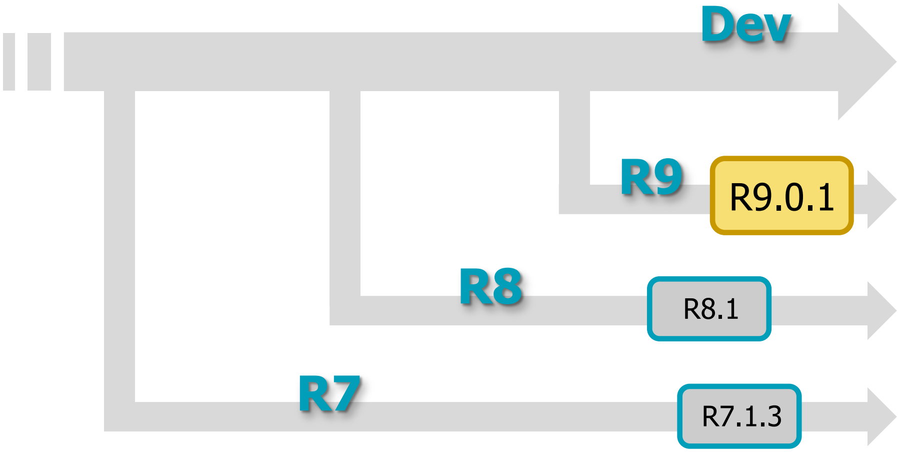
New features in LS-DYNA R9.0.1

- Release R9.0.1 published in August 2016
- This presentation about major changes since R8.1
- Comprehensive list of enhancements and corrections in http://www.dynasupport.com/news/ls-dyna-r9.0.1-r9.109912-released

LS-DYNA versions

- Version numbering scheme
  - Major branches called R6, R7, R8, R9, …
  - Official releases such as R6.1.2, R7.1.3
- Robust production version
  - Release R7.1.3 from May 2016
  - Recommended for daily use in crash and occupant simulation
- Latest official versions
  - Release R8.1 from February 2016: Webinar slides on www.dynamore.de
  - Release R9.0.1 from August 2016: New features shown in this presentation



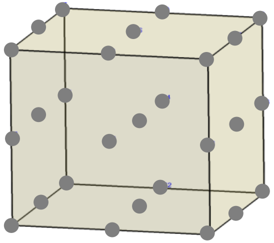
Overview

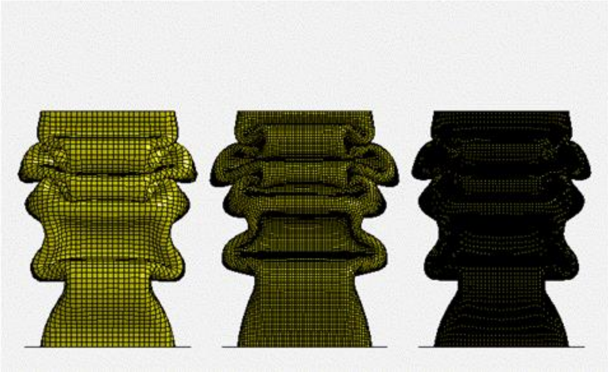
- Element Technology & IGA
- Contact
- Material models
- Forming applications
- Airbags
- Implicit analyses
- Frequency Domain
- MPP
- Miscellaneous
- Meshfree methods
- ALE / S-ALE
- Electromagnetics
- CFD & FSI
- CESE
- Bug fixes
- Conclusion

Element Technology & IGA

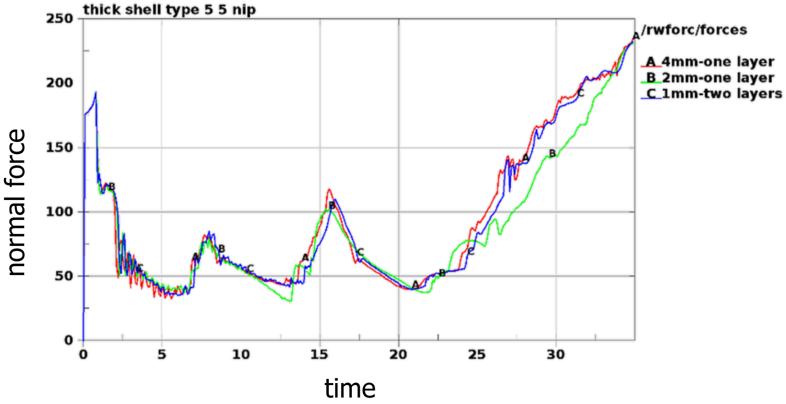
27-node solid element

- New element formulation ELFORM = 24 on *SECTION_SOLID
  - Accurate for large deformation, severe distortion
  - Selective reduced integration to alleviate volumetric locking
  - Supports *ELEMENT_SOLID_H8TOH27
  - Excellent behavior in bending with 1 element over plate thickness!





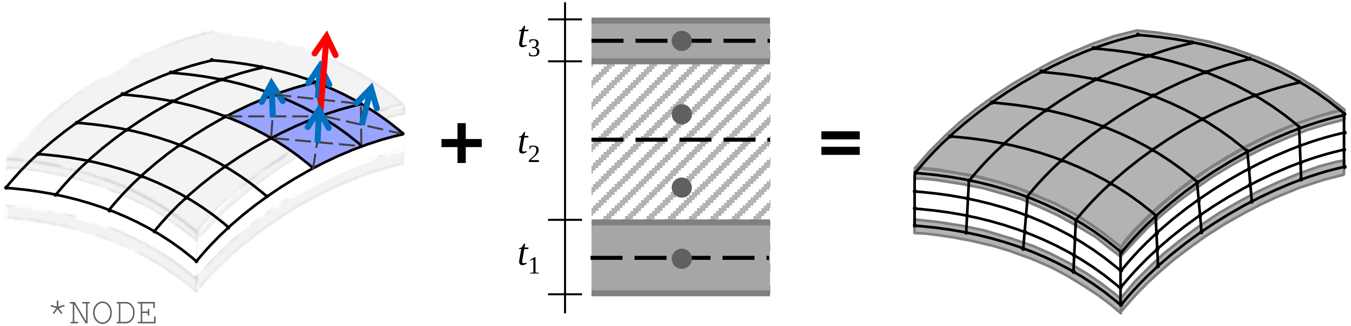
coarse-mesh accuracy



Stacked elements

- New keyword *PART_STACKED_ELEMENTS
  - Layered shell and/or solid element model for shell-like structures
  - Application examples: sandwich plate systems, composite laminates, …
  - Definition of surface geometry and layup sequence
  - Automatic mesh generation by extrusion

picture credit:
Wikipedia

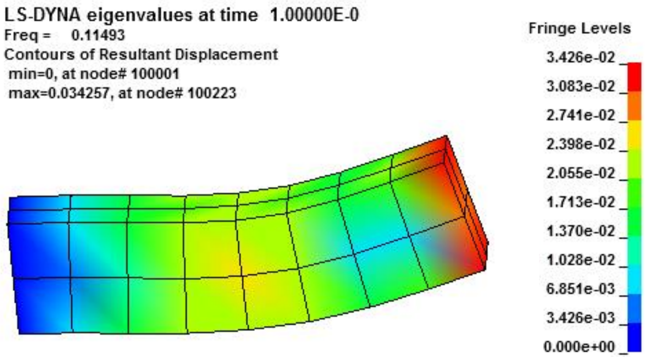


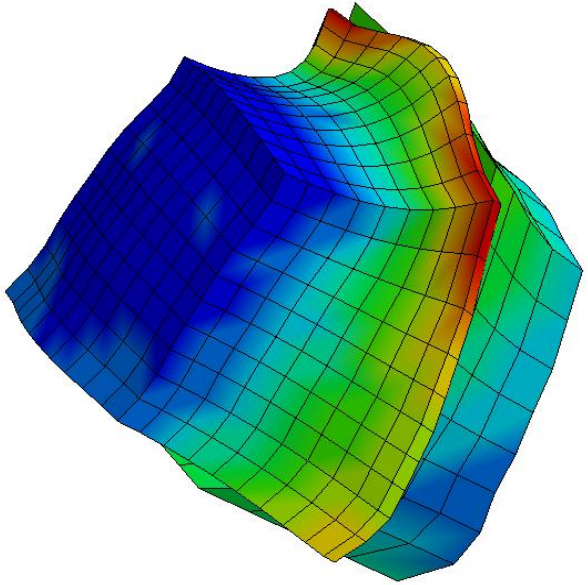
*NODE
*ELEMENT_SHELL

*PART_STACKED_ELEMENTS

IGA for solids

- New keyword *ELEMENT_SOLID_NURBS_PATCH
  - Enable isogeometric analysis for solid elements
  - Supports explicit and implicit analysis,
    contact and eigenvalue analysis, etc.
  - To be used with ELFORM=201 on *SECTION_SOLID

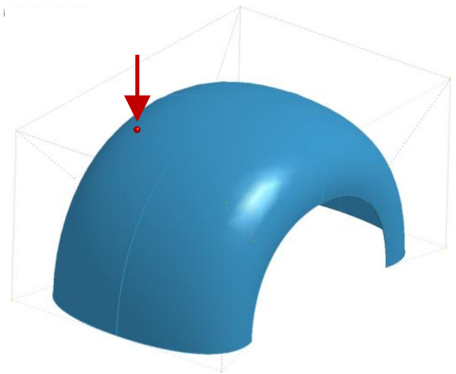




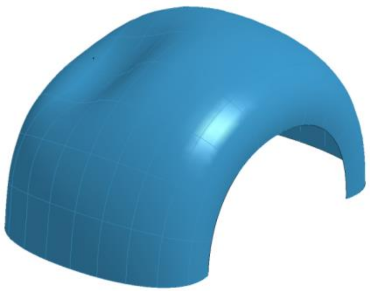
two bodies impact:
effective stress distribution

IGA boundary conditions

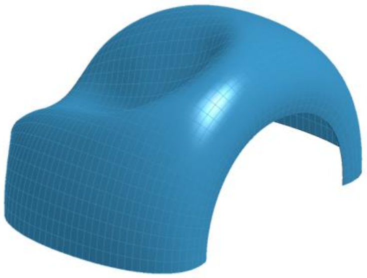
- New keyword *CONSTRAINED_NODE_TO_NURBS_PATCH
  - Add additional massless nodes (*NODE) to the surface of a NURBS patch (desired position)
  - Possibility to apply force and displacement boundary conditions at arbitrary position



Quadratic NURBS
(2x2 Elements)

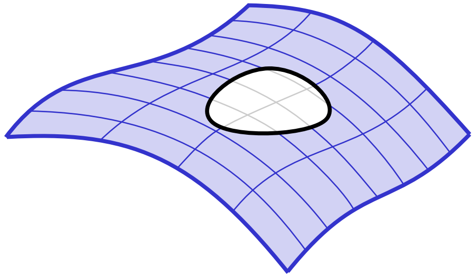


Deformation
Quadratic NURBS
(10x10 Elements)



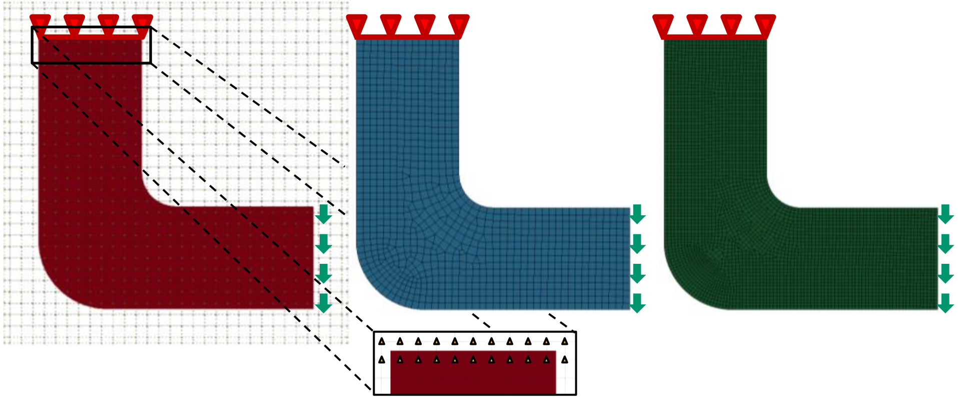
Deformation
Quadratic NURBS
(40x40 Elements)

IGA: Trimmed NURBS



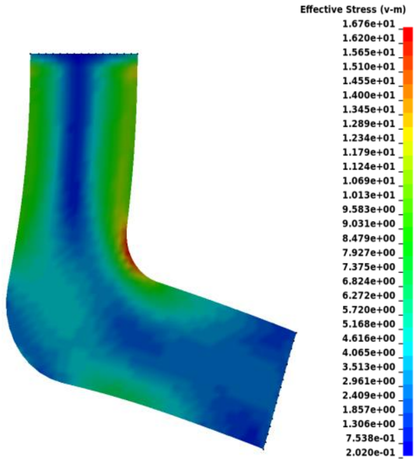
- Add trimmed NURBS capability
  - For surfaces that contain holes or have arbitrary shapes
  - Define NL trimming loops to specify a trimmed NURBS patch
  - Use *DEFINE_CURVE (DATTYP=6) to define trimming edges in the parametric space
  - Boundary conditions via new keyword *CONSTRAINED_NODE_TO_NURBS_PATCH (CNTNP)

- Example: L-Shape
  - Dirichlet-BC‘s (kinematic):
    1. via SPC on „closest“ Control Points
    2. via CNTNP (con=111111, SF varying)
  - Neumann-BC’s (load):
    via CNTNP (con=0)
    + *LOAD_NODE_SET

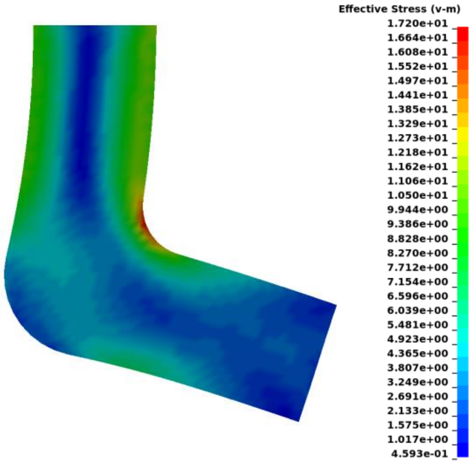


IGA: Trimmed NURBS

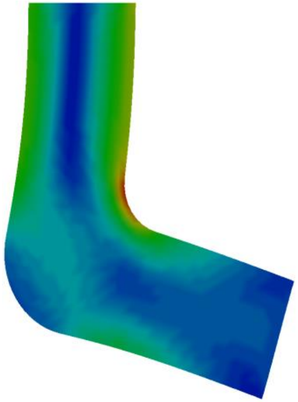
- L-Shape results: Deformation and von Mises stresses



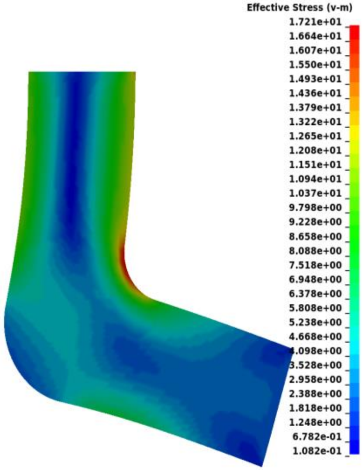
Trimmed NURBS (quadratic)
30x30 elements
mesh size: 0.33 mm
SPC on CPs



