LS-DYNA 2023R1 (R14.0)
Recent developments – Part II

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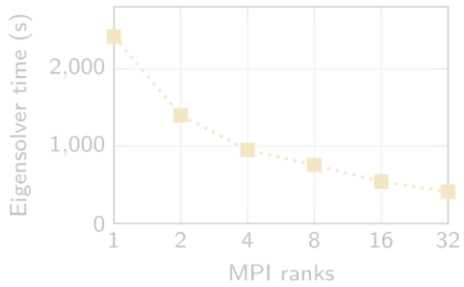
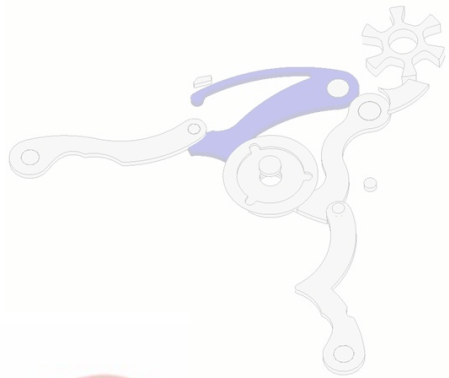
Bamberg, 12 October 2022

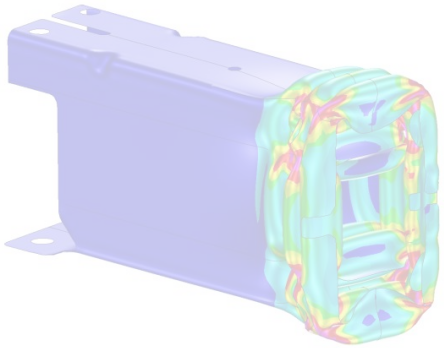
Ansys

Agenda

- Implicit
- IGA
- Materials
- Multiscale & Meshfree
- Connectors
- Thermal
- Miscellaneous
- Conclusion







Implicit

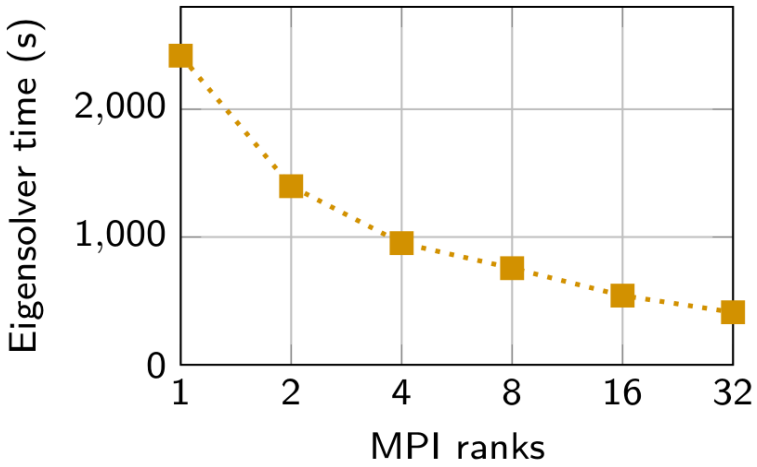
MPP new eigensolver

- LOBPCG preconditioned eigensolver
  - **L**ocally **O**ptimal **B**lock **P**re-Conditioned **C**onjugate **G**radients Method
  - Leverages a Block Low-Rank factorization preconditioner, less expensive than the exact factorization used by Lanczos
  - Effective for small numbers of modes (<100)

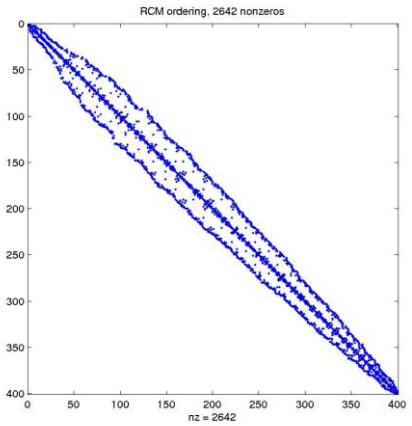
$$\mathbf{Ax} = \lambda \mathbf{Bx}$$

- Invoked by EIGMTH=102 on *CONTROL_IMPLICIT_EIGENVALUE
  - SMP implementation released in R12
  - MPP implementation released in R14

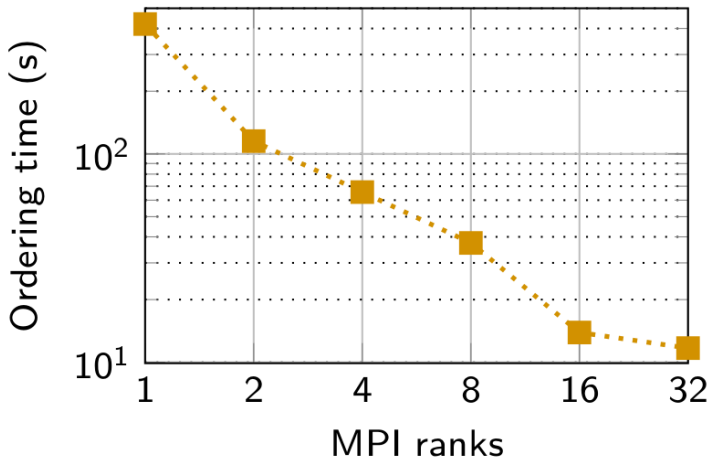
Example: 10 modes of a 25M dof electric pickup truck model



ParMETIS for fill-reducing ordering



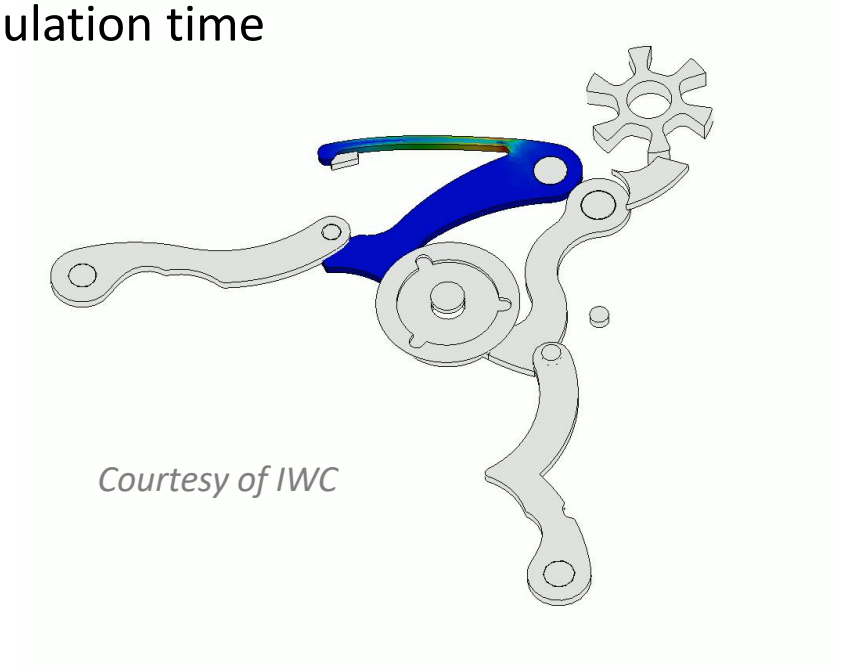
- Fill-reducing ordering: critical component of the Implicit sparse direct solvers
- Options in LS-DYNA (ORDER in *CONTROL_IMPLICIT_SOLVER)
  - MMD: for small problems
  - METIS: default option for most problems, serial algorithm
  - LS-GPart: in-house MPP algorithm for very large problems and very large number of MPI ranks (500+)
  - ParMETIS: new in R14, MPP algorithm, recommended for most users



Example: ordering time for a 33M dof jet engine model from Rolls-Royce

Implicit Developments

- New line search approach, excluding dependent degrees of freedom
  - Activated by LSTOL<0
  - Avoids choking due to “unfulfilled bc” and potentially reduces simulation time
  - Simulation to right finishes in less than 15% of the time required by default approach



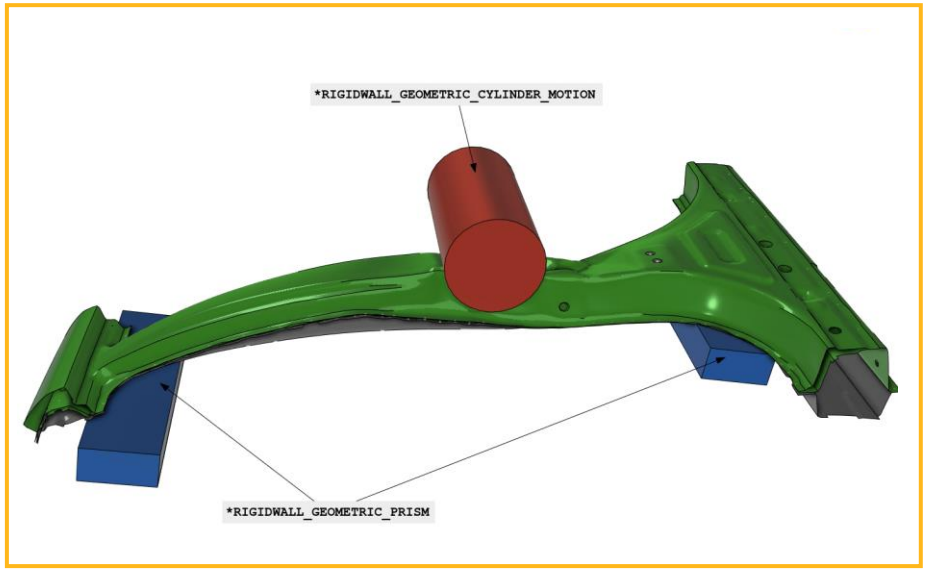
Courtesy of IWC

- Drilling energy and numerically dissipated energy reported to glstat, see *CONTROL_ENERGY
  - Used to be in hourglass and eroded energy slots

- Element formulations properly supported for linear implicit analysis (small displacements)
  - High order shells
  - Discrete elements

Implicit Developments

- Various inequality constraints are now supported by way of Lagrangian Multipliers
  - Rigid body stoppers, rigid walls, contact entity

