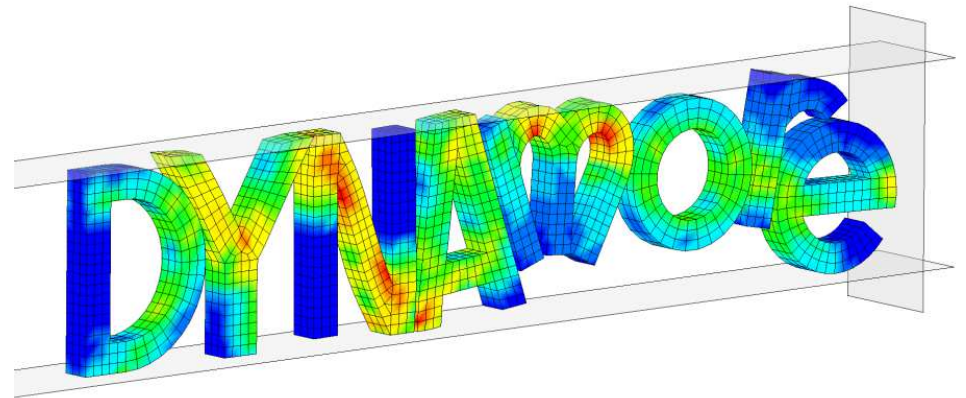


# New Features in LS-DYNA R8.1 for Structural Mechanics

Tobias Erhart, Bamberg, October 11, 2016

- Release R8.1 published in February 2016
- This presentation about major changes since R7.1.3 in the area of solid structural mechanics
- Comprehensive list of enhancements and corrections in [www.dynasupport.com/news/ls-dyna-r8.0.0-r8.95309-released](http://www.dynasupport.com/news/ls-dyna-r8.0.0-r8.95309-released)  
[www.dynasupport.com/news/ls-dyna-r8.1.0-r8.105896-released](http://www.dynasupport.com/news/ls-dyna-r8.1.0-r8.105896-released)



# LS-DYNA versions

## ■ Version numbering scheme

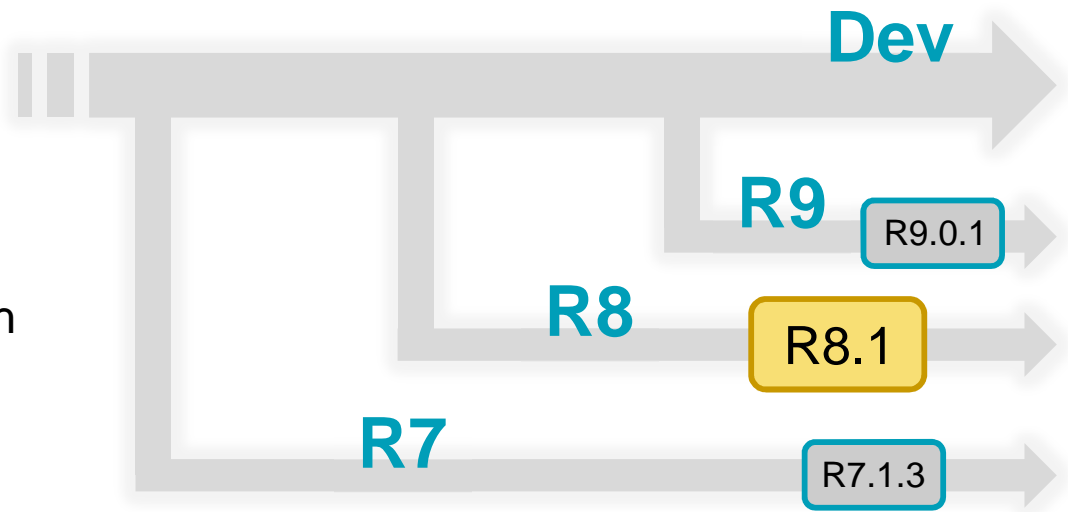
- Major branches called R6, R7, R8, R9, ...
- Official releases such as R6.1.2, R7.1.3

## ■ Robust production version

- Release R7.1.3 from May 2016 (R7.1 branch in 9/2013)
- Recommended for daily use in crash and occupant simulation

## ■ Latest official versions

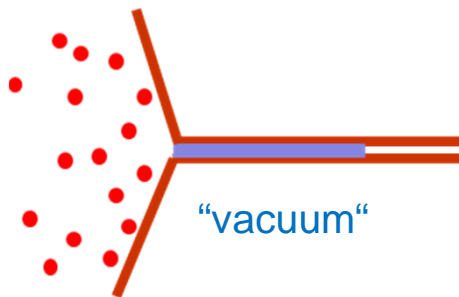
- Release R8.1 from February 2016: New features shown in this presentation
- Release R9.0.1 from August 2016: contains all R8.1 changes + many more  
→ to be presented soon (Webinar)
- Recommended for multiphysics and implicit analyses or if new options are needed



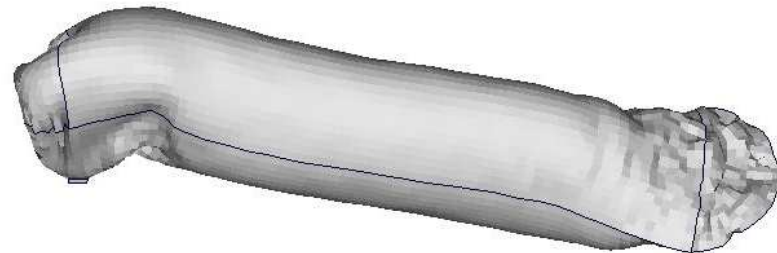
## \*AIRBAG\_PARTICLE

backported  
to R7.1.3

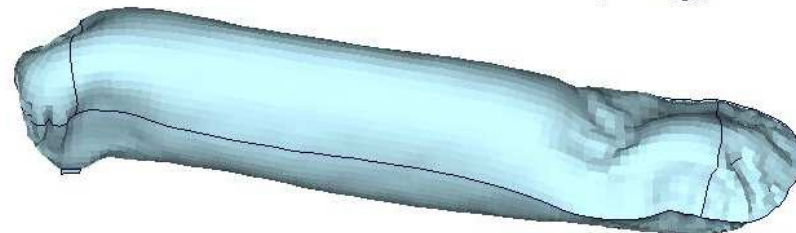
- New initial gas option IAIR=4 enables a special logic to treat the region mixed with air and inflator particles.
  - Initial air particles are used in gas front tracking algorithm and do not apply force to the collided segment. Instead, uniform pressure will be applied to it based on the ratio of air and inflator particles.
- Improves results for tight rolled curtain airbags: fast deployment



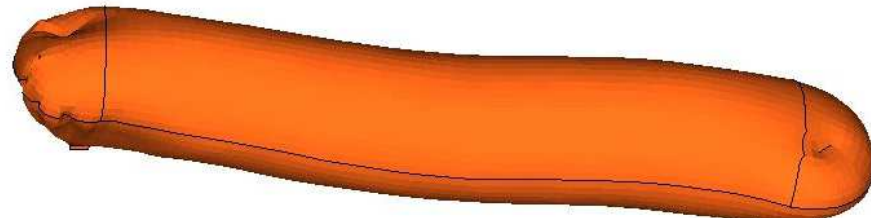
IAIR = 1



IAIR = 2



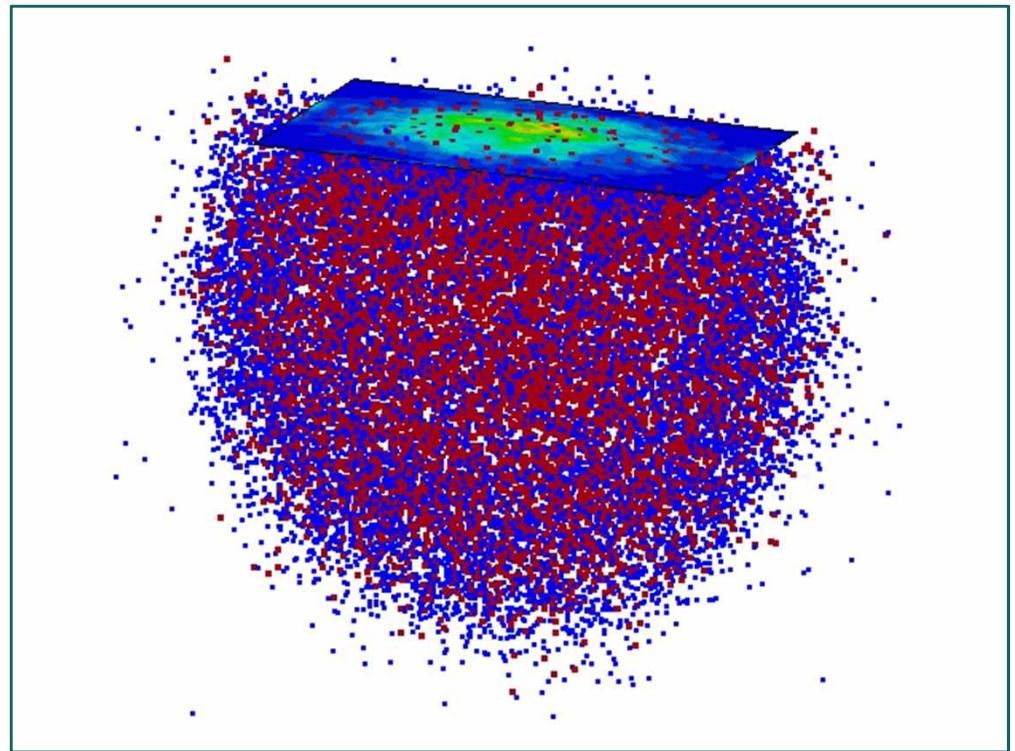
IAIR = 4



# Blast simulations

- Solid part or solid part set is now allowed for \*PARTICLE\_BLAST
- Add ambient pressure boundary condition flag BC\_P for \*PARTICLE\_BLAST
- Activate previously inactive death time BTEND for \*PARTICLE\_BLAST
- New command \*DEFINE\_PBLAST\_GEOMETRY allows the high explosive domain for \*PARTICLE\_BLAST to be defined by various geometric shapes
- Allow multiple \*PARTICLE\_BLAST definitions
- Add \*DATABASE\_PBSTAT to output particle blast statistics

clamped plate subject to the combined effect of blast and soil impact loading



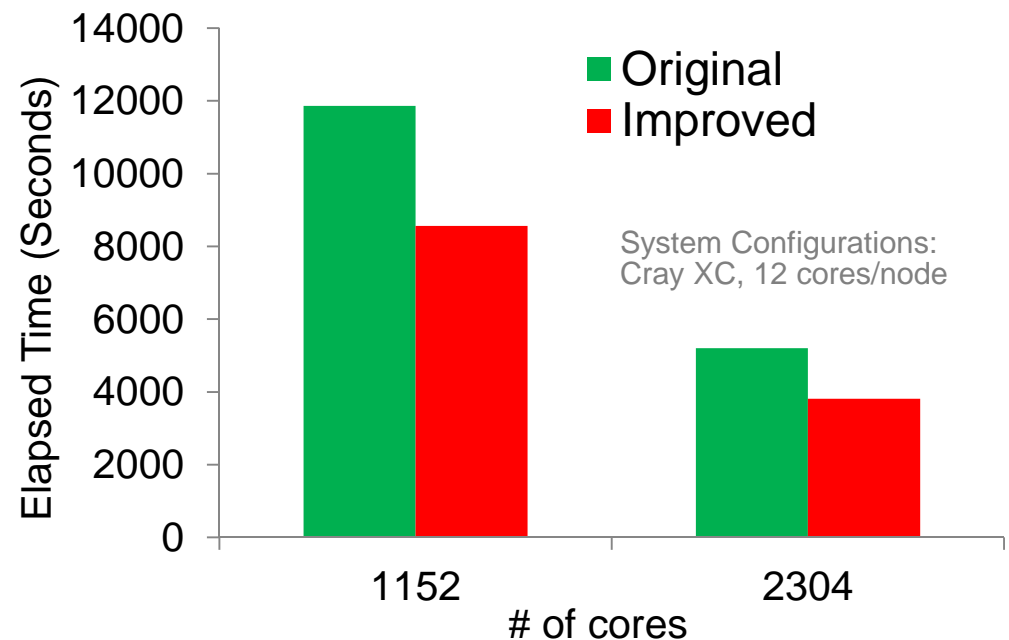
## \*CONTACT\_...

