LS-DYNA 2024R1 (R15.0)
Recent Developments

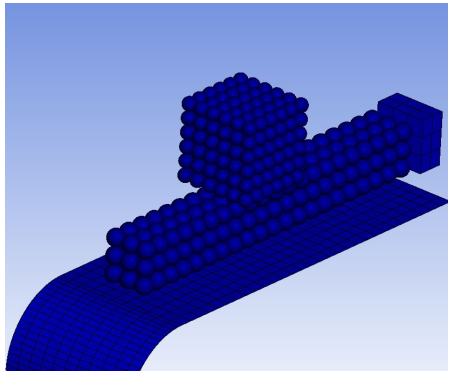
Many Many New Developments for LS-DYNA R15

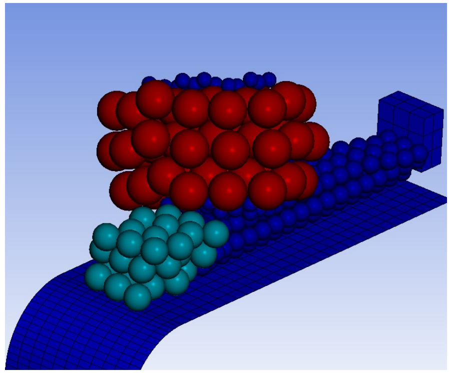
- During this Forum you have already heard about many of the New Developments for LS-DYNA R15
- This talk is just to give quick highlights of many of the New Developments you have not heard so far.
- And there are many more that we just don't have time to cover.

CPM and DEM

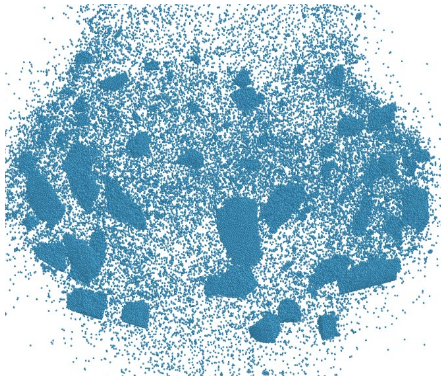
*ELEMENT_DISCRETE_SPHERE

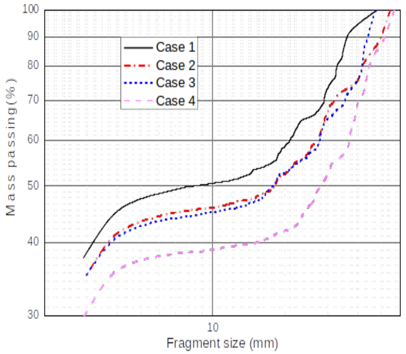
- A temperature effect on the particles of DEM is introduced.





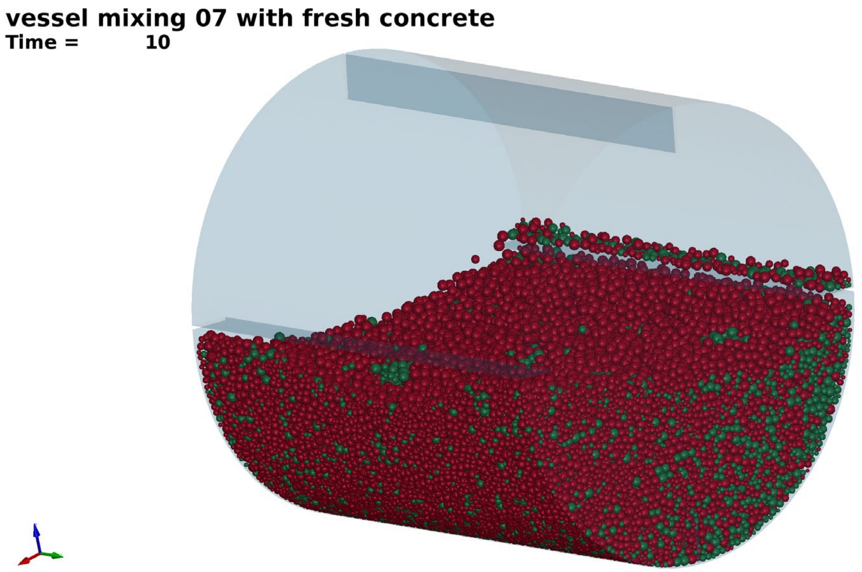
- A user can output the fragment volume, radius, and maximum size at a user specific time interval for the bonded DEM



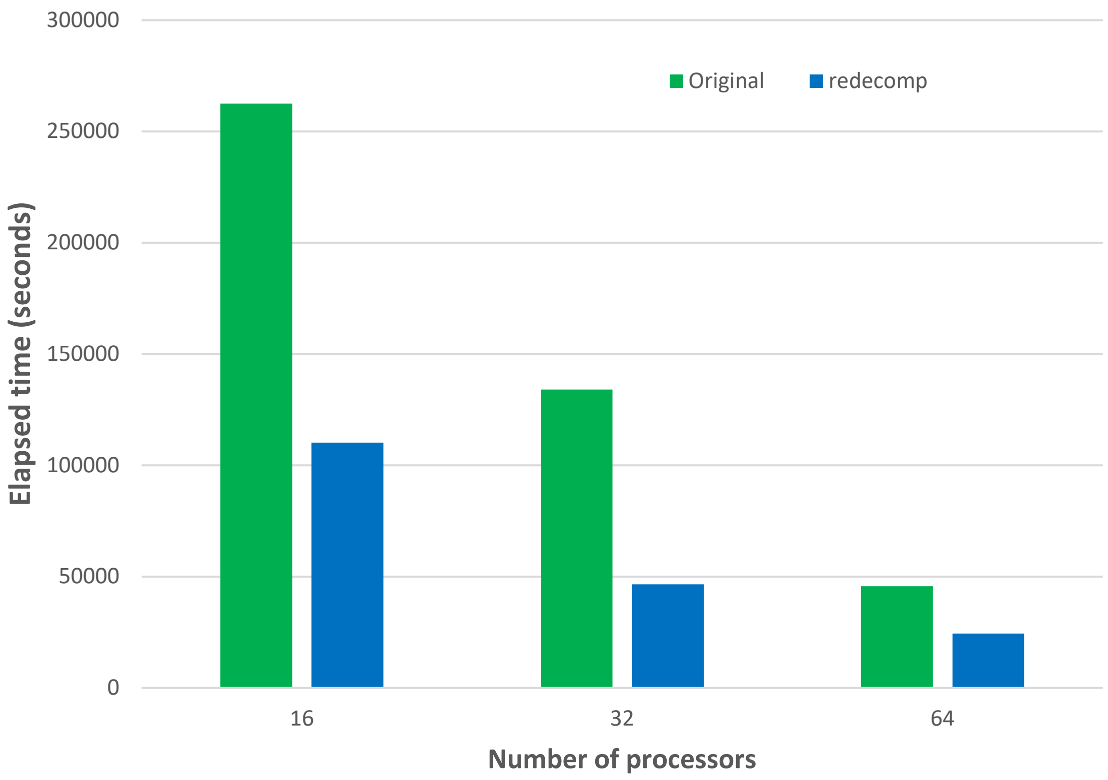


Fragmented bonded DEM particles

*ELEMENT_DISCRETE_SPHERE

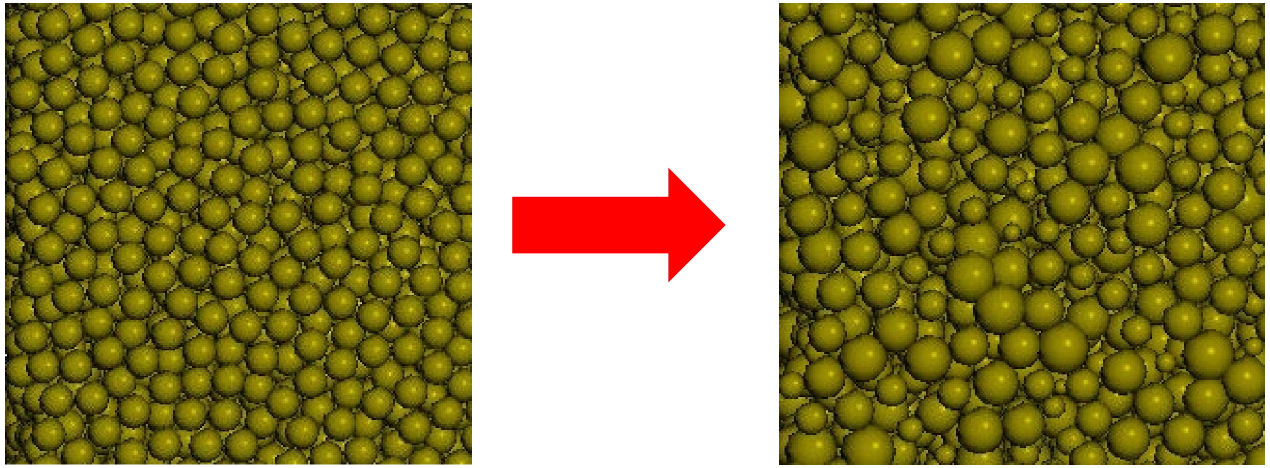


- Support REDECOMP
  - ✓ Decompose the model based on current geometry to reduce searching of neighboring particles and communication cost
  - ✓ 2x speedup



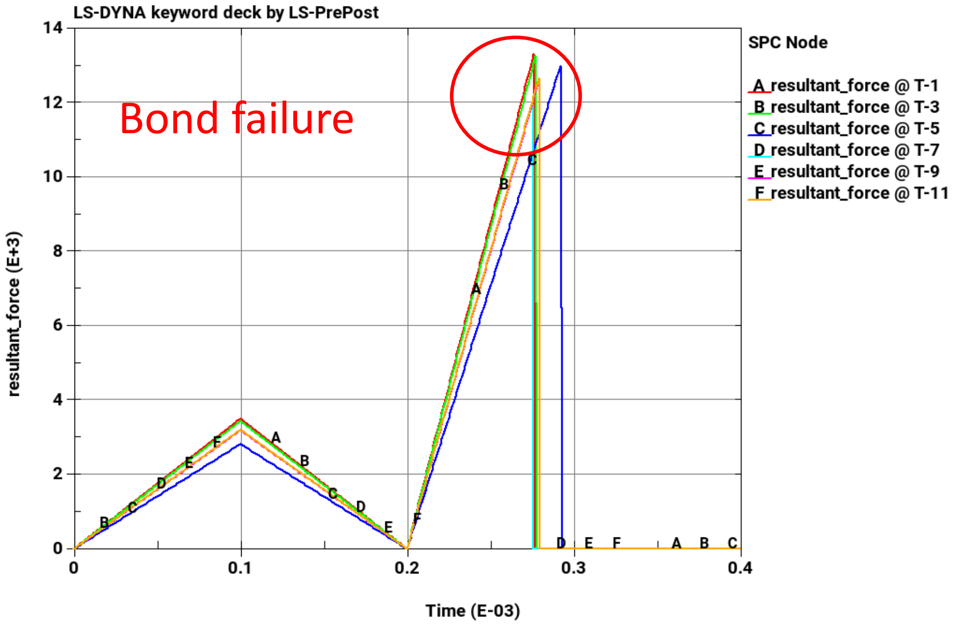
*ELEMENT_DISCRETE_SPHERE

The ability to statistically distribute Mass, Volume, Inertia, and Radii input parameters of DES with a normal or Weibull distribution.



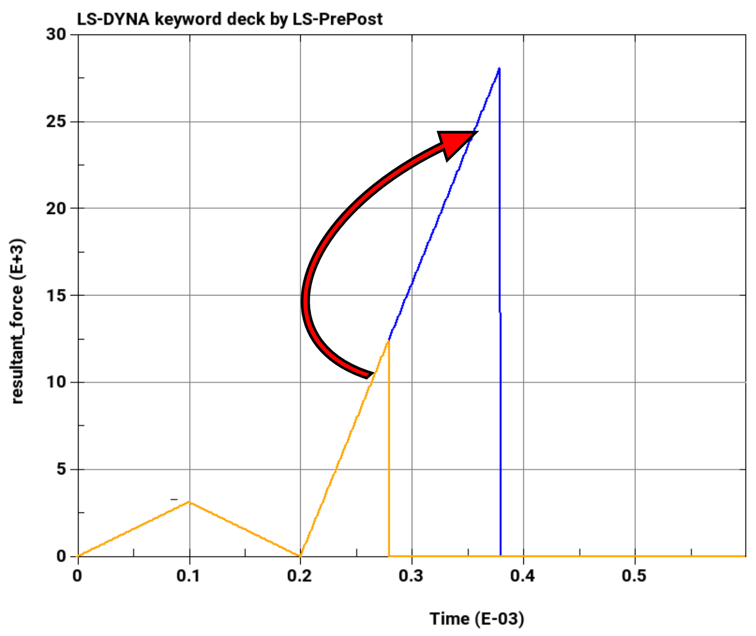
*DEFINE_DE_BOND

The ability to statistically distribute bond input parameters of BDES with a normal or Weibull distribution.

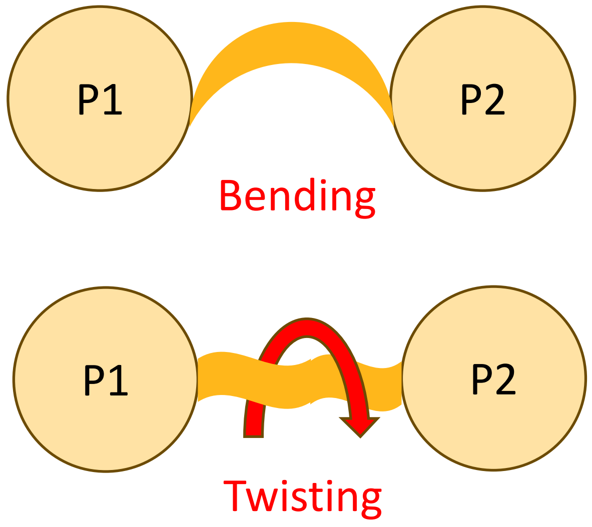


*DEFINE_DE_BOND

Bond strengths that increase linearly with deformation rate. With this, BDEM can capture the well-known strength increase with increased loading rate in rock materials.

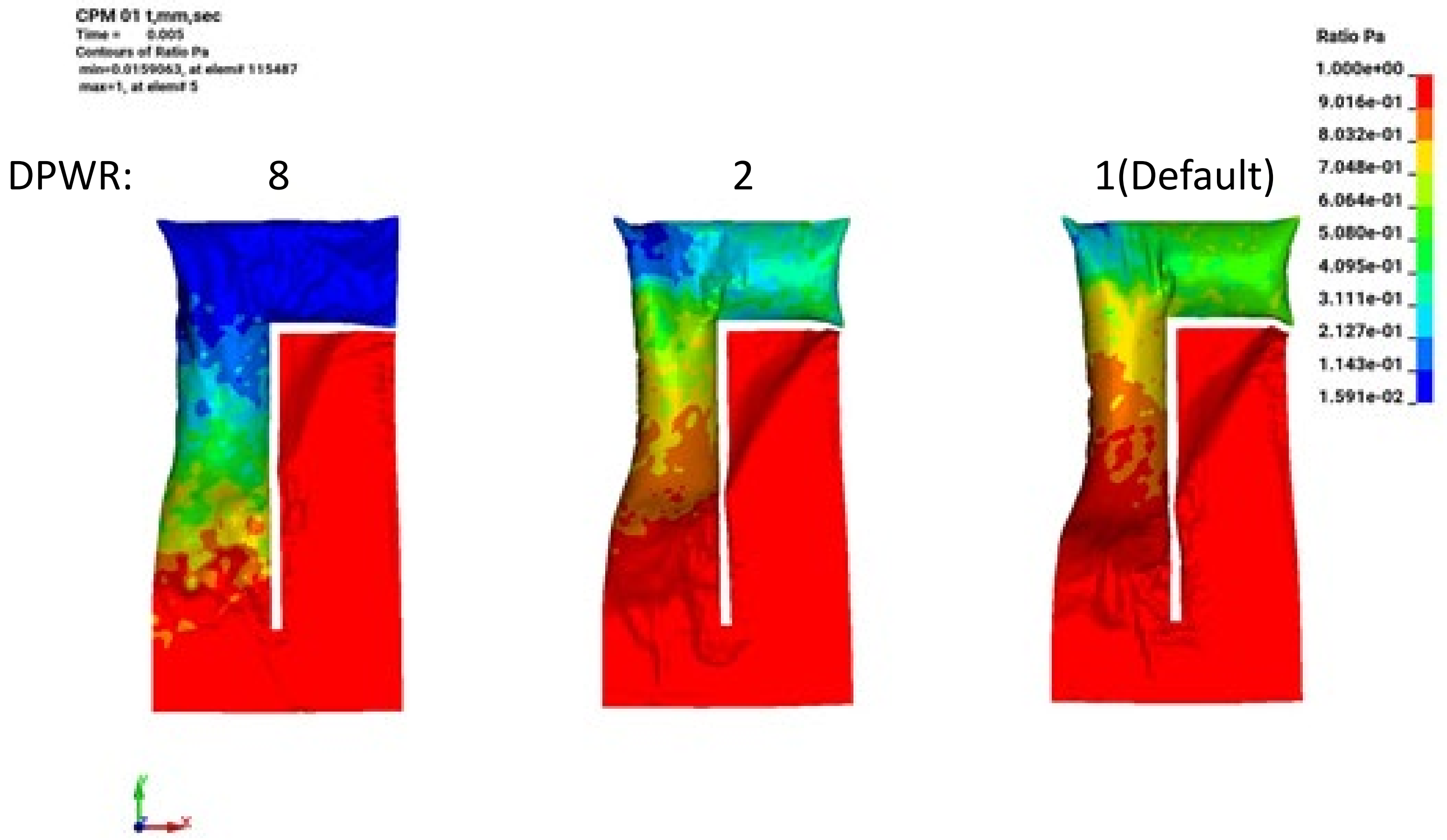


Add the option to <u>remove</u> bending/twisting from bond failure criteria. For rocks with high compressive to tensile strengths, it is benecifial to remove this influence from the failure criteria.



