Recent and Ongoing Developments in LS-DYNA

German LS-DYNA Forum 2016

Presented by Roger Grimes

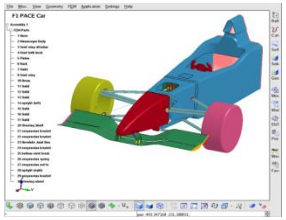
LSTC
Livermore Software
Technology Corp.

October 10-12, 2016 Bamberg, Germany

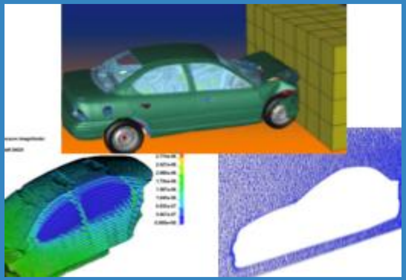
Outline

- Introduction
- Status update of
  - Isogeometric Analysis Recent Enhancements
  - Materials
  - Constraints, boundary conditions, contact & loading
  - Implicit
  - Element formulations: FEM & meshless
  - ICFD
- Summary

LSTC Products



LS-PrePost



LS-DYNA

Surface

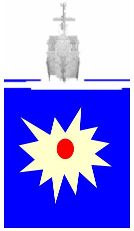
2D Interpolator

Accuracy

Sensitivity

LS-OPT/LS-TaSC

Dummies & Barriers



USA

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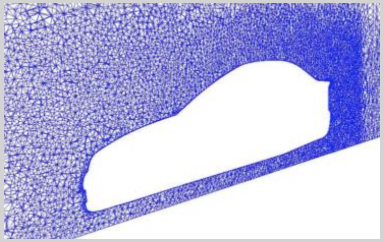
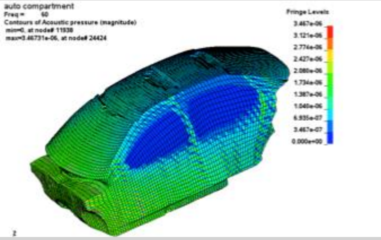
★ No additional license cost

LS-DYNA - One Code, One Model





Single Model for Multiple Disciplines

Manufacturing, Durability, NVH, Crash, FSI

Multi-physics and Multi-stage

Structure + Fluid + EM + Heat Transfer

Implicit + Explicit ….

Multi-scale

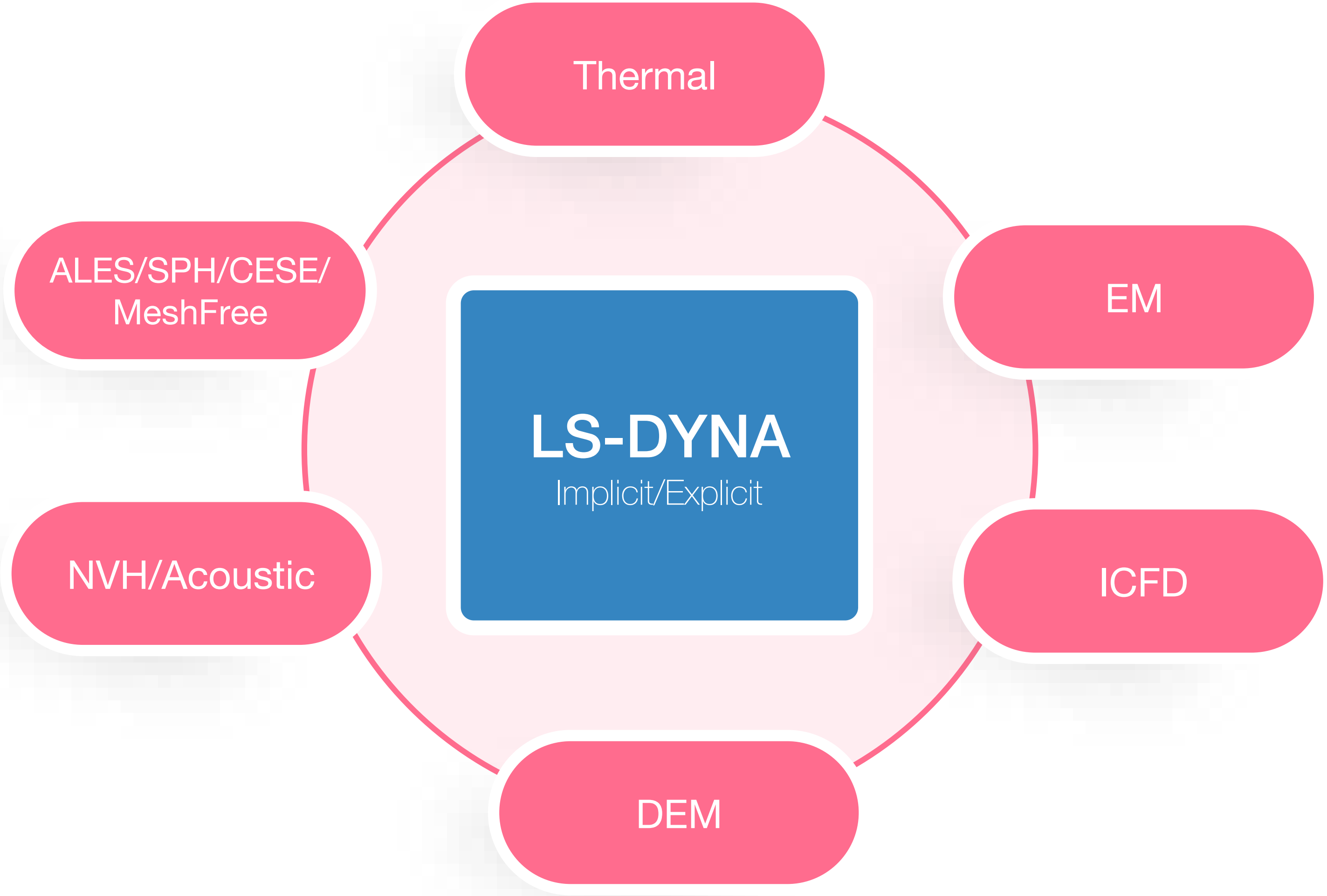
Failure predictions, i.e., spot welds

Multi-formulations

linear + nonlinear + peridynamics + …

The Neon crash model is courtesy of FHWA/NHTSA National Crash Analysis Center

Strongly Coupled Multi-Physics Solver



Thermal

ALES/SPH/CESE/
MeshFree

EM

LS-DYNA
Implicit/Explicit

NVH/Acoustic

ICFD

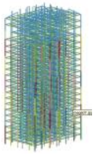
DEM

Computers that can handle multiphysics simulations are becoming affordable
Scalability is rapidly improving for solving multi-physics problems

LS-DYNA Applications

Development costs are spread across many industries

Automotive
Crash and safety
NVH & Durability
FSI

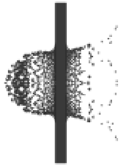


Structural
Earthquake safety
Concrete structures
Homeland security

Aerospace
Bird strike
Containment
Crash

Electronics
Drop analysis
Package analysis
Thermal

Manufacturing
Stamping
Forging
Welding



Defense
Weapons design
Blast and Penetration
Underwater Shock Analysis

Consumer Products

Biosciences

LS-DYNA - Current Capabilities

Includes coupled Multi-Physics, Multi-Scale , and Multi-Stage in one Scalable Code

- ✓ Explicit/Implicit
- ✓ Heat Transfer
- ✓ ALE & Mesh Free
  i.e., EFG, SPH, Airbag Particle
- ✓ User Interface
  Elements, Materials, Loads
- ✓ Acoustics, Frequency Response, Modal Methods

- ✓ Discrete Element Methods
- ✓ Incompressible Fluids
- ✓ CESE Compressible Fluids
- ✓ Electromagnetics
- ⚙ Control Systems

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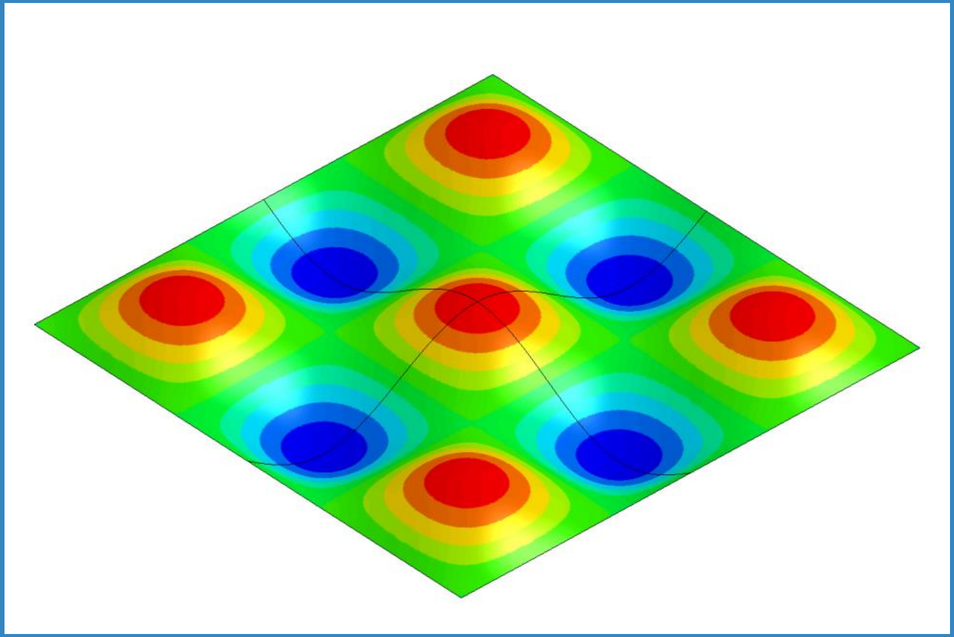


Isogeometric Analysis: Recent Enhancements

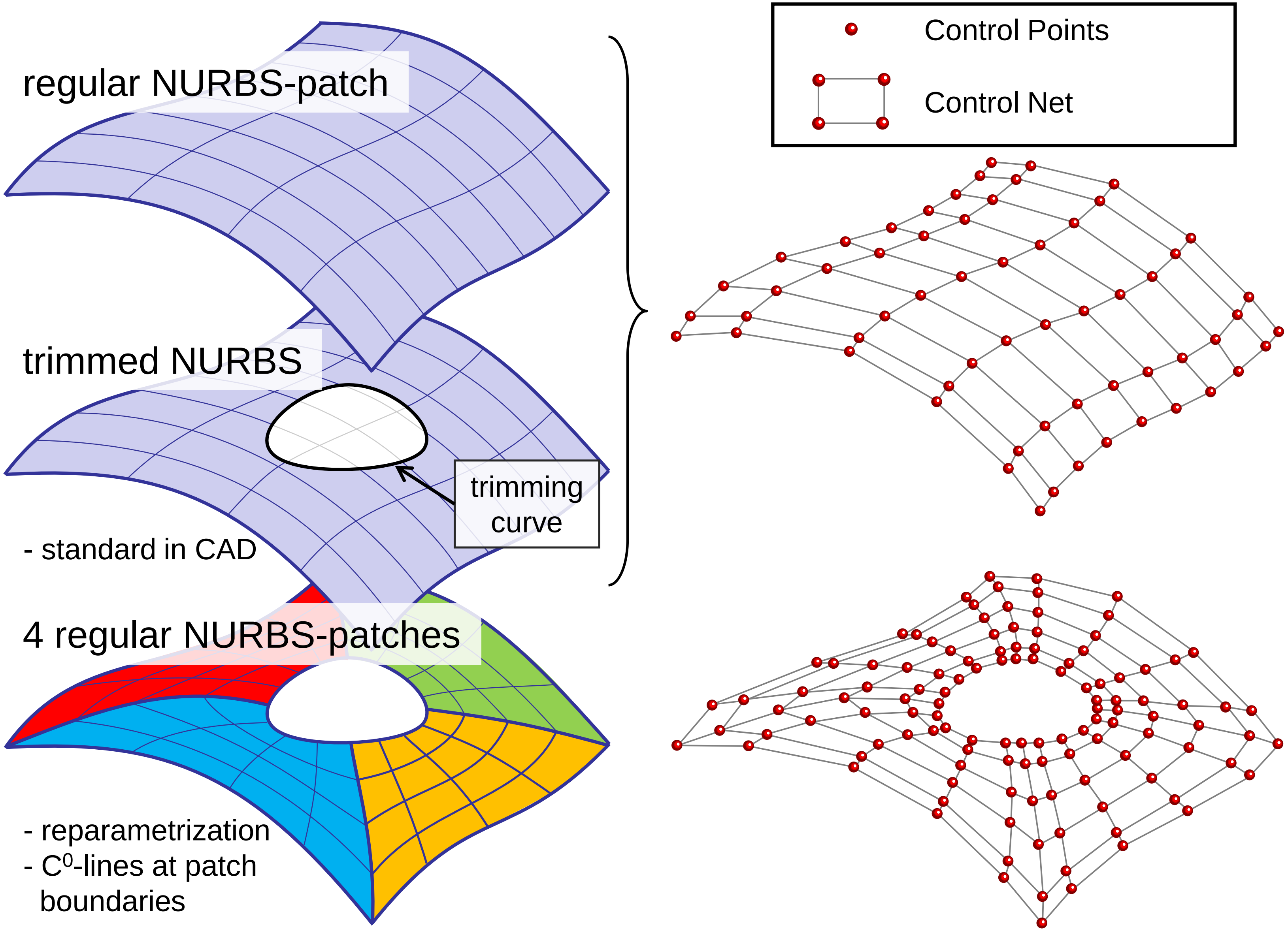
Recent Enhancements

- Element technology:
  - T-spline input (Stefan Hartmann).
  - Trimmed NURBS patches (Stefan Hartmann, Attila Nagy, David Benson).
  - Solid NURBS elements (Liping Li).
  - Mass scaling (Stefan Hartmann).
- Boundary conditions:
  - Tied edge-to-edge and edge-to-surface contact (David Benson, Stefan Hartmann).
  - Nodes-to-surface (Isheng Yeh).
  - Penalty-based boundary conditions (Isheng Yeh).
  - Pressure loading (Isheng Yeh).

Enhancements (cont.)

- Stability and performance:
  - New integration rule enhances robustness and reduces shear locking (Stefan Hartmann).
  - Stabilization of trimmed shell elements (David Benson).
  - SMP now supported in addition to MPP (Liping Li).
  - Improved stable time step estimates for trimmed elements (Liping Li).
- Integration with other analysis capabilities:
  - Fluid-structure interaction (Facundo Del Pin).
  - Frequency response analysis (Yun Huang, Liping Li).
- Pre- and post-processing (Philip Ho et. al.).

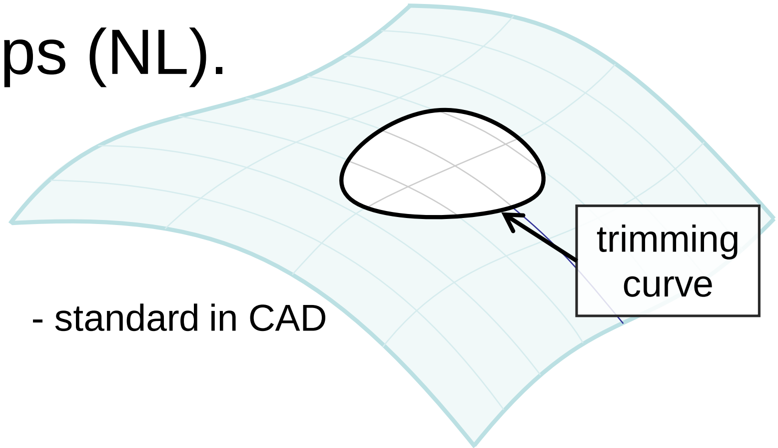
NURBS Meshes



- regular NURBS-patch
- trimmed NURBS
  - standard in CAD
- 4 regular NURBS-patches
  - reparametrization
  - C^0-lines at patch boundaries

*ELEMENT_SHELL_NURBS_PATCH

- Unlimited number of trimming loops (NL).
- Supported by LSPP.



- standard in CAD

*ELEMENT_SHELL_NURBS_PATCH

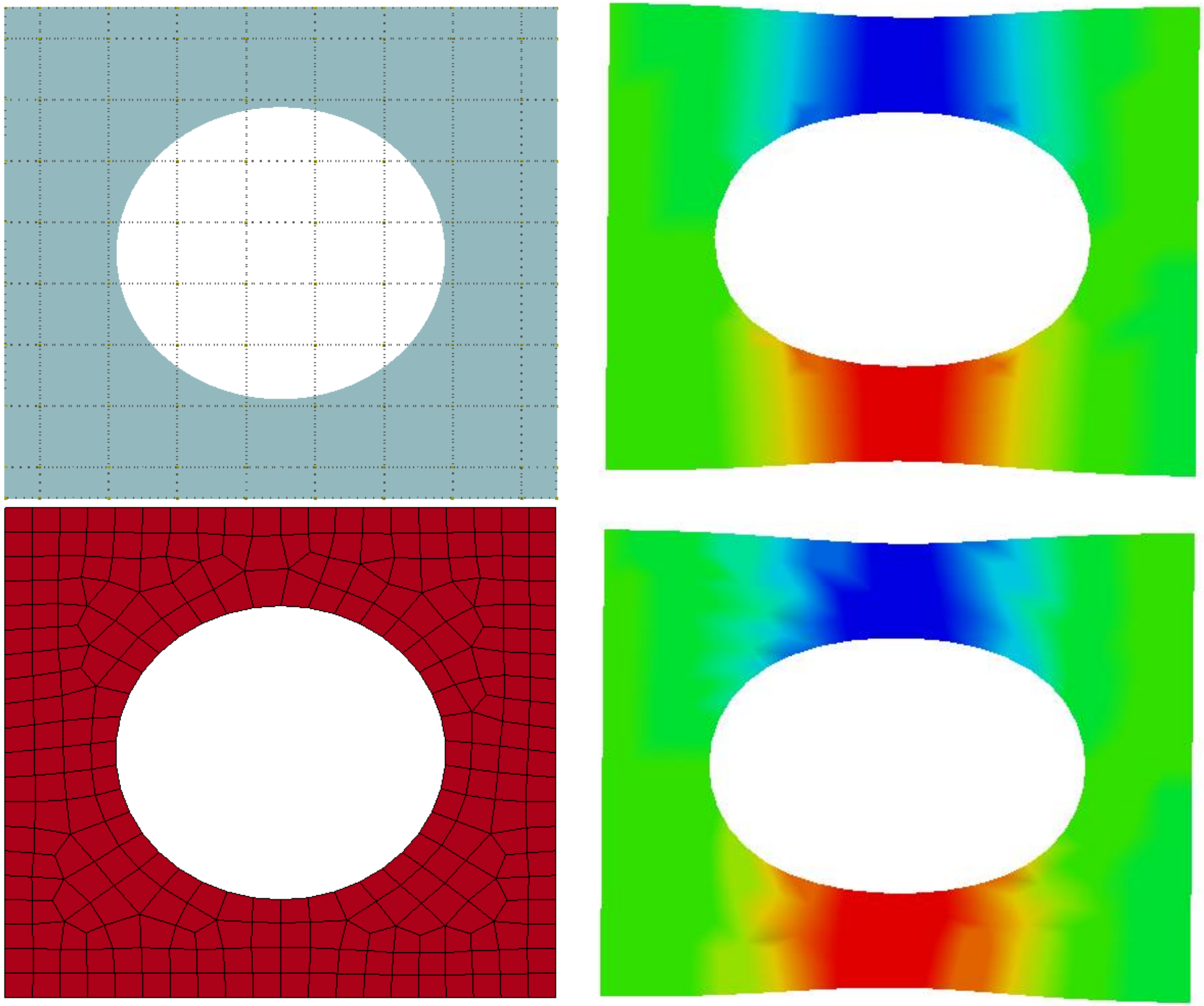
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Card 1	NPEID	PID	NPR	PR	NPS	PS		
Card 2	WFL	FORM	INT	NISR	NISS	IMASS	**NL**	
...								
Card X	NEL							
Card Y	E1	E2	E3	E4	E5	E6	E7	E8

one trimming loop

NEL: number of edges for trimming loop

E*i*: Edge (Curve) ID defining this edge - use *DEFINE_CURVE with DATTYP=6

*ELEMENT_SHELL_NURBS_PATCH



Trimmed
NURBS

displacement

Standard
Shell-Elements

displacement

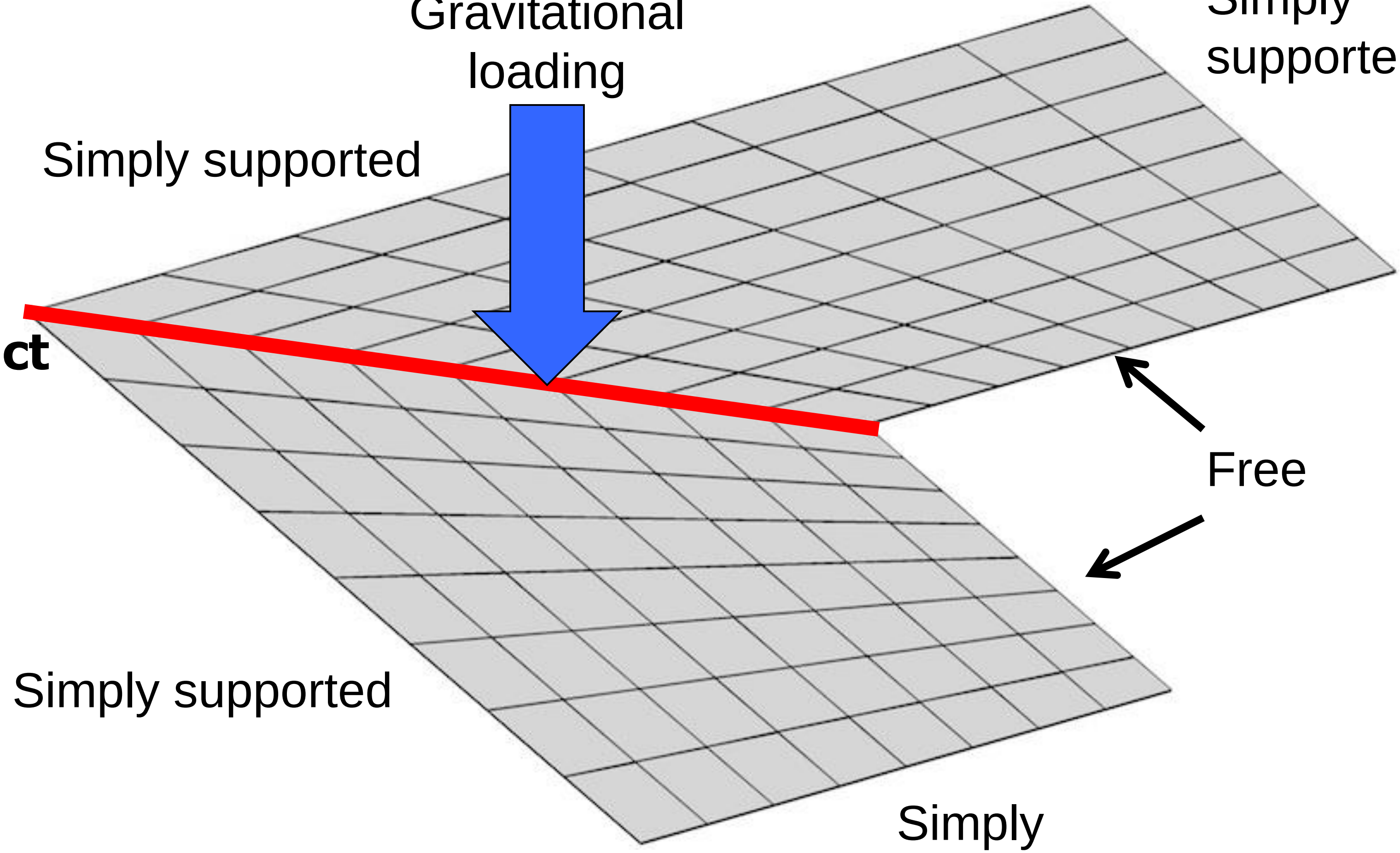
Tied Contact: Motivations

- Join discontinuous meshes.
- Adaptivity:
  - Standard FE uses constraints in *h* adaptivity for simplicity.
  - Permits *h-p* adaptivity. Standard spline formulations have a constant *p*.
- Transmit moments between patches of thin shells.