- Add frictional energy calculation for beams in \*CONTACT\_AUTOMATIC\_GENERAL
- Add keyword \*DEFINE\_CONTACT\_EXCLUSION to allow for nodes tied in some contacts to be ignored in certain other contacts
- Add EDGEONLY option to \*CONTACT\_AUTOMATIC\_GENERAL to exclude node-to-segment contact and consider only edge-to-edge and beam-to-beam
- Enable user defined friction for MPP contact SOFT=4
- Friction factors are now a function of temperature for \*CONTACT\_...\_THERMAL\_FRICTION

## \*CONTACT\_ERODING\_...

- Major rewrite to improve performance (MPP)
- The new algorithm uses a completely different approach to determining the contact surface. The old algorithm started from scratch when identifying the exterior of the parts in contact. The new algorithm is smarter about knowing what has been exposed based on what is eroded, and is faster.

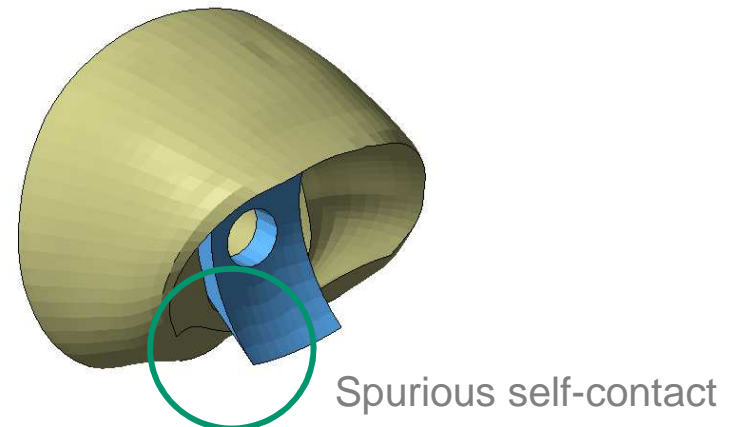
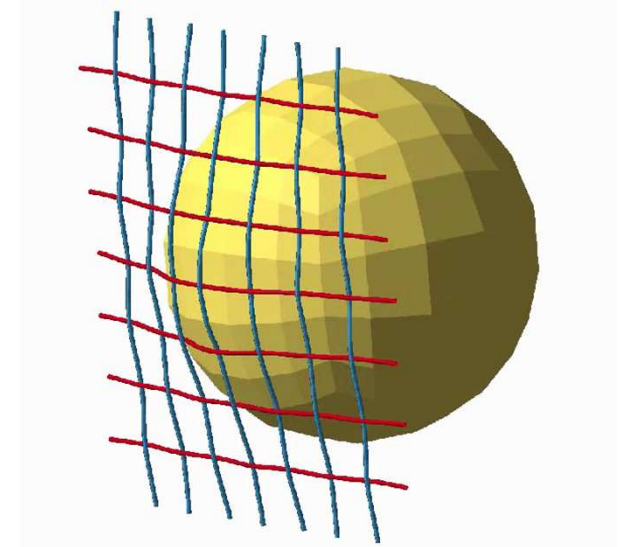
- Example:  
Fan blade out problem →





# \*CONTACT\_...\_MORTAR

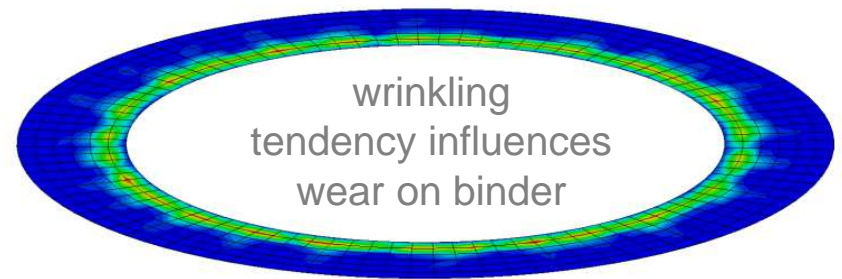
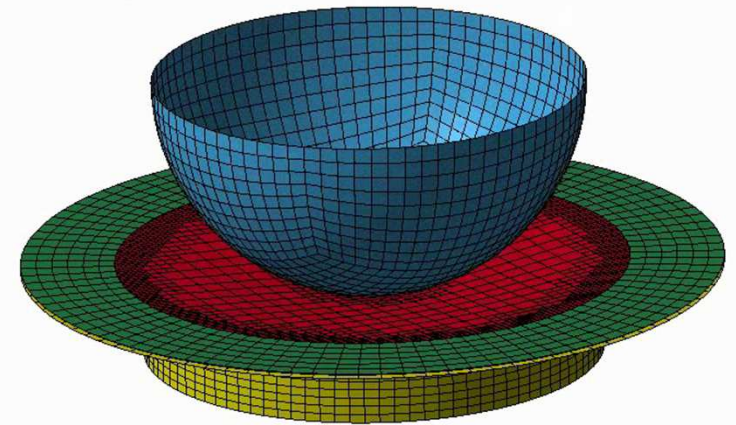
- Efficiency improvements in contact search significantly improves execution
- Supports friction options  $FS < 0$ 
  - Friction coefficients on \*PART\_CONTACT
  - Friction table \*DEFINE\_FRICTION
- Various bug fixes
  - Look ahead adaptivity reintroduced
  - Single surface beam contact
  - Reduce initialization time for forming contact
- Using IGNORE.LT.0 for single surface mortar contact will ignore penetrations of segments that belong to the same part. This will hopefully facilitate removal of initial penetrations in large models



# \*CONTACT\_ADD\_WEAR

- Hot forming is hard on tools, wear much higher than in cold forming:  
Simulating wear is of interest for improving tool design
- New keyword \*CONTACT\_ADD\_WEAR
  - Refer to a forming contact
  - Specify wear law, currently only "Archard"
- Keyword \*DATABASE\_EXTENT\_INTFOR
  - Parameter NWEAR to get wear depth  
to intfor file for post-processing
- No coupling to simulation (yet),  
only post processing

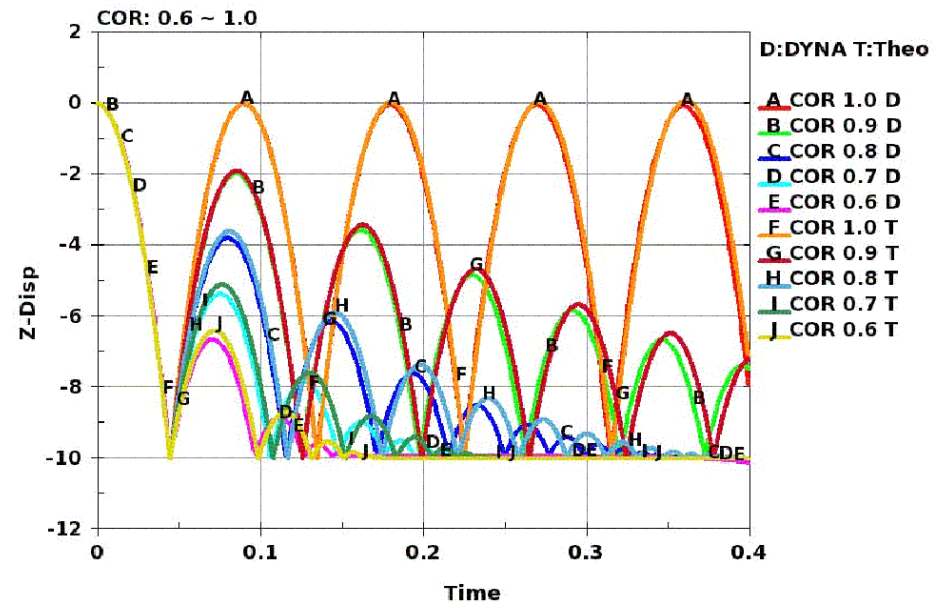
untitled  
Time = 0.0025999, #nodes=8083, #elem=7533





## \*CONTACT\_AUTOMATIC\_...

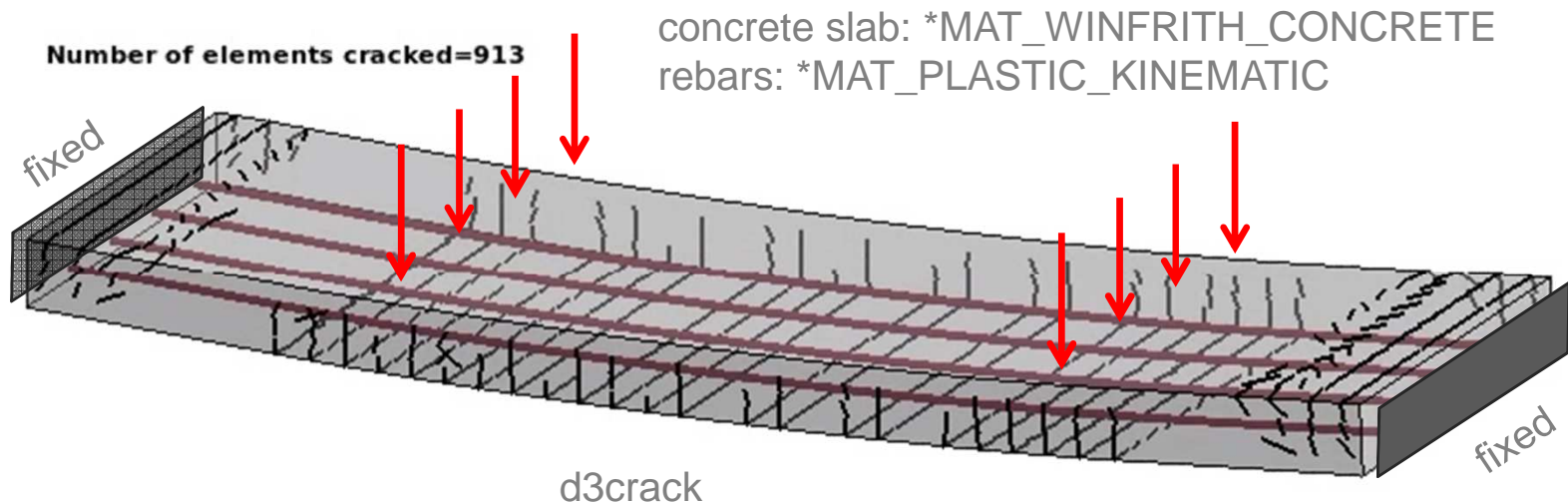
- If  $ICOR \neq 0$  on Optional Card E, the viscous damping coefficient, VDC, is the coefficient of restitution expressed as percentage of damping
- Coefficient of restitution of two colliding objects represents the ratio of speeds after and before an impact, taken along the line of the impact
- $0.0$  (plastic collision)  $\leq$  VDC (COR)  $\leq 100.0$  (elastic collision)