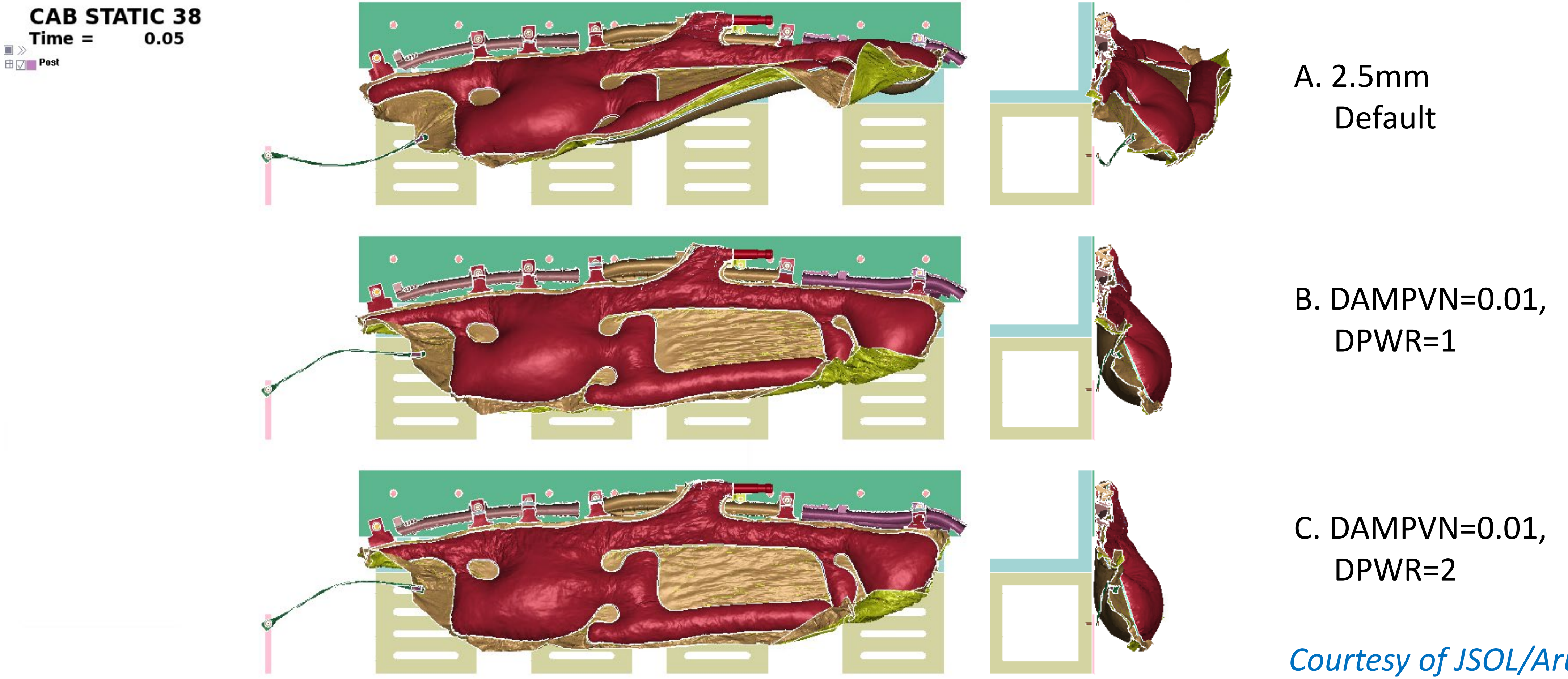
Ansys

*AIRBAG_PARTICLE



- DPWR: the rate to remove background pressure from resident air in undeployed region (higher the faster and 1 is default)
- Provide a better way than switching from IAIR 4 to IAIR 2

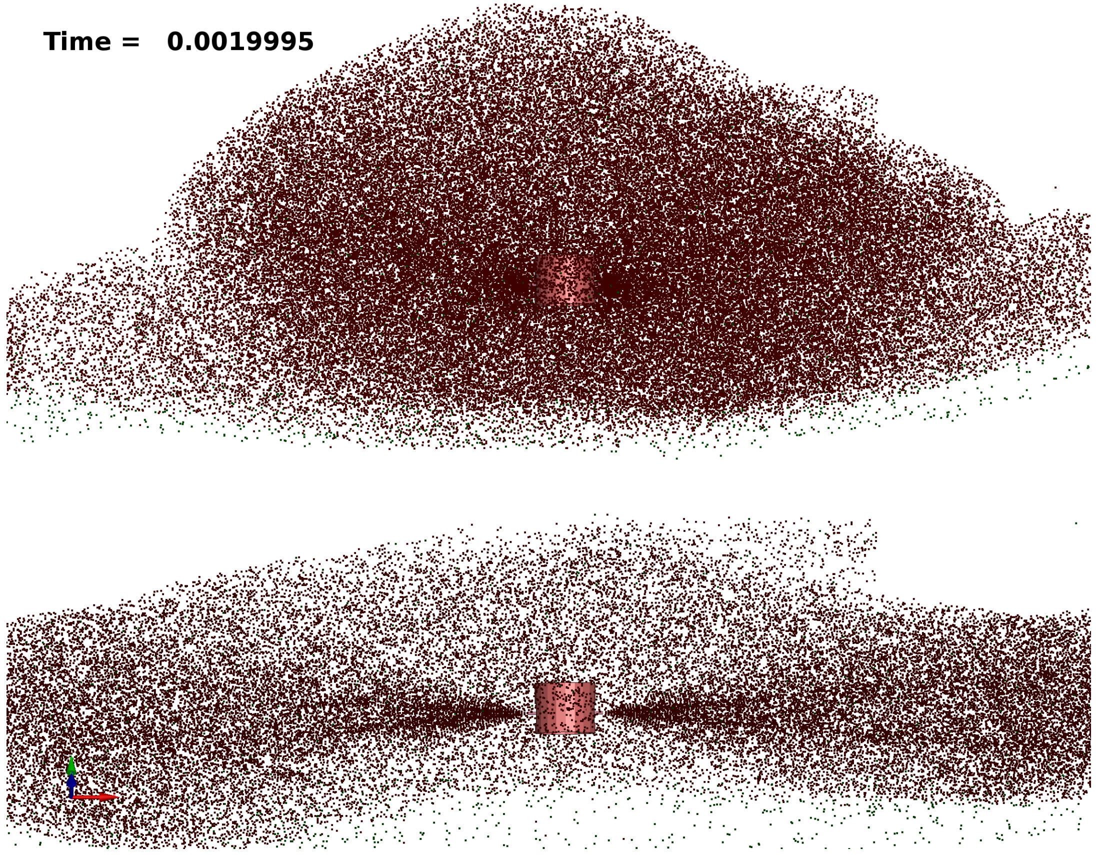
*AIRBAG_PARTICLE



Courtesy of JSOL/Arup CAB

- Original: corner of the curtain airbag starts to flip up after fully deployed (top A).
- DAMPVN: apply force on the surface normal direction against the motion – B and C
- DPWR: the rate to remove the background pressure from resident air in the folded region

*AIRBAG_PARTICLE



Without jet

With jet

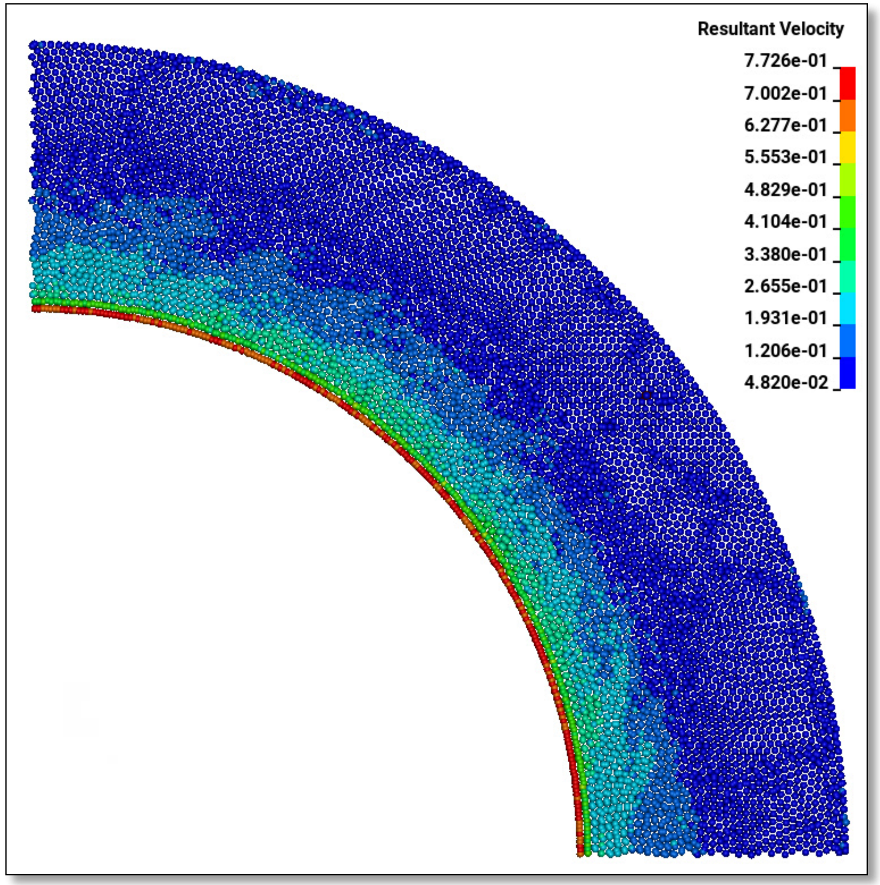
- JETLEN: omit P2P collision and delay the thermal equilibrium
- Preserve directional impulse and match better with the tests

SPH

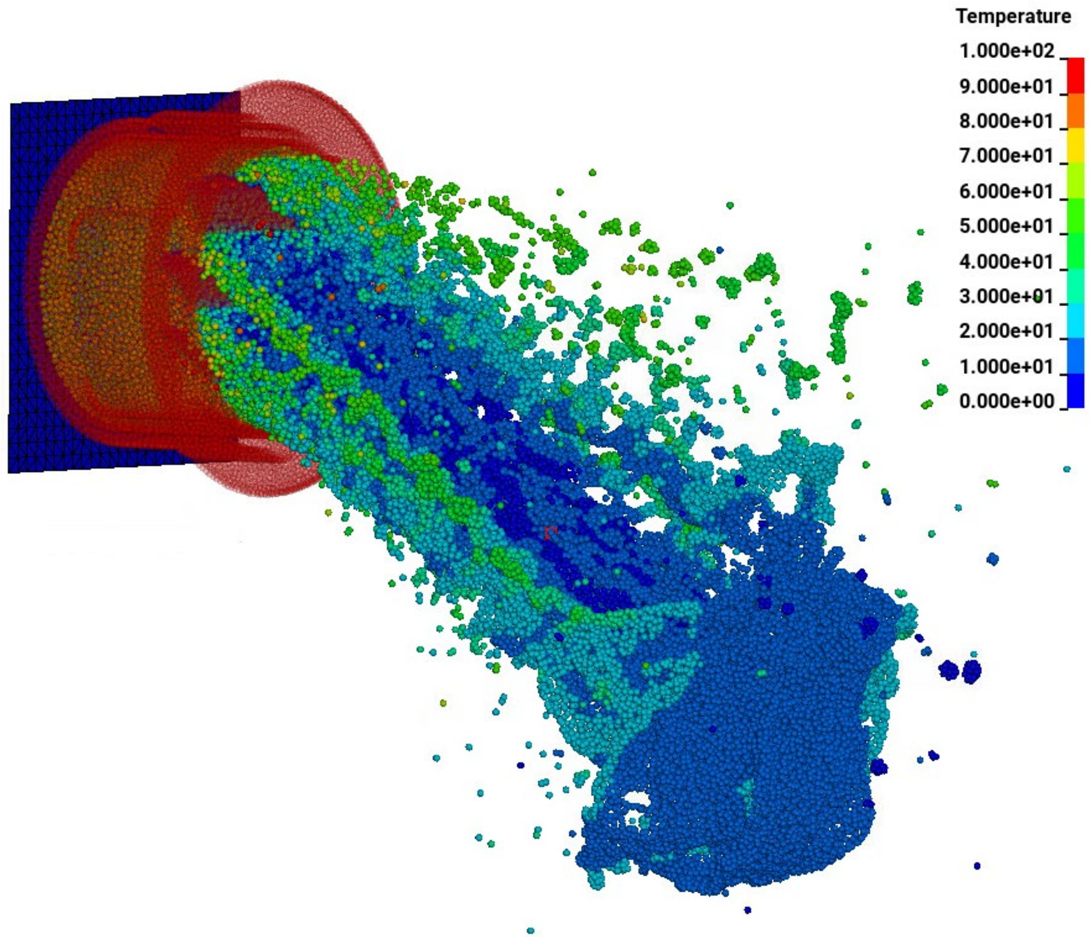
Ansys

*BOUNDARY_SPH_PERIODIC

Impose a periodic BC for SPH particles



Incompressible SPH with Heat Transfer



Implicit Linear Algebra

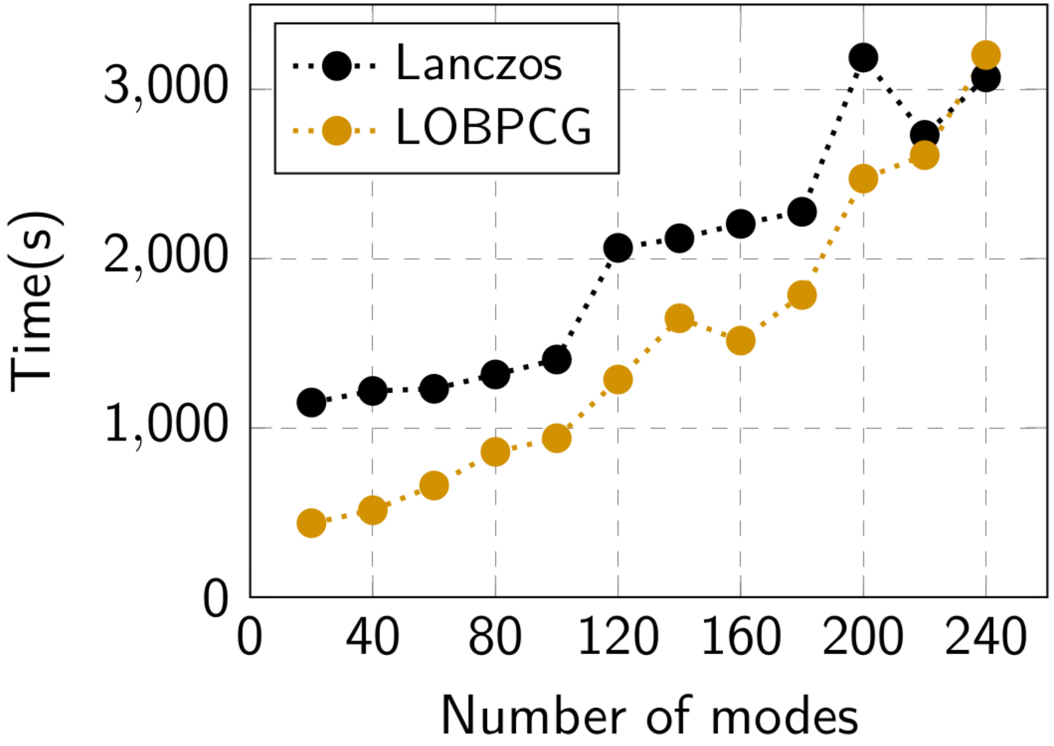
New Eigensolver Technology

- We have added two new eigensolver technologies to LS-DYNA:
  - LOBPCG: iterative solver to provide a faster solution when requesting a few modes.
  - Fast Lanczos: approximate eigensolver for computing thousands of eigenmodes for Noise-Vibration-Harshness applications.

