Recent Developments in LS-DYNA, LS-Tasc and LS-OPT

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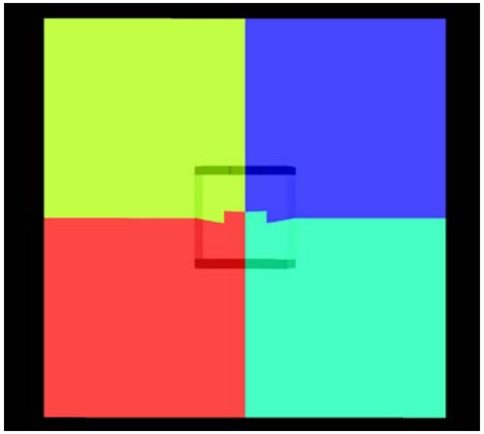
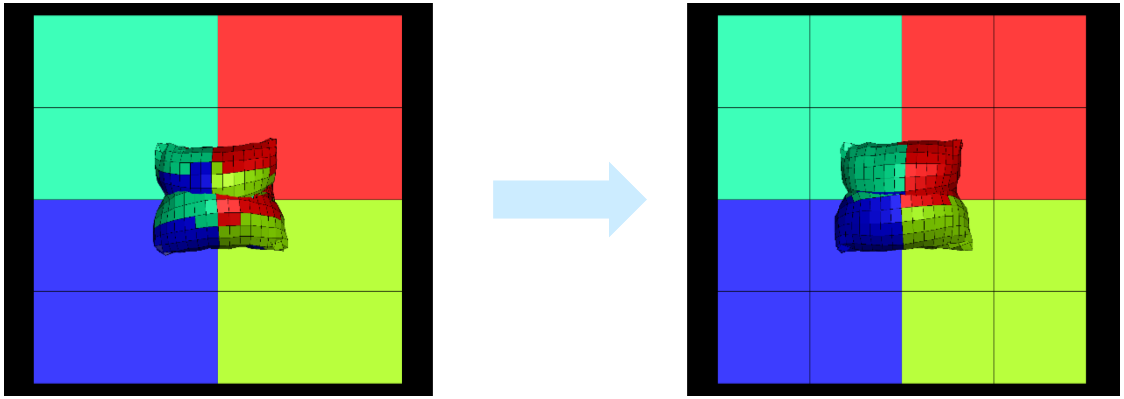
Agenda

- Speed Up and efficiency
- EM – BatMac and Battery abuse
- CFD
- Implicit – Linear and Nonlinear
- Contacts
- Connections
- Airbags
- Material and Damage models
- Metal Forming
- Thermal
- Misc LS-DYNA
- LS-TASC 4.0
- LS-OPT 6.0

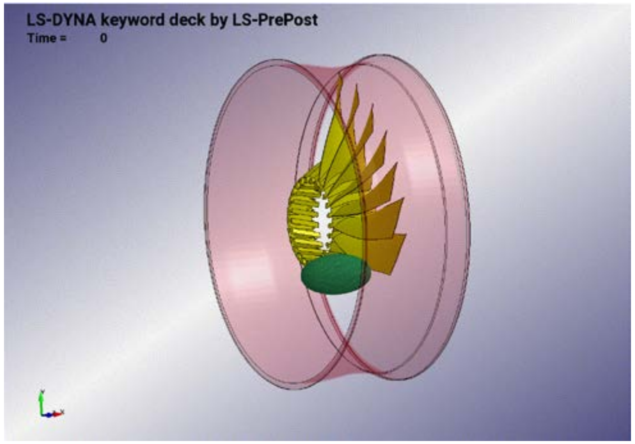
Enhance efficiency - Dynamic Load Balancing

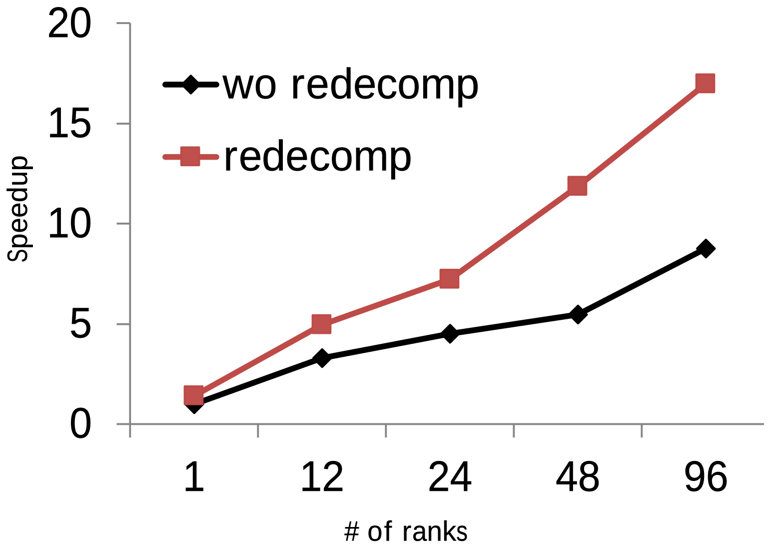
- Modifies decomposition during execution based on actual element timings
- Transfers elements and model features between processors directly via MPI
- Still in early stages of development

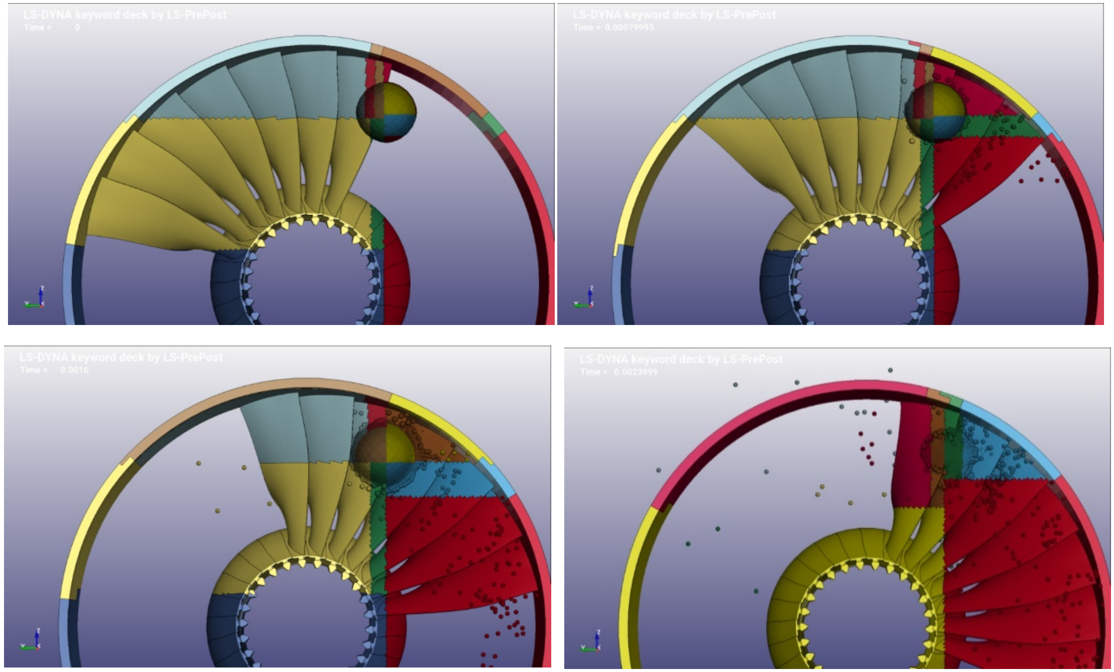




Enhance efficiency – DECOMPOSITION_REDECOMP







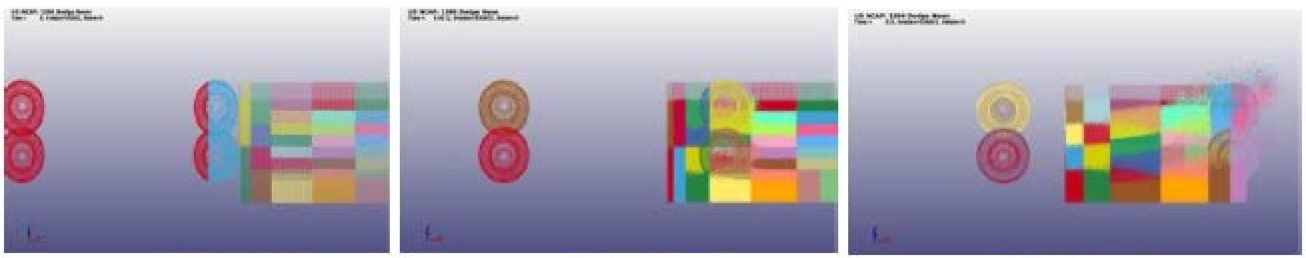
***CONTROL_MPP_DECOMPOSITION_REDECOMPOSITION**

Purpose: Redecompose a model at a given time interval. Other decomposition directives given in a pfile or defined using *CONTROL_MPP_DECOMPOSI-TION_*OPTION* remain in effect for each redecomposition. Redecomposition is intended to improve computational efficiency in simulations where large relative displacements between nodes develop and change as the simulation progresses.

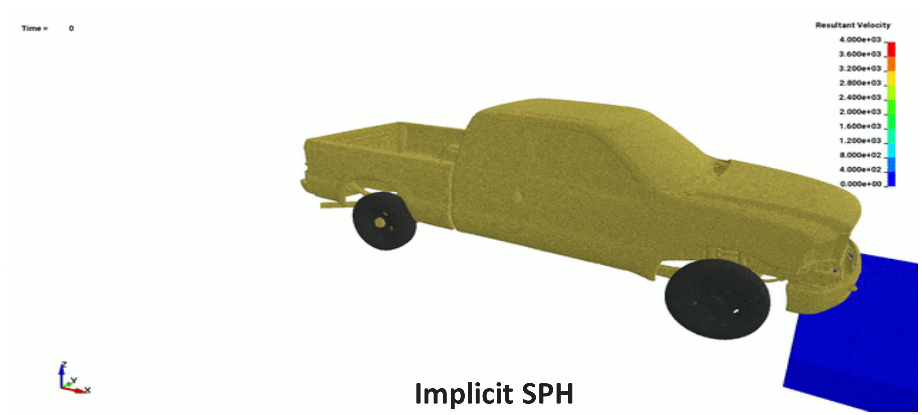
SPH

Implicit Formulation 13

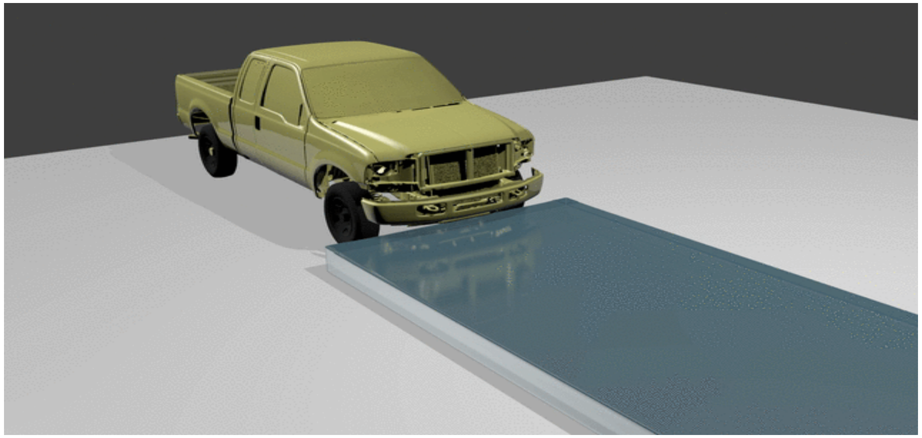
- Implicit, incompressible SPH formulation allows larger time step size
- Tailored for wading-type problems
- Example with 9.1 million particles