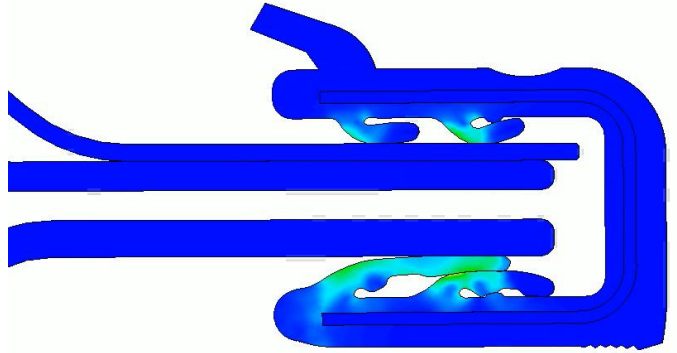


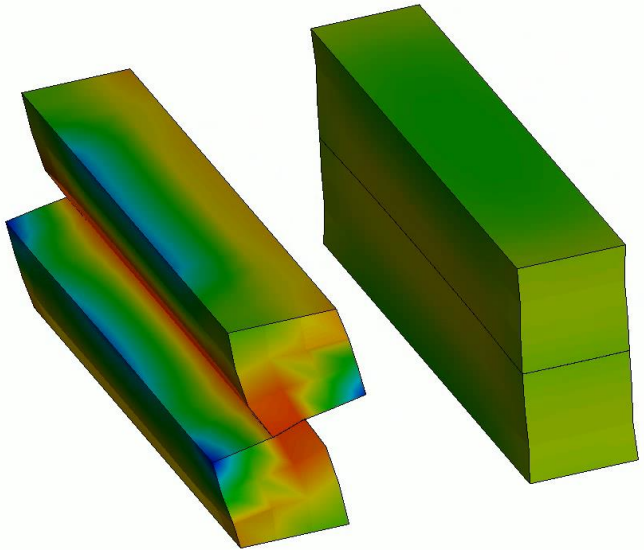
- Minor enhancements for debugging implicit models
  - Warning if support of the eigenvector is small, indicating possible spinning beams or similar
  - Output of 100 worst elements, solids and shells, wrt aspect ratio
  - Removing time dependent effects in eigenvalue analysis when computing modal stress

- The option IACC=2 on *CONTROL_ACCURACY is introduced for explicit analysis
  - For making implicit and explicit more compatible when switching between the two
  - For instance will this invoke the strongly objective tied contacts even for explicit analysis

Mortar Contact Developments

- Orthotropic friction
  - Support load curves: friction as function of vel. and press.
- 2D Mortar Contact
  - Support MPP as well as multistage analysis (dynain.lsda)
- Support “look-ahead” mesh adaptivity
  - Meaning that elements on blank are refined as tools with sufficient curvature approaches
- Tied contact
  - Support full deck restarts and redecomposition
- Support discrete beam materials 66, 67 and 119
- TIME is introduced to Mortar Tied Weld Contact
  - Welding can only occur if conditions are fulfilled for TIME consecutive time units, this to prevent “premature” welding situations with bad deformations as a result





IGA

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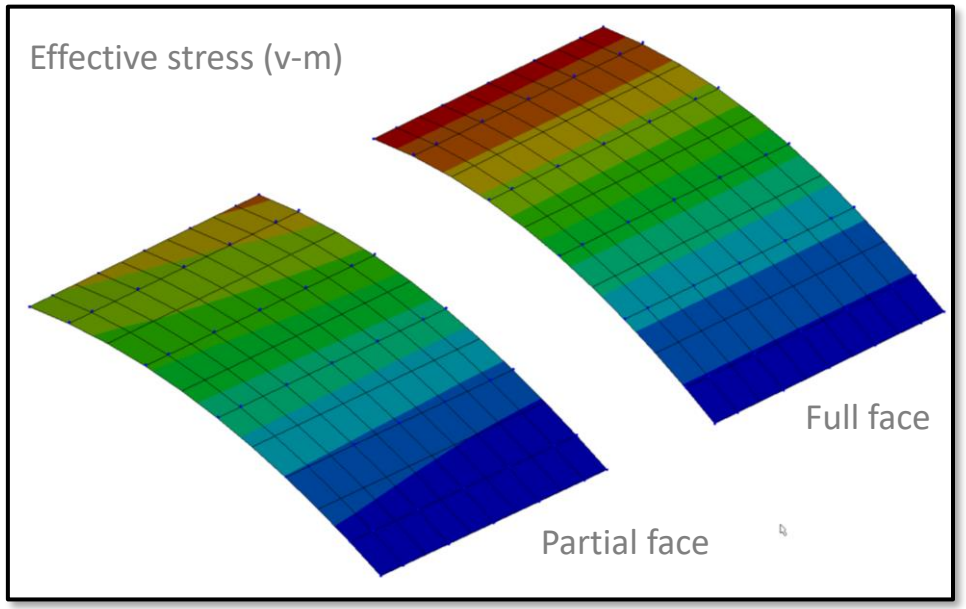
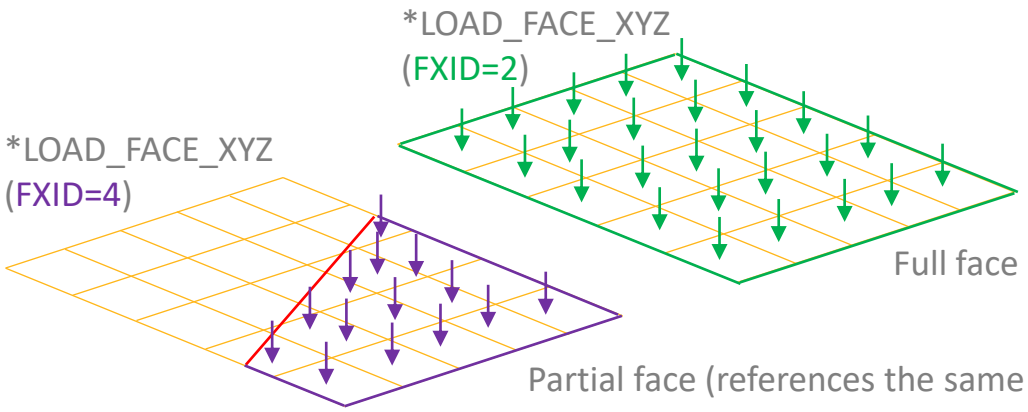
Feature-based boundary conditions and constraints

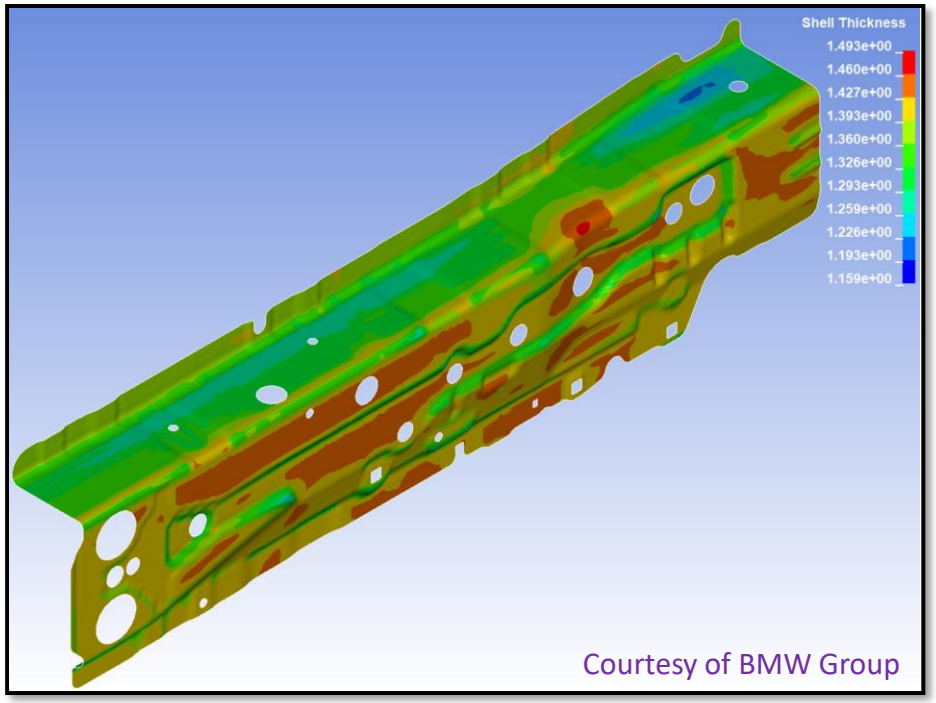
- BCs are imposed on geometric entities (points, edges, faces and volumes)
- Available keywords
  - *BOUNDARY_PRESCRIBED_MOTION_OPTION
    - Options: POINT_UVW, EDGE_UVW, FACE_XYZ
  - *LOAD_POINT_UVW(_SET)
    - Apply a point load at any location within a patch (not restricted to finite element nodes)
  - *LOAD_FACE_XYZ(_SET)
    - Apply a uniform pressure load on a selected subface of a surface





Mapping/Initializing

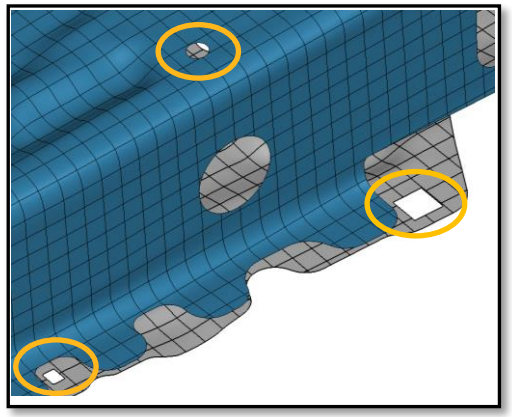
- Support multistage analysis (i.e. stamping) via dynain-file
- Keyword *INITIAL_STRESS/STRAIN_IGA_SHELL
- Allows the initialization of the following quantities at integration points:
  - Shell thickness
  - Initial stresses
  - Initial strains
  - Initial plastic strains
  - History variables



Shell thickness mapped via dynain-file using ENVYO

New 2d-mesher for interpolation shells

- Faster than the old meshing algorithm
- Improved quality of geometric boundaries
  - Accurate representation of concave areas