Constraint Enforcement Strategies

- Penalty:
  - Attractive for explicit.
  - Does not enforce constraint exactly.
  - Need to evaluate appropriate penalty stiffness.
  - Used for nonlinear thin shell rotational constraints in explicit.
- Coordinate elimination:
  - Reduces equations. Used for linear constraints in implicit.
  - Exact enforcement.
  - Translational DOF constraints in explicit for thin shells and all DOF for R-M shells/
- Lagrange multipliers:
  - Adds equations.
  - Exact enforcement.
  - For nonlinear constraints in implicit.

L-Shaped Thin Plate



Gravitational loading

Simply supported

Simply supported

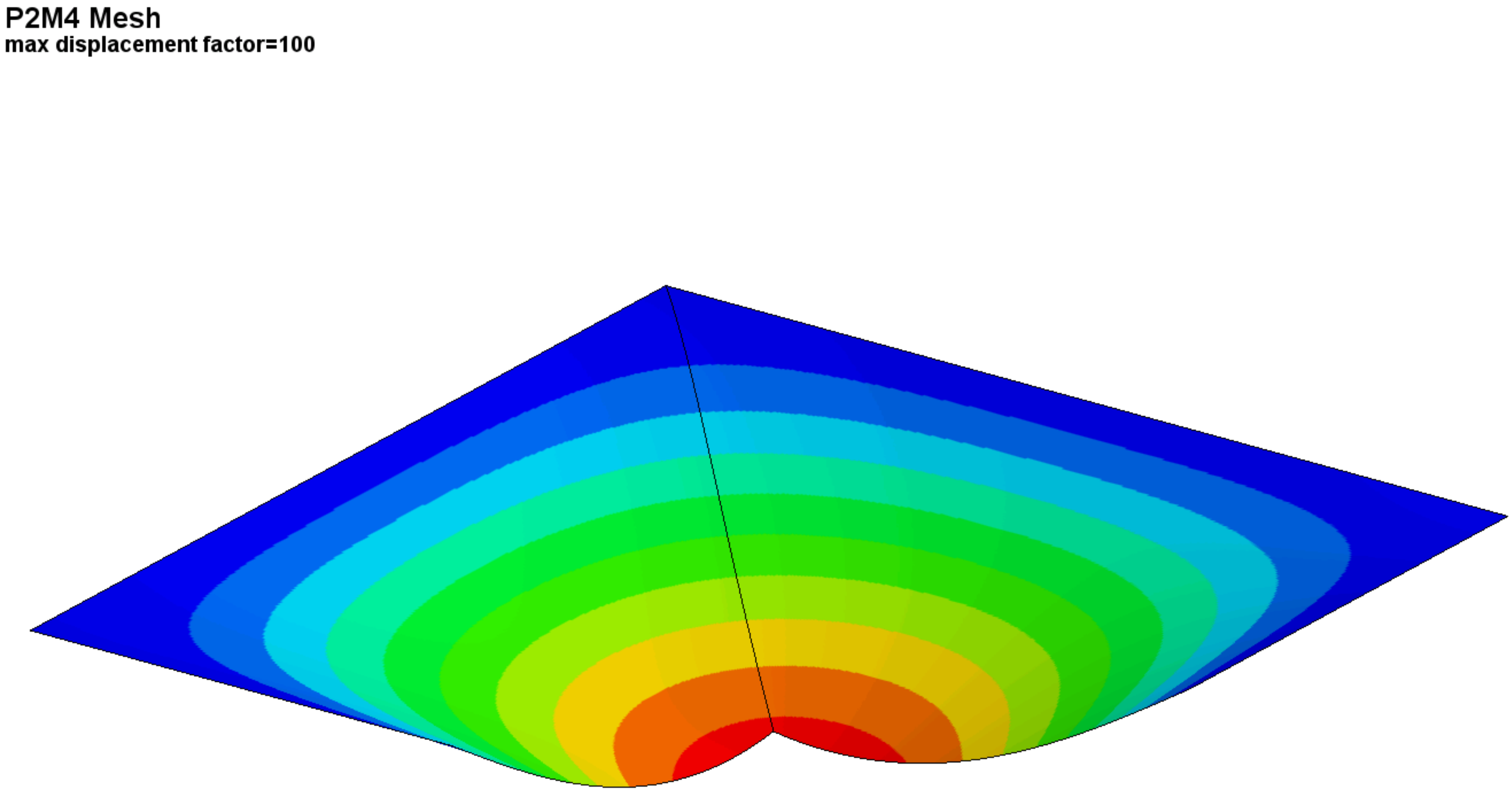
Tied contact line

Free

Simply supported

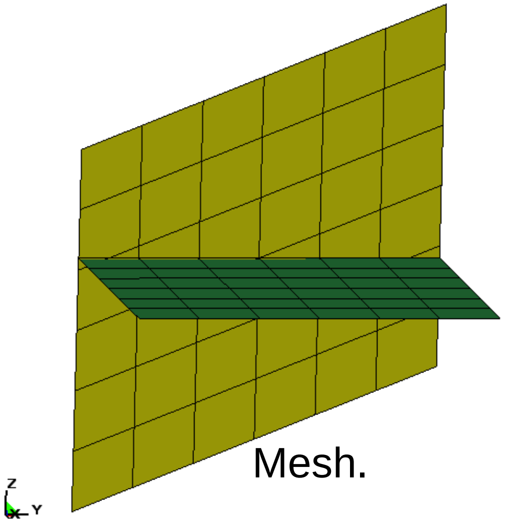
Simply supported

L-Shaped Plate Constraint Solution

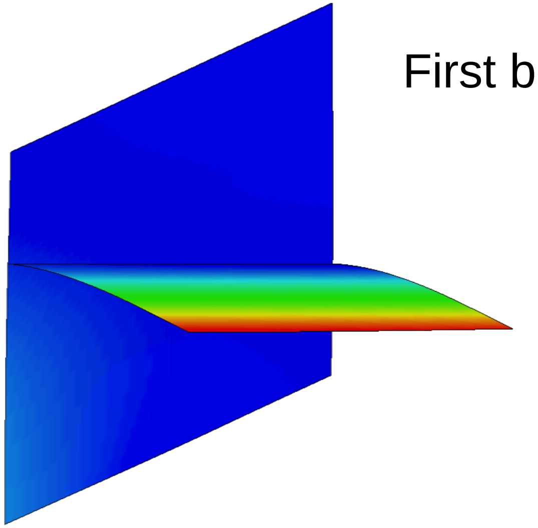


Edge to Surface Example

P=2 3x3 Patches of Thin Shells



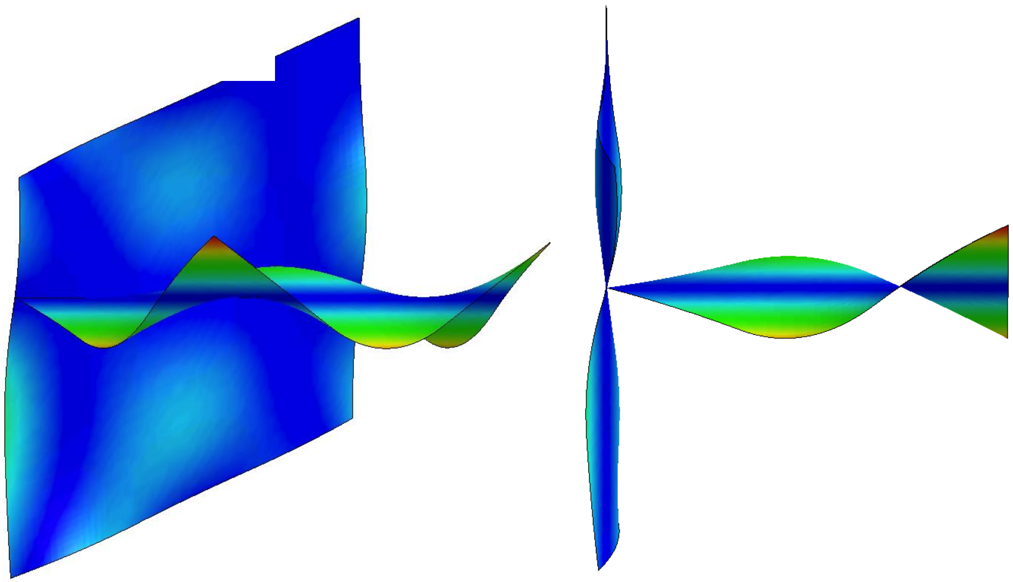
Mesh.



First bending mode.

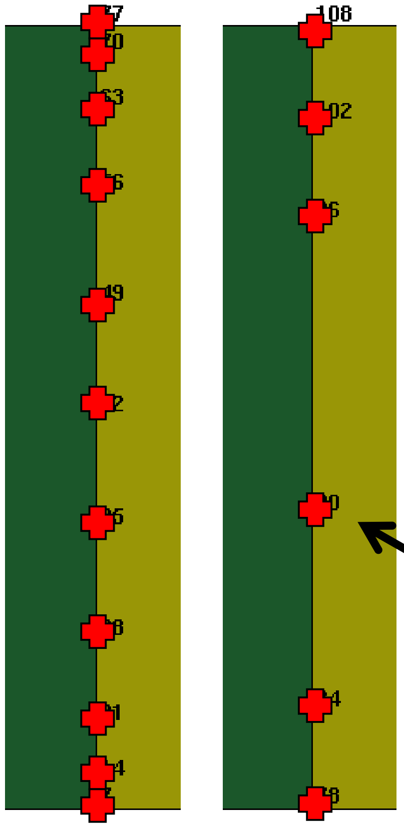
Higher order mode

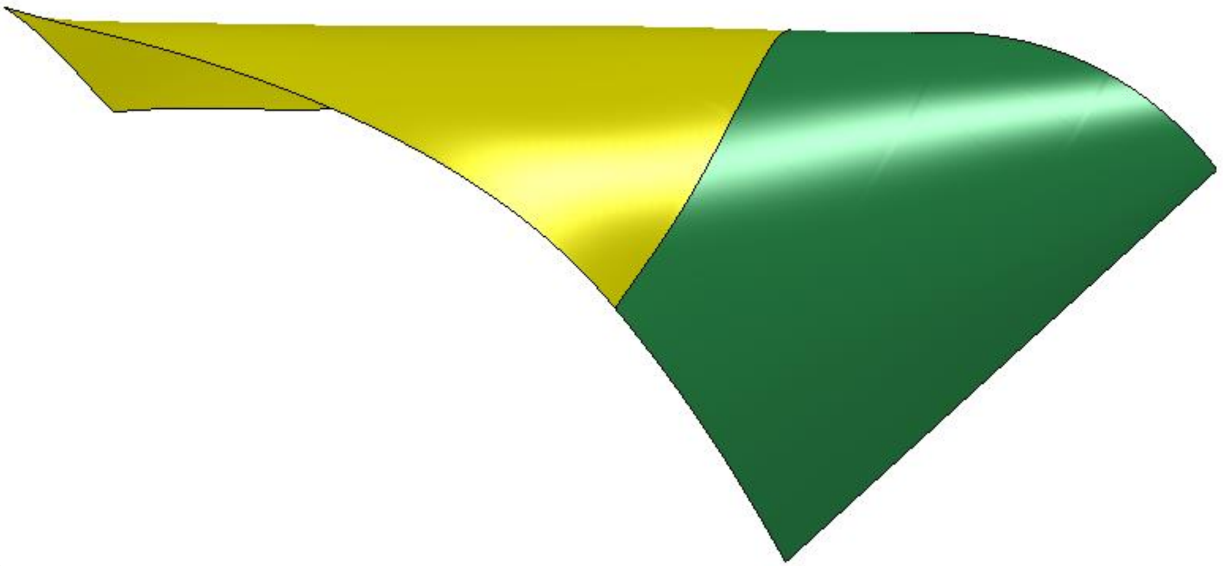
Perspective &
Side views



Large Deformation Constraint

Sensitivity to Master/Slave Choice

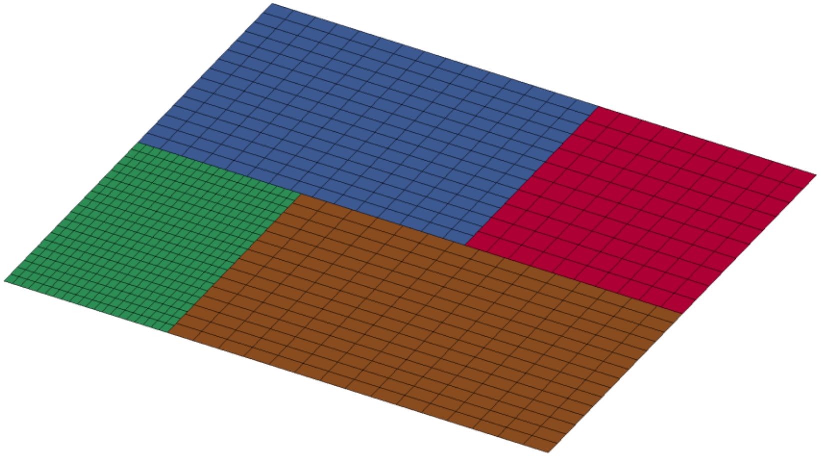


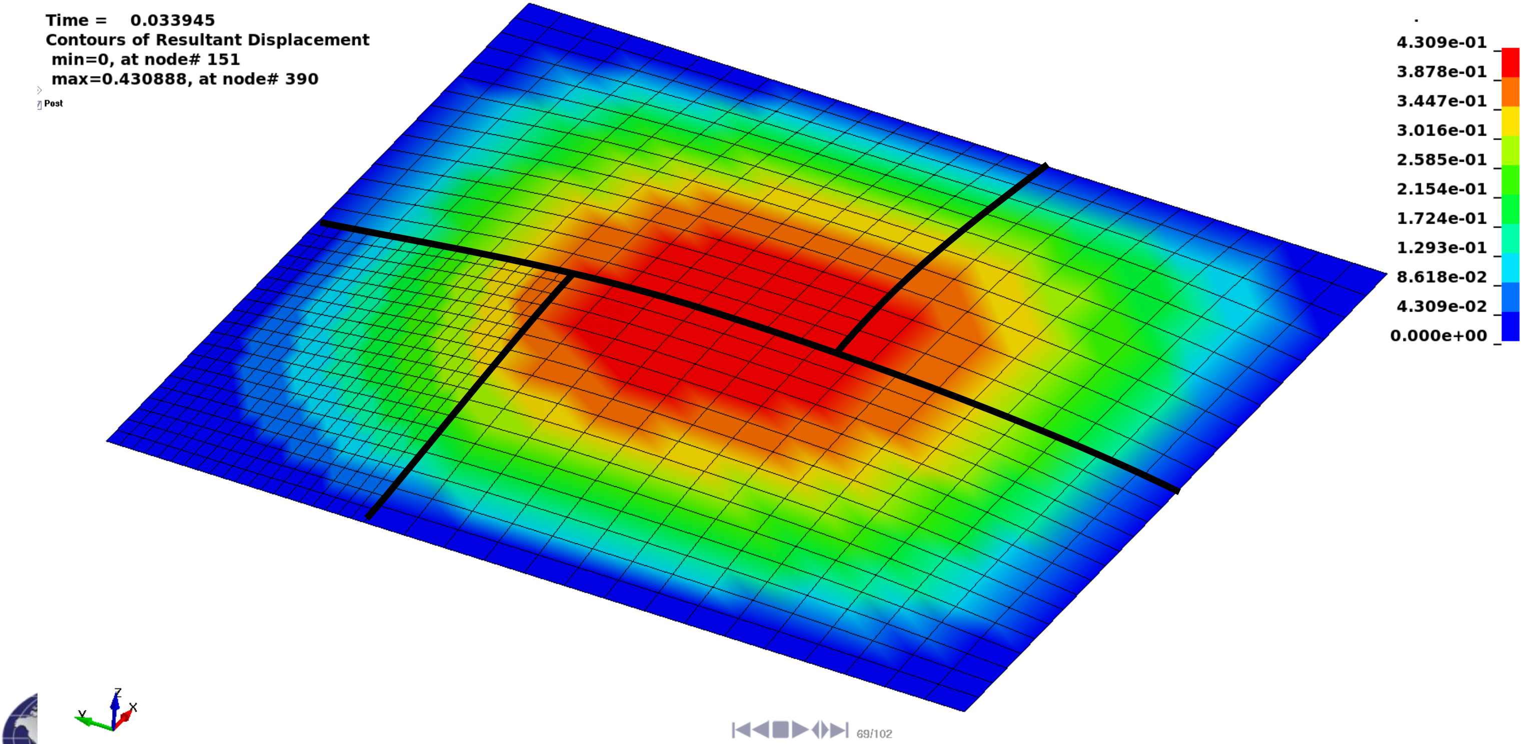


- Nonuniform coarse mesh.
- Master & slave sides reversed.
- Response virtually identical in both cases.
- Eigenvalues are somewhat different.

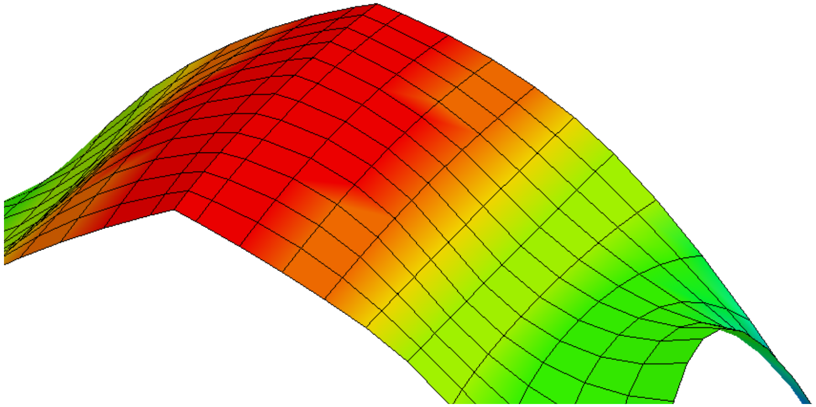
Automatic Tying at Corners

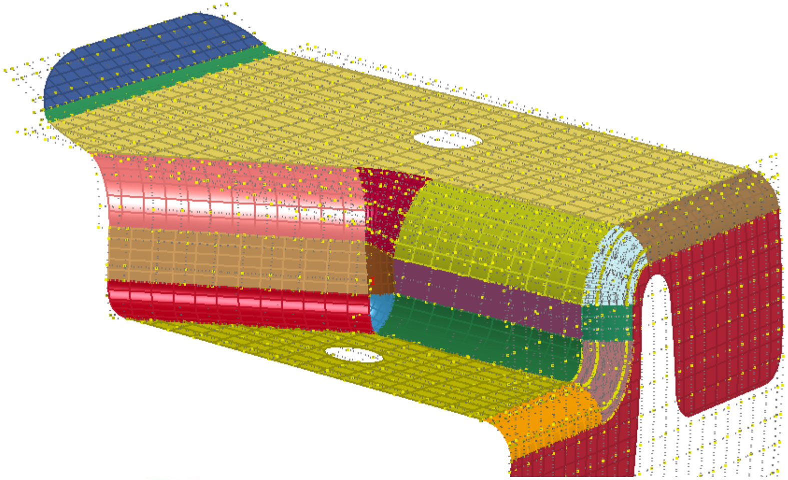
- Currently in development.
- More testing for Reissner-Mindlin.
- Issues regarding thin shells.

