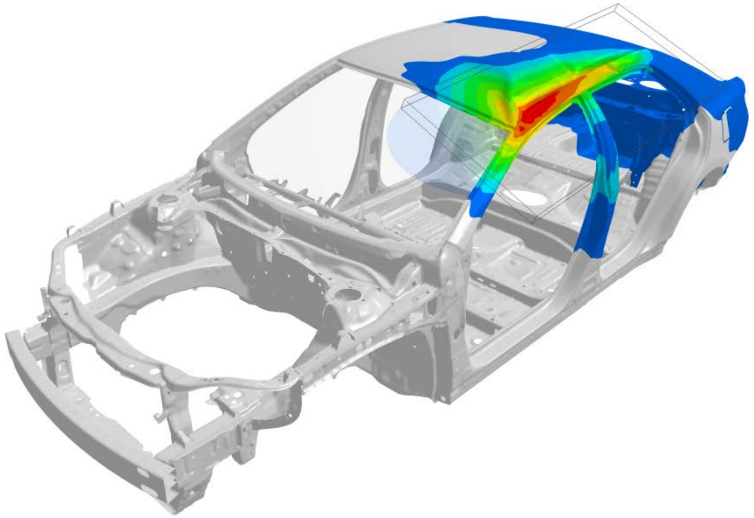
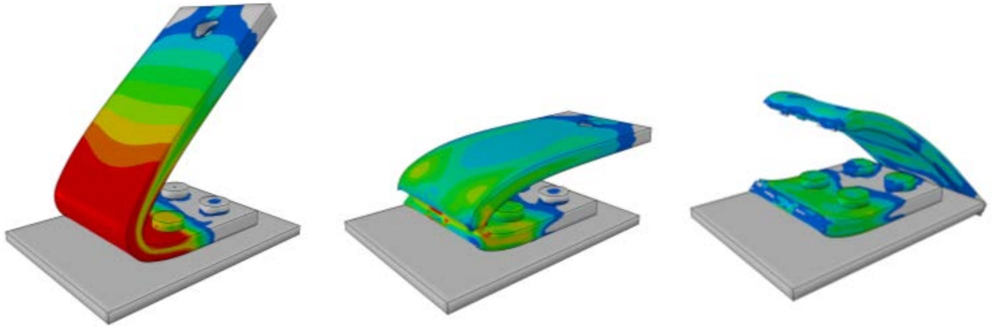
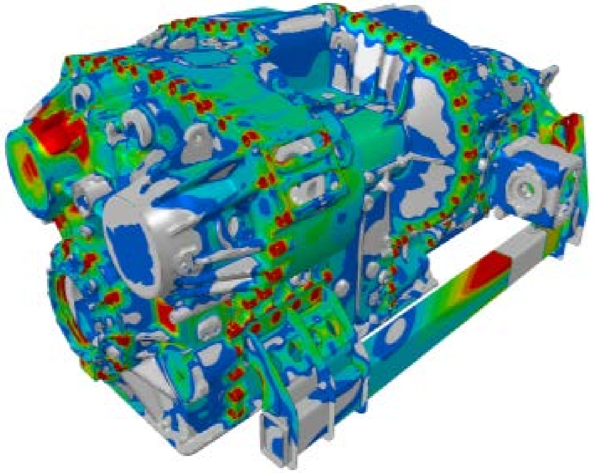
Nonlinear Implicit in the Making – the Advanced made Simple







Thomas Borrvall, DYNAmore Nordic AB

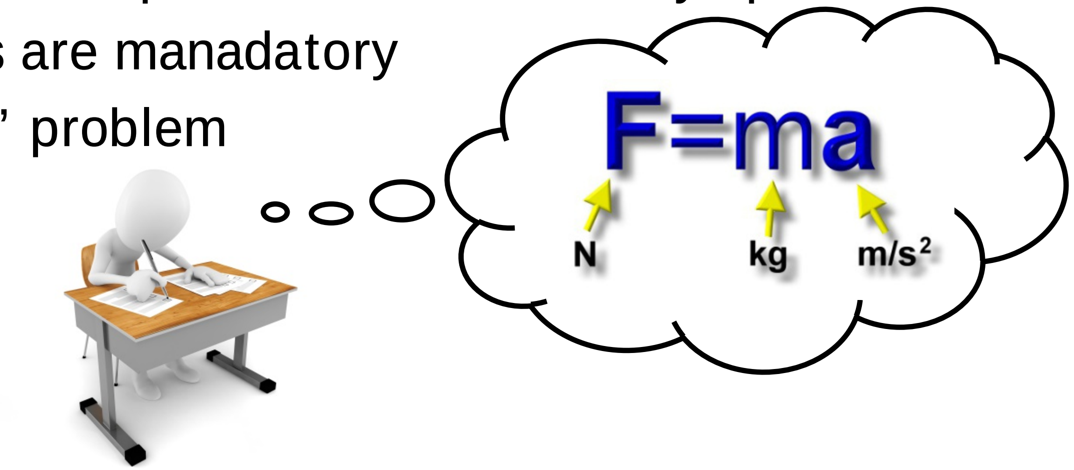
Fredrik Bengzon, Satish Pathy, Anders Jernberg, Wenhui Yu, Zhang-Cheng Ju, Zhang Zhanqun, Li Zhangsheng, Roger Grimes, etc.

