accurate prestressing
  - initial stress section accounts for bending (*INITIAL_STRESS_SECTION with IZSHEAR=2)
- Materials etc.
  - tangent moduli and stiffness matrices added and improved for, e.g., *MAT_SHAPE_MEMORY, *MAT_SOFT_TISSUE, *MAT_SAMP, *AIRBAG, …



Nonlinear Implicit (2)

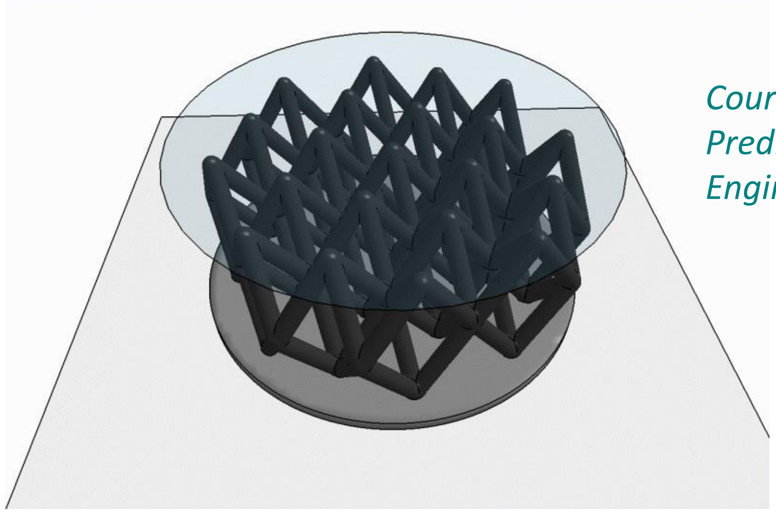
Borrvall, Bengzon, Wenhui, Jernberg, Chengju, Zhanqun, Zhansheng



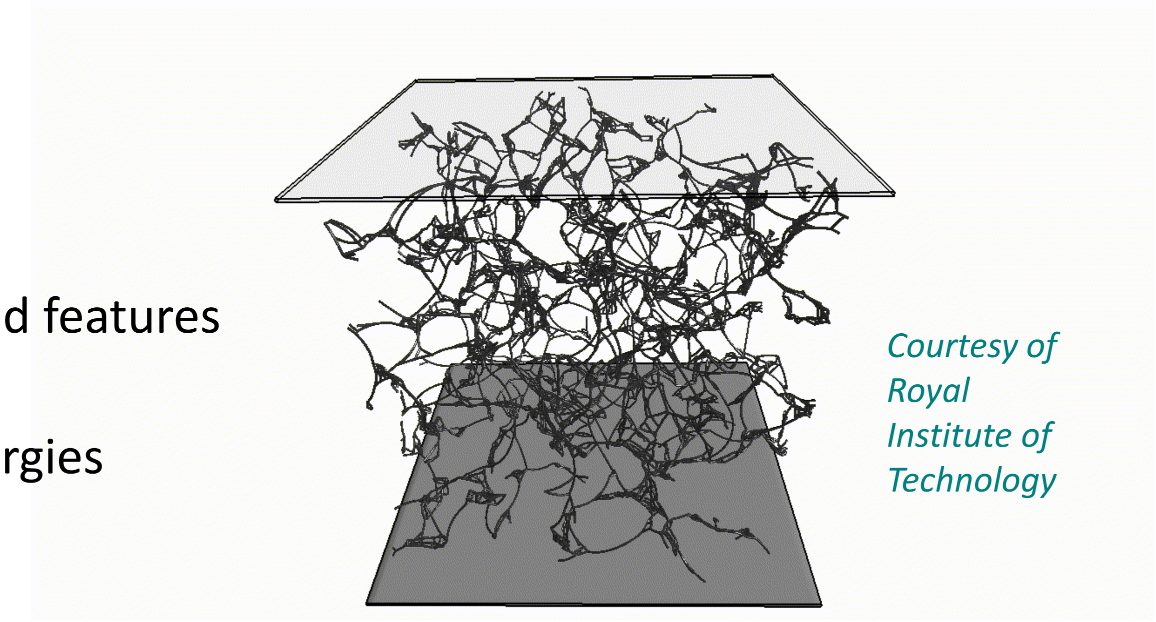
- Working on user-friendly Pre- and Post-processing (LS-Prepost)
  - model tree, parameter editor, suggested presets, error functionality, diagnostics
  - motivation: attract newcomers, facilitate migration, widen user community

Mortar Contact (1)

- Towards physical behavior and completeness
  - contacts physical surfaces of solids/shells/beams/tshells
  - sliding and tied/tiebreak/weld versions
  - user defined options
- Developed with implicit in mind
  - consistent FE treatment of kinematics/kinetics
  - robustness is primary, efficiency secondary
  - explicit serves more as a life wire
- Recent developments include
  - expansion of friction models and tied/tiebreak/weld features
  - treatment of initial penetrations,
    explicit in particular to avoid spurious negative energies
  - efficiency considerations



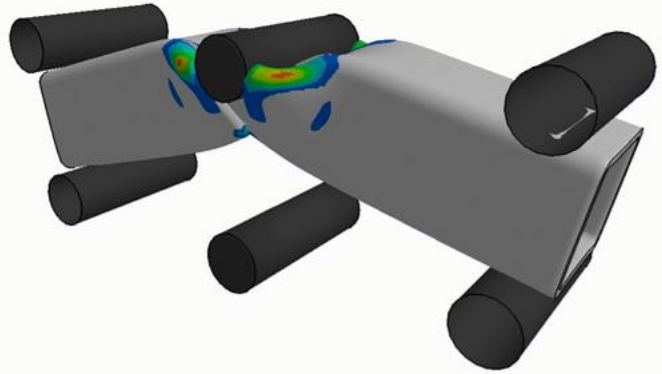
Courtesy of Predictive Engineering



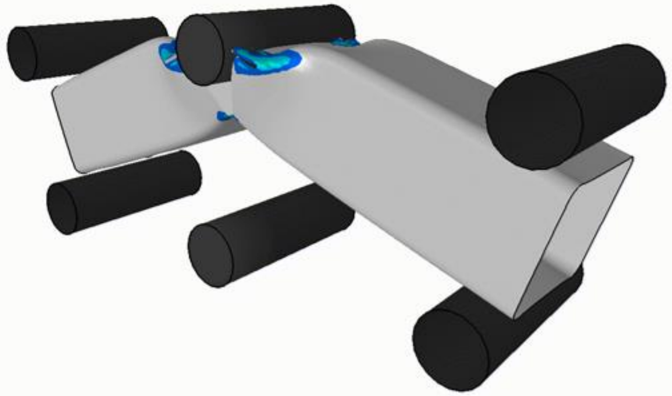
Courtesy of Royal Institute of Technology

Mortar Contact (2)

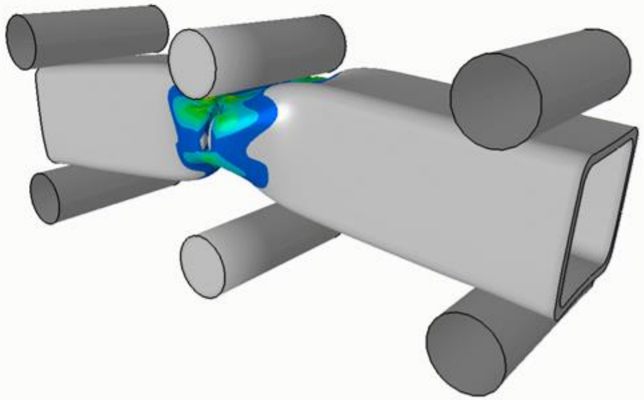
Thick shells



Shells



Solids



- Exposed segments due to erosion added to the contact
  - works for solids, shells and thick shells
- For shells, edges of eroded elements are exposed
- Supported for automatic surface to surface and single surface

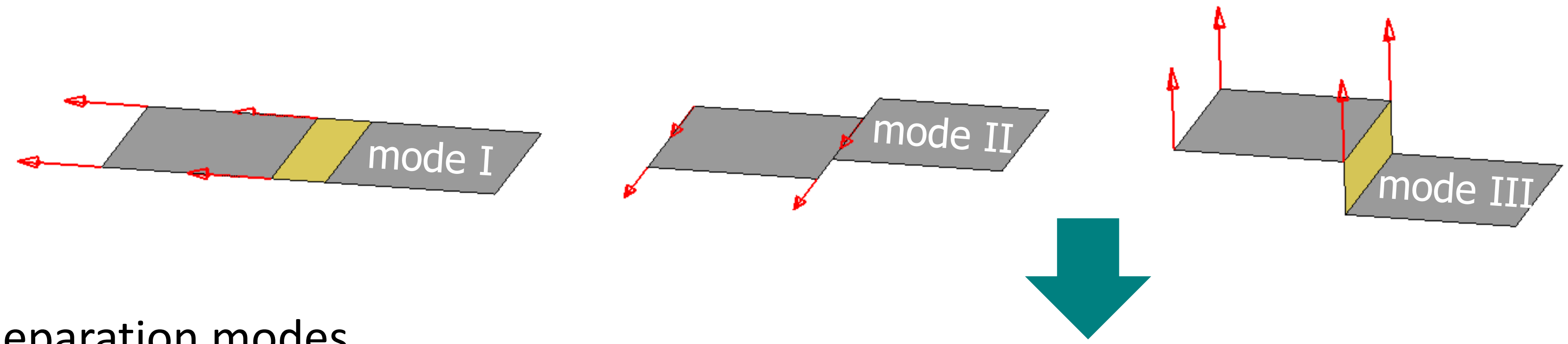
Contact | SOFT=2 (segment based)

- Spotwelds share nodes with shells
  - support SPOTHIN and SWRADF in this case as well
- Different friction coefficient for the inner and outer surface of shell elements
  - new keyword *DEFINE_FRICTION_SCALING

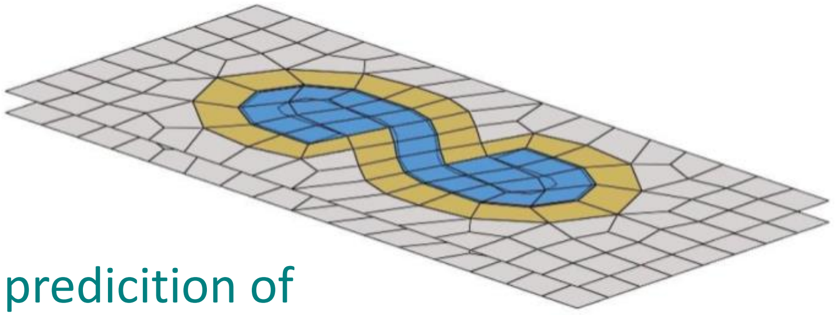
- Frictional torque correction with FTORQ=2
- Support orthotropic friction

- Support MPP groupable contact

Connections | Linear and planar



- New option for cohesive shell elements
  - clear distinction of three separation modes
- *MAT_240 now fully supports all three modes
  - new option _3MODES
  - also: thermal properties using new option _THERMAL
- Equivalent tiebreak model to *MAT_240
  - new options 13 and 14
  - allows rate dependence