LOBPCG

- Locally Optimal Block Preconditioned Conjugate Gradient (LOBPCG) [Knyazev '01]:
  - Iterative preconditioned eigensolver, an approximate inverse is used. Reduces memory footprint, can reduce time.
  - Effective for small number of modes, can be used as a quick analysis tool. For larger number of modes (50+), Lanczos is typically faster .
  - Same accuracy as Lanczos.
- In LS-DYNA:
  - MPP version in R14. Updated for R15.
  - The preconditioner is a Block Low-Rank factorization. Others to be added

Run time for a 12M dof electric sedan battery pack assembly

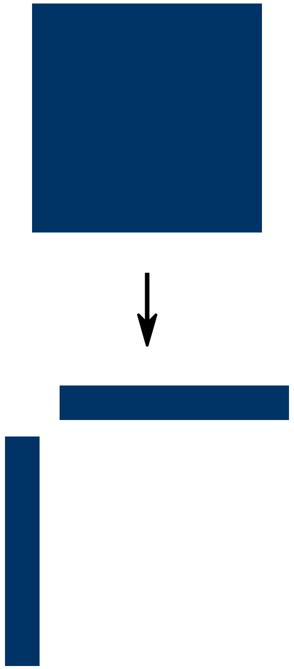


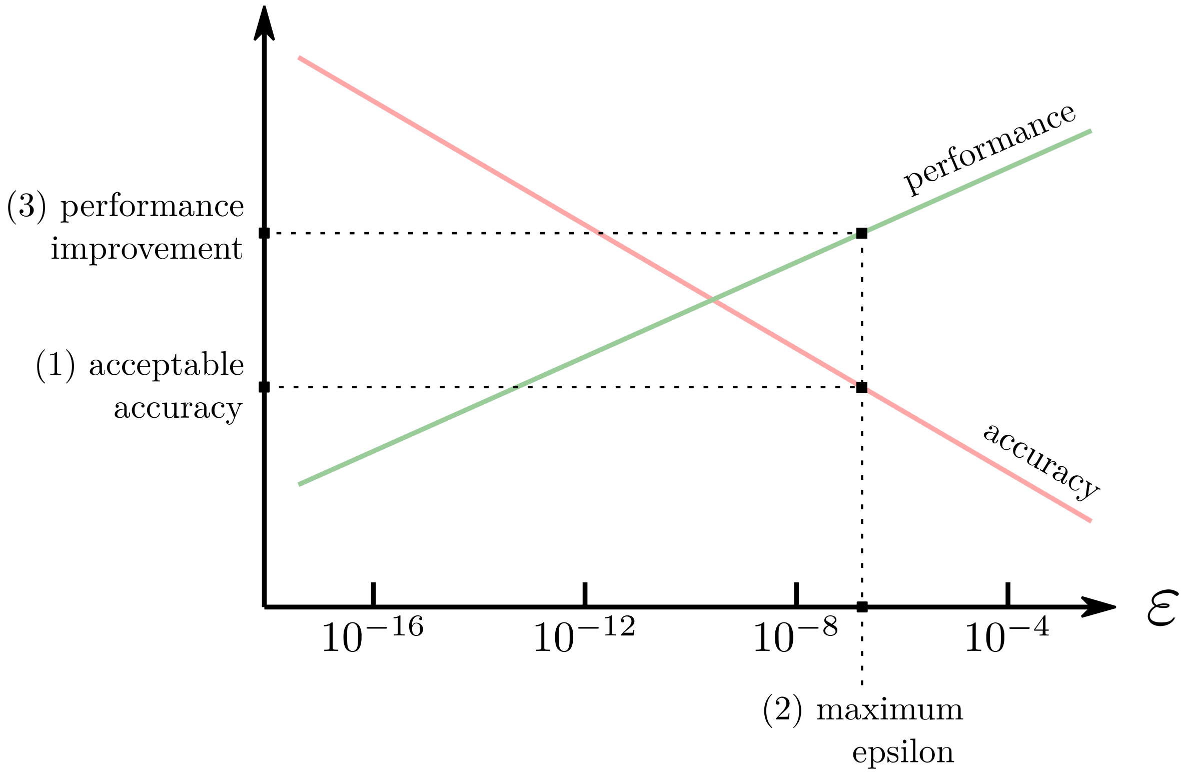
Fast Lanczos

- Fast Lanczos is based on the same Lanczos technology as the base solver but with relaxed tolerances and a more throw-caution-to-the-wind attitude to compute thousands of eigenmodes with less accuracy and at the risk of less robustness.
  - An alternative to AMLS (Automatic Multi Level Substructuring) based algorithms used by Nastran, Optistruct, ….
  - Scalable in MPP;
  - Better accuracy than AMLS throughout the spectrum. Two digits instead of one or less for AMLS;
- Available in R15
- For an electric car model (5.4M nodes, 11.5M independent dofs)
  - Lanczos takes 71701 seconds to compute 2000 modes using 32 MPI processes.
  - Fast Lanczos takes 8945 seconds – 8 times faster.
- Contact Roger Grimes (roger.grimes@ansys.com) about using this eigensolver.

Sparse Direct Solver Adds Block Low-Rank Approximation (BLR)

- Replace off-diagonal blocks of the factors with low-rank approximations
  - Reduces storage and operations
  - $O(N^3)$ extra work to compute with rank revealing QR
- Turns a sparse direct solver into a very powerful preconditioner for an iterative algorithm
  - Doesn't always converge

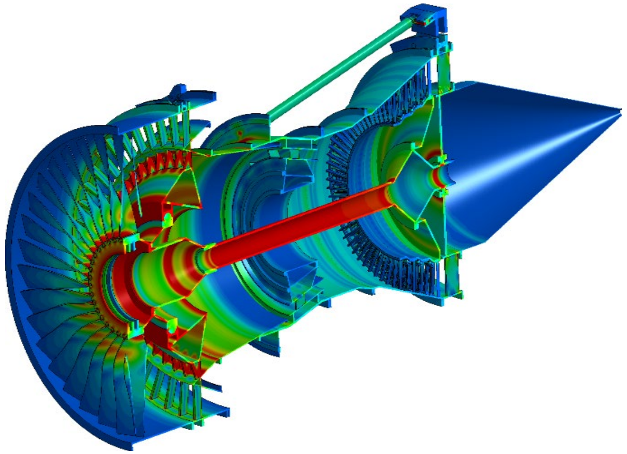


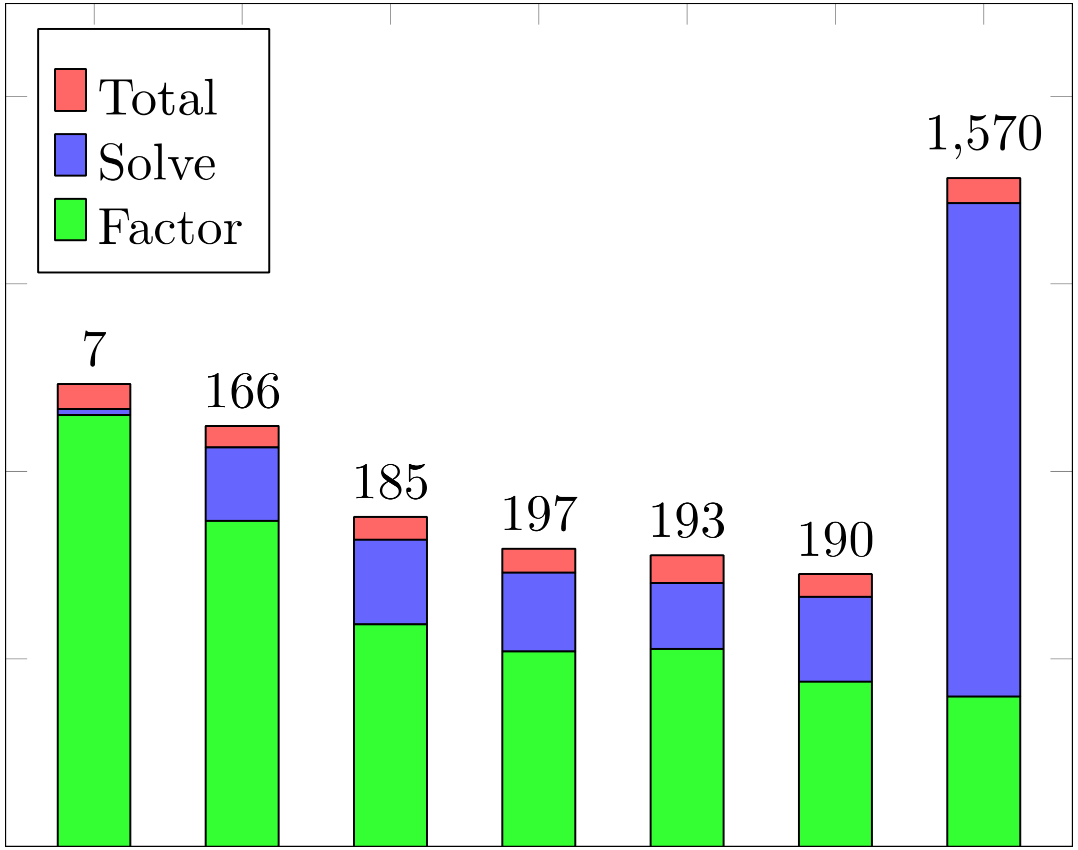


Notional relationship of performance and accuracy as a function of BLR error tolerance (epsilon).

BLR Can Save Time

- LS-DYNA runtime using 32 MPI ranks
  - Number of mixed-precision, low-rank triangular solves
  - Remainder of LS-DYNA
  - Seven solves with Conjugate Gradients
  - Four factorizations





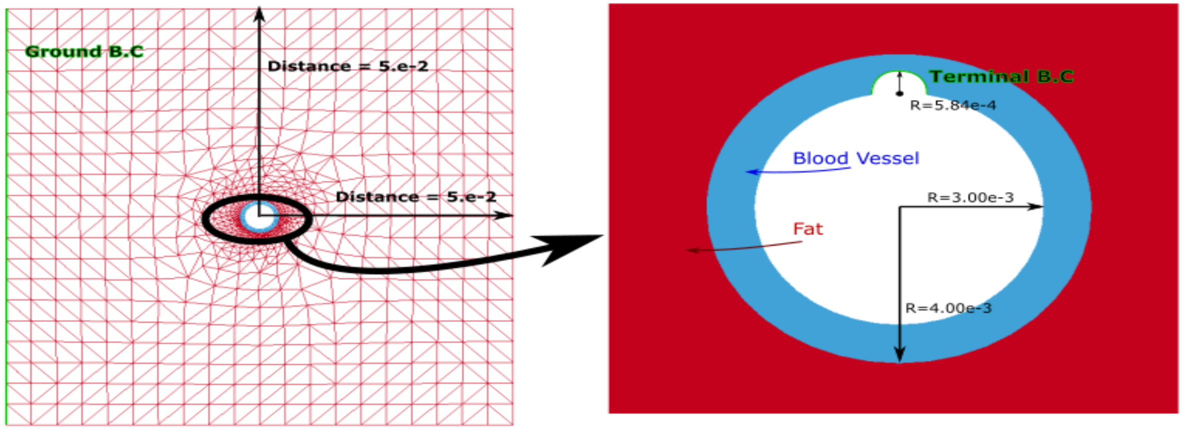
LS-DYNA runtime as a function of the BLR error tolerance

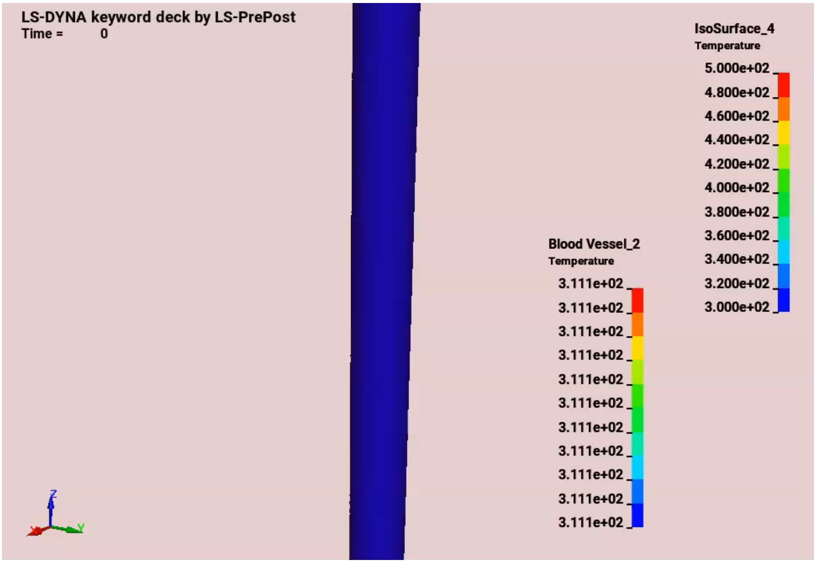
Rolls-Royce 35M Element Large Representative Engine Model

EM

EM Radiofrequency heating capabilities

- R15 introduces **Radiofrequency heating** capabilities based on dielectric properties of the material.
- For example, RF heating is present in biomedical application where RF heating of body tissues is used for muscle therapy and at higher temperature to kill tumors and cancer cells.
- It is coupled with the ICFD solver as well as the thermal solver so **Electromagnetic-fluid-thermal-structure interaction** applications can be solved.





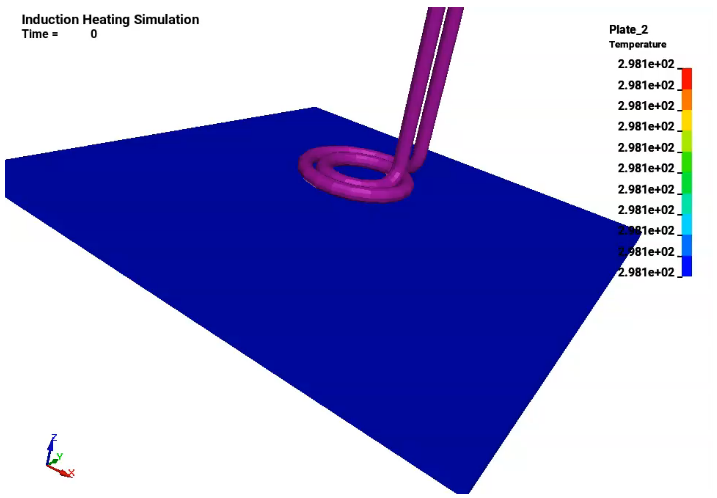
EM Inductive heating extended capabilities

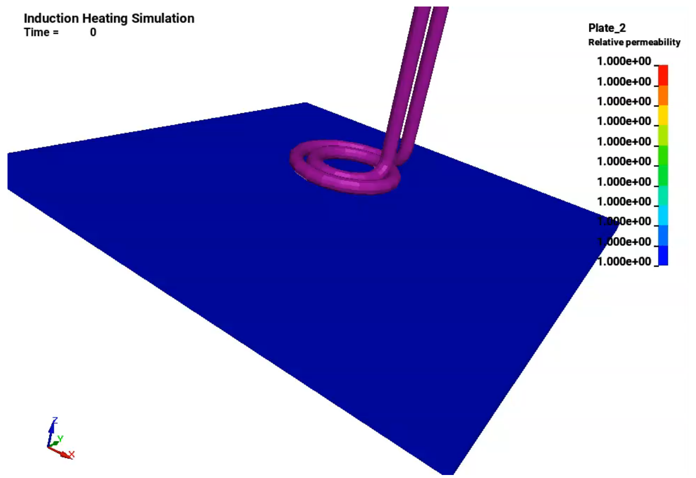
- LS-DYNA R14 version drastically expanded the EM's solver inductive heating capabilities by adding the support of non-linear magnetic materials (e.g., used in **flux concentrators**) and 2D axisymmetric.

- R15 adds **two new analytic material laws** for the inductive heating capabilities in EM to define non-linear magnetic properties (arctan and Froehlich) that also include temperature variation effects.

- It also adds a general law that allows the user to define **several B-H curves** as a function of temperature in its material definition or as a function of von Mises stresses (for magnetostriction applications).

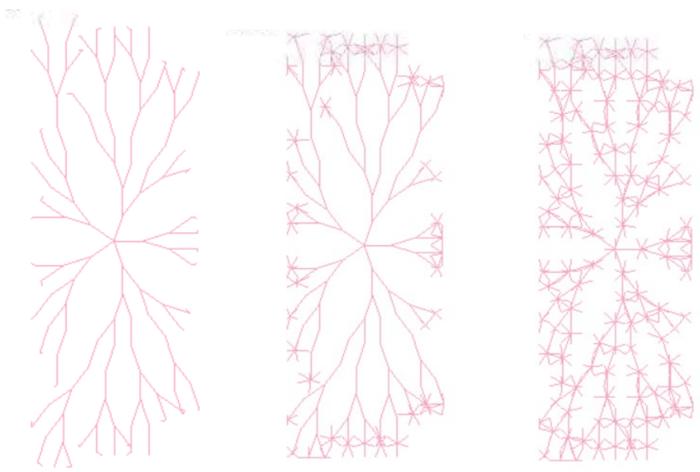
Inductive heating problem with temperature dependent non-linear magnetic material



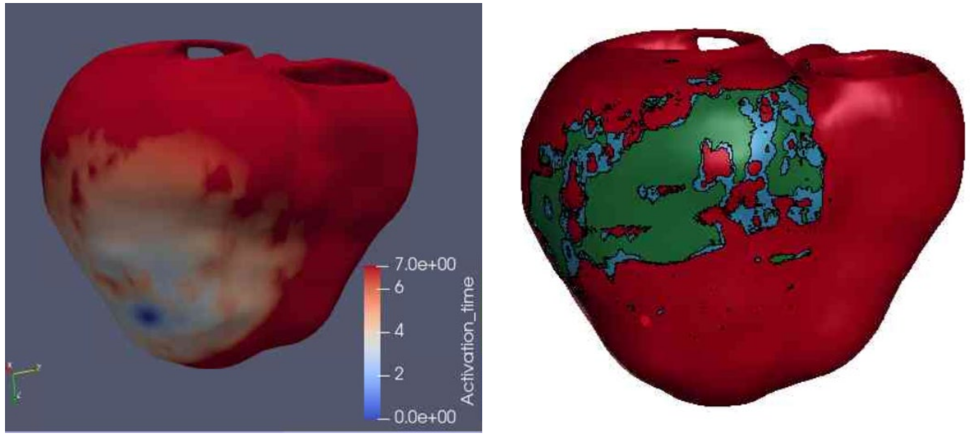


Electrophysiology

- R14 had a monodomain-bidomain model: in R15, an extra **Eikonal model** has been added. It is much faster than the mono/bidomain but only gives the activation time.
  - will soon be extended to Reaction-Eikonal models giving the other EP fields.
- Addition of **extended monodomain** (to get external potential)
- **Cell model definition** on node sets (if heterogeneity in the same part)
- **Purkinje network** coupling with 3D through resistance



Different options for coupling the Purkinje Network with 3D membranes



Eikonal activation time (left) in a biventricular model with a healthy part (right-red), a border zone part (right-blue) and a scar (right-green).