Background

- 70’s - LS-DYNA emerges in the defence industry
  - Goal is to simulate highly dynamic lapses
  - Naturally developed as an explicit code
- 80’s - LS-DYNA grows strong in the automotive industry
  - State of the art in simulating crash
  - Development evolves accordingly
- 90’s - LS-DYNA advances into competitive areas
  - Implicit introduced for (quasi-)static loading scenarios and linearphenomena
  - Potential application areas significantly increased
- 00’s - LS-DYNA expands to cover new physics
  - Electromagnetics, Fluid Dynamics, Thermal and Mechanical capabilities justifies it as being a Multi-Physics code

Current Status and Challenges – User Perspective

- LS-DYNA is one of the more advanced simulation softwares on the market
  - Expands beyond basic FE concepts to include complex features and many options
  - Goal is to predict reality, advanced features are manadatory
  - Great potential of successfully solving ”any” problem
- Learning curve is steep
  - Beginners require university education
  - Training to learn a new language - keywords
  - Mastering requires years of usage



- Experienced LS-DYNA users are uncomfortable with implicit analysis
  - Different keywords
  - Different thinking
  - Different interpretation

Current Status and Challenges – Developer Perspective

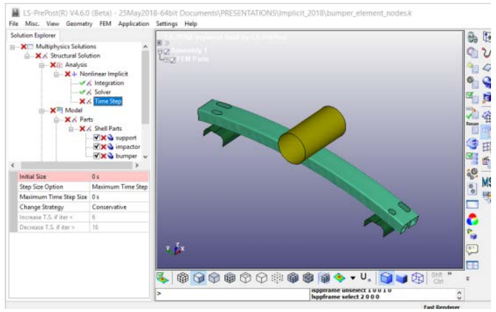
- Nonlinear implicit solver algorithm is mature and robust
  - Newton solver with BFGS accompanied with line search
  - Back bone since R9
- Explicit features needs to be ”implicitized”
  - Enhance accuracy to account for relatively coarse time discretization
    - Incremental to strong objectivity
    - Full projection schemes in plasticity algorithms
    - Tighter tolerances
  - Add and improve stiffness matrices of advanced features
  - We can afford the luxury of spending time for accuracy
- Refine number of keyword options
  - Taking continuum mechanics meticulously serious in conjunction with implicit algorithms aimed at solving problems robustly rather than quickly does away with having to tune parameters for each different problem
  - Philosophy embodied in guideline of Appendix P, LS-DYNA Keyword Manual
  - Knowledge and experience built in to GUI under development

*IACC=1 on *CONTROL_ACCURACY (implicit accuracy)*

Nonlinear Features
-"all" developers

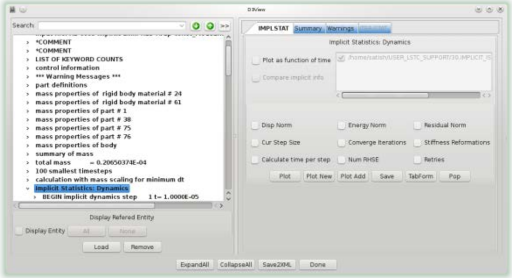
Nonlinear Implicit Solver
-Thomas Borrvall
-Fredrik Bengzon

Pre-processing
-Yu Wenhui
-Zhang Chengju
-Anders Jernberg
-Zhang Zhanqun



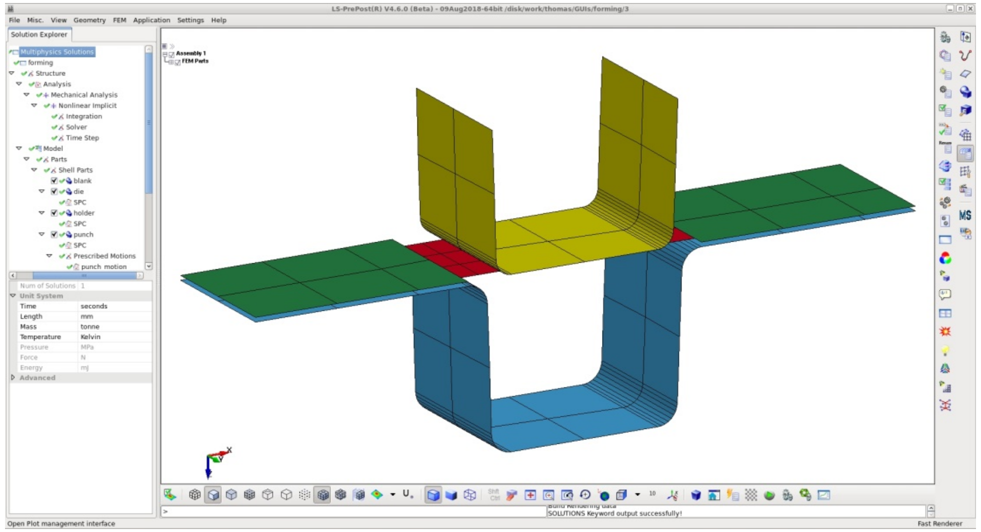
Linear Implicit Solver
-Roger Grimes
-Cleve Ashcraft
-Bob Lucas
-Francois-Henry Rouet
-Clement Wiesbecker
-Eugene Vecharynski
-Liping Li