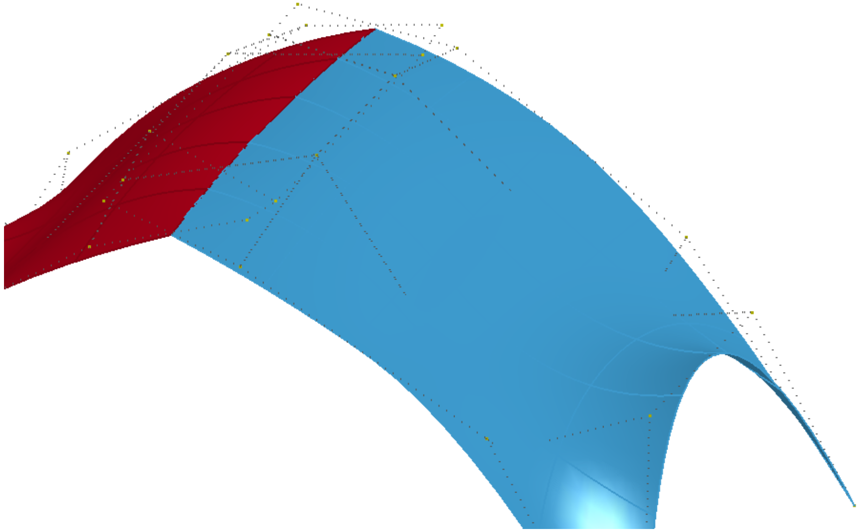


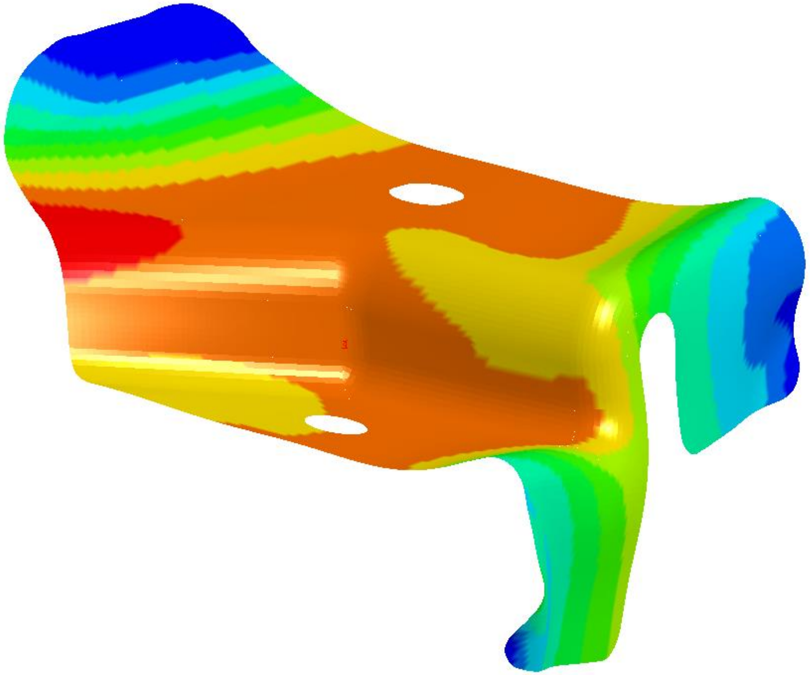


Tying Trimmed NURBS





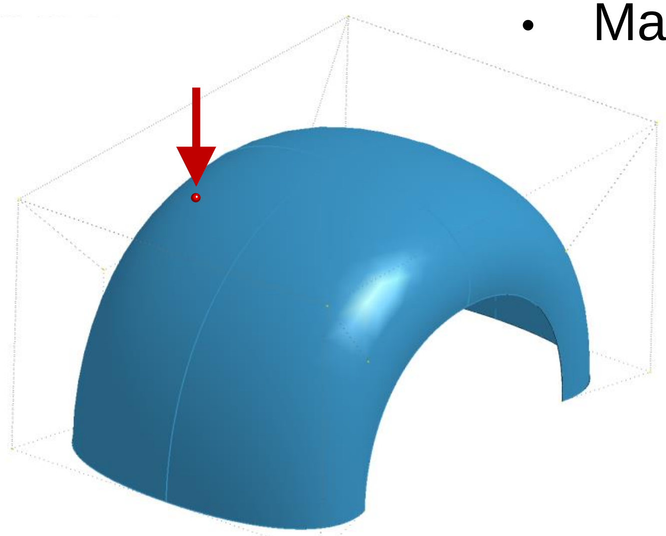




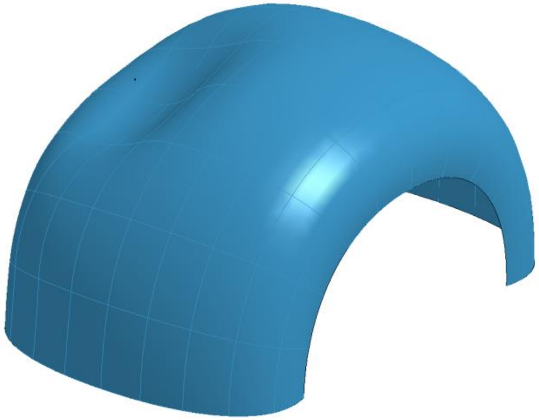
Under development

*CONSTRAINED_NODE_TO_NURBS_PATCH

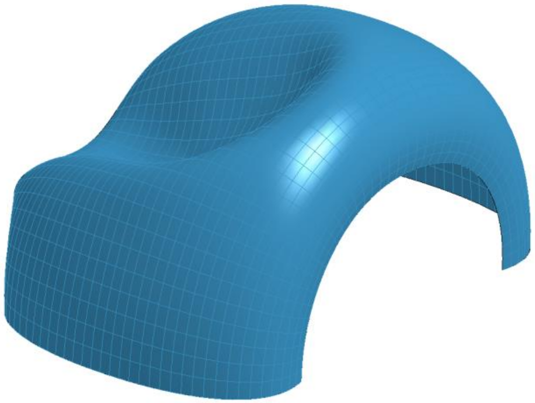
- Tie any *NODE to a NURBS surface.
- Possibility to apply force and displacement BCs.
- May be helpful for spotweld-modeling.



Quadratic NURBS
(2x2 Elements)

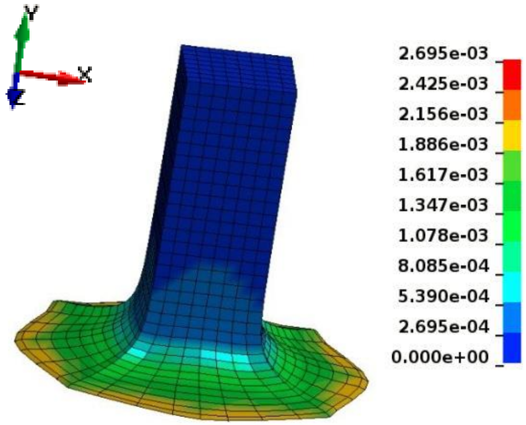


Deformation
Quadratic NURBS
(10x10 Elements)

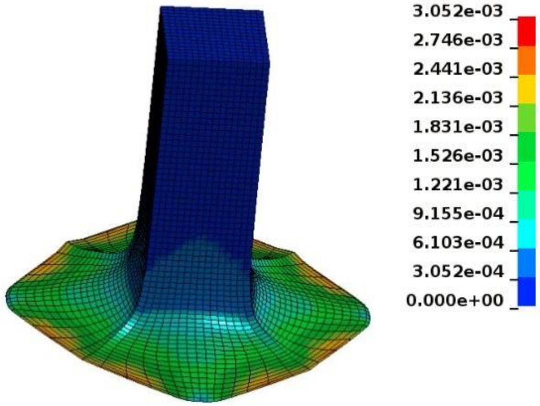


Deformation
Quadratic NURBS
(40x40 Elements)

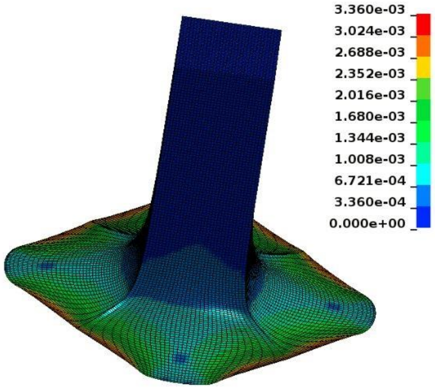
Taylor Bar With NURBS Solid Elements



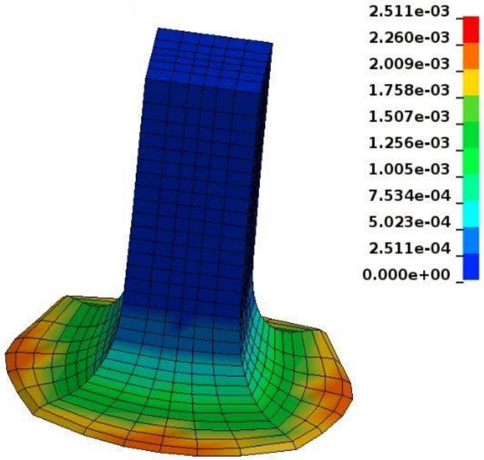
FEA: Node# 9 × 9 × 33



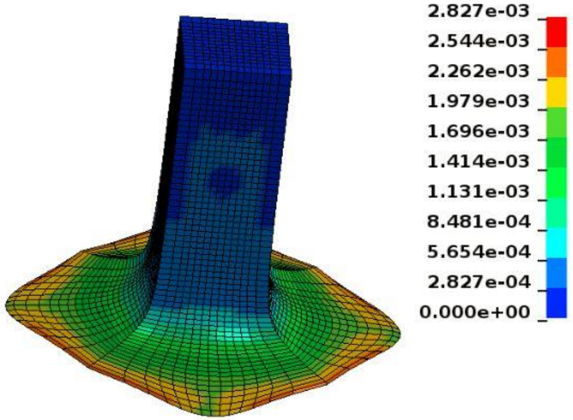
FEA: Node# 17 × 17 × 65



FEA: Node# 33 × 33 × 129 (reference)



IGA: Node# 5 × 5 × 17

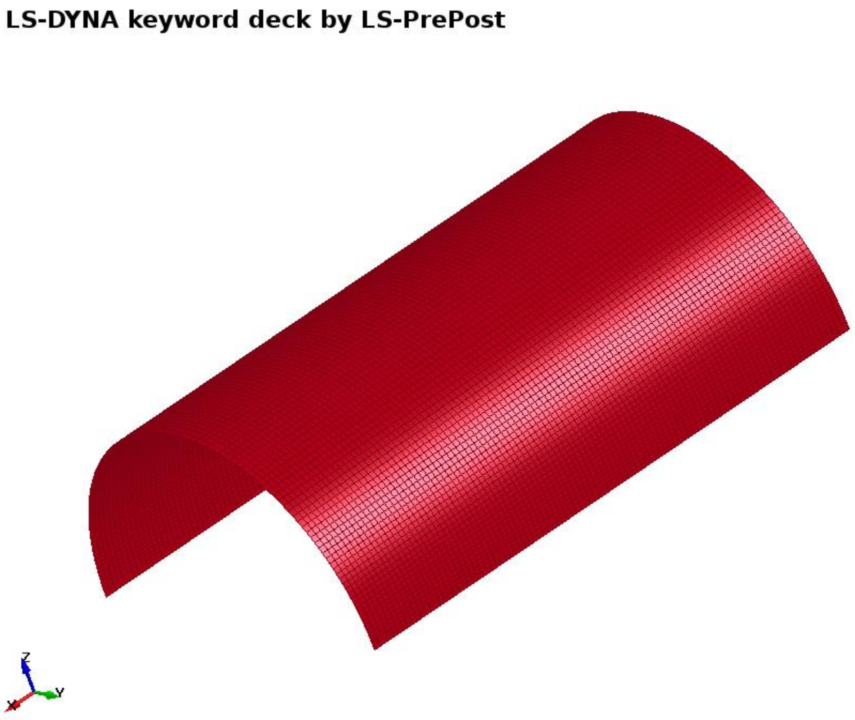


GA: Node# 9 × 9 × 33

- The stress distribution are very similar for all cases.
- When node# increase, the maximum stress is closer to the reference one.

OpenMP for IGA: Enables Hybrid MPP

OpenMP is now available for IGA shells and solids



# CPU	1	4
Clock time (minutes)	15	7

# CPU	1	4
Clock time (minutes)	78	33

Penalty-based BC Input

Available since 97790/dev

*CONSTRAINED_EXTRA_NODES_NURBS

Variable	PATCHID	NSID	CON	CID	SF			
Type	I	I	I	I	F			

CON: Constraint parameter for extra node(s) of NSID. This is same as CON2 when CM0=-1 as described in CONSTRAINED_NODAL_ROGIDBODY or MAT_RIGID. For example '1110' means constrained z-translation, x-rotation and y-rotation

CID: Coordinate system ID for constraint

SF: Penalty force scale factor

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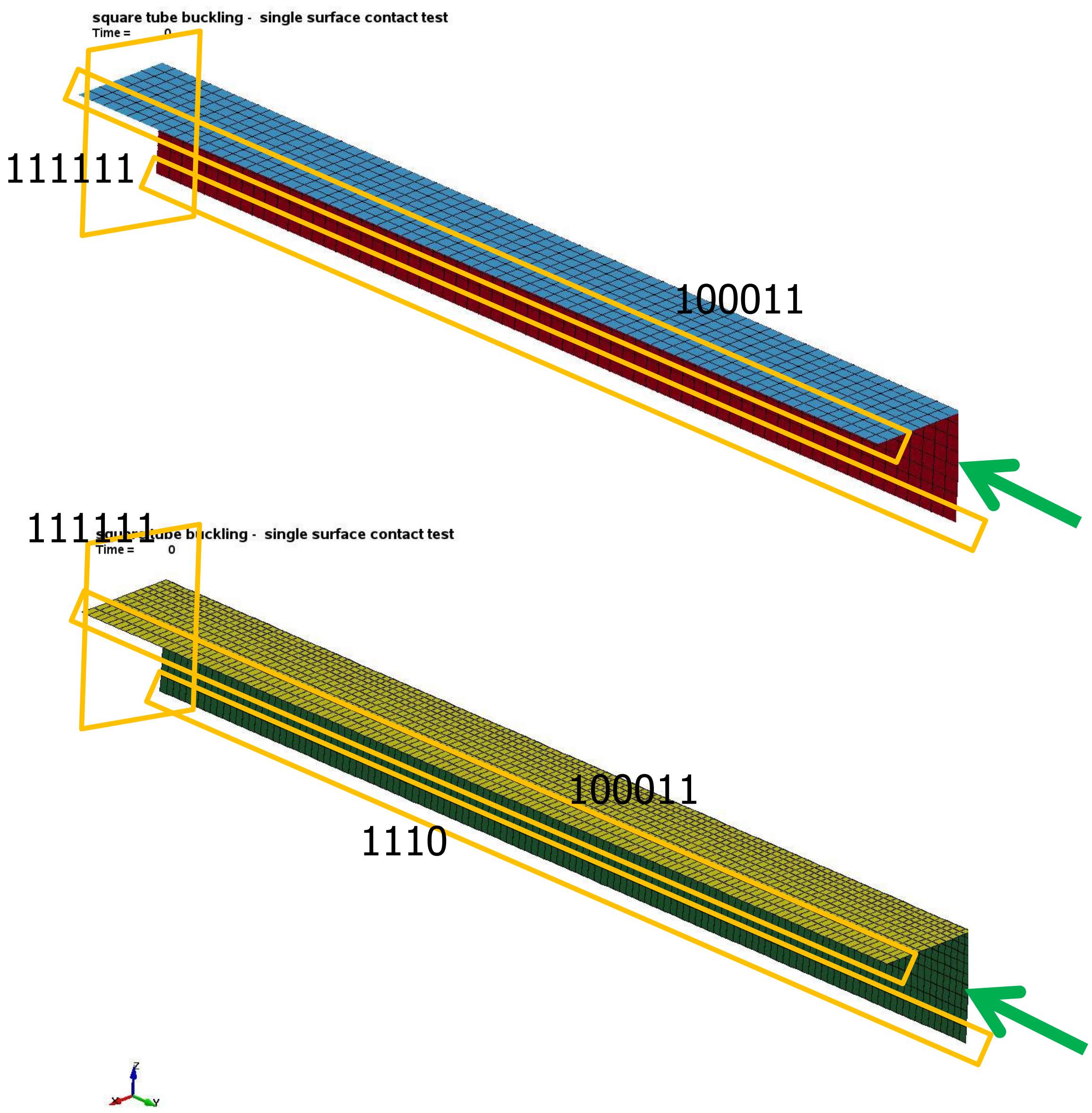
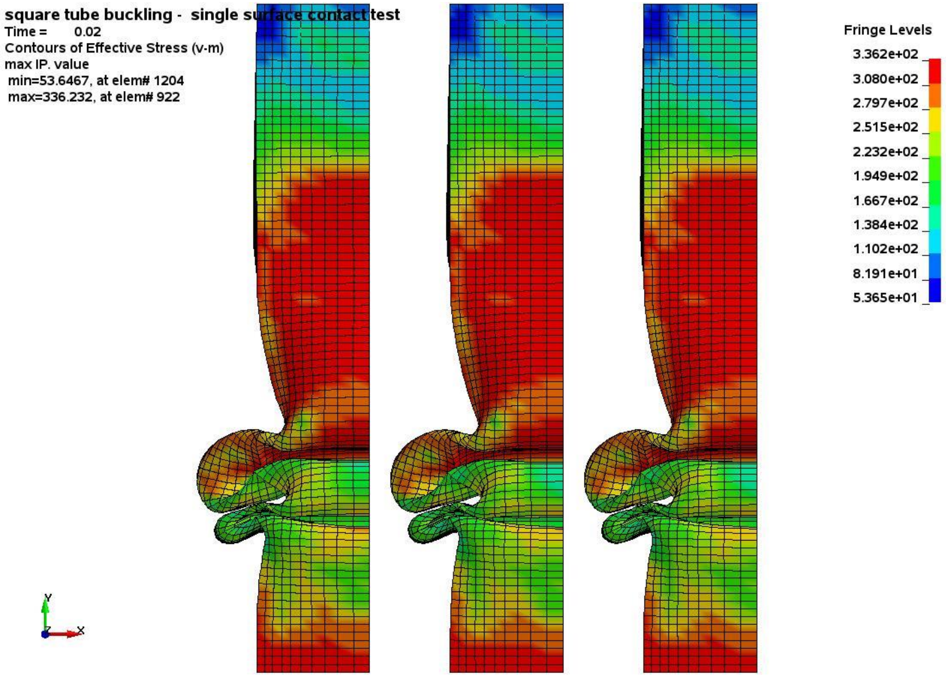
Tube Crushing

- Baseline
  - Boundary_spc on control points
- Penalty based SPC
  - constraint on extra nodes



Tube Crushing Using Segment-based Contact

Time = 0.2

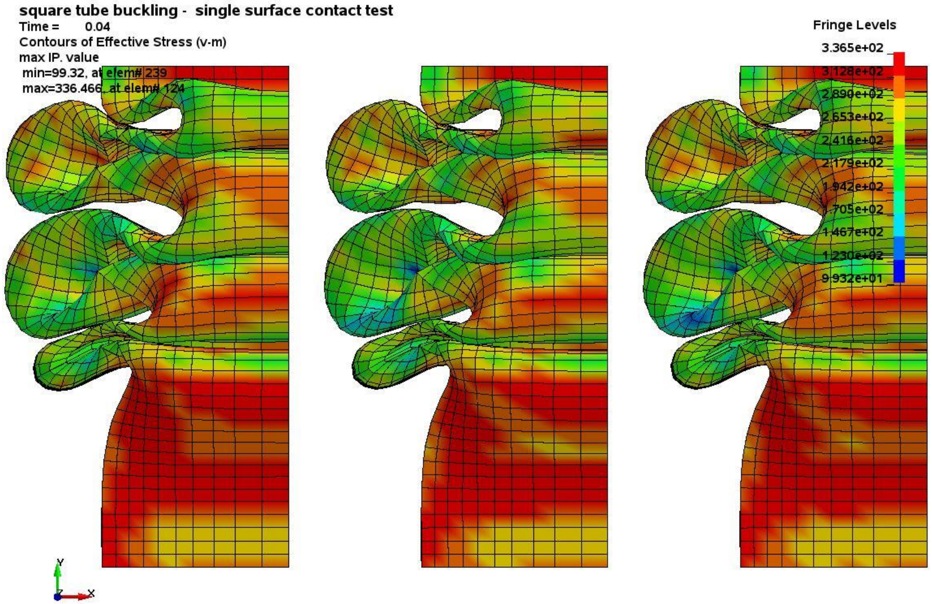


SPC Baseline 4CPU

Penalty-based 4CPU

SMP

Time = 0.4



Baseline 4CPU

Penalty-based 4CPU

SMP

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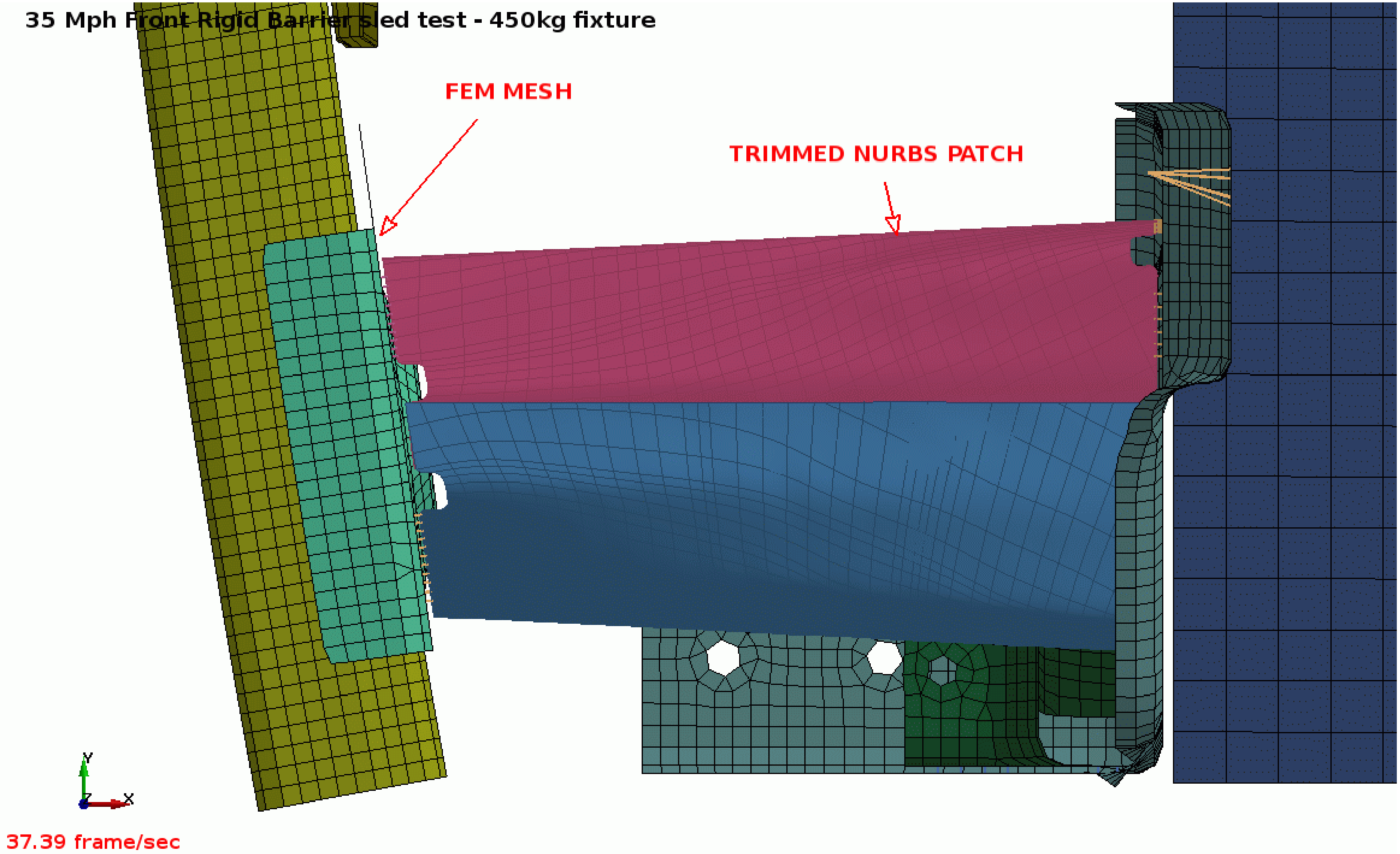
Future Tied Contact Development

- Automation for user:
  - Specify part set for automatic tying.
  - Elimination of redundant constraints.
  - Adopt technology currently used for adaptive constraints.
- New capabilities:
  - Surface-to-surface for solids.
  - Shell-to-solid tied contact.
  - Expansion of mortar contact formulation.