ICFD

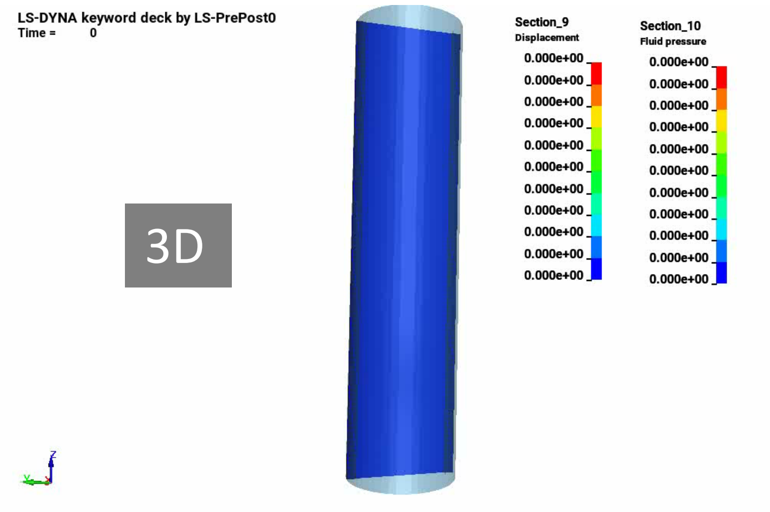
ICFD 2D Axisymmetric solver

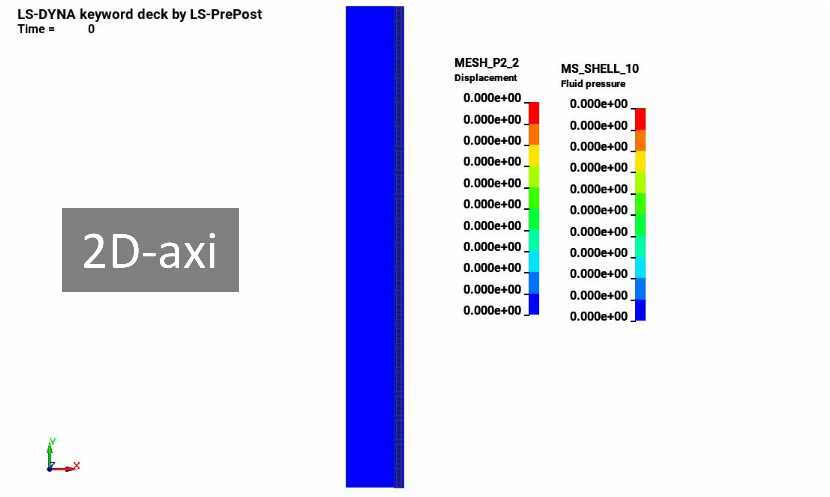
- The 2D planar solver has been extended to handle **axisymmetric flows** in order to reduce computational costs for problems that admit a rotational symmetry.

- It is compatible with LS-DYNA's solid mechanics and thermal axisymmetric solvers for **FSI and conjugate heat transfer** problems (Section shell 14,15 and Y symmetry Axis).

- Set up is straightforward (single flag to turn on, no special treatment needed for Axis).

Pressure wave in a cylinder

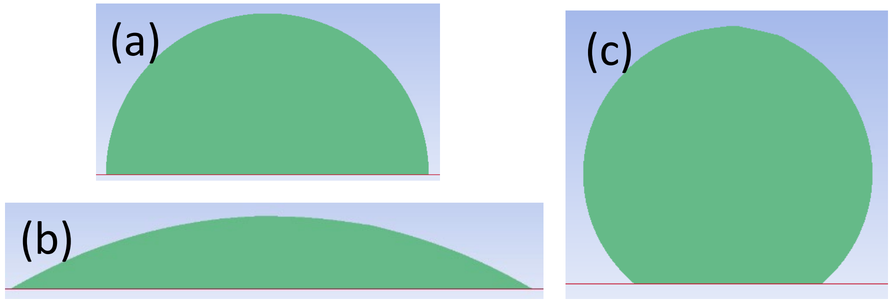




ICFD Two-Phase Level-Set Solver

*ICFD_CONTROL_LEVELSET

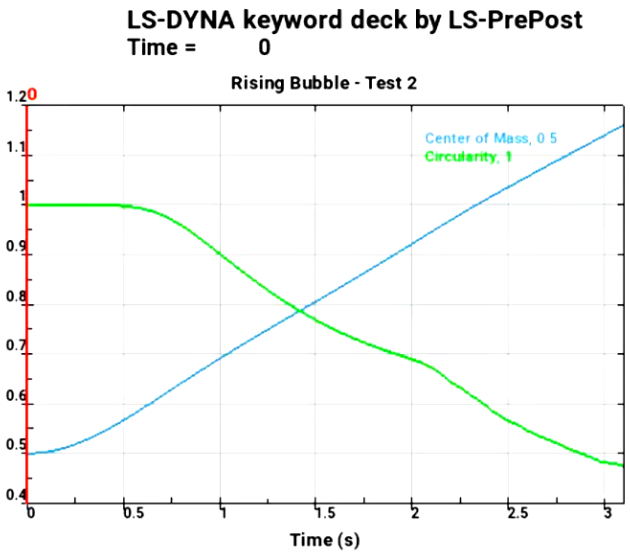
- Smoother approximates of gradient and curvature
- Advanced formulations of surface tension
- Smoother reinitialization method

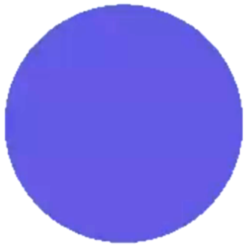


Droplet spreading: initial state (a), equilibrium states with (b) θ_{eq}=30°, (c) θ_{eq}=140°

*ICFD_CONTROL_ADVECTION

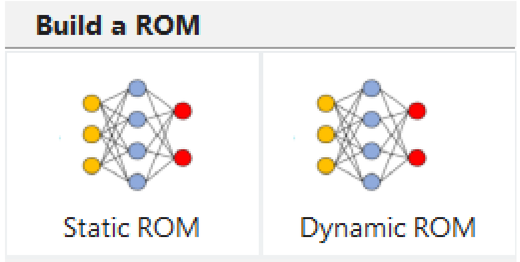
- Semi-Lagrangian advection of level set
  - Set 4th field (SLLS) to 1





Two-phase rising bubble benchmark using linear gradient and curvature approximation with the Laplace-Beltrami formulation for surface tension. The reinitialization is done using closest point..

Twin Builder Integration



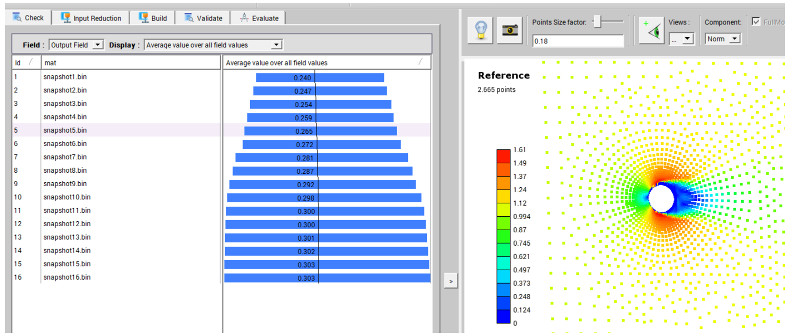
Dynamic ROMs

- Automatically export when a transient model is solved.
- Responses are time dependent. Excitations could be time dependent too. Larger amount of data.

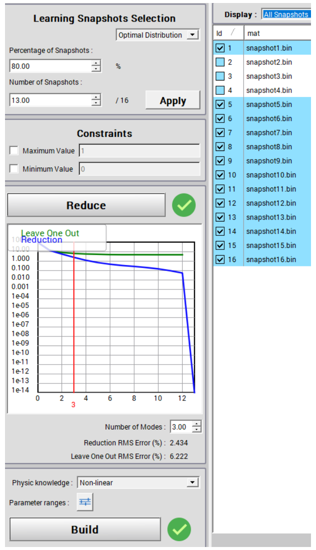
Static ROMs

- Automatically export when a steady model is solved.
- Responses are written upon convergence. Smaller data.

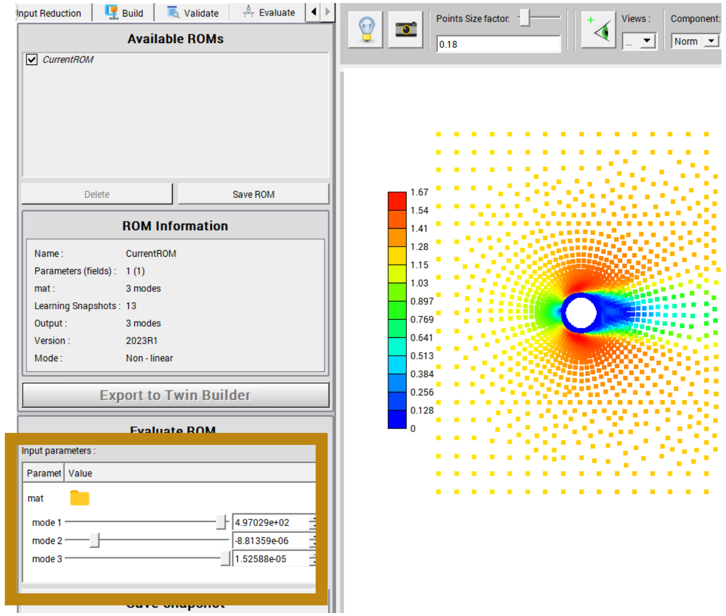
Simple data check



Reduction of data



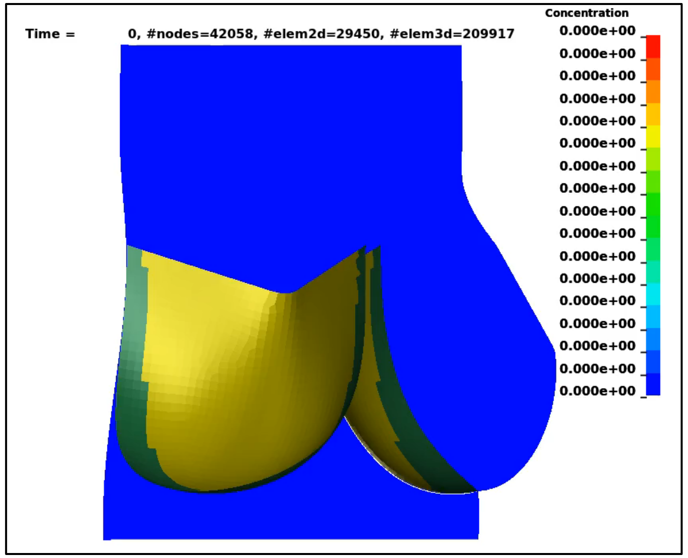
Fast evaluation

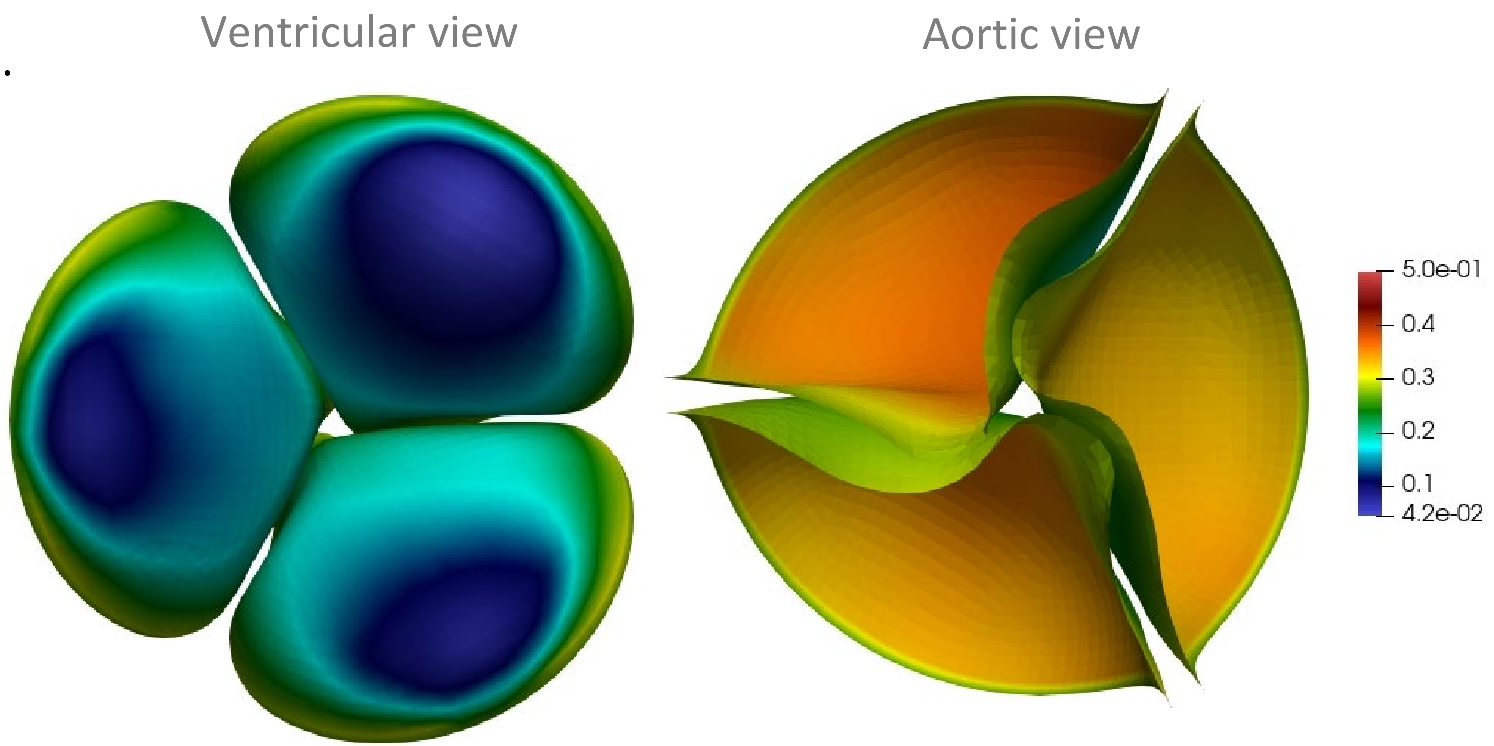


Post-processing: Residence time on leaflets

- Average residence time per leaflet for a full cardiac cycle. Aortic and ventricular side.
- % of surface area on the leaflet with a residence time larger than a given value.

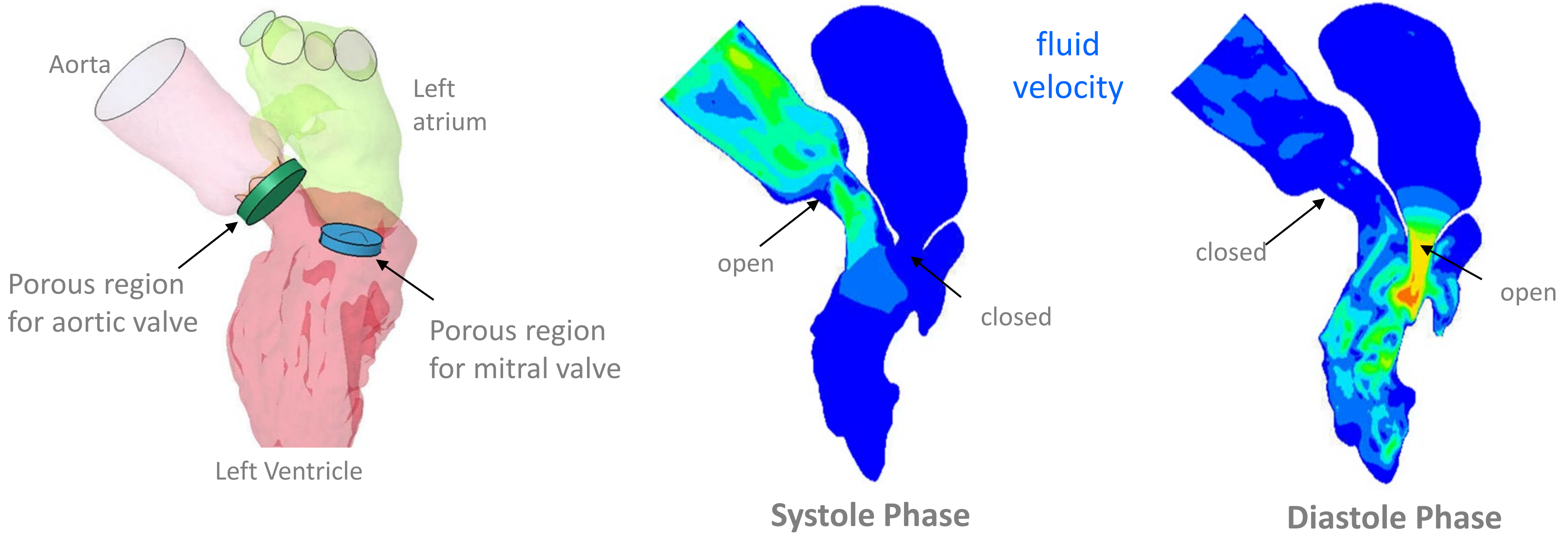
Residence Time as a biomarker to predict stagnation regions, sinus stagnation areas and thrombo-genesis.





General Purpose POROUS REGIONS WITH FSI Capabilities

- Purpose: Define **moving isotropic porous regions**. The **permeability** can be a constant value or defined through a **time-dependent** load curve or *DEFINE_FUNCTION. Alternatively, this keyword optionally enables pressure sensors to specify the permeability as a **function of the pressure** drop across the porous domain length.



This left heart model was generated using Synopsys Simpleware.