(a) time=0. (b) time=1.0 (c) time=4.0



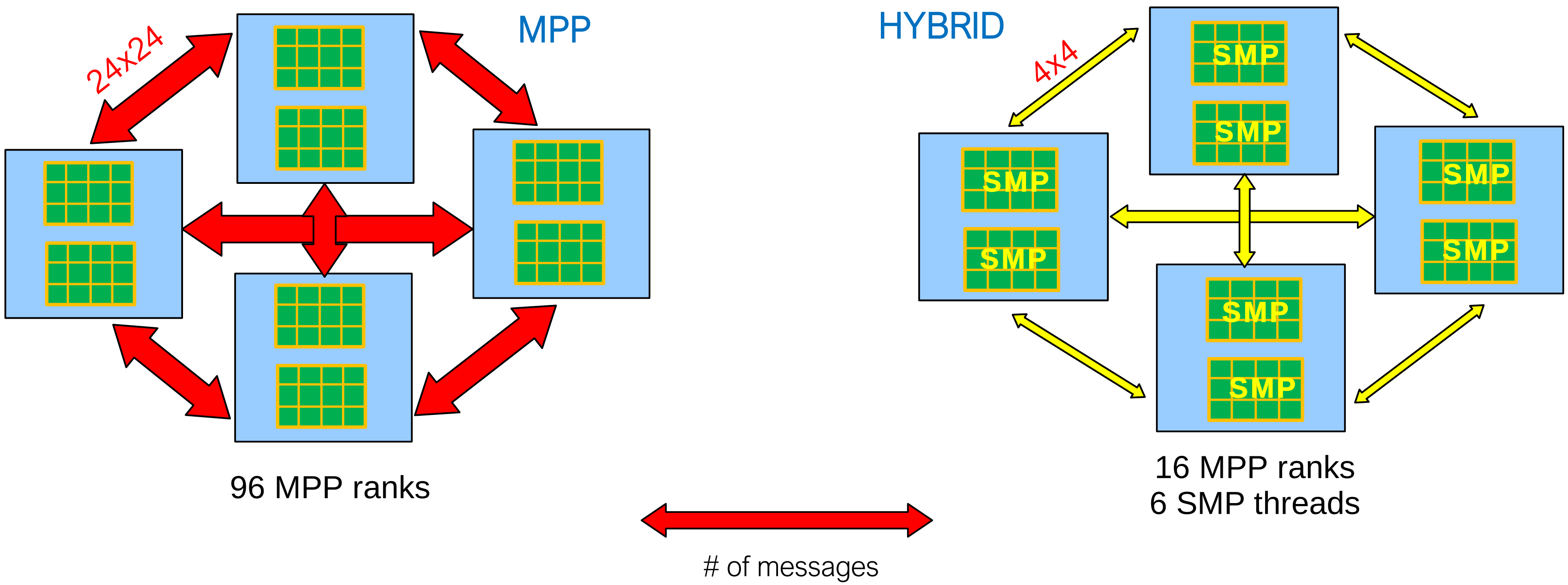
Implicit SPH
Color-coded by velocity



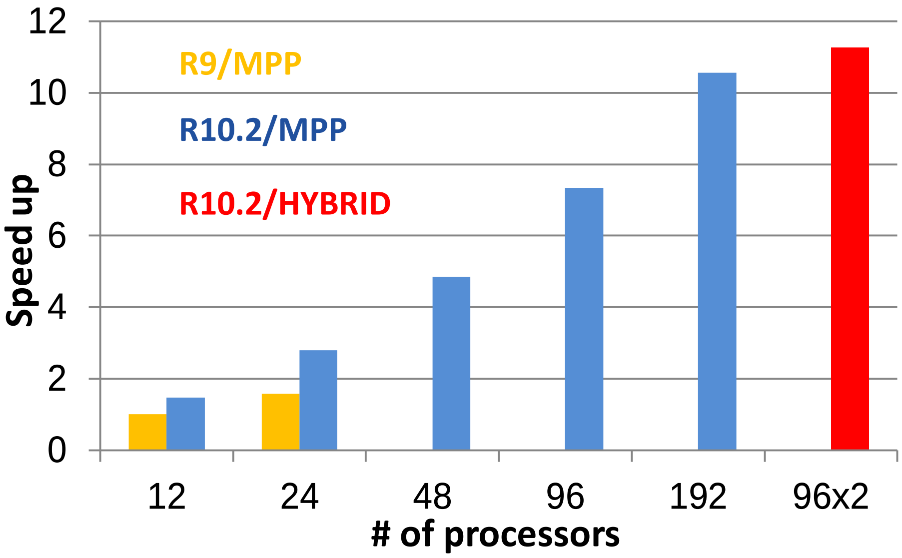
Blender rendering

SMP and MPP – HYBRID

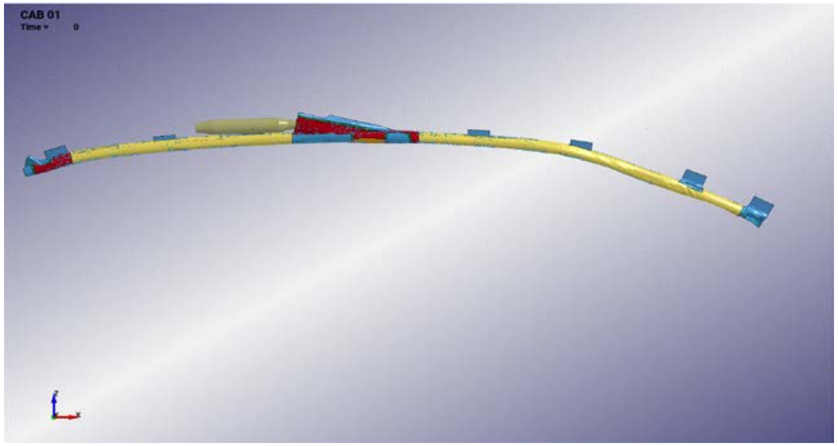
12core/2socket 4 nodes clusters



CPM | CAB Performance Improvement



CAB

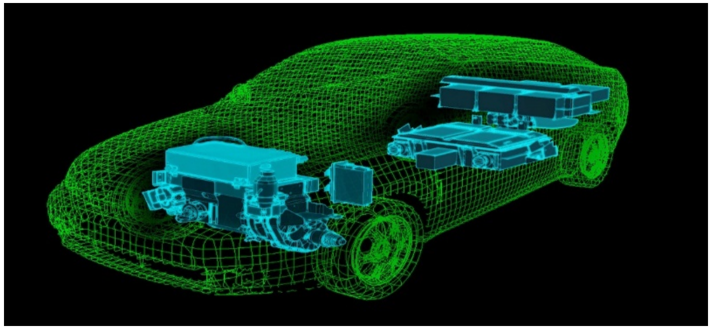


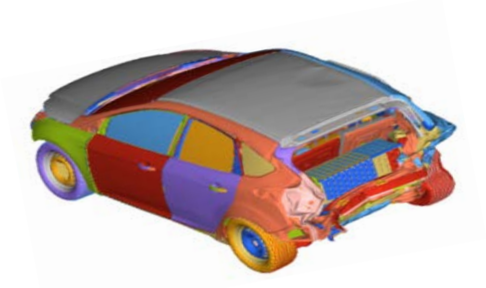
Courtesy of: Richard Taylor, Arup

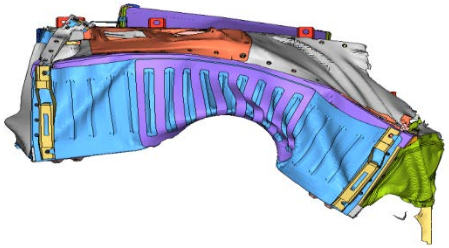
- OpenMP (HYBRID) enabled
- Reduced amount of data transferring between processors for better scaling
- More efficient particle to fabric contact algorithm
- Same input faster turn around time

Battery – Introduction

- Battery safety has been a key focus in design of electrified vehicle as battery size continues to increase.
- Understanding battery behaviors under abuse conditions is important to optimize the battery design.
- Computational modeling provides a tool to reveal the root causes of battery failure and evaluate its safety metrics.
- The models can also be used to check battery behavior in different “normal” operating conditions (Charge/discharge cycles, heating, …)

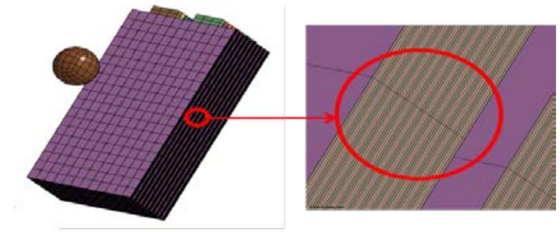




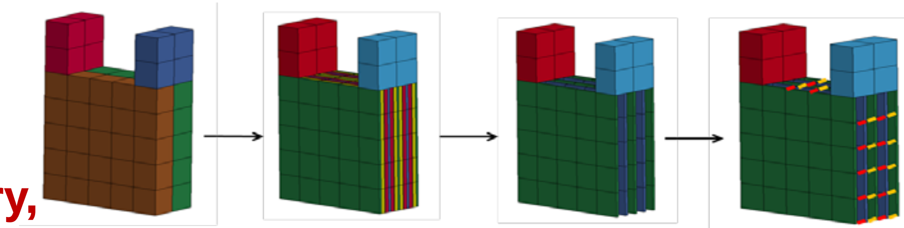


Battery : 4 models depending on the scale / detail

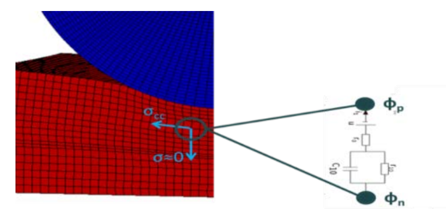
- **Solid elements: cell, internal/external shorts**
  - All the layers are meshed using solid elements
  - Same mesh used for mechanics, thermal and EM
  - Cautious with mechanics (element formulation, large aspect ratio, small time step)



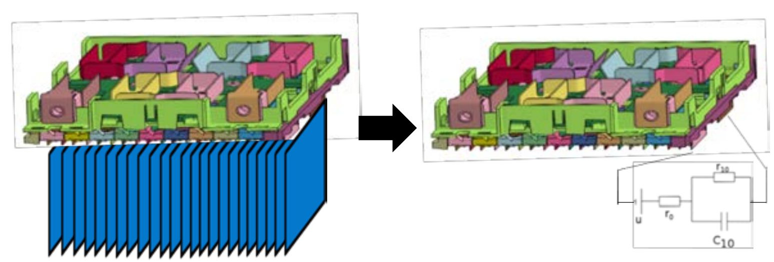
- **Composite Tshells: cell/module, internal/external**
  - Mechanics modeled using composite Tshells
  - EM and thermal use underlying solid mesh
  - More accurate detailed deformations
  - Faster runs (less elements, larger time step)



- **Battery Macro model (BatMac): pack/battery, internal/external**
  - One (or a few) solid elements through thickness for mechanics, EM and thermal
  - 2 fields at each node (positive and negative current collectors)



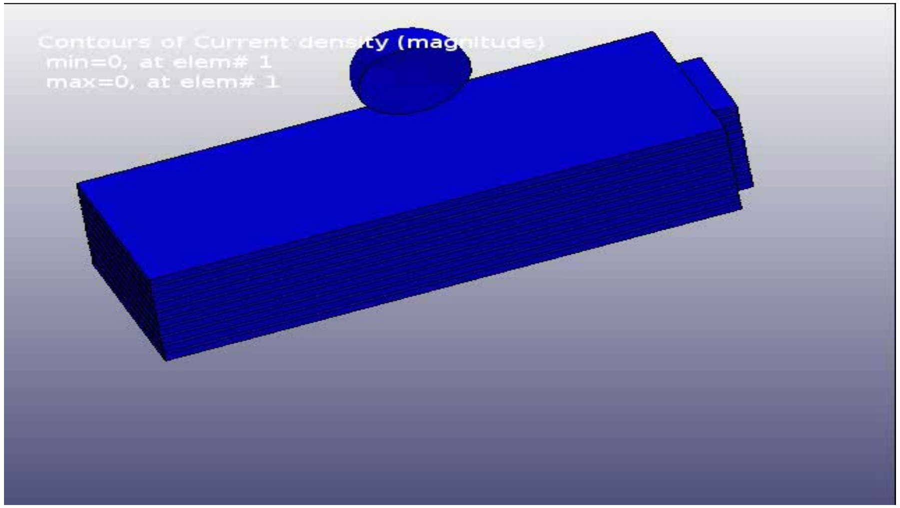
- **Meshless model: module/pack/battery, external**
  - One single equivalent circuit for the whole cell (lumped model)

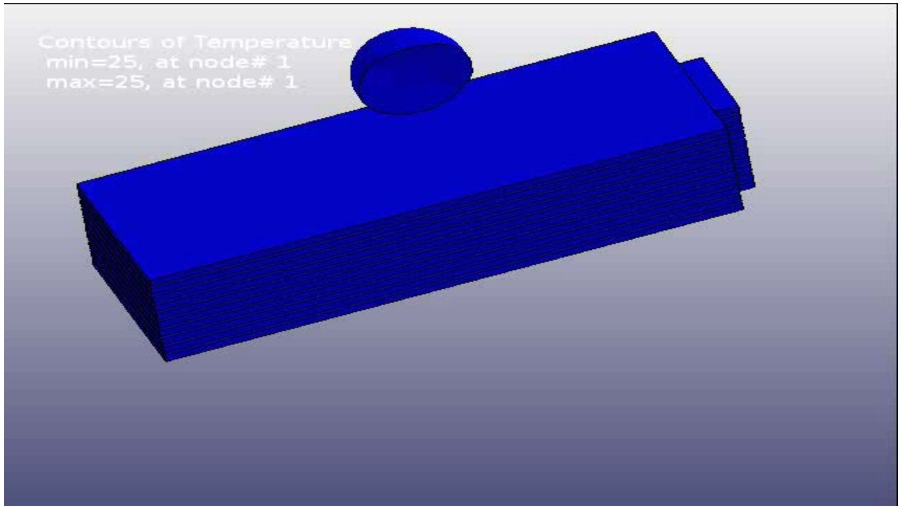


Battery: BatMac example (1)

New "BatMac" solver for large number of cells,
up to full battery in a car crash, internal/external shorts

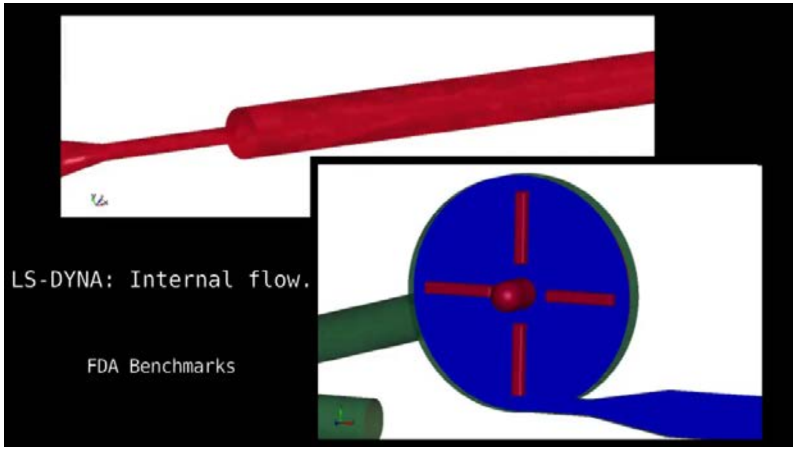
10 cells module impacted by a sphere using BatMac:
Runs in minutes, 20 times faster than composite Tshell model