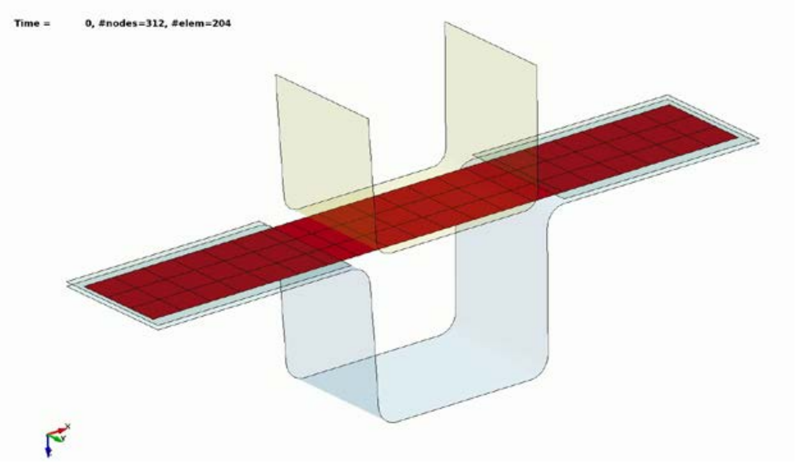
Post-processing
-Li Zhangsheng

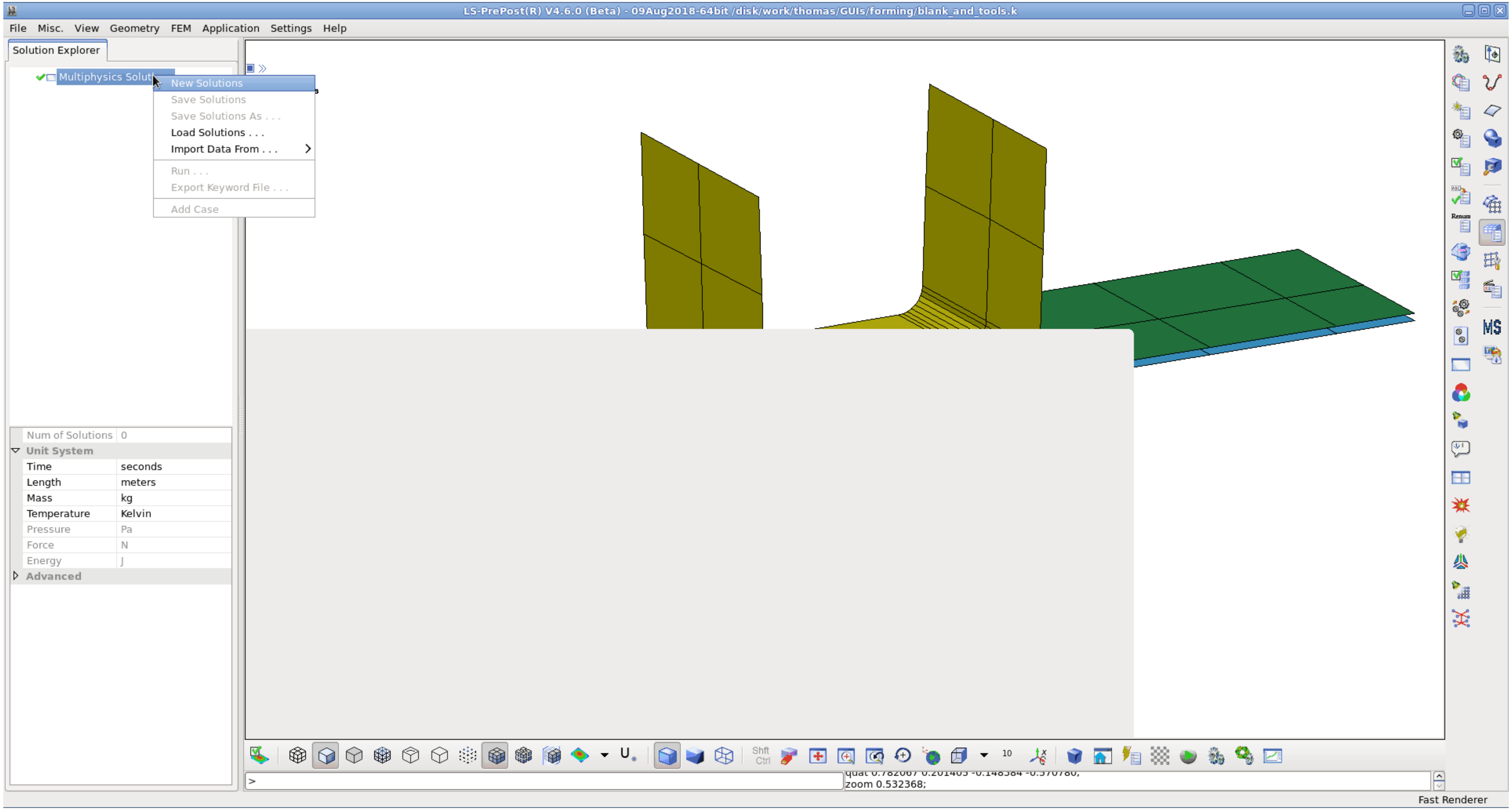


Multiphysics GUI - summary

- Model setup based on engineering concepts and high abstraction level
  - Model tree
  - Parameter editor
  - Structure and fluid
  - Mechanical and thermal
  - Less is more
  - Suggested presets
  - Error functionality
  - Case treatment
- Motivation is to facilitate the use of implicit analysis
  - Attract newcomers
  - Facilitate migration
  - Widen the user community