Trimmed NURBS (quadratic)
30x30 elements
mesh size: 0.33 mm
SPC on ”massless“ nodes via CNTNP



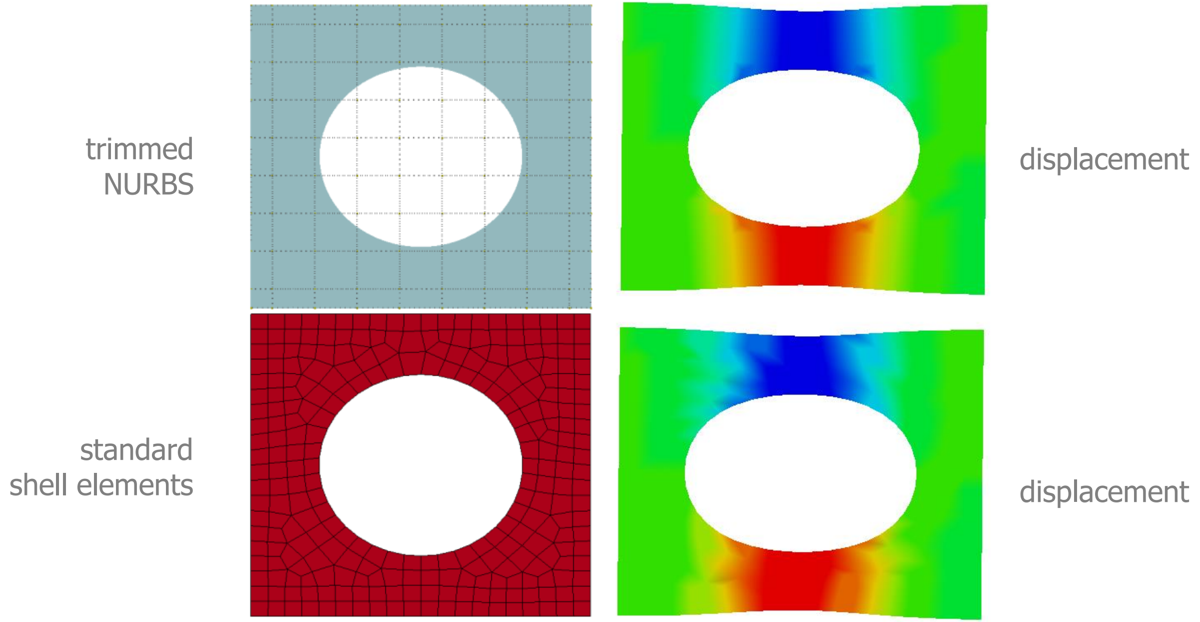
Standard FE
mesh size: 0.2 mm



Standard FE
mesh size: 0.1 mm

IGA: Trimmed NURBS

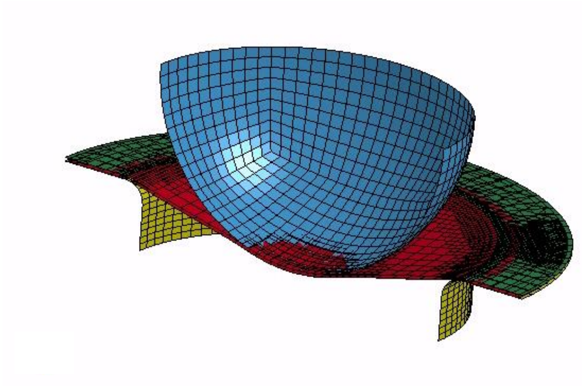
- Another example: plate with hole

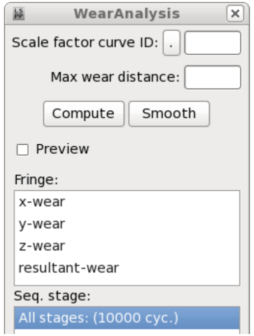


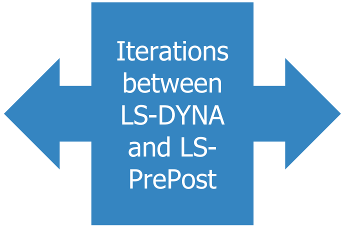
Contact

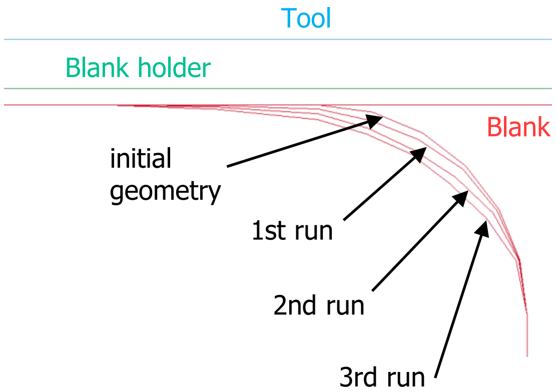
Wear processes

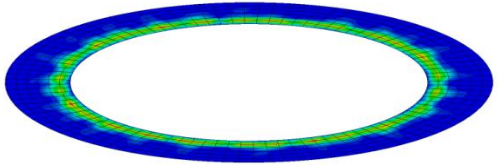
- New keyword *CONTACT_ADD_WEAR
  - Simulating wear is of interest for improving tool design
  - Archard and User wear laws
  - Post process wear in LS-PrePost
  - Modify geometry in LS-PrePost based on wear, using *INITIAL_CONTACT_WEAR







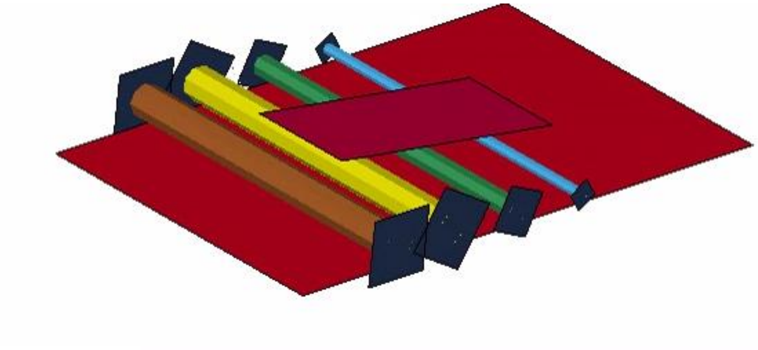


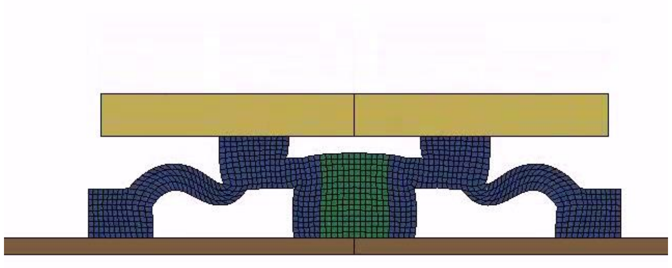


wrinkling tendency influences wear on binder

Mortar contact

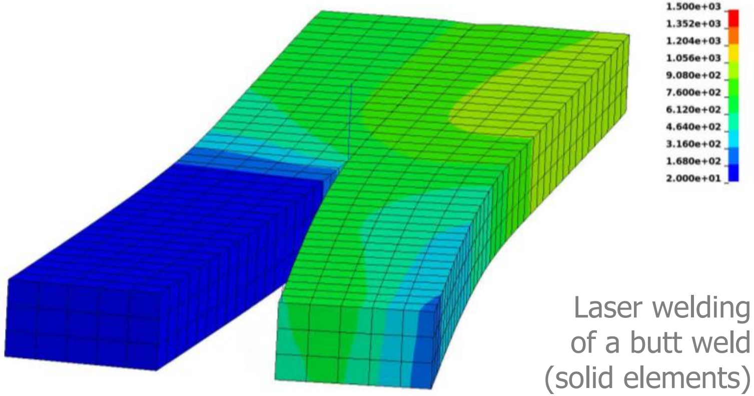
- Several enhancements and improvements
  - Forming mortar contact now runs
    with deformable solid tools and honors ADPENE
  - Support rotational degrees of freedom
    when contact with beam elements
  - Maximum allowable penetration takes
    master thickness into account
  - Account for sharp edges in solid elements
  - When solid elements are involved,
    default stiffness is increased by a factor of 10
  - The OPTT parameter on *PART_CONTACT
    for the contact thickness of beams is now supported



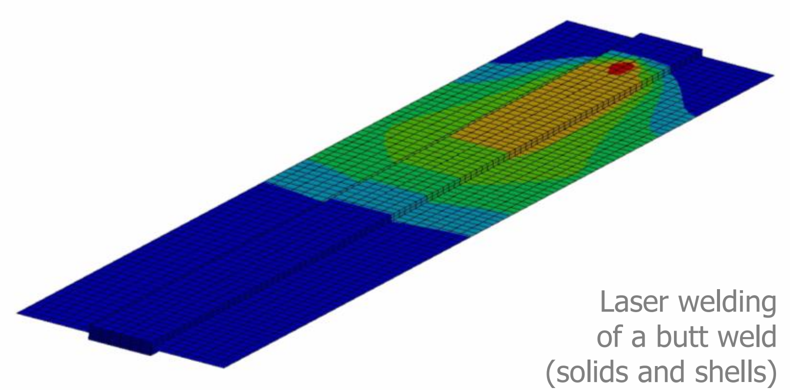


Tied contact for welding

- New keyword *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIED_WELD_THERMAL
  - As regions of the surfaces are heated to the welding temperature and come into contact, the nodes are tied. (Below welding temperature: standard sliding contact behavior)
  - Heat transfer in welded contact zones differs as compared to unwelded regions



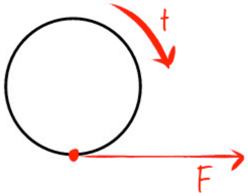
Laser welding of a butt weld (solid elements)



Laser welding of a butt weld (solids and shells)

More contact enhancements

- Change “interface pressure“ report in **intfor** file from abs(force/area) to –force/area for correct representation of tied interfaces in tension
- Add support for ***DEFINE_REGION** to define an active contact region for MPP contacts
- Add **frictional work calculation for beams** in *CONTACT_AUTOMATIC_GENERAL
- Add new option FTORQ for **torque introduced by friction** (beams in *CONTACT_AUTOMATIC_GENERAL)



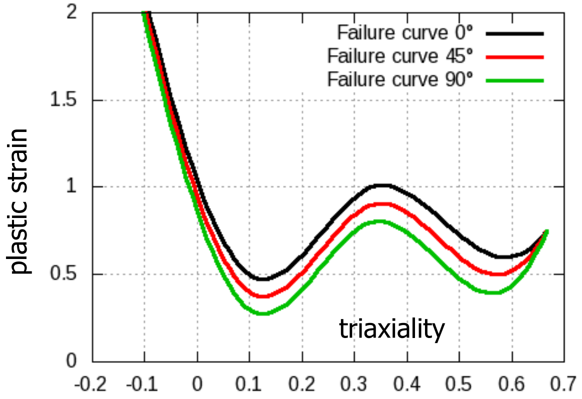
- Added support to SOFT=2 contact for **SRNDE** parameter (non-extended shell edges)
- *SENSOR can now be used to control ***CONTACT_GUIDED_CABLE**
- Add ***CONTACT_TIED_SHELL_EDGE_TO_SOLID** to transmit shell or beam moments into solids using force pairs

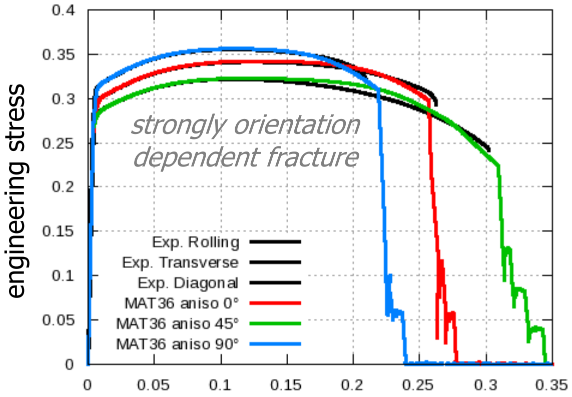
Material models

Generalized damage model

- New keyword *MAT_ADD_GENERALIZED_DAMAGE (MAGD)
  - General damage model as add-on for other material models
  - Intention: non-isotropic damage as in aluminum extrusions, …
  - Up to 3 history variables as damage driving quantities
  - Very flexible due to input via *DEFINE_FUNCTIONs

$$\begin{bmatrix}\sigma_{11}\\ \sigma_{22}\\ 0\\ \sigma_{12}\\ \sigma_{23}\\ \sigma_{31}\end{bmatrix}=\begin{bmatrix}D_{11} & D_{12} & 0 & D_{14} & 0 & 0\\ D_{21} & D_{22} & 0 & D_{24} & 0 & 0\\ 0 & 0 & D_{33} & 0 & 0 & 0\\ D_{41} & D_{42} & 0 & D_{44} & 0 & 0\\ 0 & 0 & 0 & 0 & D_{55} & 0\\ 0 & 0 & 0 & 0 & 0 & D_{66}\end{bmatrix}\begin{bmatrix}\tilde{\sigma}_{11}\\ \tilde{\sigma}_{22}\\ 0\\ \tilde{\sigma}_{12}\\ \tilde{\sigma}_{23}\\ \tilde{\sigma}_{31}\end{bmatrix}$$

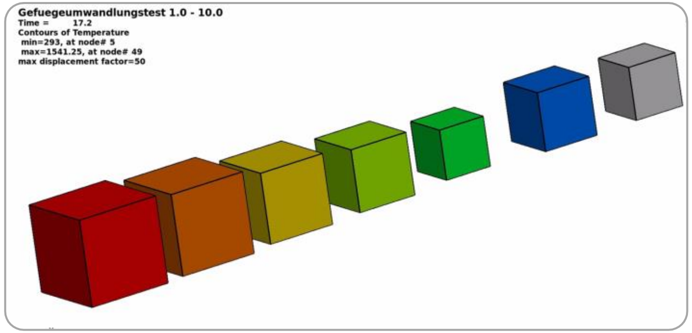


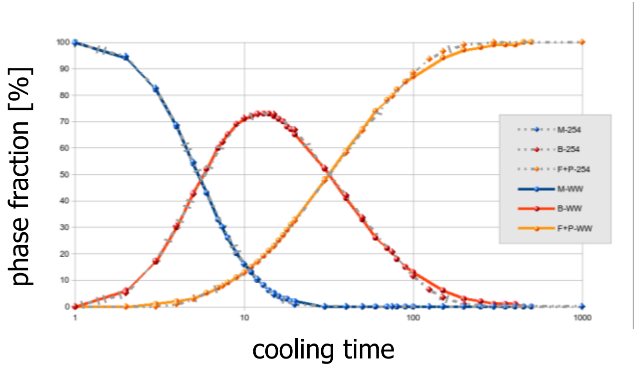


… and many other possible application areas

General phase change material

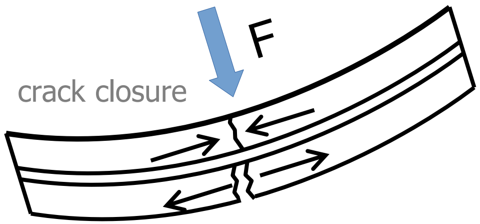
- New material model *MAT_GENERALIZED_PHASE_CHANGE or *MAT_254
  - Very general material implemented to capture micro-structure evolution in welding and heat treatment
  - Up to 24 individual phases
  - For any of the possible phase transformation user can choose from a list of generic phase change mechanisms (e.g. Leblond, JMAK, Koistinen-Marburger, Kirkaldy, …)
  - Parameters for transformation law directly given in tables
  - Additional features
    - Transformation induced strains
    - Transformation induced plasticity (TRIP)
    - Temperature and strain rate dependent plasticity
  - Ongoing development