Trimmed NURBS (CAD)

R13

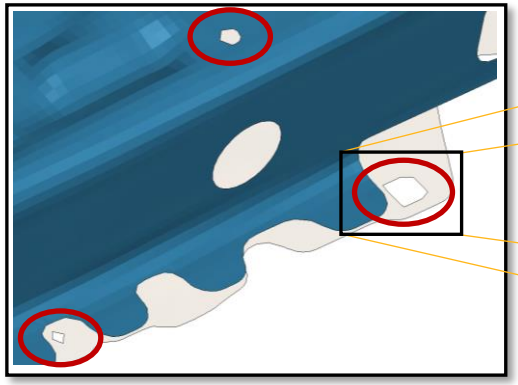
takes **34s**

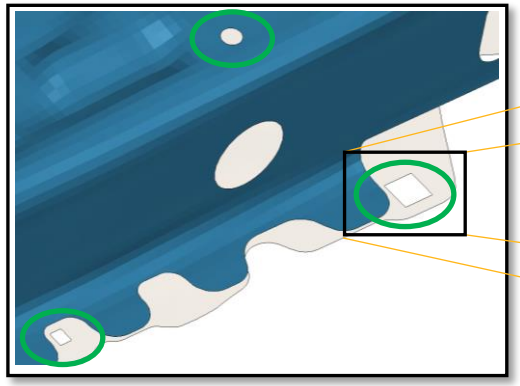
✗

R14

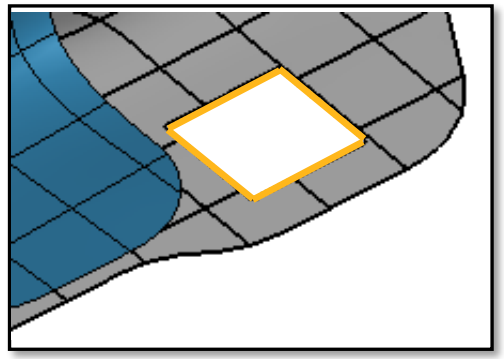
takes **2s**

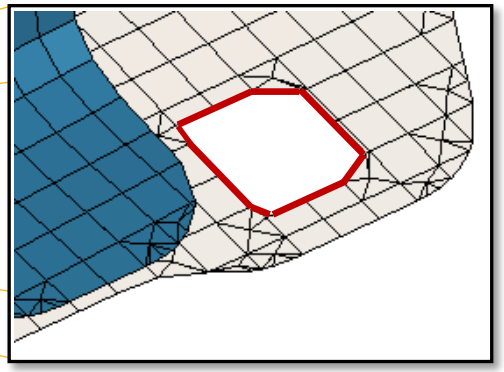
✓





Trimmed NURBS (CAD)





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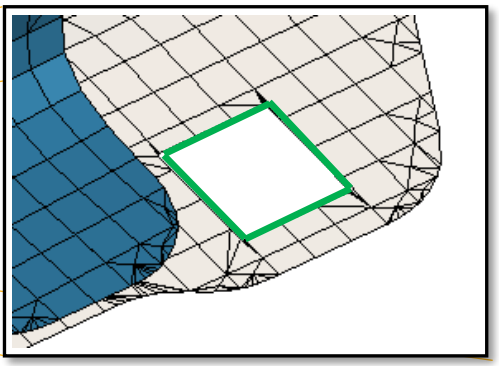
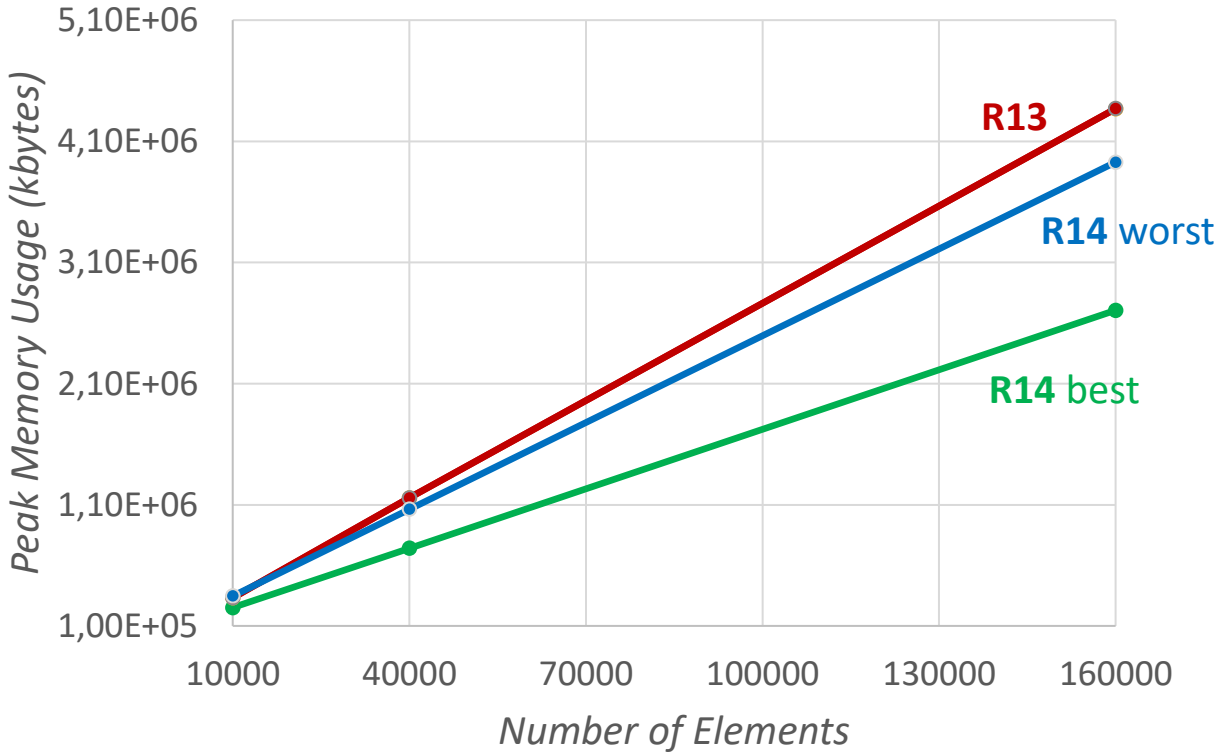


✓

Interpolation mesh

Restructured memory

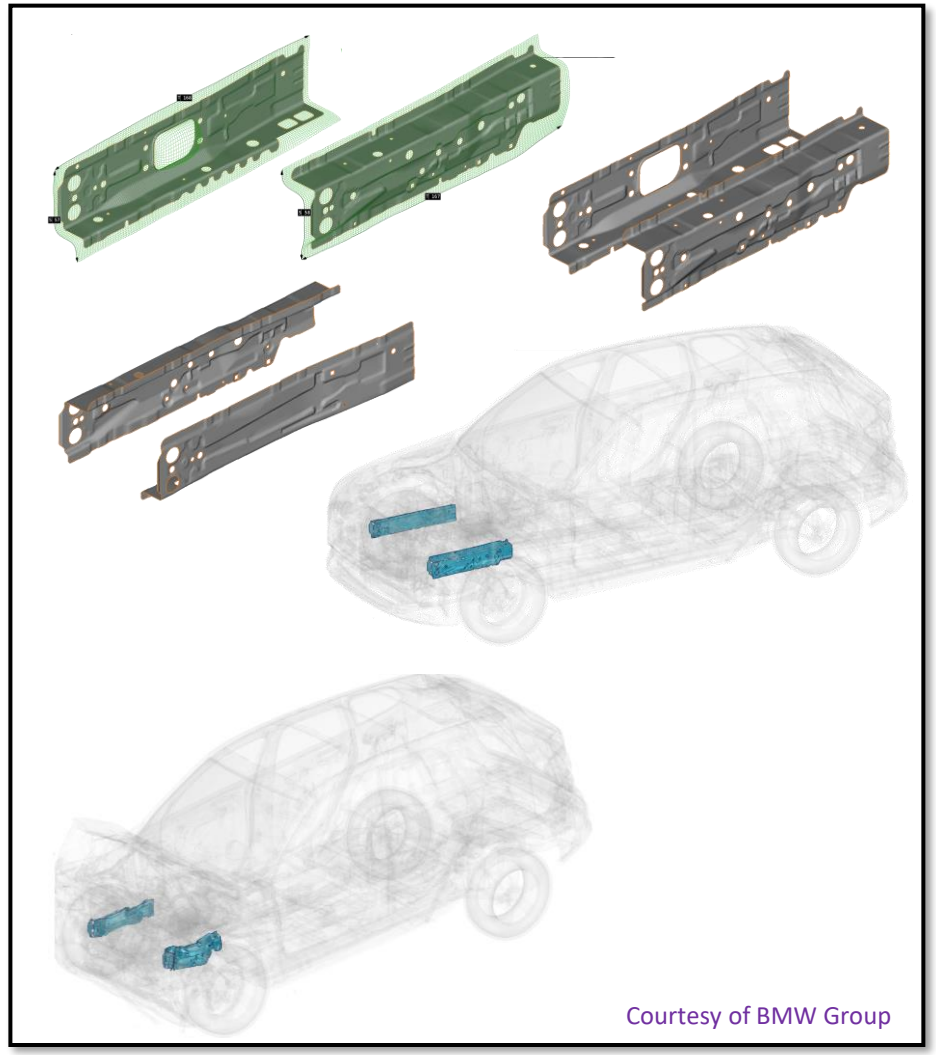
- Complete restructuring of data structure and memory scheme
  - Reduce utilized memory, speed up computation *without* compromising on accuracy



- Improvement is model dependent
- R14 saves up to 40% in memory and about 20% in computation time in comparison to R13