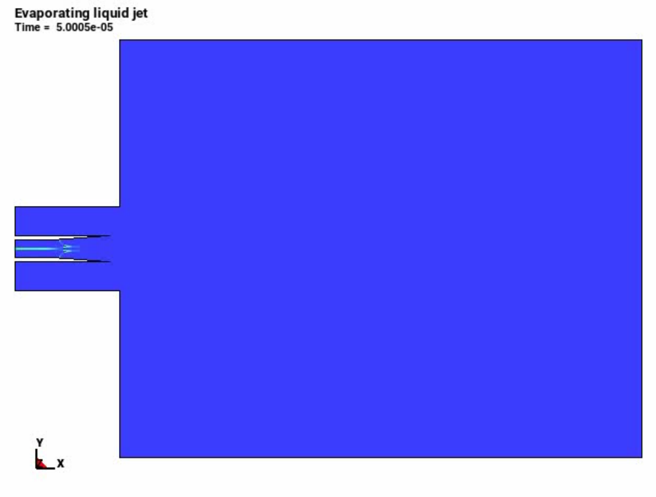
Compressible CFD:

Dual CESE

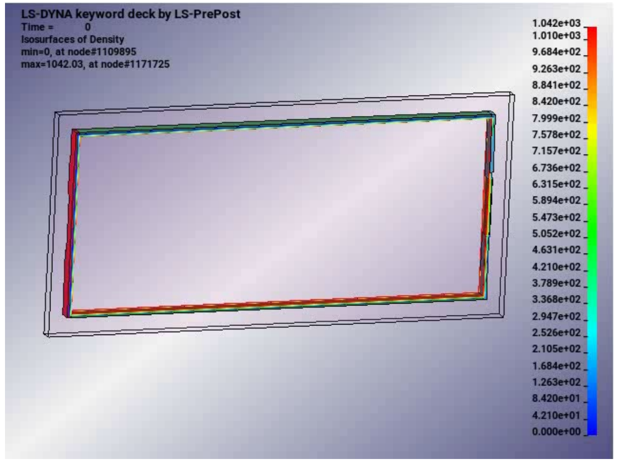
Ansys

Phase-change model added to the multiphase flow solver

- Thermochemical relaxation algorithm is adapted in this model
- Three materials (**liquid, vapor & air**) can be used
- EOSes: “Nobel-Abel Stiffened Gas” (NASG) EOS (including ideal gas EOS as a special case)
- Main Applications: cavitation, evaporation, condensation, etc.
- Coupled with the LS-DYNA structural solver to enable **phase-change FSI problems**

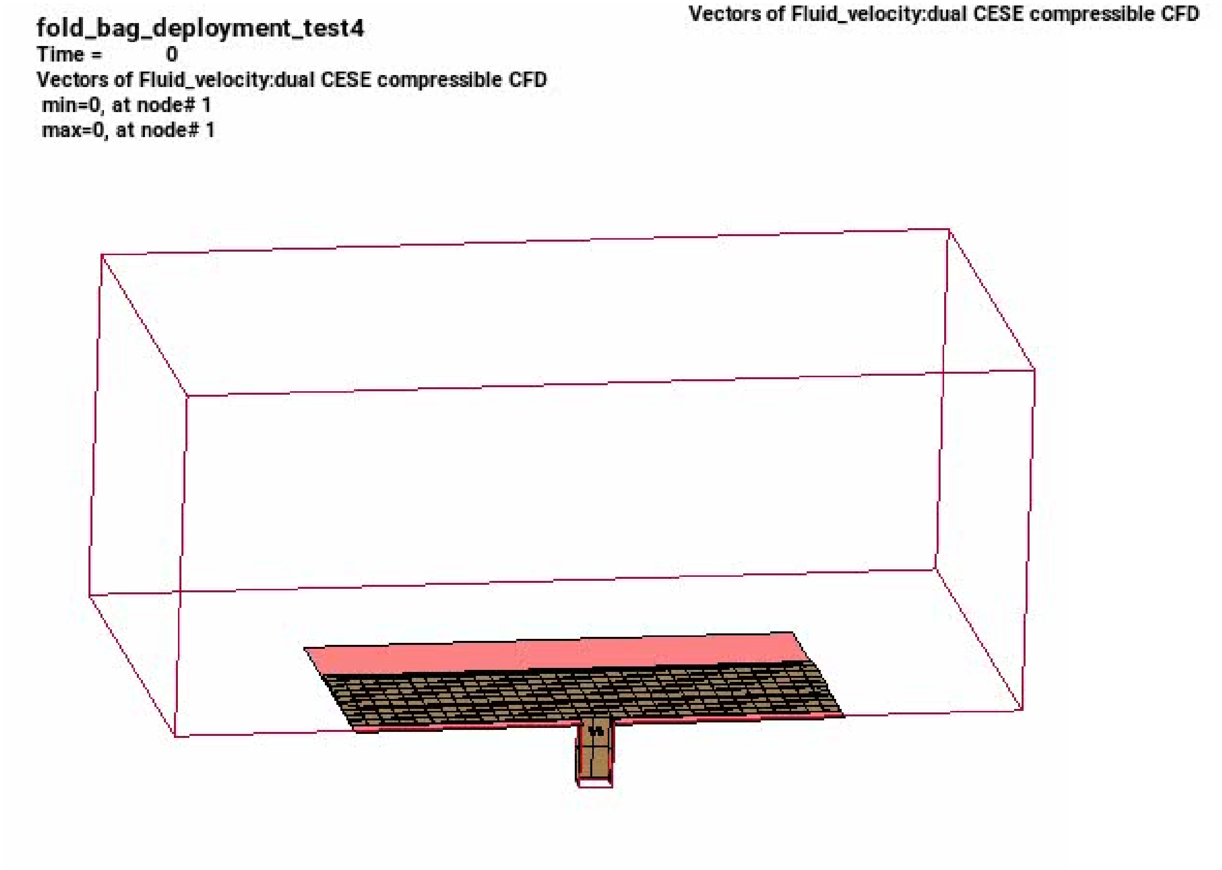


Vapor fraction contours of evaporating liquid jet in conditions of cryotechnic rocket engine at ignition



Density contours of a fuel tank impulse/penetrated by a bullet

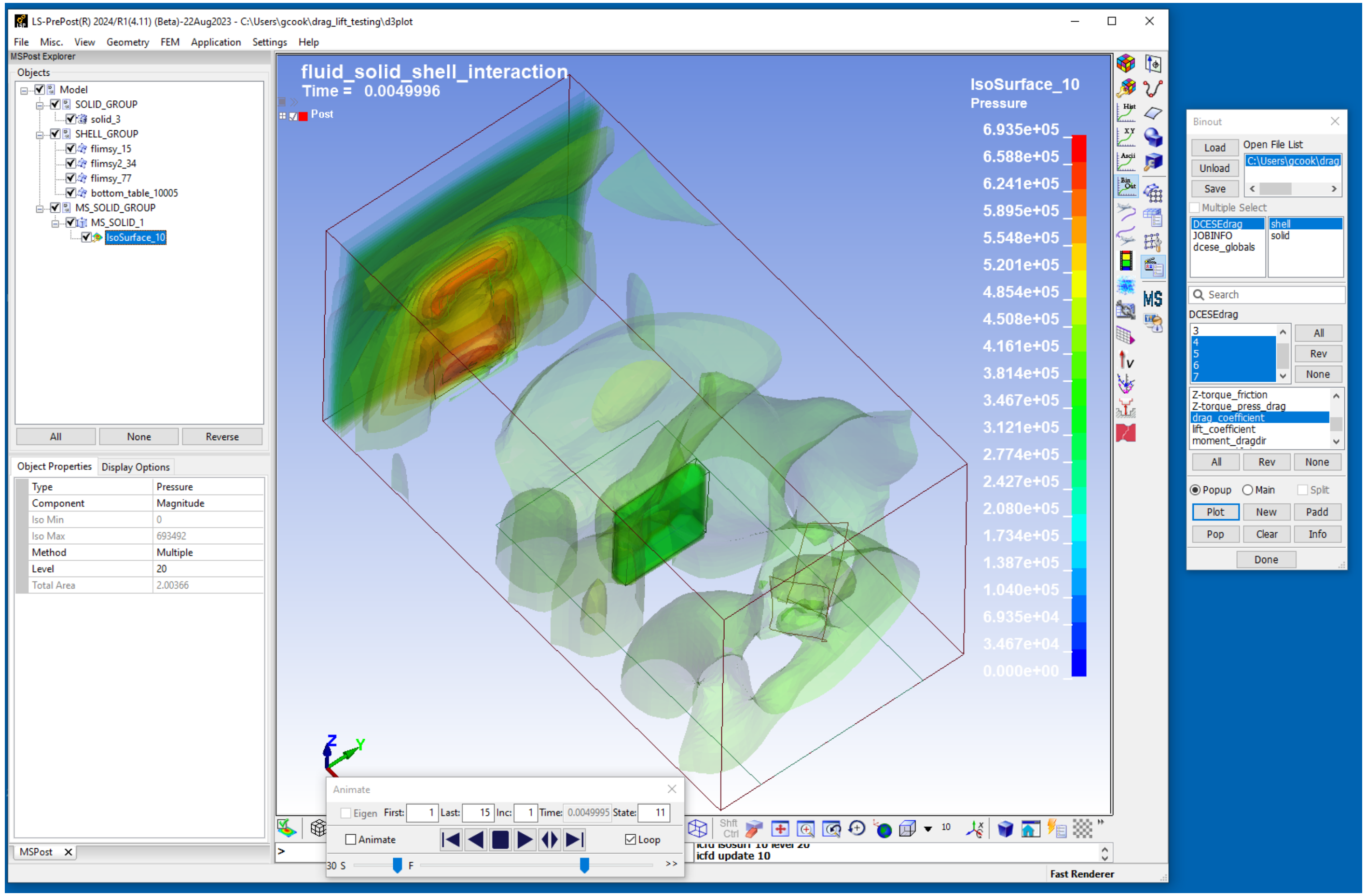
Point source capability added to CFD and two-phase flow solvers



Velocity vectors during a folded-bag deployment

- Point source capability has been added in the pure CFD and its FSI-ibm solver
- This capability has also been implemented in the two-phase and its FSI-ibm solver
- User can specify the mass flow rate and/or other proper flow variables as a point source at any point inside the fluid domain

Drag/lift history variables for IBM-FSI dual CESE solvers



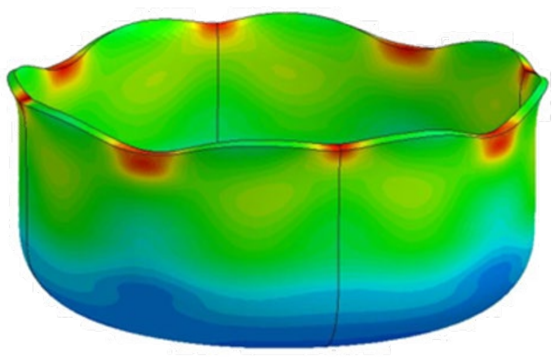
Drag coefficient time history selection in the binout dialog box of LSPP 4.11

- Computed for each topologically separate piece of all the structural parts involved in immersed boundary FSI
- With material erosion during an immersed boundary FSI simulation
  - New pieces can be created (breaking)
  - Pieces can disappear (erosion)

Material Models

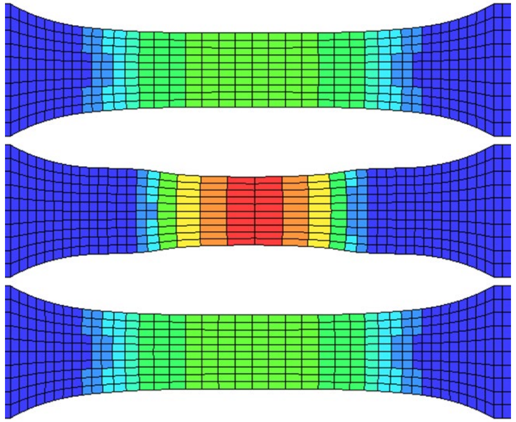
Metals

- Spatial variation of stiffness in *MAT_TAILORED_PROPERTIES (251)
- *MAT_264 (for HCP metals like titanium) supports thick shell elements
- Extended plastic anisotropy description in *MAT_BARLAT_YLD2004 (199)
  - Better prediction of earing in cup drawing



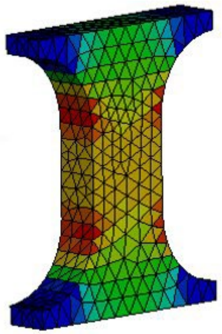
Polymers

- Viscoplastic option for *MAT_SAMP_LIGHT (187L)
  - important for **rate dependent plastic yielding**



Foams

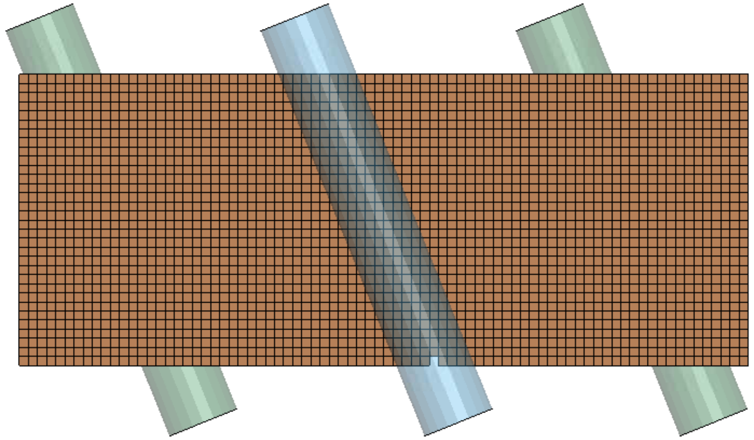
- *MAT_CRUSHABLE_FOAM (063)
  - New tension-compression asymmetric model MODEL=2
  - Improve viscoplastic algorithm

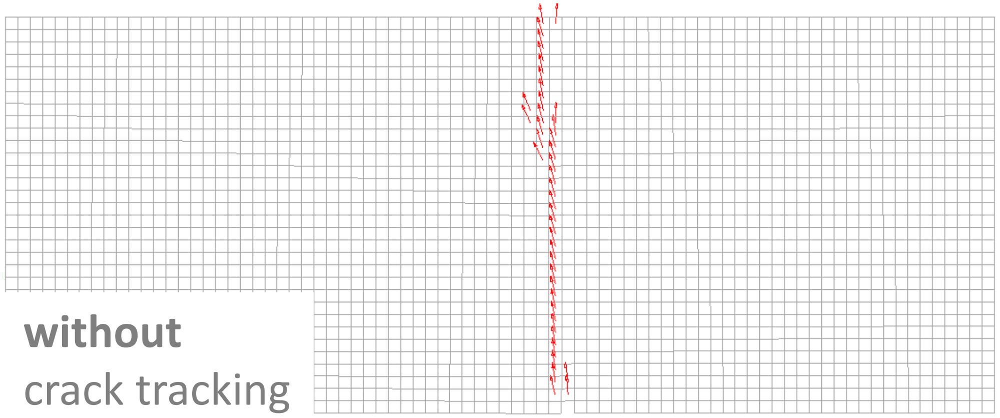


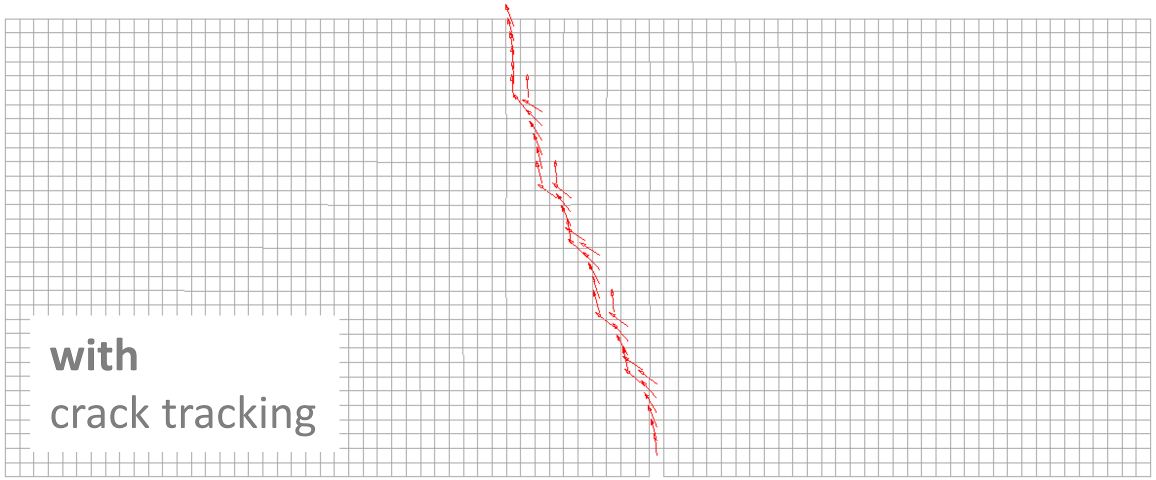
Glass

- Optional **crack tracking** algorithm in *MAT_GLASS (280)

oblique 3-point bending of laminated glass
with initial crack (top view)