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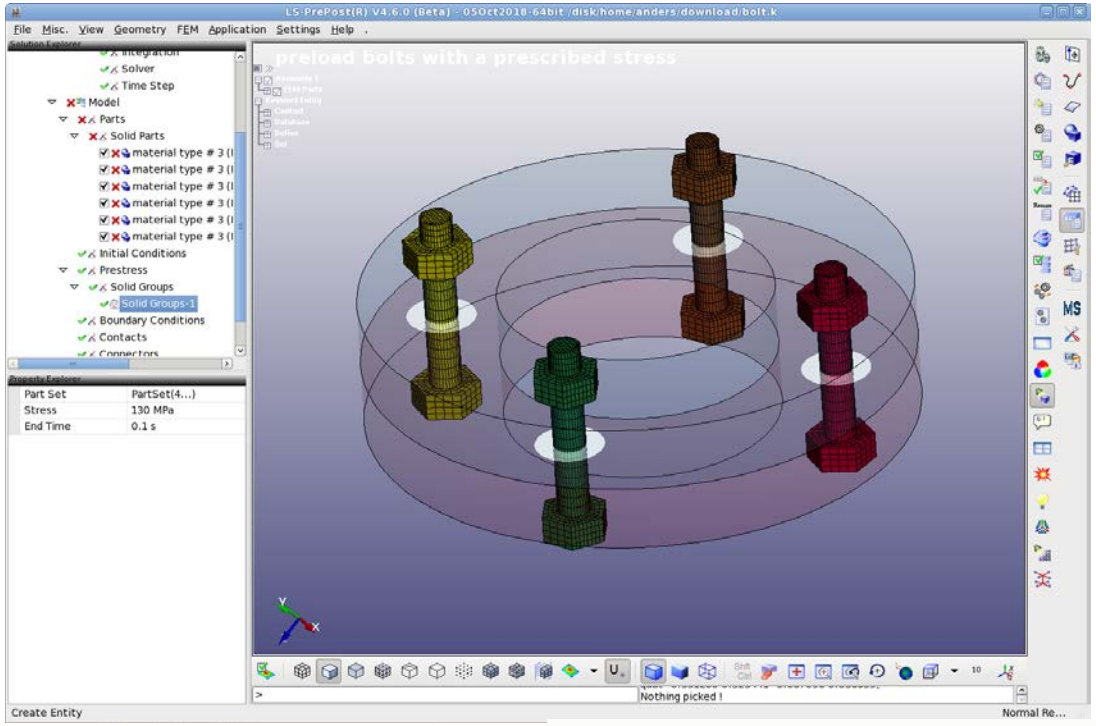
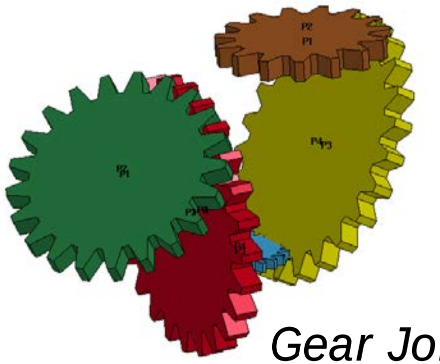
Fast Renderer

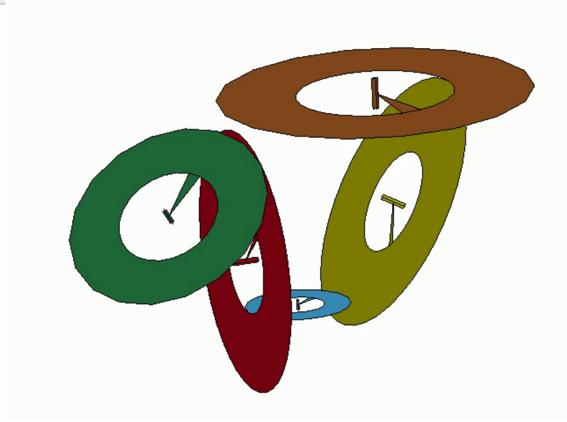
Key features – a visionary outlook

- Simple
  - Reduced number of options
  - Intuitive interpretation of parameters
  - Show only essentials – advanced options hidden
- Safe
  - Error and warning indicators
  - Help texts
- Efficient
  - Multiple selections
  - Reduce mouse clicks and motion
- Nice
  - Realistic visual representations
- Adaptive
  - Best possible practice adopted
  - May change over time
- Multi-physics applications
  - Couple mechanical-thermal-cfd-em
- Post-processing capabilities
  - Same model tree exposes results in runtime



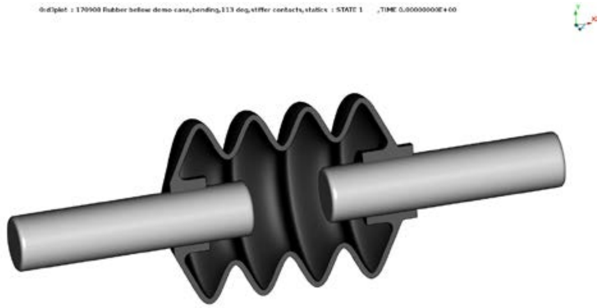


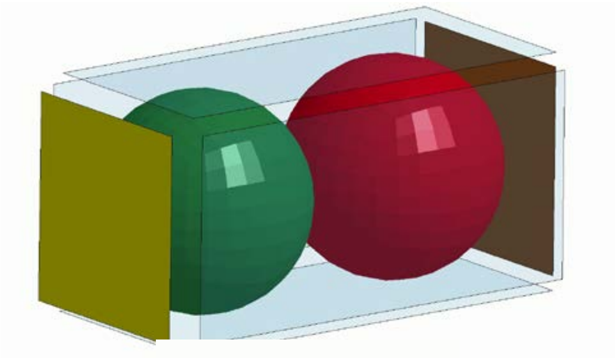
Gear Joints

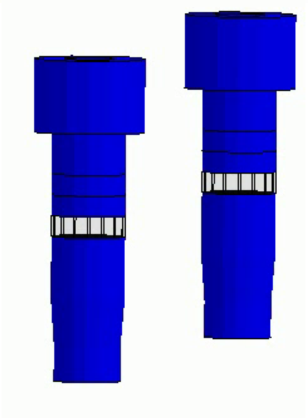


Nonlinear Implicit – Recent and Ongoing Development

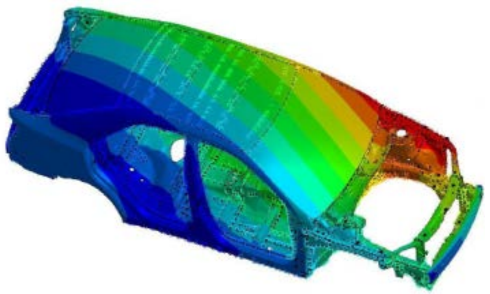
- Material and elements
  - Geometric stiffness by part sets and compression elimination
  - Increase accuracy in materials based on customer feedback
  - Rejections, throwing exceptions to be caught by implicit solver
  - Consistent tangents, accounting for failure/damage
- Airbag
  - Control volume airbag treatment supported
  - Accounts for the all-to-all coupling between nodes
  - Improves convergence without sacrificing speed that would result from assembling a dense stiffness matrix
- Prestress
  - Prestressing of bolts accounts for bending
  - Instead of imposing stress in each element, the average cross sectional stress is prescribed
  - Preserves structural integrity