Miscellaneous

- New timestep estimate (IGADO=1, *CONTROL_TIMESTEP)
  - May result in significantly (>50%) larger stable timestep!
- Allow the use of *IGA_SHELL elements as rigid bodies
- Support for *INITIAL_VELOCITY_GENERATION
- Enable *MAT_ADD_DAMAGE_DIEM/GISSMO
- Enable definition of HAZ (heat affected zone)
- Enable various connection modeling techniques to allow for hybrid models (standard FE and IGA)
  - Spotwelds (SPR3), Bolts, CNRBs
- Enable various implicit penalty contacts (via interpolation elements) for MPP
  - *CONTACT_xxx_MORTAR
  - *CONTACT_TIED_SHELL_EDGE_TO_SURFACE(_BEAM)_OFFSET
  - *CONTACT_TIED_SURFACE_TO_SURFACE_OFFSET
- Various improvements for nonlinear implicit analysis



Hybrid assembly – Full vehicle front crash

Materials

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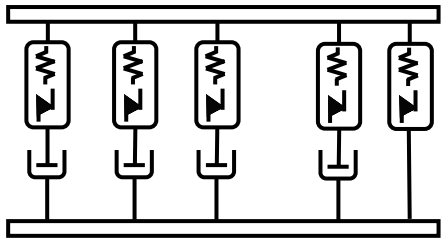
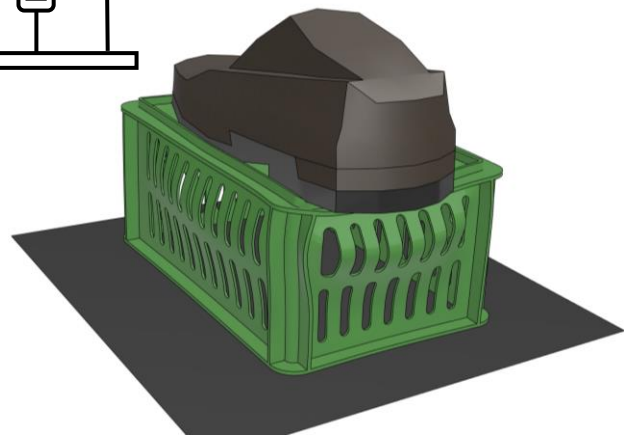
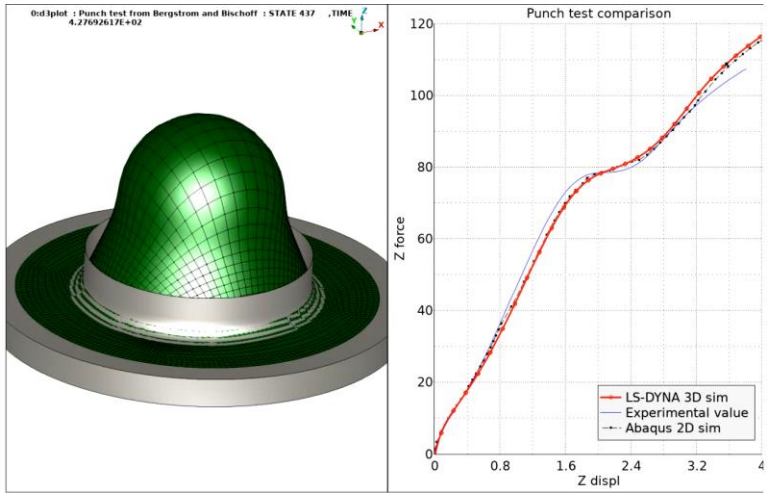
Nonlinear Viscoelasticity (Creep)





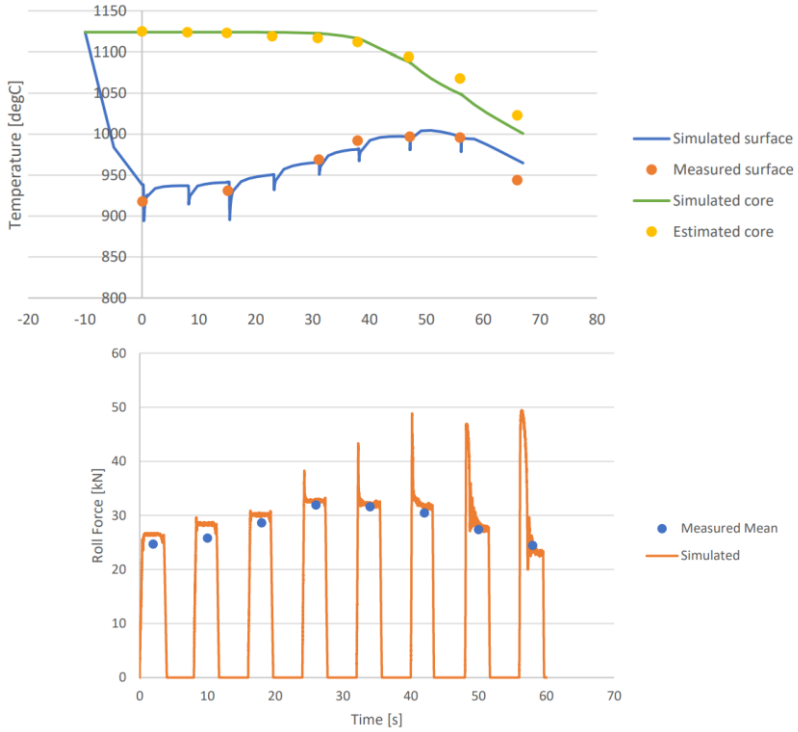
- Enhancements for *MAT_ADD_INELASTICITY
  - supplemented with nonlinear viscoelastic laws, efficient variants of the creep laws
  - The relaxation coefficients in Prony series can depend on stress and strain to effectively support the Norton-Bailey and Bergström-Boyce creep laws
  - Paper by Bengzon et al. (2021), see www.dynalook.com

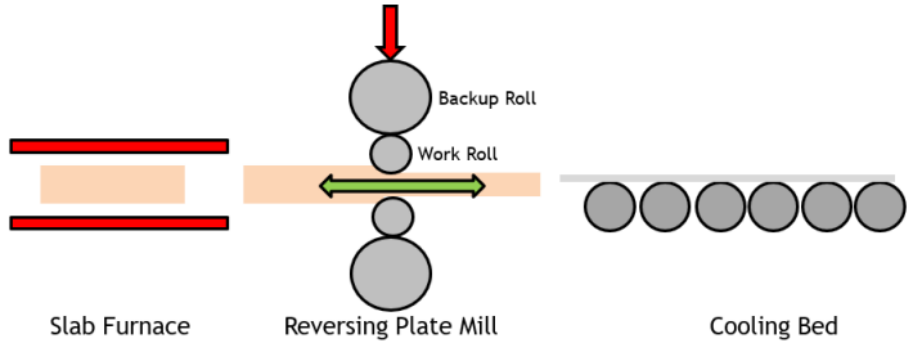
- New *MAT_318 aka *MAT_TNM_POLYMER
  - Model for thermoplastics
  - Two viscous links with interdependence, and one elastic link
  - Available for solids, explicit and implicit analysis
  - Paper by Bergström and Bischoff (2010)
  - https://polymerfem.com/three-network-model

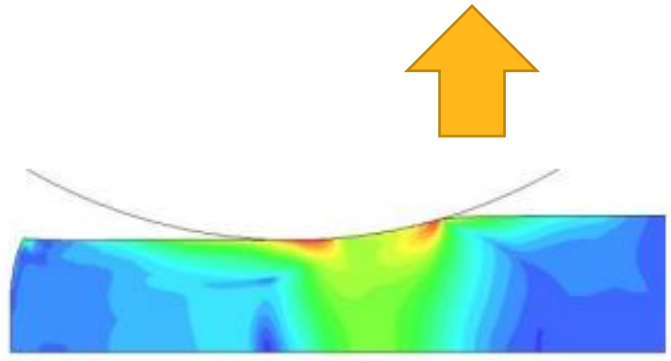


Hot Forming and Thermoplasticity

- New *MAT_HOT_PLATE_ROLLING (*MAT_305)
- Thermoelastoplastic material for hot rolling
  - Features: work hardening, dynamic softening, static recovery, and static recrystallization
  - Input parameters: calibrated from Gleeble tests at various deformation rates and temperatures
  - Developed in cooperation with Swedish steel industry to create virtual process lines for working and heat treatment processes
  - Paper by Schill et al. (2021), see www.dynalook.com



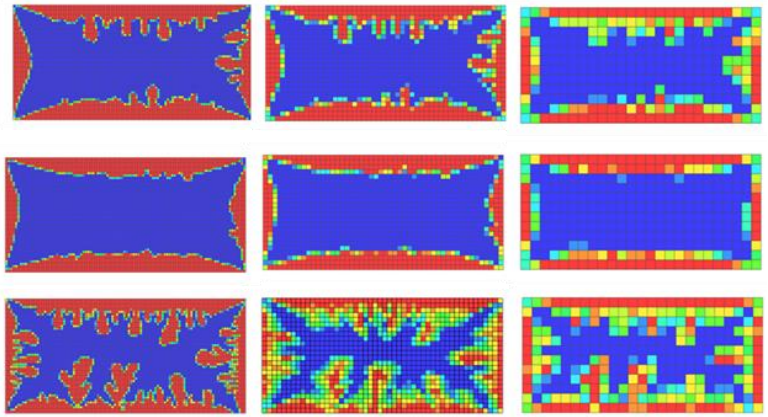




*MAT_307 / *MAT_GENERALIZED_ADHESIVE_CURING

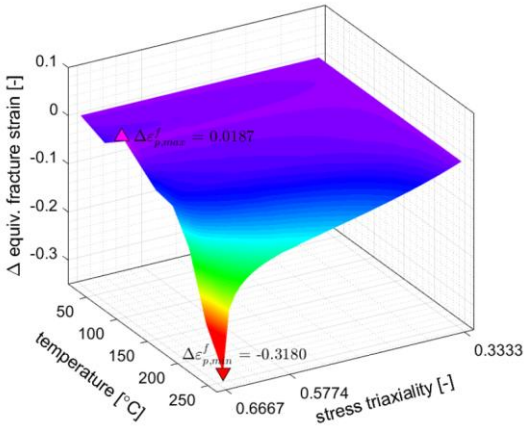
- Material to model adhesives during the complete manufacturing-crashworthiness process chain
  - In manufacturing simulation, critical effects such as the $\Delta\alpha$–problem and viscous fingering must be accounted for
  - In crashworthiness analysis, rather complex plasticity and damaging behavior is required
- Implementation basis
  - Combines and extends the existing material models *MAT_252 (TAPO) and *MAT_277
  - Temperature and degree of cure dependent viscoelastic-viscoplastic material formulation
  - Latest enhancements
    - Distortional hardening with respect to temperature variations
    - Differentiation of damage mechanisms

Viscous fingering on a LWF KS2-Specimen



Updates for *MAT_ADD_DAMAGE_GISSMO

- Properties depending on more and more variables
  - Failure/critical strain as function of plastic strain rate, temperature, Lode parameter, and triaxiality
  - Regularization factor as function of Lode parameter, triaxiality, and element size
  - Fading exponent as function of element size, triaxiality, and Lode parameter
  - Analytical failure strain, i.e. LCSDG<0 refers to *DEFINE_FUNCTION, got new arguments: plastic strain rate, temperature, history, element size.