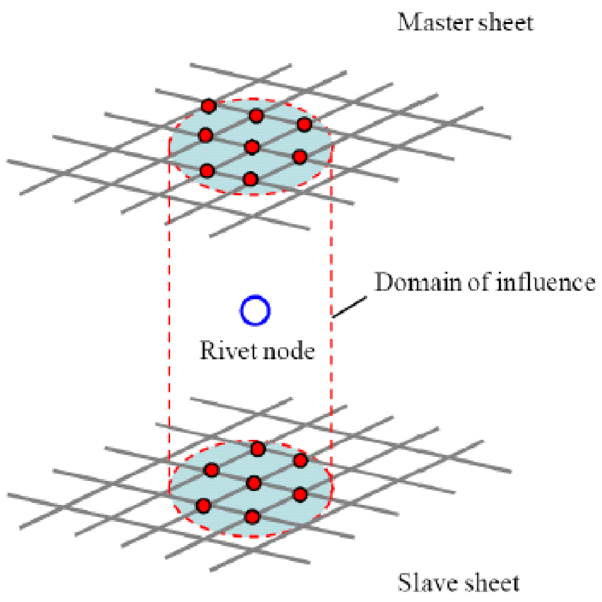


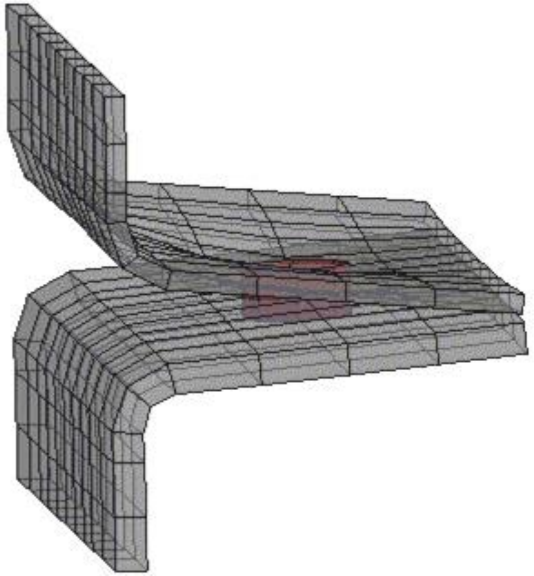
predicition of
laser weld plug out

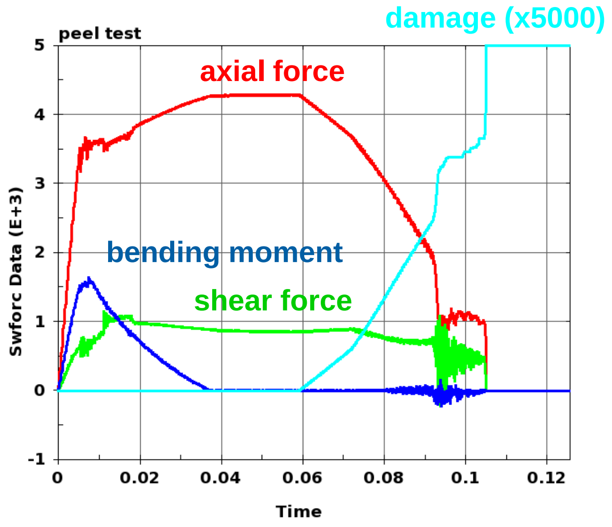
Ford Motor Co., Ltd.

Connections | Point-shaped

- *CONSTRAINED_INTERPOLATION_SPOTWELD (“SPR3”)
  - separate input for material data via new *MAT_265 (*MAT_CONSTRAINED_SPR3, also for _SPR2)
  - separate stiffnesses for tension, shear, bending
  - alternative deformation kinematics
  - exponential damage evolution
  - now also works for beam connections
  - ”self-connection” of a shell part
  - accuracy improvements
  - new option for visualization beams
  - more output
  - etc.





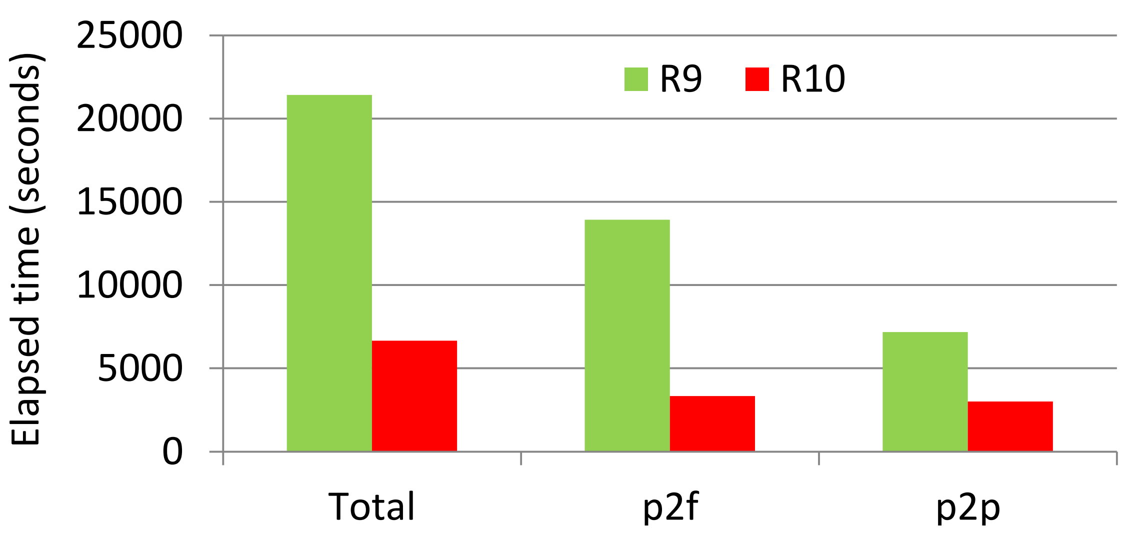


Airbags | New CPM contact algorithms

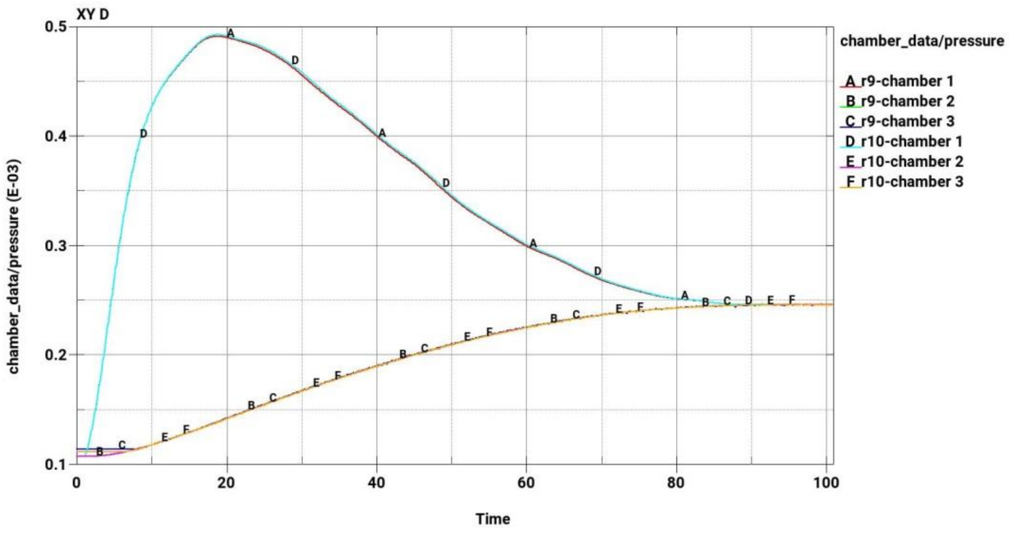
Jason Wang

- Main cost for airbag simulation: airbag self contact (1), p2f (2) and p2p (3)
- New and faster particle to fabric (p2f) contact algorithm
- Redistribute CPM particles among processors to achieve better scaling and efficient particle to particle (p2p) collisions