Combined FEA + IGA



Talk 6.2 *Current Status of LS-DYNA® Iso-geometric Analysis in Crash Simulation*
Y. Chen, S-P. Lin, O. Faruque, J. Alanoly, M. El-Essawi, R. Baskaran

Future Element Development

- Element failure and erosion.
- T-splines for solids.
- Enhanced through-thickness kinematics:
  - Metal stamping (with 3-D material models).
  - Laminated composites.
  - Sandwich structures.
- Include more materials

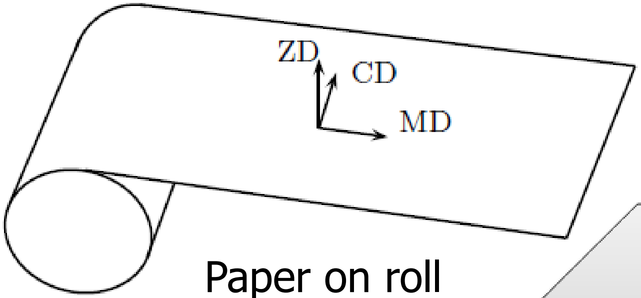
Future Evolution

- Many of the basics (element types, contact, materials, etc.) are available or will soon be available.
- Incremental improvements will be required as user needs and applications evolve.
- Making IGA compatible with the specialized capabilities of LS-DYNA will occur as the need arises.
- Pre- and post-processing will also evolve.
  - Although IGA was promised to work without mesh generation, the reality is different.
  - OpenGL is surprisingly inefficient in handling NURBS.
  - Keyword addition is progressing smoothly.

Material

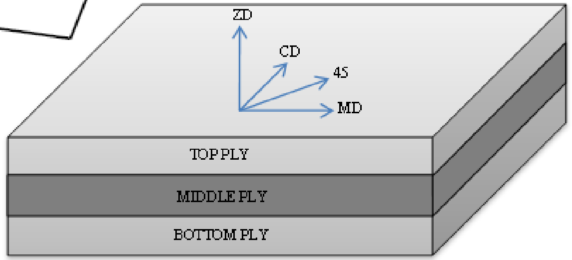
Paperboard Modeling

- For shell or solid modeling
- *MAT_PAPER (*MAT_274)
  - Hyp(er/o)elastic-plastic orthotropic model
  - Out-of-plane elasticity non-linear in compression
  - In-plane and out-of plane plasticity models uncoupled
    - In-plane yield surface consists of 6 planes (tension/compression in MD,CD,MD/CD)
    - Out-of-plane yield surfaces in compression and transverse shear
- *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

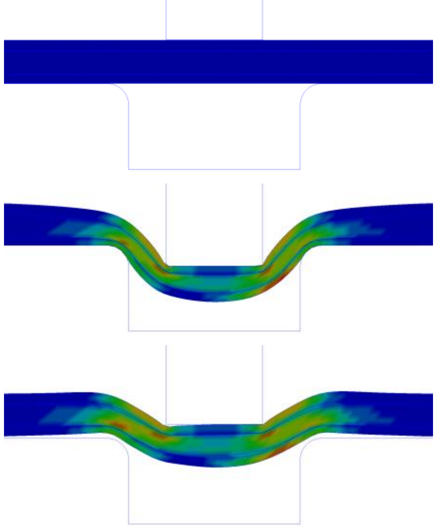


Paper on roll

Laminate

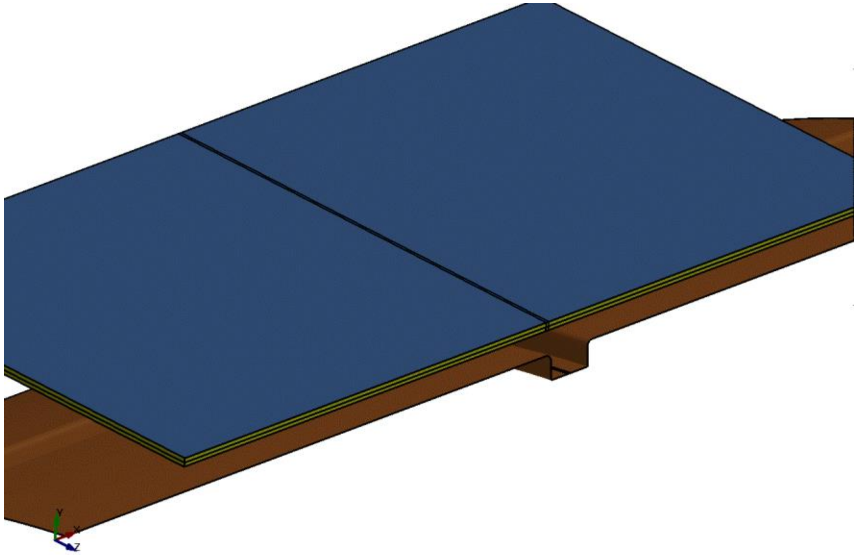


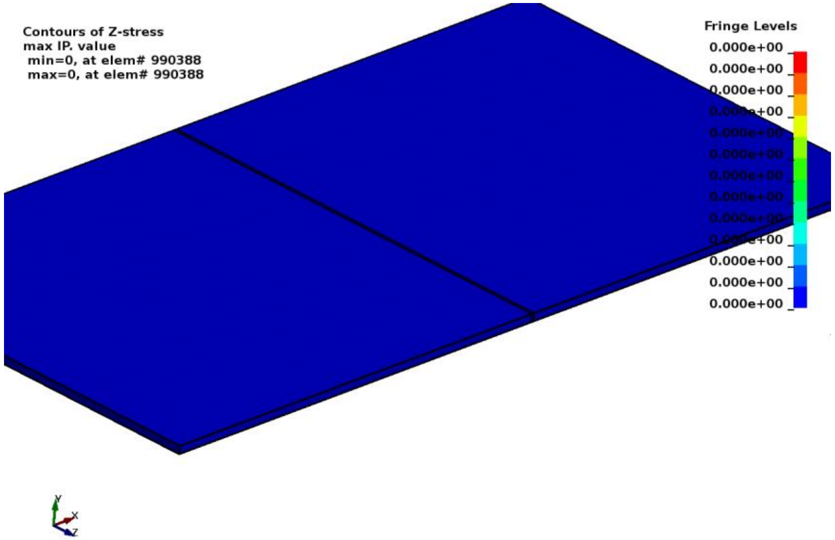
Creasing of paperboard



Jesper Karlsson,
"Two New Models for Paperboard Materials"

Rotational Creasing Simulation and Forming





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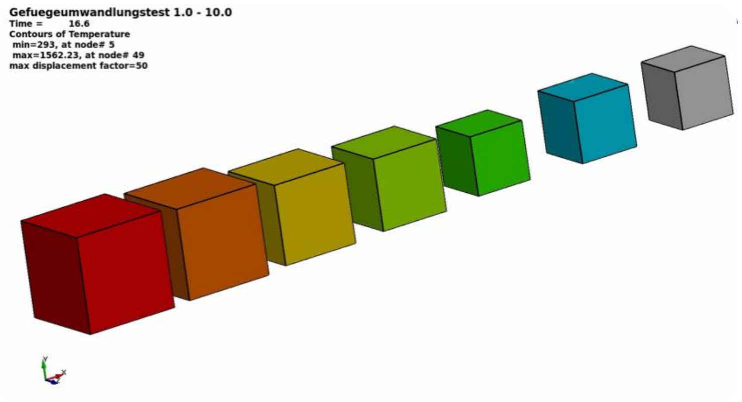
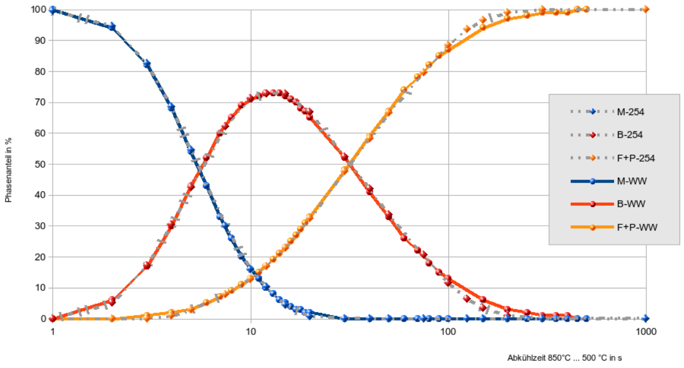
*MAT_254 / *MAT_GENERALIZED_PHASECHANGE

- 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 chose from a list of generic phase change mechanisms:
  - Leblond,
  - JMAK,
  - Koistinen-Marburger,
  - Kirkaldy,
  - Oddy, …



- Parameters for transformation law are directly given in tables
- Additional features:
  - Transformation induced strains
  - Transformation induced plasticity (TRIP)
  - Temperature and strain rate dependent plasticity
- Ongoing development



*MAT_277 / *MAT_ADHESIVE_CURING_VISCOELASTIC

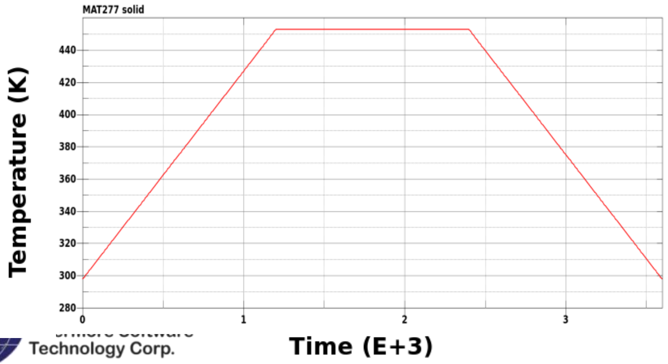
- Curing of epoxy adhesives and implied changes of mechanical behavior
- Curing kinetics computed with the Kamal model for degree of cure α:
- Visco-elastic material with Prony-series representation
  - State of cure dependence

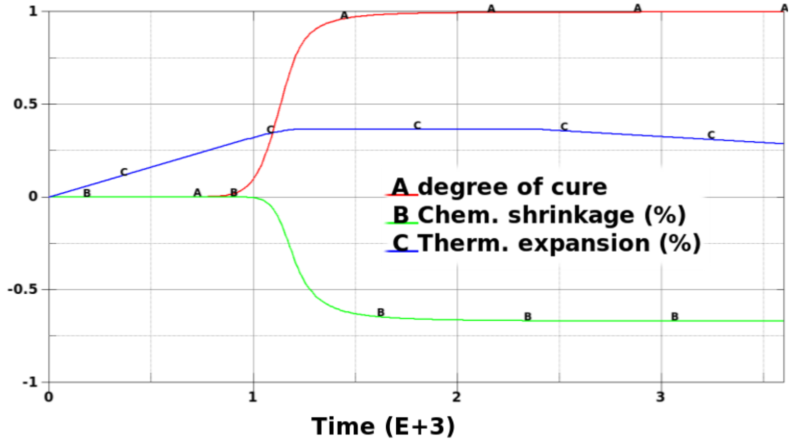
$$G(t,\alpha) = G_\infty(\alpha) + \sum_{i=1}^{N} G_i(\alpha)\, e^{-t/\tau_i} = G_0(\alpha)\left(1-\sum_{i=1}^{N}\frac{G_i(\alpha_{1.0})}{G_0(\alpha_{1.0})}\left(1-e^{-\beta_i t}\right)\right)$$

  - WLF shift based on temperature

$$\tau_i(T) = a_T(T)\cdot\tau_{i,0}, \quad \ln a_T = \frac{-A\left(T-T_{ref}\right)}{B+\left(T-T_{ref}\right)}$$

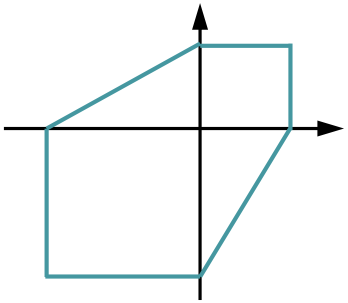
- Chemical shrinkage as function of state of cure α
- Coefficient of thermal expansion as function of temperature T and degree of cure α

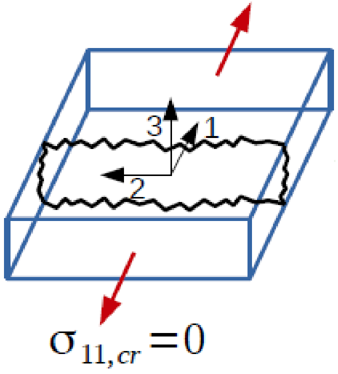


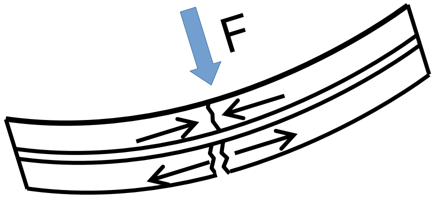


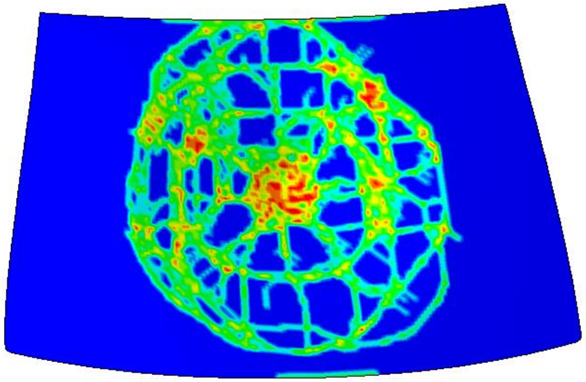
*MAT_280 / *MAT_GLASS

- New material model for fracture of glass
- Developed as user material, now implemented as *MAT_280
- Brittle smeared fixed crack model for shell elements (plane stress)
- Failure criteria: Rankine, Mohr-Coulomb, Drucker-Prager, …
- Incorporates up to 2 cracks, simultaneous failure over thickness, crack closure effect (no element deletion), …







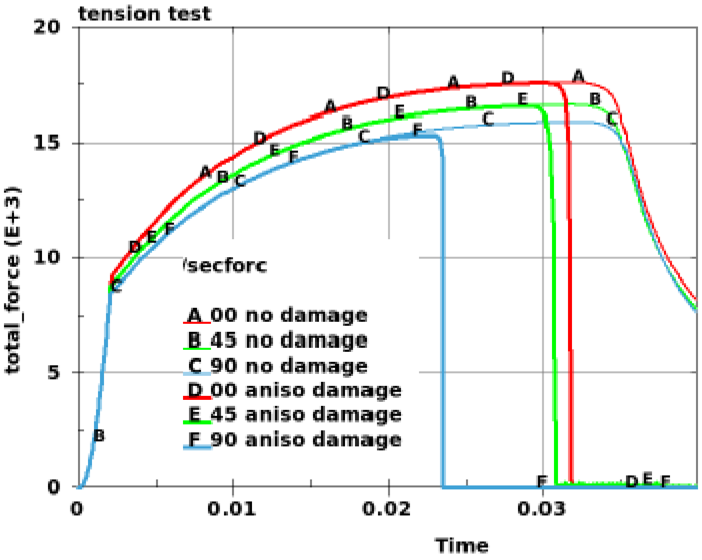


*MAT_ADD_GENERALIZED_DAMAGE (MAGD)

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

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

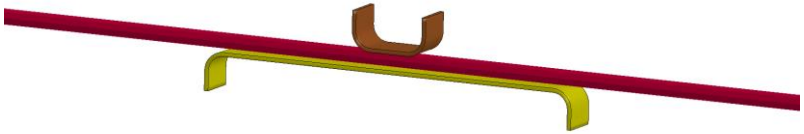
```
*DEFINE_FUNCTION
101
Func101(d1,d2,d3)=1.0-d1
```

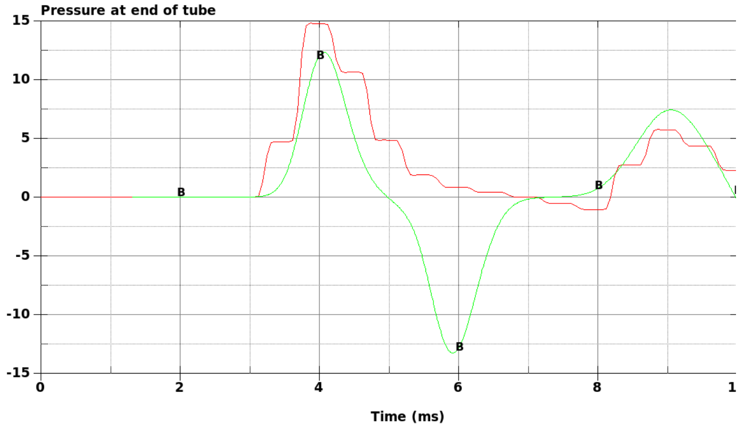


Keynote talk by P. Du Bois: “A new versatile tool for simulation of failure in LS-DYNand the application to aluminum extrusions“

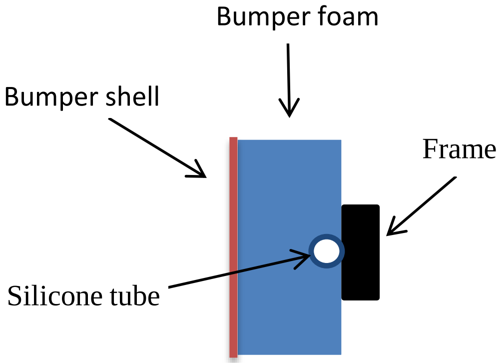
Contact , B.C, Constraint & Loading

Pressure Tube





- *DEFINE_PRESSURE_TUBE
  - Air filled silicone tube embedded in bumper foam
  - Pressure sensors at tube ends detects crash
- Acoustic approximation of 1D compressible Euler for pipes with varying cross section area
- Tube defined by beam elements, area changes due to contact penetration



Bumper foam

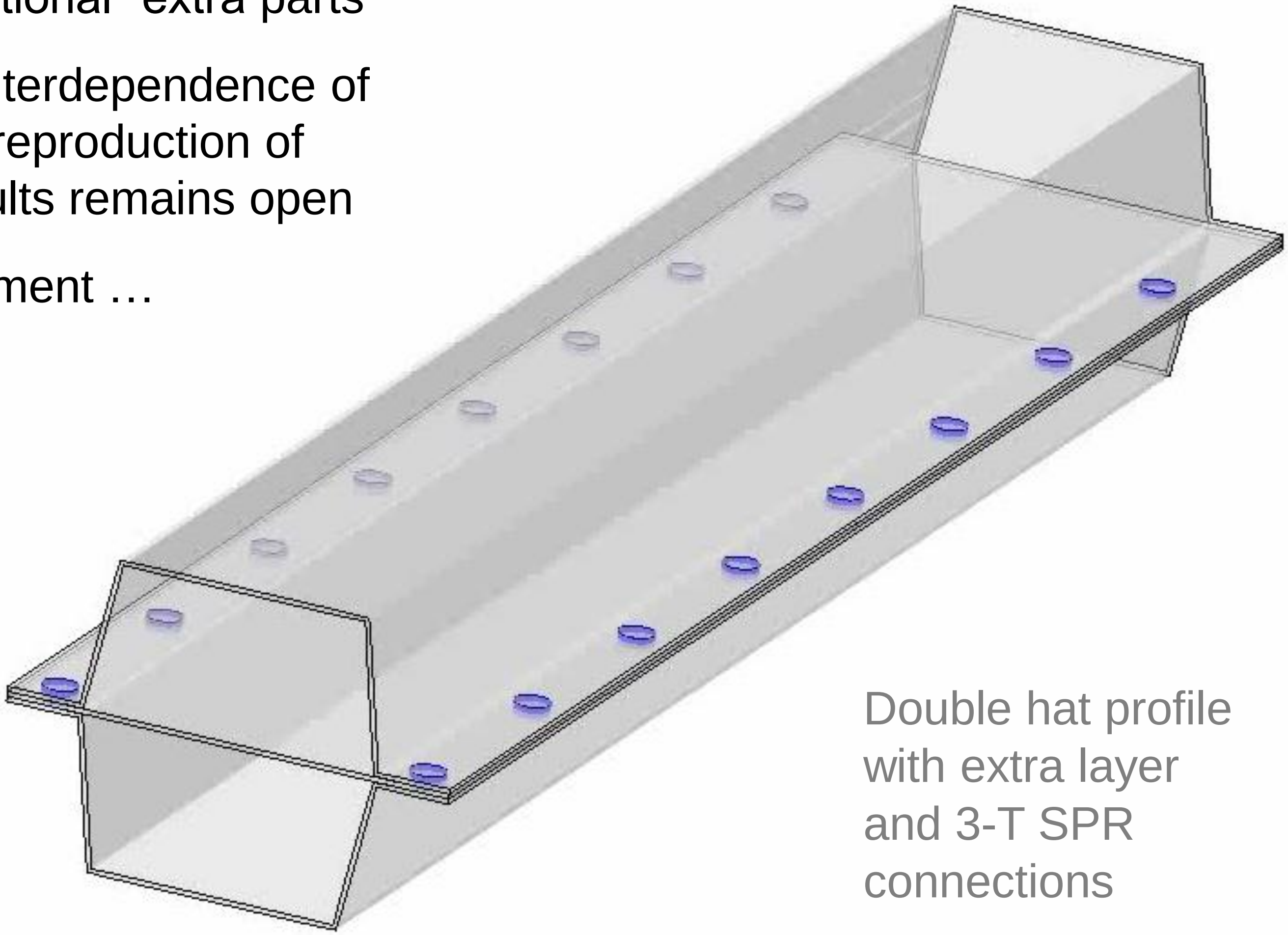
Bumper shell

Frame

Silicone tube

*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
- Ongoing development …



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

*CONTACT_AUTOMATIC_..._TIEBREAK_USER

- User-defined interface for tiebreak contact
- Alternative models to Dycoss and others can be implemented
- Available for SMP and MPP

```
 subroutine utb101(sig_n,sig_t,disp_n,disp_t,vel_n,vel_t,cn,ct,
     . uparm,uhis,idcon,idsn,idms,areasn,areams,time,dt2,ncycle,crv,
     . nnpcrv,temp,ifail,ioffset)
c
c     User subroutine for tiebreak contact: OPTION=101
c
c     Purpose: To define normal and tangential stresses and possible failure
c              in a contact with tiebreak connection
c
c     Variables:
c
c     sig_n,sig_t    = normal and tangential stress (output)
c     disp_n,disp_t  = normal and tangential displacement (input)
c     vel_n,vel_t    = normal and tangential relative velocity (input)
c     cn,ct          = normal and tangential stiffness (input)
c     uparm          = user defined tiebreak parameters (input)
c     uhis           = user defined tiebreak history variables (input/output)
c     ...
```

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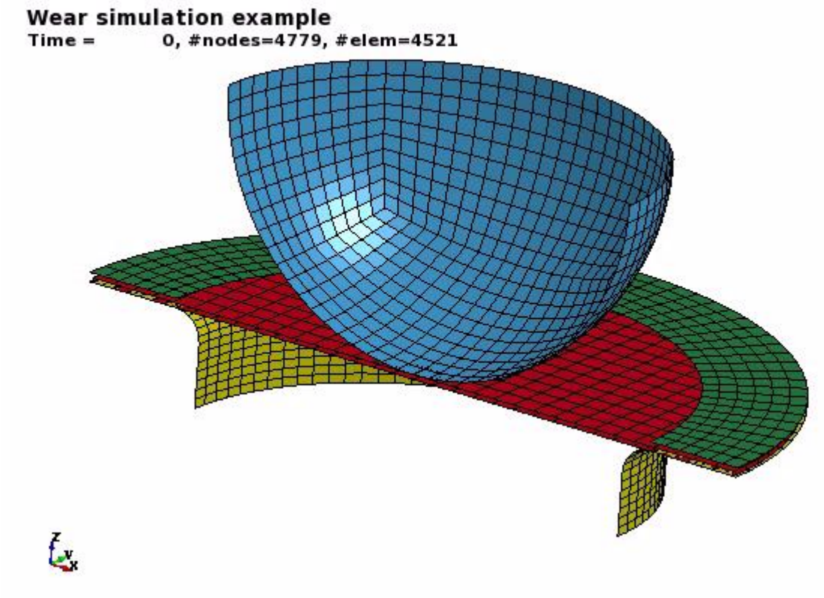
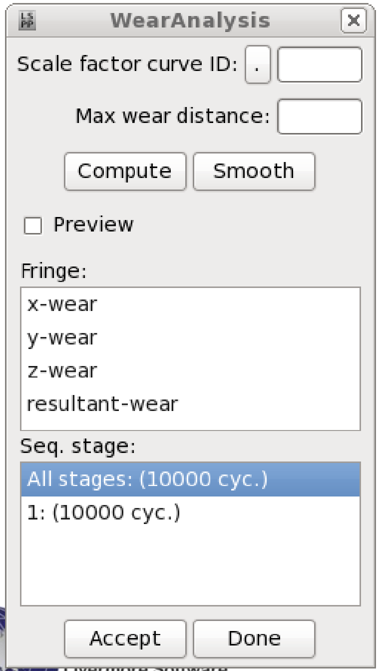
Wear Processes

- *CONTACT_ADD_WEAR
  - Archard and User wear laws
  - Post process wear in LS-PrePost
  - Modify geometry in LS-PrePost based on wear, using *INITIAL_CONTACT_WEAR





Scale factor curve ID: .