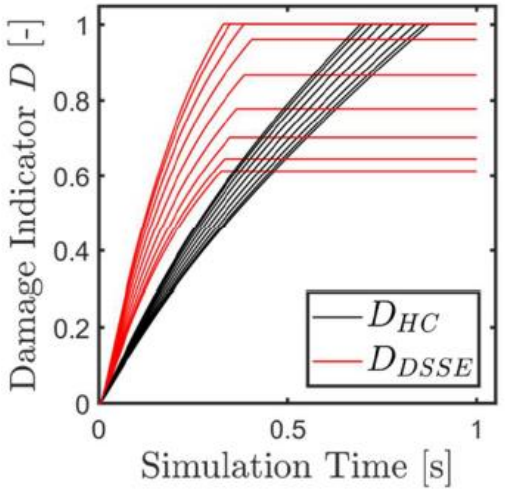
→ **Improved failure prediction for large variety of applications**

- Added new flag INSTF for instability treatment
  - This flag governs the behavior of instability measure, F , and fading exponent, FADEXP

→ **Better agreement with experimental data in post-necking behavior under various stress states**

Enhancements for generalized damage model

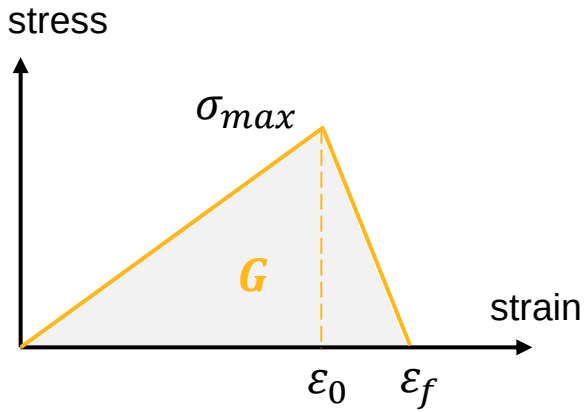
- Keyword *MAT_ADD_GENERALIZED_DAMAGE aka “eGISSMO”
- Domain of Shell-to-Solid Equivalence (DSSE) for shell elements
  - IFLG3=2: special model by Pack & Mohr (2017) for necking under bending
- Total strains as damage drivers (IFLG1=3)
  - This could be interesting for materials without plasticity



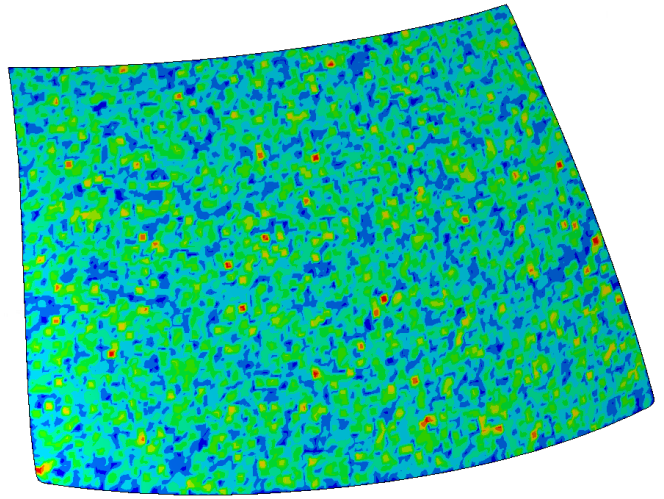
- Improvement for cyclic loading if damage driver drops now and then
  - New option IFLG4=1 prevents undesired damage evolution
- More solid material models supported
  - *MAT_058 (composites), *MAT_133 , *MAT_199, *MAT_233 (rolled/extruded metals)

Glass model enhancements (*MAT_280)

- Optional damage model invoked by input of fracture energy
  - Orthotropic damage model with linear softening governed by crack opening strain
  - This can replace the existing approach of stress reduction over a few cycles



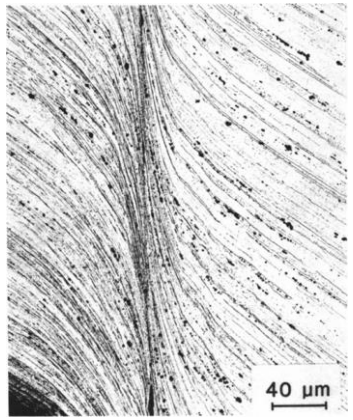
- Spatially varying distribution of properties
  - Scale factor for FT (tensile strength) on history variable #13 can be defined per element with *INITIAL_STRESS_SHELL
  - … or as automatically generated distribution by the new keyword option _STOCHASTIC (needs *DEFINE_STOCHASTIC_VARIATION)

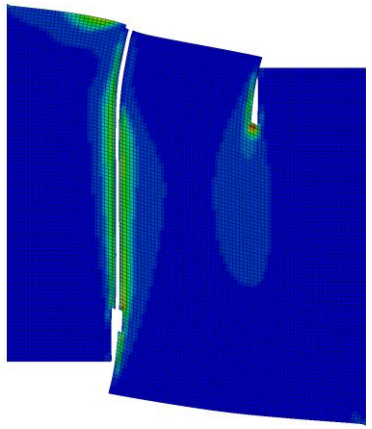


e.g. windshield with inhomogeneous defects

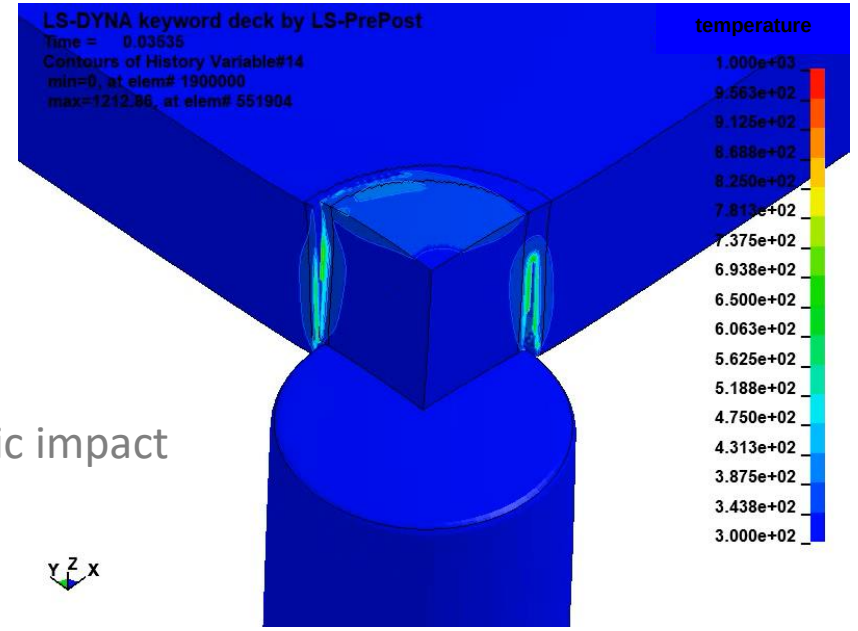
Adiabatic shear bands (ASB) in thick ductile metals

- New option for *MAT_TABULATED_JOHNSON_COOK (MAT_224)
  - BFLG=1: dissipation factor β (aka “Taylor-Quinney coefficient”) can now be a function of maximum shear strain, strain rate, and element size using a TABLE_3D
  - This allows simulating ASB initiation (thermal softening) using meshes with element sizes relevant to practical aerospace applications
  - Based on PhD research by S. Dolci (GMU) for





ASB: concentrated shear deformation



ballistic impact

Multiscale & Mesh-free

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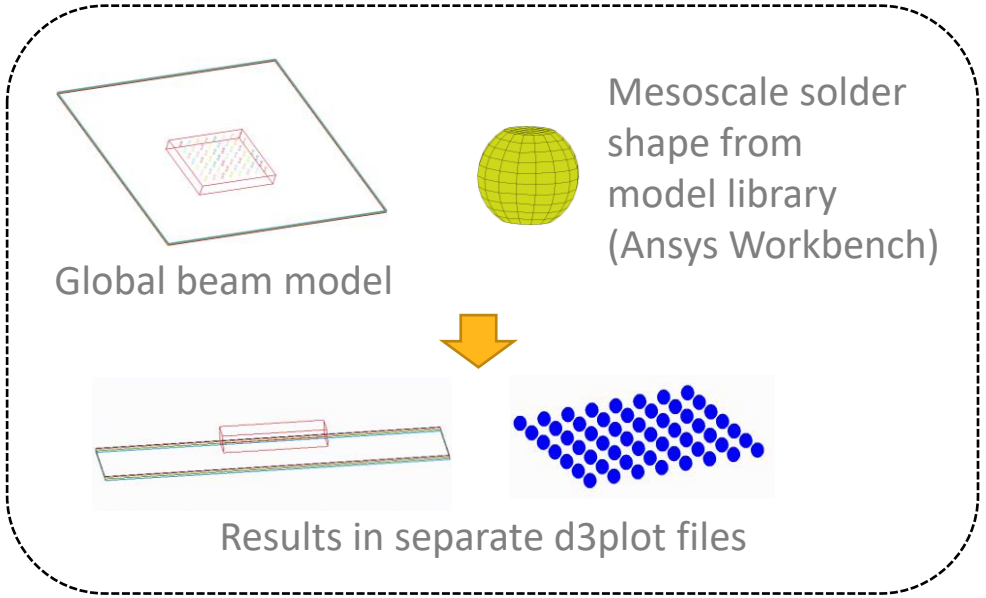
Two-scale co-simulation