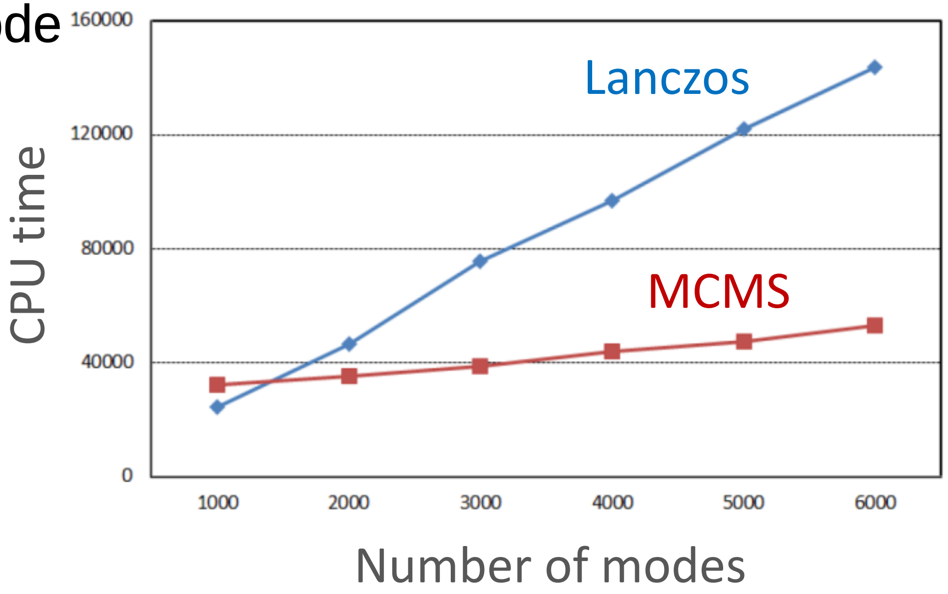


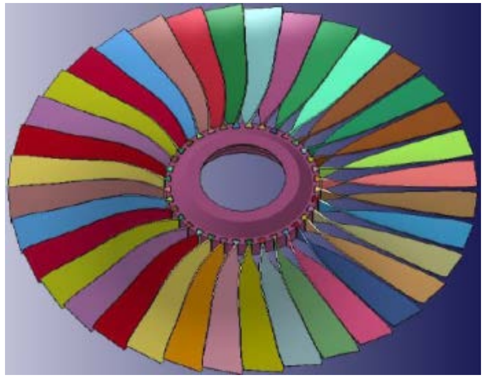


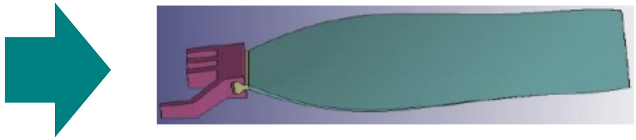
Linear Implicit – Eigenvalue Analysis



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