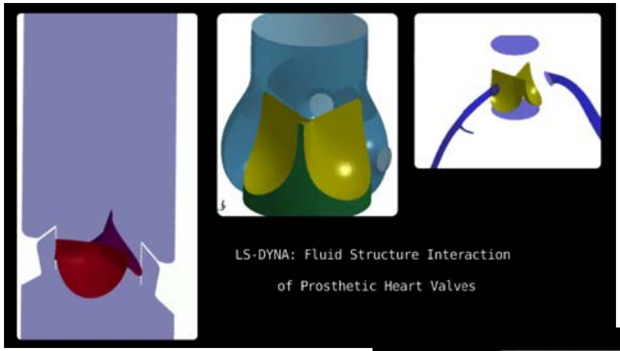


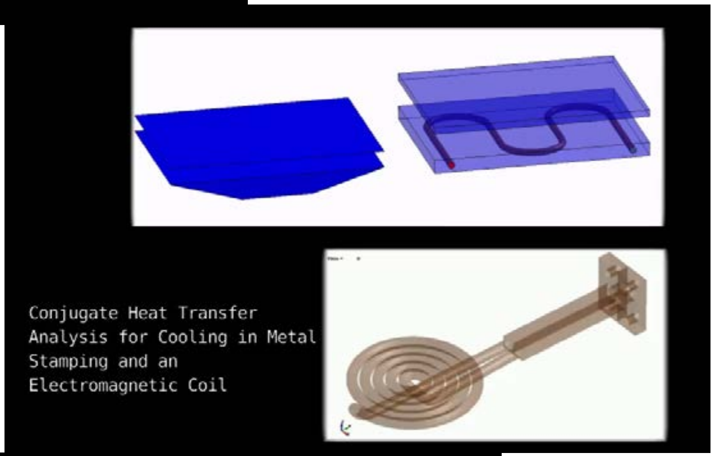


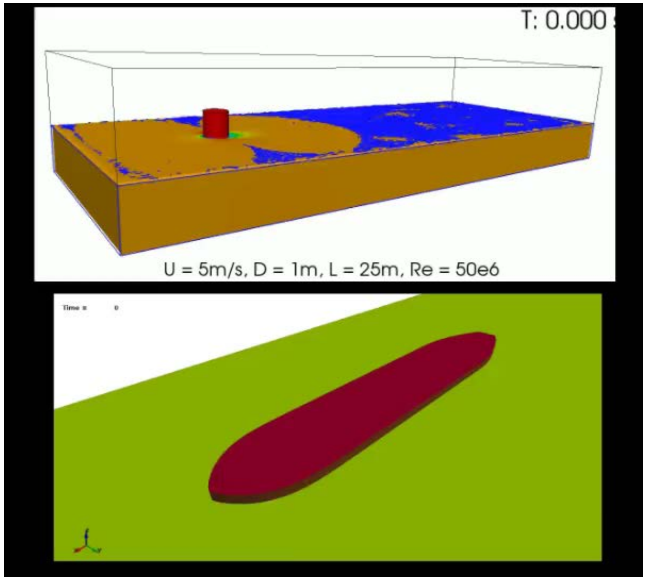
Current density Temperature

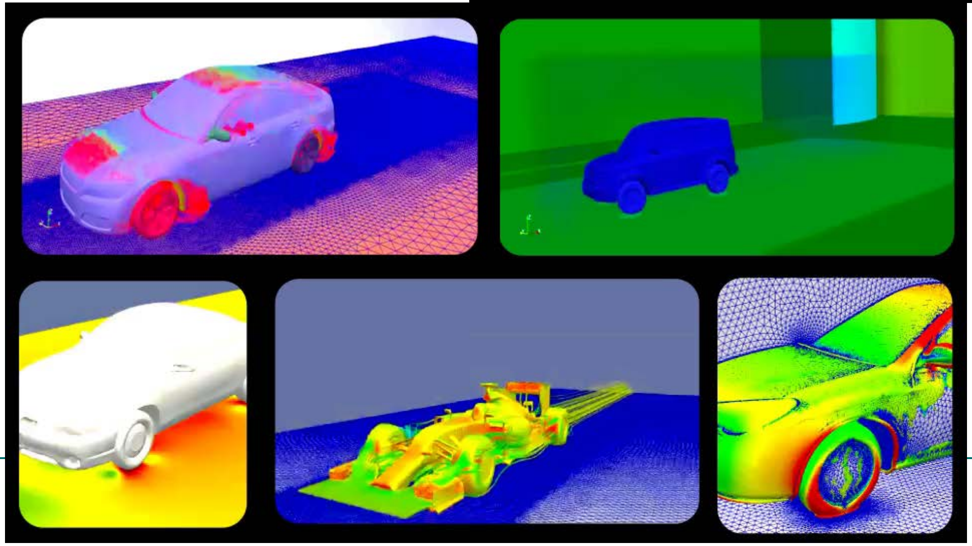
ICFD


LS-DYNA: Internal flow.
FDA Benchmarks

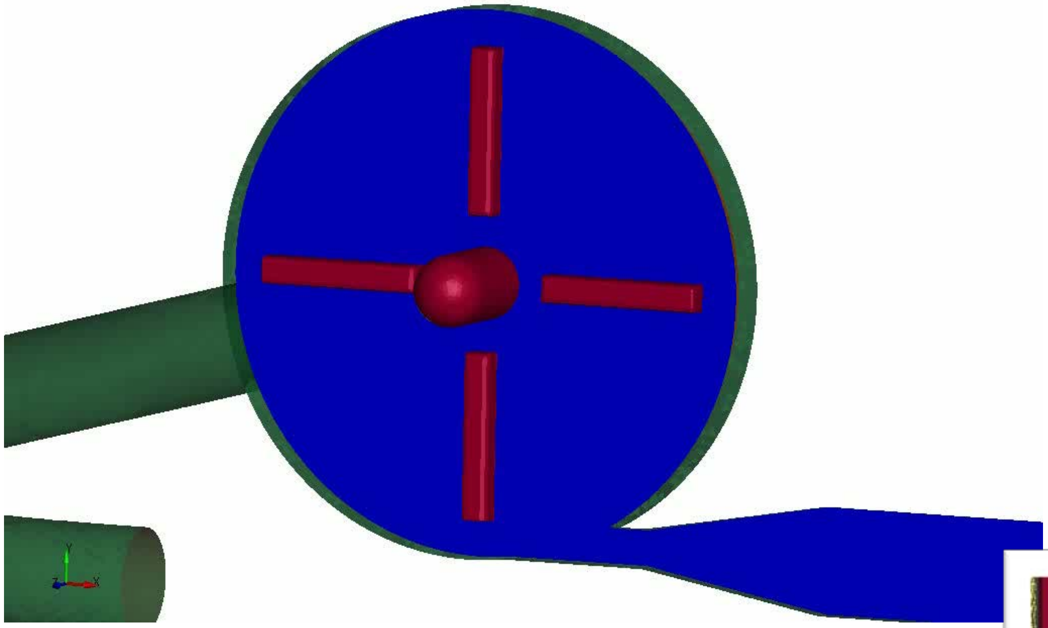

LS-DYNA: Fluid Structure Interaction
of Prosthetic Heart Valves

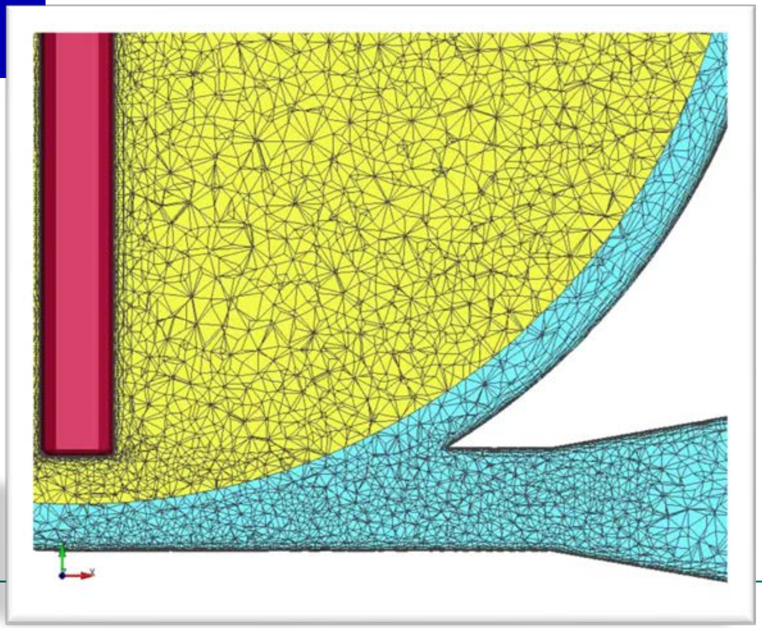

Conjugate Heat Transfer
Analysis for Cooling in Metal
Stamping and an
Electromagnetic Coil


T: 0.000
U = 5m/s, D = 1m, L = 25m, Re = 50e6

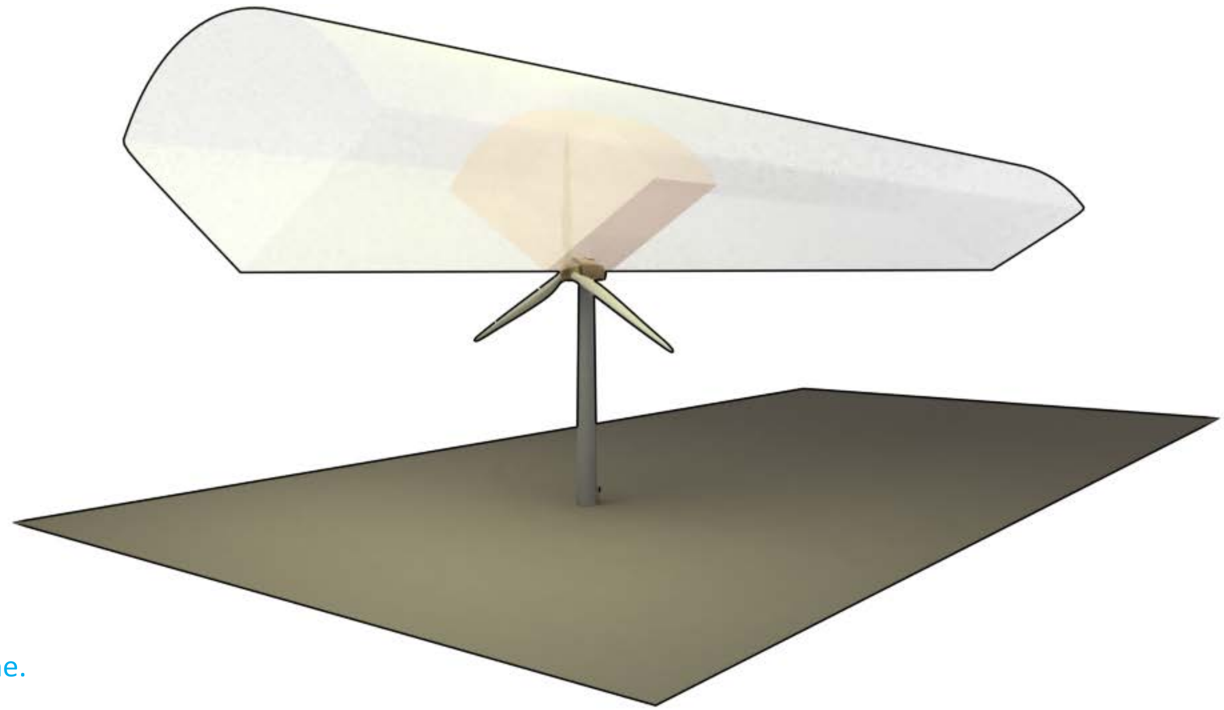


ICFD - Sliding mesh





ICFD - Periodic Boundary Conditions

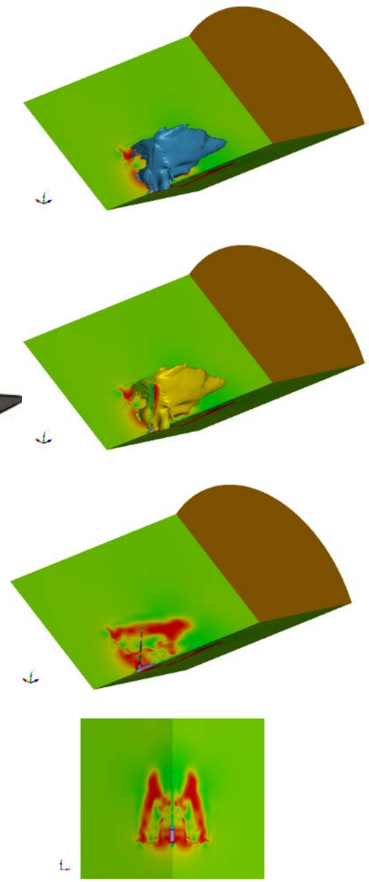


Horizontal Wind Turbine.

Model a third of the cylinder that contains the turbine. Take advantage of repeating pattern in the flow. Use non-inertial ref. frame with periodic boundary conditions.

ICFD - Periodic Boundary Conditions

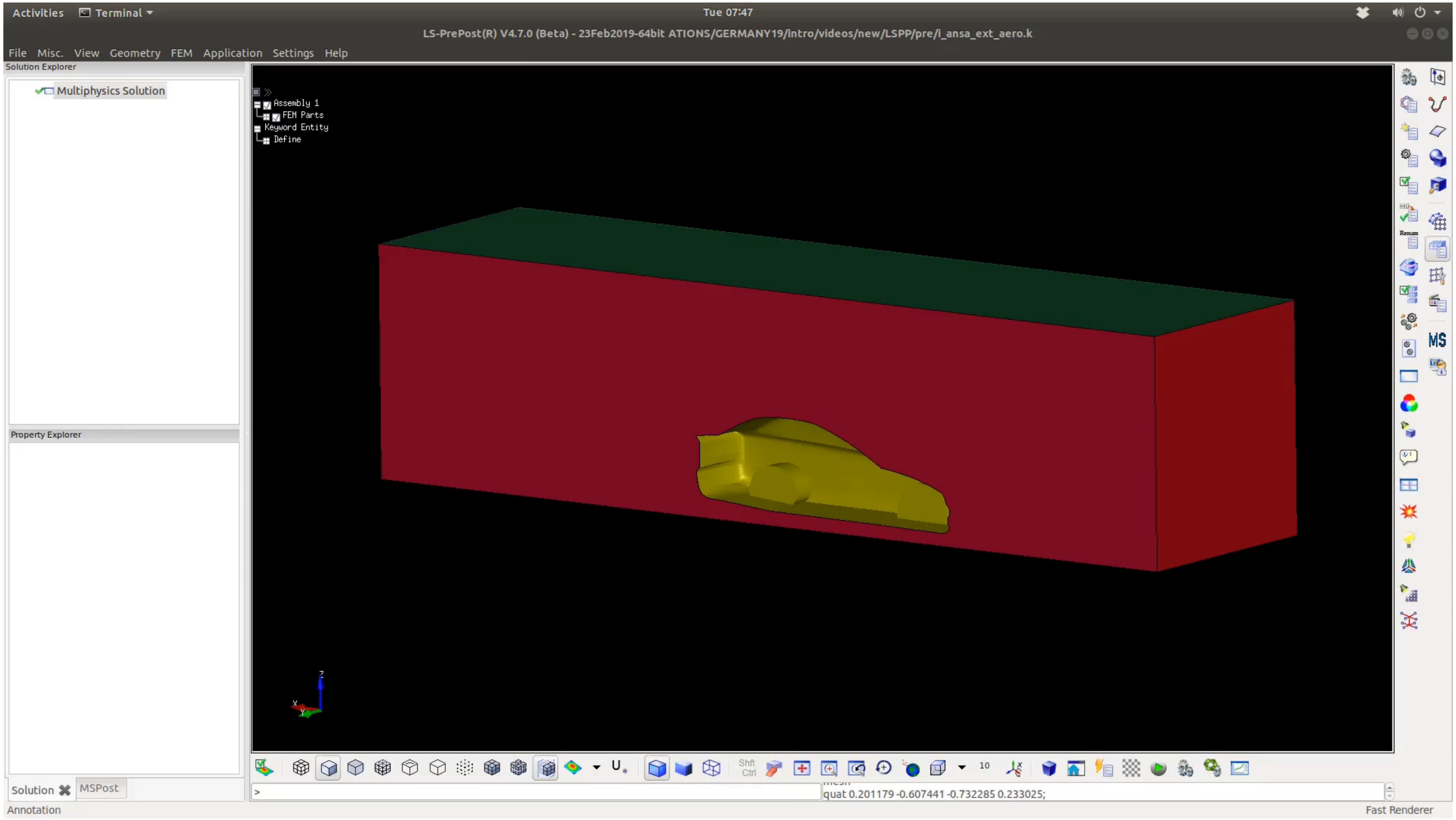
Periodic Boundary



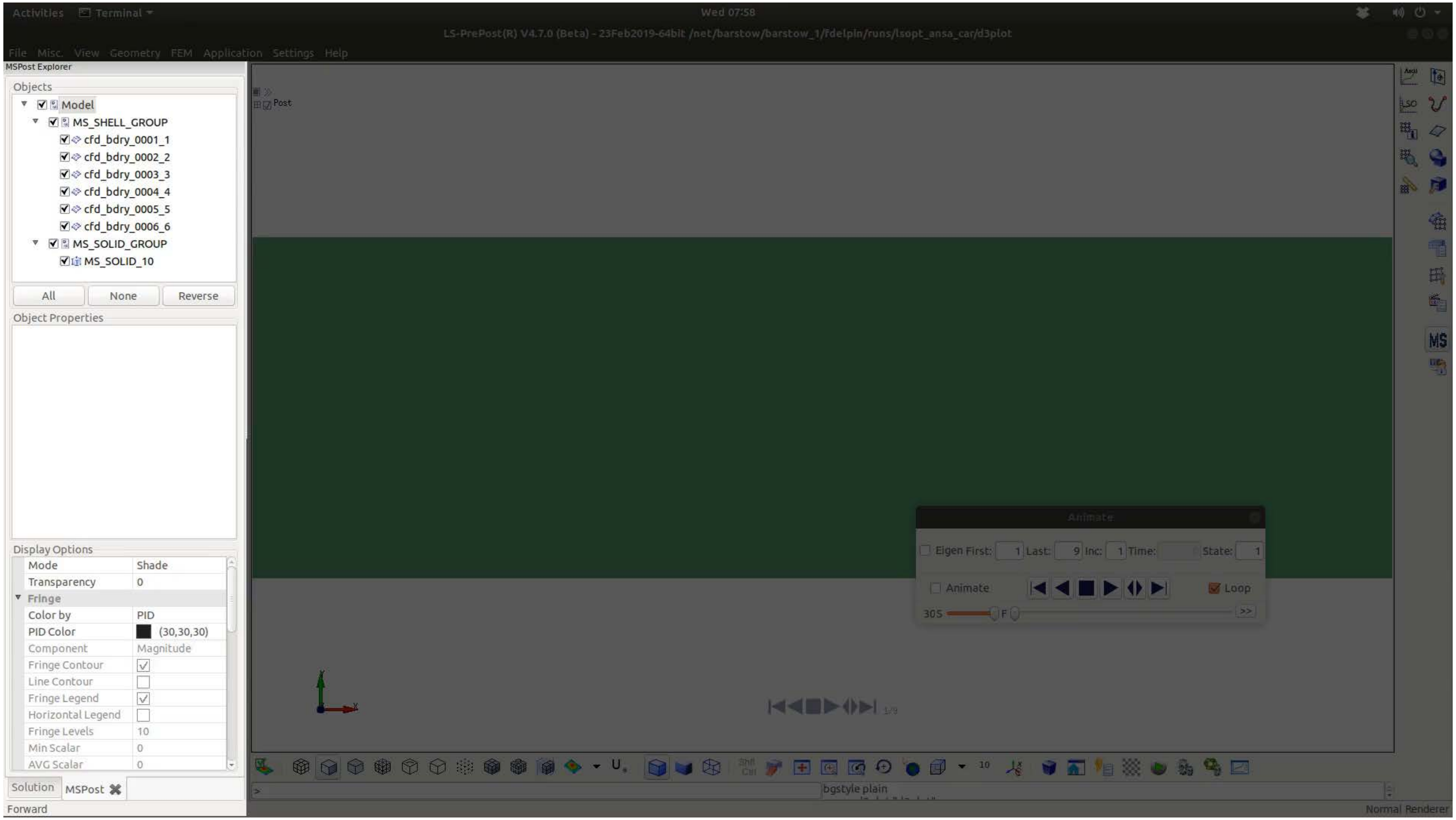
Horizontal Wind Turbine.