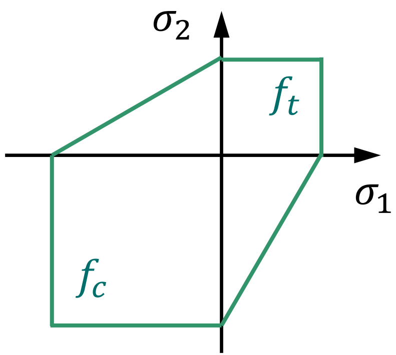


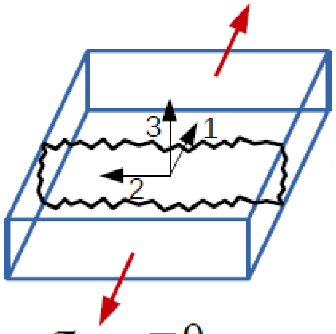


Glass model

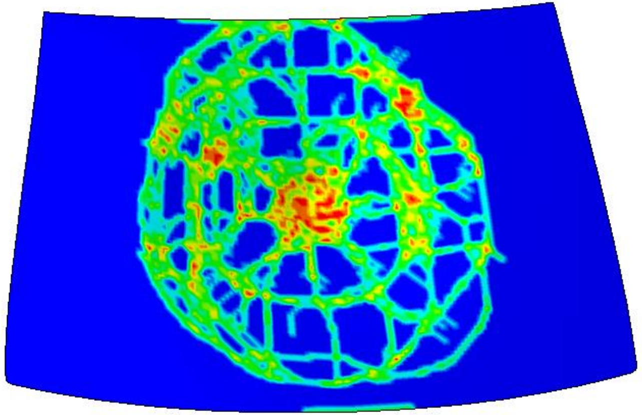
- New material *MAT_GLASS (*MAT_280)
  - Material model for fracture of (laminated) safety glass
  - Brittle smeared fixed crack model for shell elements (plane stress)
  - Failure criteria: Rankine, Mohr-Coulomb, or Drucker-Prager
  - Incorporates up to 2 cracks, simultaneous failure over thickness, crack closure effect (no element deletion)



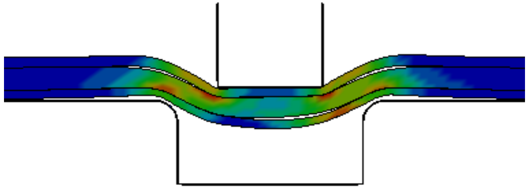




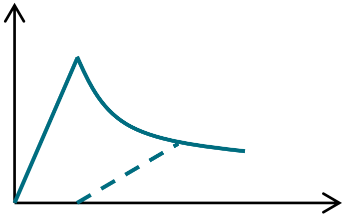
windshield
head impact

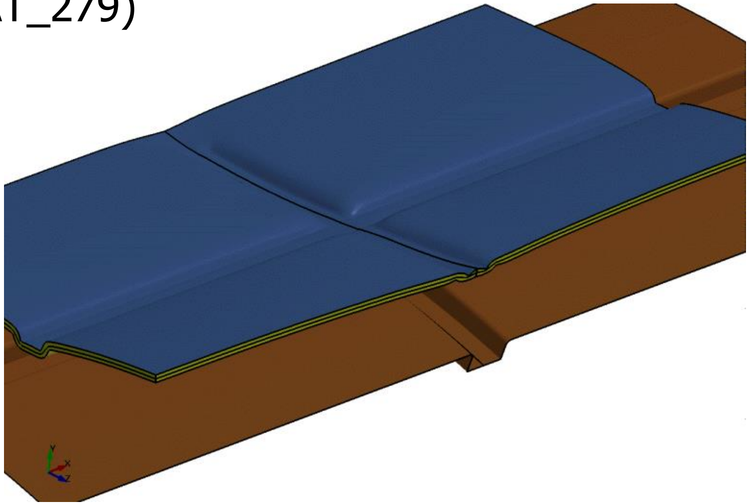


Paperboard modeling



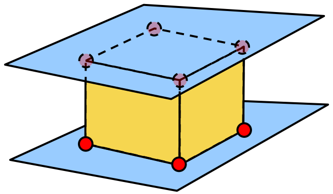
- *MAT_PAPER or *MAT_274 already available in R7.1.3
  - Orthotropic elastoplastic model for shell and solid elements
  - For creasing simulation with delamination of individual plies
- New cohesive model *MAT_COHESIVE_PAPER (*MAT_279)
  - For modeling delamination in conjunction with *MAT_PAPER and shells
  - In-plane and out-of-plane models uncoupled
  - Normal compression nonlinearly elastic
  - Normal tension and tangential traction given by elastoplastic traction-separation law:

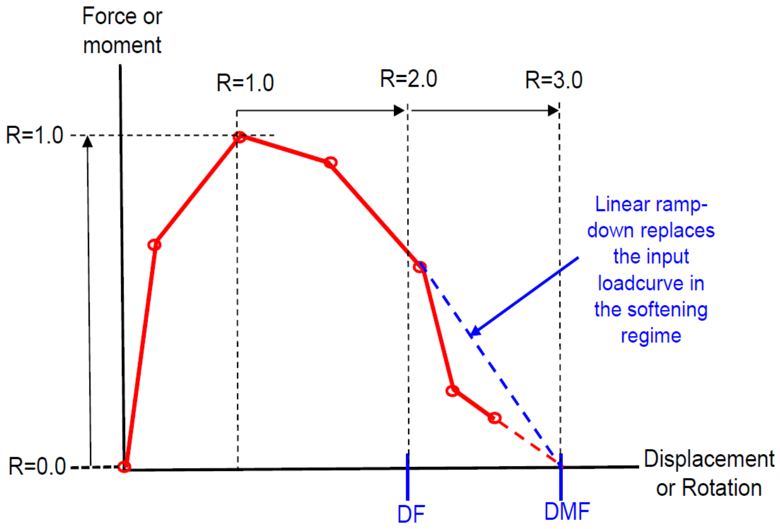




Material model for self-piercing rivets

- Keyword is *MAT_SPR_JLR or *MAT_211
  - Already available since R7, now stable and extensively documented in User's Manual of R9
  - SPR discretized as hexahedron ELFORM=1 but uses separate unique element formulation
  - Covers several special features suitable for SPR (head-tail distinction, axial-shear-bending, non-linear force-displacement, softening, …)
  - Comprehensive output capabilities





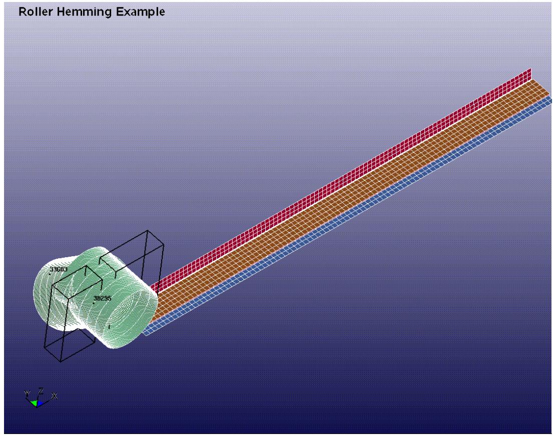
More material enhancements

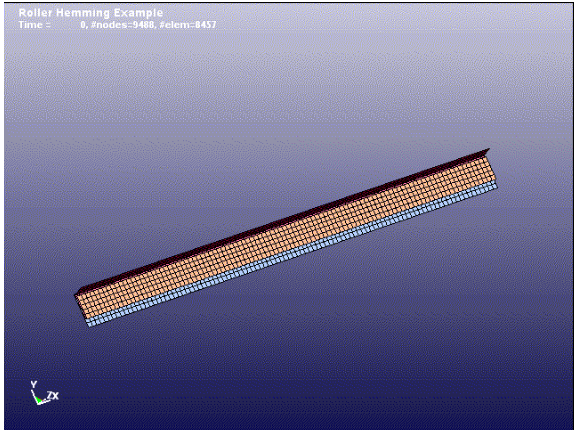
- New keyword ***DEFINE_MATERIAL_HISTORIES** for organizing history outputs
- Modified ***MAT_FABRIC** FORM=24 so that Poisson's effects occur in tension only
- Add thick shell support for the **STOCHASTIC** option of materials 10, 15, 24, 81, and 98
- Added support for ***MAT_BRITTLE_DAMAGE** for solid element types 3, 4, 15, 18, and 23
- Add implicit iteration abort flag "reject" to **user-defined materials**
- Several improvements for **DIEM**: efficiency, new options, output, …
- Rate dependent plasticity and strengths for ***MAT_261** and ***MAT_262**
- Add possibility to use *DEFINE_FUNCTION for ***MAT_SPOTWELD**, OPT=-1/0
- Improve performance of **GISSMO** and ***MAT_187**
- Add **implicit** capability for materials 120, 121, 157, 181 (2D), 254, 274, 275

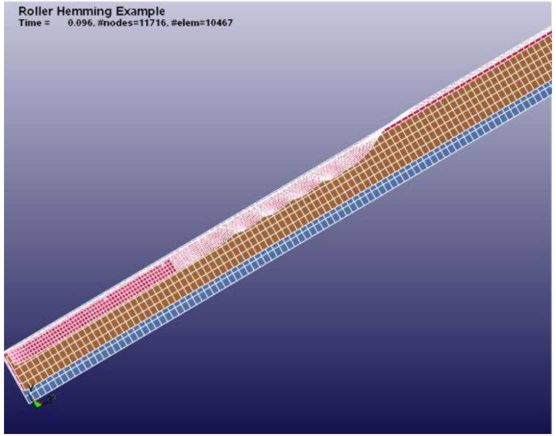
Forming applications

Enhanced adaptive box

- Mesh fission and fusion in a user defined region changing over time
  - Moving box to control mesh refinement and coarsening
  - New option in *DEFINE_BOX_ADAPTIVE
  - Useful in roller hemming and incremental forming

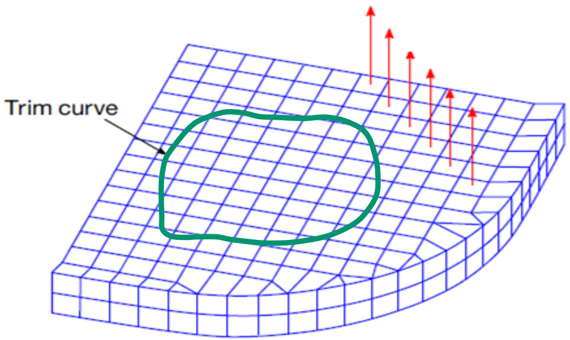




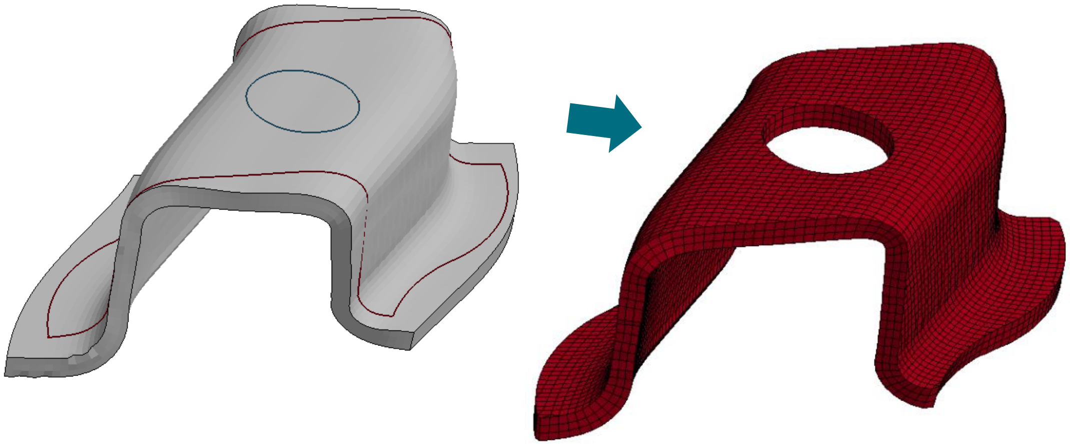


Trimming extensions

- NEW: 2D and 3D trimming of solids (and laminates)
  - Inputs to trim solid elements are the same as for trimming of shell elements
  - *INCLUDE_TRIM has to be used (new efficient method to include mesh for trimming)
  - Additional input to indicate solid normals: TDIR on *DEFINE_CURVE_TRIM_3D

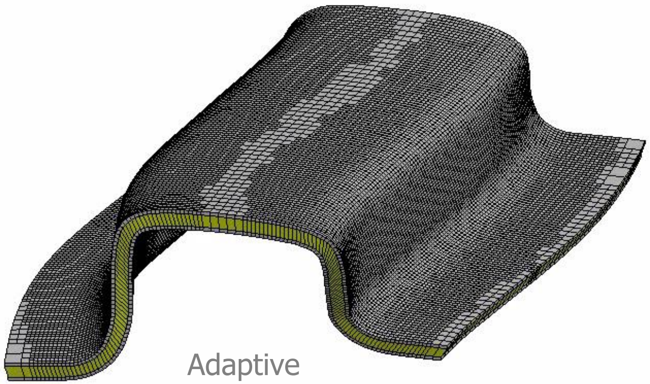


TDIR = 1:   trim curve near top surface
TDIR = -1:   trim curve near bottom surface

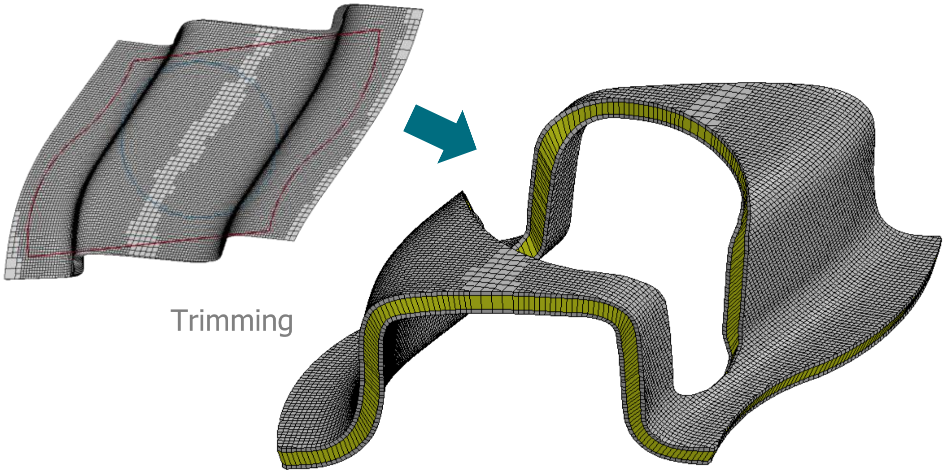


Sandwich sheets

- New features to treat shell-solid-shell models in metalforming
  - For sandwich structures such as metal sheets with polymer core layer
  - Option IFSAND on *CONTROL_ADAPTIVE for adaptive refinement
  - Trimming via *DEFINE_CURVE_TRIM_3D now supports solid elements and sandwiches