# \*CONSTRAINED

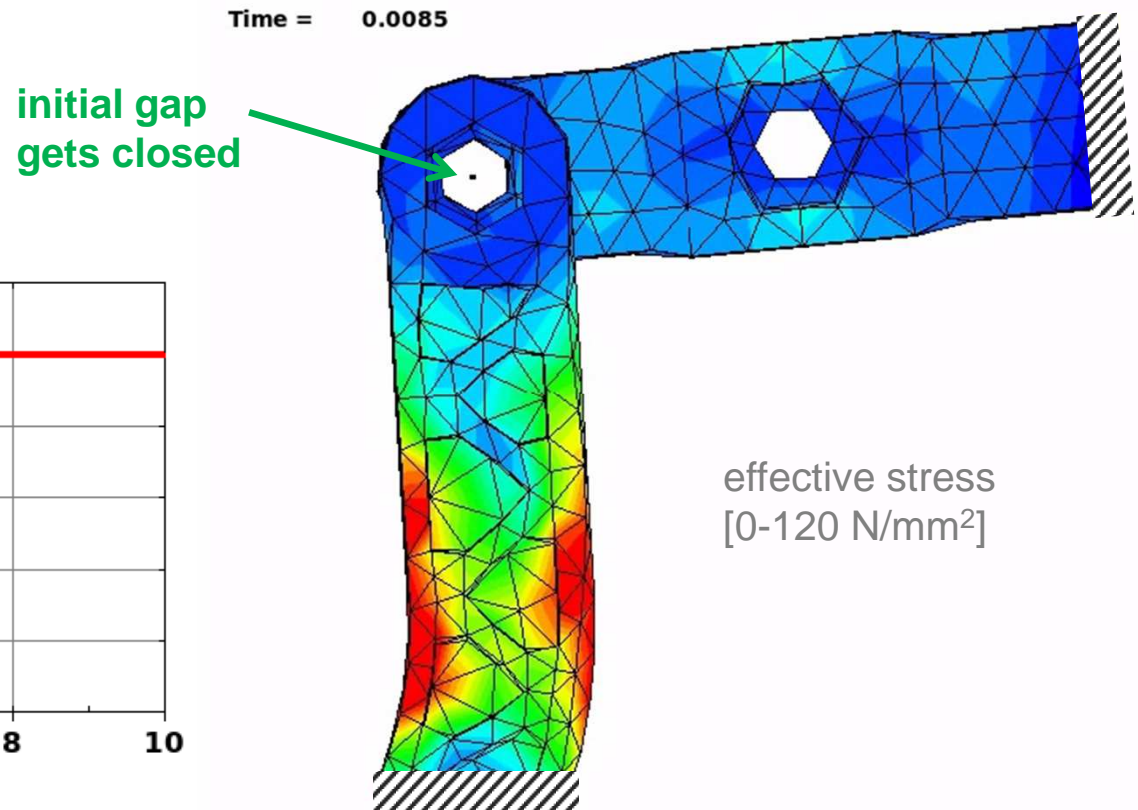
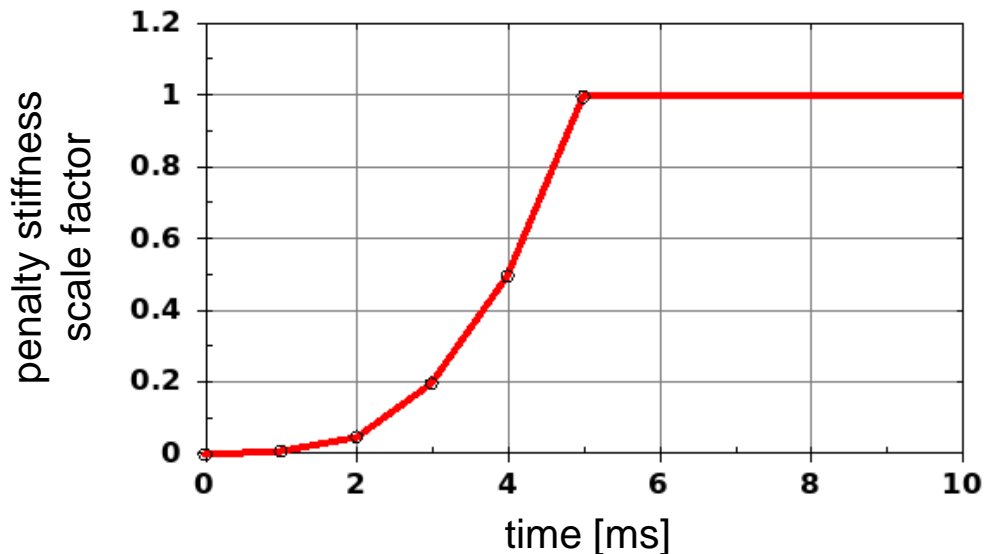
## ■ New keyword \*CONSTRAINED\_BEAM\_IN\_SOLID:

- This feature is basically an overhauled constraint coupling between beams and Lagrangian solids that includes features that make it more attractive in some cases than \*CONSTRAINED\_LAGRANGE\_IN\_SOLID, for example, in modeling coupling of rebars in concrete.
- Allows coupling only in normal directions (optional)
- De-bonding process via axial coupling force (\*DEFINE\_FUNCTION: force vs. slip)
- Correct energy balance



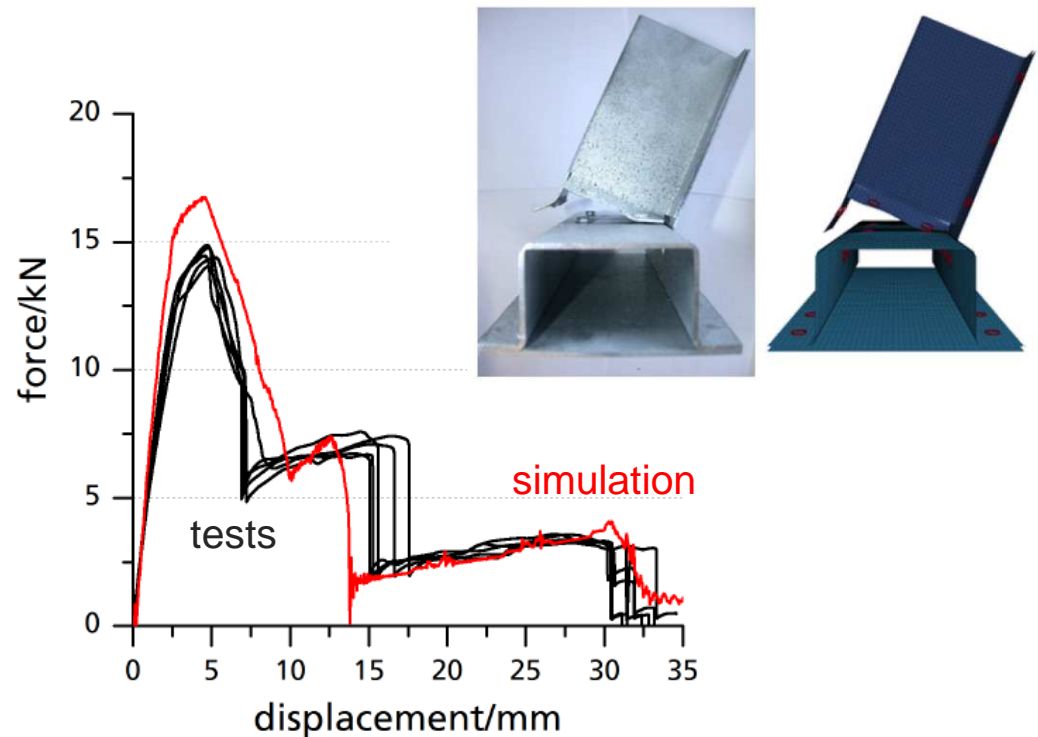
## \*CONSTRAINED\_JOINT

- For penalty-based joints, relative penalty stiffness can now be defined as time dependent value given by load curve (option RPS<0)
  - Nodal points of connected parts must not coincide initially anymore
  - For pre-stressing of joint connections
  - Works for options...  
SPHERICAL,  
REVOLUTE,  
CYLINDRICAL



## \*CONSTRAINED\_SPR2/3

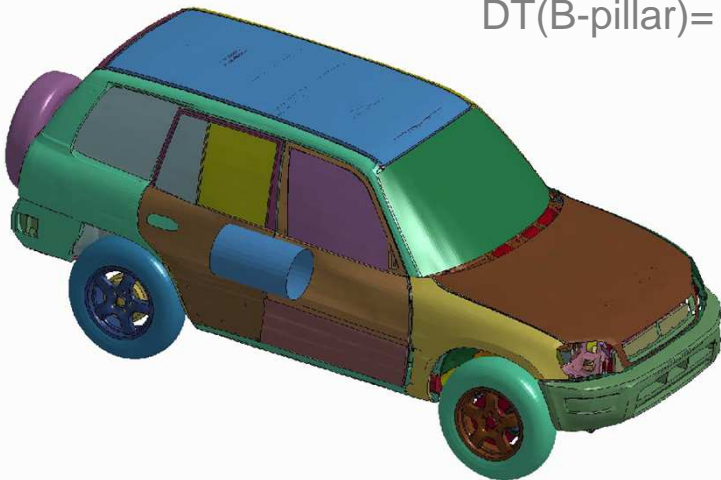
- Add failure reports and more d3hsp output
- Add new option to \*CONSTRAINED\_INTERPOLATION\_SPOTWELD: “SPR4”
  - There is a new parameter MODEL to select the new method
- Add new feature MODEL.GE.10 to \*CONSTRAINED\_SPR3
  - This allows parameters STIFF, ALPHA1, RN, RS, and BETA to be defined as \*DEFINE\_FUNCTIONS of thicknesses and maximum engineering yield stresses of connected sheets



# \*CONTROL\_SUBCYCLE

- New subcycling scheme activated for \*CONTROL\_SUBCYCLE\_K\_L (subcycling) and \*CONTROL\_SUBCYCLE\_MASS\_SCALED\_PART (multi-scale)
  - Simplified input: time step ratios for internal and external force calculations
  - Multi-scale: User may manually designate parts to be integrated at specific time steps
  - Improved robustness and performance

B-pillar refined  
DT2MS = -1.0  $\mu$ s  
DT(B-pillar)= 0.1  $\mu$ s



Paper by Borrvall et al. (2014)