Model a third of the cylinder that contains the turbine. Take advantage of repeating pattern in the flow. Use non-inertial ref. frame with periodic boundary conditions.

ICFD - LSPP pre-processor Multi-Solver menu

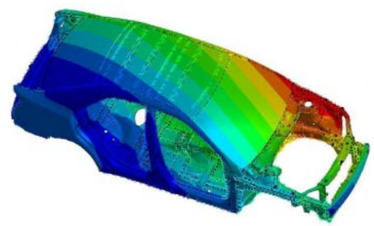


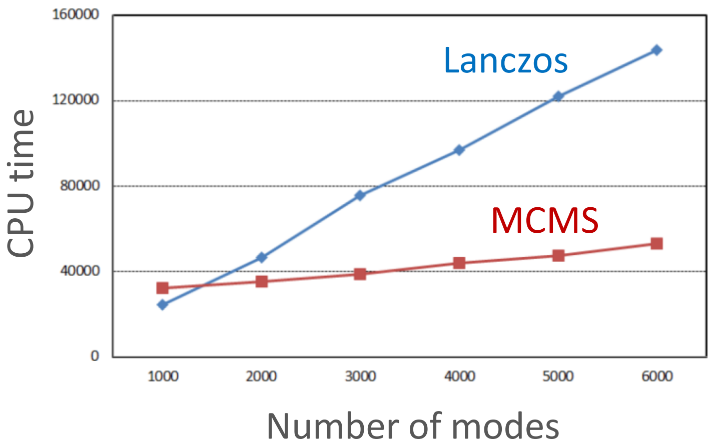
ICFD - LSPP **post**-processor Multi-Solver menu



Linear Implicit (1)

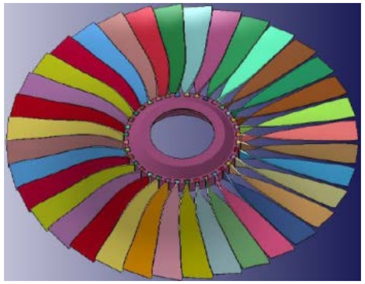
- New eigenvalue extraction method: MCMS
  - Multilevel Component Mode Synthesis
  - less accurate than Lanczos, but far less computer resources
  - useful for NVH applications that want thousands of modes





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

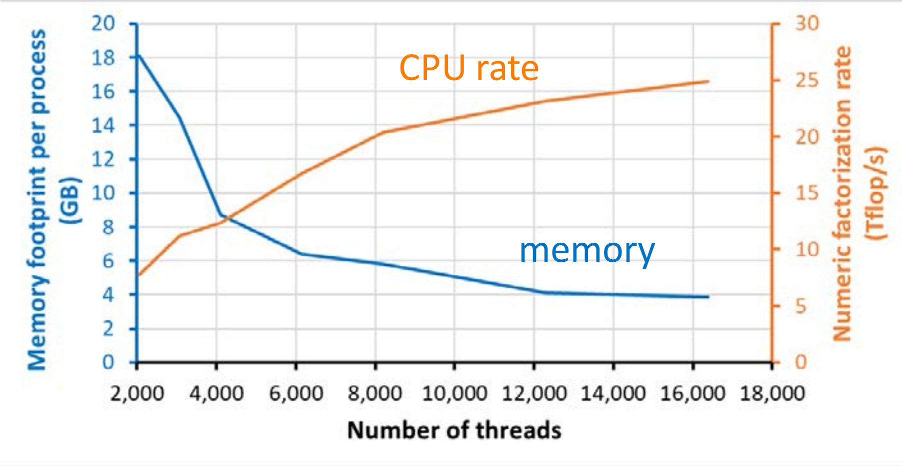
- And always…

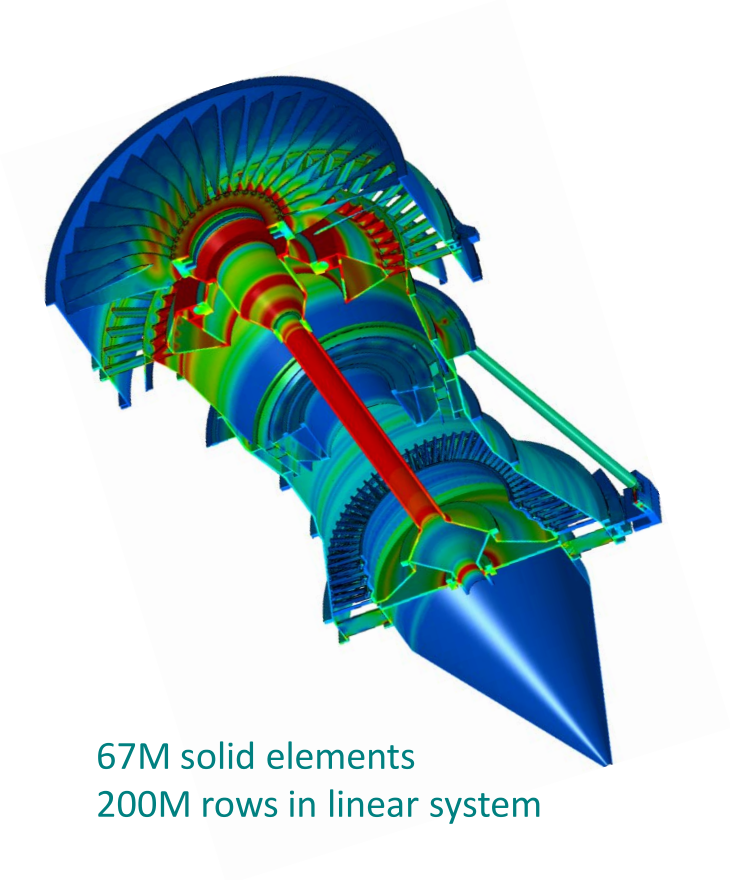


huge CPU/memory savings

Linear Implicit (2)

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

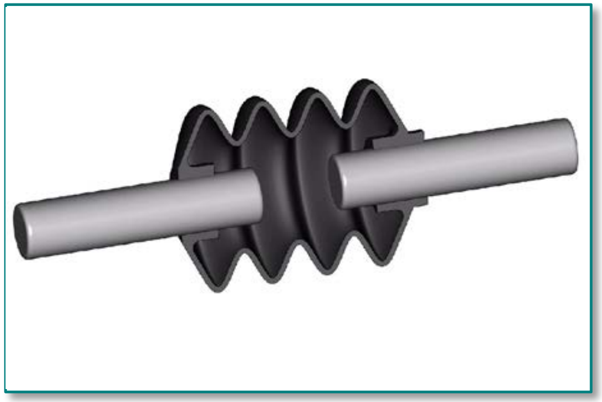




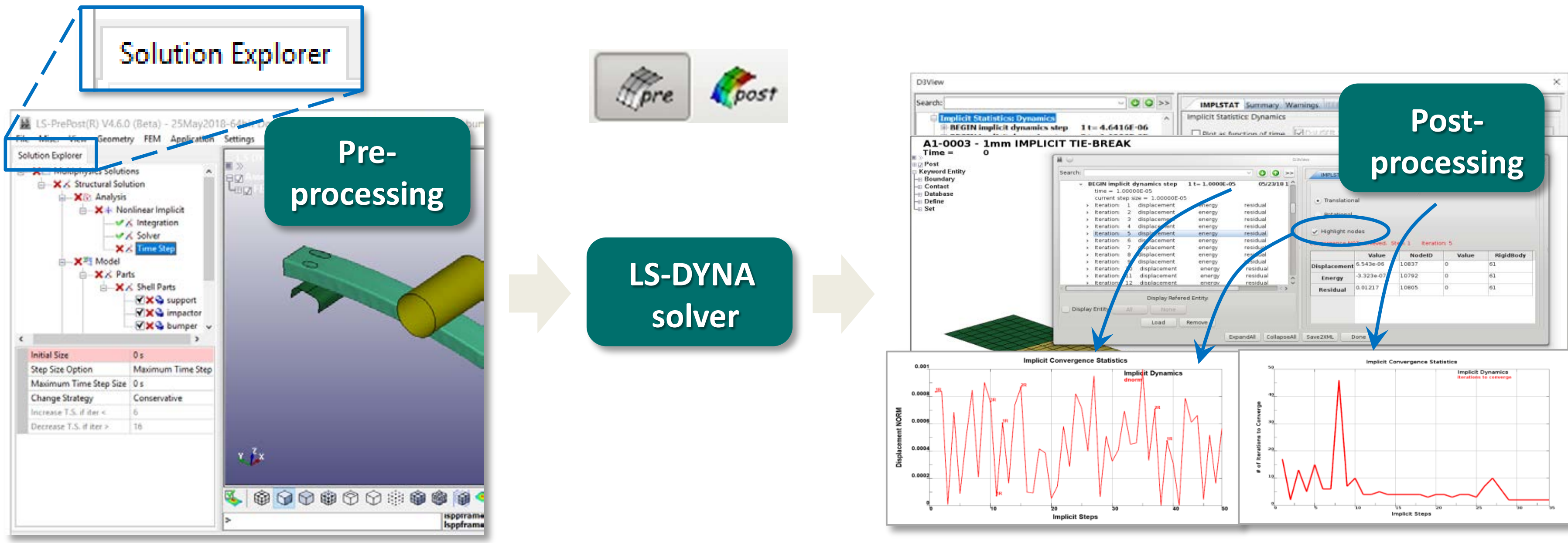
67M solid elements
200M rows in linear system

Nonlinear Implicit (1)

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



Nonlinear Implicit (2)

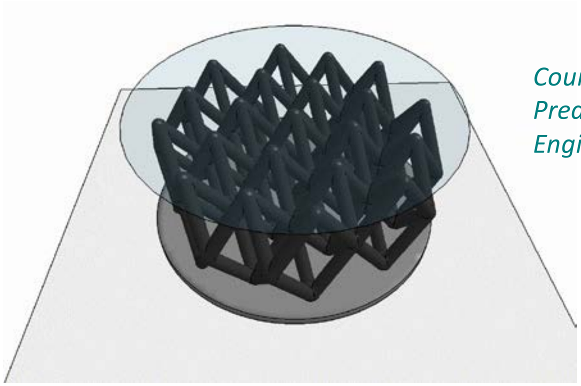


- Working on user-friendly Pre- and Post-processing (LS-Prepost)
  - model tree, parameter editor, suggested presets, error functionality, diagnostics
  - motivation: attract newcomers, facilitate migration, widen user community

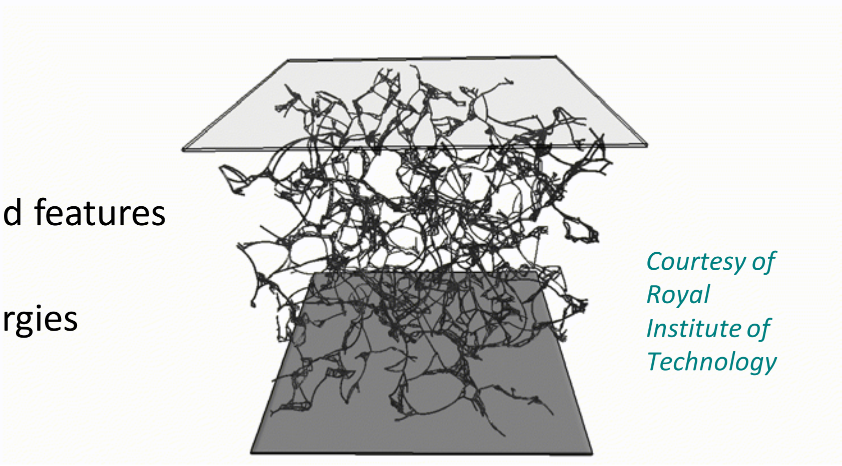
Mortar Contact (1)

Borrvall

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



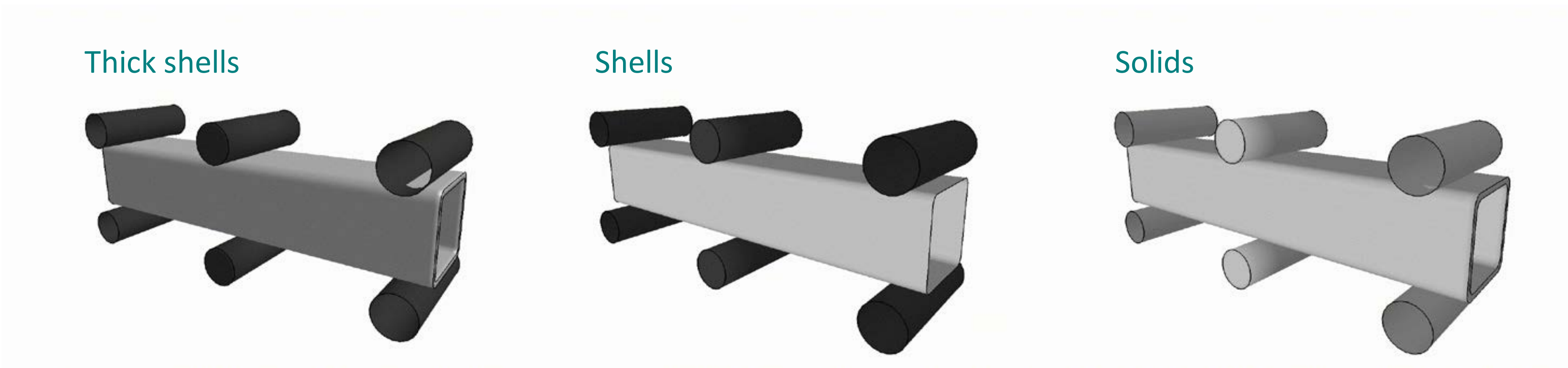
Courtesy of Predictive Engineering



Courtesy of Royal Institute of Technology

Mortar Contact (2)