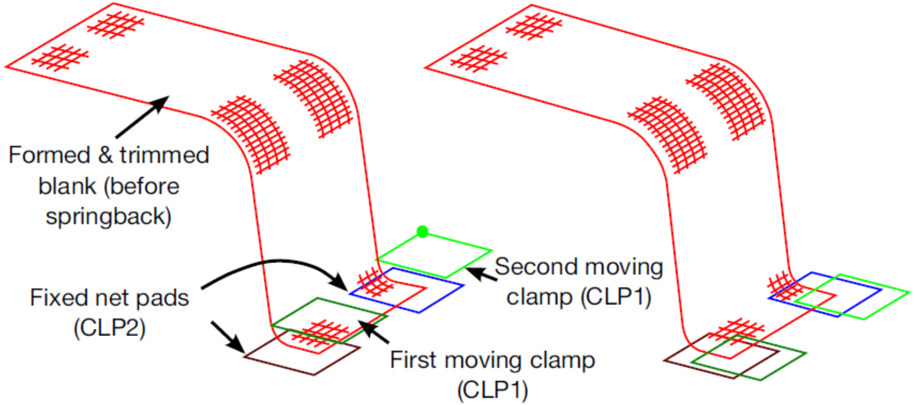
Adaptive refinement

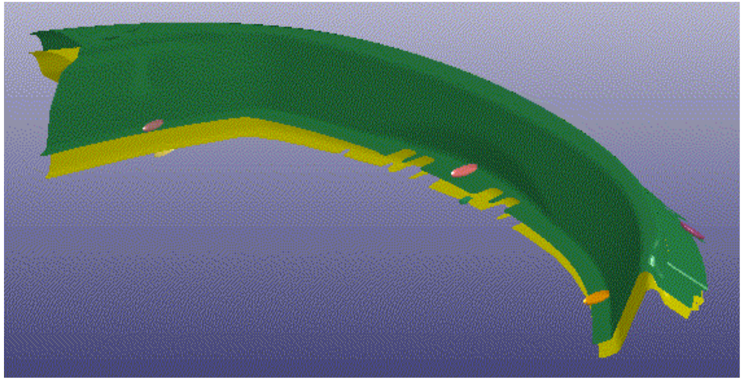


Trimming

Clamping simulation

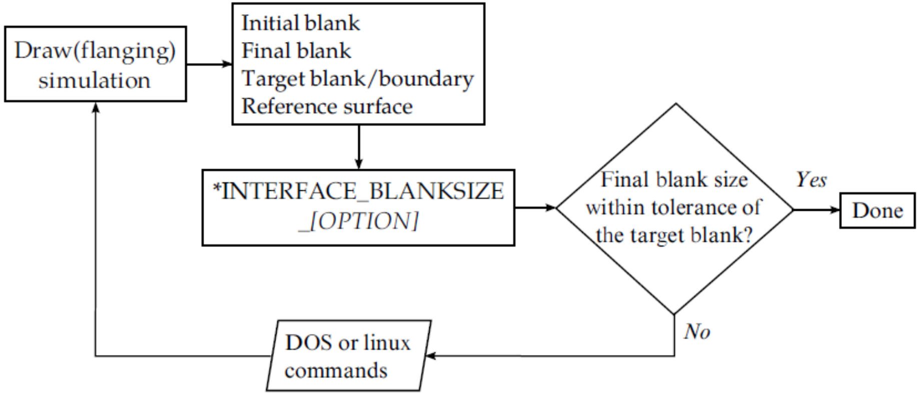
- New keywords *DEFINE_FORMING_CLAMP and *DEFINE_FORMING_CONTACT
  - Macros serving as placeholders for the combination of cards needed to model a clamping process
  - Eliminate the need to use auto-position cards between the formed panel and clamps
  - Prescribed motions are automatically (internally) assigned to the clamps
  - Simplifies the contact definition between the panel and the clamps

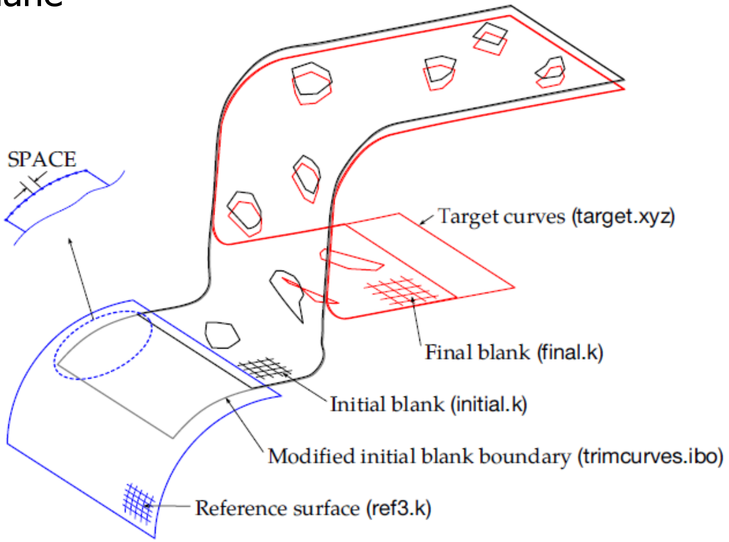




Blank size development

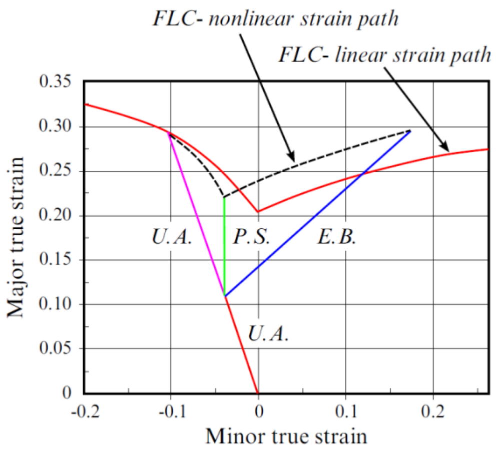
- New features for *INTERFACE_BLANKSIZE_DEVELOPMENT_...
  - SCALE_FACTOR allows user to include or exclude a target curve in the calculation of the initial curve. It also allows user to scale up or down in size of a target curve involved in the calculation.
  - SYMMETRIC_PLANE allows user to define a symmetric plane
  - and others…





More enhancements for forming

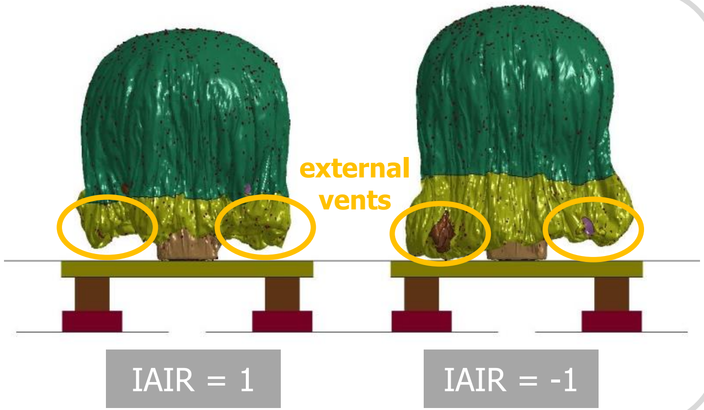
- Add a new keyword *CONTROL_FORMING_BESTFIT
  - This rigidly moves two parts so that they maximally coincide
- Improvements to springback compensations
  - e.g. output of new trimming curve format
- Improvements to *CONTROL_FORMING_AUTOCHECK
  - e.g. output rigid tool mesh in offset position
- Improvements to *CONTROL_FORMING_UNFLANGING
  - e.g. allow non-smooth flange edge
- Add formability index to *MAT_036, *MAT_037, *MAT_226
- Add a new material model *MAT_260 (2 forms)
  - *MAT_260A: "Stoughton non-associated flow"
  - *MAT_260B: "Mohr non-associated flow"



Airbags

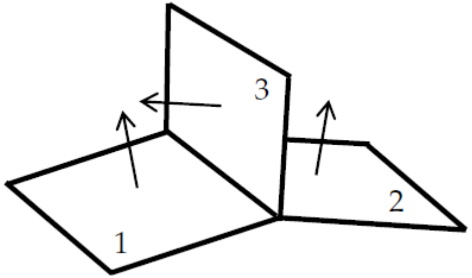
CPM for Airbag Modeling

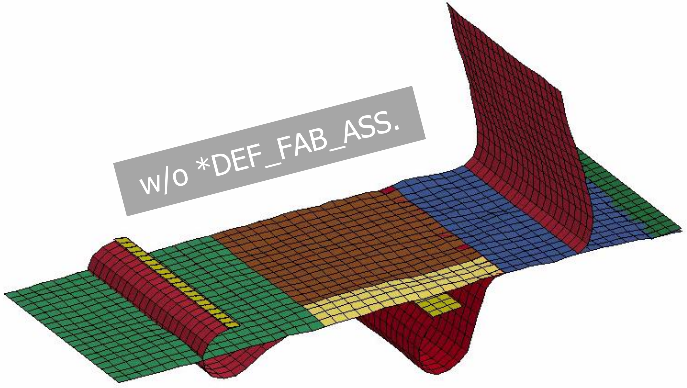
- Several enhancements and improvements
  - New option IAIR=-1 allows external vents to draw in outside air (if $p_{bag} < p_{atm}$)
  - Treat heat convection when chamber is defined
  - Allow IAIR=4 to gradually switch to IAIR=2 to avoid instability
  - Allow using shell to define inflator orifice
  - New feature to collect all ring vents into a single vent in order to correctly treat enhanced venting option
  - Support vent/fabric blockage for CPM and ALE coupled analysis
  - New option in *CONTROL_CPM to allow user defined smoothing of impact forces



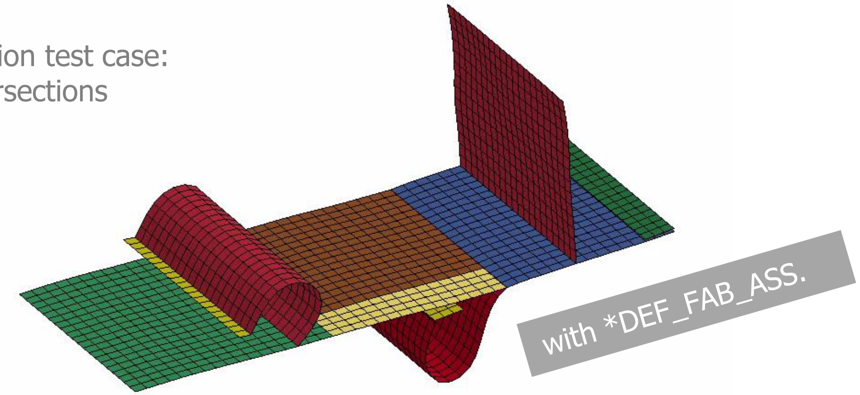
Fabric assemblies

- Proper treatment of bending of t-intersecting fabrics
  - New keyword *DEFINE_FABRIC_ASSEMBLIES
  - List of part sets to treat fabric bending between parts
  - Works with *MAT_FABRIC‘s optional coating feature (ECOAT, SCOAT, TCOAT)





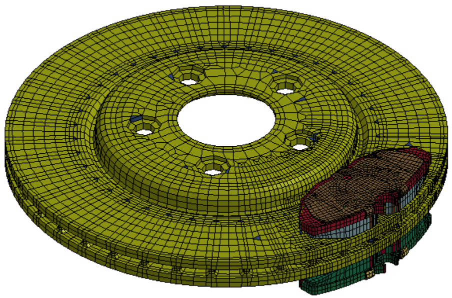
numerical verification test case:
various t-intersections



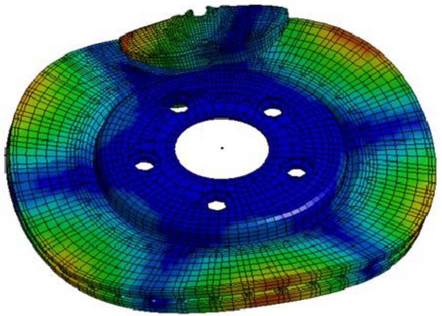
Implicit analyses

Brake squeal analysis

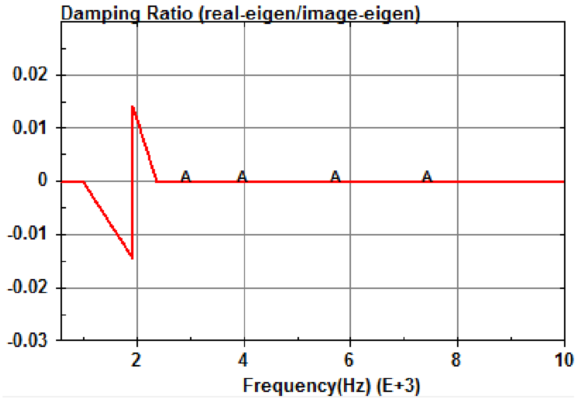
- Rotor dynamics application with *CONTROL_IMPLICIT_ROTATIONAL_DYNAMICS
  - Brake squeal noise as a result of friction-induced vibration
  - Intermittent eigenvalue analysis:
    combination of transient analysis and complex eigenvalue analysis (instability detection)
  - Pad-Disk contact (MORTAR) introduces non-symmetry to the stiffness matrix:
    LCPACK=3 on *CONTROL_IMPLICIT_SOLVER



Disk brake model

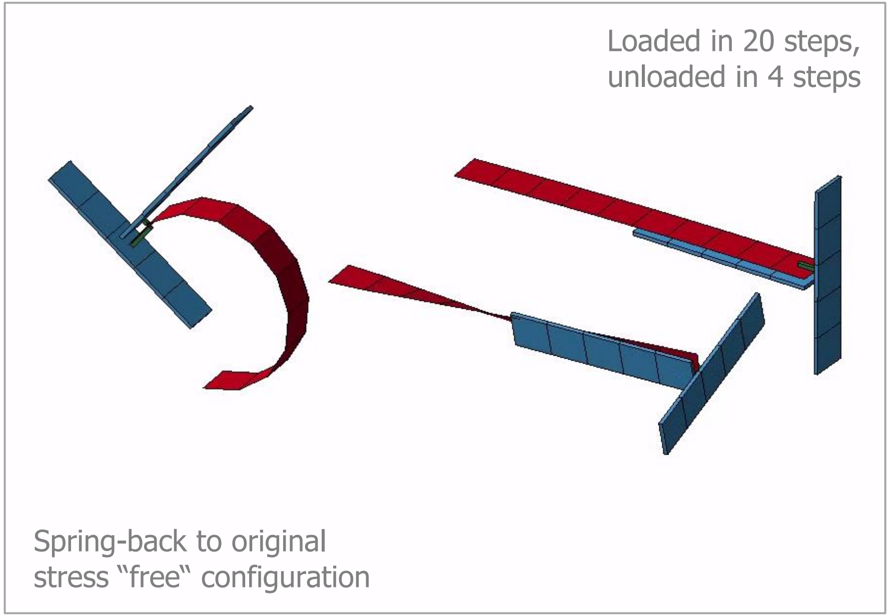


Resultant displacements at 2000 Hz



Implicit accuracy

- Implicit accuracy option IACC=1 on *CONTROL_ACCURACY
  - Larger implicit steps demand for stronger objectivity and higher accuracy
  - Higher accuracy in selected material models
    - Fully iterative plasticity
    - Tightened tolerances
  - Strong objectivity and consistency in selected tied contacts
    - Physical (only ties to DOFs that are ”real”) bending/torsion whenever applicable
    - Finite rotation
  - Strong objectivity and increased accuracy in selected elements
  - Finite rotation support for hypoelasticity