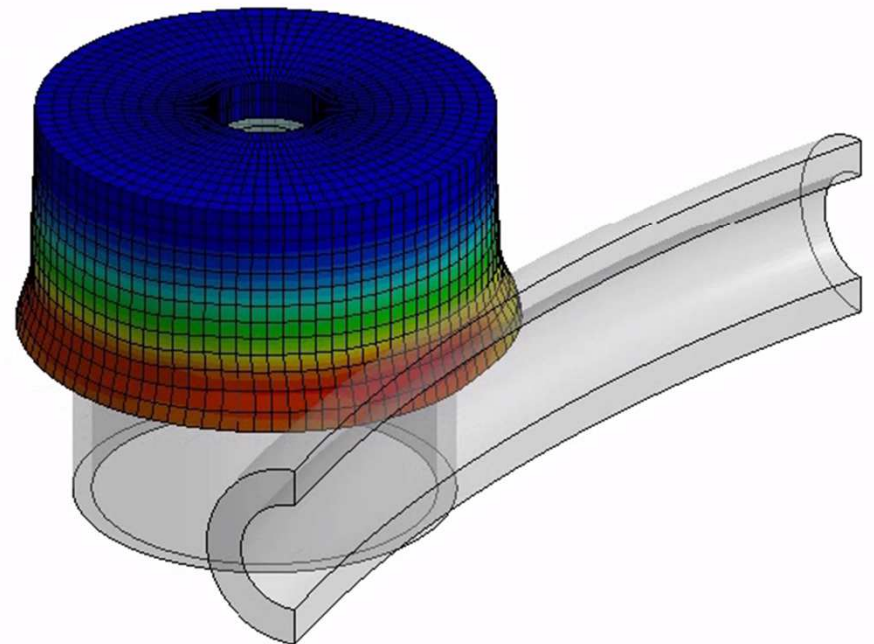
CPU timings (s)	Subcycling, K=64, L=4	Multi-scale, L=4	Default
Contacts	133	133	288
Elements	194	206	636

# \*CONTROL\_REMESHING

- New method for axisymmetric remeshing (\*PART with ADPOPT=3)
- Works with hexahedral and pentahedral elements (quads and trias in sections)
- Number of elements can increase and decrease

Contours of Effective Plastic Strain  
min=1.53211e-05, at elem# 16821  
max=1.7563, at elem# 15266

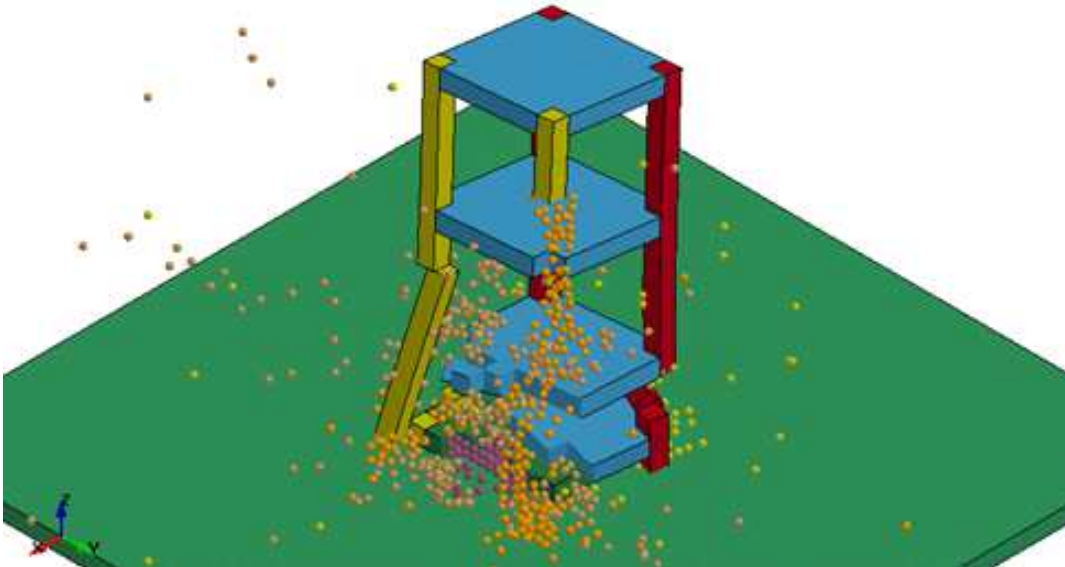
application area:  
3-D orbital forming





## \*DEFINE\_ADAPTIVE\_SOLID\_TO\_DES

- Adaptively transform a Lagrangian solid Part or Part Set to DES particles when the Lagrangian solid elements comprising those parts fail.
- One or more DES particles (elements) will be generated for each failed element.
- The DES particles replacing the failed element inherit all of the properties of the failed solid element, e.g. mass, kinematic variables, and constitutive properties.



controlled demolition  
of a building

Courtesy of  
Institut für Mechanik



Universität Karlsruhe (TH)  
Forschungsuniversität • gegründet 1825

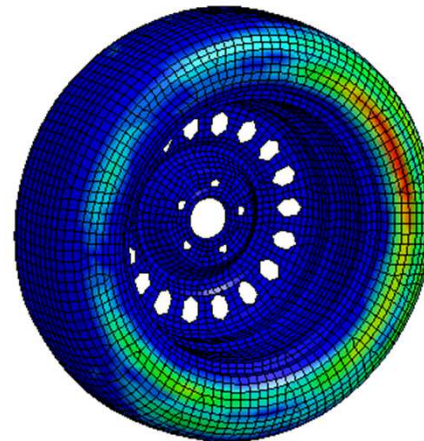
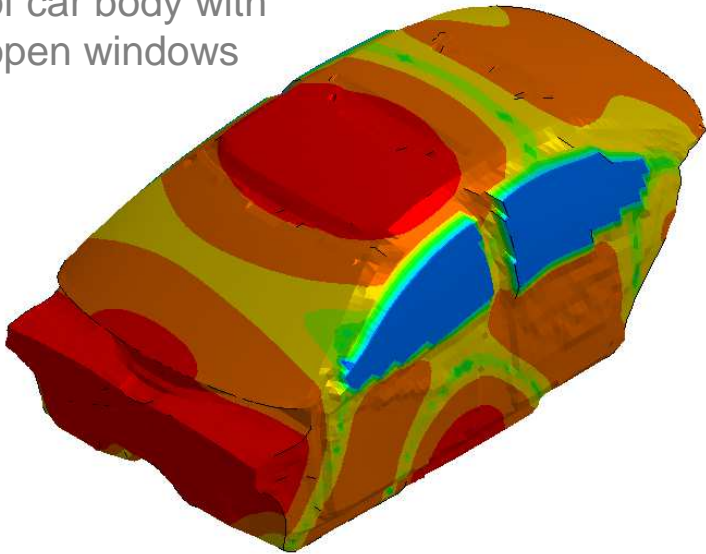
## \*FREQUENCY\_DOMAIN\_...

### ■ Several enhancements and new features in different areas

- acoustic solvers: boundary conditions, output, eigenvalue analysis, incident wave, ...
- fatigue solvers: multi-slope S-N curves, multiple damage ratios, new stress index, ...
- vibration solvers: random vibration, modal analysis, ...

### ■ New GUI in LS-Prepost 4.2 for FD databases

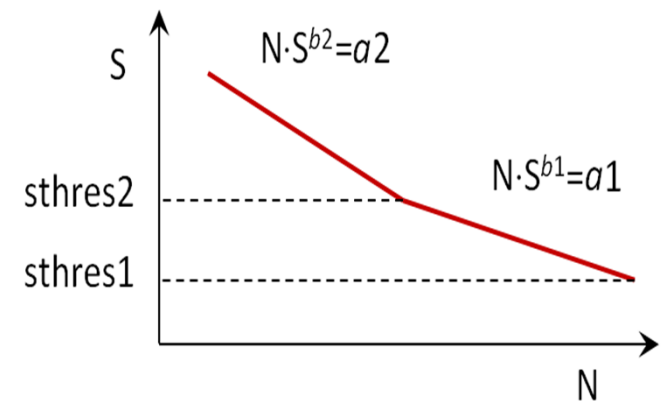
sound pressure level  
of car body with  
open windows



tire noise radiation:  
harmonic response

new keyword

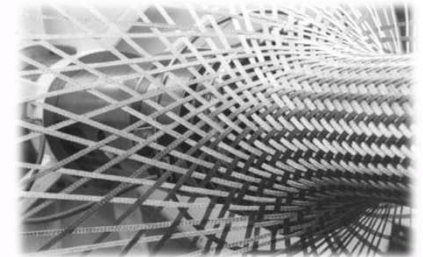
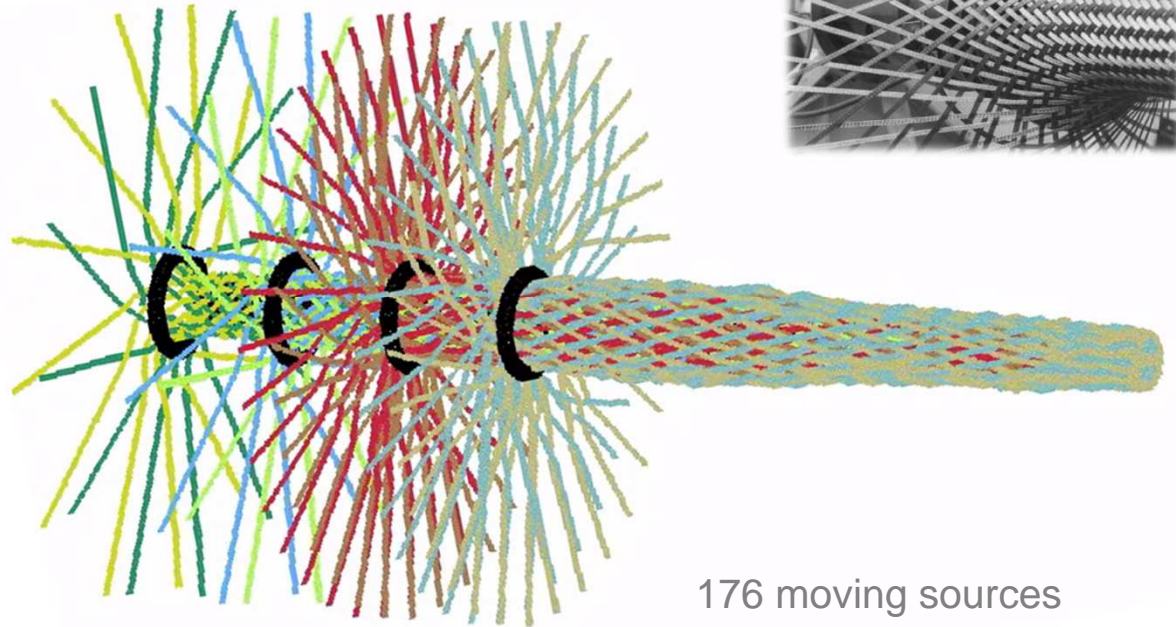
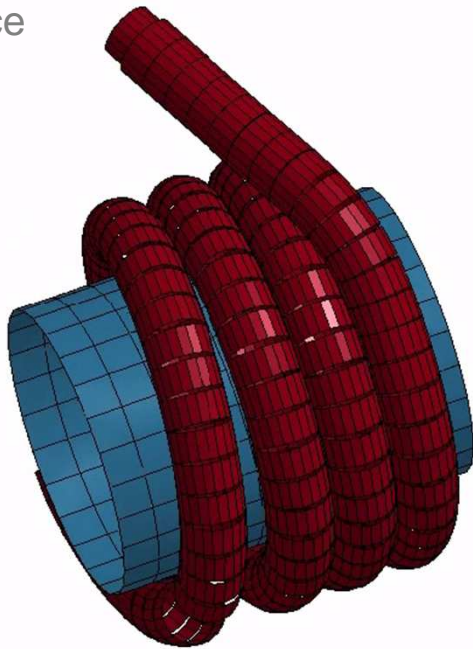
\*MAT\_ADD\_FATIGUE:  
definition of S-N (Wöhler) curve  
for material models