3x speedup for tank test

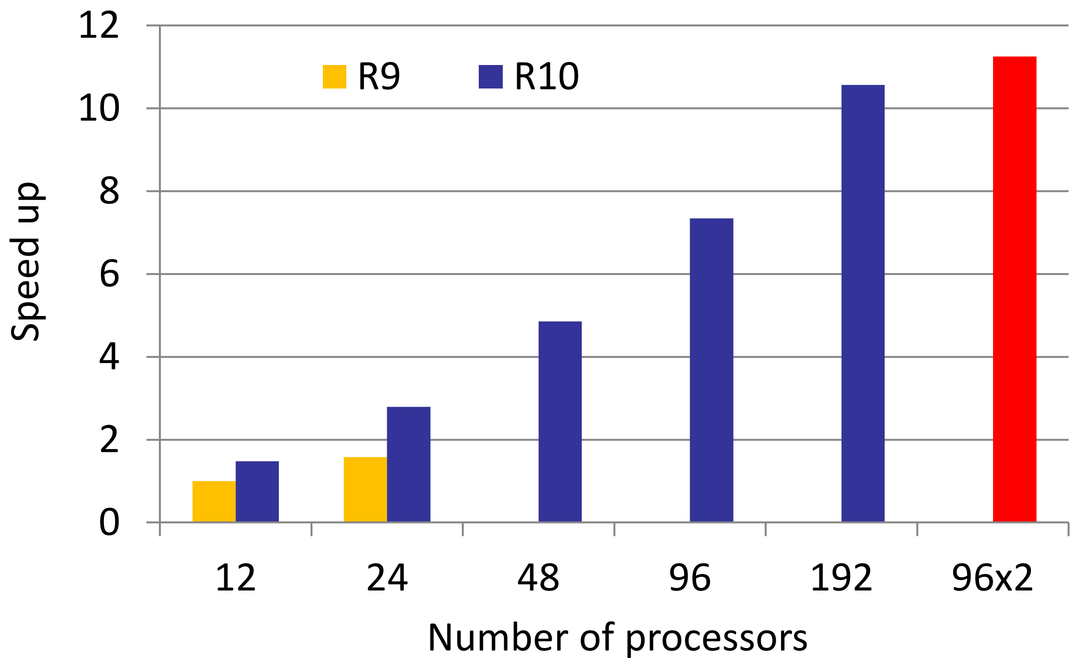


pressure history is consistent between releases

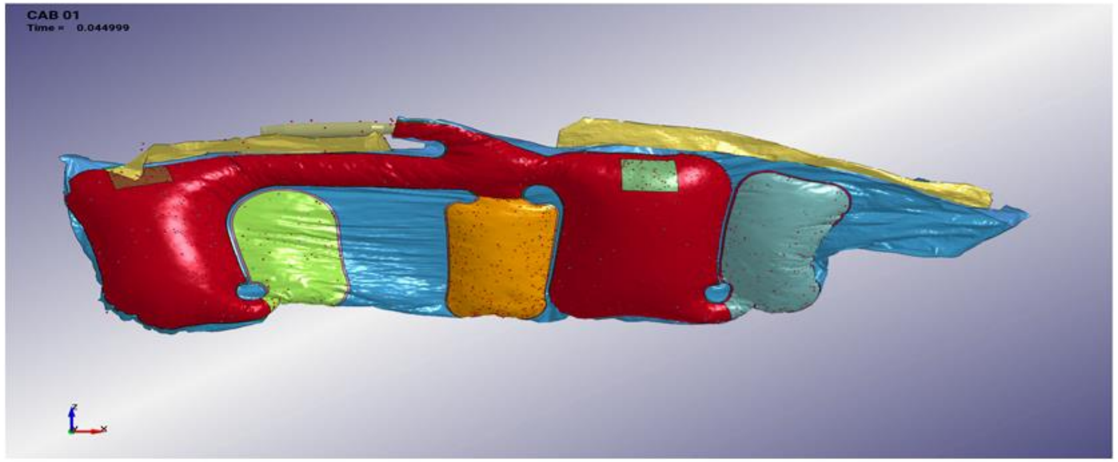


Airbags | CAB Performance Improvement

Jason Wang



CAB

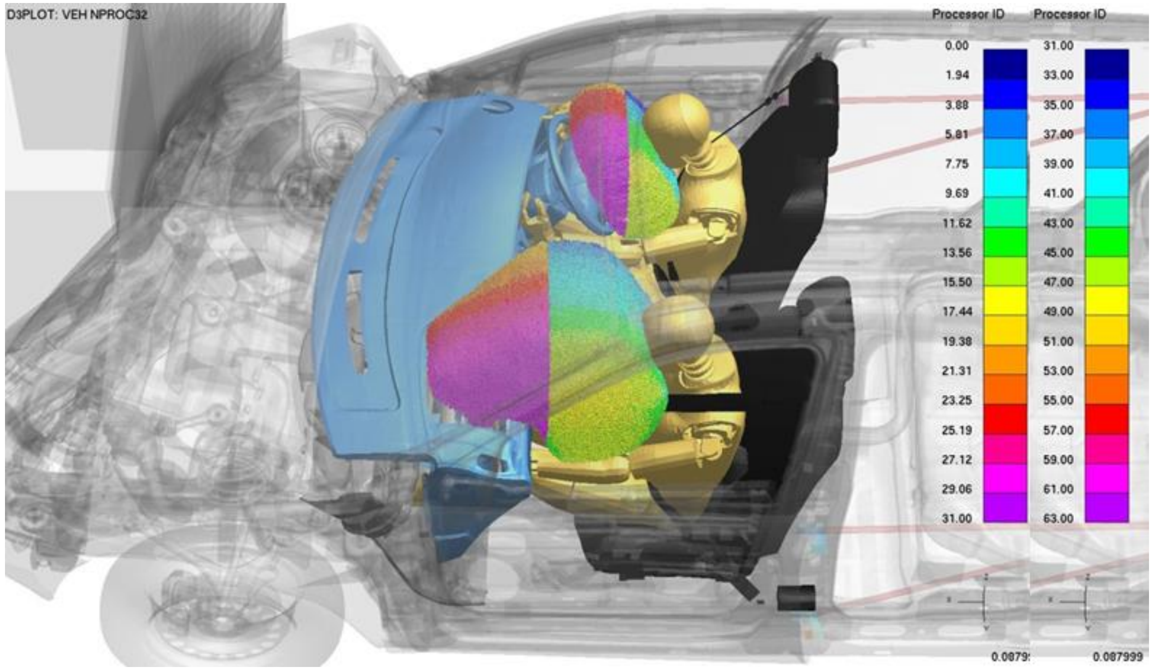


- OpenMP (HYBRID) enabled
- Reduced amount of data transferring between processors for better scaling
- It is more efficient for the full vehicle simulation which uses more than 200 processors
- Same input faster turn around time

Airbags | more enhancements

Jason Wang

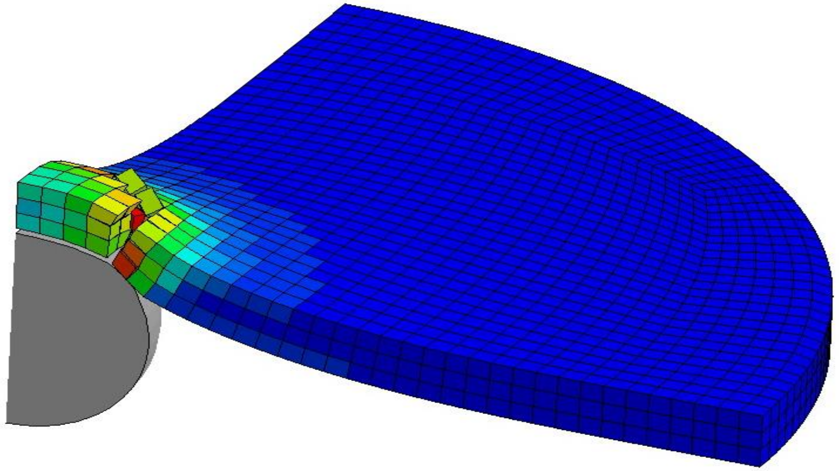
- Particle splitting to improve particle density
- Support *MAT_ADD_AIRBAG_POROSITY_LEAKAGE
- Molar fraction based inflator
- Orifice area as a function of time
- Output material leakage information
- Venting holes by part set
- Particle deflection angle
  via *DEFINE_FUNCTION
- …



Materials | Failure and Damage

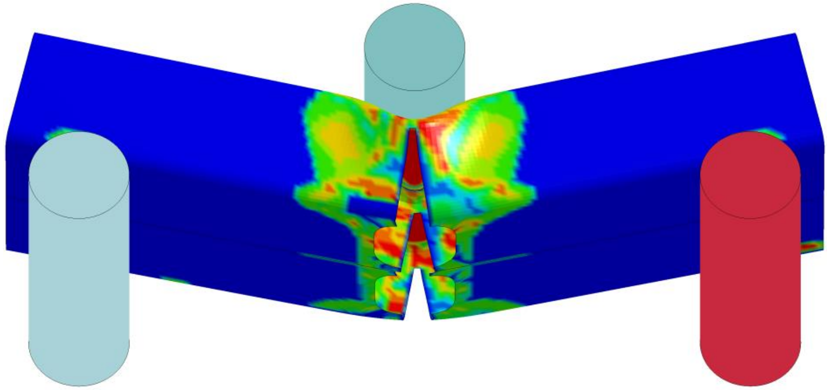
Borrvall, Erhart, Lum

- New keywords *MAT_ADD_DAMAGE_{GISSMO|DIEM}
  - separated from *MAT_ADD_EROSION to make input clearer: pure failure vs. damage
- Now available for more elements/methods
  - beams, higher order solids, SPH, SPG, and *CONSTRAINED_TIED_NODES_FAILURE
- ADD_EROSION: new failure criteria
  - e.g. maximum temperature, minimum step size
- GISSMO: new features
  - e.g. damage limitation, mid-surface treatment, stochastic variation of failure strain, crash front methodology ("SOFT"), temperature dependence

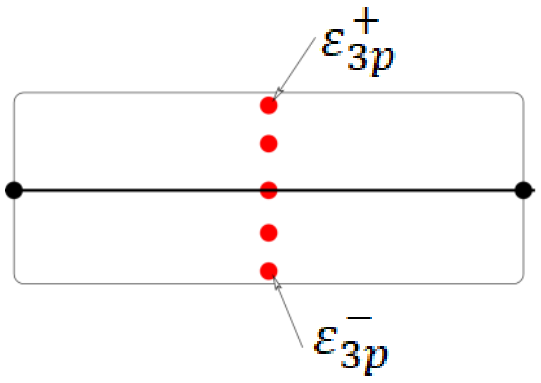


Materials | Regularized Failure Model

- New model *MAT_258: “NON_QUADRATIC_FAILURE”
- Non-quadratic yield surface: Hersey/Hosford
- Voce hardening and J-C type visco-plasticity
- Fracture criterion: Extended Cockcroft-Latham
- Bending-enhanced regularization
  - Fracture parameter W_c depends on characteristic element size, shell thickness, and a bending indicator Ω
  - Better distinction between pure membrane loading and bending

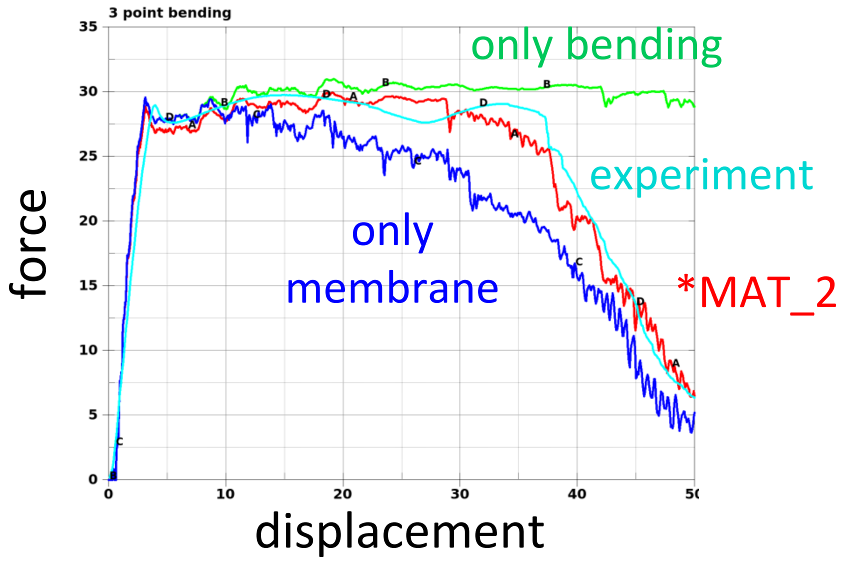


3-point bending of aluminum profile with hole: critical fracture value



$$W_c = \Omega W_c^b + (1-\Omega) W_c^m$$

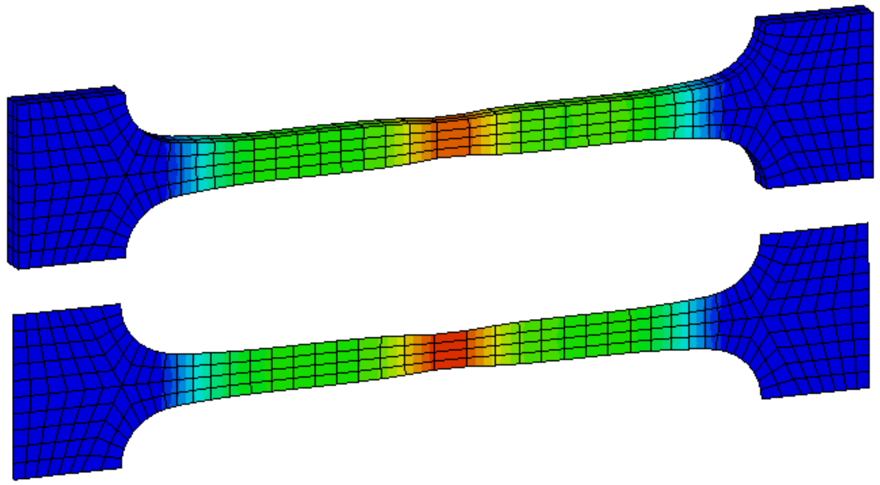
$$\Omega = \frac{1}{2}\frac{\left|\varepsilon_{3p}^{+} - \varepsilon_{3p}^{-}\right|}{\max\left(\left|\varepsilon_{3p}^{+}\right|, \left|\varepsilon_{3p}^{-}\right|\right)}$$