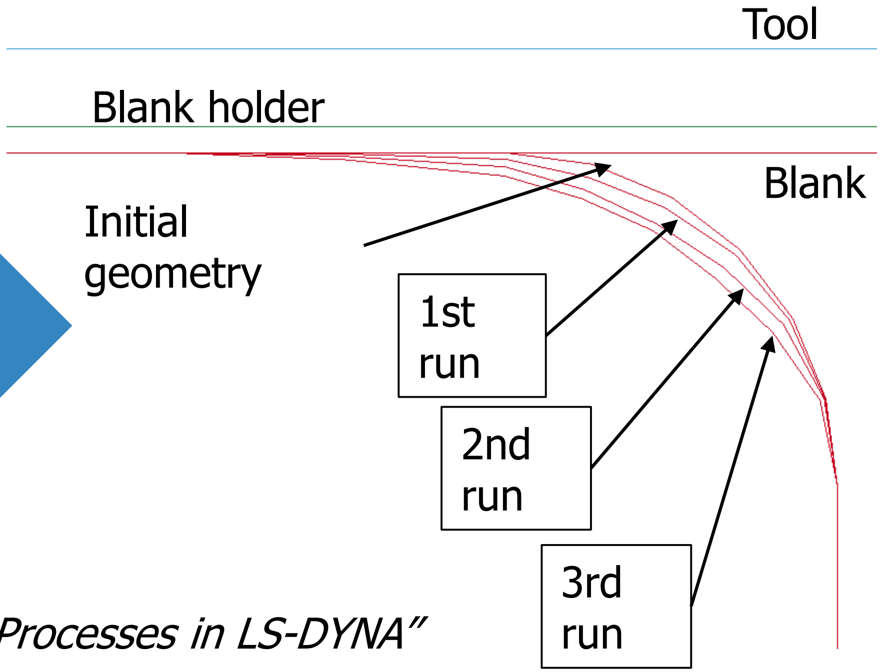
Max wear distance:

☐ Preview

Fringe:
- x-wear
- y-wear
- z-wear
- resultant-wear

Seq. stage:
- All stages: (10000 cyc.)
- 1: (10000 cyc.)

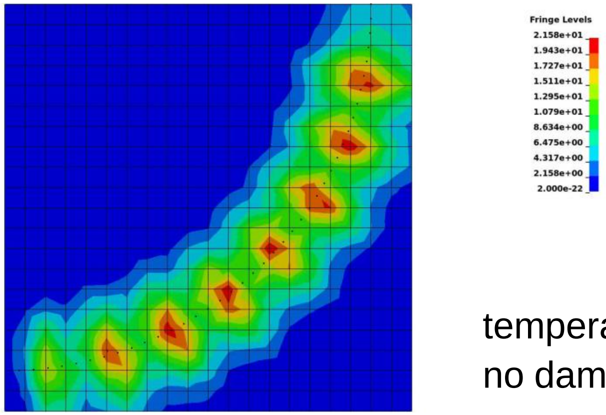
Iterations between LS-DYNA and LS-PrePost



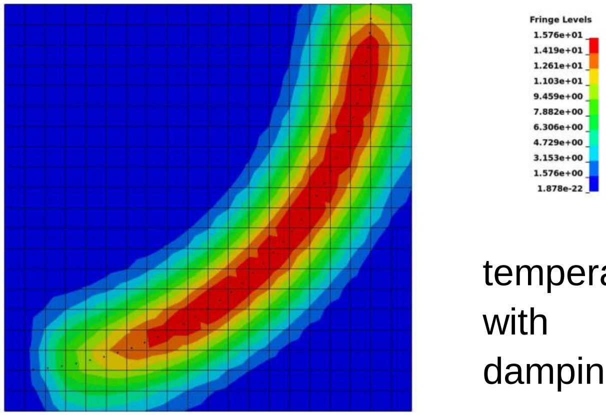
Borrvall et al,
"Simulation of Wear Processes in LS-DYNA"

*BOUNDARY_THERMAL_WELD_TRAJECTORY

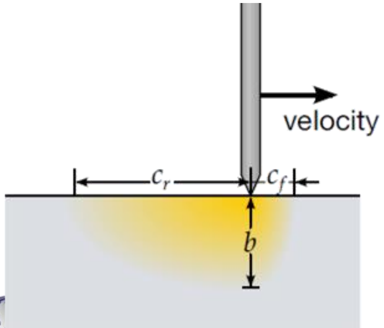
- Define a heat source motion along a trajectory (nodal path) with a prescribed velocity
- Works in thermal-only and coupled analyses (SMP and MPP)
- Weld beam aiming direction can be defined
  - By a constant vector
  - Normal to a segment set
  - By a second trajectory
- Applicable to solids and thermal thick shells
- User can choose from a list of pre-defined equivalent heat sources

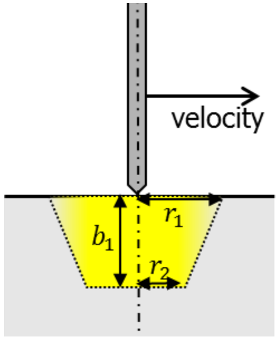


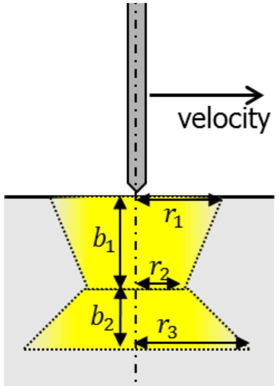
temperature
no damping



temperature
with
damping

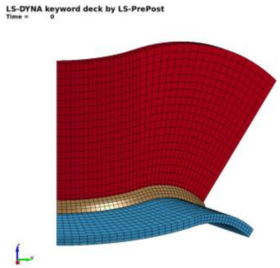






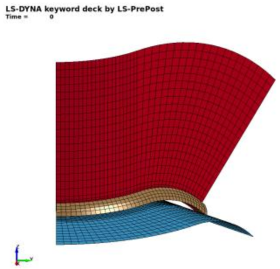
*BOUNDARY_THERMAL_WELD_TRAJECTORY

Example: Three-dimensional curved T-Joint, thermal-only analysis



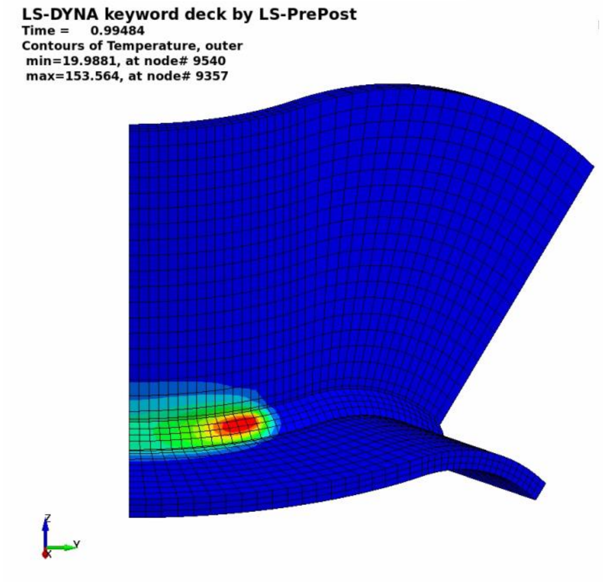
```
LS-DYNA keyword deck by LS-PrePost
Time =        0
```

Solids



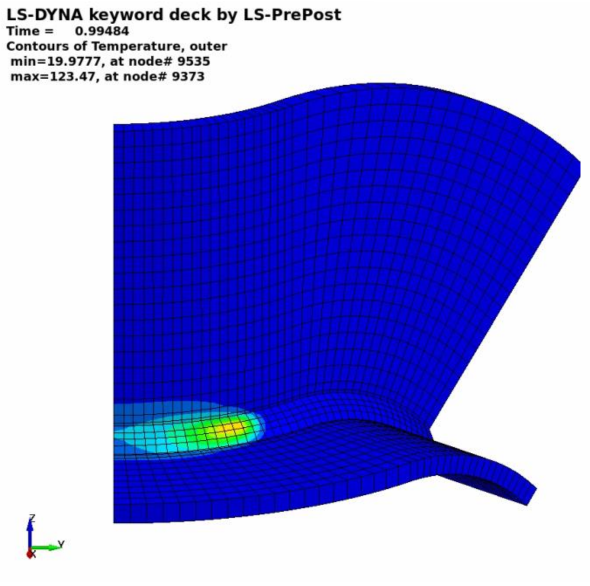
```
LS-DYNA keyword deck by LS-PrePost
Time =        0
```

Solids and shells



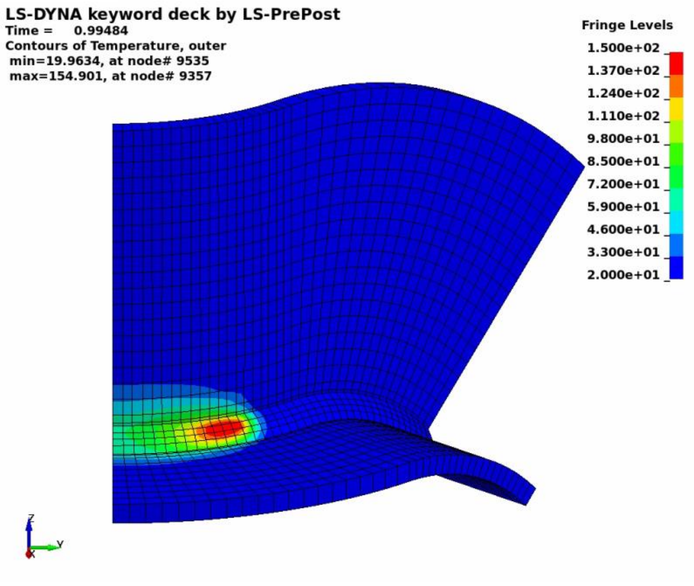
```
LS-DYNA keyword deck by LS-PrePost
Time =     0.99484
Contours of Temperature, outer
 min=19.9881, at node# 9540
 max=153.564, at node# 9357
```

BC on all solids



```
LS-DYNA keyword deck by LS-PrePost
Time =     0.99484
Contours of Temperature, outer
 min=19.9777, at node# 9535
 max=123.47, at node# 9373
```

BC on solids only



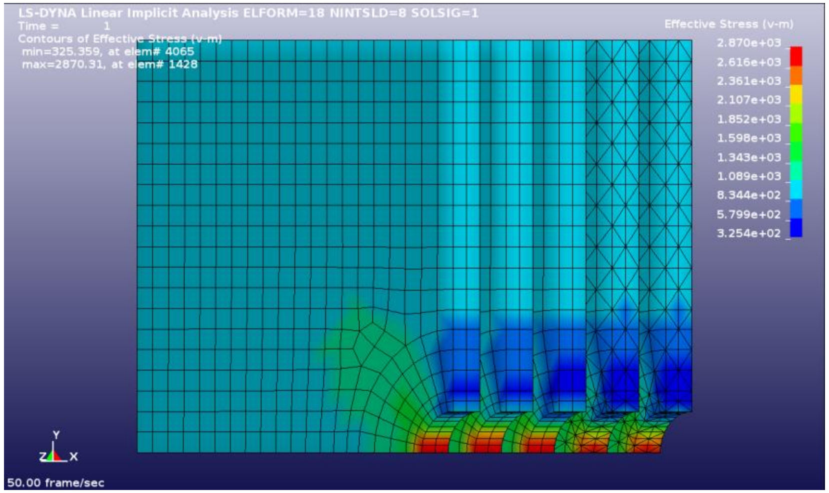
```
LS-DYNA keyword deck by LS-PrePost
Time =     0.99484
Contours of Temperature, outer
 min=19.9634, at node# 9535
 max=154.901, at node# 9357
```

BC on solids and shells

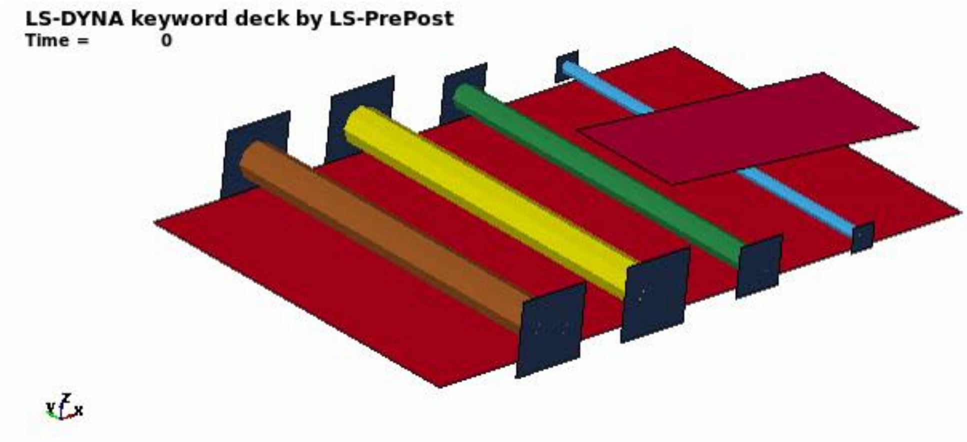
Presentation by Thomas Kloeppel: “Recent Updates for the Heat Transfer Solver in LS-DYNA ® with focus on computational welding mechanics”

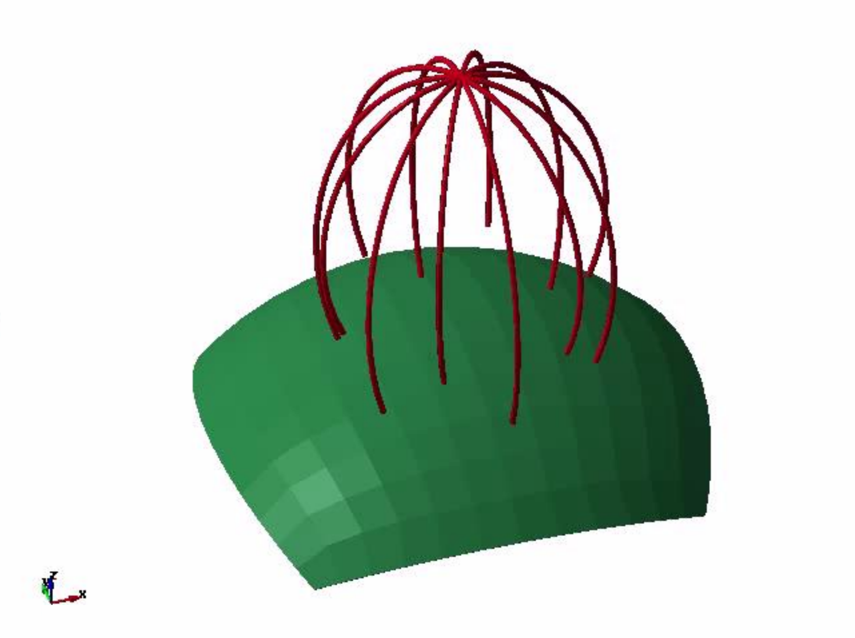
Mortar Contact for Classical FEM

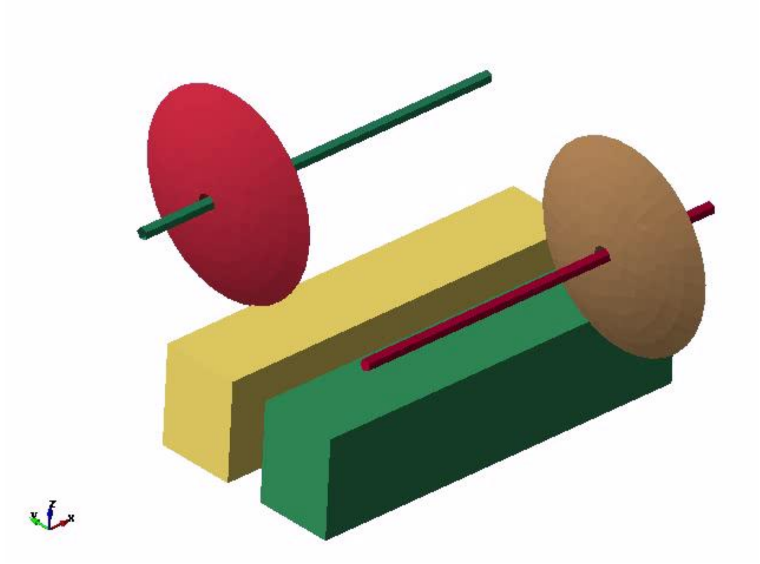
- Goal to make it simple and universal with minimal options
  - Additional CPU time for increased accuracy
  - Same contact in SMP/MPP, Implicit/Explicit
- Features and recent developments
  - Element Types Supported
    - Solids, Shells, Beams, Thick Shells, 2D solids (2D in SMP Implicit *only*)
  - Physical Geometry Contact
    - Flat edges on shells
    - Beams are cylinders with flat ends
    - Couples to rotations for beams to exert moments
    - Contact with sharp edges on solids and thick shells
  - Friction
    - Table, part and dynamic friction
    - Wear
  - *Transducers and NLOC on shells supported*
  - *Bucket sort frequency for explicit*
  - *Various tiebreak formulations implemented*
- Ongoing work
  - Implicit
    - High Order Element support
  - Explicit
    - SMP parallelism and Hybrid support

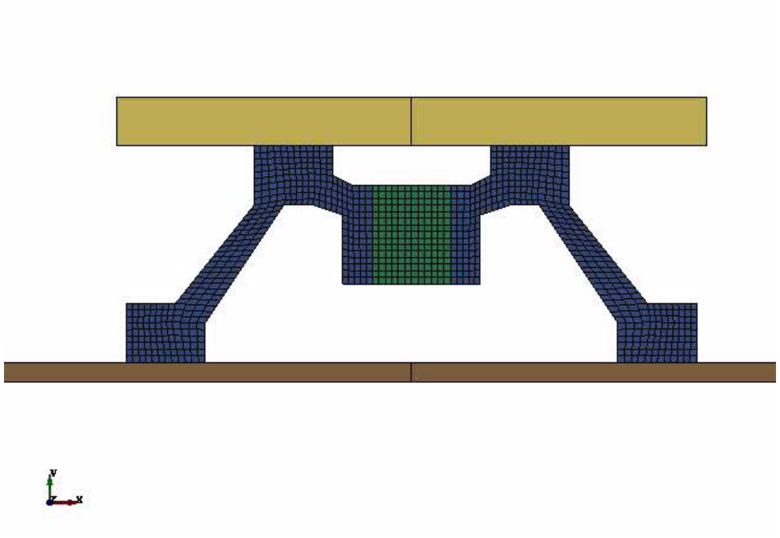


Implicit Examples



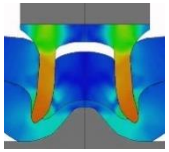






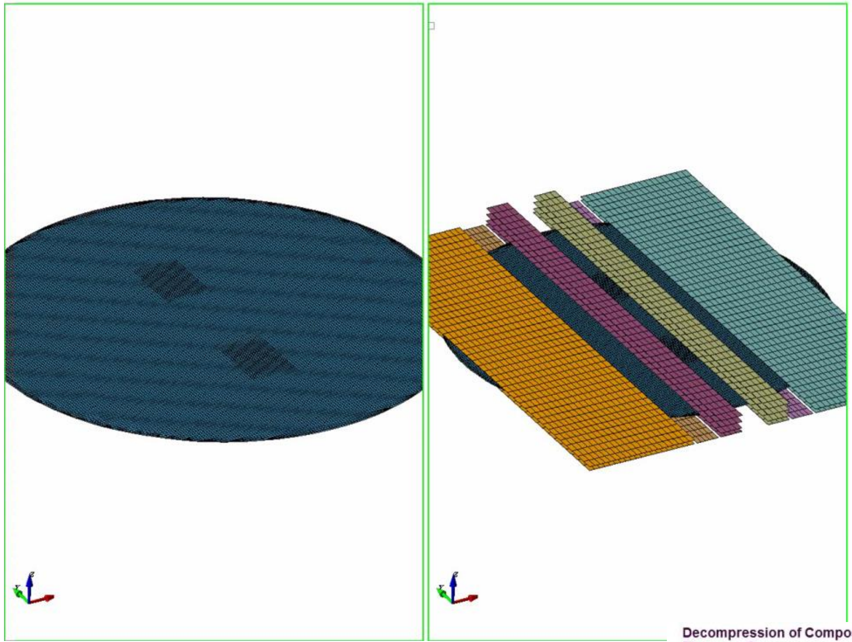
Mortar Contact – Current State for Explicit Analysis