## \*ELEMENT\_BEAM\_SOURCE

- New keyword to define a point source (node) where a cable / thread / yarn with pre-defined length can be pulled out
- Input parameters are node id, number of elements to be drawn out, beam element fed length, pull-out force, and minimum beam element length
- Application: e.g. yarn feeders for braiding/weaving processes

moving  
source

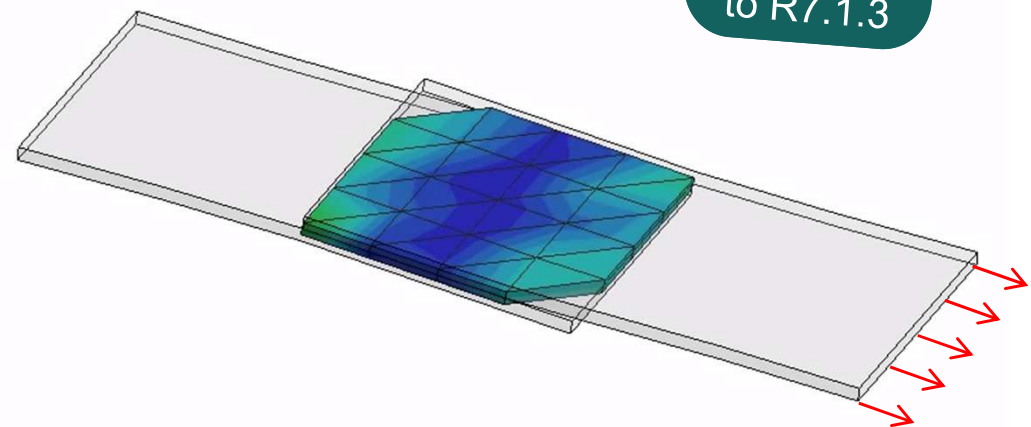


## \*ELEMENT\_TSHELL\_BETA

- Works in a similar way like \*ELEMENT\_SHELL\_BETA
- Allows direct thickness extrusion SHELL → TSHELL without loss of material orientation

## Cohesive Elements (\*SECTION\_SOLID, ELFORM=19-22)

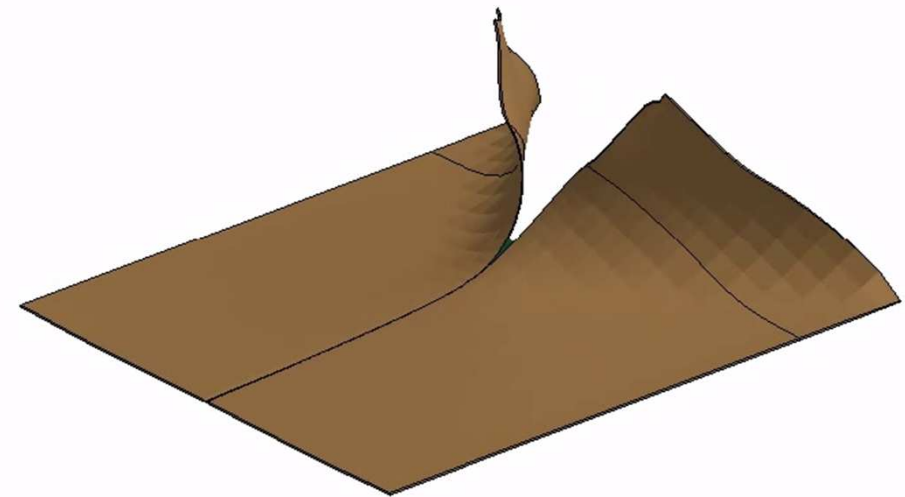
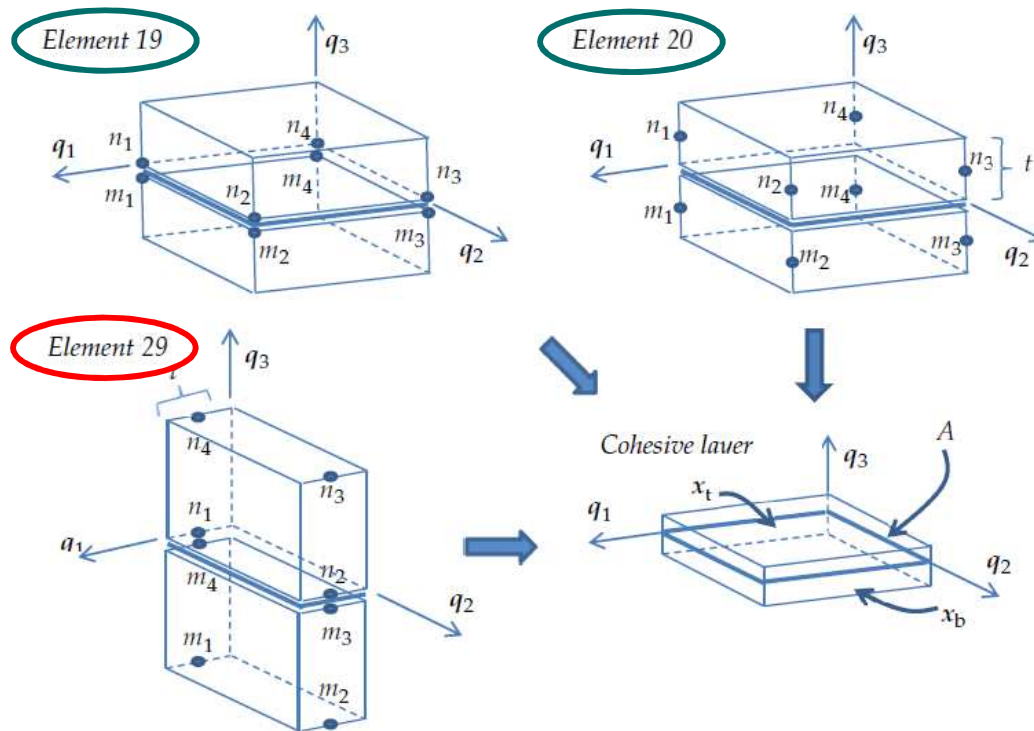
- Improved stability for ELFORM=20 (with offsets for use with shells)
  - New incremental formulation to properly handle large rotations
- Add pentahedron elements
  - ELFORM=21 (6-noded pentahedron)
  - ELFORM=22 (6-noded pentahedron with offsets for use with shells)
  - ESORT.gt.0 in \*CONTROL\_SOLID automatically activates element sorting of pentahedron solid elements





## \*SECTION\_SHELL, new ELFORM=29

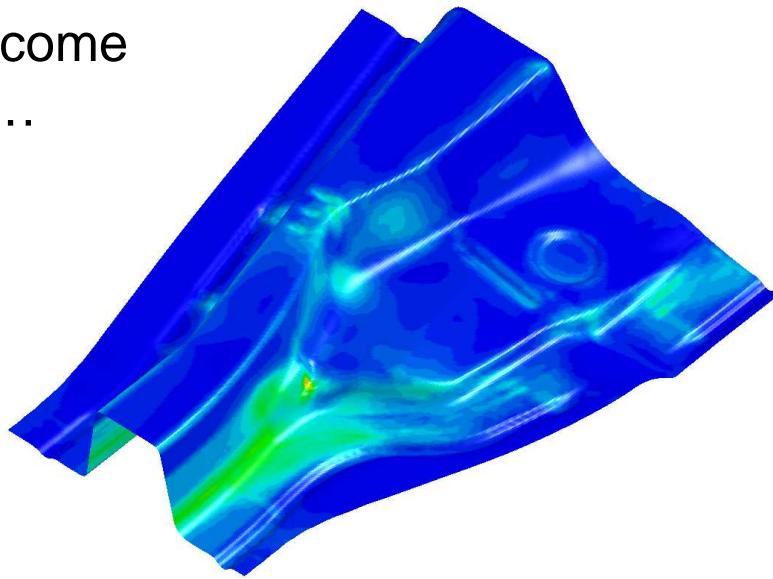
- New cohesive shell element for edge-to-edge connectivity between shells
- Takes bending into account, supports MPP and Implicit
- Can be used with usual cohesive material laws (138, 186, 240, 252)
- Paper by Jesper Karlsson (2015) on [www.dynalook.com](http://www.dynalook.com)



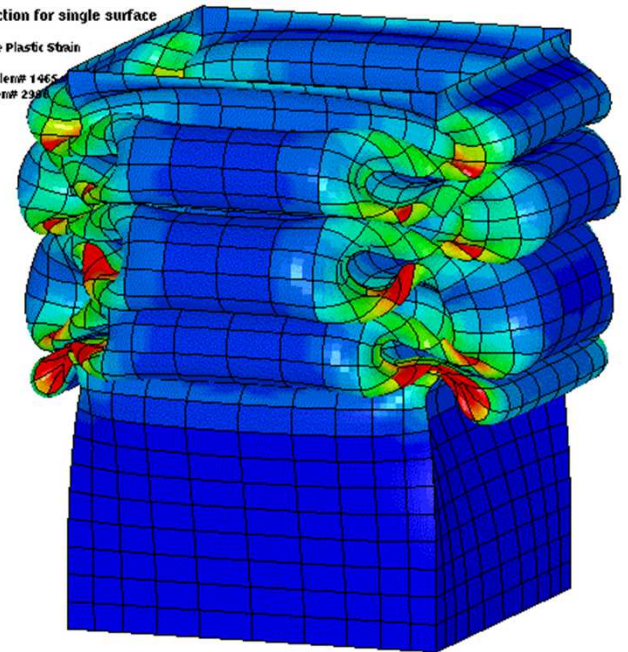
ripping of pre-notched clamped plate

## \*ELEMENT\_SHELL\_NURBS\_PATCH

- Several enhancements in the area of Isogeometric Analysis (IGA)
  - Add support for dumping of strain tensor (STRFLG.eq.1) for isogeometric shells via interpolation shells
  - Add support for dumping of shell internal energy density for isogeometric shells via interpolation shells
  - Add conventional mass-scaling for isogeometric shells
  - Improved writing of IGAPLOT-file
- Much more to come in version R9 ...