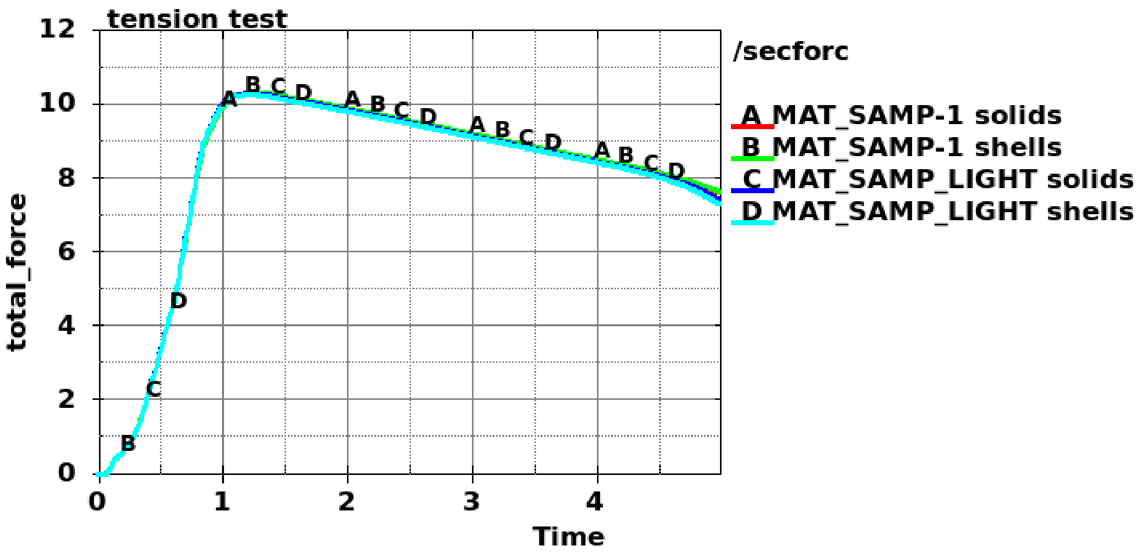


Materials | Polymers

A. Erhart

- New model *MAT_187L: “SAMP_LIGHT”
- Simplified form of *MAT_SAMP-1
  - reduced number of options (only tension/compression, no damage)
  - more efficient implementation (reduced CPU time)
  - filtered strain rate instead of viscoplastic
  - for solid and shell elements
  - only explicit for now
- Example: tension test w/ solids and shells
  - seven times faster with new model
  - comparable results

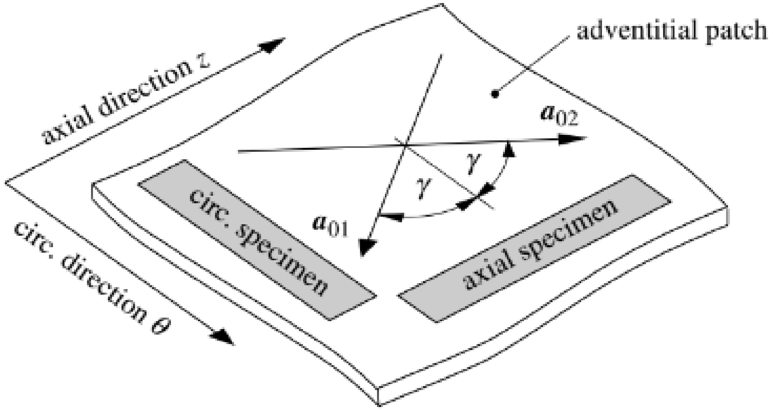


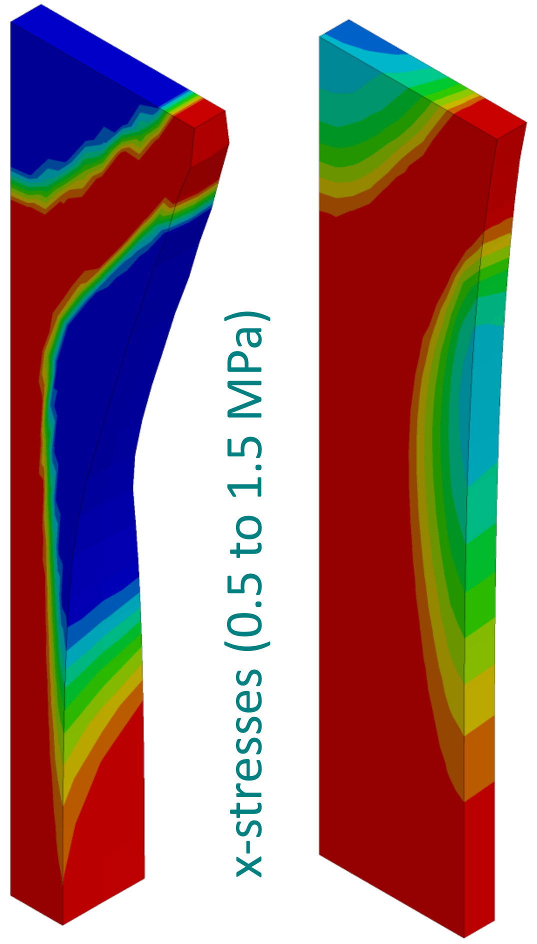


Materials | Biological Soft Tissues

- New model *MAT_295: “ANISOTROPIC_HYPERELASTIC”
- Modular material model for e.g. biological soft tissues or fiber-reinforced elastomers featuring:
  - Nearly-incompressible and compressible models
  - Rotationally non-symmetric fiber dispersion
  - Electro-mechanical coupling (muscle activation)

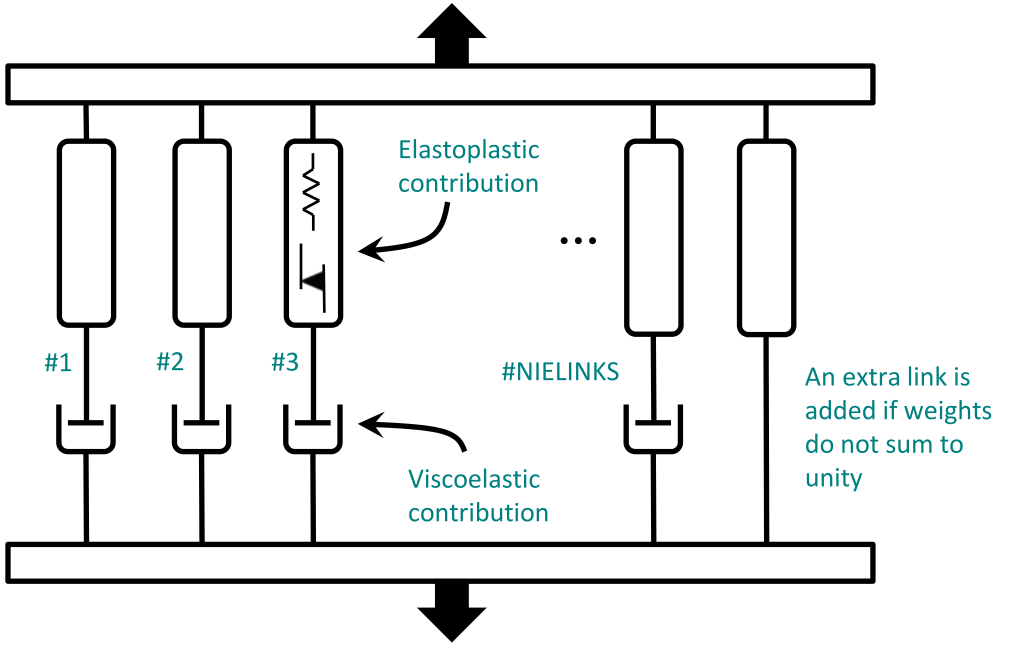
- Example problem - Gasser et al. (2006)
  - Uniaxial tension of an iliac adventitial strip (axial case)
  - Nearly-incompressible formulation
  - Two fiber families with and without fiber dispersion





Materials | Add-on Inelasticity

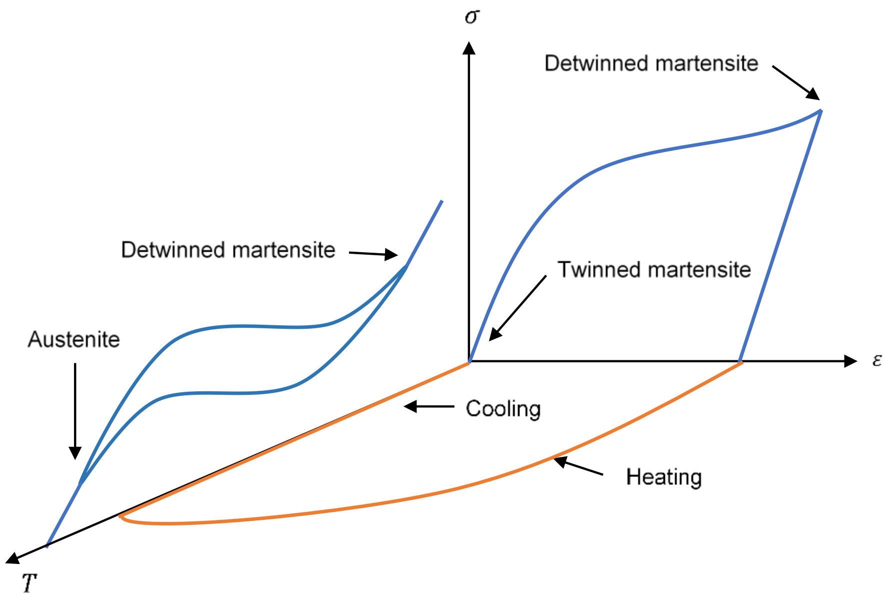
- New model *MAT_ADD_INELASTICITY
- To amend ”any” material model
  with an inelasticity feature
  - plasticity (partially supported, incremental models)
    - von Mises isotropic hardening viscoplasticity
  - creep (partially supported, incremental models)
    - Norton creep variants
  - viscoelasticity (supported)
    - Prony series
  - thermal expansion (not supported)

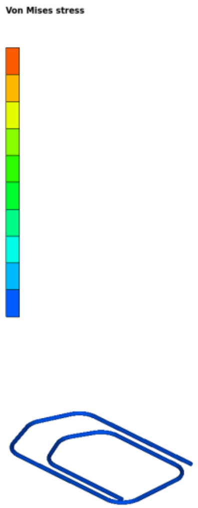


- Intention is not to replace any material model
  but to complement with potentially missing features
  and accept an incurred cost when doing so