- New coupling interface: *INCLUDE_MULTISCALE
  - Automatic generation of solder ball models (meso-scale solid models from macro-scale beams)
  - Replaces the previous two-scale **one-way** co-simulation and allows users to perform two-scale **two-way** co-simulation (*INCLUDE_COSIM) using the global beam model to obtain high fidelity results effectively

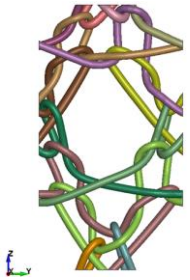


two-scale two-way co-simulation

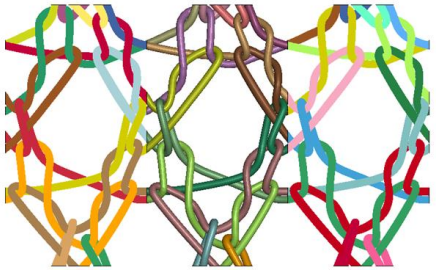
- Other highlights in new version
  - New command line flag ncsp to specify number of MPI processes for local model
    - `mpirun -np 96 mppdyna i=input.key ncsp=32`
    - Allows to run two-scale co-sim job in the very similar way of running single LS-DYNA MPP job
  - Enhancement on tie-contact based coupling
    - Consider shell offsets
    - Improve the numerical stability by redistributing interface nodal mass from local to global

RVE Package for Multiscale Material Modeling

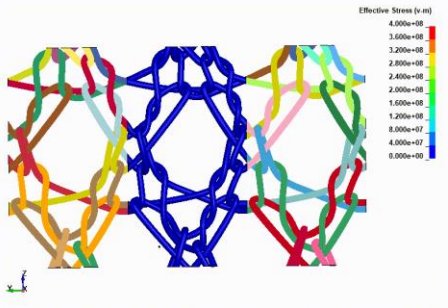
- New feature to model textile material in RVE analysis (*RVE_ANALYSIS_FEM)
  - Automatically creates image RVE in RVE solver to impose the periodicity of contact
  - Motion of the image RVE follows true RVE with an offset to preserve structural continuity
    - achieved by enhancing the current capability of *CONSTRAINED_NODE_INTERPOLATION
  - Enables to perform RVE analysis and predict homogenized property of textile RVEs
    - impose partially periodic boundary conditions to textile RVEs



RVE model



Two image RVEs
and one true RVE

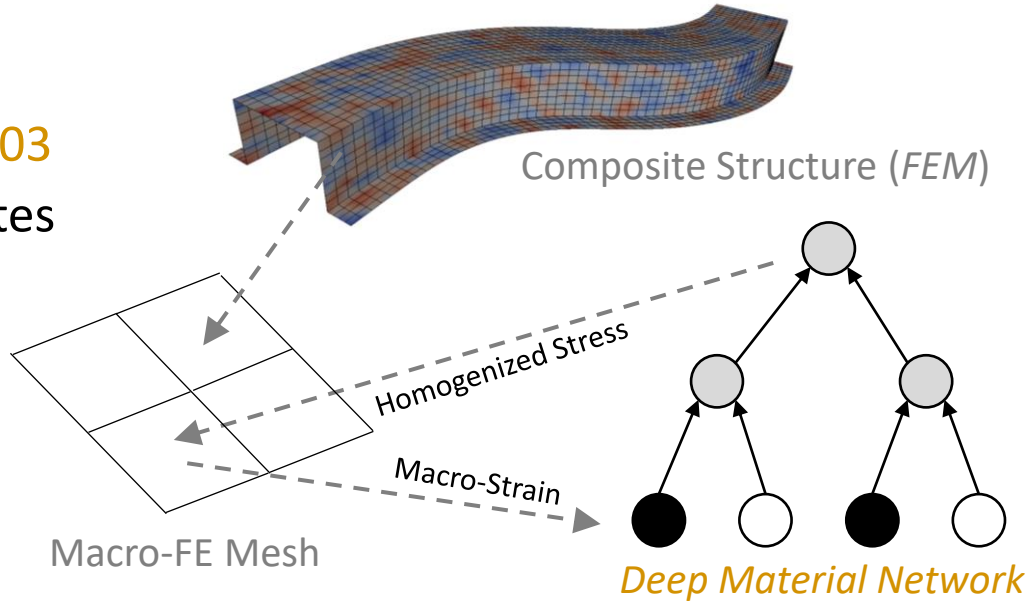


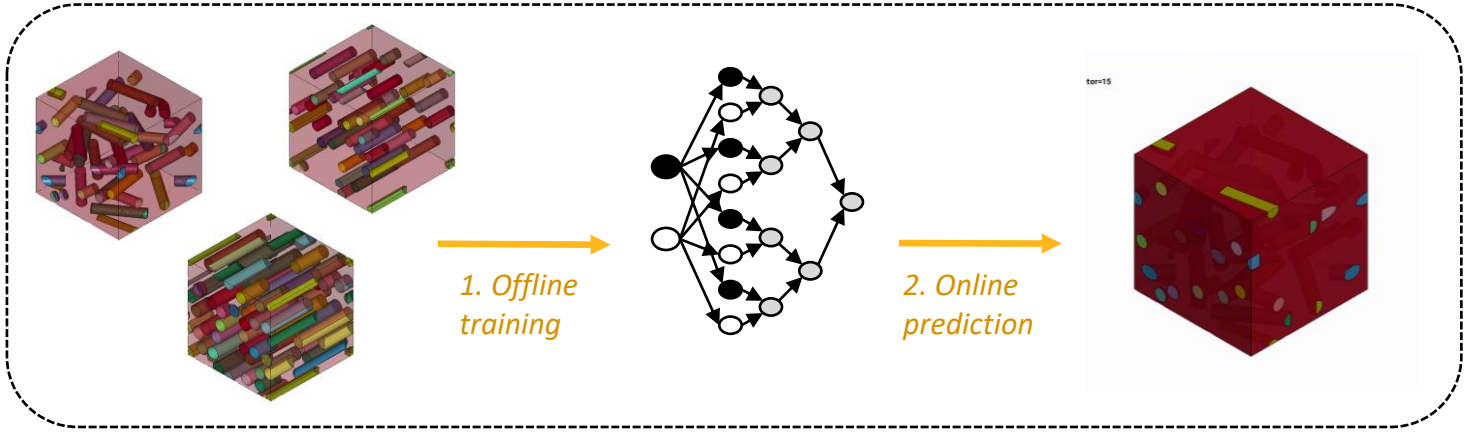
Simulation movie
(Von Mises stress)

Courtesy of Medtronic

Machine Learning-based Multiscale Analysis of Composites

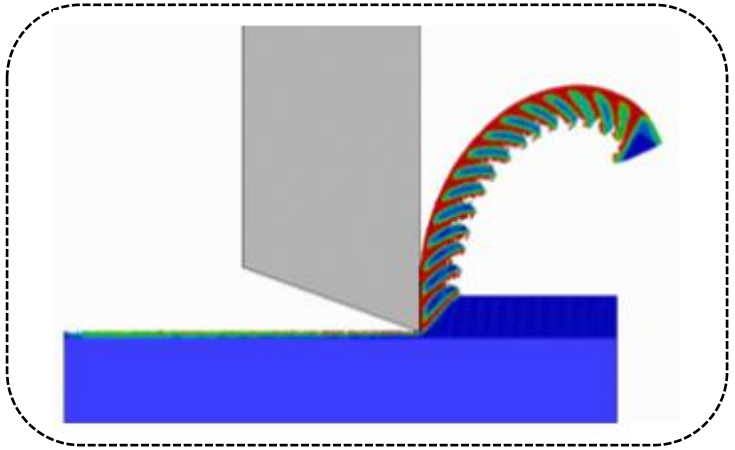
- New data-driven material model
  - New keyword *MAT_DMN_COMPOSITE_FRC or *MAT_303
  - For multiscale analysis of short fiber reinforced composites
  - Multiscale: predicts macroscale composite responses based on heterogeneous microstructures
  - Anisotropic: captures effects of fiber orientations, volume fractions, aspect ratios
  - Nonlinear: models tension-compression asymmetric elastoplastic material responses
  - Machine Learning: offline training followed by online prediction
  - Seamless Workflow: Moldex3D->LSPP->LS-DYNA
  - Details in Wei et al. (2021), see www.dynalook.com





Enhancements for SPG

- Thermal-mechanical Coupling
  - Thermal effects in metal fabrication simulations
    - Temperature dependent material properties
    - Thermal expansion, thermal conductivity, heat generation due to friction and plastic material work



Metal cutting: temperature distribution

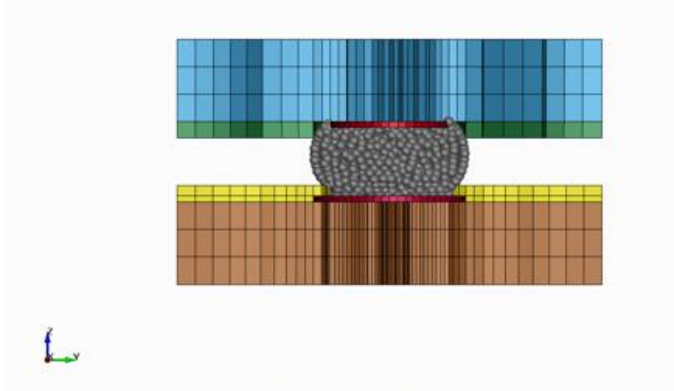
Courtesy of Mercedes

- Two new mechanisms for material failure analysis
  - *SECTION_SOLID_SPG with IDAM=11/13: brittle/ductile failure

- Particle-to-particle damping for MC-SPG
  - Developed to stabilize the MC-SPG solution in severe bond-breakage of particles without non-physical flying particles
  - Preserves the desired conservation of linear momentum and angular momentum properties