More enhancements for Implicit

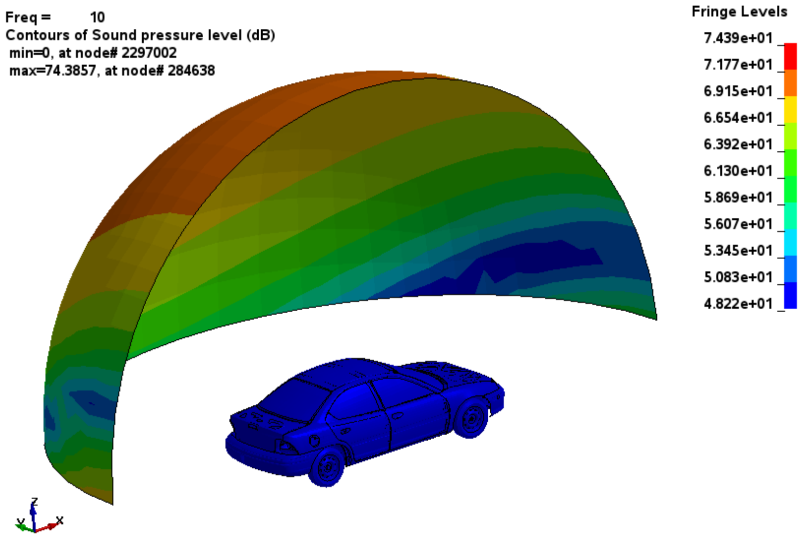
- Nonlinear implicit solver 12 is made default aiming for improved robustness
- Reduce symbolic processing time and cost of numerical factorization in MPP
  - Done by reuse of matrix reordering and prediction of non tied contacts
- Apply improvements to Metis memory requirements used in MPP
- Add coupling of prescribed motion constraints for Modal Dynamics by using constraint modes
- Several enhancements for matrix dumping (MTXDMP)
- Enhancements for implicit-explicit switching
  - e.g. time step adjustements, intermittent eigenvalue analysis, …
- Add support for *CONSTRAINED_LINEAR for 2D problems
- Bathe composite time integration implemented for increased stability and conservation of energy/momentum, see ALPHA on *CONTROL_IMPLICIT_DYNAMICS

4	5	6	7	8
TDYBIR	TDYDTH	TDYBUR	IRATE	ALPHA
F	F	F	I	F
0.0	10^{28}	10^{28}	0	0

Frequency Domain

Acoustic fringe plot

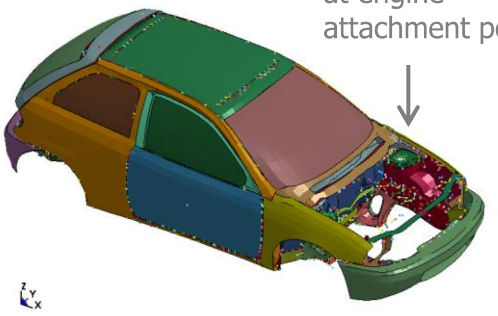
- New keyword *FREQUENCY_DOMAIN_ACOUSTIC_FRINGE_PLOT
  - Define field points for acoustic pressure computation and use D3ACS binary database to visualize the pressure distribution
  - Either for existing structure components … (PART, PART_SET, NODE_SET)
  - … or for automatically generated geometries (plate, sphere)
  - Results comprise real part, imaginary part, and absolute value of acoustic pressure as well as sound pressure level (dB)
  - Supported by LS-Prepost 4.2 and above



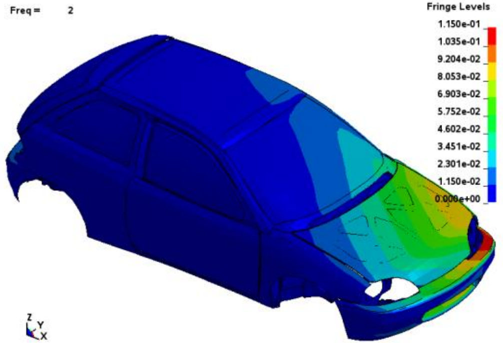
Equivalent Radiated Power (ERP) calculation

- New option _ERP for *FREQUENCY_DOMAIN_SSD
  - Fast and simplified way to characterize acoustic behavior of vibrating structures
  - Gives user a good look at how panels contribute to total noise radiation (valuable tool in early phase of product development)
  - Results are saved in binary plot database d3erp, and ASCII xyplot files ERP_abs and ERP_dB

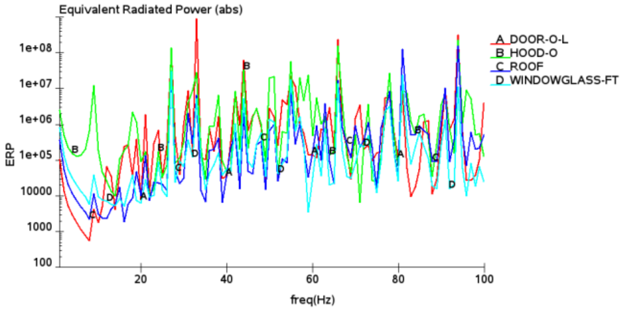
Nodal force applied at engine attachment point



ERP density (d3erp)



contribution to the radiated noise from each panel

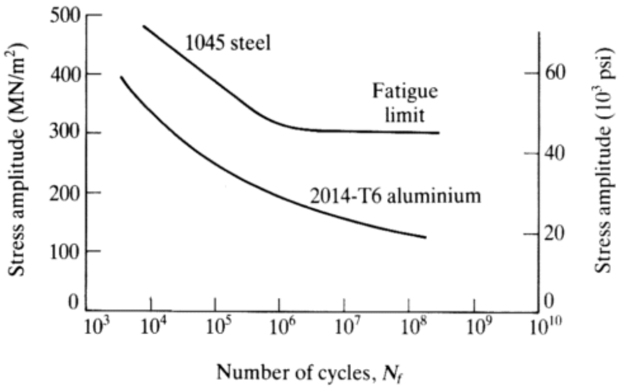


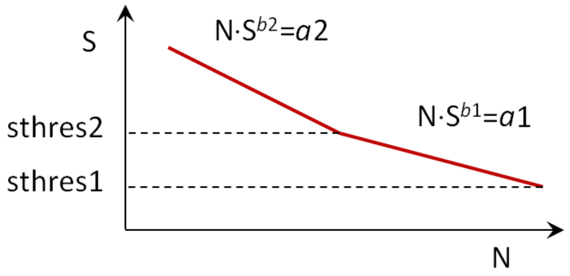
S-N fatigue curves

- New options for *MAT_ADD_FATIGUE
  - Implemented multi slope SN curves to be used in random vibration fatigue (*F_D_RANDOM_VIBRATION_FATIGUE) and SSD fatigue (*F_D_SSD_FATIGUE)
  - Modular use with other material models
  - Either with *DEFINE_CURVE
  - Or typical equations:

$$N\,S^b = a$$

$$\log(S) = a - b\log(N)$$





MPP

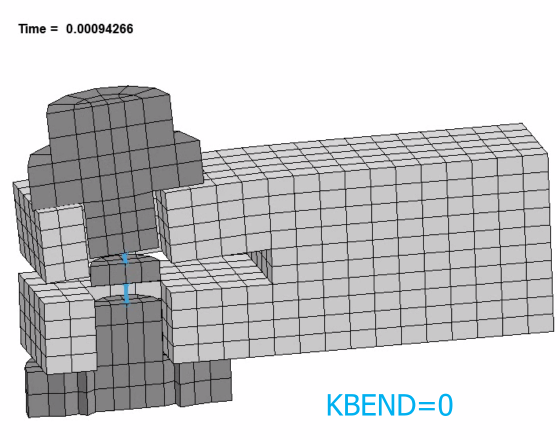
MPP related enhancements

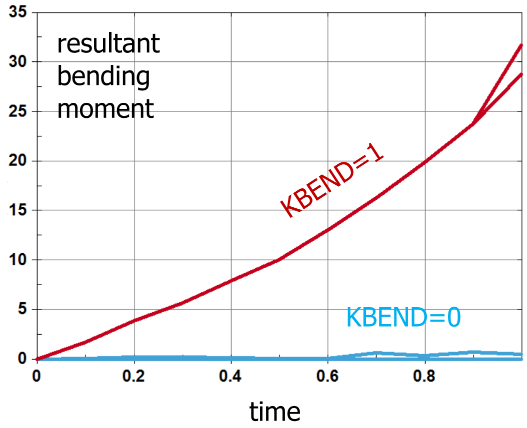
- Output two csv files for user to check MPP performance:
  - load_profile.csv: general load balance
  - cont_profile.csv: contact load balance
- The following decomposition related keywords now have a _LOCAL option:
  - *CONTROL_MPP_DECOMPOSITION_PARTS_DISTRIBUTE_LOCAL
  - *CONTROL_MPP_DECOMPOSITION_PARTSET_DISTRIBUTE_LOCAL
  - *CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS_LOCAL
  - *CONTROL_MPP_DECOMPOSITION_CONTACT_DISTRIBUTE_LOCAL
- memory2=… option on *KEYWORD line
- Allow user to control decomp/distribution of multiple airbags using *CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS

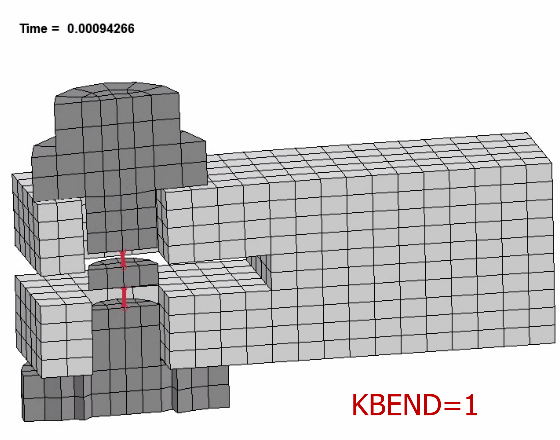
Miscellaneous

Bending stiffness of pre-stressed bolts

- New option KBEND on *INITIAL_AXIAL_FORCE
  - With KBEND=1, bending stiffness is retained in beam elements that have prescribed axial force
  - Uses appropriate modification at each integration point such that the resultant axial force is correct, but the stress gradient remains unchanged
  - Recommended in general

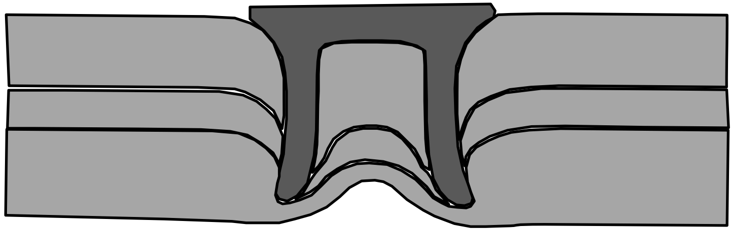


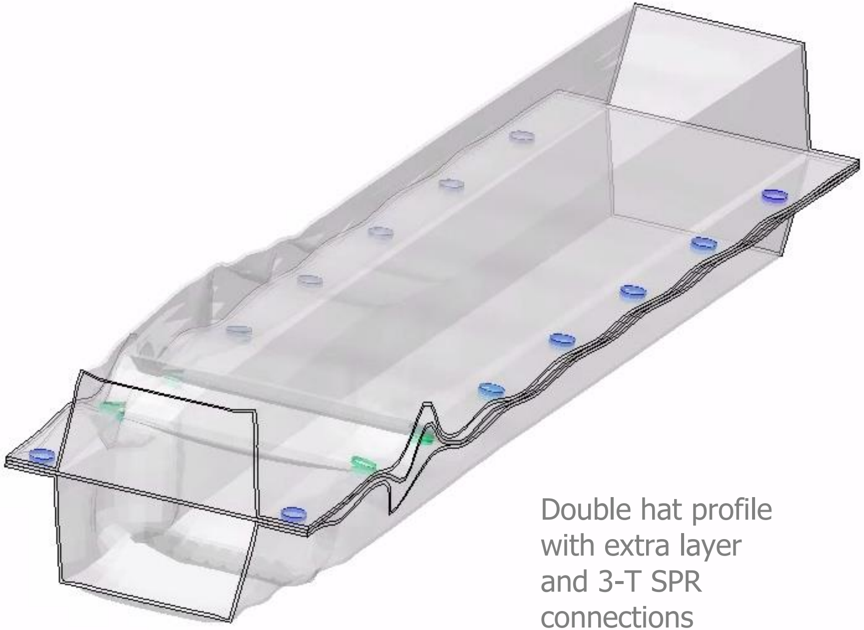




Multi-sheet SPR

- New option for *CONSTRAINED_SPR2
  - Multi-sheet connection for self-piercing rivets
  - Before: only 2 parts (master and slave)
  - Now: up to 4 additional “extra parts“
  - Question about interdependence of connections and reproduction of experimental results remains open