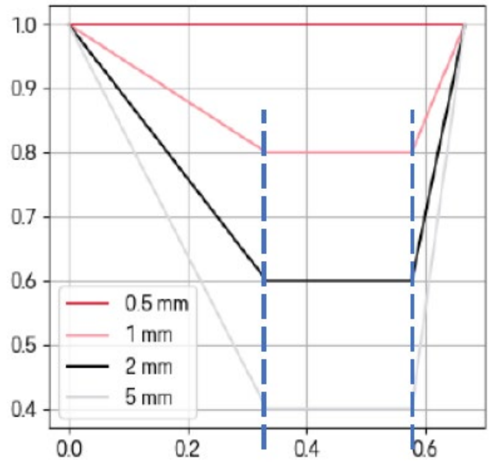






Damage & failure

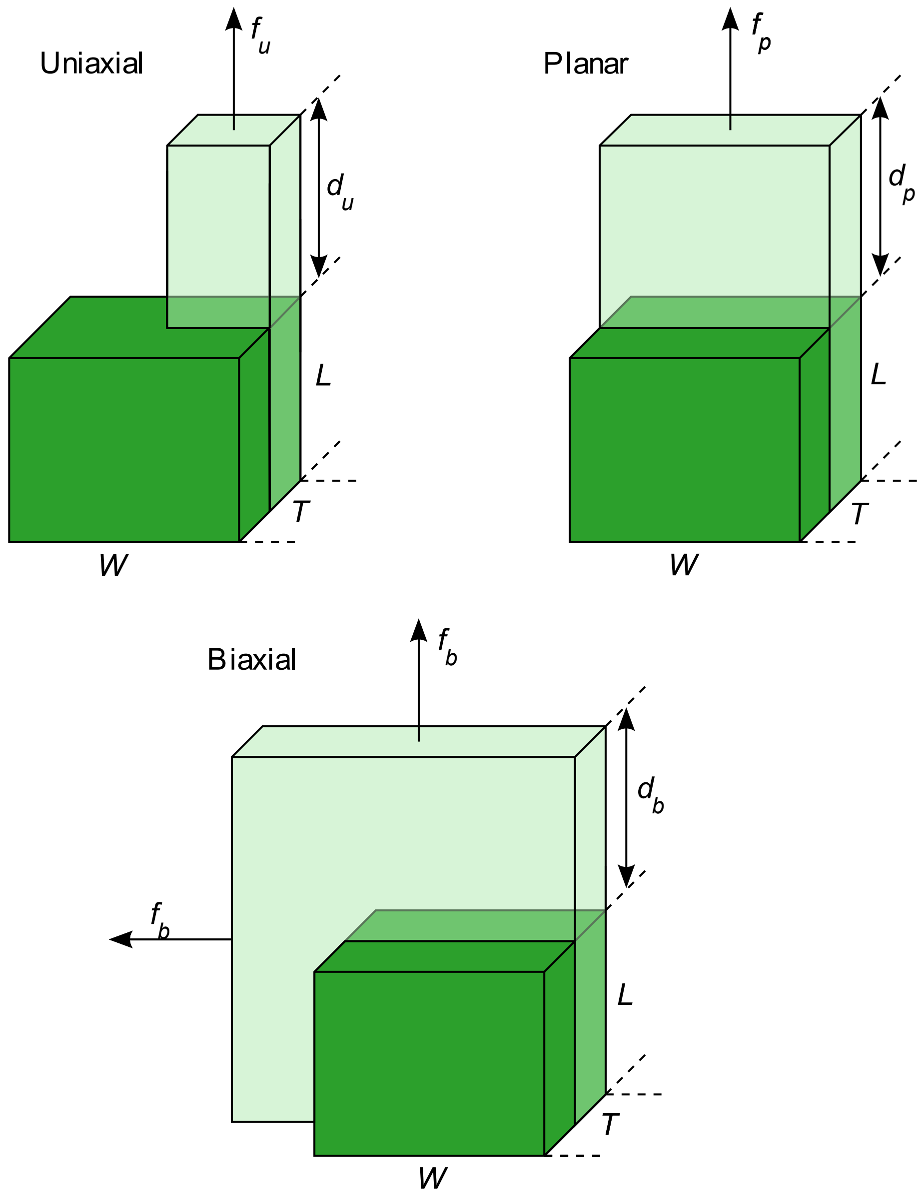
- *MAT_ADD_EROSION: (filtered) strain rate dependent max. principal stress
- GISSMO: stress-state and element size dependent crash front
  - new option LCSOFT: strength reduction as function of triaxiality and element size
- GISSMO: user-friendly triaxiality dependent regularization
  - specific shape of reg. fac. versus traxiality now easily accessible



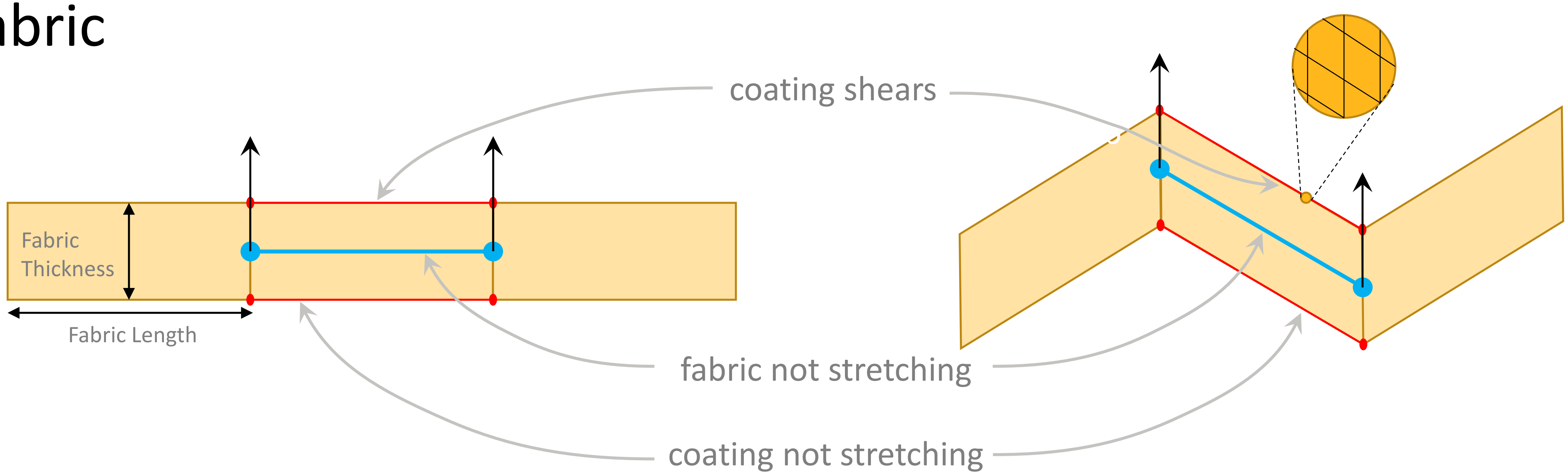
- Improve combination of DIEM/GISSMO with IGA
  - add definition of VOLFRAC
    (volume fraction required to fail before element is deleted)

Rubber

- For material 77 (*MAT_GENERAL_HYPERELASTIC_RUBBER/ *MAT_OGDEN_RUBBER), a **simultaneous fit** of uniaxial/planar/biaxial data can be done



Fabric

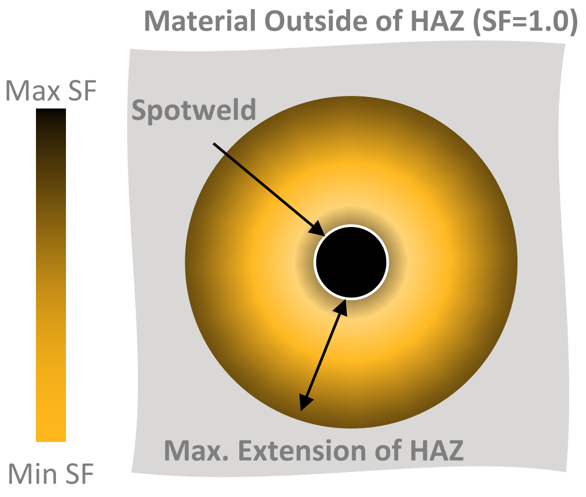


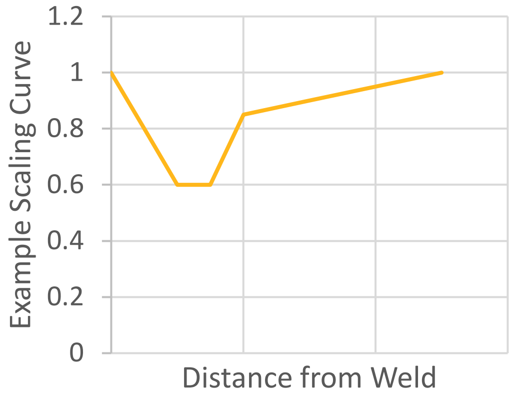
- Seen from a section cut view, the zig-zag motion of fabrics won't induce any deformation, it is essentially a zero-energy mode
- The transverse shear deformation in the coating is the only thing that can resist such a motion
- By allowing SHRF to scale the transverse shear stiffness in coatings, it can be prevented

Heat Affected Zone for Welds

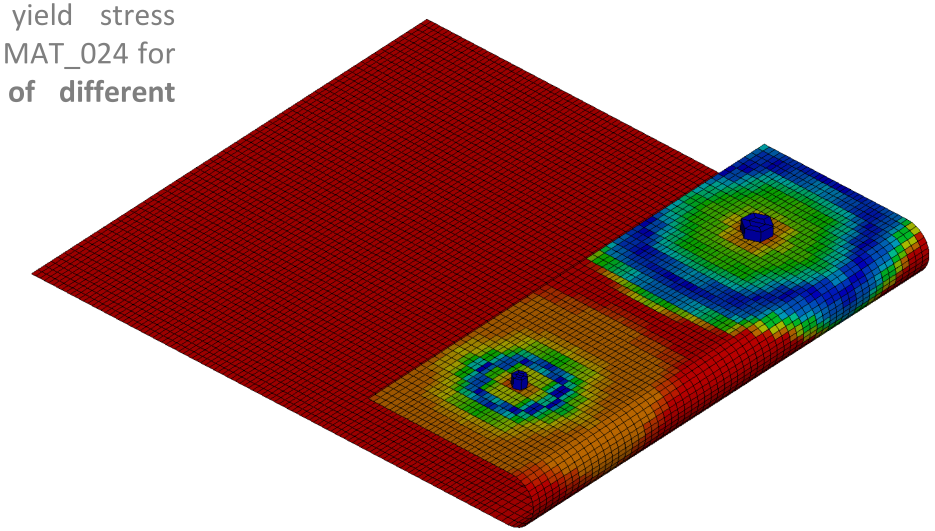
Heat Affected Zone (HAZ) can be defined on FE and IGA shells in the proximity of welded connections. **New features:**

- Support definition of HAZ for user-defined material models.
- Support for 2D table-based definition of HAZ scaling factors that allows to scale material parameters as functions of:
  - Distance from the closest weld
  - Dimension of the closest weld
- Support definition of active weld part IDs to be considered for the evaluation of scaling factors within any specific HAZ





Fringe plot of yield stress scaling factor for MAT_024 for two **spotwelds of different dimension**



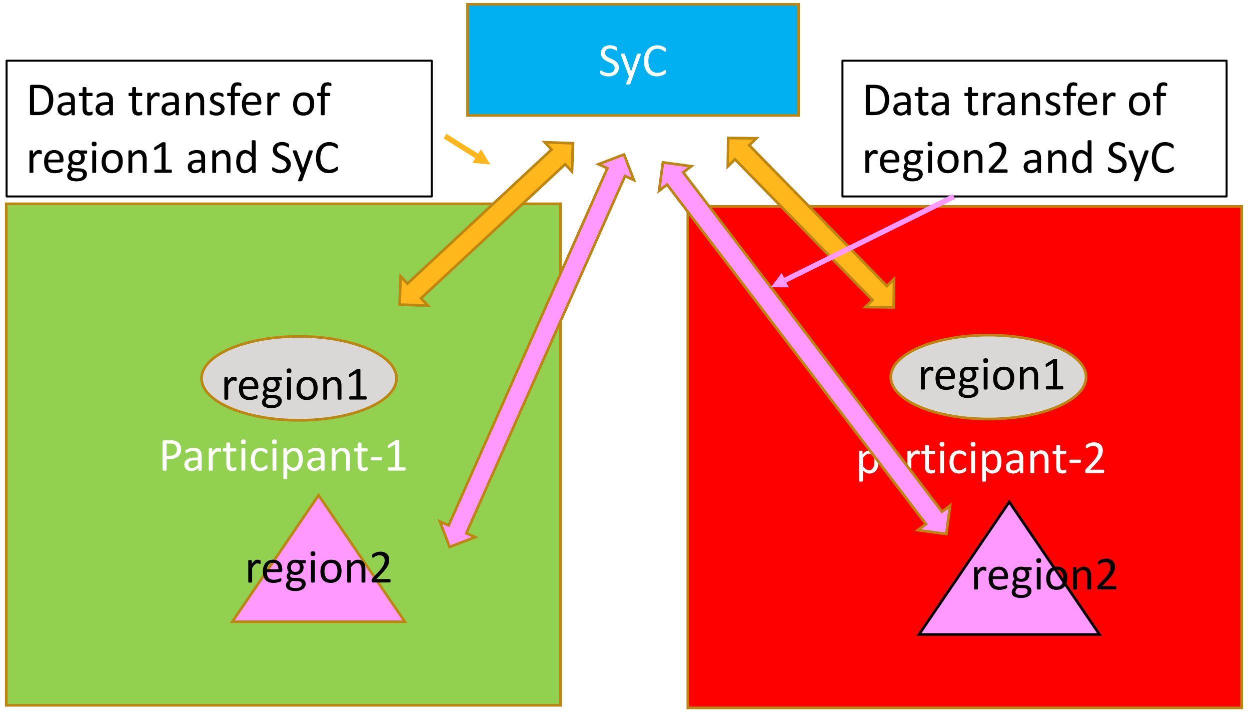
Miscellaneous

System coupling, Belts, Sensors,

Connections, …

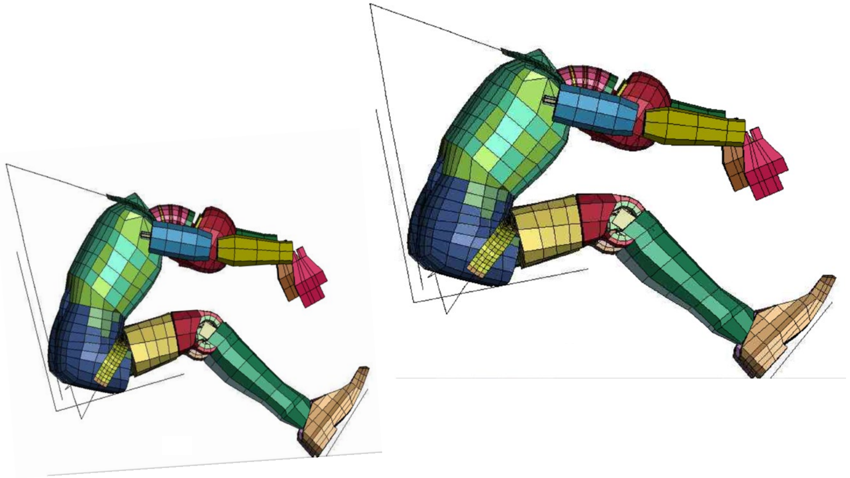
SyC: System Coupling

- A tool for co-simulation among Ansys solvers
  - Structures: Mechanical, **LS-DYNA**, Electronics: Maxwell, Fluids: Fluent, CFX, Forte, …
- SyC serves as a coupling coordinator
  - Execution synchronization
  - Analysis evolution
  - Collect, map, and serve data
  - Solution stabilization & acceleration
  - Convergence checking
  - Result & restart point creation and synchronization
  - Error handling



Belts & Sensors

- Adaptive load limiter for **seatbelt retractor**
  - Uses sensors to adjust the load limit on the occupant based on the circumstances of each crash, such as the size and position of the occupant and the crash severity



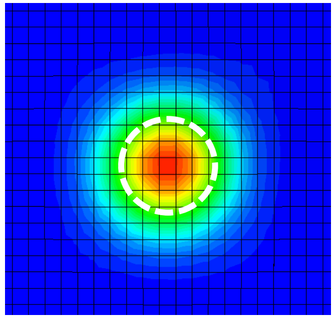
- Enhancements for **sensors**
  - New database SNSROUT to get sensed values or status of general sensors
  - More detailed CPU timing information
  - Trace more data, e.g., min. distance between 2 sets of nodes, added mass, hydrostatic stress, maximum shear, principal and von Mises stress
  - New options to activate/deactivate curves, or adding offsets

Spotwelds & Rivets

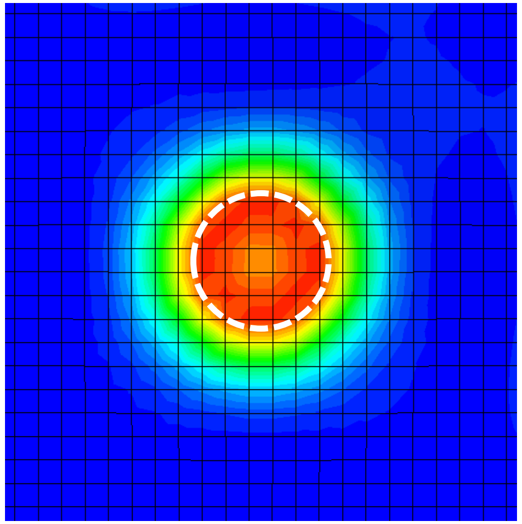
- Performance improvement
  - strongly **reduced initialization time** for SPR2 and SPR3 (*CONSTRAINED_...)
  - replaced brute force search by bucket sort approach
  - about 10 times faster for this task

- New interpolation method for SPR2 and SPR3
  - INTP=3 invokes quadratic weighting, i.e., scale factor increases with squared distance from center
  - to achieve higher stresses at the connector periphery
  - better representation of **stiff/rigid spot welding nugget**

plastic strains
in connected sheet



INTP=0/1

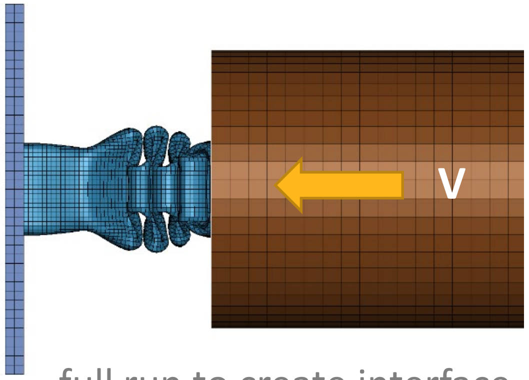


INTP=3

Continuity Level in Interface Linking Motion

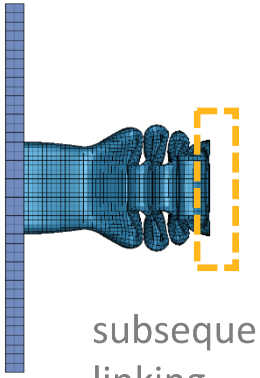
- New option for smoother results
  - New option ISFCNT on *CONTROL_OUTPUT

```
continuity level in applying interface motion..        3
       eq.1: continuity in displacements
       eq.2: continuity in velocities
       eq.3: continuity in accelerations
```