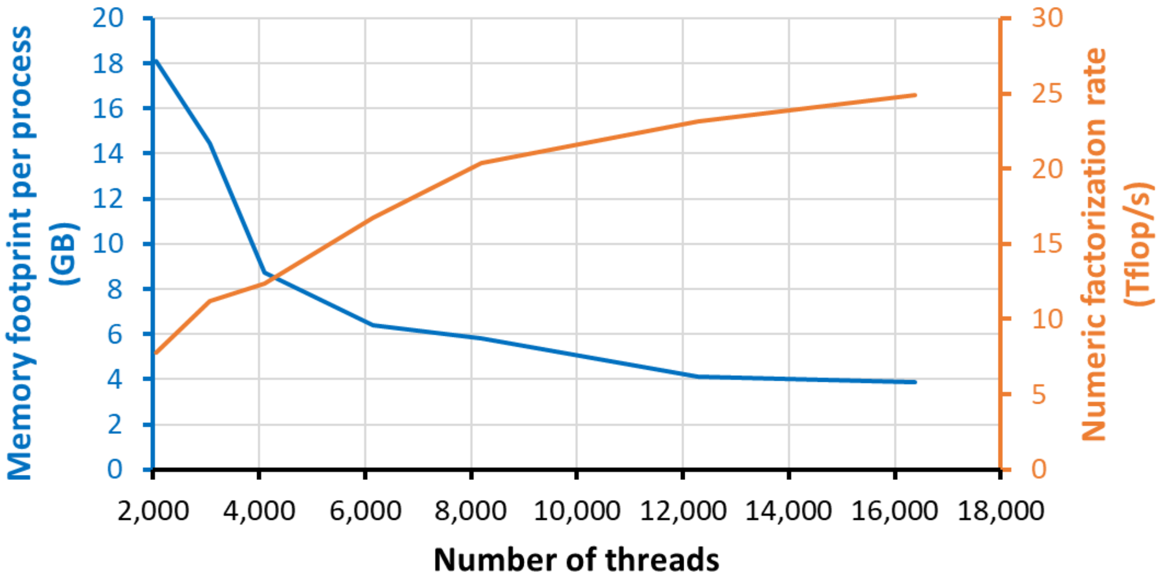


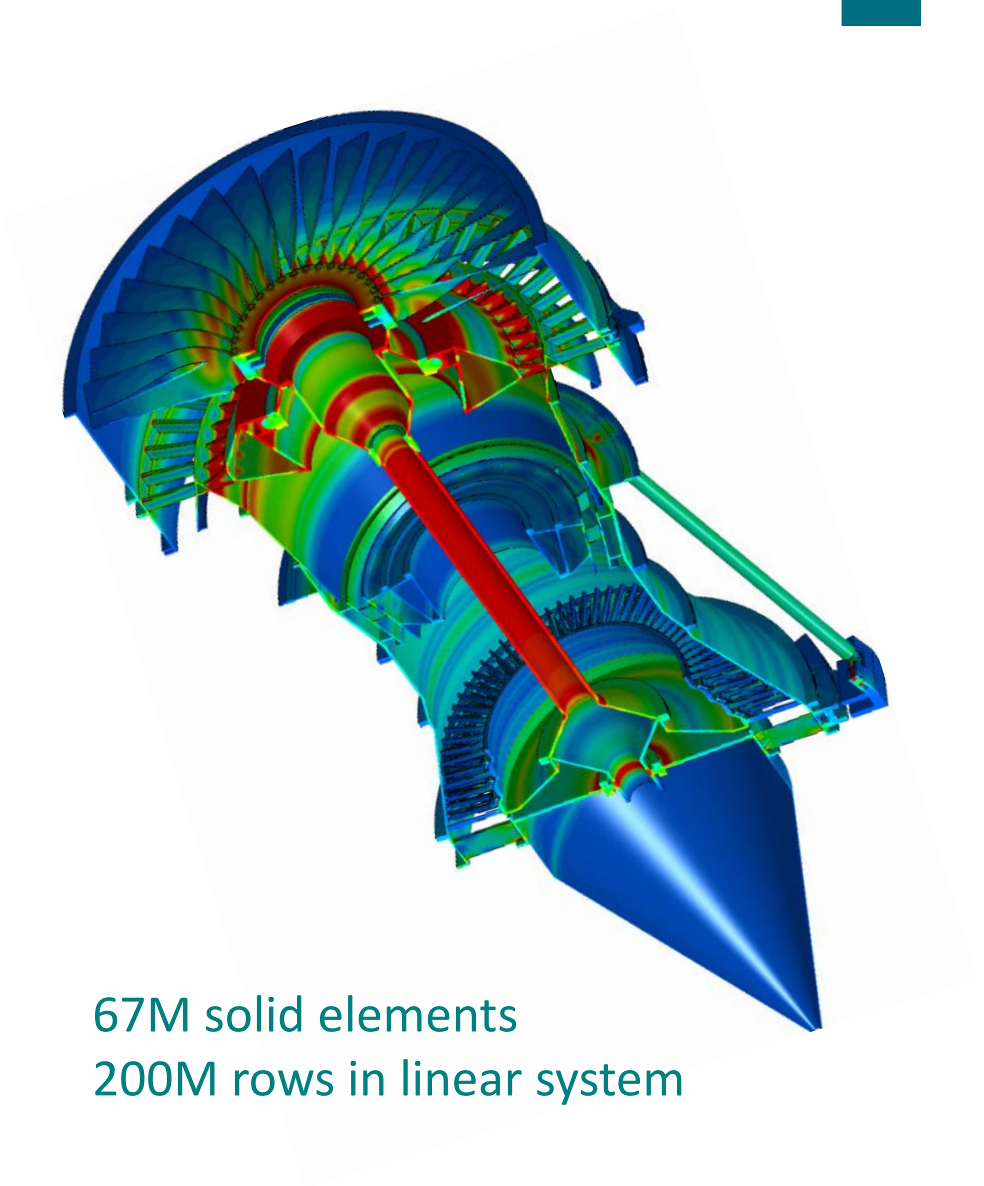


huge CPU/memory savings

Linear Implicit – Linear Solver

- Working on larger and larger models!!!
  - 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