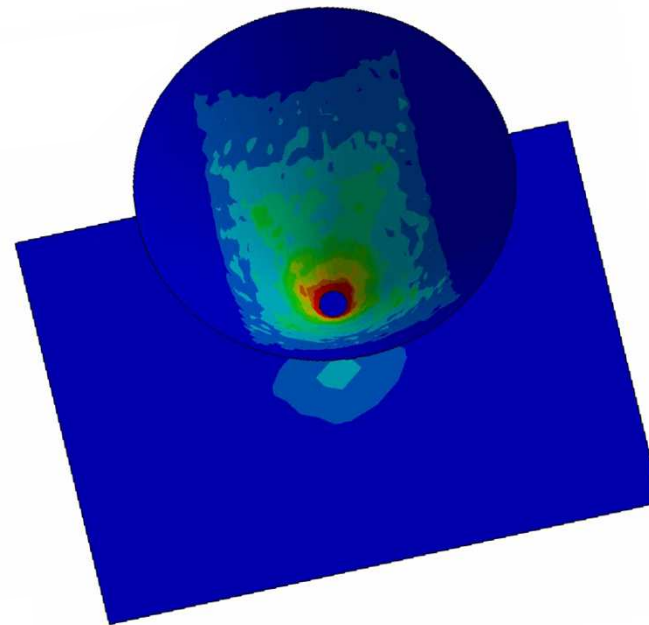
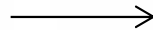
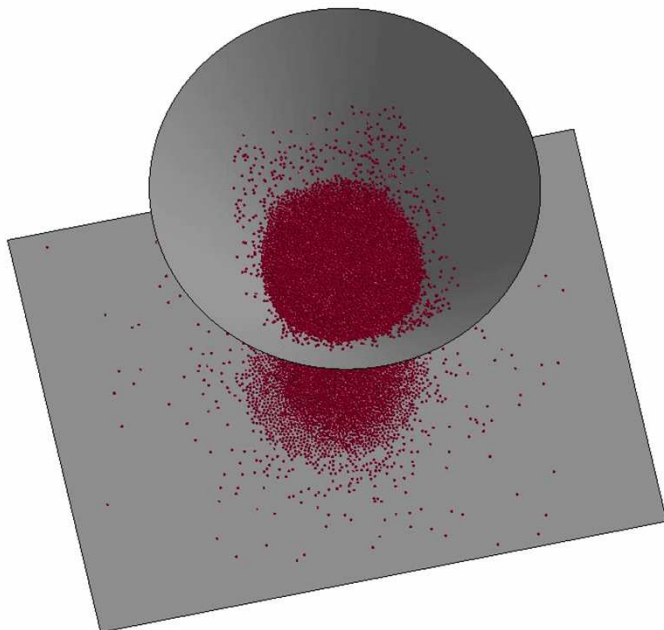
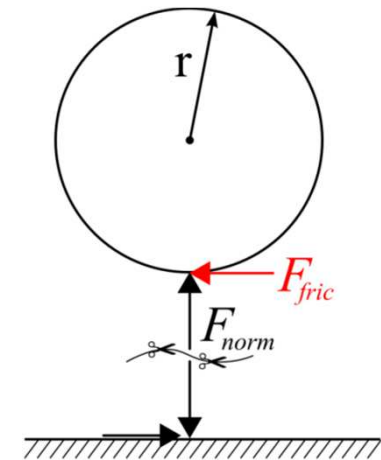
square cross section for single surface  
Time = 0.038761  
Contours of Effective Plastic Strain  
max ip1 value  
min=0.0016475, at elem# 1465  
max=58.8404, at elem# 238





## \*ELEMENT\_DISCRETE

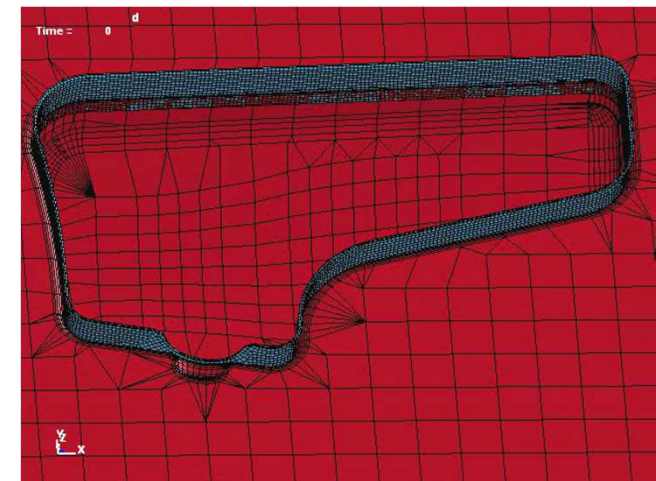
- \*DEFINE\_DE\_TO\_SURFACE\_COUPLING:  
Particle-structure contact with “new” contact definitions
  - Developed especially for discrete element to Lagrangian structure interaction
  - Archard's Wear Law to predict surface wear
  - Wear depth is output to the DEM interface force file (\*DATABASE\_BINARY\_DEMFOR)



fringe plot of  
surface wear

# Forming related features

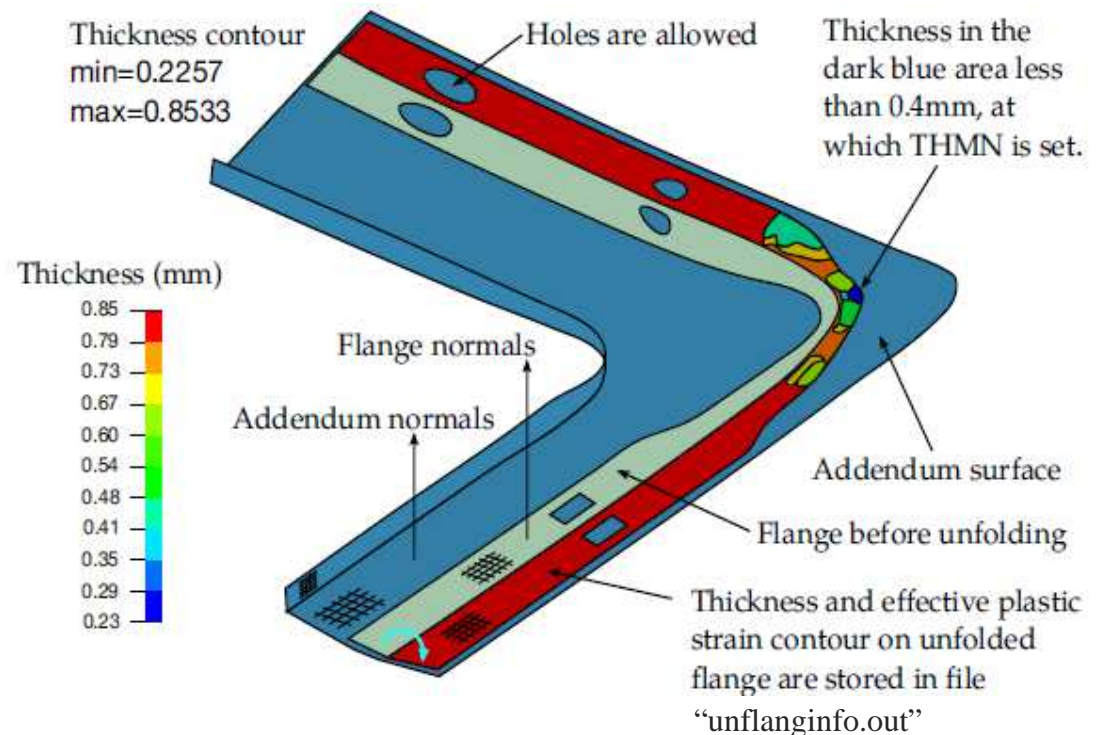
- \*CONTROL\_FORMING\_AUTOCHECK
- \*CONTROL\_FORMING\_ONESTEP
- \*CONTROL\_FORMING\_OUTPUT
- \*CONTROL\_FORMING\_SCRAP\_FALL
- \*CONTROL\_FORMING\_TRIM\_MERGE
- \*CONTROL\_FORMING\_TRIMMING
- \*CONTROL\_FORMING\_UNFLANGING
- \*DEFINE\_CURVE\_TRIM\_3D/NEW
- \*ELEMENT\_LANCING
- \*INTERFACE\_COMPENSATION\_NEW
- \*INTERFACE\_BLANKSIZE\_DEVELOPMENT
- ...



## e.g. \*CONTROL\_FORMING\_UNFLANGING

### ■ Several new features for unflanging

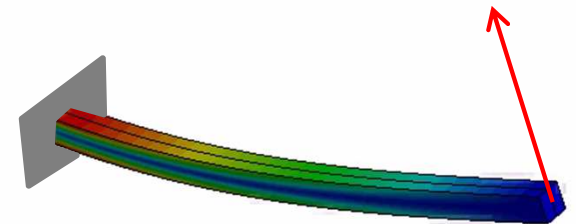
- The incoming flange mesh will be automatically checked for mesh quality
- Allow thickness offset of deformable flange to use the blank thickness from user's input
- Add a new parameter CHARLEN to limit the search region
- Allow holes to exist in the flange regions
- Output a suggested flange part after unflanging simulation, with the failed elements deleted from the unflanged part
- Add output of forming thickness, effective strain and trim curves after unflanging



# New implicit features

- Dumping of system matrices, see MTXDMP in \*CONTROL\_IMPLICIT\_SOLVER
  - Can now dump the damping matrix (in addition to stiffness and mass matrices)
  - Extend matrix dumping capability to MPP
  - MTXDMP<0 will terminate the run after dumping of matrices
- \*CONTROL\_IMPLICIT\_SOLVER
  - Nonsymmetric linear solver can be used by specifying LCPACK=3
  - Allow unsymmetric terms to the assembled stiffness matrix from some implicit features (nonuniform follower loads, user elements)
- \*MAT\_FABRIC now available
- \*MAT\_SEATBELT now available

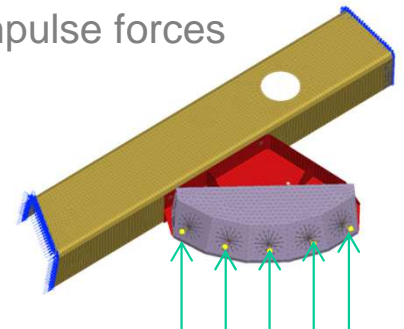
academic example:  
follower load



# \*CONTROL\_IMPLICIT\_MODAL\_DYNAMIC

- Modal Dynamics is used to reduce the cost of analysis. Element and Material computations are replaced by two multiplications by  $\Phi$
- This has been in LS-DYNA since LS-DYNA 960 using \*CONTROL\_IMPLICIT\_DYNAMICS with IMASS = 2 or 3
- Now, Modal Dynamics has been enhanced with new features and keywords.
  - \*CONTROL\_IMPLICIT\_MODAL\_DYNAMIC  
To activate modal dynamic analysis
  - \*CONTROL\_IMPLICIT\_MODAL\_DYNAMIC\_MODE  
To select a subset of modes to use in the analysis
  - \*CONTROL\_IMPLICIT\_MODAL\_DYNAMIC\_DAMPING  
To specify damping coefficients for modal damping.
- Paper by Roger Grimes (2014)  
on [www.dynalook.com](http://www.dynalook.com)

instrument bracket  
with impulse forces



transient explicit: 220 min (single precision)  
transient non-linear implicit: 265 min  
transient modal dynamics: 4 min