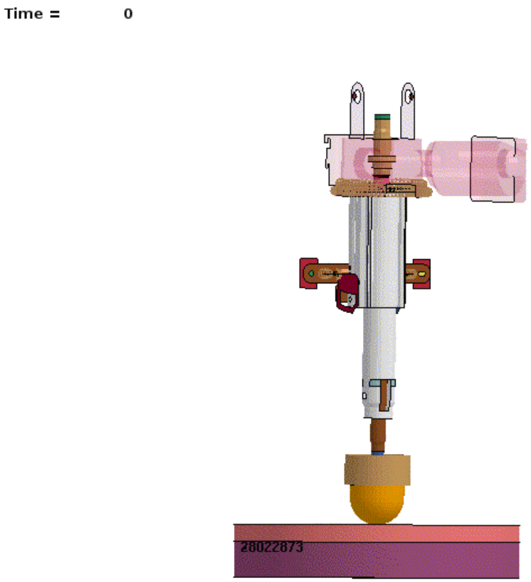
- The same contact regardless of analysis type or version
  - SMP and MPP the same
  - Implicit and Explicit the same
  - Suitable for Implicit/Explicit switch
- Explicit is supported by means of providing an alternative to well established contacts when
  - Contact results are of importance
    - Pressure distribution and friction response
  - Other contacts go unstable
- Mortar will never be as fast as the traditional SOFT contacts
  - Goal is to not fall too far behind
  - Bucket sort frequency defaulted to 100 in recent development versions



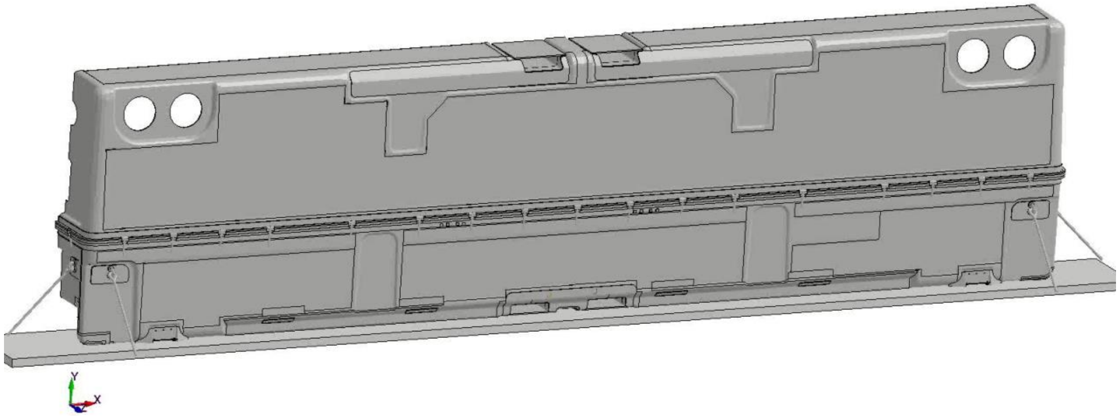
Problem	SOFT=0		SOFT=2		MORTAR	
SPR detachment (24 cores, MPP single)	1.13	2.02	1.00	1.00	1.89	6.27
					2.68	11.38
B-pillar bend (8 cores, MPP single)	1.13	1.47	1.00	1.00	2.32	10.03
					7.48	45.76

Explicit Examples





Decompression of Composite Container
Time = 0

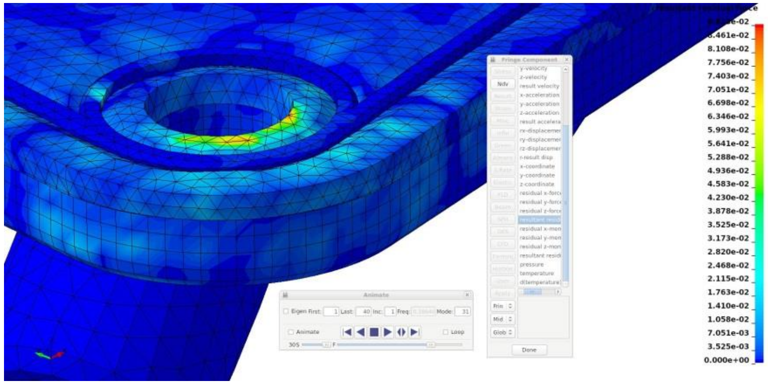


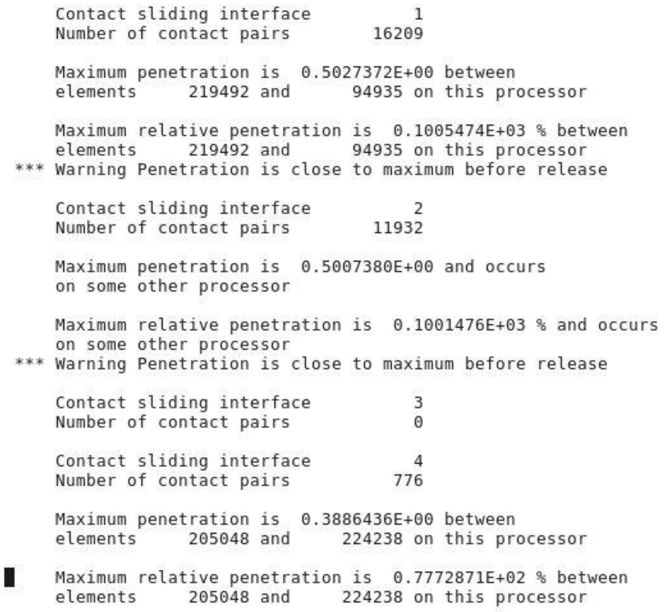
Jensen et al,
"Broad-Spectrum Stress and Vibration Analysis of Large Composite Container"

Implicit

Implicit Development – General Overview

- Linear Solvers
  - Linear Algebra team constantly working on efficiency related issues
  - Expand range of applications
  - *Nonsymmetric solver available*
- Nonlinear Solver
  - *New default in R9.0*
  - Minimize total number of iterations and stiffness reformations
    - BFGS
    - Robust line search
    - Cut-back strategies
    - Tolerances
- Features
  - Think different
    - Accurate Modeling improves robustness and convergence
    - Speed not as important as in explicit analysis
- Output
  - Facilitate debugging
    - Binary d3iter (graphical) and ascii message (text)
    - Implstat in LS-PrePost
- Documentation
  - Appendix P and Theory Manual
    - Implicit Guide
    - Nonlinear implicit and mortar contact theory





```
    Contact sliding interface          1
    Number of contact pairs        16209

    Maximum penetration is  0.5027372E+00 between
    elements     219492 and      94935 on this processor

    Maximum relative penetration is  0.1005474E+03 % between
    elements     219492 and      94935 on this processor
*** Warning Penetration is close to maximum before release

    Contact sliding interface          2
    Number of contact pairs        11932

    Maximum penetration is  0.5007380E+00 and occurs
    on some other processor

    Maximum relative penetration is  0.1001476E+03 % and occurs
    on some other processor
*** Warning Penetration is close to maximum before release

    Contact sliding interface          3
    Number of contact pairs            0

    Contact sliding interface          4
    Number of contact pairs          776

    Maximum penetration is  0.3886436E+00 between
    elements     205048 and     224238 on this processor

    Maximum relative penetration is  0.7772871E+02 % between
    elements     205048 and     224238 on this processor
```

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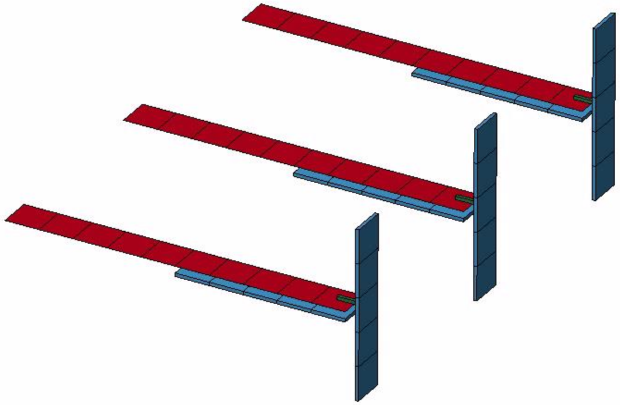
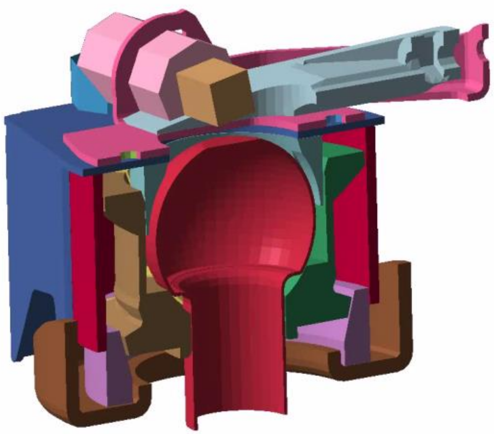
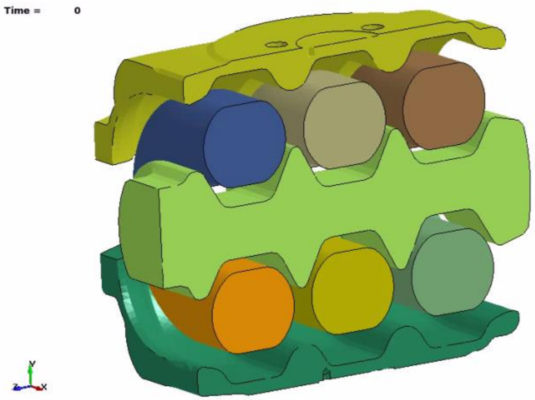
Implicit Accuracy



- Implicit accuracy option IACC=1 on *CONTROL_ACCURACY
  - Higher accuracy in selected material models
    - Fully iterative plasticity
    - Tightened tolerances
  - Strong objectivity and consistency in selected tied contacts
    - Physical (only ties to degrees of freedoms that are ”real”) – bending/torsion whenever applicable
    - Finite rotation
  - Strong objectivity and increased accuracy in selected elements
    - Finite rotation support for hypoelasticity
- In line with the general philospophy ”Increased accuracy implies better convergence”

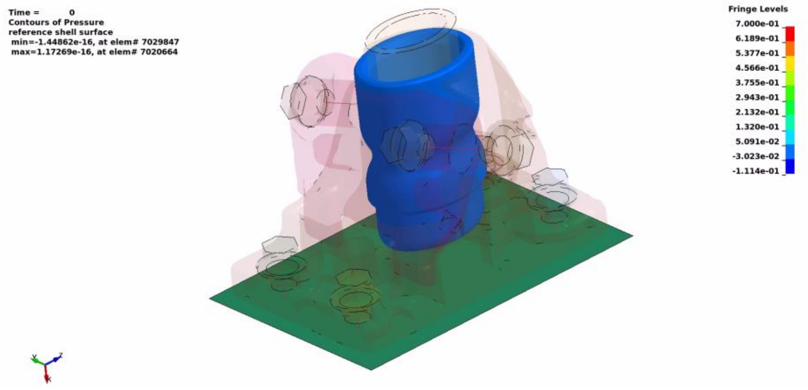
Typical Implicit Applications

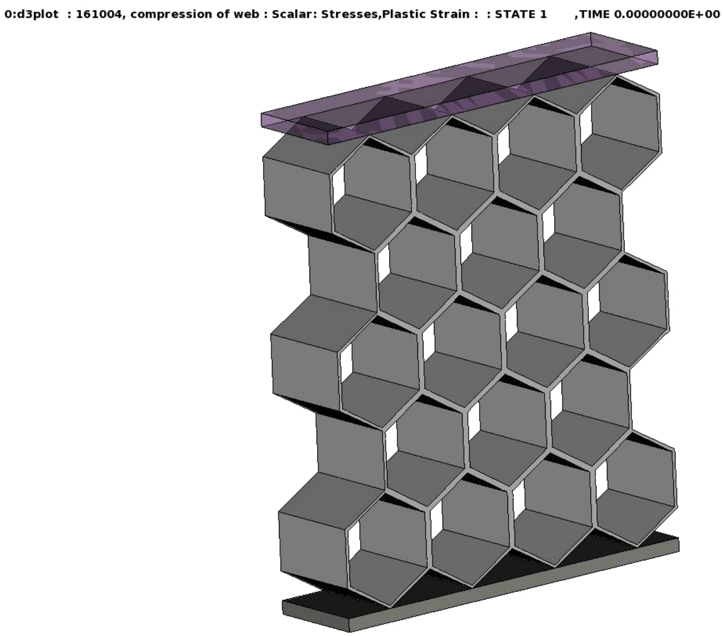


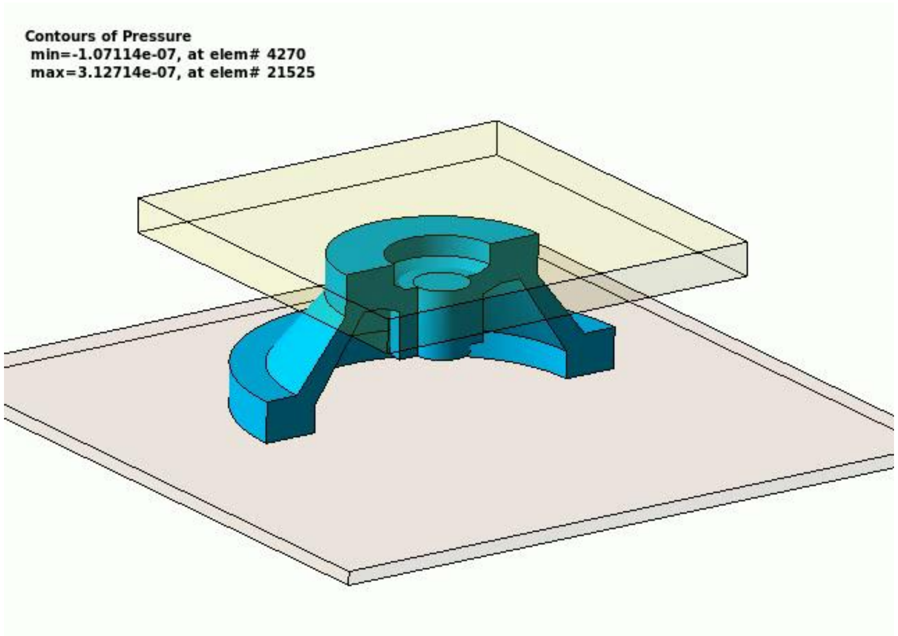


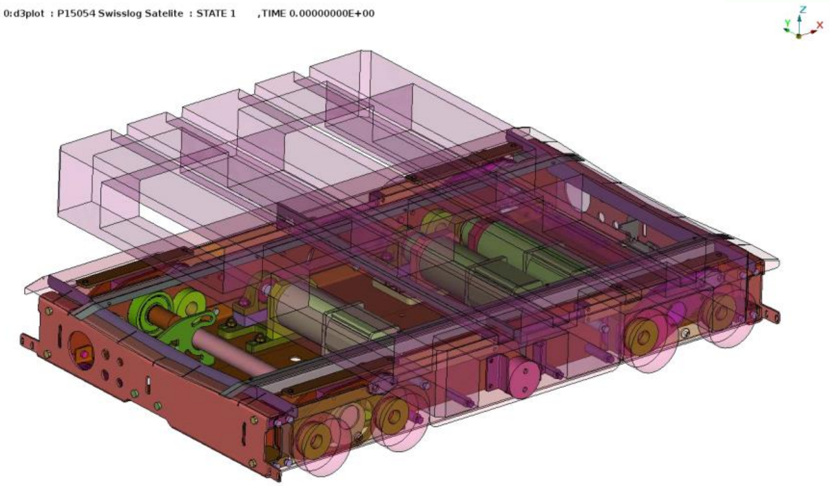
- Characterized by
  - Contacts
  - High order elements
  - Rubbers
  - Prestress
    - Inteference
    - Initial stress/force

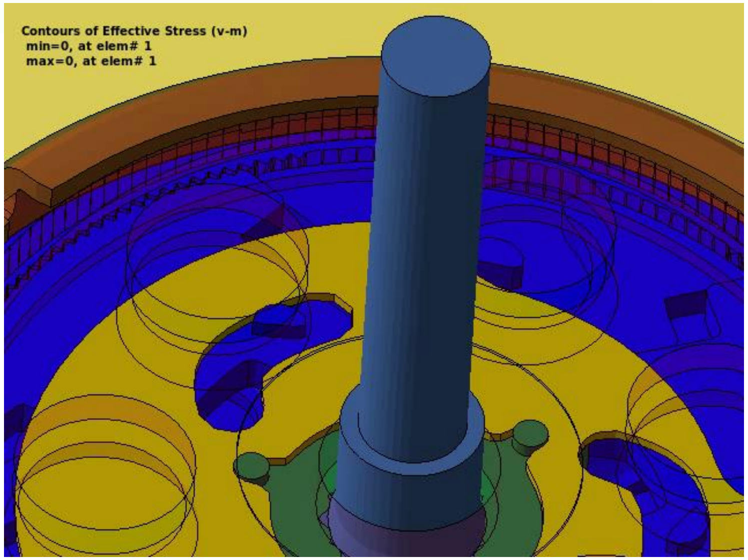
Courtesy of Kongsberg Automotive, Thule Sweden, Volvo GTT and Dellner Couplers











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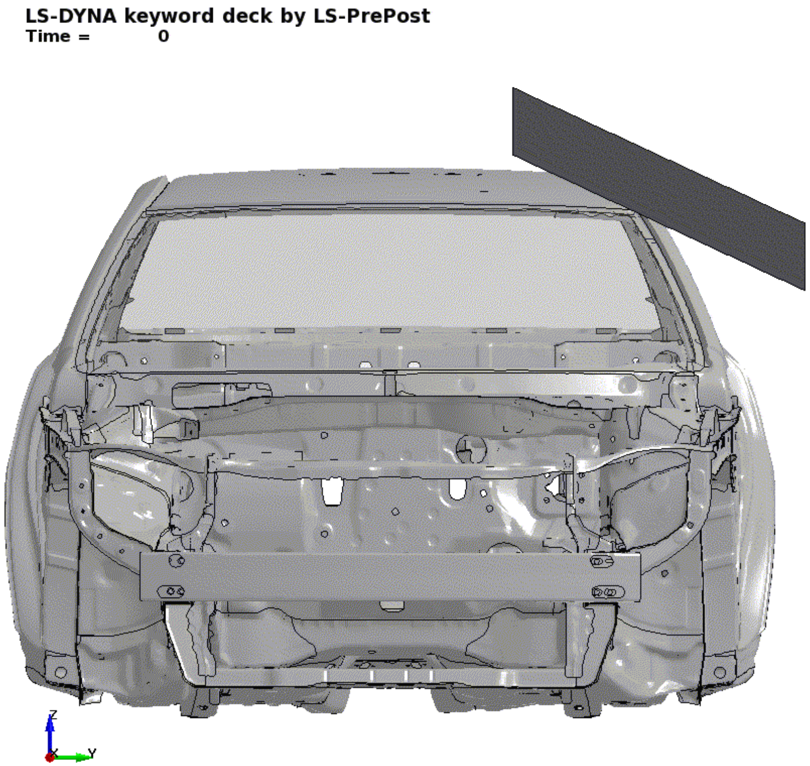
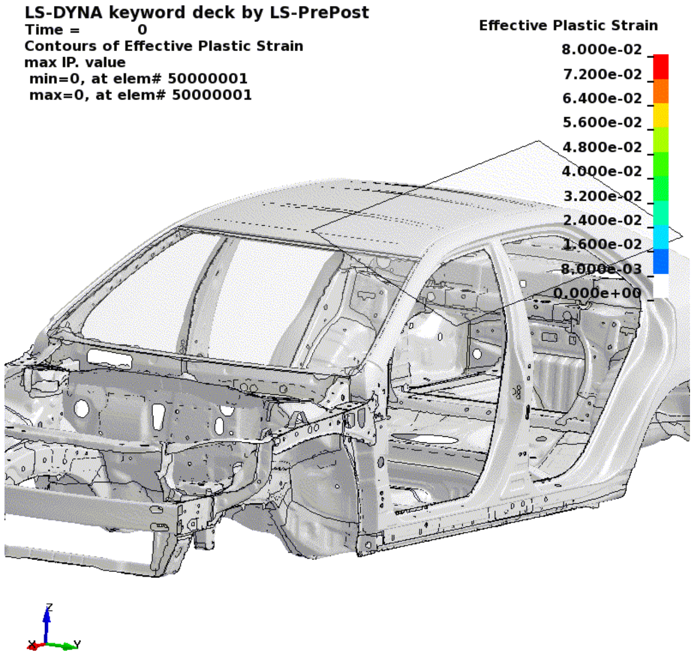
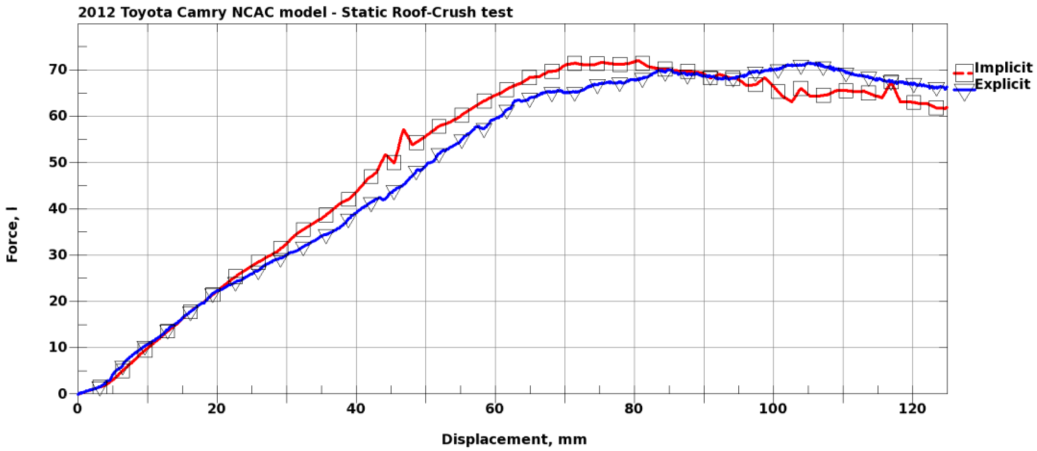
Courtesy of Royal Institute of Technology, Kaizenat Technologies, AGS and Swisslog

Implicit Roof Crush







- No speed up
- Robust
- Comparable to explicit

Satish Pathy and Thomas Borrvall,
"Quasi-Static Simulations using Implicit LS-DYNA"