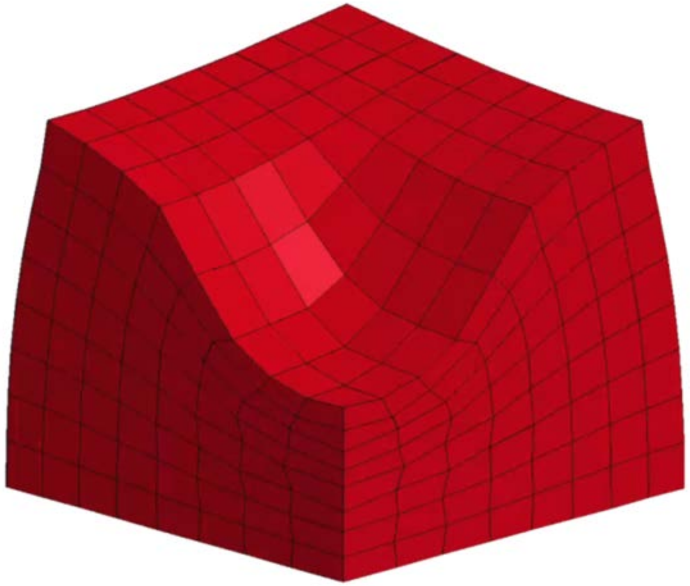


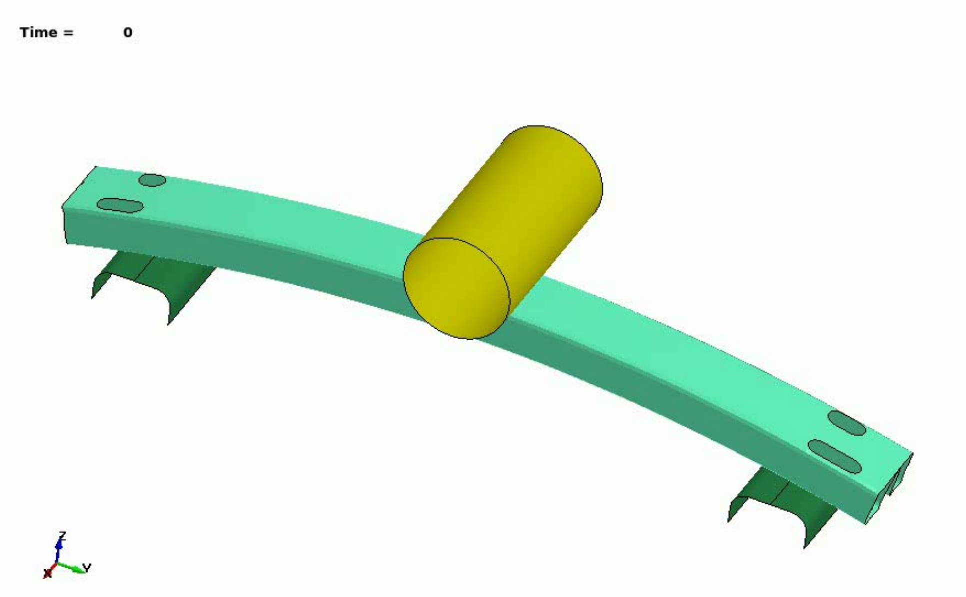


67M solid elements
200M rows in linear system

Miscellaneous developments

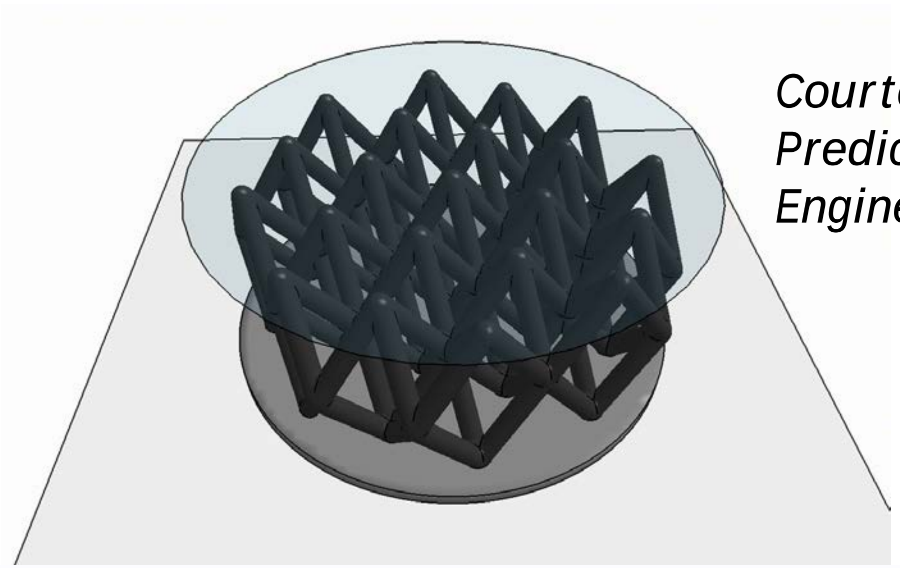
- New hexahedral solid element for nonlinear implicit
  - enhanced assumed strains (EAS) approach
  - generalization of linear solid #18 to nonlinear analysis
  - very good coarse mesh accuracy
- Convergence tolerances
  - Maximum norm tolerances DMTOL/EMTOL/RMTOL
  - Consistent norms
- Boundary conditions
  - Accurate representation of boundary conditions, velocity and acceleration
  - Treat situations where initiation of motion results in zero residual force, movement of rigid bodies
- Sense switches supported
- Energy calculations refined
  - Accounting for numerically dissipated energy – placed in eroded kinetic/internal energy