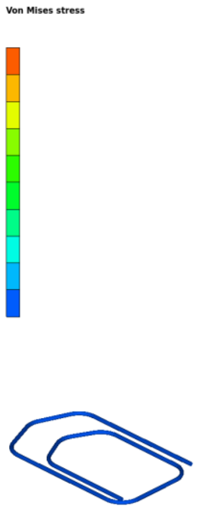
Materials | Shape Memory Alloy

- New model *MAT_291: “SHAPE_MEMORY_ALLOY”
- A new micromechanics-inspired model for shape memory alloys
- Medical applications: self-expanding stents, heart valve frames
- Based on strain split $\varepsilon = \varepsilon_e + \lambda\varepsilon_m$ and minimizing Helmoltz’ free energy
- Supports implicit/explicit/thermal for solids



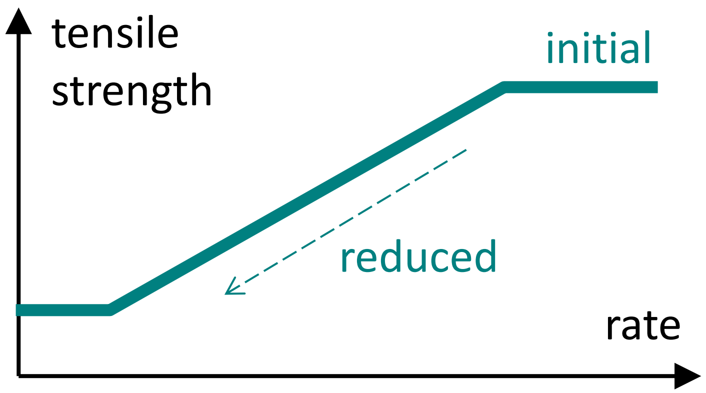


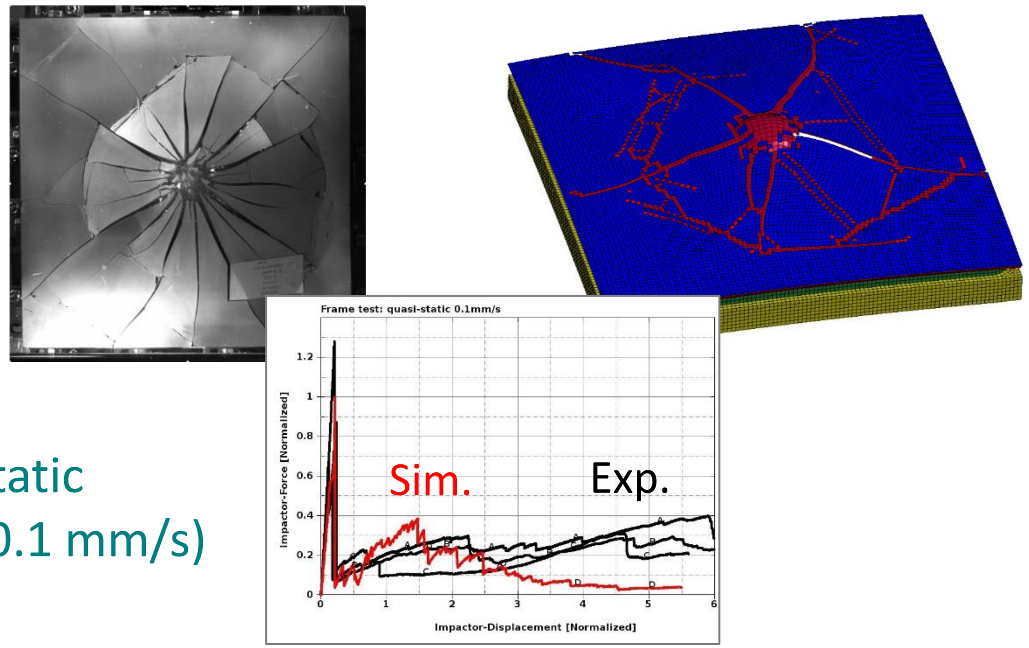
high temperature
austenite phase



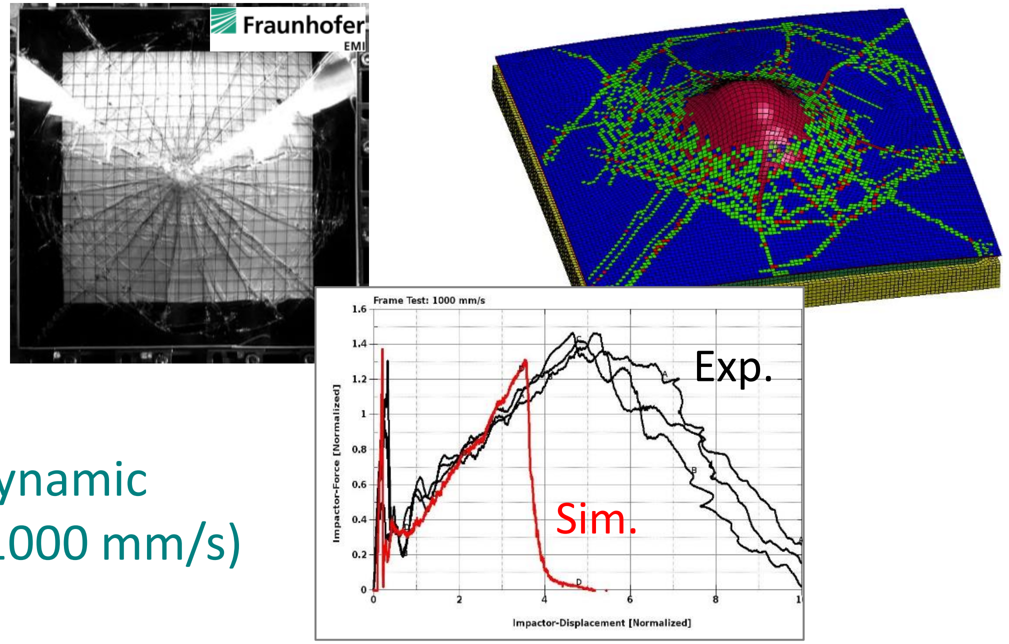
low temperature
martensite phase

- Improvements for *MAT_280 (GLASS)
  - nonlocal extension: rate-dependent strength reduction in elements around cracks
  - better agreement with tests (static & dynamic)
  - project with Jaguar Land Rover, Volvo, EMI, and others





static
(0.1 mm/s)

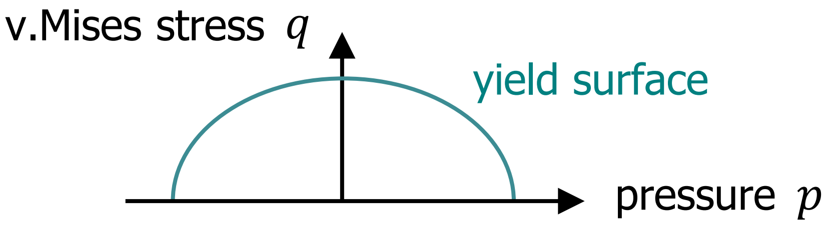


dynamic
(1000 mm/s)

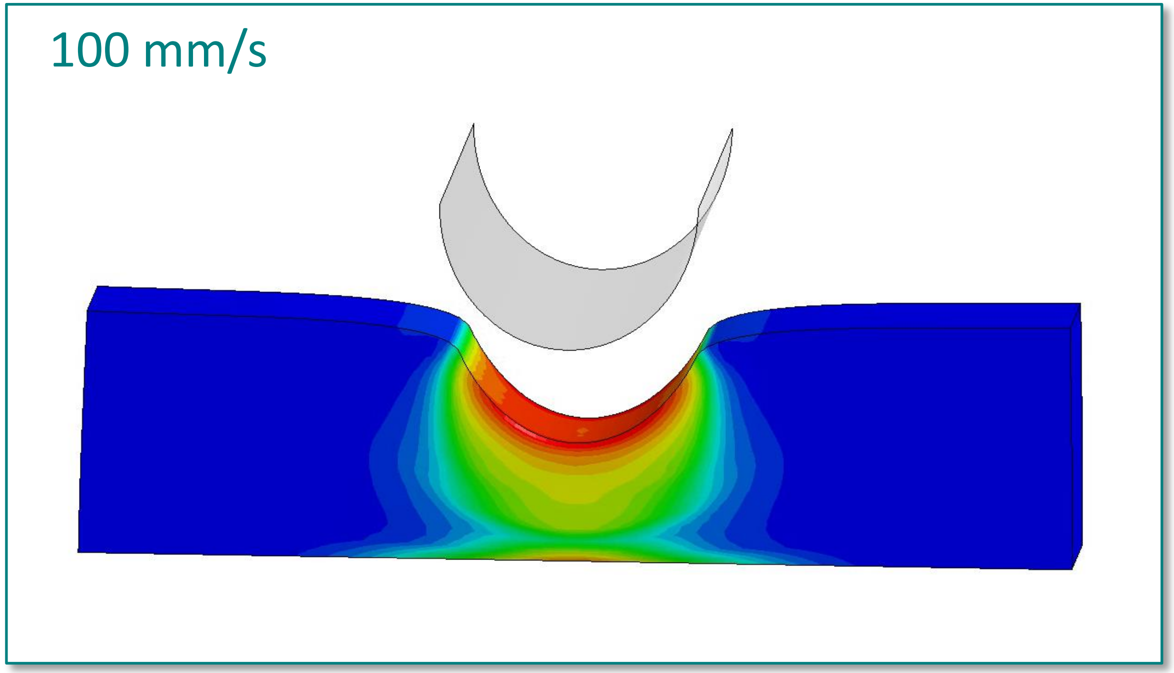
Materials | Foam

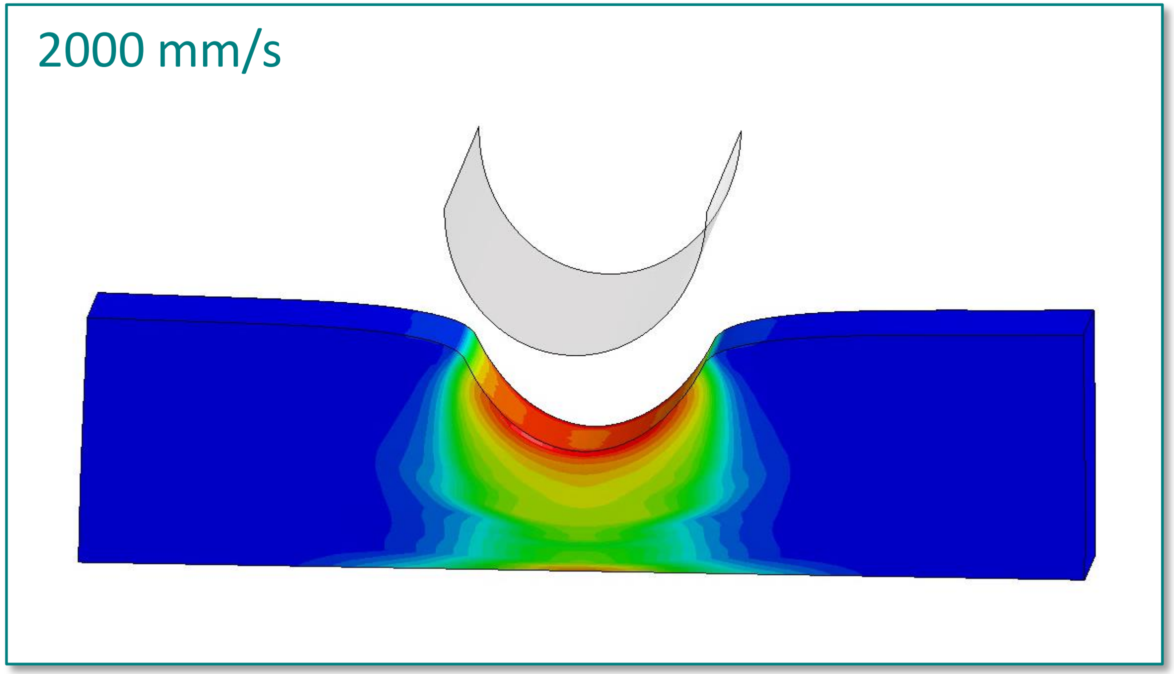
A. Erhart

- *MAT_063 (CRUSHABLE_FOAM) MODEL=1
  - alternative formulation for crushable foams
  - elliptical yield surface (*p*-*q* space)
  - individual elastic and plastic Poisson's ratio
  - rate dependent hardening
  - stabilizing (penalty) stiffness for very high compression