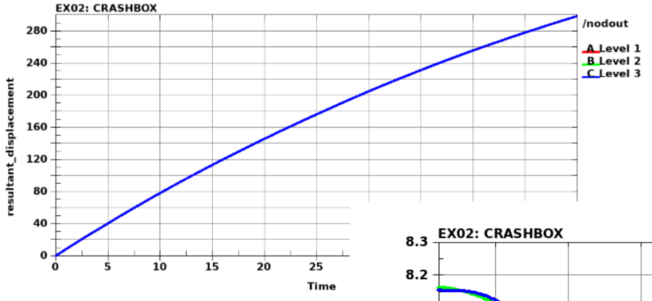
full run to create interface

*INTERFACE_COMPONENT
*INTERFACE_LINKING

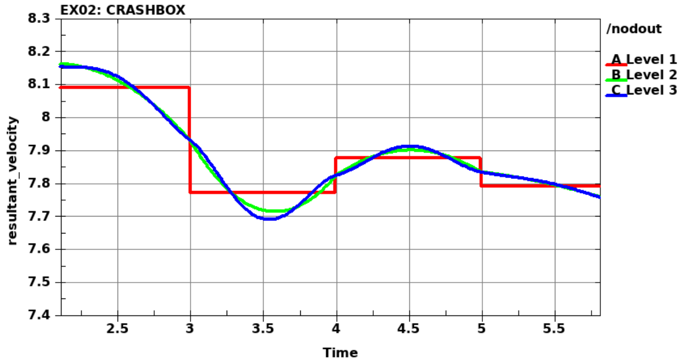


subsequent linking calculations

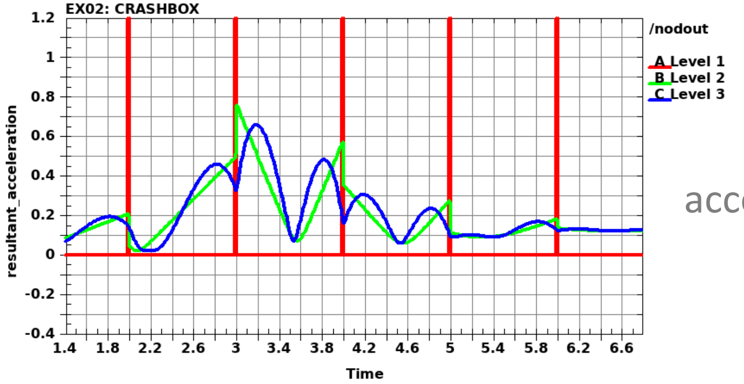
displacement



velocity



Motion smoothness: Best with Level 3



acceleration

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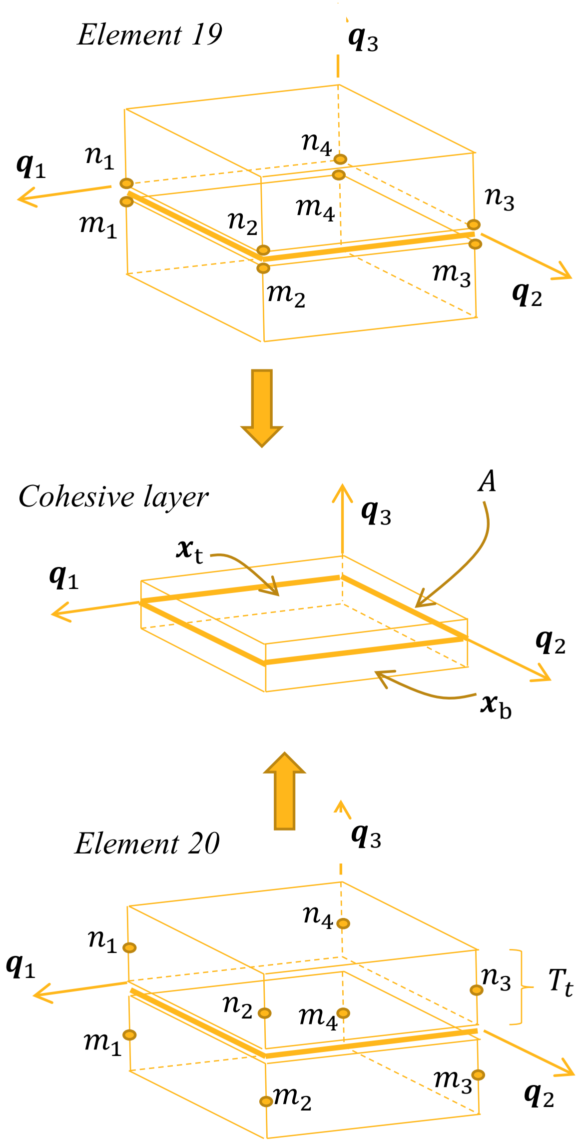
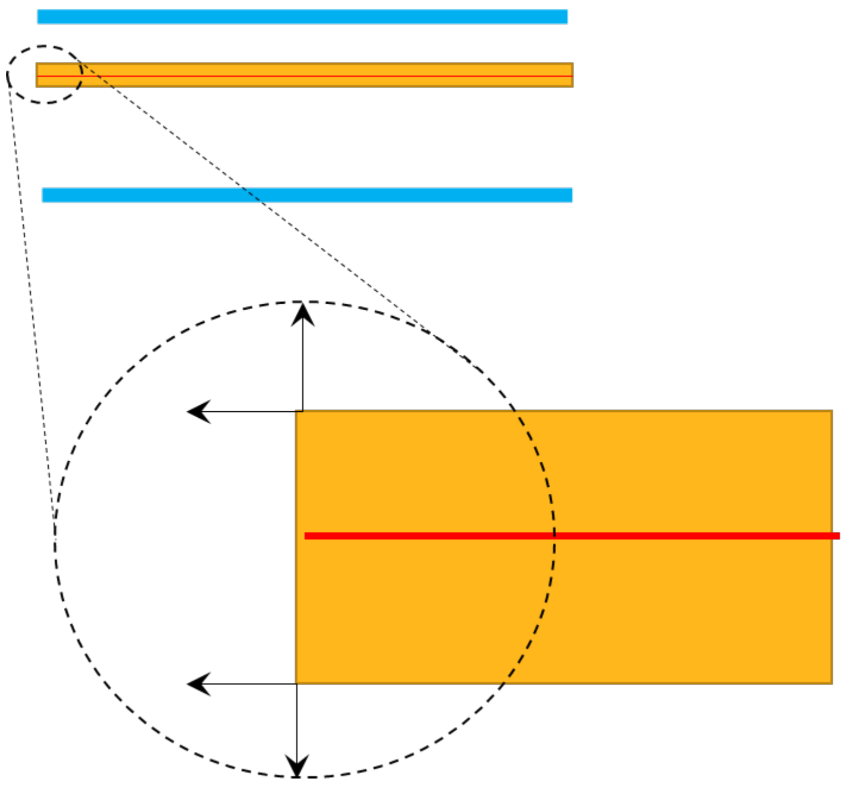
A generic cohesive element, ELFORM=-19

- Cohesive elements are used to model adhesive bonds
- Two kinds of formulations exist to date
  - Element 19 with translational kinematics
  - Element 20 with translational and rotational kinematics
- The recommendations have been to use 19 for modelling solid to solid and 20 for modelling shell to shell
  - With recent developments, a more liberal approach is justified
- Cohesive element -19 is a **general-purpose cohesive element** for explicit analysis
  - Similar to +19 but objective despite using large offsets
  - applicable for shell to shell and even shell to solid bondings



DIR_TIE – for directional tie of thin solid components

- Thin solid components between two structural parts: **adhesive bond**
- Tied contact will pull solid element nodes to the closest side
  - May result in collapse of solid elements
- New option DIR_TIE=1 on *CONTROL_CONTACT creates node normals that point "outwards" from the solid layer, and **changes the tying logic** to
  - For each node, tie primarily to surfaces located in the outward direction, EVEN if it is not the closest one
  - If no such surface is found, then fall back to tying to closest segment

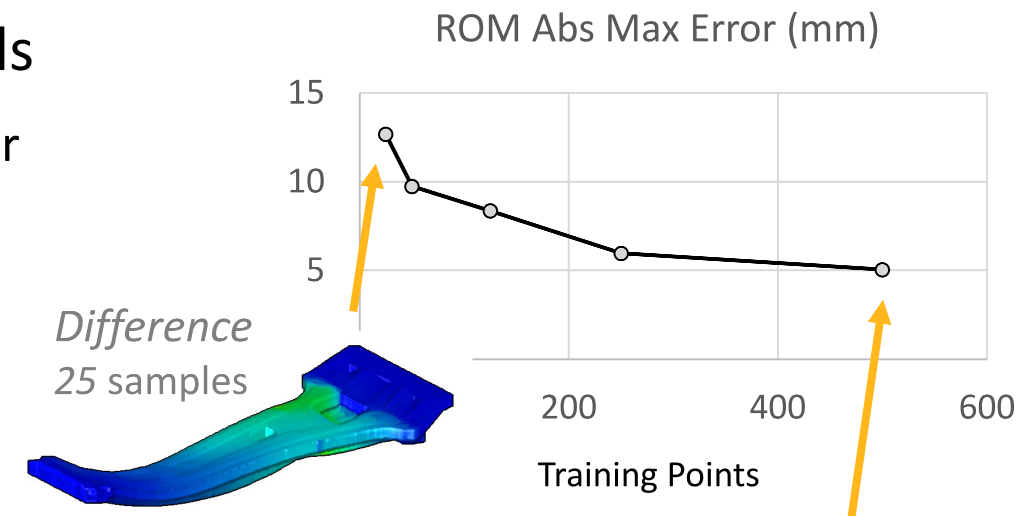


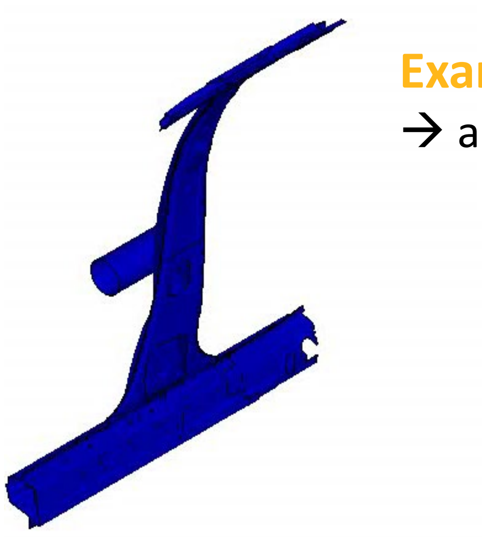
DISCLAIMER
Only works for non-groupable MPP tied contacts

LS-OPT, LS-TaSC

LS-OPT®: Full-field ROM generation

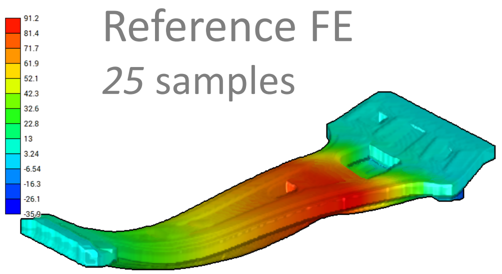
- Methodology for creating fast surrogate models
  - Integration of LS-OPT, LS-DYNA and Ansys Twin Builder
  - LS-OPT generates and schedules multiple LS-DYNA simulations according to an experimental design
  - Dynamic field results gathered as input to create a Reduced Order Model (ROM) using Twin Builder

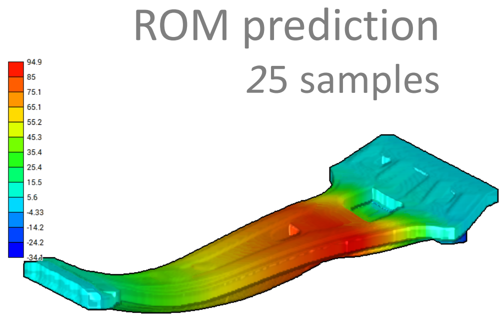


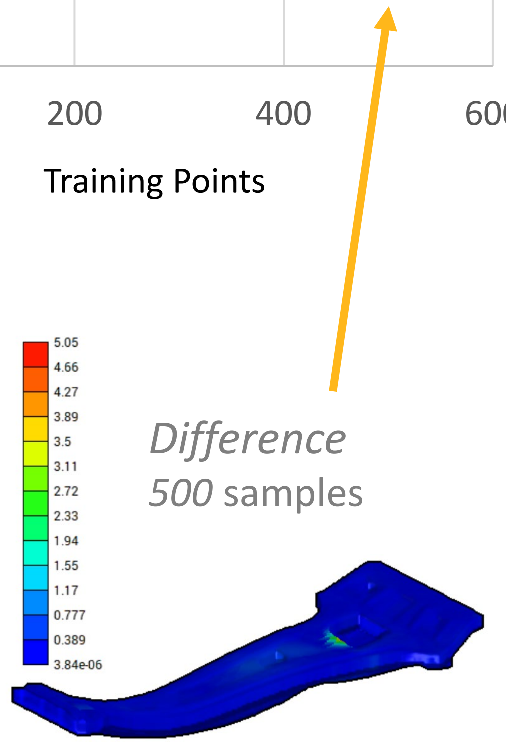


Example: side impact of a vehicle B-pillar

→ approximate the y-displacement field (7 thickness parameters)





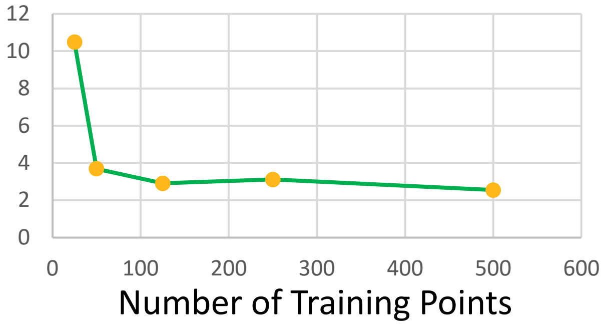


LS-OPT®/Twin Builder Full-field Dynamic Reduced Order Model

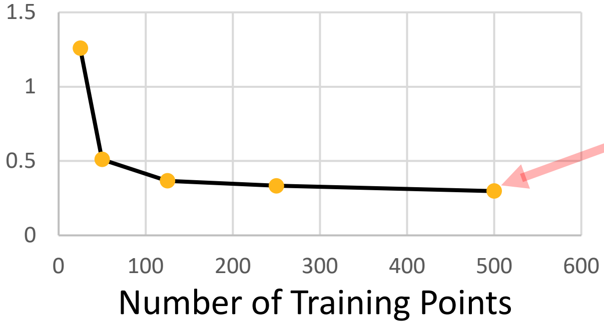
Left Ventricle Displacement Vector Field (10 material parameters)

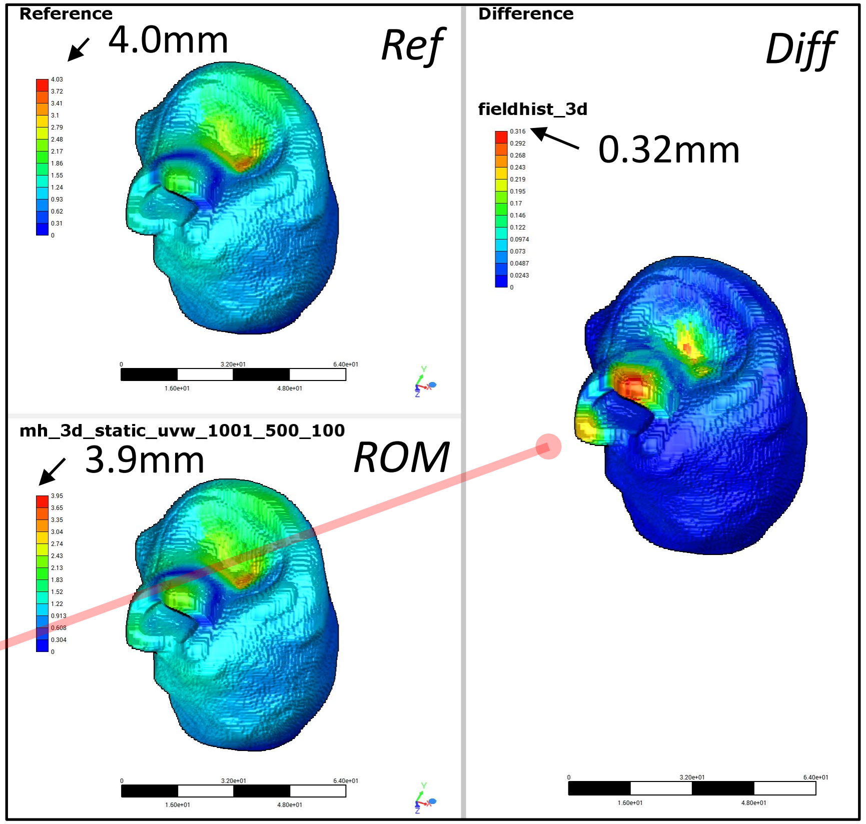
ROM Accuracy

Relative Error (%)

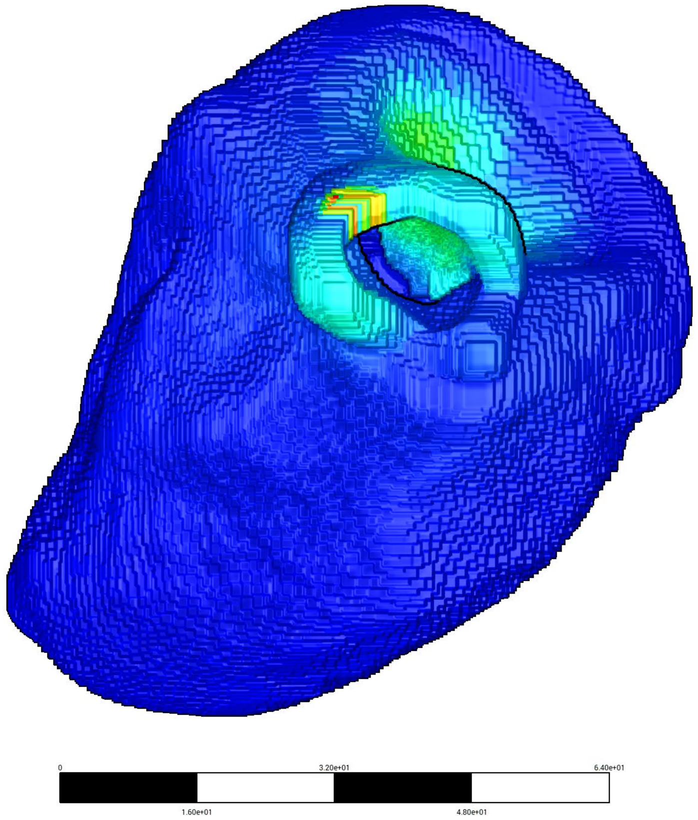


Abs Max Error (mm)





Heart model courtesy of and in collaboration with Synopsys. Automated mesh generation with Simpleware software from CT scans.