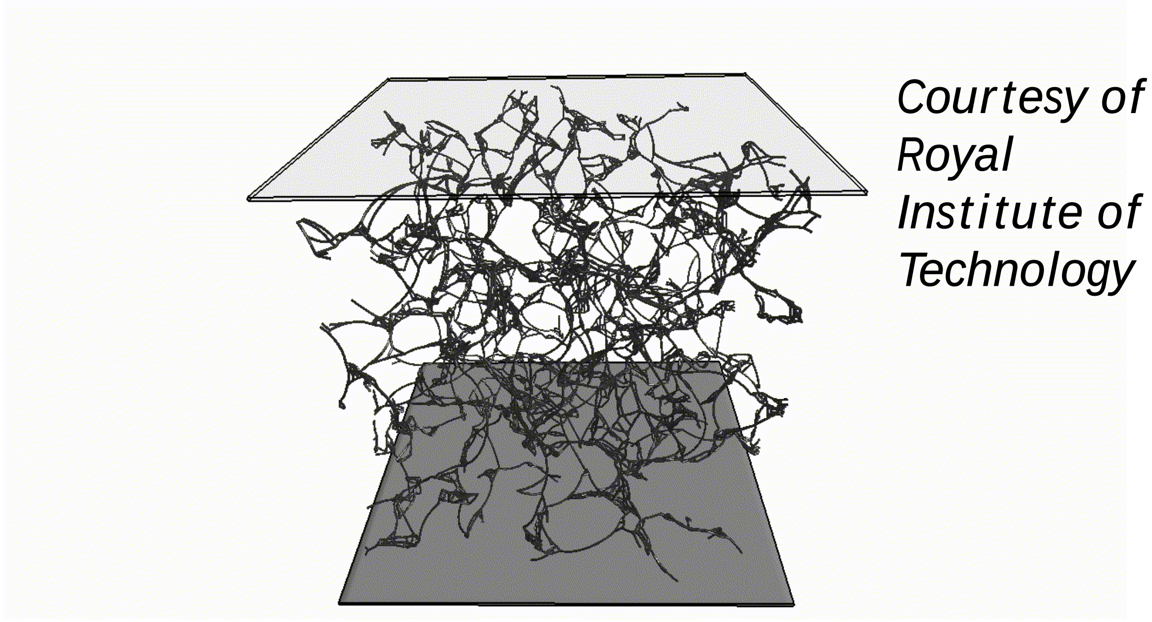


Mortar Contact - General

- 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
- Recent developments include
  - Rejections, throwing exceptions to be caught by implicit solver
  - Expansion of friction models and tied/tiebreak/weld features

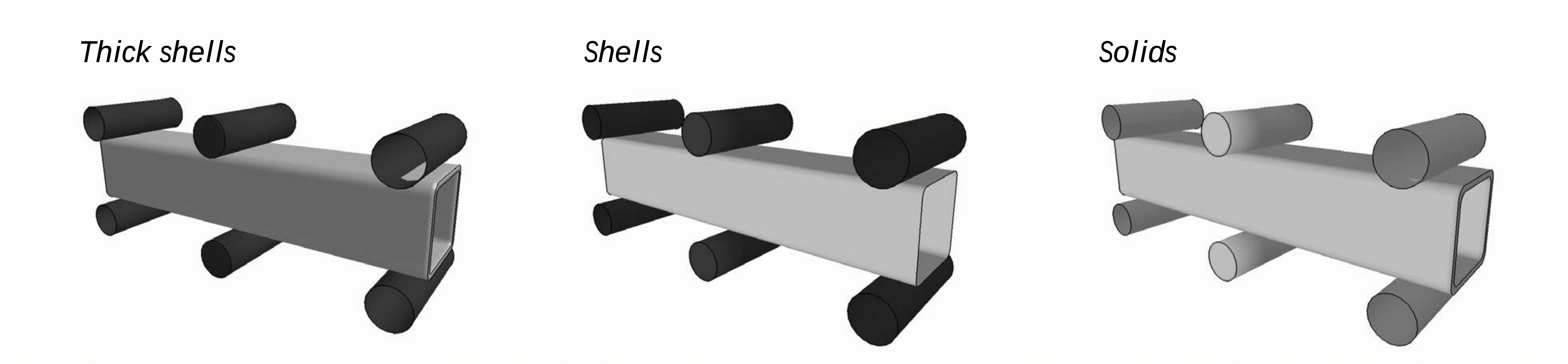


Courtesy of Predictive Engineering



Courtesy of Royal Institute of Technology

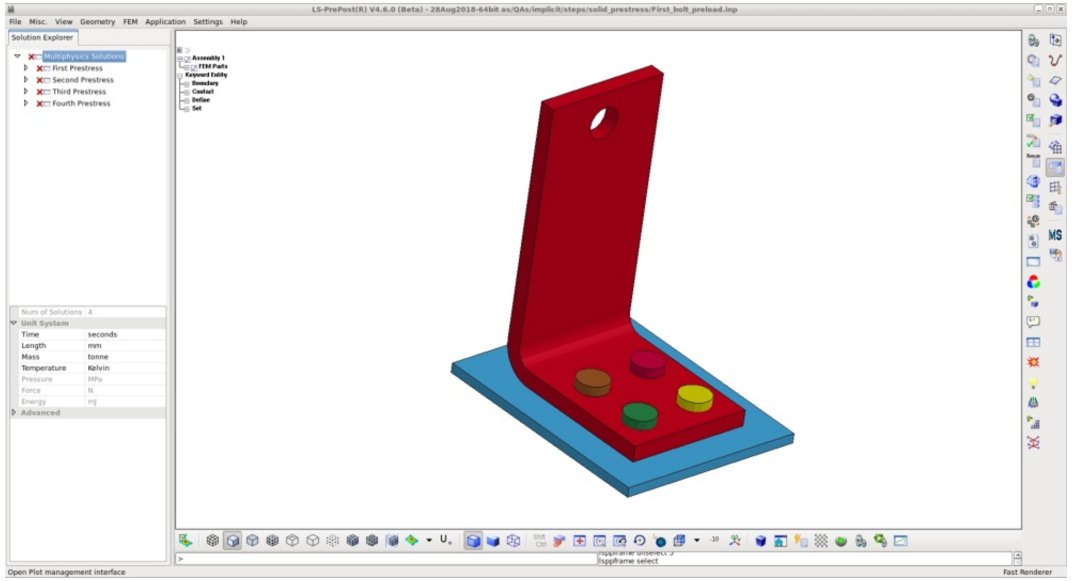
Mortar Contact - Erosion



- 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

Process Splitting – a GUI feature

- ”Complicated” process split into ”simple” steps/cases
- Each case is ”clean”, no birth/death times
  and using simple curves
- *Entire* system state is transferred between each case
- Flexible, many changes can be made between each
  step
- ”Restart” can be made from any step after possible
  modifications



Summary

- Nonlinear Implicit development progresses at a steady pace
  - Supporting and enhancing features is at the forefront
- Solution Explorer (GUI) is developed to facilitate the entry to the world of implicit
  - Long term vision is to make it a generic Multi-Physics graphical user interface
- Complementing it with LS-Run makes it a neat and easy-to-use package
  - Powerful? We'll see…