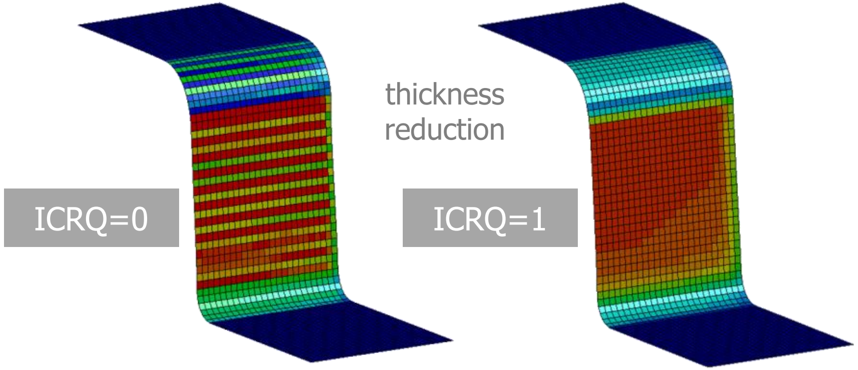


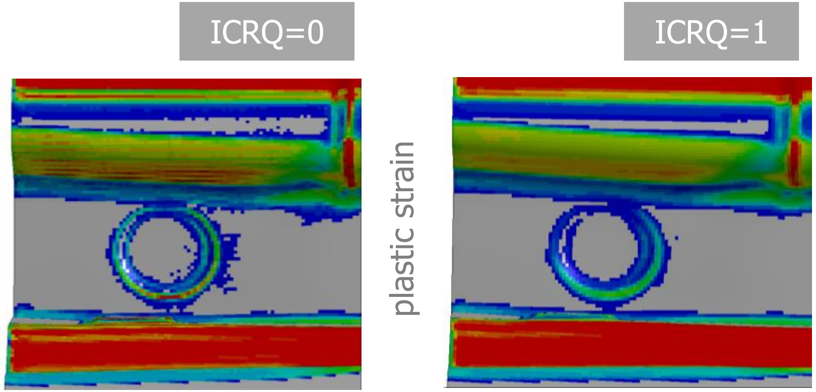


Double hat profile with extra layer and 3-T SPR connections

Continuous result quantities

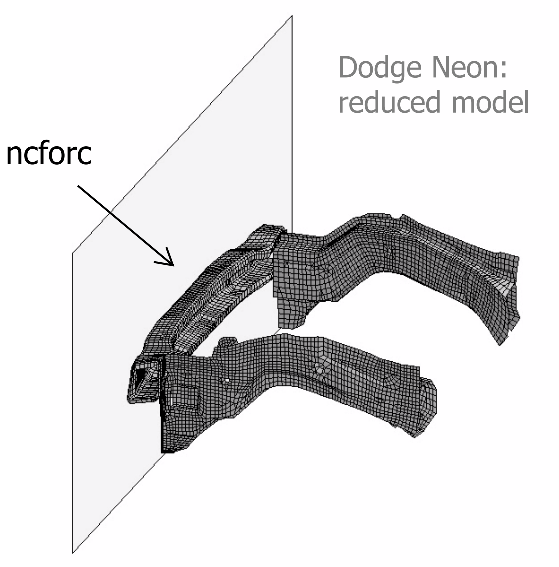
- New option ICRQ on *CONTROL_SHELL
  - Continuous treatment of thickness and plastic strain across element edges for shell element formulations 2, 4, and 16 with max. 9 integration points through the thickness
  - Similar to MAT_NONLOCAL, but only direct neighbors are used for node-based smoothing
  - Reduces alternating weak localizations sometimes observed in metal forming applications when shell elements get stretch-bended over small radii

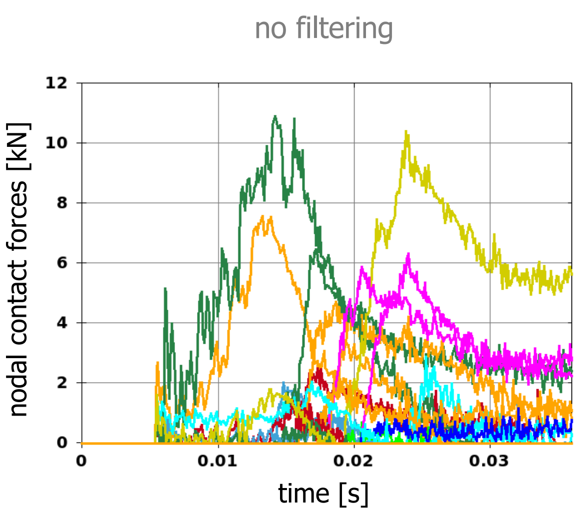


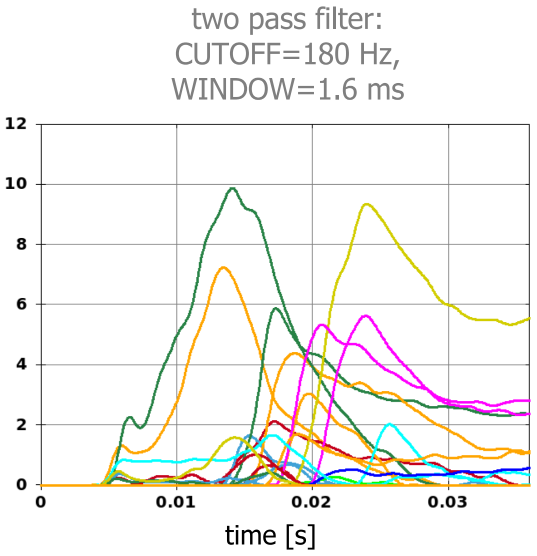


Results filtering

- New options for *DATABASE_BINARY_D3PLOT and *DATABASE_NCFORC
  - Single pass or double pass Butterworth filtering to smooth the output
  - Input parameters are time interval between filter sampling, frequency cut-off, window width

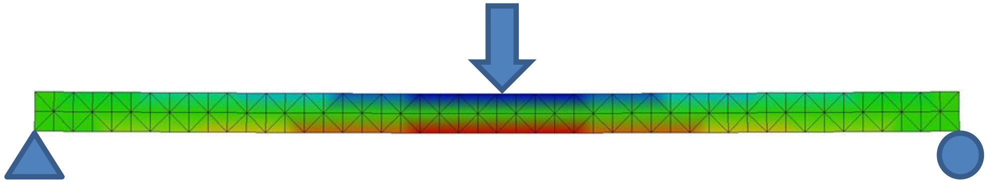






Stress result recovery

- New keyword *DATABASE_RECOVER_NODE
  - Recovers stresses at nodal points by using Zienkiewicz-Zhu's Superconvergent Patch Recovery
  - Available for solid and thin shell elements
  - "x/y/z-Acceleration" in LS-Prepost will be replaced by selected stress measures
  - Generally improves quality of results (accuracy)



Single span beam with concentrated load

Maximum axial stress results

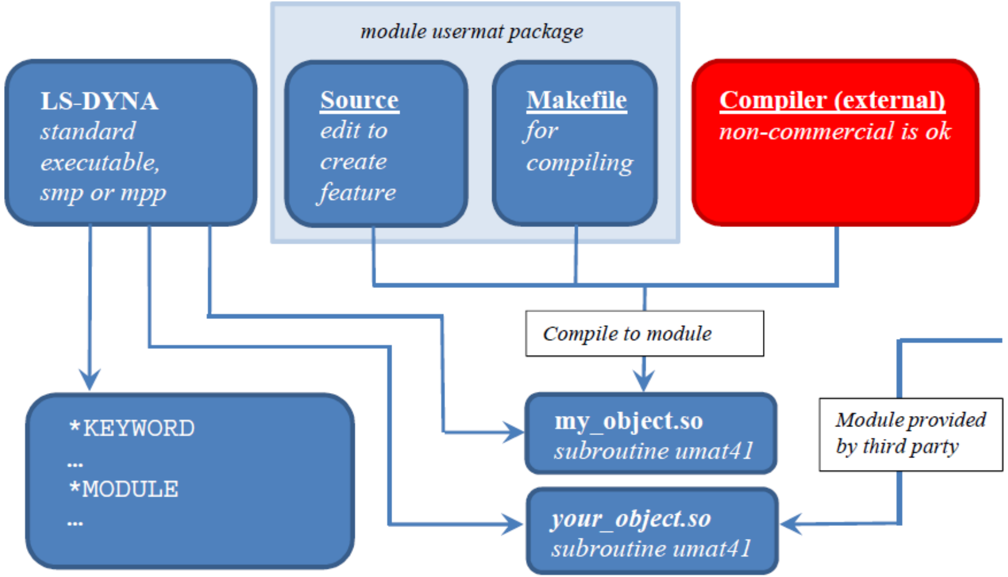
analytical: 6.0

element-based: 5.19 (error = 13.5 %)

recovered node based: 5.96 (error = 0.7 %)

Module Concept for User Defined Features (UDF)

- Shared object approach and new keyword *MODULE
  - To facilitate working with UDFs in that the content of the usermat package is reduced, replaced by *MODULE
  - To enhance flexibility when incorporating features delivered as shared objects by third parties
  - *MODULE_PATH: specify multiple paths (directories)
  - *MODULE_LOAD: load dynamic library (file name)
  - *MODULE_USE: define rules for mapping user subroutines to the model



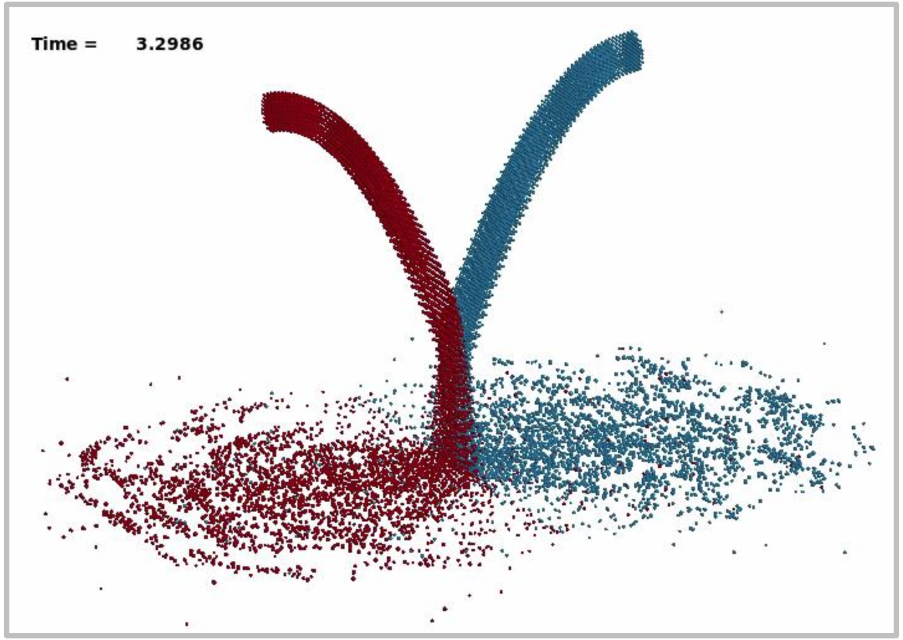
Miscellaneous

- Add ability to specify unique values **LCINT for each curve**
- Add new input check for **quality of rediscretized curves**
- Add new option ***INTERFACE_SPRINGBACK_EXCLUDE** to exclude selected portions from the generated dynain file
- Add ***NODE_THICKNESS** to override usual shell nodal thickness
- Add options MIRROR and POS6N to ***DEFINE_TRANSFORMATION**
- The DELFR flag in *CONTROL_SHELL has new options for controlling **deletion of elements**
- New option ICOHED of *CONTROL_SOLID to control **cohesive element erosion** when neighboring (nodewise connected) shell or solid elements fail
- New keyword ***CONSTRAINED_RIGID_BODY_INSERT** for modeling ”die inserts”
- Add **Rayleigh damping** (*DAMPING_PART_STIFFNESS) for thick shell formulations 1, 2, 6

Meshfree methods

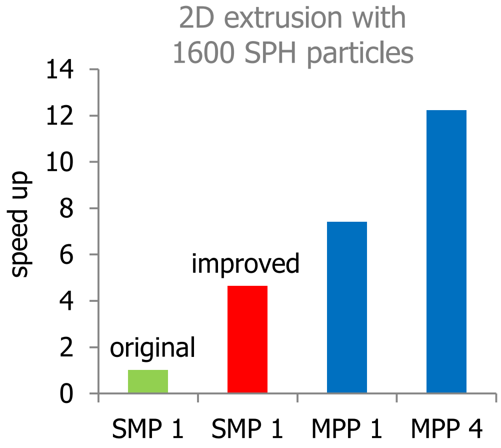
SPH particles injection

- New keyword *DEFINE_SPH_INJECTION
  - Injection of SPH elements automatic generation of SPH particles
  - Multiple injection planes
  - User defined injection speed & area
  - Birth and death times
  - e.g. for filling simulations



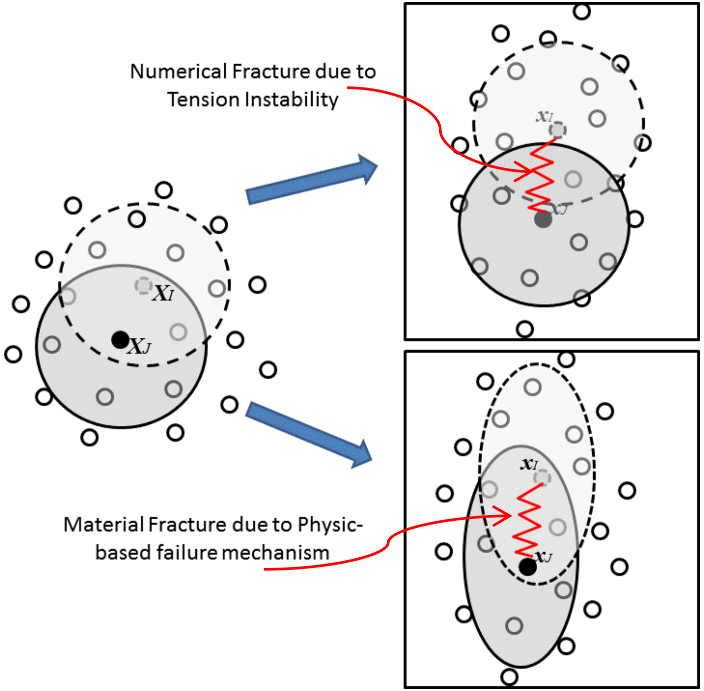
More SPH enhancements

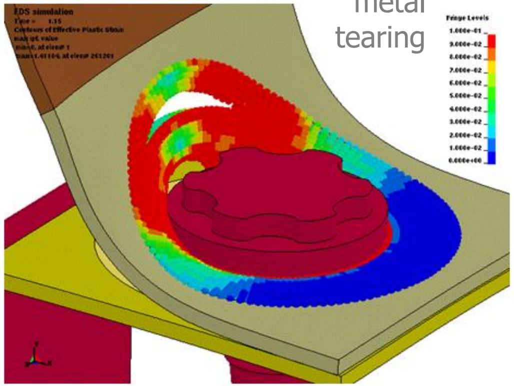
- Several new features and improvements, e.g.
  - *DEFINE_ADAPTIVE_SOLID_TO_SPH now supports 2D
  - New bucket sort algorithm for *CONTACT_2D_NODE_TO_SOLID
  - Add support for materials 98, 181, 275
  - Add support for OSU=1 (objective stress update)
  - Output contact forces between SPH parts into sphout



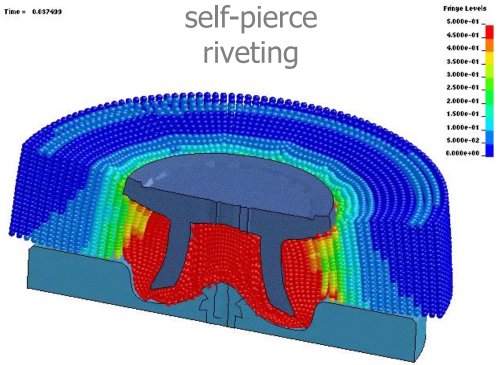
Smoothed Particle Galerkin (SPG)

- Improved physical material fracture
  - Related keyword is *SECTION_SOLID_SPG
  - The dilation parameters of SPG Eulerian kernel are automatically adjusted according to the local material deformation to prevent tensile instability