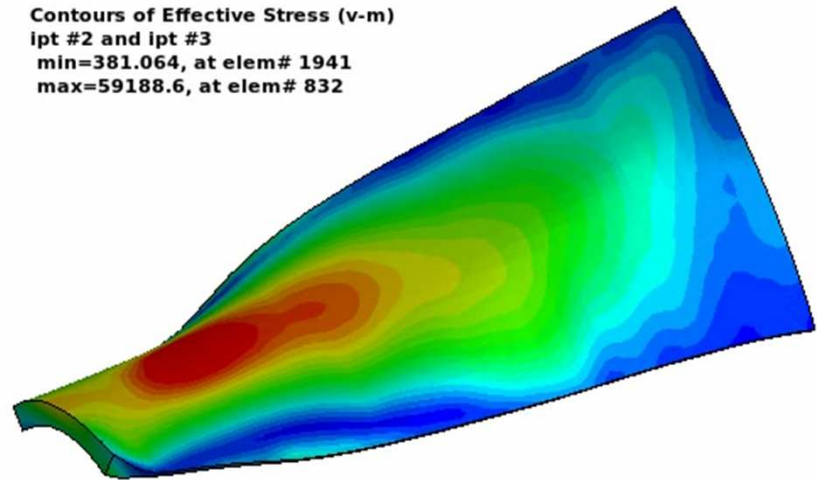
# \*CONTROL\_IMPLICIT\_ROTATIONAL\_DYNAMICS

- New keyword is added to study Rotordynamics using the implicit time integrator
- Linearized equilibrium equation in the rotating coordinate system includes **gyroscopic damping** (Coriolis contribution) and **centrifugal stiffness**

$$\mathbf{M}\mathbf{u} + (\mathbf{D} + 2\Omega\mathbf{C})\dot{\mathbf{u}} + (\mathbf{K} - \Omega^2\mathbf{K}_G)\mathbf{u} = \mathbf{F}$$

- Applications: transient and vibration analysis of rotating parts such as turbine blades, propellers in aircraft, and rotating disks in hard disk drives.
- It is available for beam, shell, solid and thick shell elements.
- Currently only SMP double, MPP under development.

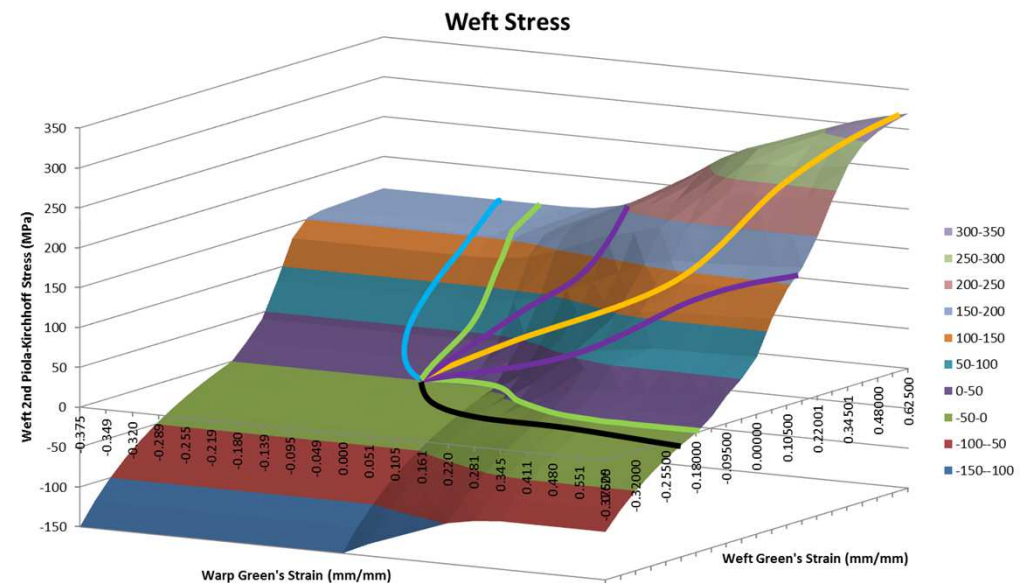
Contours of Effective Stress (v-m)  
ipt #2 and ipt #3  
min=381.064, at elem# 1941  
max=59188.6, at elem# 832





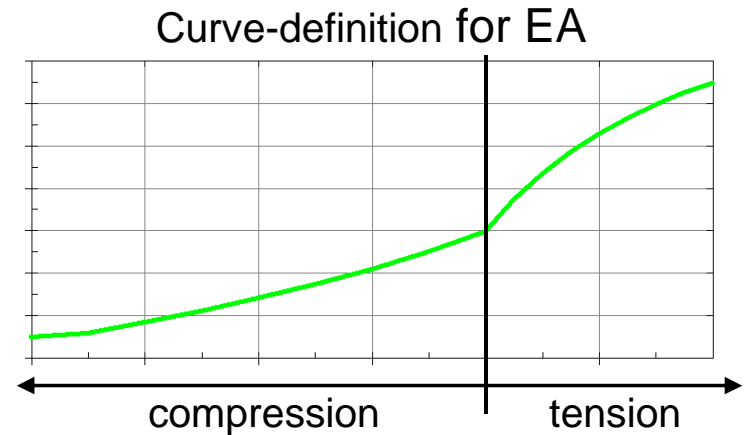
## \*MAT\_FABRIC (\*MAT\_034)

- Add new formulation FORM = 24 as modified version of FORM = 14
  - The main improvement is that the Poisson's effects work correctly with the nonlinear curves for fiber stress.
  - Also, the output of stress and strain to d3plot are engineering stress and strain instead of 2nd PK stress and Green's strain.
- New material model \*MAT\_FABRIC\_MAP
  - stress response is given exclusively by tables, or maps, and where some obsolete features in \*MAT\_FABRIC have been deliberately excluded to allow for a clean input and better overview of the model
  - Paper by Thomas Borrvall (2015) on [www.dynalook.com](http://www.dynalook.com)



## \*MAT\_LAMINATED\_COMPOSITE\_FABRIC (\*MAT\_058)

- Added possibility to define „arbitrary“ uniaxial elastic stress vs. strain behavior using curve definitions (valid for EA, EB, GAB)
  - non-linear elastic behavior
  - different stiffness in tension and compression
- Strain rate dependent stiffness using table definition (stress vs. strain vs. strain rate)



## \*MAT\_SPOTWELD (\*MAT\_100)

- Add option to use yield curve or table for solid elements (SIGY<0)
- Enable force filtering option NF for solids and solid assemblies
- New “uniaxial option” activated by E<0

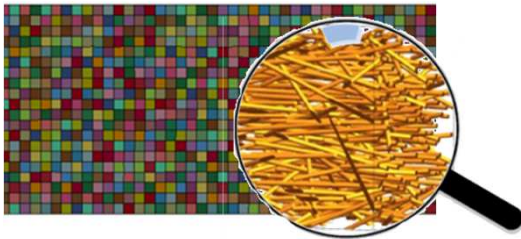
backported  
to R7.1.3

backported  
to R7.1.3

# \*MAT\_ANISOTROPIC\_ELASTIC\_PLASTIC (\*MAT\_157)

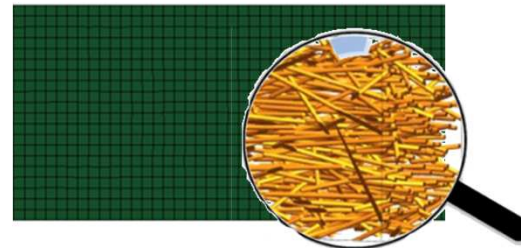
- Well suited for short-fiber reinforced composites due to anisotropy in elastic and plastic regime
- Added VP=1 (viscoplastic formulation) for shells
- \*MAT\_157 implemented for solids (including VP=1)
- Possibility to initialize various anisotropic material properties via \*INITIAL\_STRESS\_SHELL/SOLID on a per-element basis (IHIS)

## In material card



Drawback: inhomogeneous distribution (e.g. from previous short fiber filling simulation) in component needs individual part definition for every element

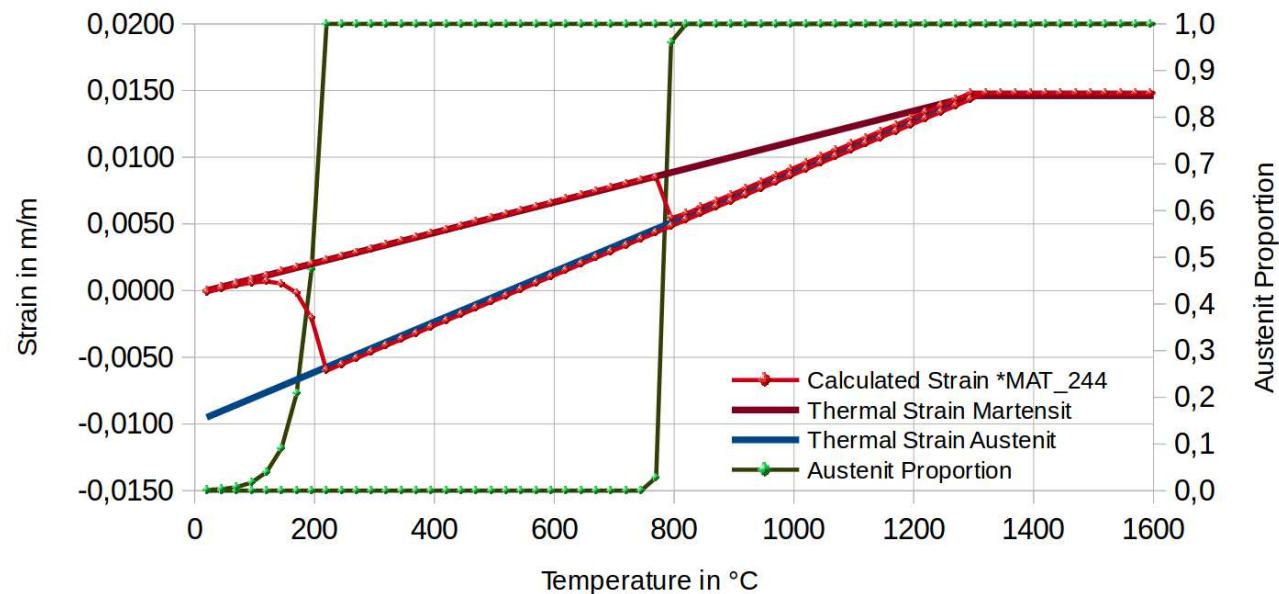
## With \*INITIAL\_STRESS\_SOLID



Only one part definition for whole component. Anisotropic coefficients are part of material's history field and can therefore be initialized for each integration point individually