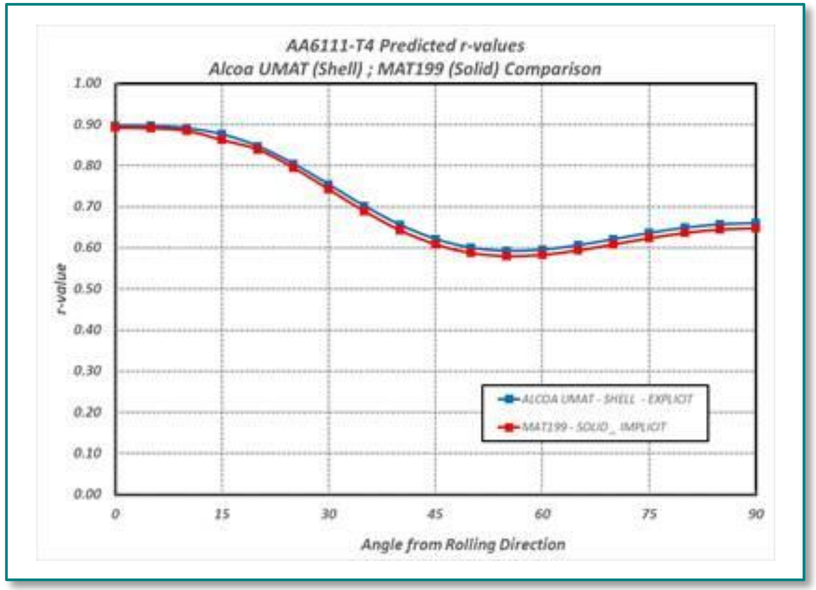
$$F = \sqrt{q^2 + \alpha^2 p^2} - B(\sigma^y) = 0$$

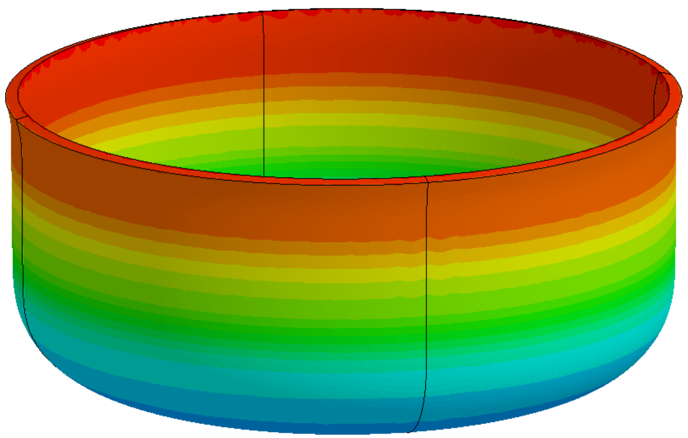




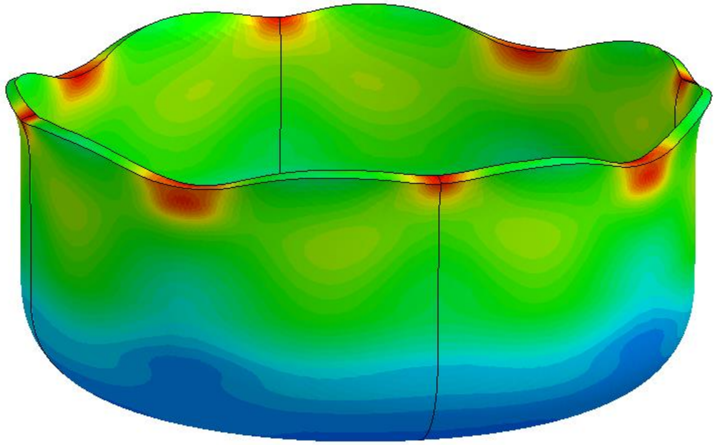
Materials | Anisotropic Yield (1)

- Most forming materials use plane stress assumption
- New 3D material model 199 for solids & explicit analysis
  - keyword *MAT_BARLAT_YLD_2004
  - based on ”Linear transformation-based anisotropic yield functions” by Barlat et al. (2005)
  - uniaxial tests in 0, 15, 30, 45, 60, 75, and 90 degree; biaxial tests; out-of-plane properties
  - capable to predict 6 and 8 ears in cup drawing





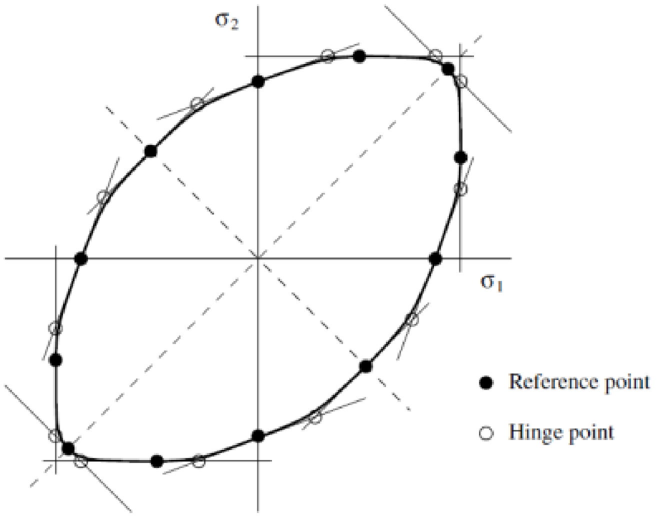
*MAT_024

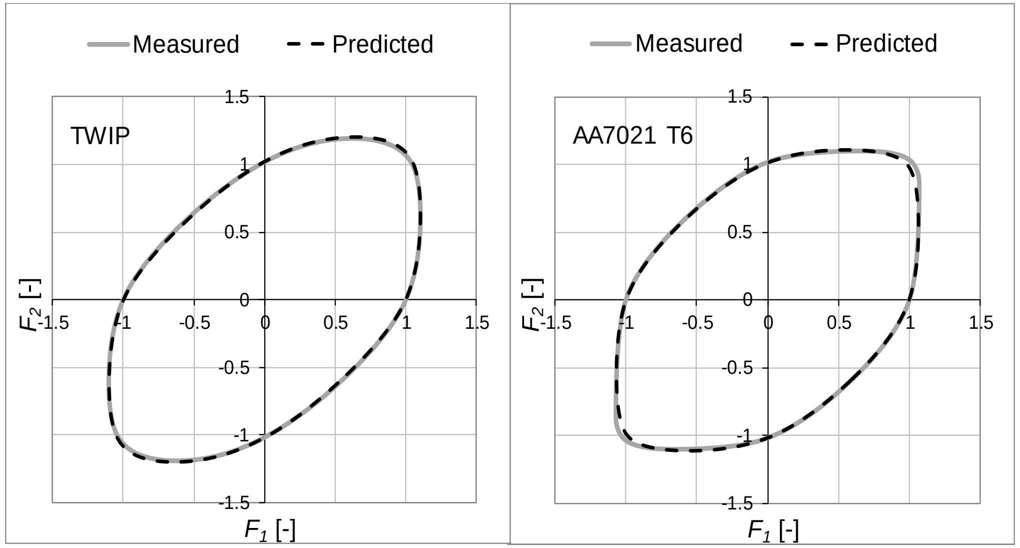


*MAT_199

Materials | Anisotropic Yield (2)

- Vegter material (*MAT_136) allows describing complex yield surfaces with a B-Splines representation
- New option _2017:
  - only data from uniaxial tensile tests (0°,45°,90°) required
  - biaxial, plane strain and shear points are predicted using the method proposed in [2]
  - strain rate effects are accounted for
- Material is able to accurately predict advanced yield loci while only requiring standard tensile test data
- Applicable to steel, stainless steel, and aluminium types



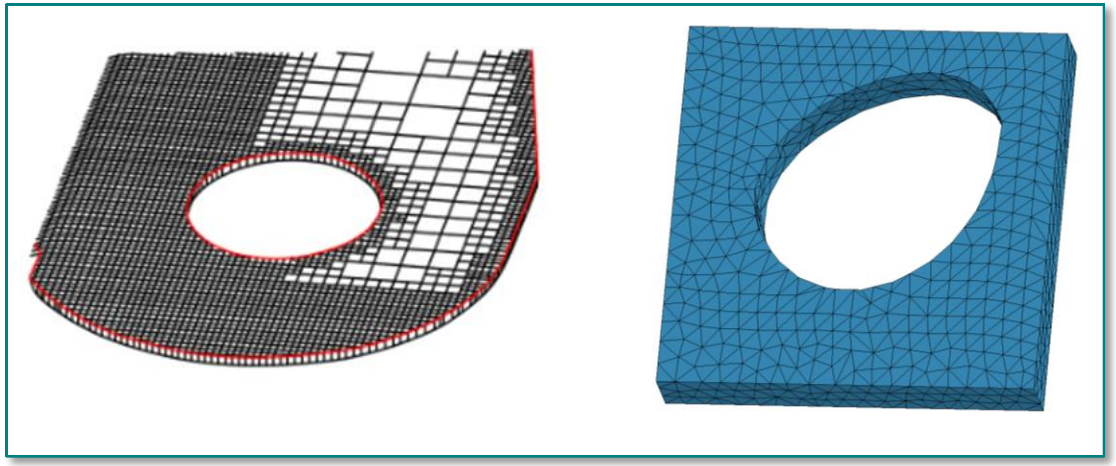


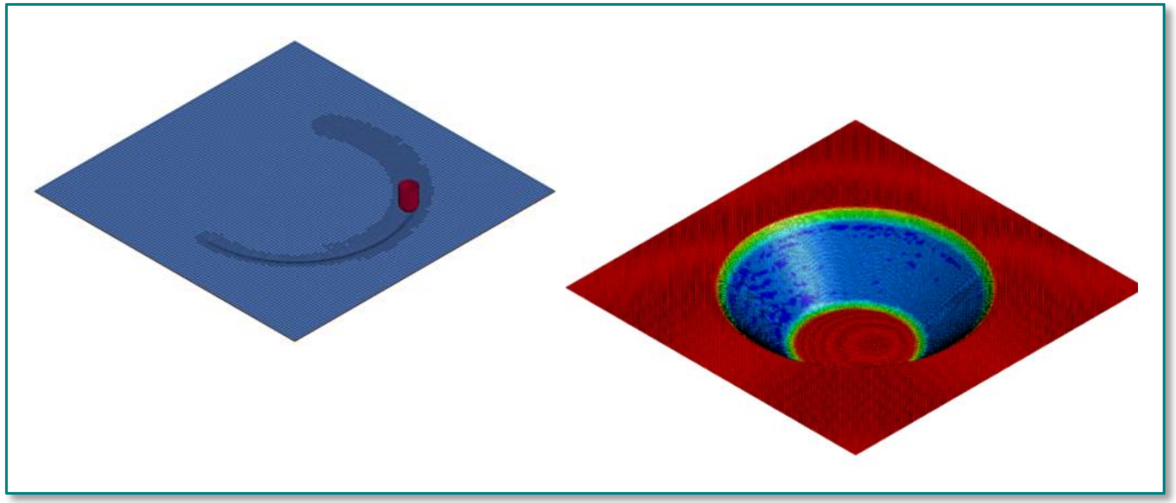
[1] Vegter, Boogaard; 2006 [2] Abspoel et al, 2017