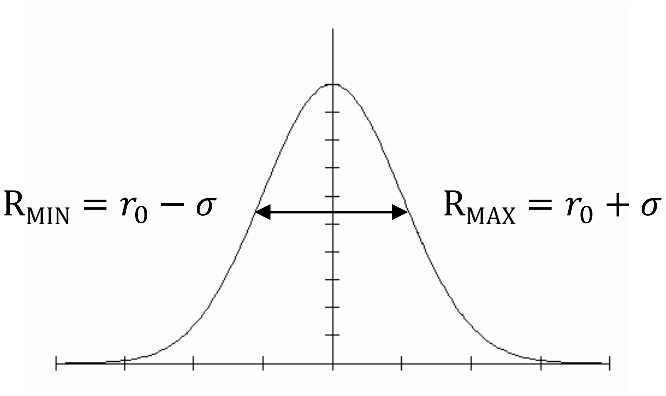
metal tearing

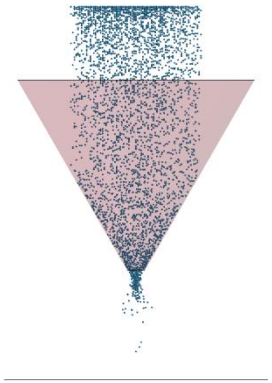


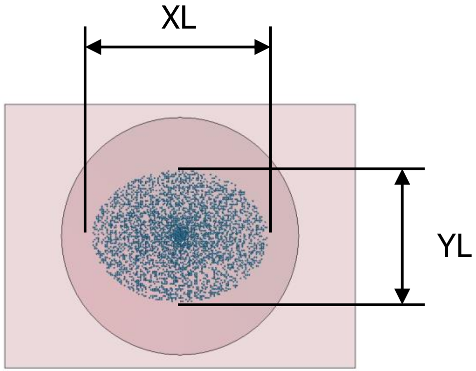
self-pierce riveting

Discrete Elements (DEM): injection

- New options for *DEFINE_DE_INJECTION
  - Gauss distribution of newly generated particles
  - Option _ELLIPSE to define an elliptical injection region

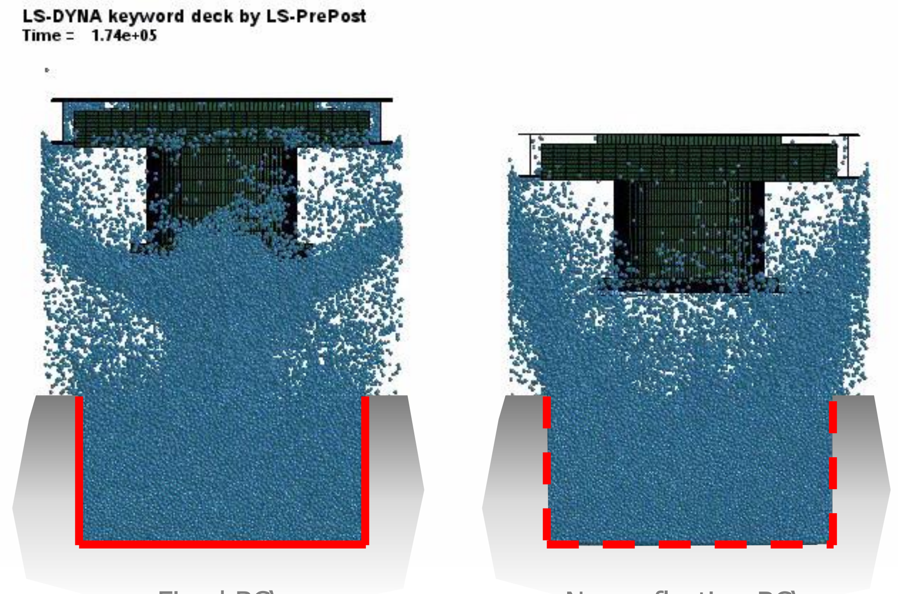






DEM: non-reflecting boundaries

- New keyword *BOUNDARY_DE_NON_REFLECTING
  - Non-reflecting boundary conditions for discrete element spheres
  - Used on the exterior boundaries of an analysis model of an infinite domain, such as a half-space
  - Prevents artificial stress wave reflections generated at the model boundaries from reentering the model and contaminating the results
  - Example: soil buried explosion →

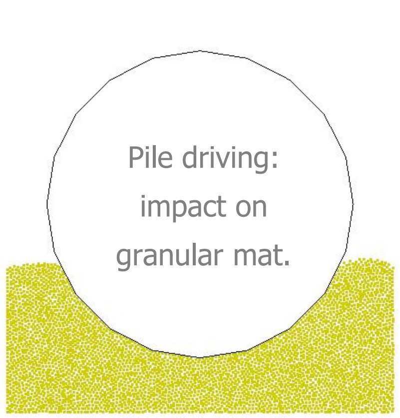


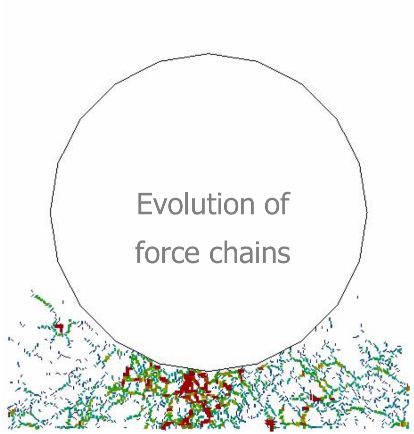
Fixed BC's

Non-reflecting BC's

DEM: output enhancements

- New result quantities for binary and ascii databases
  - Stress, force, pressure, density, force chain, and damage to d3plot
  - Porosity, void ratio, stress, pressure, and density to demtrh (*DATABASE_TRACER_DE)
  - Corresponding values are evaluated for representative volume element (RVE) defined by DE tracer



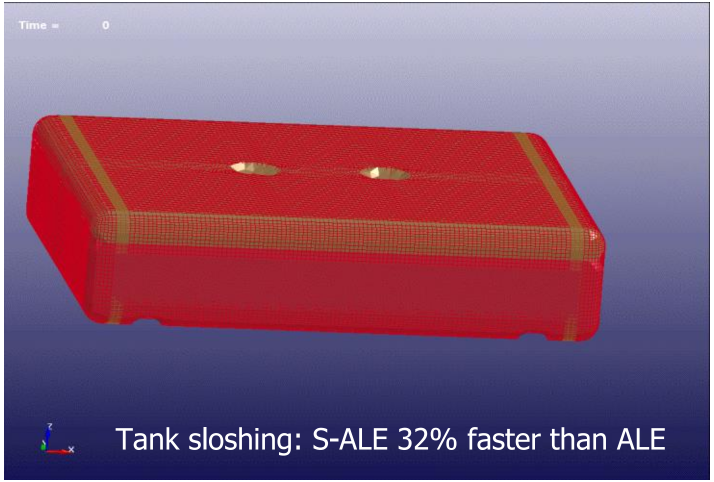


"A force chain consists of a set of particles within a compressed granular material that are held together and jammed into place by a network of mutual compressive forces"

ALE / S-ALE

Structured ALE solver (S-ALE)

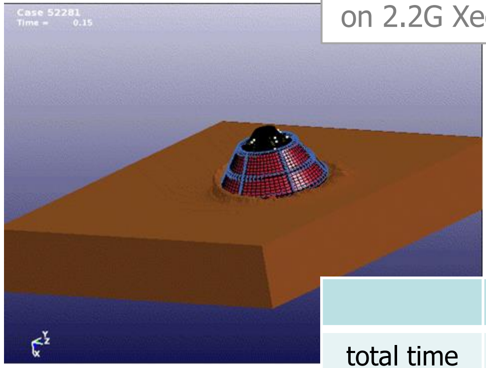
- Newly implemented scheme for Arbitrary Lagrangian Eulerian method
  - Same theory: advection (remapping), interface reconstruction, FSI - coupling to Lagrange structure
  - Different Implementation: new automated mesh generation, much more compact solver, time saving in searching and sorting, stable and user-friendly
  - Structured ALE mesh automatically generated by *ALE_STRUCTURED_MESH
  - SMP, MPP, MPP-Hybrid supported:
    Redesigned algorithm enabled SMP parallelization
    Enhancement on MPP efficiency
  - Documents, Tutorials, Examples on
    http://ftp.lstc.com/anonymous/outgoing/hao/sale



Tank sloshing: S-ALE 32% faster than ALE

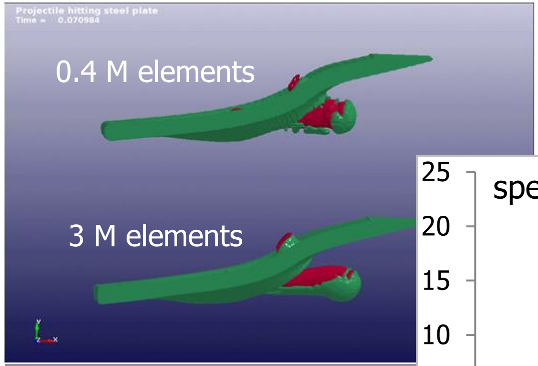
Structured ALE solver (S-ALE)

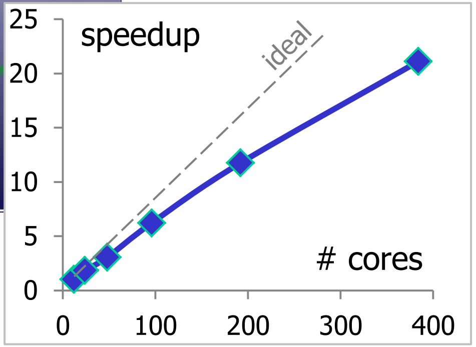
- Newly implemented scheme for Arbitrary Lagrangian Eulerian method
  - Applications: AWG/Orion problem (left) and oblique long rod penetration (right)



MPP single precision 12 cpu run
on 2.2G Xeon E5-4640 cluster

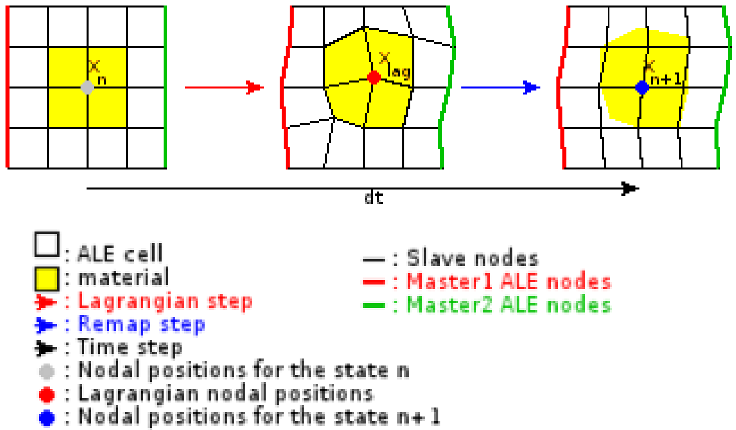
	ALE	S-ALE
total time	25,276 s	14,204 s
advection	11,140 s	5,350 s
FSI	5,746 s	3,983 s
memory	34M	23M

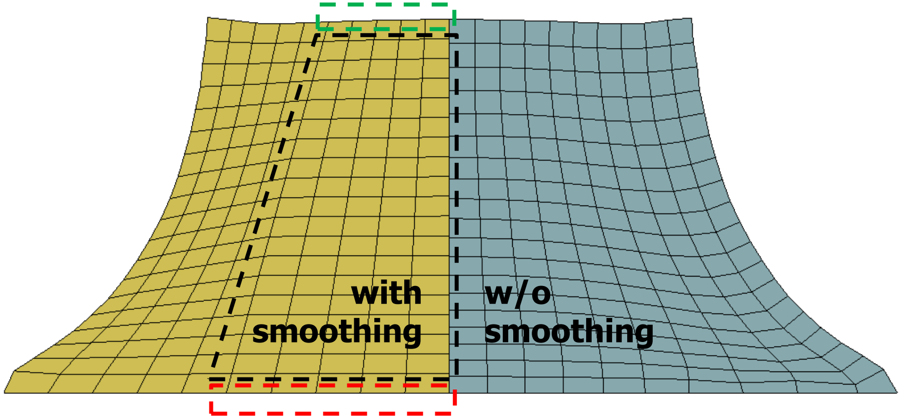




ALE interpolation smoothing

- New keyword *ALE_SMOOTHING for higher mesh quality
  - Smoothing constraint keeps ALE slave nodes at their initial parametric locations between other ALE nodes. If these nodes are not ALE nodes, the slave node has to follow their motion.
  - Supported for ALE solids, ALE shells, and ALE beams

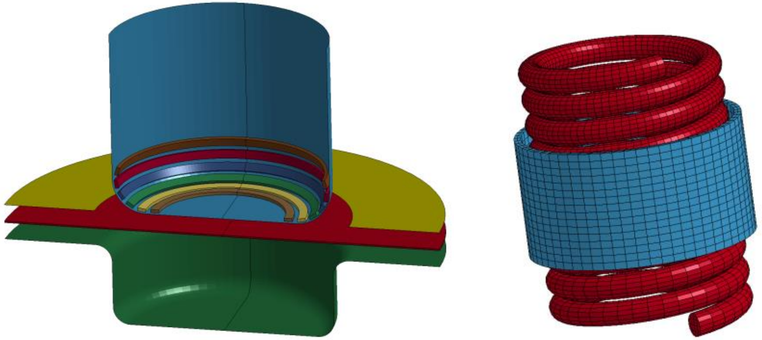


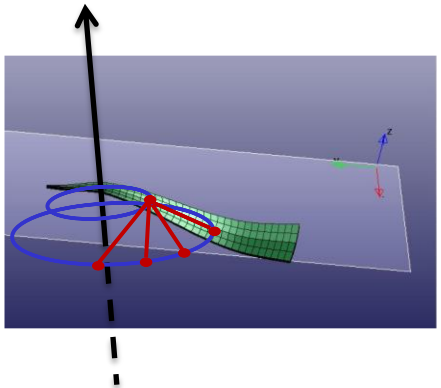


Electromagnetics

Electromagnetics: 2D axisymmetric solver

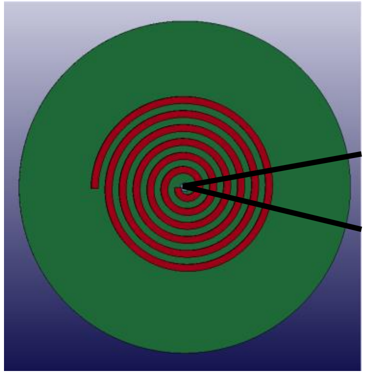
- Motivation and Overview
  - Many EM models are (quasi) axisymmetric: geometries have cylindrical invariance (coils, field shapers, …)
  - Introduction of EM 2D axisymmetric solver to save computation time
  - EM 2D coupled with mechanics and thermal 3D
  - User needs to provide a 3D mesh with rotational invariance
  - Coupled with 3D mechanics and thermal, hence all the 3D features of LS-DYNA are available
  - EM solved by combined FEM + BEM (as in 3D)
  - The simulation can be done on a slice of the full 360°, with suitable mechanical and thermal boundary conditions