Borrvall

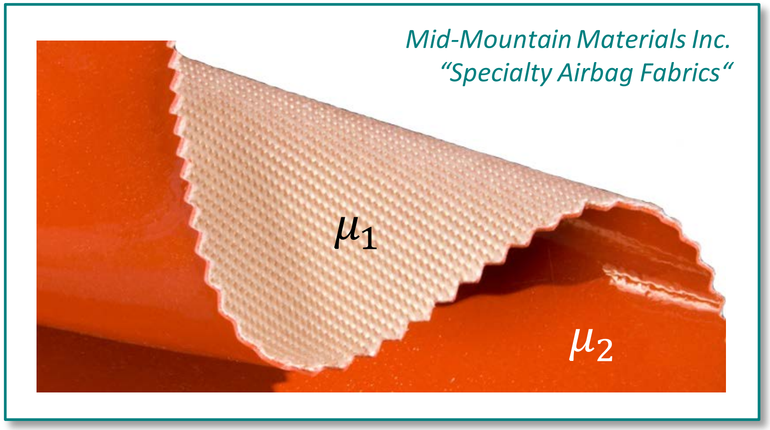


- Exposed segments due to erosion added to the contact
  - works for solids, shells and thick shells
- For shells, edges of eroded elements are exposed
- Supported for automatic surface to surface and single surface

Contact | SOFT=2 (segment based)

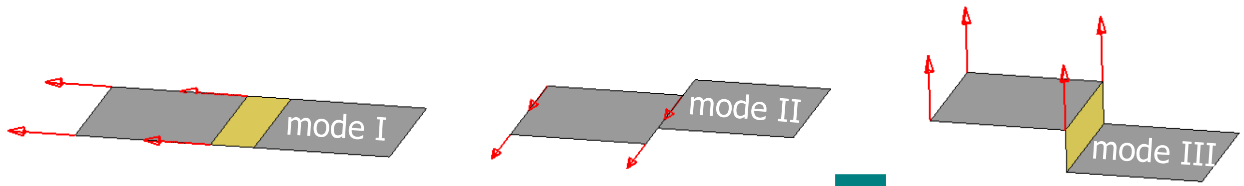
Bindeman

- Spotwelds share nodes with shells
  - support SPOTHIN and SWRADF in this case as well
- Different friction coefficient for the inner and outer surface of shell elements
  - new keyword *DEFINE_FRICTION_SCALING
- Frictional torque correction with FTORQ=2
- Support orthotropic friction
- Support MPP groupable contact

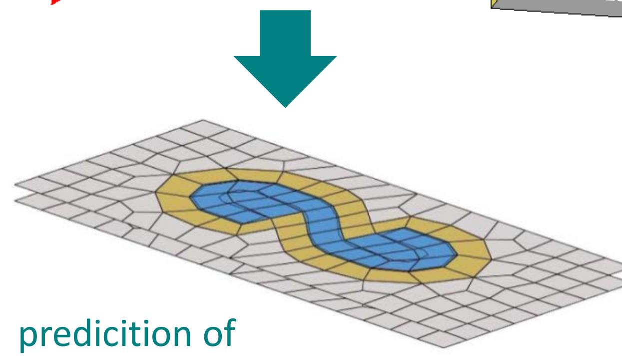


Connections | Linear and planar

Erhart, Karlsson



- New option for cohesive shell elements
  - clear distinction of three separation modes



predicition of
laser weld plug out

- *MAT_240 now fully supports all three modes
  - new option _3MODES for mode 3 deformation
  - also: thermal properties using new option _THERMAL

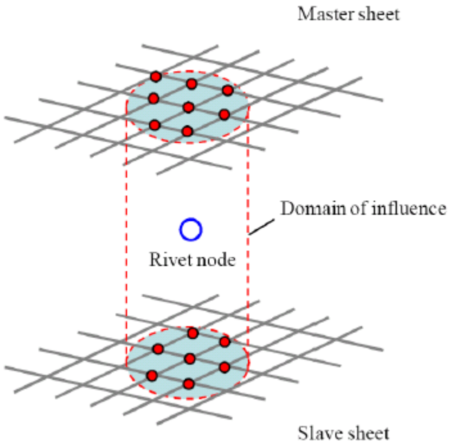
- Equivalent tiebreak model to *MAT_240
  - new options 13 and 14
  - allows rate dependence

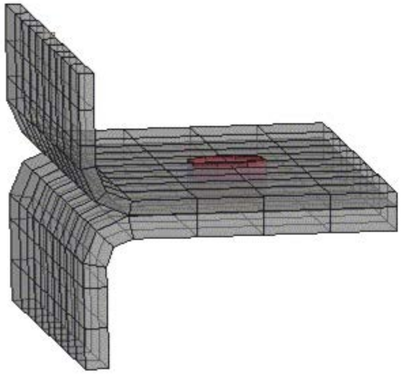
Ford Motor Co., Ltd.

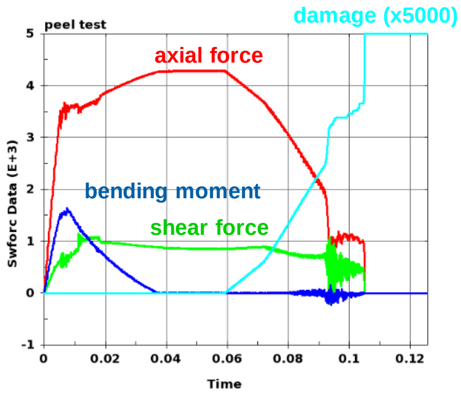
Connections | Point-shaped

Erhart

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





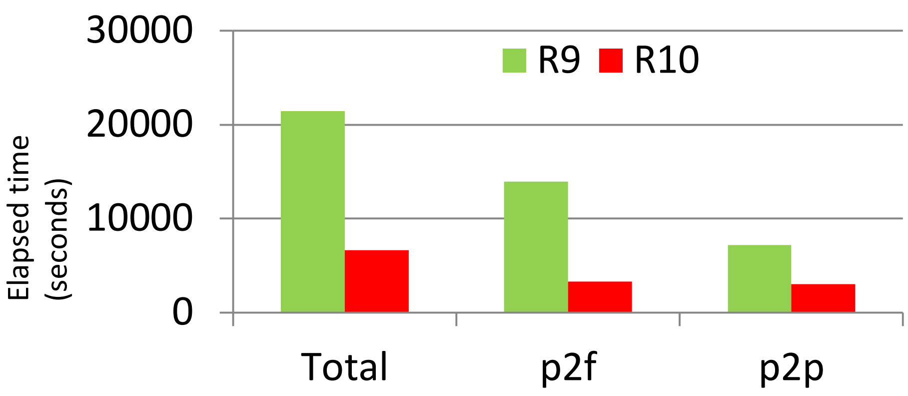


Airbags | New CPM contact algorithms

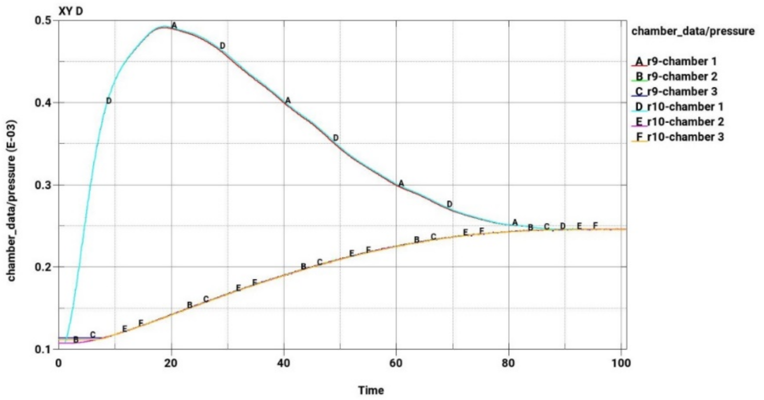
Jason Wang

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

3x speedup for tank test



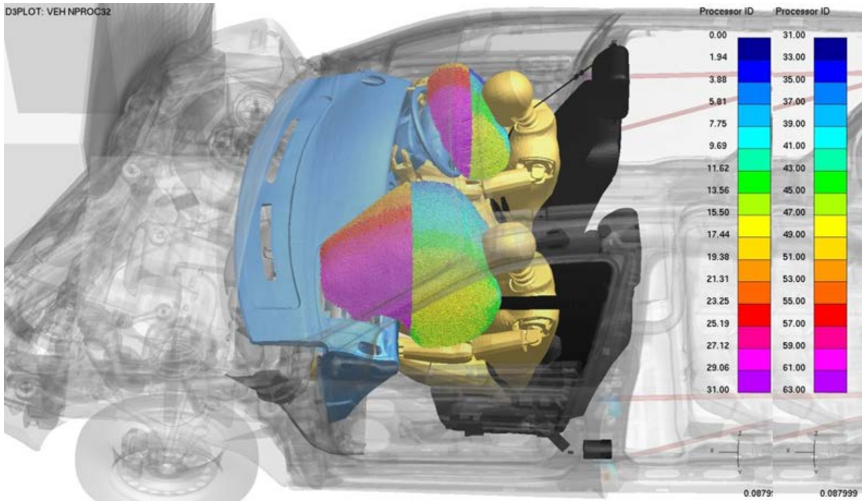
pressure history is consistent between releases



Airbags | more enhancements

Jason Wang

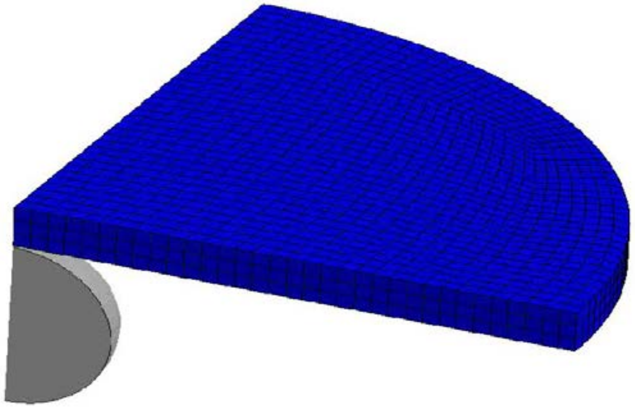
- Particle splitting to improve particle density
- Support *MAT_ADD_AIRBAG_POROSITY_LEAKAGE
- Molar fraction based inflator
- Orifice area as a function of time
- Output material leakage information
- Venting holes by part set
- Particle deflection angle
  via *DEFINE_FUNCTION
- …

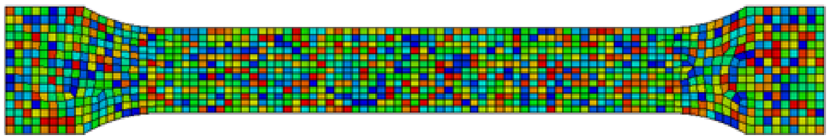


Materials | Failure and Damage

Borrvall, Erhart, Lum

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

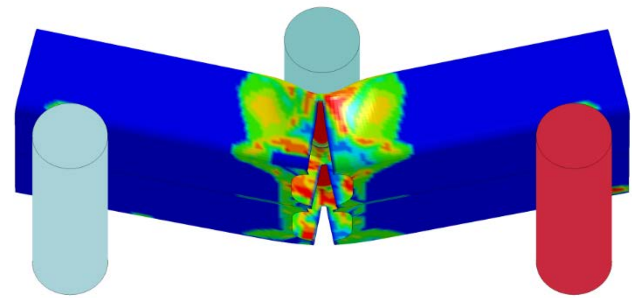




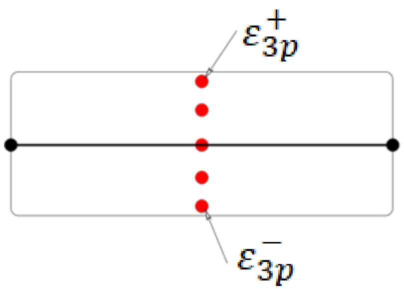
Materials | Regularized Failure Model

Berstad (NTNU)

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

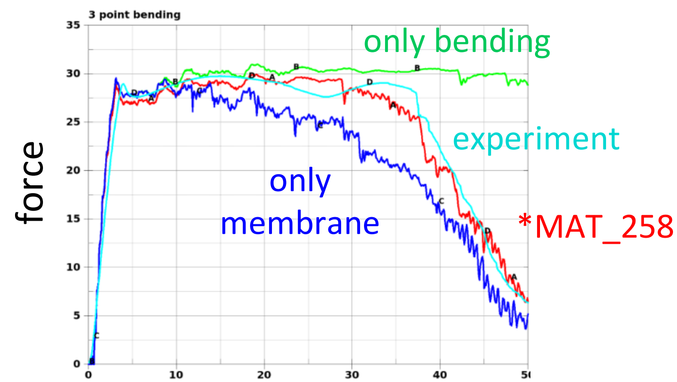


3-point bending of aluminum profile with hole: critical fracture value



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

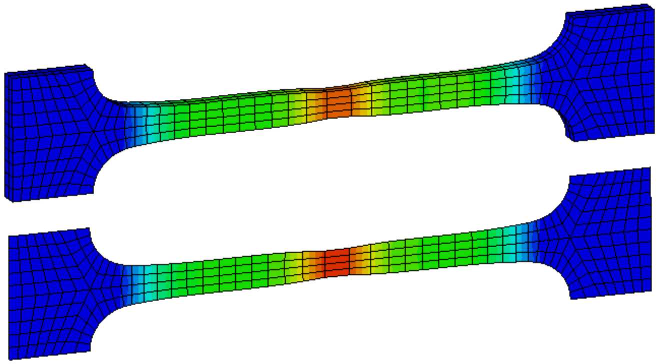
$$\Omega = \frac{1}{2}\frac{\left|\varepsilon_{3p}^{+} - \varepsilon_{3p}^{-}\right|}{\max\left(\left|\varepsilon_{3p}^{+}\right|, \left|\varepsilon_{3p}^{-}\right|\right)}$$



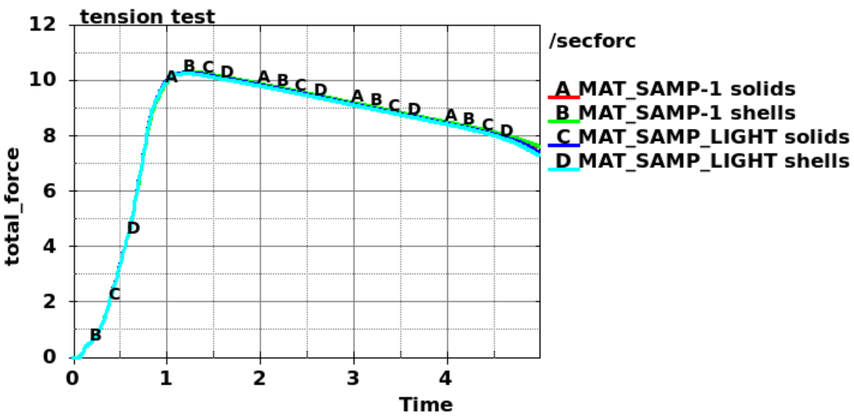
Materials | Polymers

A. Erhart

- New model *MAT_187L: “SAMP_LIGHT”
- Simplified form of *MAT_SAMP-1
  - reduced number of options
    (only tension/compression, no damage)
  - Strain dependent plastic Poisson’s ratio
  - more efficient implementation
    (reduced CPU time)
  - filtered strain rate instead of viscoplastic
  - for solid and shell elements
  - only explicit for now