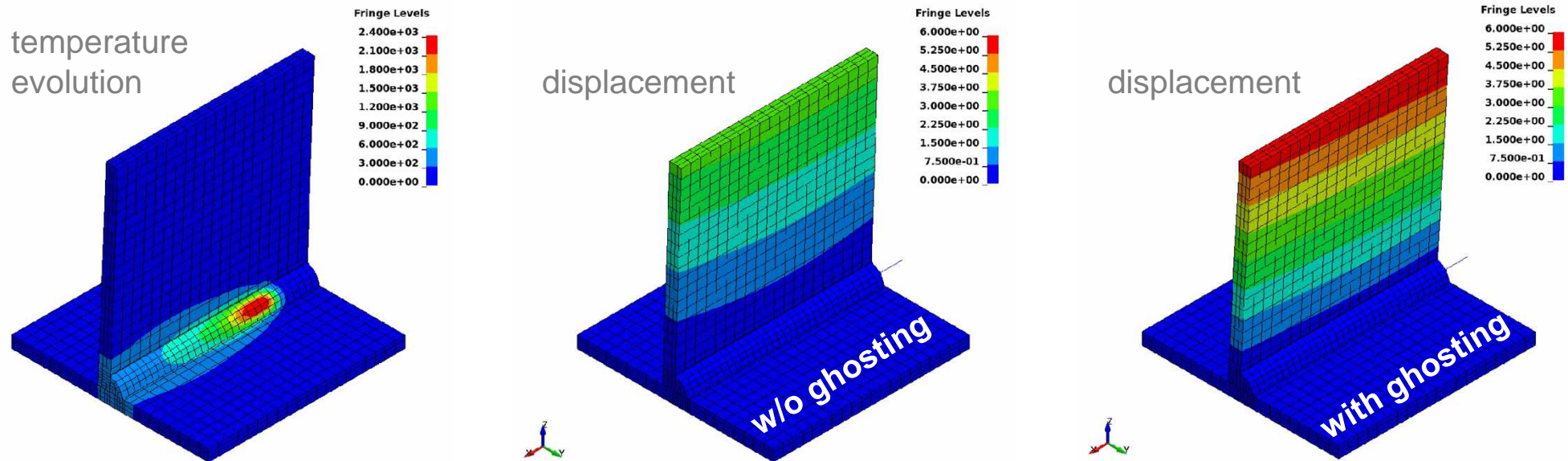
## \*MAT\_UHS\_STEEL (\*MAT\_244)

- By default same start temperatures for phase transitions are assumed for heating and cooling
- Now, advanced reaction kinetics input (REACT=1) accepts load curve IDs (input as negative values) for FS, PS, BS, and MS
- Temperature dependent thermal expansion for austenite and hard phases
- Added load curve for transformation induced strains



## \*MAT\_UHS\_STEEL (\*MAT\_244)

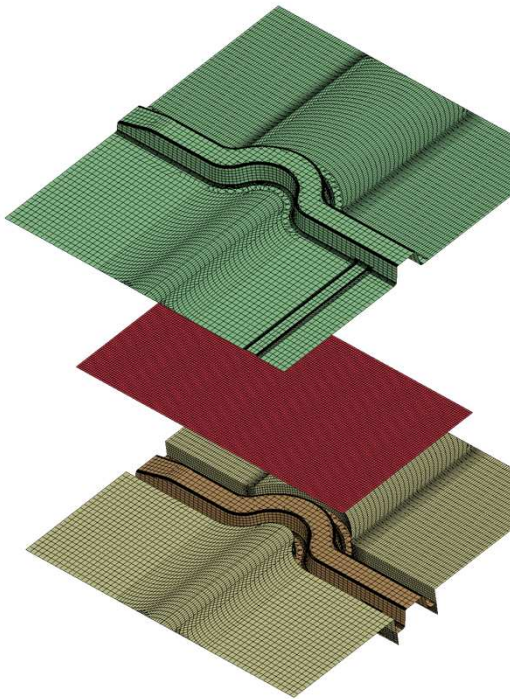
- New features for welding
- Ghost material approach as in \*MAT\_270
  - Material is inactive at the beginning, but is activated by temperature
- Annealing is also considered (history variables reset)
- Can be combined with \*MAT\_THERMAL\_CWM





# \*MAT\_REINFORCED\_THERMOPLASTIC (\*MAT\_249)

- Material model for process simulations of fiber reinforced thermoplastics
  - Matrix: temperature and strain rate dependent elastic-plastic material
  - Fiber: anisotropic and hyperelastic formulation
- Material allows to define up to three individual fiber families and keeps track of their elongation and reorientation





# More material model updates

- Add a keyword option called MIDFAIL for \*MAT\_024
  - failure by plastic strain will only be checked at the mid-plane
- New options for \*MAT\_224 (TABULATED\_JOHNSON\_COOK)
  - BETA .LT. 0: strain rate dependent amount given by load curve ID = -BETA
- New options for \*MAT\_ARUP\_ADHESIVE (\*MAT\_169)
  - Strength values as functions of properties of connection partners
  - In-plane failure strain criterion
- Global deactivation of all \*MAT\_ADD\_EROSION definitions via MAEF=1 on new keyword \*CONTROL\_MAT
- New thermal option for \*MAT\_HYPERELASTIC\_RUBBER (\*MAT\_077) to specify some material properties as functions of temperature

# MPP enhancements

- For MPP, set a "last known location" flag to give some indication of where the processors were if an error termination happens. Each writes a message to their own message file. Look for a line that says "When error termination was triggered, this processor was".
- Allow memory2 option in \*KEYWORD, for example,  
`*KEYWORD memory=1G memory2=200m`
- Tune Xeon 64 AVX2 executable for better performance, AVX2 is about 10% better than SSE2 exe.
- Two csv files will be generated after each MPP execution: "load\_profile.csv" and "cont\_profile.csv". These will give general information about load balancing and cost profile of the job.
- Many more ...

# Miscellaneous

- Add a new keyword `*BOUNDARY_SPC_SYMMETRY_PLANE`
  - Define constraints to enforce planar symmetry for nodes on or near a specified plane. These constraints will be enforced even during adaptivity. This command is similar to `*CONSTRAINED_LOCAL` but allows selectivity via a part ID.
  
- `*DATABASE_SECFORC`, `*DATABASE_CROSS_SECTION`
  - The secforc data for cross-sections through 2D seatbelt elements is recoded to provide more robust and accurate results.
  
- `*DATABASE_EXTENT_BINARY`, `*MAT` , `*SECTION`
  - For some materials and elements, thermal and plastic strain tensors can be output to d3plot database, see STRFLG.
  
- `*INCLUDE_UNITCELL`
  - New keyword to create an input file containing user-defined unit cell information with periodic boundary conditions

# Miscellaneous

- \*CONTROL\_OUTPUT and command line option “msg=all” or “msg=10087”
  - Add option for detailed warning/error messages to d3msg, parameter MSGFLG
  - Only a few "long" versions of warnings/errors at this time but that list is expected to grow

```
*** Message      10087 (KEY+87)
    in *INCLUDE file name:
    File AAA does not exist
    Keyword read will continue but numerous errors may result
```

LS-DYNA couldn't read the include file specified in the input deck.

The include file may be improperly specified in the input file. Please ensure that the path to the include file is specified correctly. Or, you may use batch queuing system which is allowed to deal input files only. Please ask your system administrators if the system considers not only LS-DYNA input file but also include files you use.

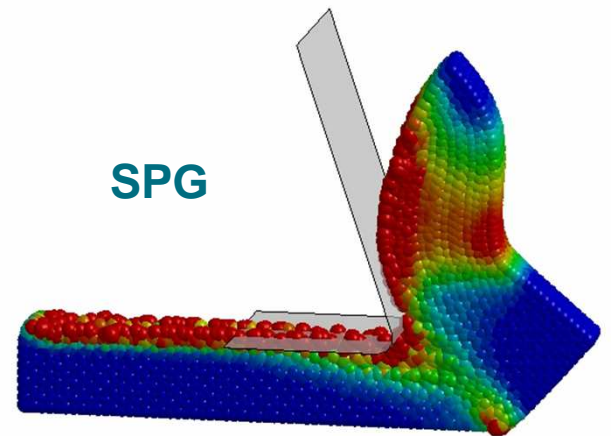
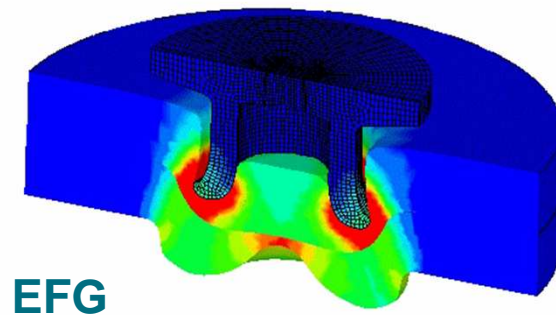
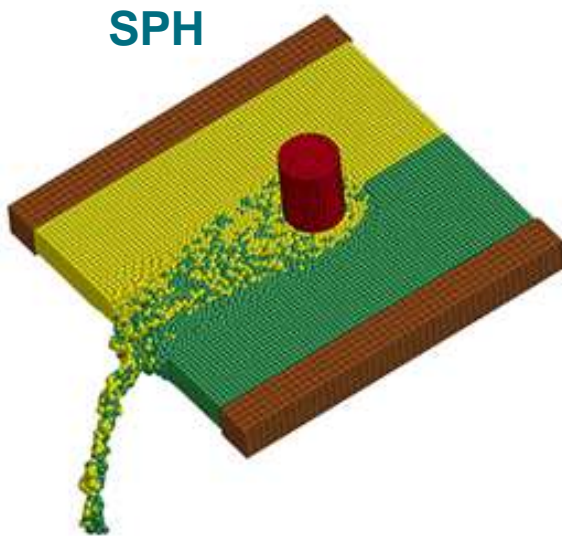
# Bug fixes

- A wide range of code corrections, inter alia,
  - Fix \*BOUNDARY\_SPC\_SET\_BIRTH\_DEATH which was not working for MPP when the birth and death time were set to non-zero.
  - Fixes related to contact's intfor database (\*DATABASE\_BINARY\_INTFOR).
  - MPP contact: fix routine that updates segment thicknesses for solid elements (every cycle) so that it honors the OPTT parameter in \*PART\_CONTACT.
  - Fix MPP adaptivity for very large models: the reading of the adaptive dump file was not working properly for files over 8GB.
  - Update SOFT=2 contact to improve accuracy at points far away from the origin.
  - Correct contact penalty stiffness for cohesive elements.
  - Several fixes pertaining to thick shell elements (\*ELEMENT\_TSHELL).
  - Fix MPP implicit's output of forces to bndout due to prescribed motion on nodes.
  - Fix rate effects problem in \*MAT\_ARUP\_ADHESIVE.
  - Fix for combination of \*MAT\_USER with GISSMO.
  - Fix single precision issue in strain calculation of \*MAT\_FABRIC with FORM = 12, 13, 14.
  - ...



# Conclusion: LS-DYNA R8.1

- Many more developments and enhancements in other areas (ALE, EFG, SPG, SPH, Thermal, ...) and the multiphysics solvers (ICFD, CESE, EM, Chemistry)



- R8 Keyword User's Manual can be downloaded from [www.dynamore.de/en/downloads/manuals/](http://www.dynamore.de/en/downloads/manuals/)

# Outlook: LS-DYNA R9

- Contact: robustness, efficiency, generality, ...
- Elements: higher order formulations, stacked shells/solids, ...
- Materials: curing, phase change, glass, general damage, ...
- Implicit: efficiency, robustness, accuracy, ...
- IGA: solid elements, trimmed NURBS, ...
- Forming: trimming/adaptivity of sandwich parts, ...
- Thermal: welding related enhancements, ...
- MPP: performance, output, ...
- Frequency Domain: acoustics, random vibration, SSD, ...
- CESE, Chemistry, EM, ICFD: numerous new capabilities
- Airbags: explicit/implicit switch, dynamic relaxation, ...
- SPG, SPH, EFG, XFEM, DEM, ...