Metal forming (1)

Zhu, Fan, Zheng

- Trimming of shells, solids, tshells, and laminates
  - now available for tetrahedral elements
  - mesh refinement along trimming curves



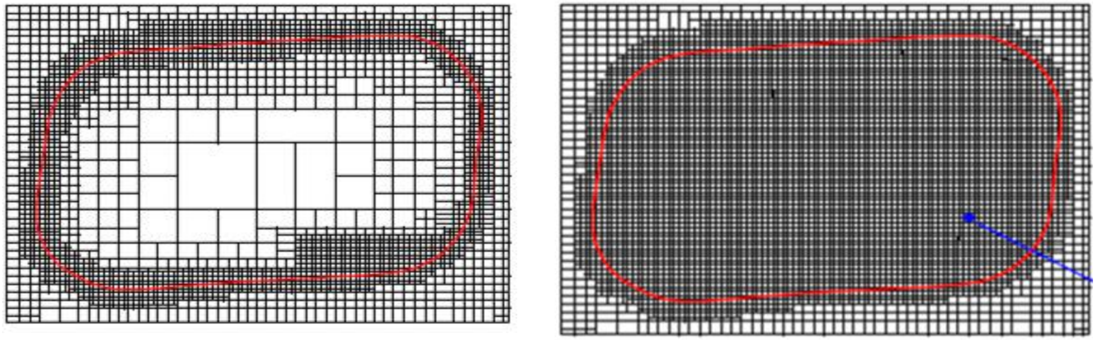


- Mesh fusion (adaptive re-coarsening)
  - completely reworked & extended to MPP
  - uses average information of merged elements
  - with tube adaptivity for incremental forming

Metal forming (2)

Zhu, Fan, Zheng

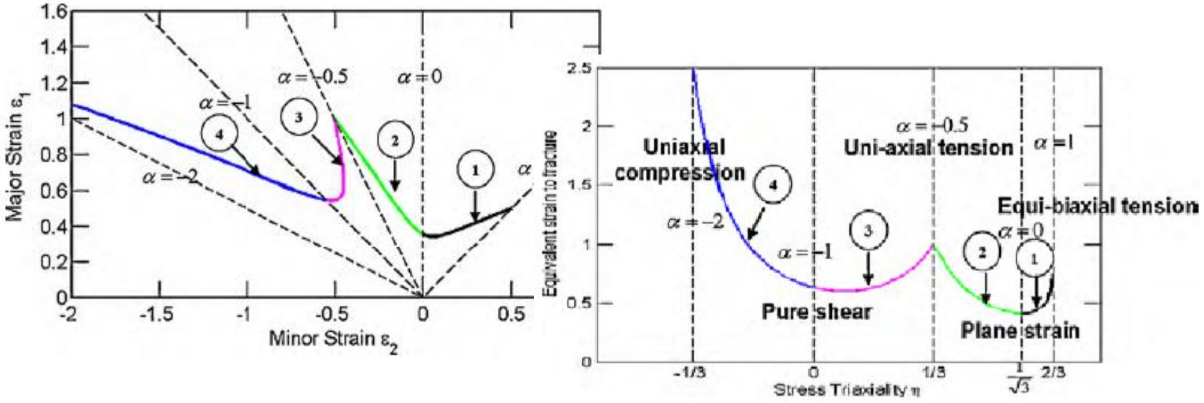
- New mesh refinement options
  - along given curve or inside domain
  - *CONTROL_ADAPTIVE_CURVE: ”ITRIOPT”



e.g. for stoning

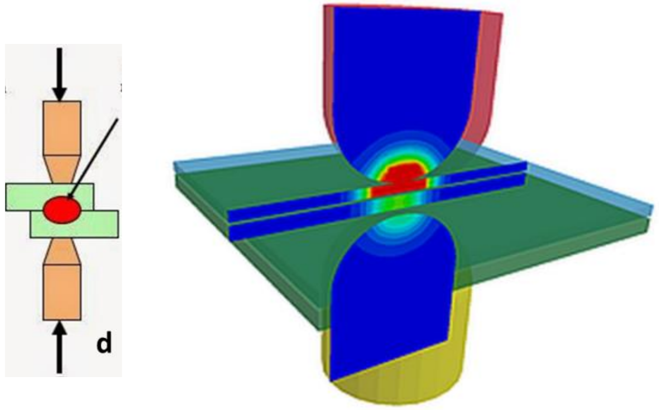
- Analytical hardening functions
  - new keyword *DEFINE_CURVE_STRESS
  - automatic creation of stress-strain curves for Swift, Voce, Hockett-Sherby, …
  - or weighted combinations of them

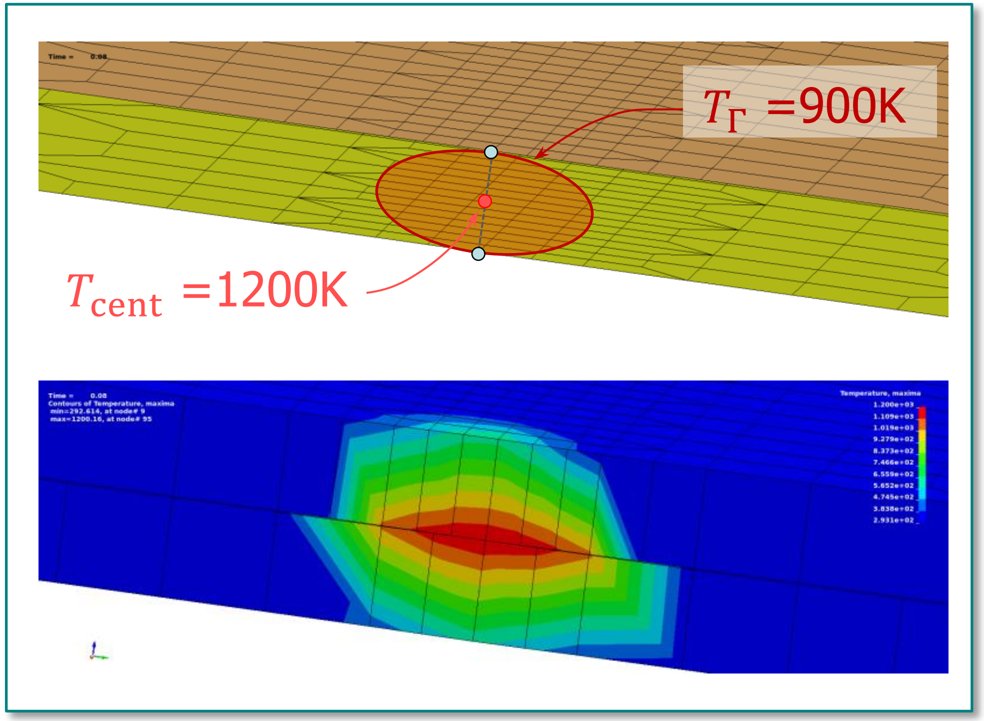
- Automatic conversion FLD to triaxiality curve (and vice versa)
  - *DEFINE_CURVE_TRIAXIAL_LIMIT_FROM_FLD



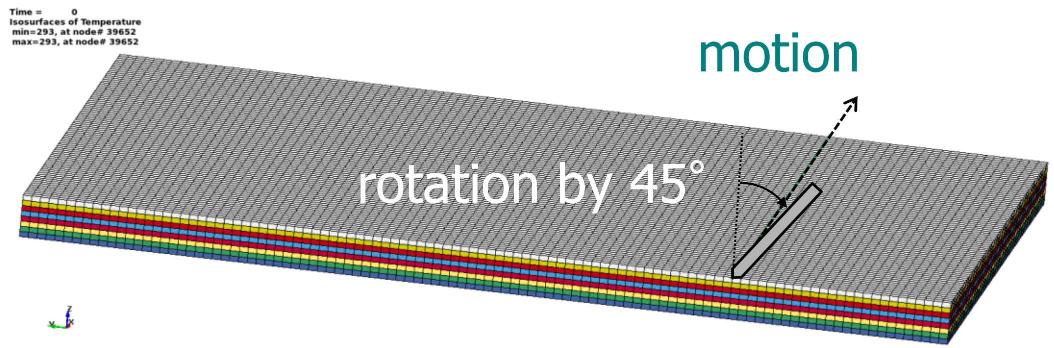
Thermal Analysis | RSW

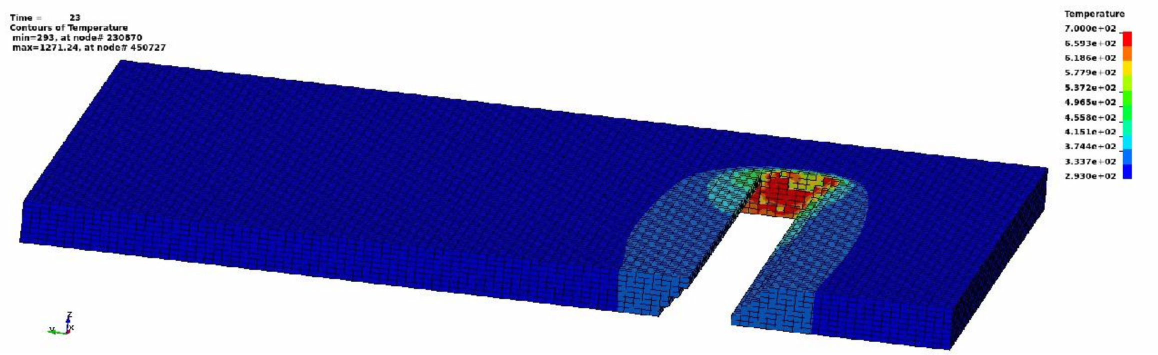
- Resistance Spot Welding
- Keyword *BOUNDARY_TEMPERATURE_RSW
  - simplified and fast boundary conditions
  - direct definition of the temperatures for nodes in the weld nugget
  - temperature preset at the center and the boundary
  - quadratic approximation of the temperature field
  - birth and death time
  - nodes outside the nugget are not affected
  - position is given with respect to two nodes
  - nugget can move over time
- … applicable to solid and thermal thick shell models