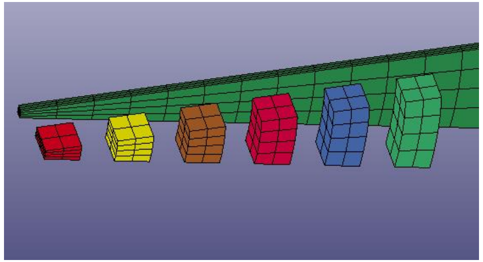




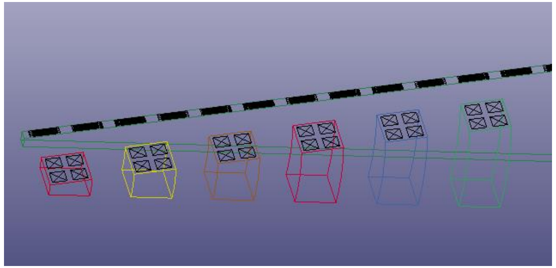
2D axisymmetric EM solver

- How to set up a 2D axisymmetric case
  - New keywords *EM_2DAXI, *EM_CIRCUIT_CONNECT, *EM_ROTATION_AXIS





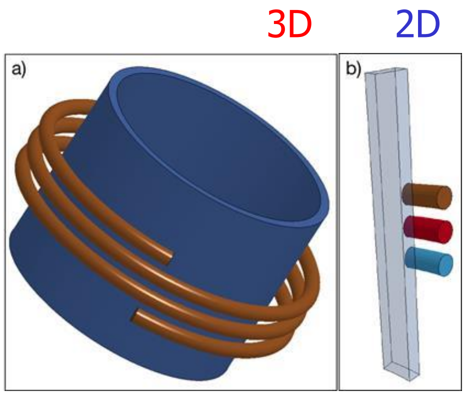
Slice of the full 360° mesh



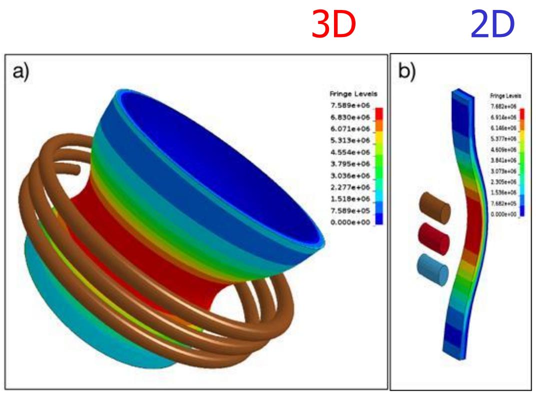
Define mechanical/thermal boundary conditions and electromagnetic properties

2D axisymmetric EM solver

- Comparison with 3-dimensional EM solver
  - Forming of a tube with a helix coil
  - 2D much faster, but same accuracy

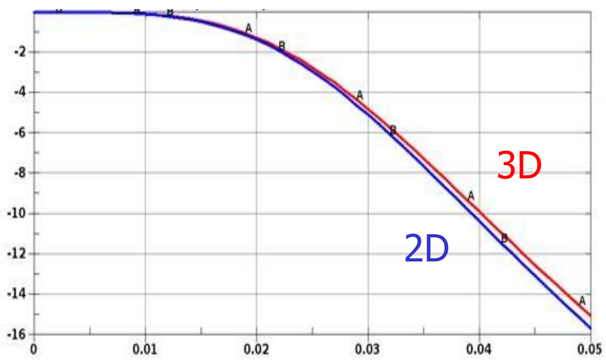


Setup for ring expansion



Current density distribution

Max. displacement vs time



Computation time

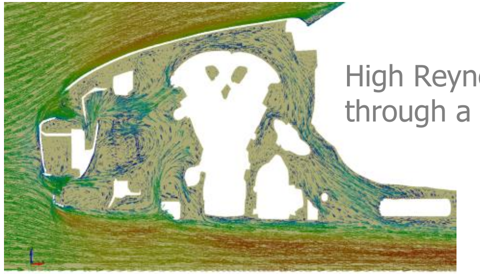
3D: 2 hours on 24 cores

2D: 5 minutes on 1 core

CFD & FSI

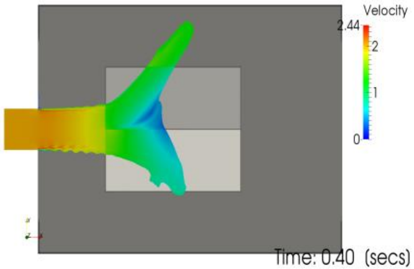
Flow in Porous Media

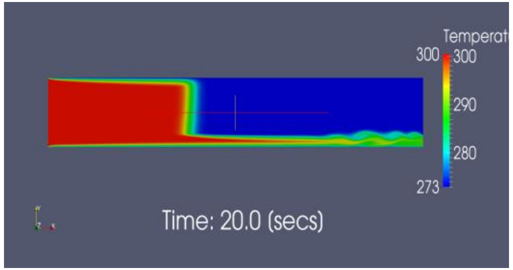
- New features for porous media simulations
  - Choose between anisotropic Navier-Stokes model and Darcy-Forcheimer model as porous media solver via *ICFD_CONTROL_SOLVE
  - Added new porous media models for *ICFD_MODEL_POROUS, e.g. depending on anisotropy and permeability



High Reynolds Flow through a car radiator

Mold filling analysis

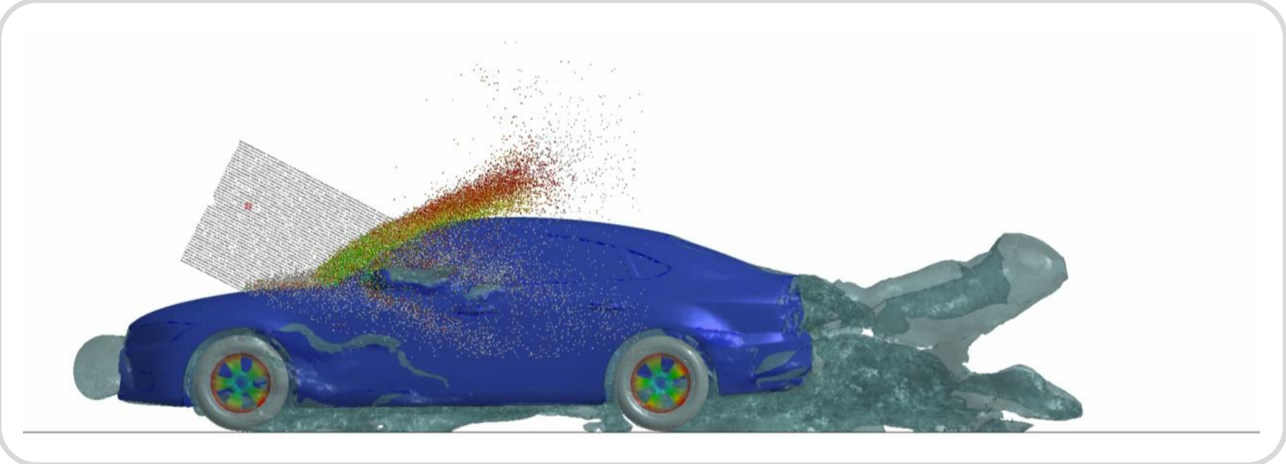


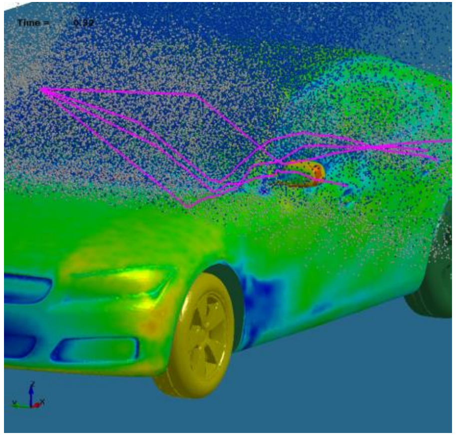


Heat transfer in a hybrid channel

Coupling with Discrete Elements

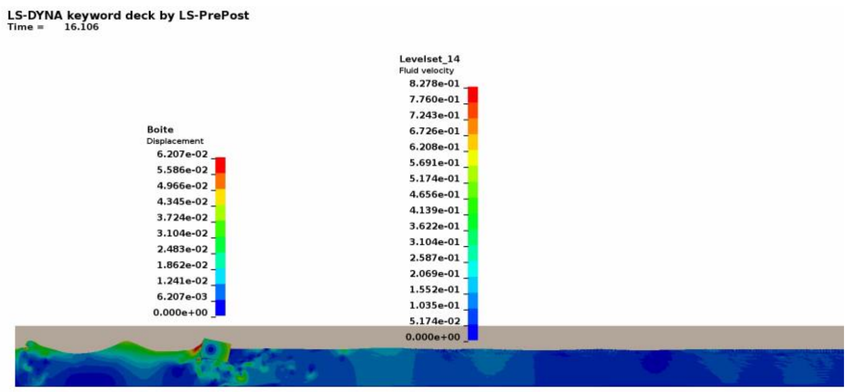
- New keyword *ICFD_CONTROL_DEM_COUPLING
  - One-way or two-way coupling between the fluid and the solid particles
  - Allows wide range of applications that include erosion, fracture and particle interaction
  - Example: Water management, rain simulation

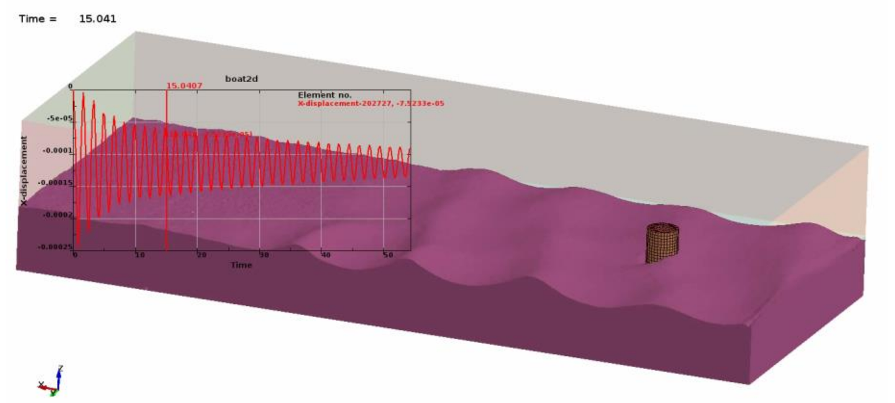




Free surface wave generation

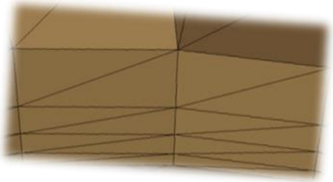
- New inflow boundary condition for wave generation
  - With new keyword *ICFD_BOUNDARY_FSWAVE
  - 1st order Stokes waves with free surface
  - Definition of wave amplitude, wave length, and wave incidence angle





More CFD enhancements

- Added new features for *ICFD_CONTROL_TURBULENCE
  - e.g. new turbulence sub-models (Realizable k-epsilon, Standard Wilcox 98/06, SST Menter 2003)
- New keyword *MESH_BL
  - Define a boundary-layer mesh as a refinement on the volume mesh
  - Constructed by subdividing elements near the surface



- New keyword *ICFD_MODEL_NONNEWT
  - Added a few models for non newtonian materials and temperature dependant viscosity, i.a. power law, Carreau, Cross, Herschel-Bulkley, Sutherland, …
- New option _VOL for *ICFD_DATABASE_DRAG
  - For computing pressure forces on volumes ID
    (useful for forces in porous domains),
    output in icfdragivol.dat and icfdragivol.#VID.dat

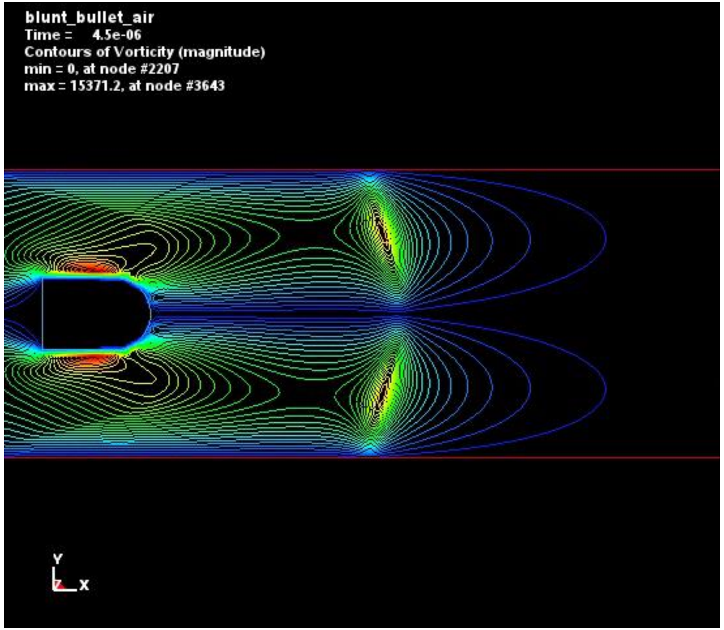
CESE

Compressible CFD Solver (CESE)

- New energy conservative conjugate heat transfer method
  - Standard conjugate-heat transfer (CHT) methods for compressible flows do not conserve energy, this leads to time-dependent errors in such simulations.
  - A class of new energy-conservative conjugate-heat transfer (CHT) methods for compressible flows has been developed recently (Radenac et al. 2014).
  - Now implemented in 3 different sets:
    1) Fixed mesh (both structure and fluid) CESE Navier-Stokes solvers.
    2) Moving mesh CESE Navier-Stokes FSI solvers.
    3) Immersed boundary method (IBM) Navier-Stokes FSI solvers
  - Unique features include:
    - A unified treatment of space and time
    - The introduction of the conservation element and the solution element as a vehicle for enforcing space-time flux conservation, locally and globally.
    - A novel shock capturing strategy without a Riemann solver.
    - Unlike conventional schemes, flow variables and their derivatives are solved simultaneously.

Compressible CFD Solver (CESE)

- New energy conservative conjugate heat transfer method
  - Advantages
    - Permits CESE to maintain its energy conservation property
    - Efficient: the boundary condition remains local
    - Robust: fluid and structure solutions advance independently, with the heat flux being accumulated to pass to the structural thermal solver



- Example: 2D Blunt bullet problem
  - Fluid vorticity

First stable release of R9

Bug fixes

- A wide range of code corrections, inter alia,
  - Correct calculation of wrap angle in seatbelt retractor
  - Fixed thick shell forms 3 and 5 when used in implicit solutions with non-isotropic materials
  - Fix possible issue related to constrained contacts in MPP implicit not initializing properly
  - Fixed stress initialization (*INITIAL_STRESS_SECTION) for type 13 tetrahedral elements
  - Fix for the combination of type 13 tet elements and *INITIAL_STRESS_SOLID
  - Fixed issues involving *LOAD_THERMAL_D3PLOT
  - Fixed the TRUE_T option on *MAT_100 and *MAT_100_DA
  - Correct/improve material tangent for *MAT_181 with PR>0 (foam option)
  - Fix for D3PLOT output of very large data sets in single precision
  - Fixes for writing and reading of dynain data in LSDA format
  - Fix thick shells stress/strain output to dynain
  - Fix a bug that occurs when *DEFINE_BOX is included by *INCLUDE_TRANSFORM
  - …

… find more in release notes:

http://www.dynasupport.com/news/ls-dyna-r9.0.1-r9.109912-released

Conclusion: LS-DYNA R9.0.1

- Newest release contains variety of new features
- Recommended for multiphysics and implicit analyses or if new options are needed
- R9 Keyword User‘s Manual can be downloaded from www.dynamore.de/en/downloads/manuals