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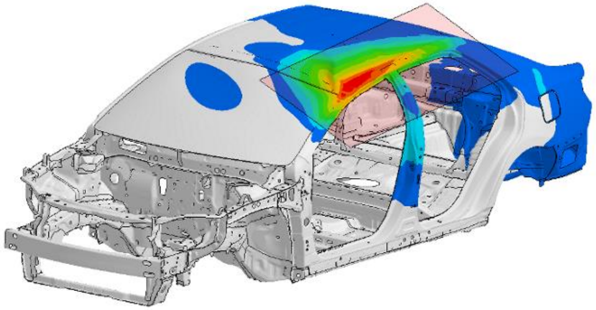
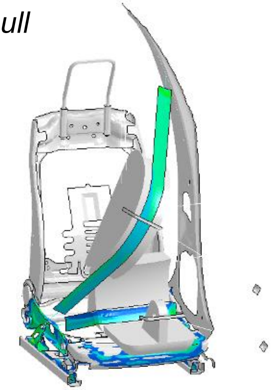
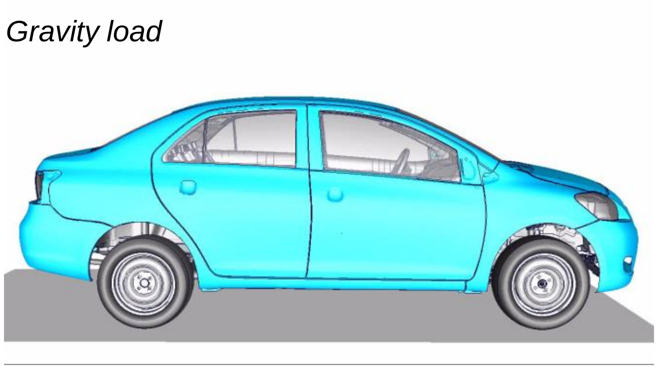
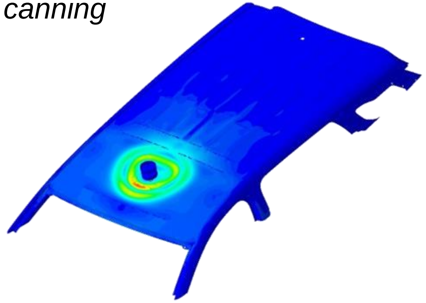
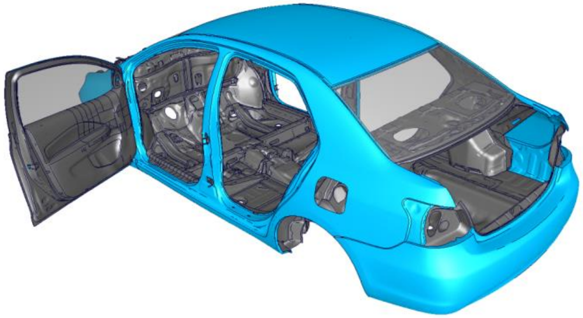
Implicit in Automotive

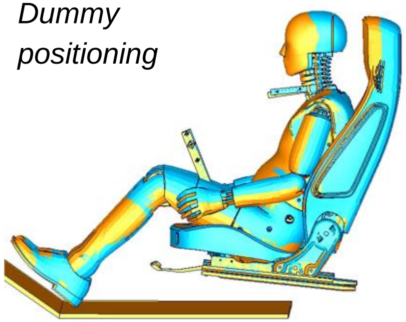

Roof crush


Seat pull


Gravity load


Oil canning


Door sag


Dummy positioning

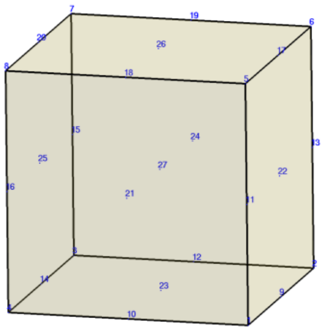
- OEM applications suitable for implicit have been solved in LS-DYNA
- Rhymes well with the One-Code/One-Model vision of LSTC
- Ongoing work, to improve and to cope with ”explicit” features common in this area

Element Formulation

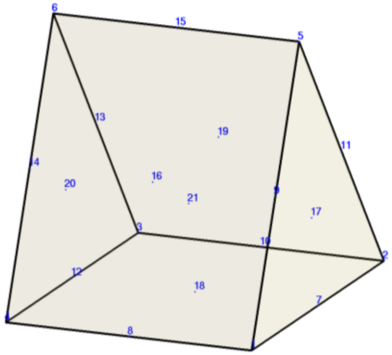
FEM and Meshfree

27-node Solid Element

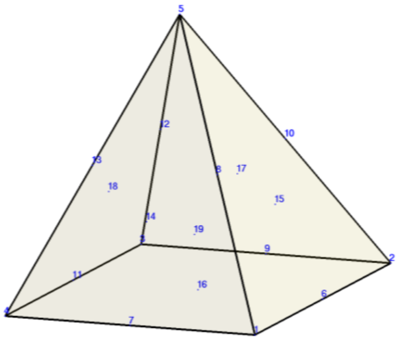
- Solid Formulation 24
  - Accurate for large deformation, severe distortion
  - Non-uniform row summation mass lumping
  - Selective reduced integration to alleviate volumetric locking
  - Excellent behavior in bending, one element is used over plate thickness
  - Support *ELEMENT_SOLID_H8TOH27



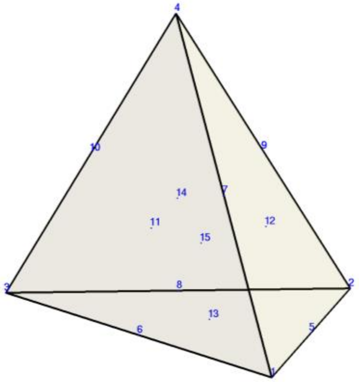
27-node Hexahedron



21-node Pentahedron



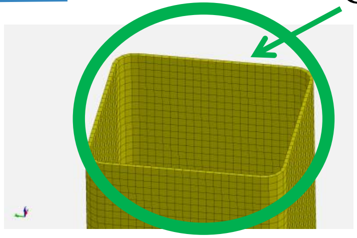
19-node Pyramid

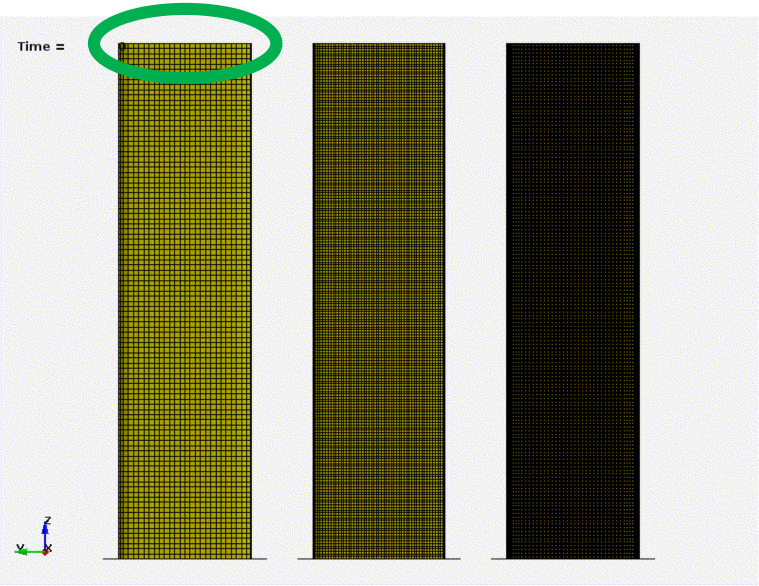


15-node Tetrahedral

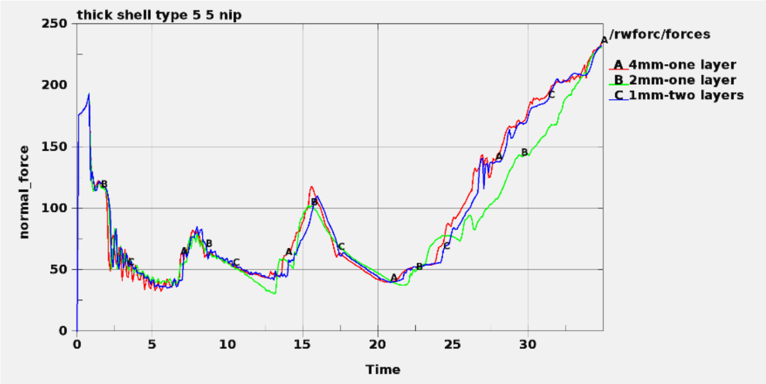
Solid 24

One layer element over thickness direction

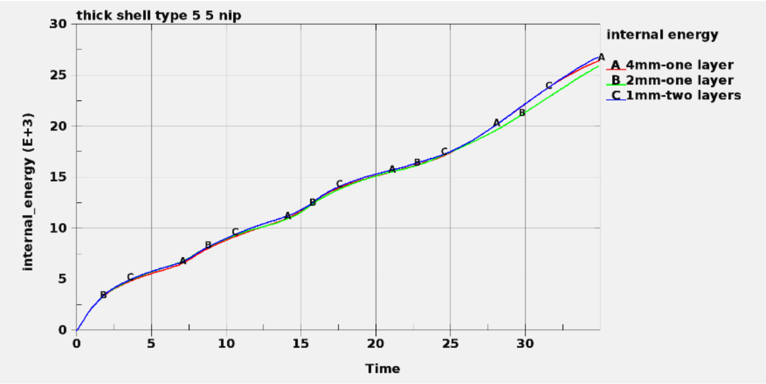




4mm 2mm 1mm



Contact Force



Relative coarse mesh can get converged results

Internal energy

Elform2 fine	27 node coarse	27 node fine
1	1.35	28

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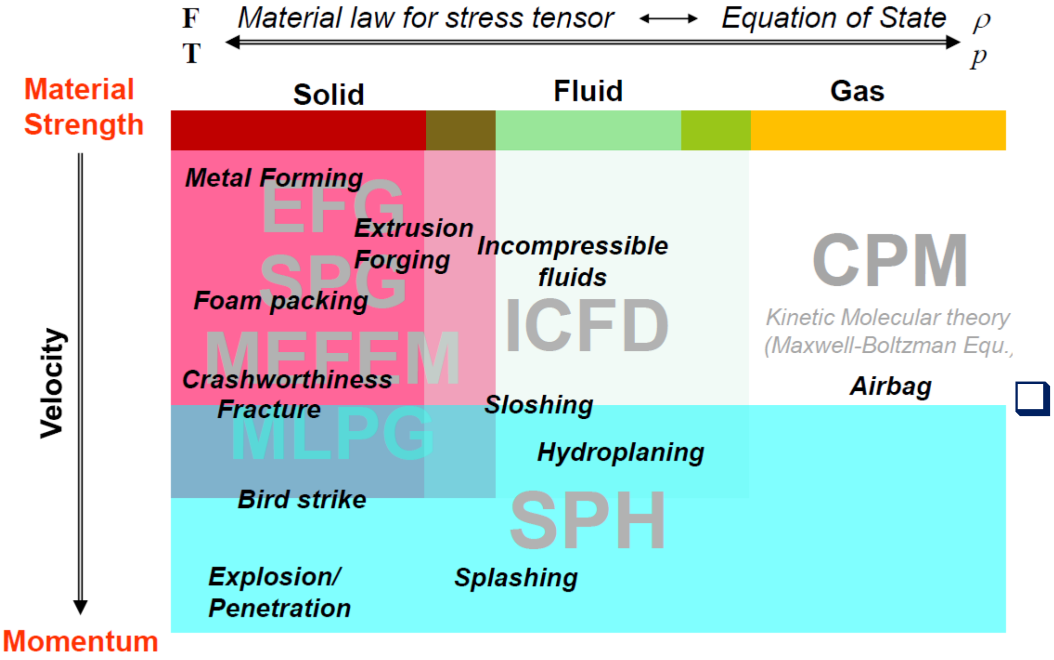
Meshfree Methods in LS-DYNA

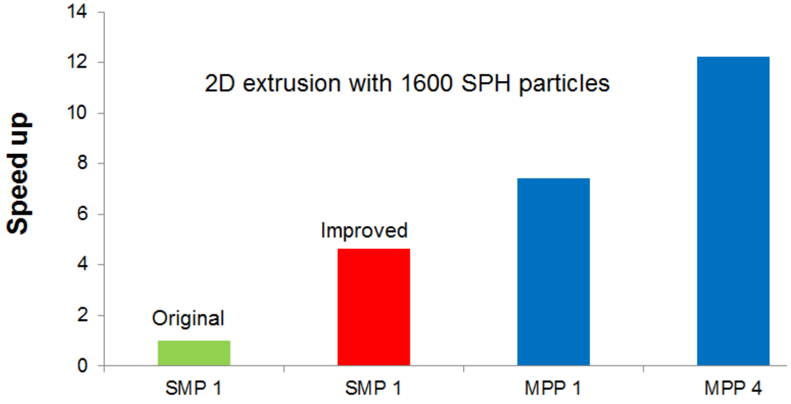
- Discrete
  - Explicit
    - DEM (Discrete Element Method)
    - CPM (Particle Gas)



- Continuum
  - Explicit Meshfree Collocation
    - SPH
  - Explicit Meshfree Galerkin
    - EFG, SOLID41&42, SHELL41~44
    - MEFEM for nearly incompressible material,SOLID43
    - SPG (Smooth Particle Galerkin), SOLID47
    - Peridynamics (Discontinuous Galerkin) for brittle fracture, MAT_ELASTIC_PERI
  - Implicit Meshfree Galerkin
    - EFG, SOLID41&42, SHELL41~44
    - MEFEM, SOLID43

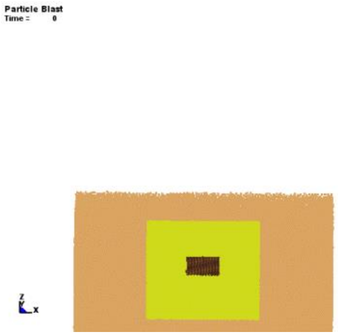
SPH Enhancements

- MPP enabled and SMP enhanced for *CONTACT_2D_NODE_TO_SOLID



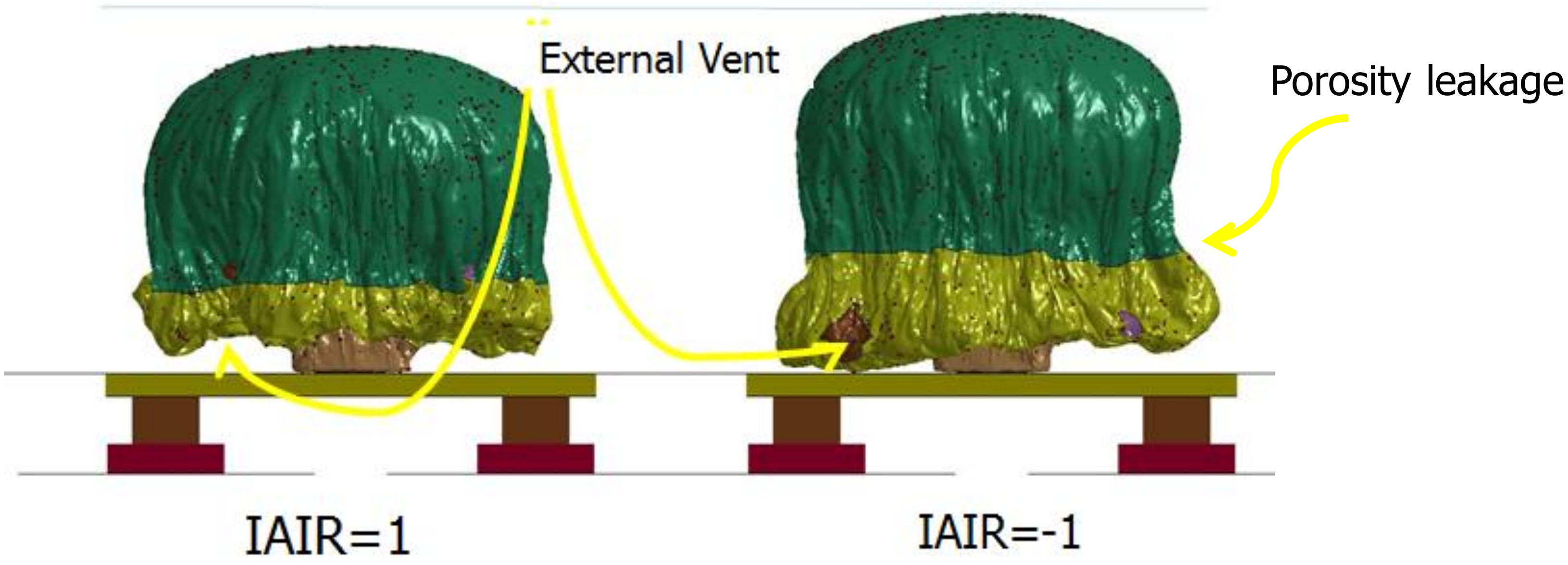
- *DEFINE_SPH_INJECTION injects SPH flows

- *DEFINE_SPH_DE_COUPLING for SPH/SPH and SPH/DEM contact



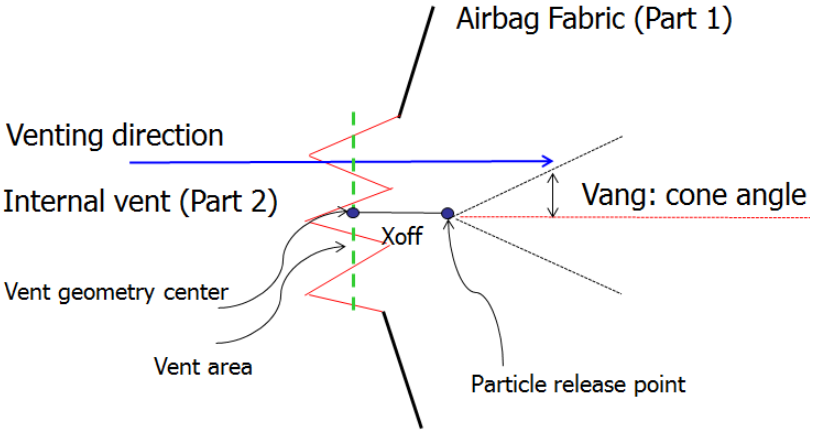
CPM Airbag Enhancement on venting

- At the beginning of the bag inflation, the bag pressure may drop below ambient pressure due to jetting. When IAIR/*AIRBAG_PARTICLE =-1, it will allow external vents to draw in outside air
- The feature has been extended for porosity leakage
- Works also after CPM switch to UP airbag



CPM Airbag Enhancement on venting

- Internal vent with uni-direction/cone angle, VANG



Airbag Fabric (Part 1)

Venting direction

Internal vent (Part 2)

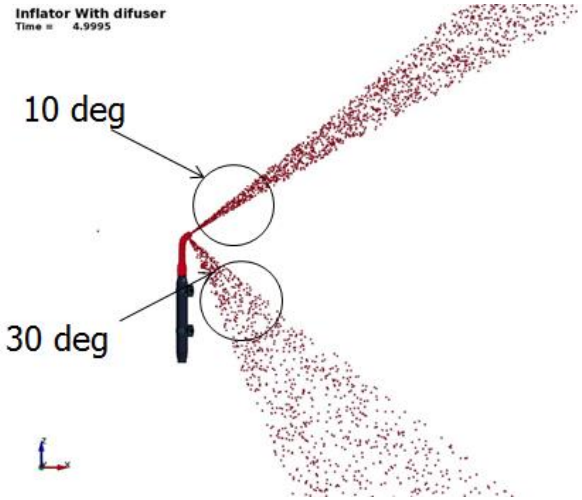
Vang: cone angle

Xoff

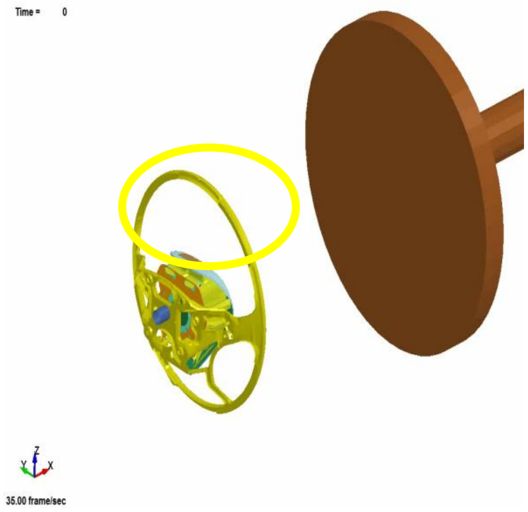
Vent geometry center

Vent area

Particle release point

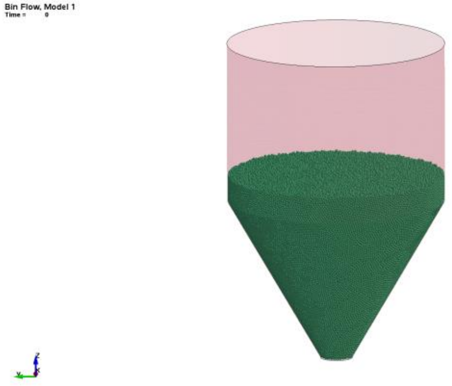


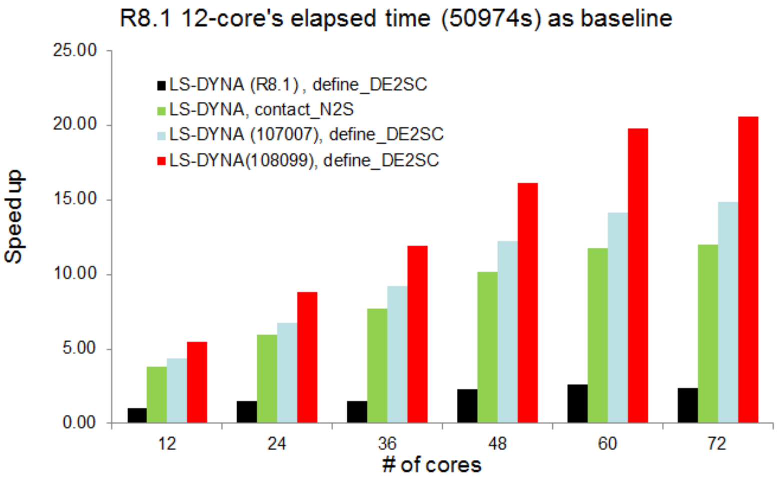
- Push-out venting, IOPT=200



DEM Enhancements -1

- MPP Performance:
  - Use DE2SC instead of N2S



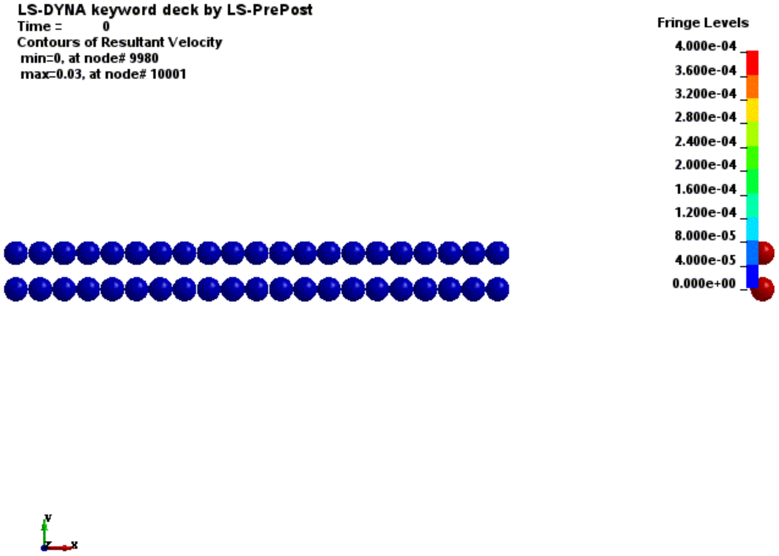


- Non-reflecting B.C. used on the exterior boundaries of an analysis model of an infinite domain