- Fully implicit ISPG method for large-scale fluid modeling

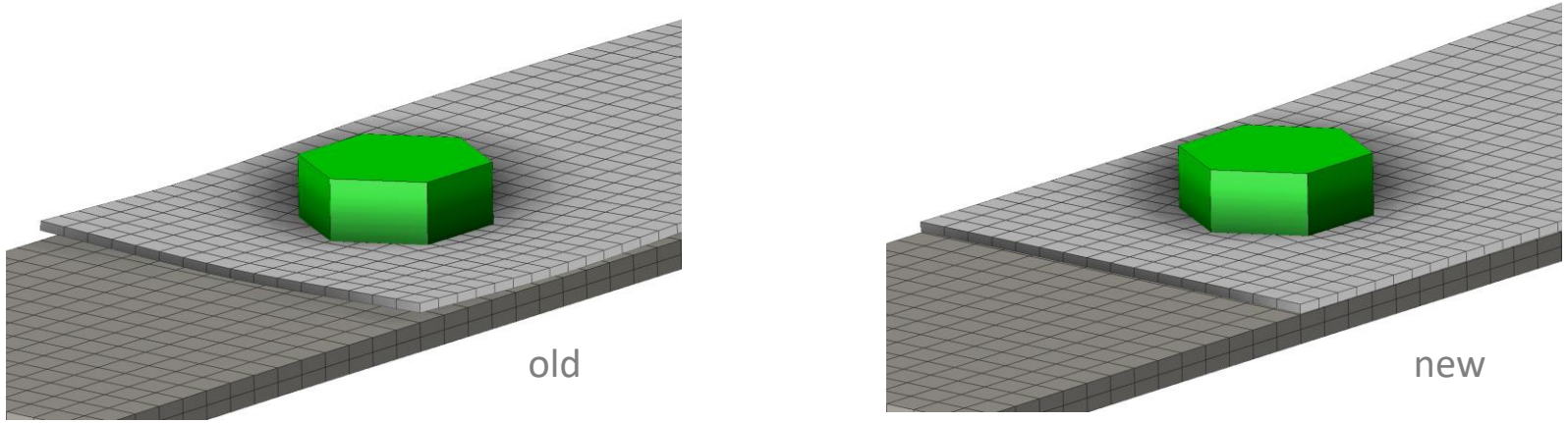
Gravitational reflowing of solder ball



Connections

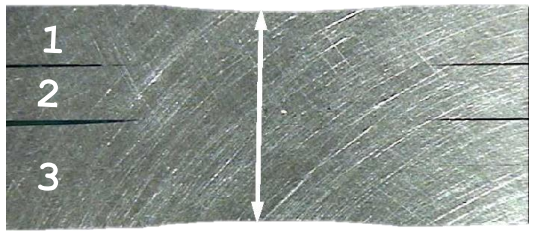
Preloading Bolts

- IZSHEAR=2 for solid element bolts has been extended to KBEND=2 for beam bolts
  - Bending resistance invoked to protect the structural integrity of the bolt
    → **more robust and realistic**
  - The prescribed force is distributed over all specified beams to avoid special purpose modelling
    → **more robust and easier to handle**
  - The contraction rate of beams has an upper limit to avoid dynamic effects as bolt heads may otherwise impact plates with arbitrary velocity. This applies to both solid (IZSHEAR=2) and beam (KBEND=2) element bolts. → **noise reduction in bolts with play**

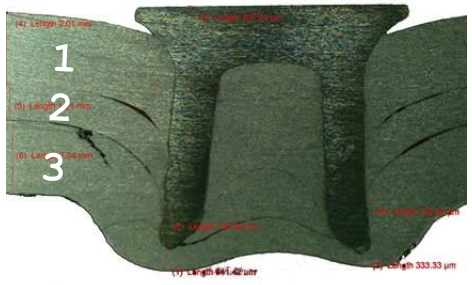


Spot welds or rivets joining more than 2 flanges

- New keyword *DEFINE_MULTI_SHEET_CONNECTORS
  - *n* sheets/panels connected by *n*-1 joining elements (current max. *n*=4)
  - Material and failure behavior of joining elements can be described based on geometric and material properties (thicknesses, yield stresses, etc.) of all *n* sheets involved
  - Better failure prediction through this information exchange
  - Currently available for single hex elements with *MAT_100_DA

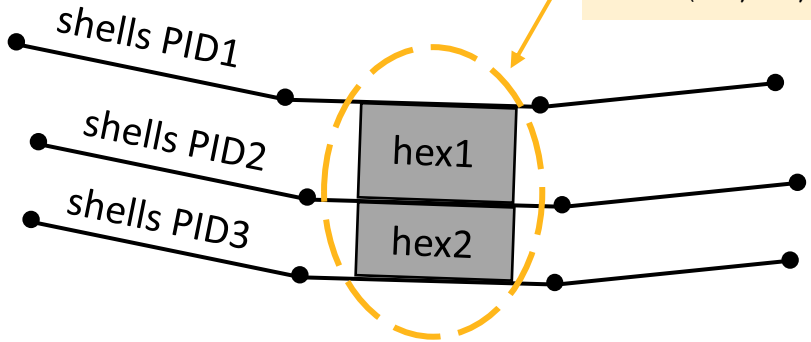


3-sheet SW



3-sheet rivet

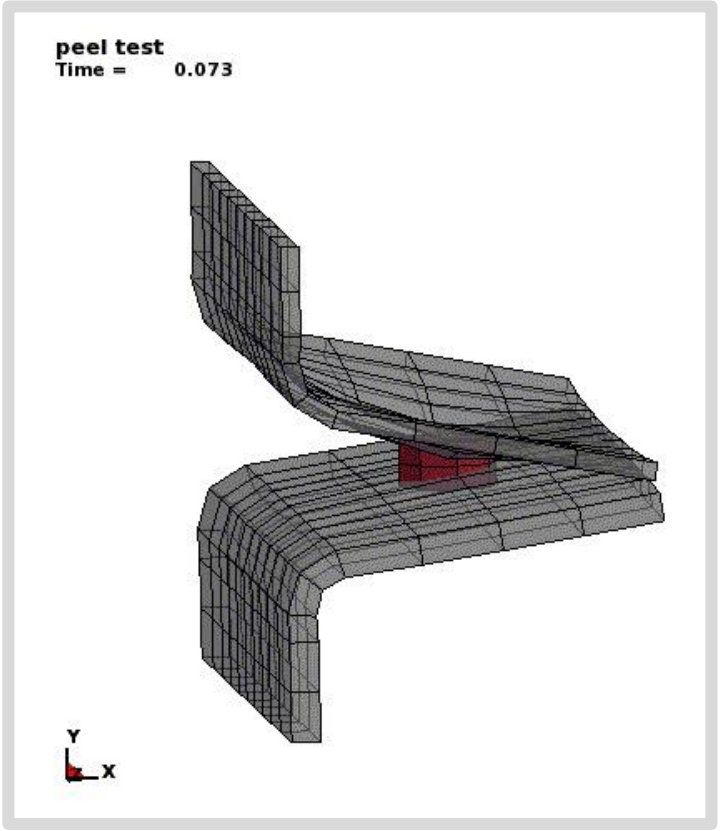
```
$                D_SIGY
                    100
*DEFINE_FUNCTION
        100
func(t1,t2,t3,t4,sy1,sy2,sy3,sy4,...)=...
```



Updates for SPR3 connectors

New options for *CONSTRAINED_INTERPOLATION_SPOTWELD aka “SPR3”

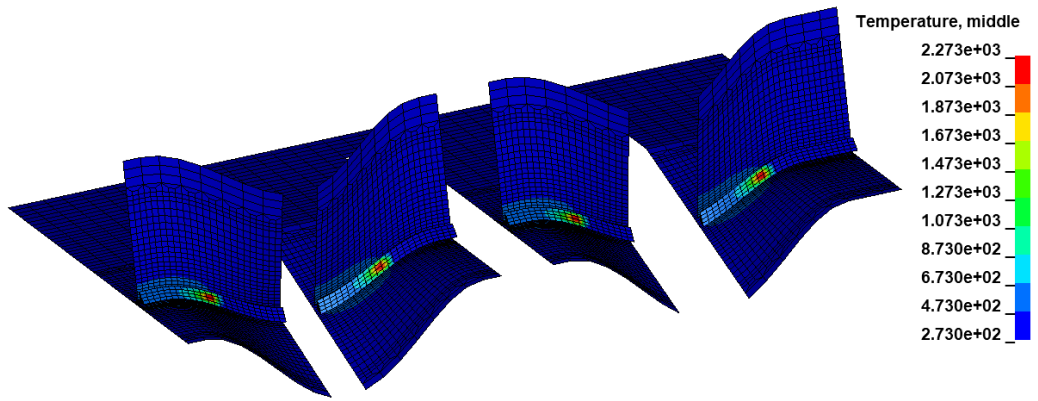
- Connection to thick sheets or volume components
  - Meets increased demand for using hex and tet elements
- Connection to in-plane composed parts, i.e., part sets
  - E.g. tailor welded blanks or other areas with different properties
- Introduction of “peel ratio”
  - Better load and failure prediction in bending-dominated cases
- Simplified scaling of properties
  - Modify strengths, but keep shape of load-displacement curve



Thermal

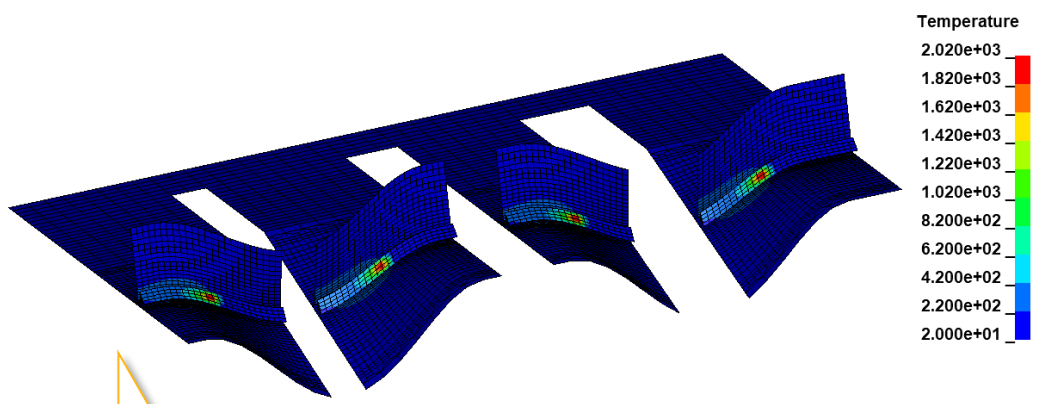
New option for data transfer in one-way coupled simulations