Reduced Order Model: Displacement vector field at $t = 200\text{ms}$

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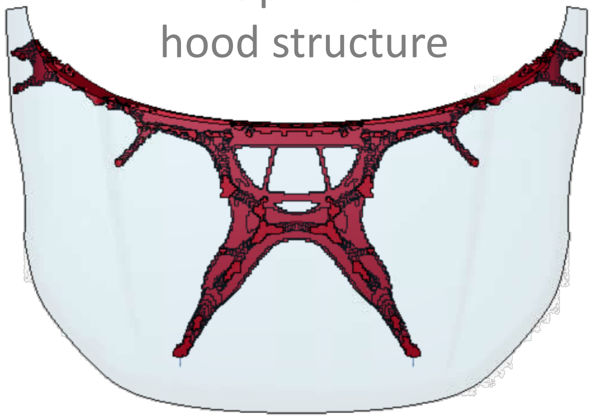
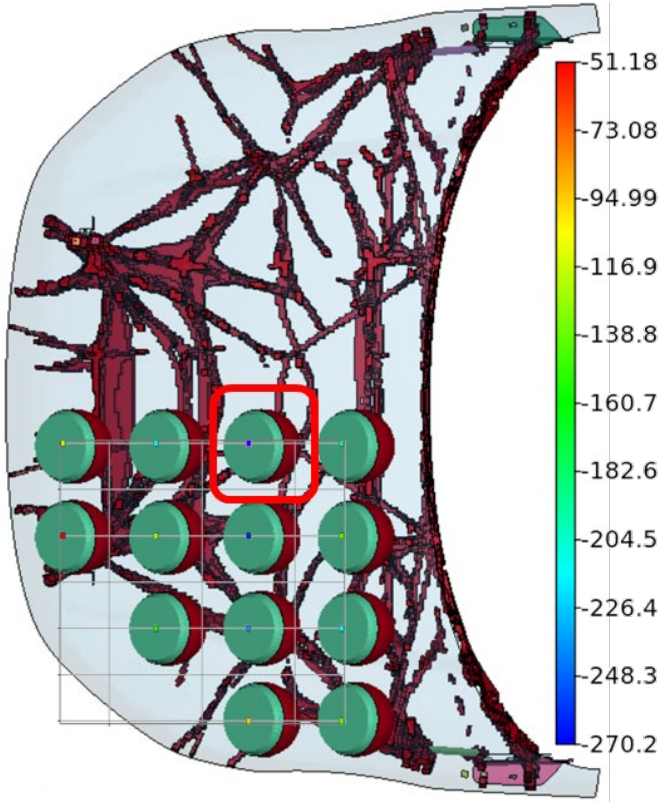
LS-TaSC: Complex topology problems

The enhancements focus on **simultaneously designing** for:

- Design codes such as Euro NCAP pedestrian protection
  - hundreds of head impact locations specified in testing protocol
- Nonlinear response such as HIC
- Multi-disciplinary use
  - impact, statics, and NVH
- Creating thin-walled structures

Optimal
hood structure



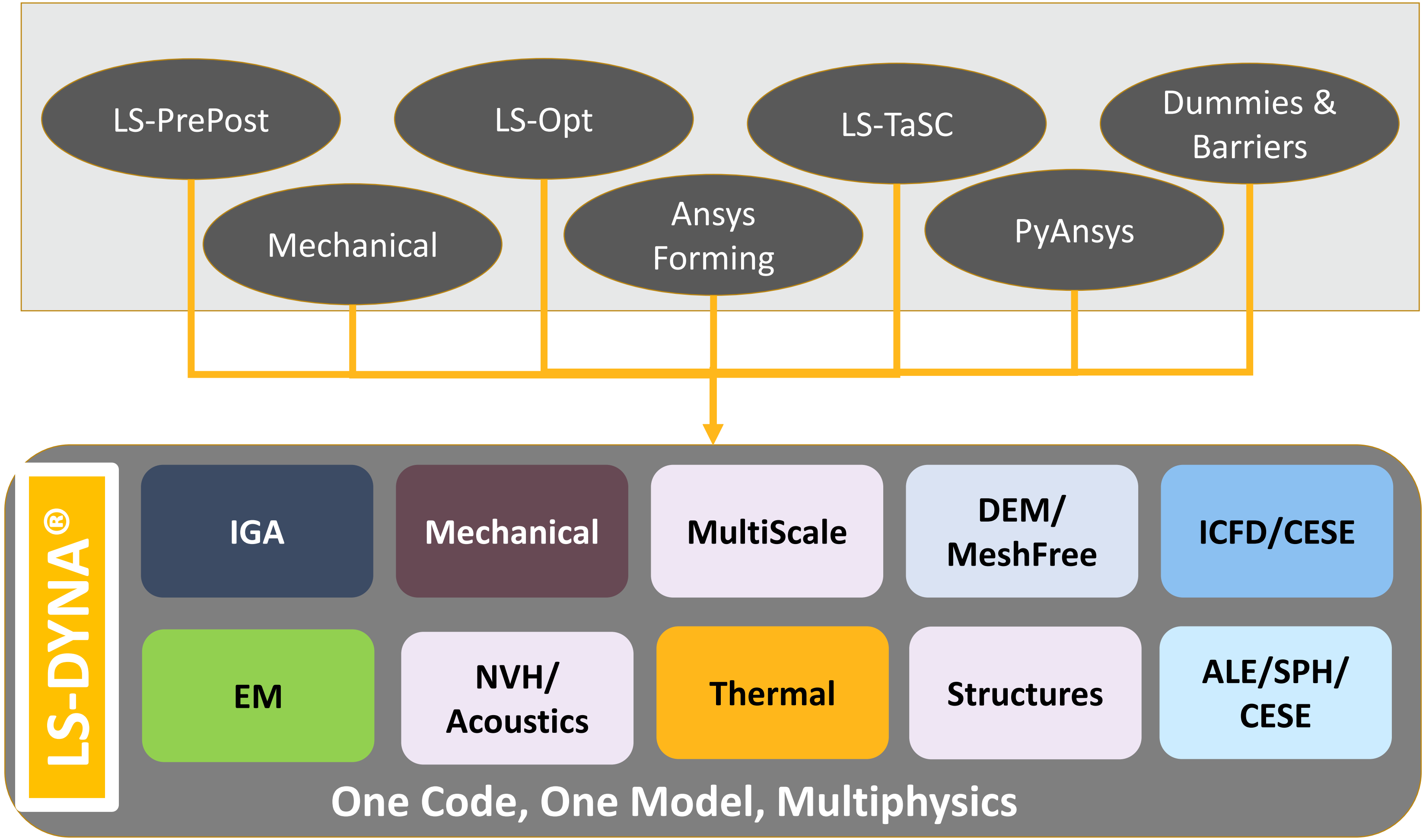


Overlay of topologies from a **worst-case design study** of a hood for NCAP

Conclusion

Release Management

- We continue to release new version with new features every year.
- Every alternative year LS-DYNA release will get Long-term support– E.g. 14, 16, 18…
- Existing versions used in production will continue to get LTS support until discontinued.
- Detailed documentation in User’s Manuals



Ansys Commitment

- We are committed to helping customers achieve their simulation needs
- LS-DYNA solver is moving towards enabling Digital trials & certification
- We appreciate the importance of customer engagement and collaboration

THANK YOU!

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HPC

Explicit - car2car (2.4 million elements, 30 ms)

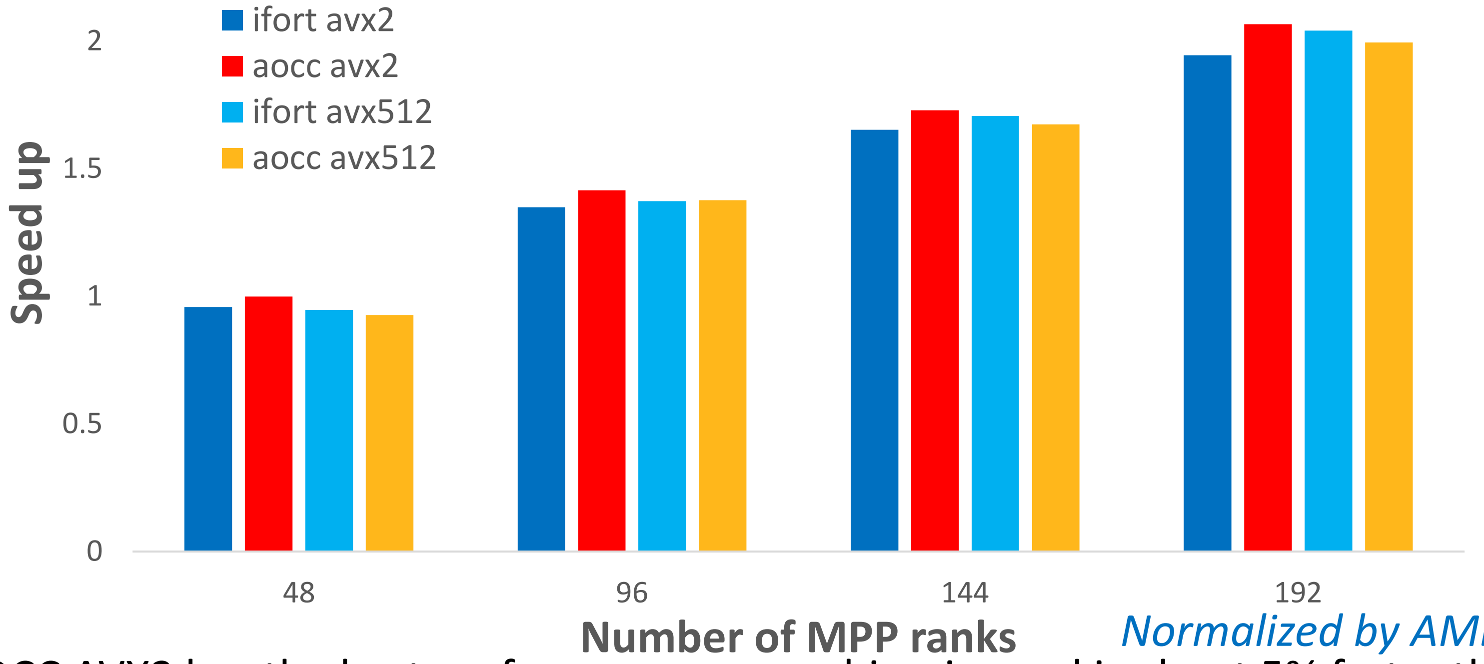
LS-DYNA Binaries

binary	Compiler options
ifort 2019.6.324 avx2	-march=core-avx2 -mtune=core-avx2 -align array32byte
aocc 4.0.0 avx2	-mavx2
ifort 2019.6.324 avx512	-march=skylake-AVX512 -mtune=skylake-AVX512 -align array64byte -qopt-zmm-usage=high
aocc 4.0.0 avx512	-mavx512f

- Tested with Intel MPI
- No hardware dependent options but instruction set dependent options
- Produce same numerical results from different generations/brands of CPUs

AMD EPYC 9654 (Zen4/192 cores) : car2car

Number of ranks	Intel MPI runtime options
48	-genv I_MPI_PIN_PROCESSOR_LIST=allcores:shift=4 -np 48 -ppn 192
96	-genv I_MPI_PIN_PROCESSOR_LIST=allcores:shift=2 -np 96 -ppn 192
144	-genv I_MPI_PIN_PROCESSOR_LIST=allcores:shift -np 144 -ppn 192
192	-genv I_MPI_PIN_PROCESSOR_LIST=allcores:shift -np 192 -ppn 192

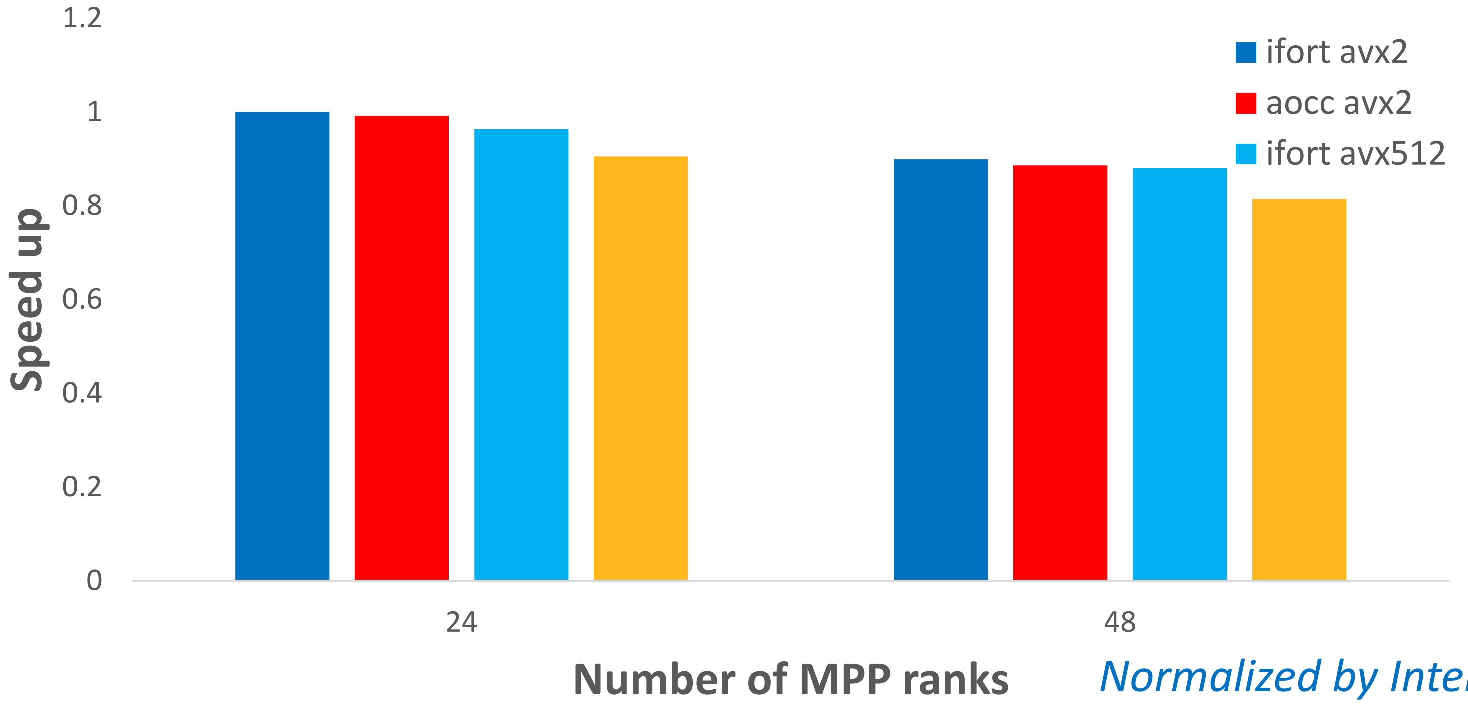


Normalized by AMD aocc avx2 48-core timing

- AOCC AVX2 has the best performance among binaries and is about 5% faster than ifort AVX2.
- Ifort AVX512 is a little faster than ifort AVX2
- Zen4 is the first AMD chip support AVX512.

Intel Xeon Gold 1642 (48 cores): car2car

Number of ranks	Intel MPI runtime options
24	-genv I_MPI_PIN_PROCESSOR_LIST=allcores:shift=2 -np 24 -ppn 48
48	-genv I_MPI_PIN_PROCESSOR_LIST=allcores:shift -np 48 -ppn 48



Normalized by Intel ifort avx2 24-core timing

- Ifort AVX2 has the best performance among 4 binaries and is about 1% faster than AOCC AVX2.
- AVX512 has less performance than AVX2 for both compilers
- AOCC AVX512 does not perform well on Intel chips.

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Implicit – Cycl1e6 (1 million elements)

CPU

- AMD EPYC 9654
- Intel Xeon Gold 1642

Normalized by the best timing on each hardware

	AMD Zen -96 ranks		Intel Scalable - 32 ranks	
	Extra environment variable	**Speedup**	**Extra environment variable**	**Speedup**
AOCC/MKL	MKL_DEBUG_CPU_TYPE=5	0.97	MKL_DEBUG_CPU_TYPE=5	0.82
		0.44		0.82
AOCC/AOCL	BLIS_ARCH_TYPE=zen4	0.97	BLIS_ARCH_TYPE=zen4	0.83
		0.95		0.24
IFORT/MKL	MKL_DEBUG_CPU_TYPE=5	1	MKL_DEBUG_CPU_TYPE=5	0.86
		0.92		1

- Ifort/MKL has the best performance on both hardware ***(different environment variable setting)***
- Without proper environment variable, ***MKL and AOCL perform poorly***.
- Will release AOCC/AOCL and IFORT/MKL.***(AOCC/MKL for internal testing only)***
- AMD mentioned AOCL does not need the flag in the future release.

AMD Zen and Intel Scalable – Numerical consistency

Identical results for explicit analysis

- Same decomposition
- Set lstc_reduce on
- Set the following runtime option for Intel MPI (2019 and above)

    -genv I_MPI_CBWR=2

    https://cdrdv2-public.intel.com/671217/mpi-dev-ref-lin-u6.pdf

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