Without

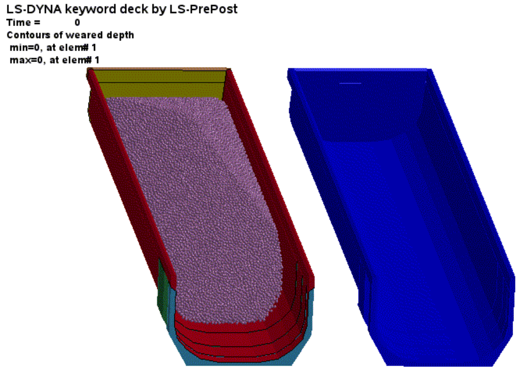
NRBC

With

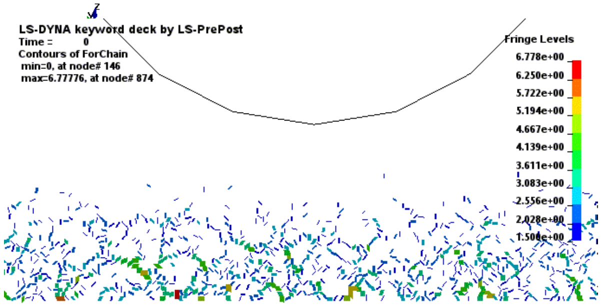


DEM Enhancements-2

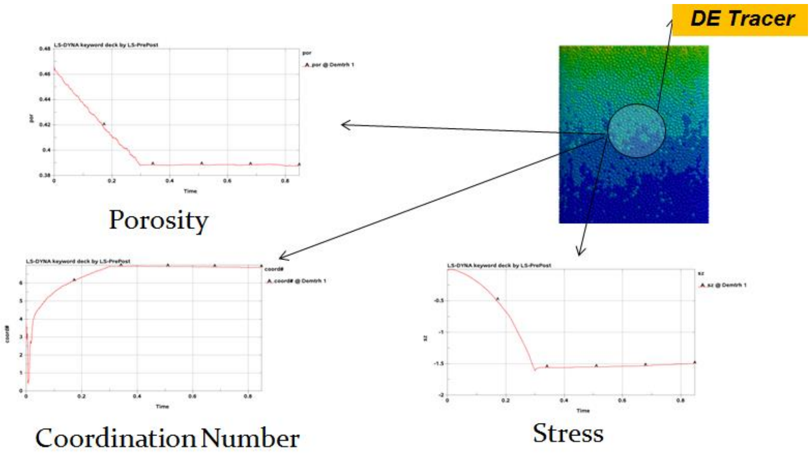
- Wear prediction using *DEFINE_DE_TO_SURFACE_COUPLING



- Force chain fringe plot

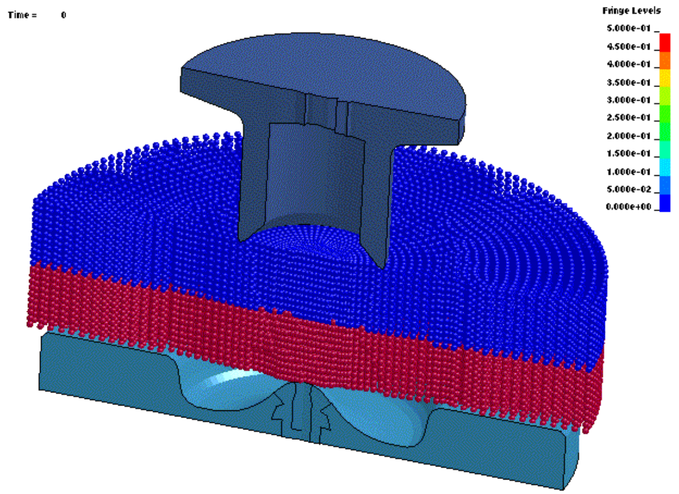


- Porosity, void ratio and coordination number can be traced by *DATABASE_TRACER_DE

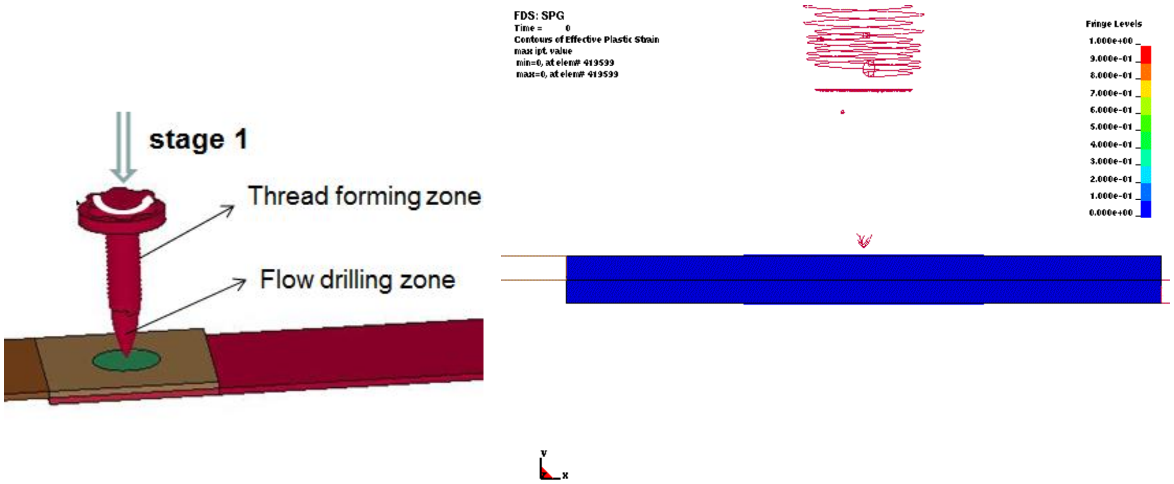


Smoothed Particle Galerkin (SPG) Method

- based on a smoothed displacement field within the meshfree Galerkin variational framework
- discretized system of equations are integrated at the particles,
- solid element formulation 47, currently explicit only
- strain-based failure w/o element erosion or manual cut of the model
- for manufacturing simulation involving ductile failure



SPR w. SPG



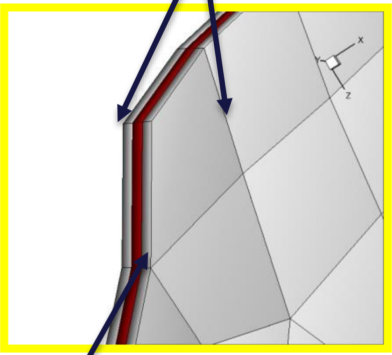
Flow Drill Screw (FDS) w. SPG

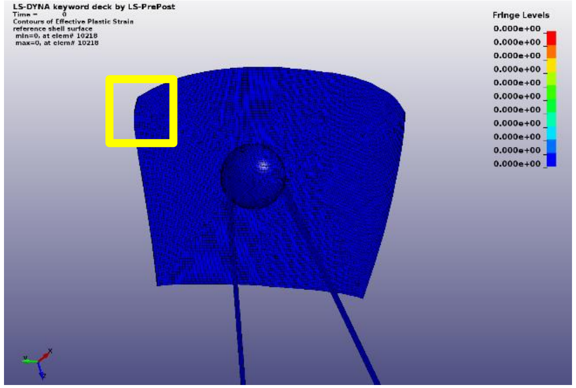
Peridynamics Method

- Developed by Dr. Steward Silling at Sandia Nat. Lab.
- Discontinuous Galerkin (DG) FEM approach with bond-based Peridynamics theory.
- Extension of classical continuum mechanics, which is based on partial differential equations, which do not exist on crack surfaces and other singularities. In contrast, the Peridynamic balance of linear momentum is formulated as an integral equation, which remains valid in the presence of material discontinuities.
- Allow the direct enforcement of boundary conditions and constraints.
- Failure is based on critical energy released rate. No element deletion is needed to advance the cracks.
- Branching of the cracks is an outcome of the DG approach. Self-contact between cracks is possible but CPU time consuming.
- For brittle fracture analysis. In crashworthiness simulation, it is useful for windshield or plastic panels damage analysis.

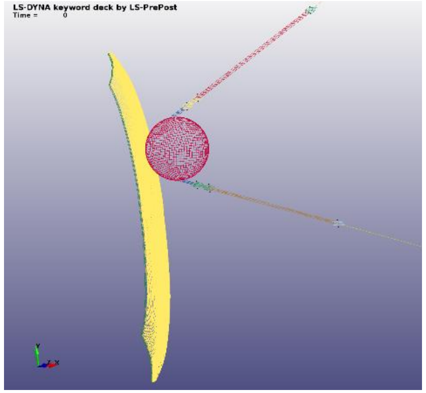
Windshield failure analysis by Peridynamics

Glass layers, Peridynamic Model, MAT_ELASTIC_PERI





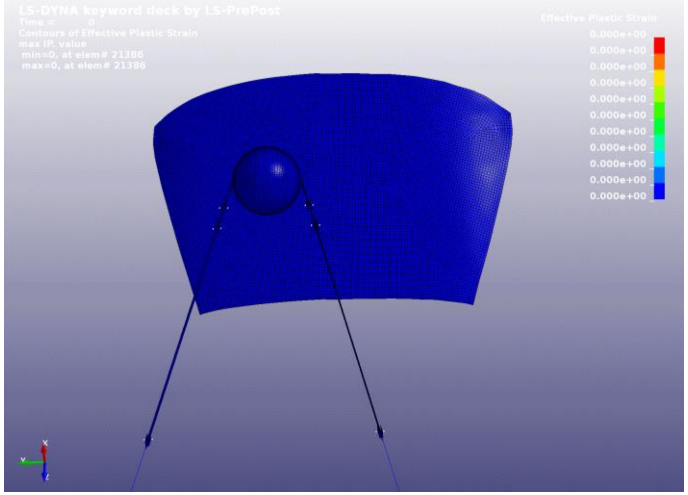
LS-DYNA keyword deck by LS-PrePost
Time = 0
Contours of Effective Plastic Strain
reference shell surface
min=0, at elem# 10218
max=0, at elem# 10218



LS-DYNA keyword deck by LS-PrePost
Time = 0

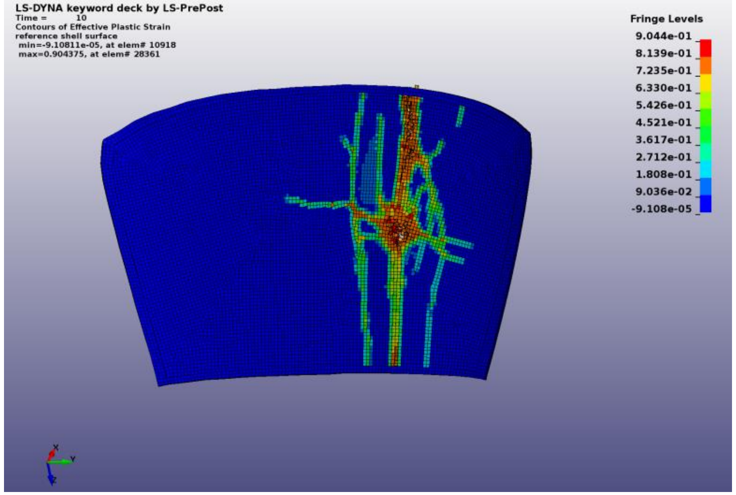
vinyl layer, FEM Model,
MAT_PIECEWISE_LINEAR_PLASTICITY

Interface of Vinyl and glasses:
CONTACT_TIED_SURFACE_TO_SURFACE_OFFSET



LS-DYNA keyword deck by LS-PrePost
Time = 0
Contours of Effective Plastic Strain
max IP. value
min=0, at elem# 21386
max=0, at elem# 21386

top view



LS-DYNA keyword deck by LS-PrePost
Time = 10
Contours of Effective Plastic Strain
reference shell surface
min=-9.10811e-05, at elem# 10918
max=0.904375, at elem# 28361

rear view

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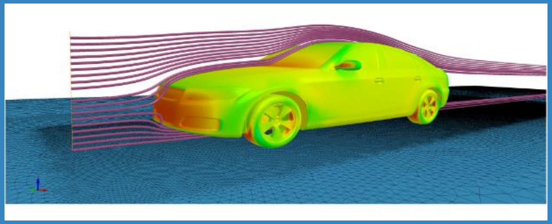


Incompressible Computational Fluid Dynamics (ICFD)

NEW ICFD Features

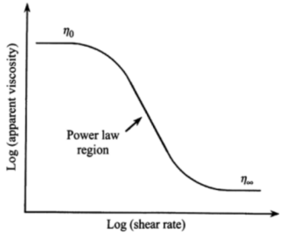
- Turbulence models
  - New RANS models: Realizable K-epsilon, K-Omega, K-Omega SST, Spalart-Almaras.
  - Related keywords include ***ICFD_CONTROL_TURBULENCE**, ***ICFD_BOUNDARY_TURBULENCE and *ICFD_INITIAL_TURBULENCE**
- ***MESH_BL** constructs a boundary-layer mesh by subdividing volume-mesh near the surface.
- New non-Newtonian fluids: Power-Law, Carreau and Cross.

$$\sigma = \eta \dot{\gamma}$$

- Newtonian model

$$\eta_a = \eta_\infty + \frac{\eta_0 - \eta_\infty}{1 + (\alpha_c \dot{\gamma})^m}$$

- Cross model for data over a wide range of shear rates



$$\eta_a = \eta_\infty + \frac{\eta_0 - \eta_\infty}{[1 + (\lambda_c \dot{\gamma})^2]^N}$$

- Carreau model for data over a wide range of shear rates

$$\sigma = K \dot{\gamma}^n$$

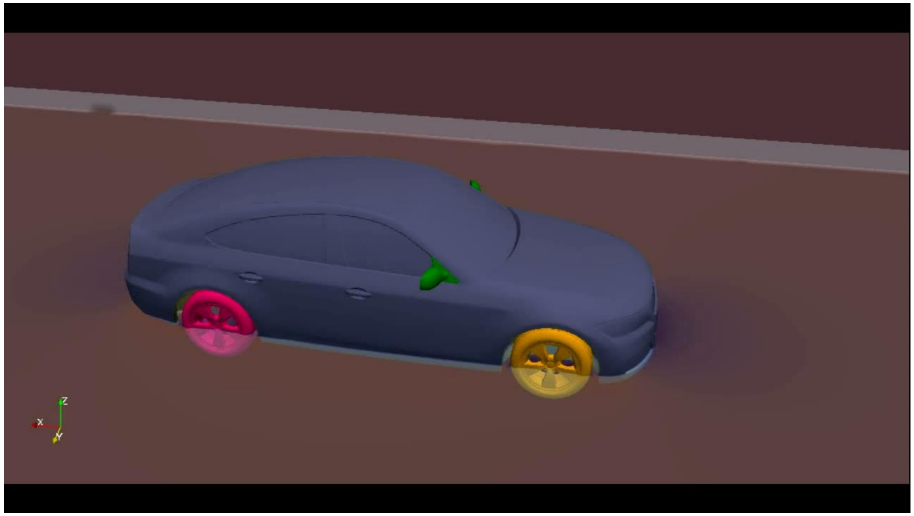
- Power law model used extensively in handling applications

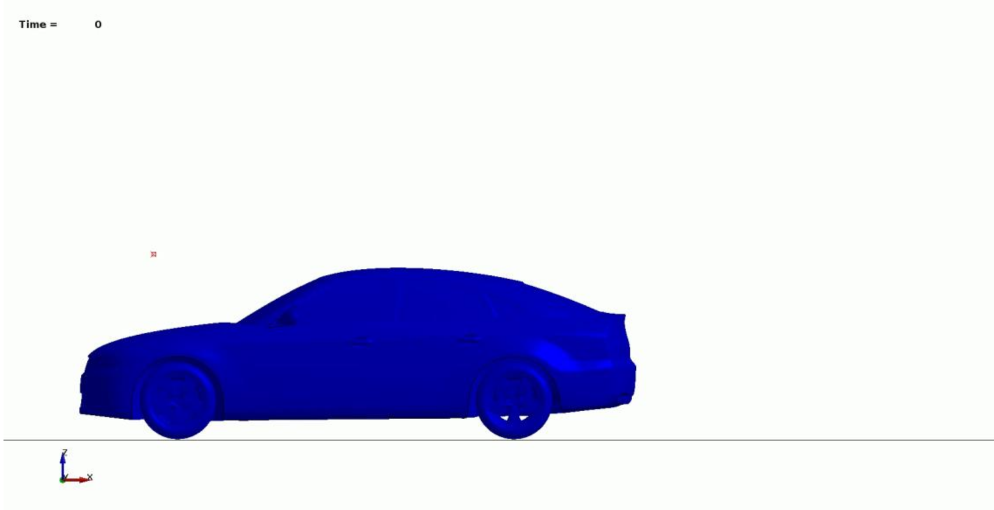
NEW ICFD Features

- Thermal
  - New GMRES solver for conjugate heat transfer for calculation speed ups up to a factor ten on mid size problems (over 1M elements)
  - Added temperature dependent viscosity laws to take into account solidification process in mold flow applications
  - Keyword **CONTROL_THERMAL_SOLVER** (solver type 17), **ICFD_MAT**, **ICFD_MODEL_NONNEWT** and **ICFD_CONTROL_CONJ**
- ***ICFD_CONTROL_IMPOSED_MOVE** allows the user to impose a velocity on specific part of the model. This can be used to save calculation time in certain applications such as sloshing where the modeling of the whole fluid box and the solving of the consequent FSI problem is not necessarily needed.

DEM coupling

- *ICFD_CONTROL_DEM_COUPLING couples ICFD and DEM
  - Requested by the automotive industry to study mud and snow deposition on vehicles
  - Potential applications include drug delivery and erosion of river bed

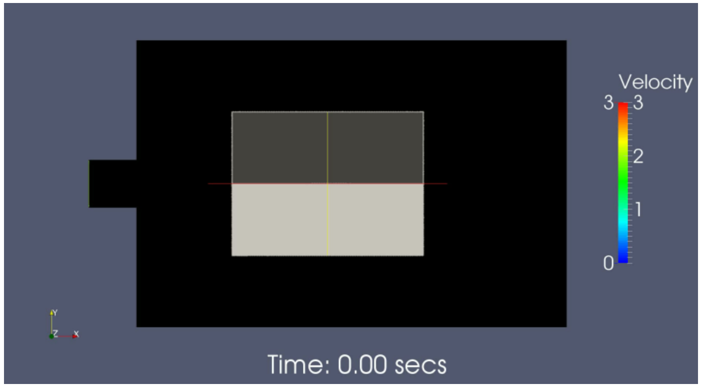


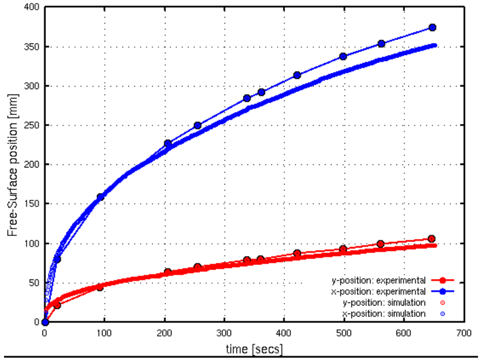


Flow in Anisotropic/Isotropic Porous Media

*ICFD_MAT and *OCFD_MODEL_POROUS allows the simulation of fluid flowing through porous materials

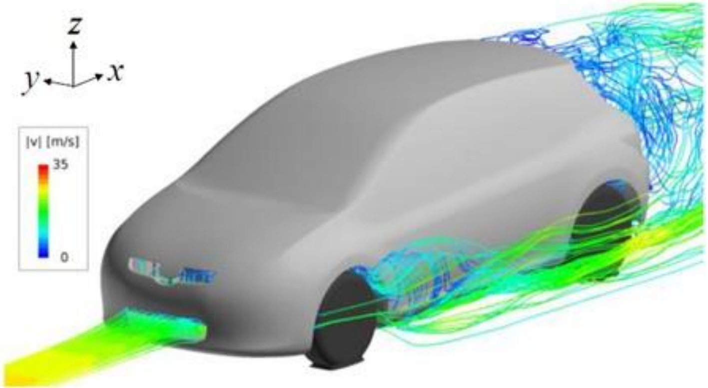
Mold Filling with Anisotropic Material

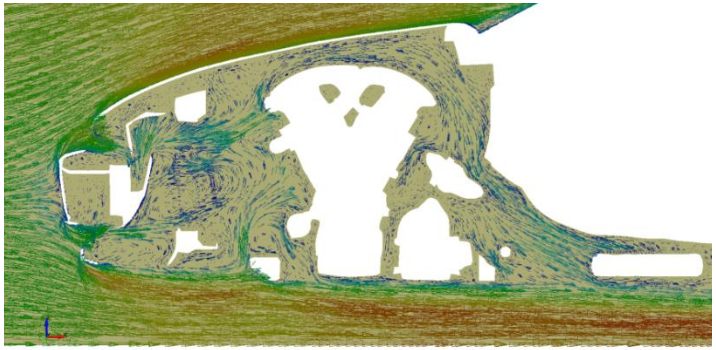




RTM Validation by Sandia National Lab.
Exp06 in www.sandia.gov/wind/other/040076.pdf)

High Reynolds Flow through a car radiator





"Analysis of Unsteady Aerodynamics of a Car Model with Radiator in Dynamic Pitching Motion", Y. Nakae, *10th European LS-DYNA Conference 2015*

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Summary

Our ultimate goal is to deliver one highly scalable software to replace the multiplicity of software products currently used for analysis in the engineering design process. ***Only one model is needed and created.***

Capabilities

Multi-physics and Multi-stage

Structure + Fluid + EM + Heat Transfer

Implicit + Explicit ….

Multi-scale

Accurate failure predictions

Multi-formulations

linear + nonlinear + peridynamics + …

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Future

- New features and algorithms will be continuously implemented to handle new challenges and applications
  - Electromagnetics,
  - Acoustics,
  - Compressible and incompressible fluids
  - Isogeometric shell & solid elements, isogeometric contact algorithms
  - Discrete elements
  - Peridynamics
  - Simulation based airbag folding and THUMS dummy positioning
  - Control systems and links to 3rd party control systems software
  - Composite material manufacturing
  - Battery response in crashworthiness simulations
  - Sparse solver developments for scalability to huge # of cores
  - Multi-scale capabilities are under development

Conferences

Nordic Users‘ Conference 2016

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THANK YOU!