- Example:
  tension test w/ solids and shells
  - seven times faster with new model
  - comparable results

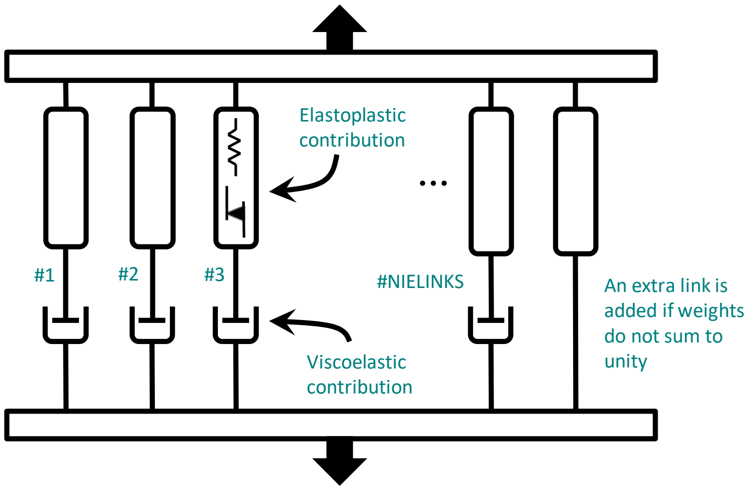


DYNA MORE NORDIC

Materials | Add-on Inelasticity

Borrvall, Bengzon

- New model *MAT_ADD_INELASTICITY
- Inelastic contribution from userdefined number of link groups with a weight factor.
- To amend ”any” material model with an inelasticity feature
  - plasticity (partially supported, incremental models)
    - von Mises isotropic hardening viscoplasticity
  - creep (partially supported, incremental models)
    - Norton creep variants
  - viscoelasticity (supported)
    - Prony series
  - Explicit and implicit, shells and solids



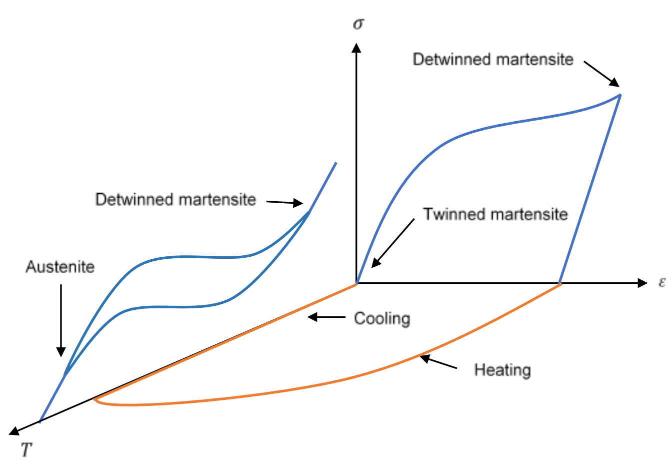
$$\sigma = \sum_{I=1}^{NIELINKS(+1)} w_I \sigma_I .$$

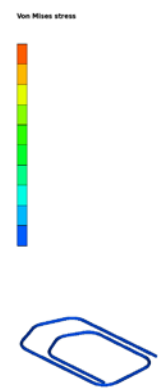
- Intention is not to replace any material model but to complement with potentially missing features and accept an incurred cost when doing so

Materials | Shape Memory Alloy

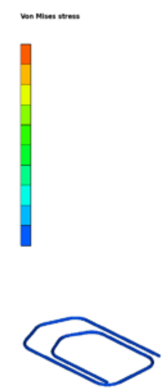
Karlsson

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





high temperature
austenite phase

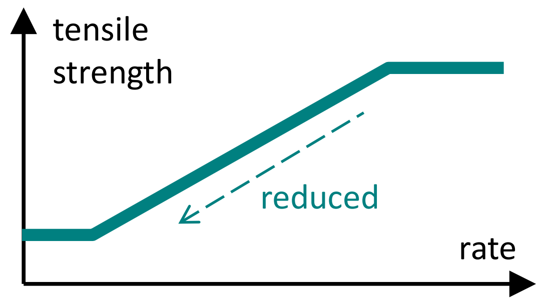


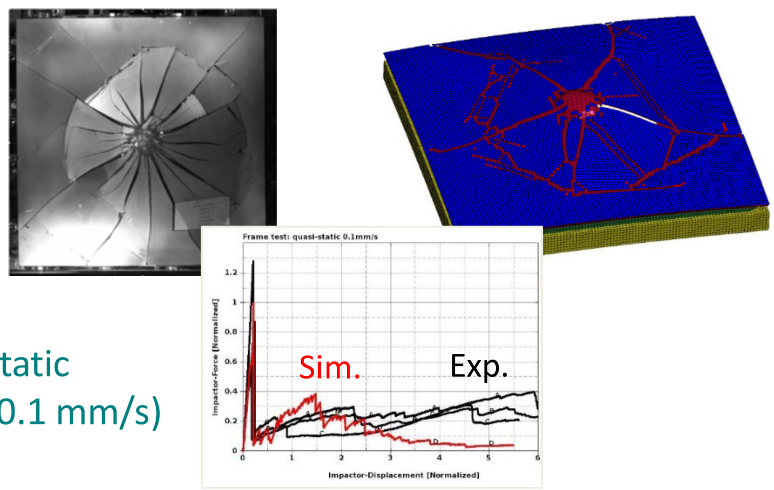
low temperature
martensite phase

Materials | Glass

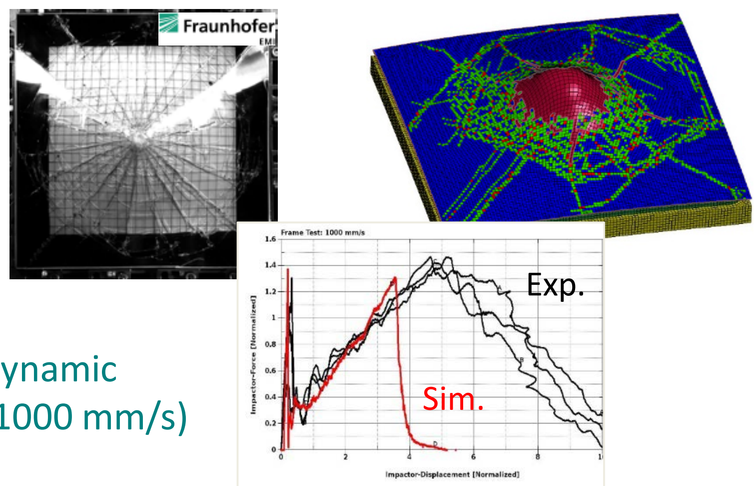
A. Erhart

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





static
(0.1 mm/s)

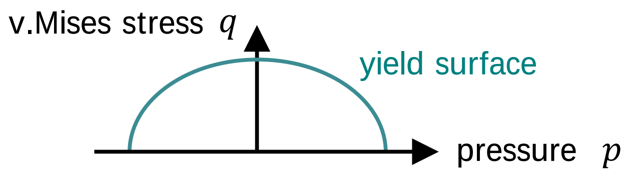


dynamic
(1000 mm/s)

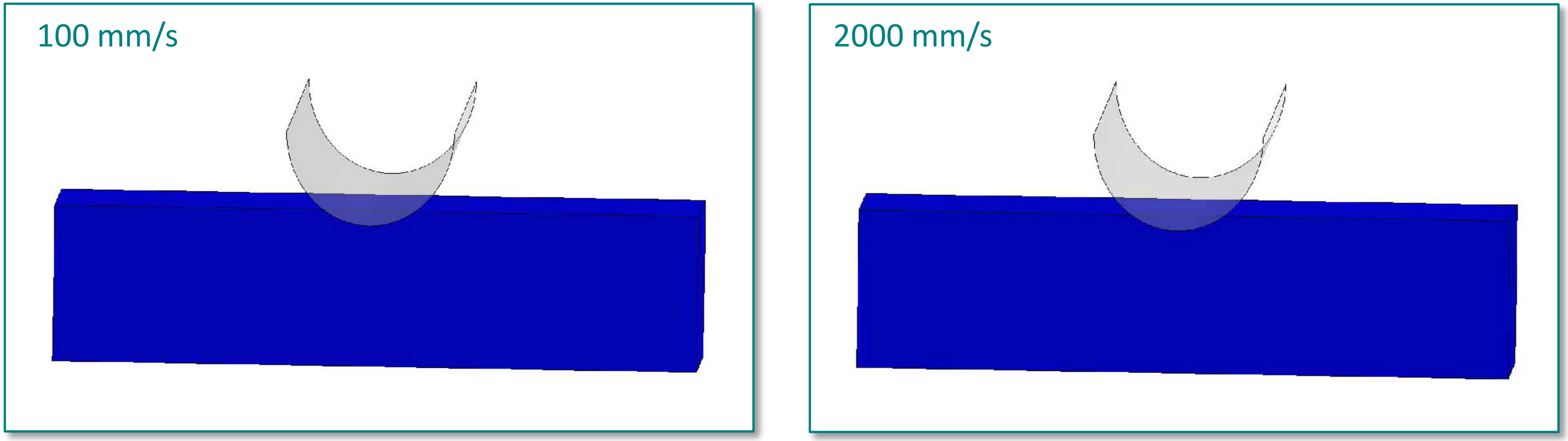
Materials | Foam

A. Erhart

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



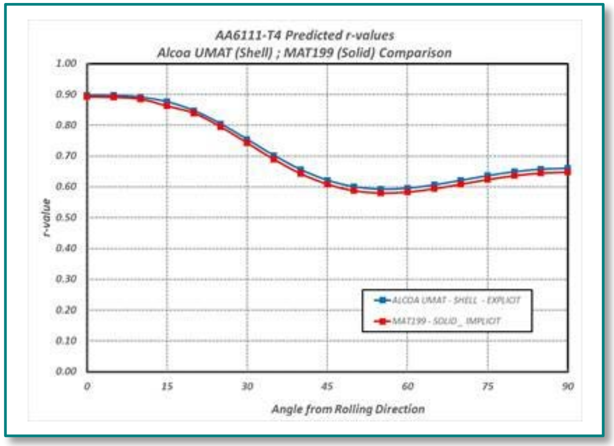
$$F = \sqrt{q^2 + \alpha^2 p^2} - B(\sigma^y) = 0$$

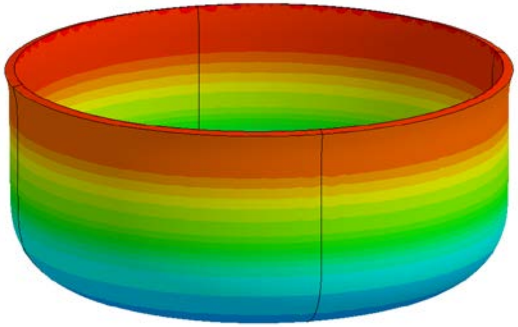


Materials | Anisotropic Yield (1)

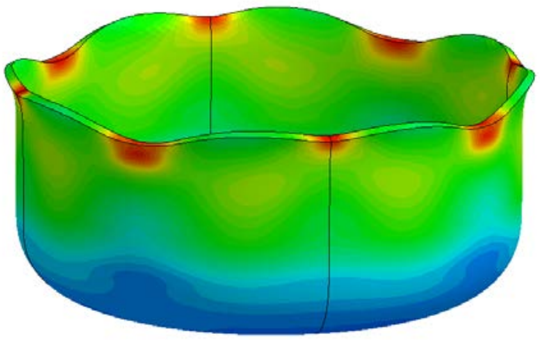
Erhart

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





*MAT_024

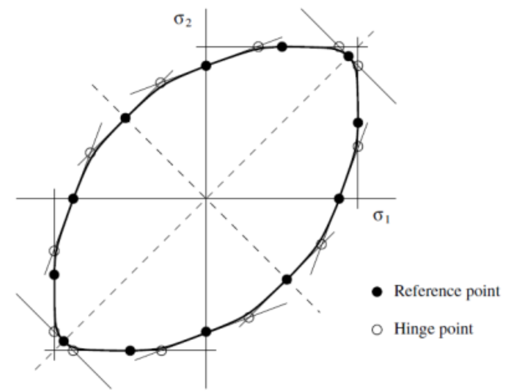


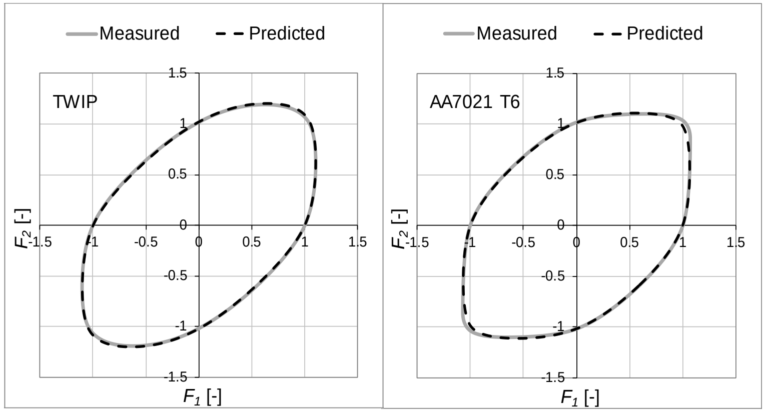
*MAT_199

Materials | Anisotropic Yield (2)

Klöppel

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



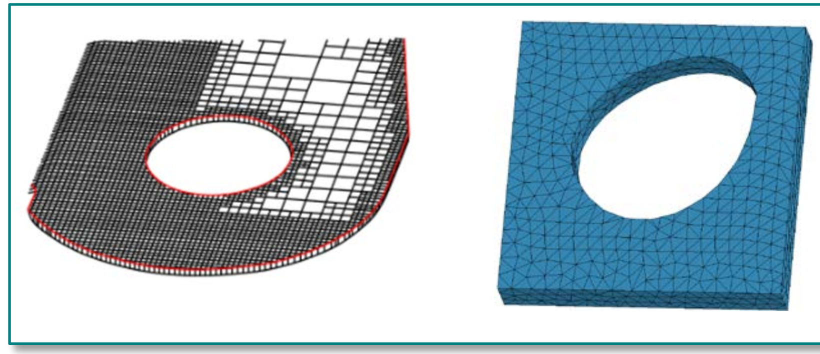


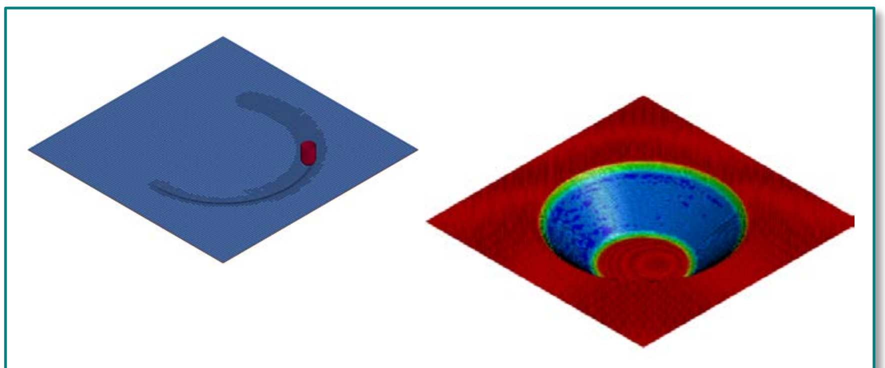
[1] Vegter, Boogaard; 2006 [2] Abspoel et al, 2017