- Offset of temperature results when used as thermal loading
  - New parameter TMPOFF in *LOAD_THERMAL_BINOUT
  - Enables the switch of temperature scales, such that results from a thermal-only simulation in the Kelvin scale can be applied in a structure-only simulation in the Celsius scale



Thermal-only welding simulation with temperatures in Kelvin scale

*LOAD_THERMAL_BINOUT (TMPOFF=-273)

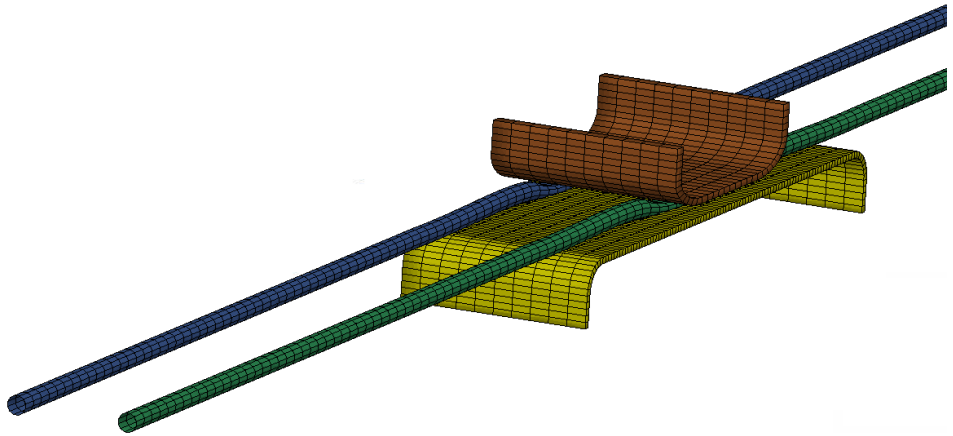


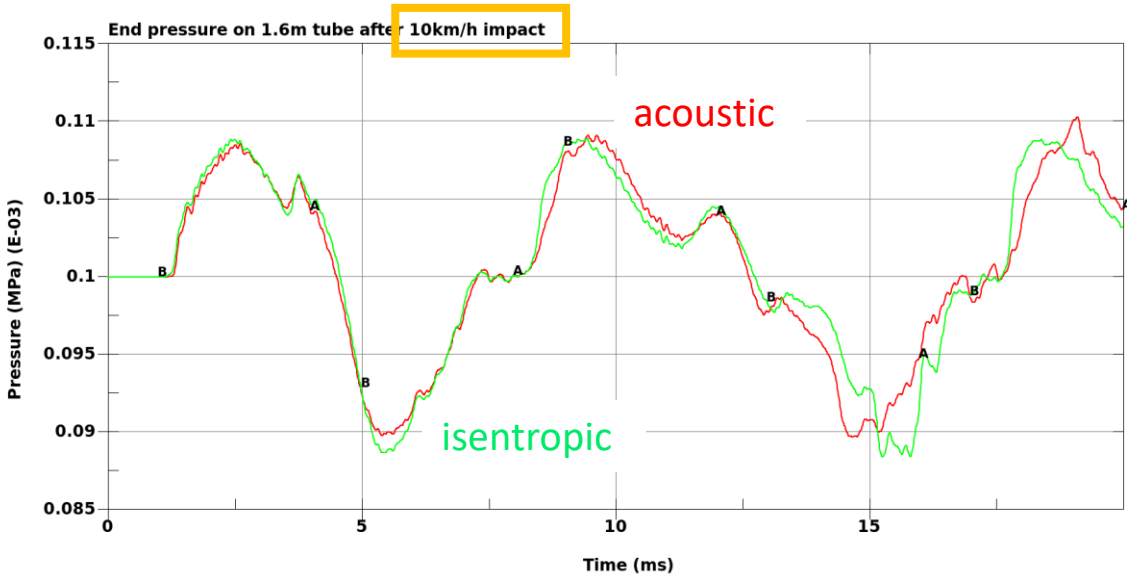
Structure-only welding simulation with temperatures in Celsius scale and an adapted mesh

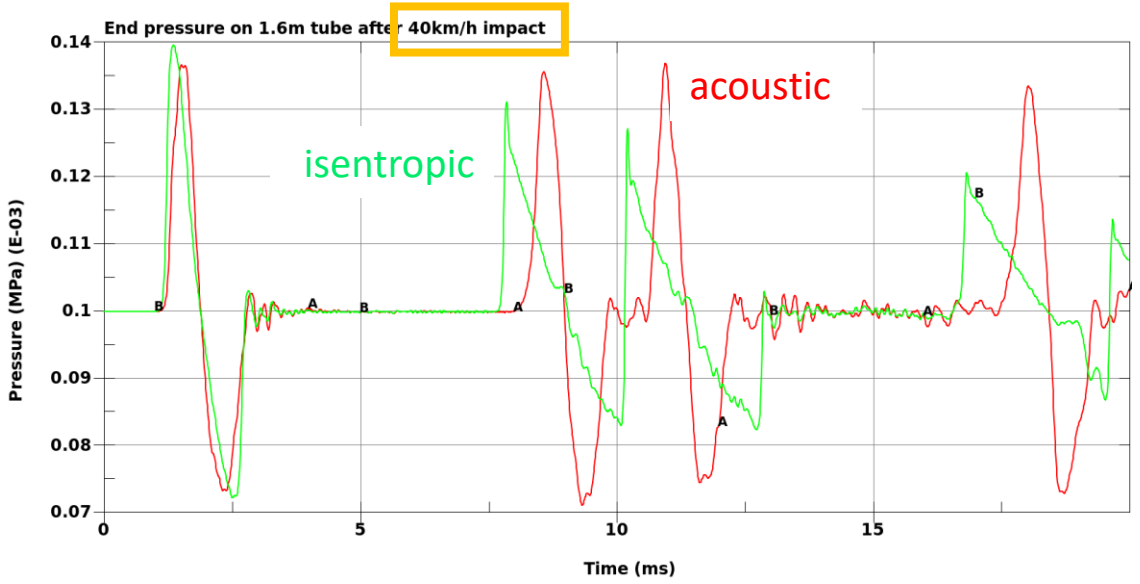
Miscellaneous

*DEFINE_PRESSURE_TUBE

- Supports isentropic Euler (MTD=2) with adiabatic index ≥1 (GAMMA)
  - Captures non-linear effects, primarily in high velocity impacts

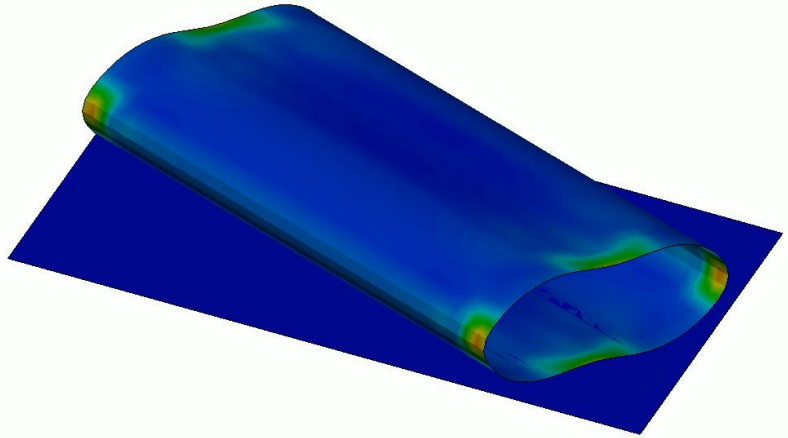


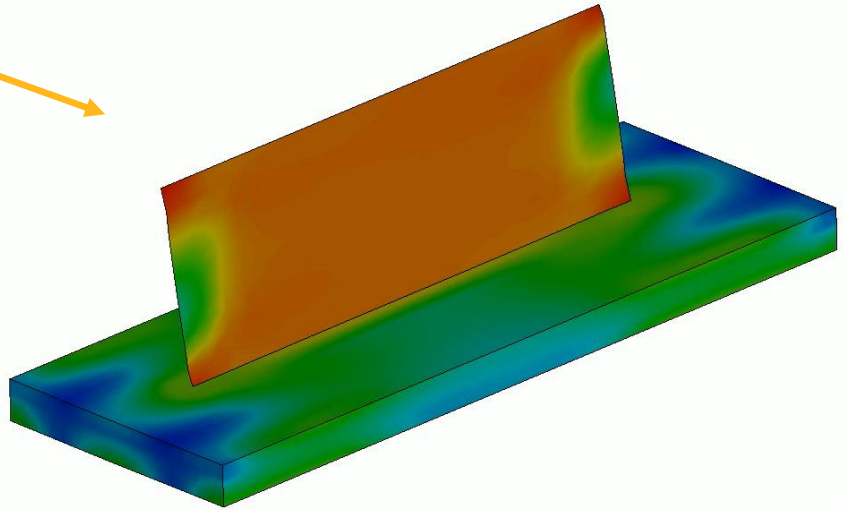




Mass Scaling Enhancements

- Consider added mass in gravity loading
  - See EMSCL on *CONTROL_TIMESTEP and *LOAD_BODY
- SMS now supports moving rigid walls
  - By incorporating the motion of the rigid wall into the set of unknown variables in the mass acceleration system
- SMS now supports tied shell edge to solid contact
  - By incorporating the rotation degrees of freedom of SURFA into the set of unknown variables in the mass acceleration system
- SMS now supports inertia element on rigid bodies
  - These were inadvertently omitted in the past
- Mass by part is output to matsum files
  - Both for conventional and selective mass scaling





Conclusion

2023R1 (R14) Release features

- Vast amount of new capabilities
- All integrated in One Code strategy
  - Tightly Coupled, Scalable Multi-Physics Solver
- Product available in January 2023
  - Minor release 2023R2 in July 2023
  - Service packs as needed
  - All other tools are released at the same time: ANSYS Forming, LS-OPT Pro, LS-TaSC, …
- Detailed documentation in User's Manuals
- Complete list will be available
  - https://www.dynasupport.com/release-notes