Thermal Analysis | Laser Cutting

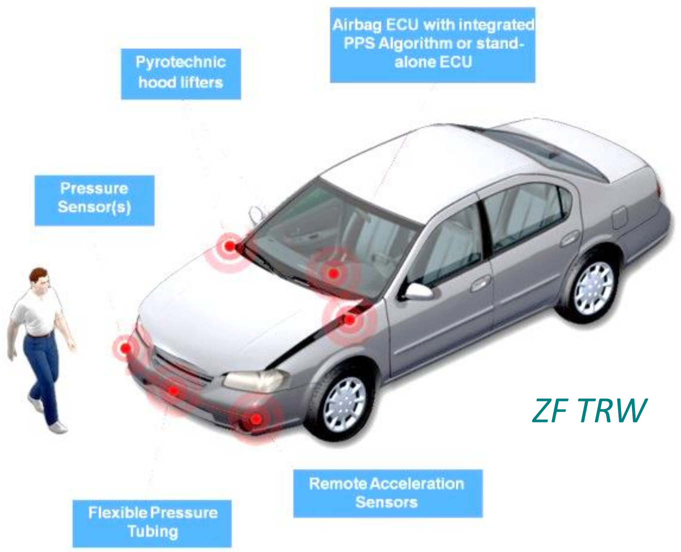




- New keyword *BOUNDARY_FLUX_TRAJECTORY
  - aims to simulate a moving surface heat source, e.g. a laser, on a structure
  - keyword allows for an easy definition of surface fluxes
    motion along a nodal path given by *SET_NODE
    geometry and heat distribution of heat source either from list or given as user-defined function
    tilting of heat source is accounted for
  - after element erosion flux propagates to exposed segments (for laser cutting)

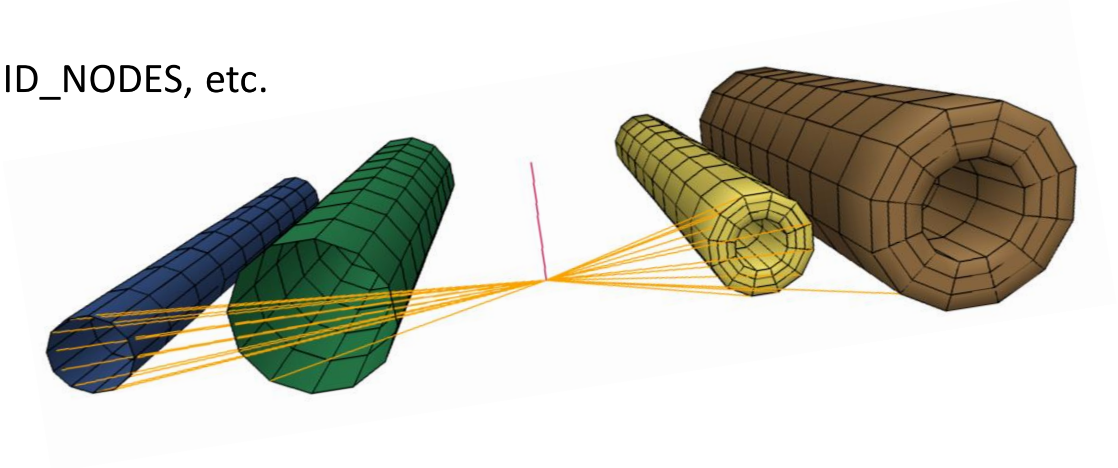
Misc | Pressure Tube

- Keyword *DEFINE_PRESSURE_TUBE
  - models acoustic pressure waves in a thin long tube
  - embedded in bumber to detect collisions with pedestrians
  - available since R9.3



ZF TRW

- New developments
  - automatic generation of shell/solid tubes from beams
    - Increased pressure accuracy and tube radial response
  - automatic generation of shell/solid boundary conditions from beams
    - *BOUNDARY_SPC, *PRESCRIBED_BOUNDARY_MOTION, *CONSTRAINED_NODAL_RIGID_BODY, *CONSTRAINED_RIGID_NODES, etc.
  - new pressure boundary conditions
    - open/closed/non-reflective/partially damped
    - end cavities and interior boundary conditions



Misc | Post-processing

- Output of history variables
  - up to now, numbers from 1 to …
    for each material model / element type
  - meaning of variables described in manual
    or on www.dynasupport.com

***MAT_024**	1	effective strain rate (VP=0); effective plastic strain rate (VP=1)
	4	current hardening slope
	5	current yield stress Remark: 4 and 5 apply only to non-strain-rate option.

- Names of history variables in databases
  - new option HISNOUT on *CONTROL_OUTPUT
    - HISNOUT=1: info written to d3hsp
    - HISNOUT=2: info written to d3hsp and new file hisnames.xml
  - user-relevant names listed for each PART separately
  - at first, most common materials supported
    1, 3, 4, 15, 24, 34, 36, 54, 58, 63, 81, 82, 83, 89, 98, 100, 106, 120, 123, 138, 169, 183, 187, 188, 224, 240, 252, 254, 270, 277, 280, GISSMO, DIEM
  - can be combined with *DEFINE_MATERIAL_HISTORIES

```
<?xml version='1.0' encoding='UTF-8'?>
<hisnames>
  <part>
    <id>45000</id>
    <title>front rail                        </title>
    <ele_type>shells </ele_type>
    <mat_law>24</mat_law>
    <mat_add>GISSMO</mat_add>
    <extra_history>
      <order_id>1</order_id>
      <label>effective strain rate         </label>
      <order_id>4</order_id>
      <label>hardening slope               </label>
      <order_id>5</order_id>
      <label>yield stress                  </label>
      <order_id>6</order_id>
      <label>damage                        </label>
      ...
    </extra_history>
  </part>
  . . .
```

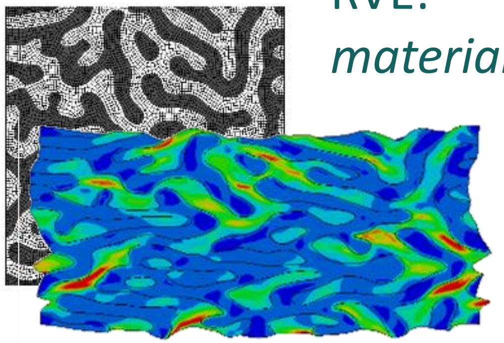
Misc | more …

- New options for *CONSTRAINED_BEAM_IN_SOLID
  - e.g. implicit support for IDIR=1 and AXFOR, coupling to thermal solver, …
- New features and improvements for staged construction
- Add new keyword *USER_NONLOCAL_SEARCH
- Add cross section forces (*DATABASE_SECFORC) for 20-node and 27-node hexas
- *SENSOR: New entities to be controlled / traced
  - energies, number of failed elements, curve values, thermal loads, …
- Add warning message for *DEFINE_FUNCTION
  - if the function name starts with i, j, k, l, m, n, I, J, K, L, M, or N, it will return an integer value
- …

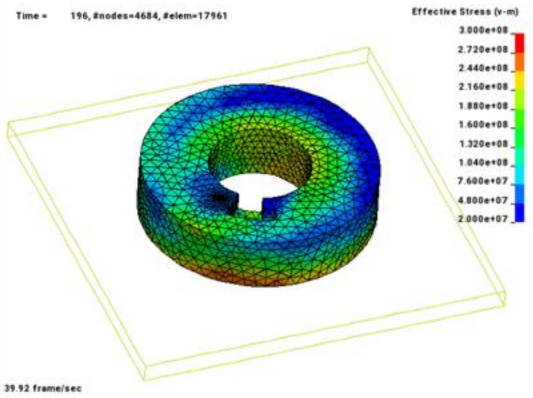
Multi-Scale Mechanics

- Several numerical methods under constant development
  - 3D Adaptivity, DDD, EFG, Immersed, MEFEM, Peridynamic, Reduced-order, RVE, SPG, XFEM

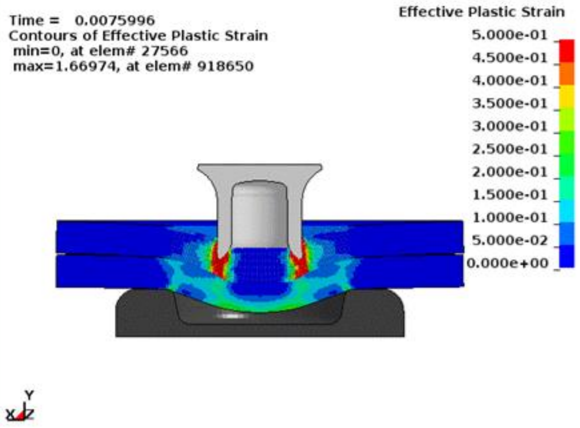
RVE:
material design



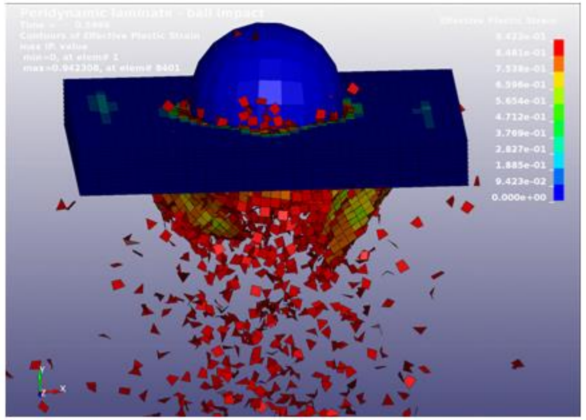
Adaptive EFG:
3-d printing



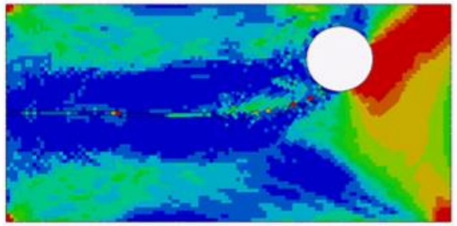
SPG:
self-pierce riveting



Peridynamic:
CFRP plate impact



XFEM:
crack propagation



Conclusion and Remarks

- More developments in other areas (not covered in this Webinar)
  - ALE / SPH / Particle Methods
  - NVH and Fatigue Analysis
  - Fluid Solvers / ICFD / CESE / FSI
  - EM / Batteries
  - MPP / Hybrid / load balancing
  - etc…

https://www.dynamore.de/en/downloads/papers/copy_of_european-ls-dyna-conference/presentations/recent-developments-in-ls-dyna-part-i

- This presentation will be available on www.dynamore.de
- Please check release notes for availability of features
- **Webinar "New Features in LS-OPT" on October 24, 2019**

LSTC
Livermore Software Technology Corp.

DYNA MORE

Thank you!