Metal forming (1)

Zhu, Fan, Zheng

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



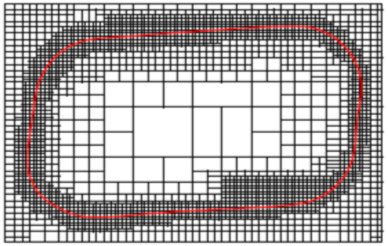


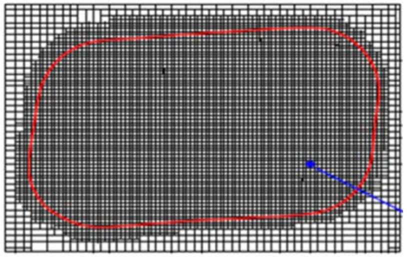
- Mesh fusion (adaptive re-coarsening)
  - completely reworked & extended to MPP
  - uses average information of merged elements
  - with tube adaptivity for incremental forming

Metal forming (2)

Zhu, Fan, Zheng

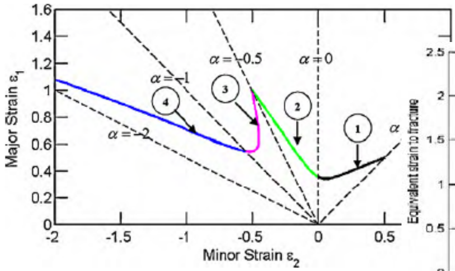
- New mesh refinement options
  - along given curve or inside domain
  - *CONTROL_ADAPTIVE_CURVE: ”ITRIOPT”

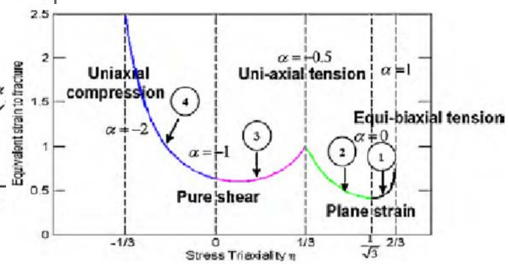




e.g. for stoning

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

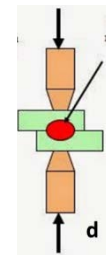


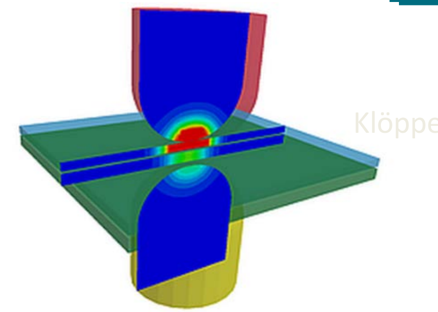


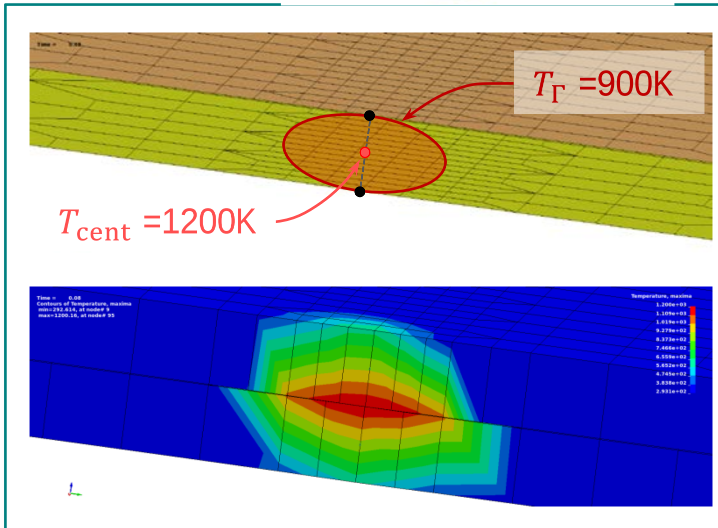
- Automatic conversion FLD to triaxiality curve (and vice versa)
  - *DEFINE_CURVE_TRIAXIAL_LIMIT_FROM_FLD

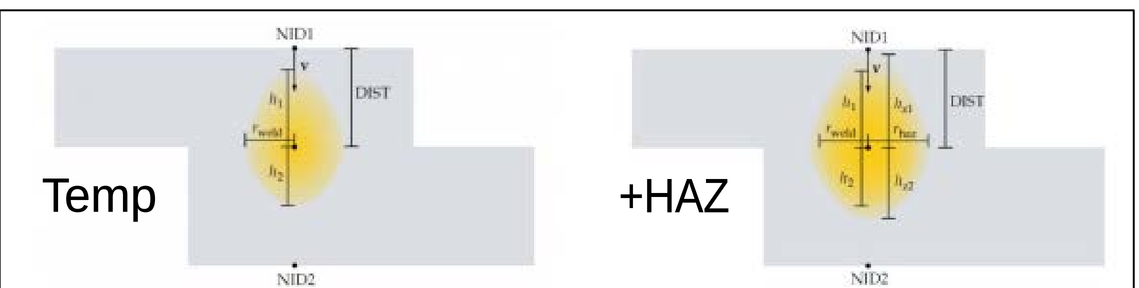
Thermal Analysis | RSW

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



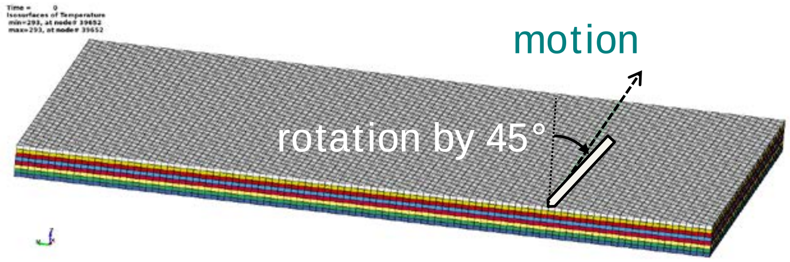


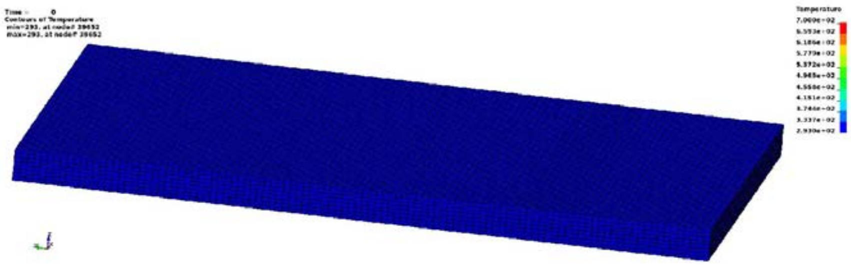




Thermal Analysis | Laser Cutting

Klöppel





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

Misc | Post-processing

Erhart

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

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

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

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

Misc | more …

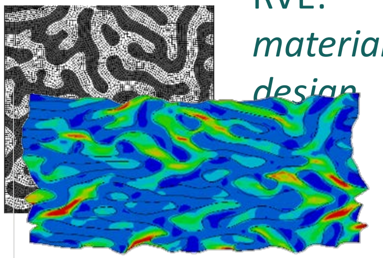
- New options for *CONSTRAINED_BEAM_IN_SOLID
  - e.g. implicit support for IDIR=1 and AXFOR, coupling to thermal solver, …
- New features and improvements for staged construction
- Add new keyword *USER_NONLOCAL_SEARCH
- Add cross section forces (*DATABASE_SECFORC) for 20-node and 27-node hexas
- *SENSOR: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

Multi-Scale Mechanics

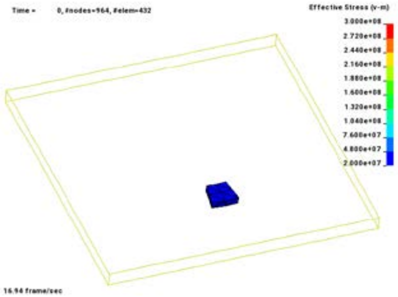
Wu et al.

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

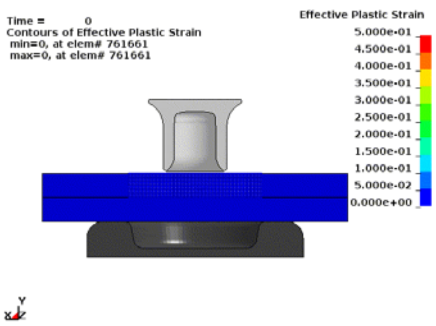
RVE:
material design



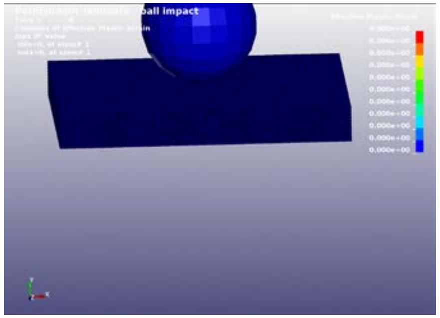
Adaptive EFG:
3-d printing



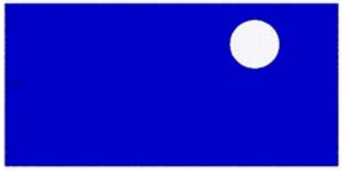
SPG:
self-pierce riveting



Peridynamic:
CFRP plate impact



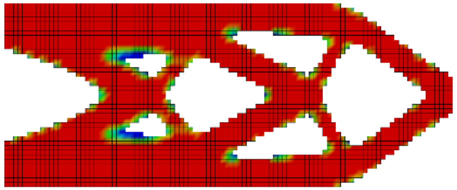
XFEM:
crack propagation



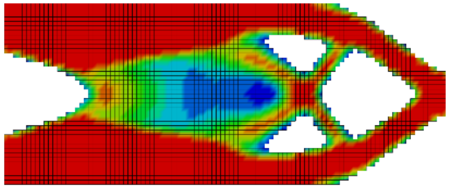
LS – TASC 4.0

LS-TaSC 4 focuses on the design of huge models for a combination of **statics, NVH, and impact**

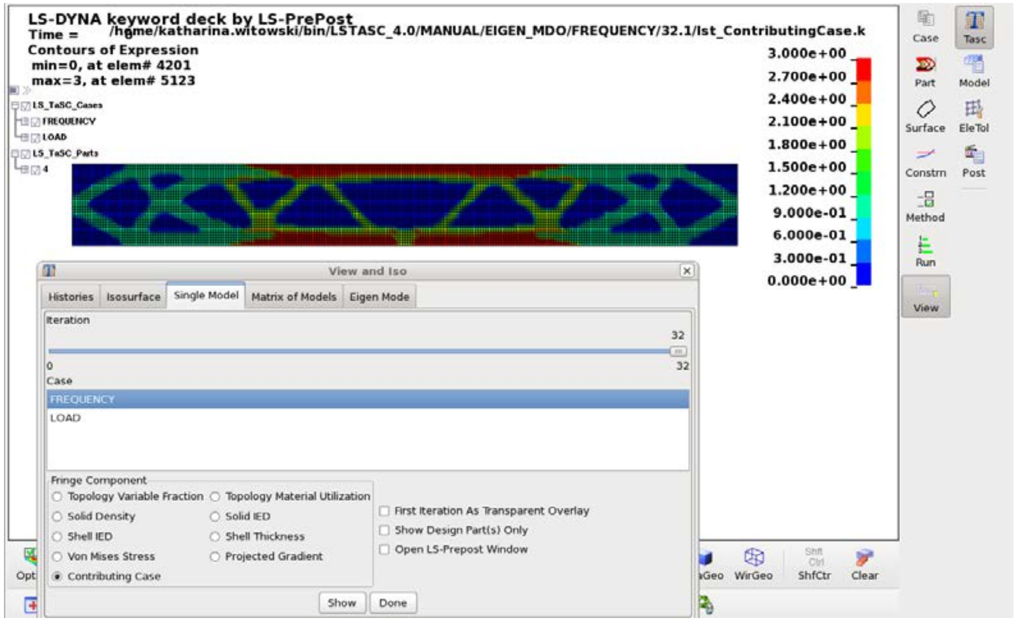
- Multidisciplinary methodology
  - Projected subgradient
  - Multidisciplinary optimization
  - Visualization

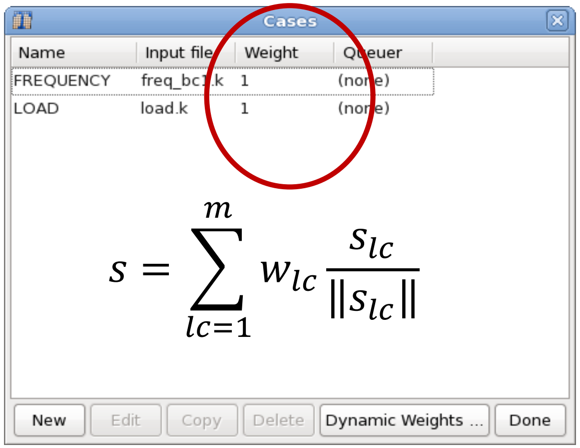


4.0



3.2



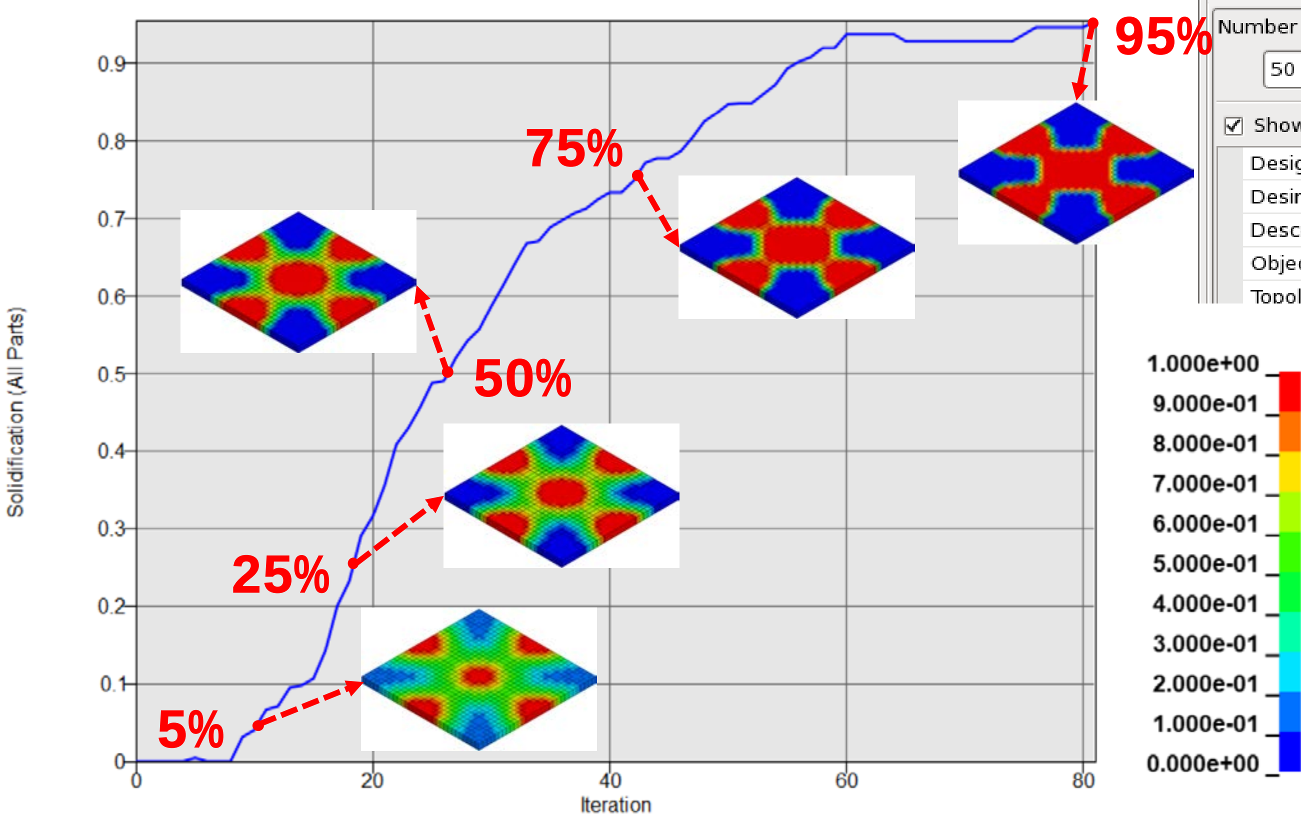


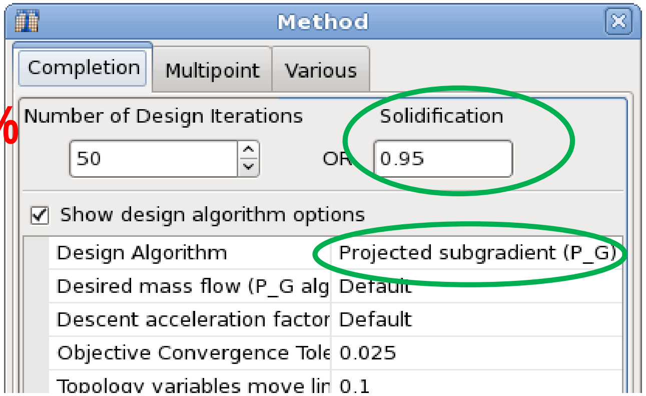
$$s = \sum_{lc=1}^{m} w_{lc} \frac{s_{lc}}{\|s_{lc}\|}$$

LS-TaSC 4: Designing for the combination of impact, statics, and NVH
Katharina Witowski, DYNAmore GmbH et al.

LS – TASC 4.0 – Stopping Criteria

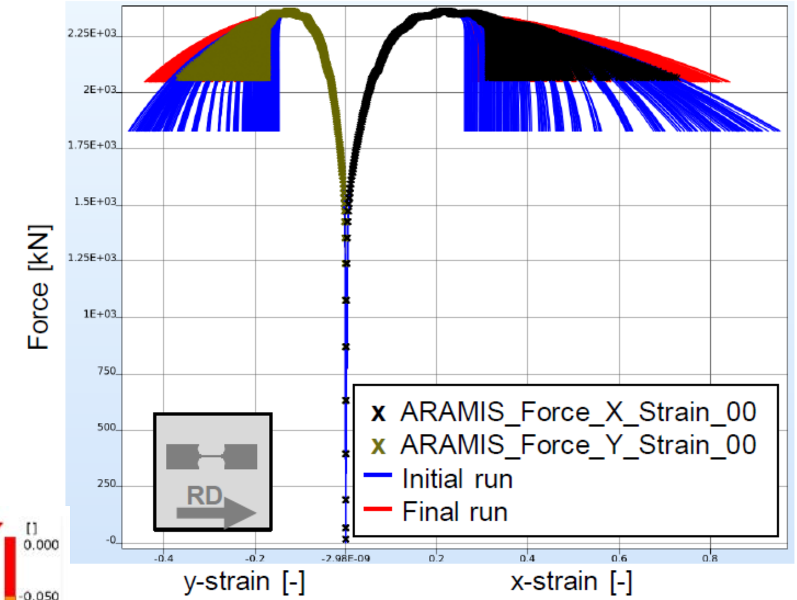
- The Projected Subgradient Method uses a new stopping criterion called Solidification, which measures the discreteness of optimized designs → fractions of elements fully used or deleted
- $M = 1$ → fully converged design

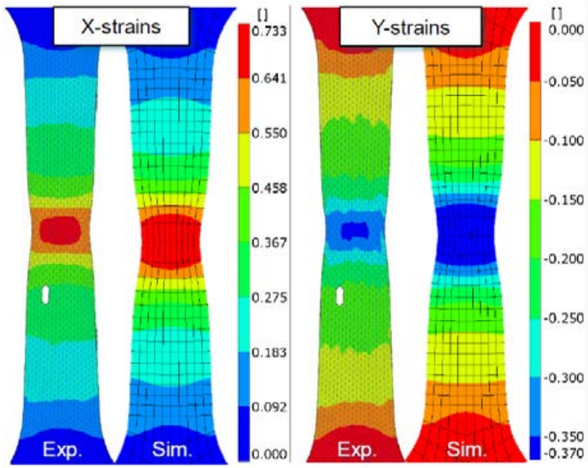




LS-OPT 6.0 - DIC

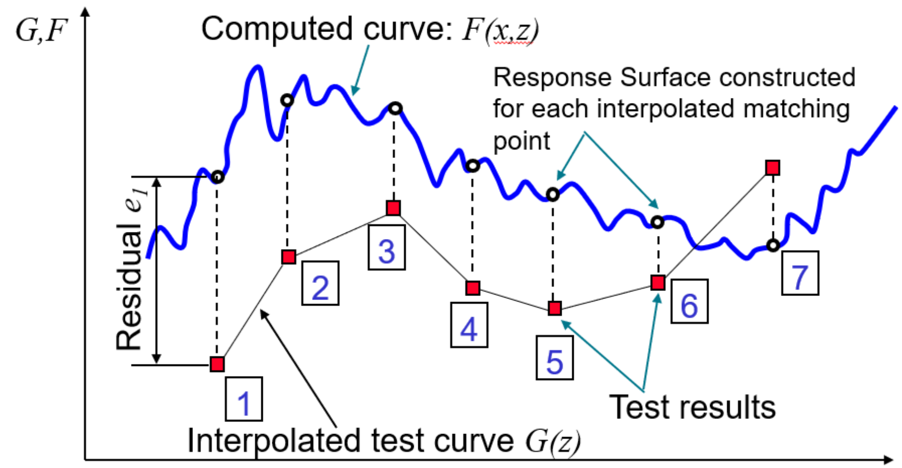
- Parameter Identification problems are non-linear inverse problems solved using optimization
- Global data from experiment is used
- Problems:
  - Instability typical in calibration problems, especially complex models with many parameters
  - Local phenomena such as coupon necking/barreling missed
- Interfaces (LS-OPT 6.0) Multihistories and Histories
  - ARAMIS (gom)
  - GENEX

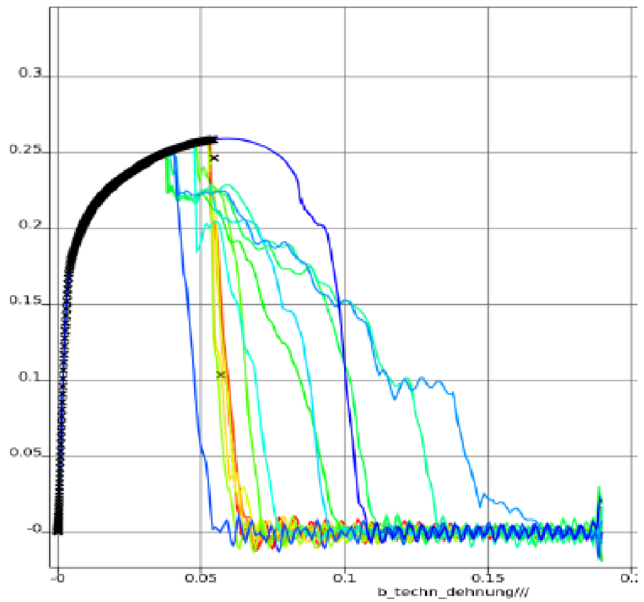


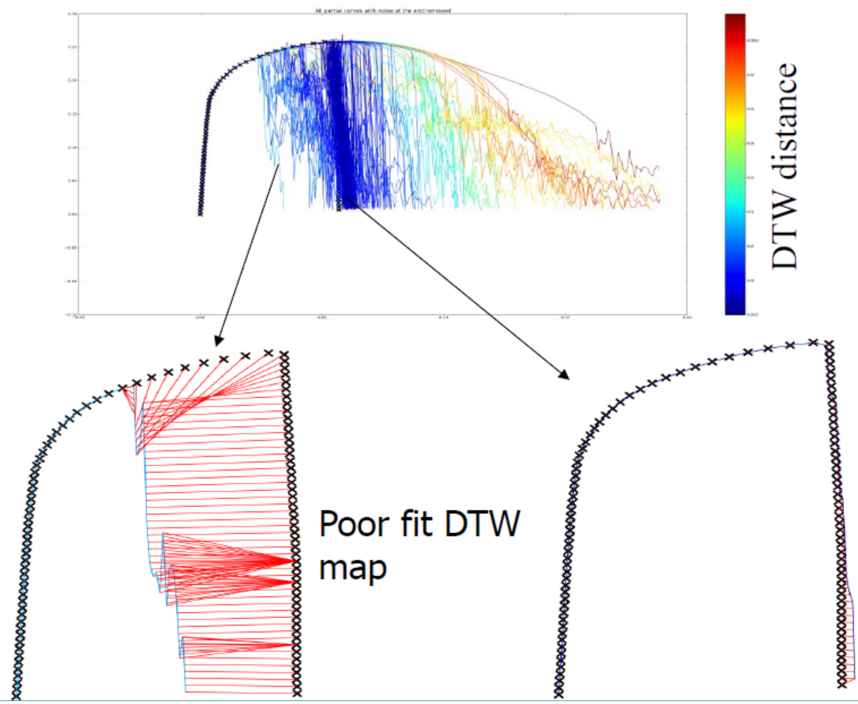


LS-OPT – Curve Matching

- Response (LS-OPT 6.0)
  - Matching of histories and multihistories
    - Mean Square Error
    - Partial Curve Mapping
    - Discrete Fréchet
    - Dynamic Time Warping

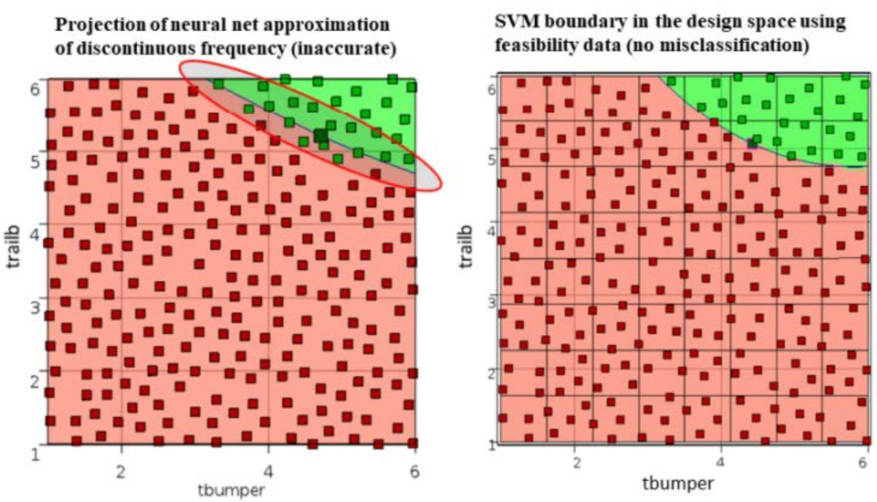


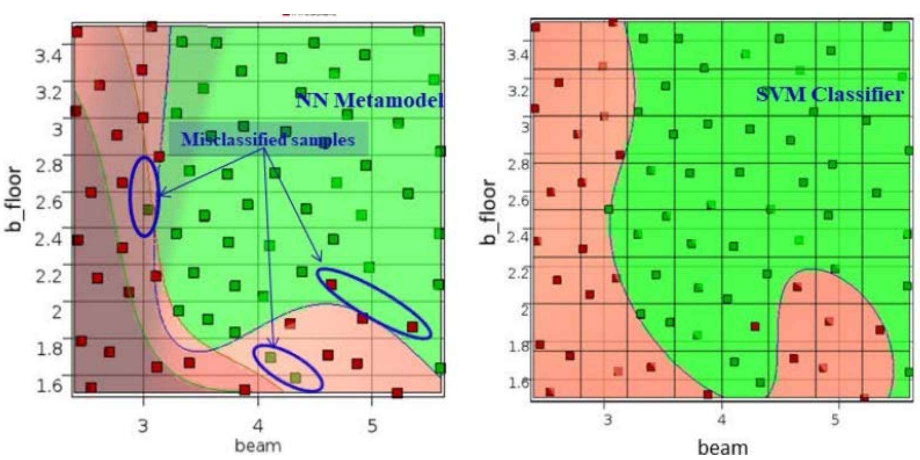




LS-OPT - Classifiers

- For better handling of discontinuous or binary responses where metamodel based methods struggles.
- Instead of a response value, a classifier is used to decide if the solution is feasible or not.
- Useful for:
  - Binary problems, e.g. Fail or no fail
  - Discontinous responses
  - System reliability with multiple failure modes
  - Multi objective optimization
- Support Vector Machine is used to determine the decision boundary





More Information on the LSTC Product Suite

- DYNAmore Nordic
  www.dynamore.se
- Livermore Software Technology Corp. (LSTC)
  www.lstc.com
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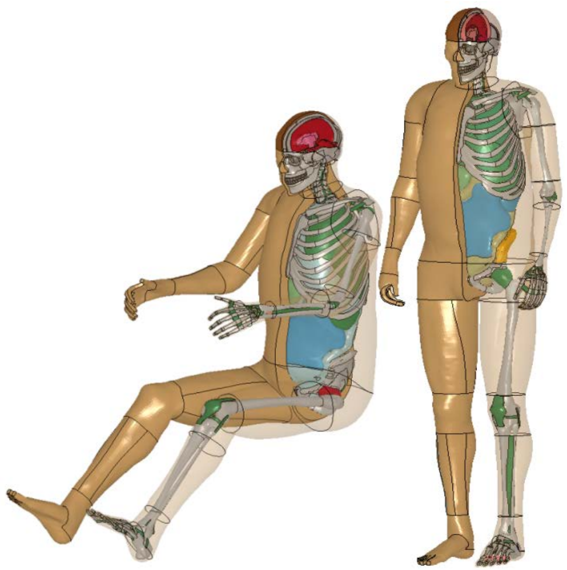

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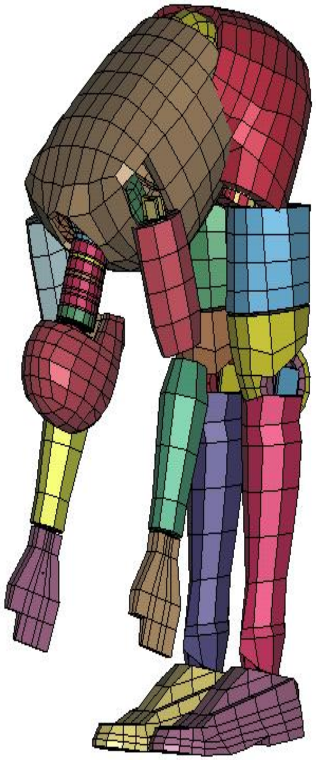
Thank you!



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