# Recent Developments in LS-DYNA – II

John Hallquist

Livermore Software Technology Corporation, Livermore, USA

# Version 971_R3 developments

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# Nonlinear shell element with thickness stretch

- Includes thickness degrees-of-freedom
  - Requires 4 scalar nodes with 2 dof each
    - Generated automatically
- Calls 3D constitutive models
- Shell types available
  - Type 27 Triangle (new in R3)
  - Type 25 Quadrilateral
  - Type 26 Quadrilateral
- Can now be used in metal stamping with adaptive remeshing (new in R3)

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# Nonlinear shell element with thickness stretch

- Main applications
  - Metal forming where normal loading is important, e.g., hydroforming.
  - Crash analysis
  - Composite analysis
- Forming material models implemented:
  - *Mat_3-parameter_barlat (36)
  - *Mat_transversely_anisotropic_elastic_plastic (37)
  - *Mat_barlat_yld2000 (133)

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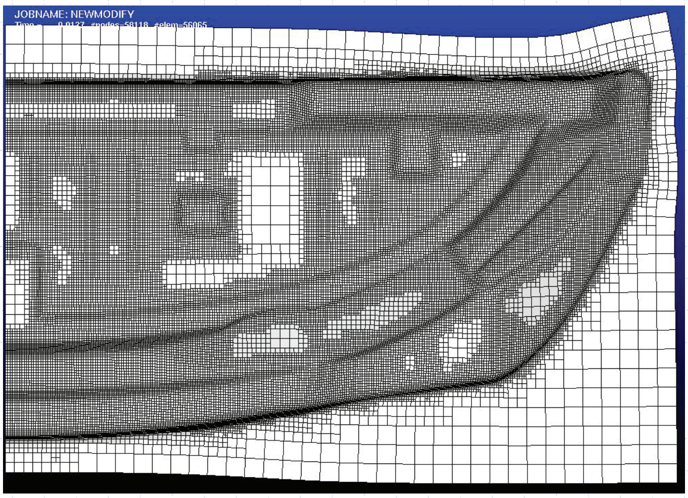
# Example forming problem

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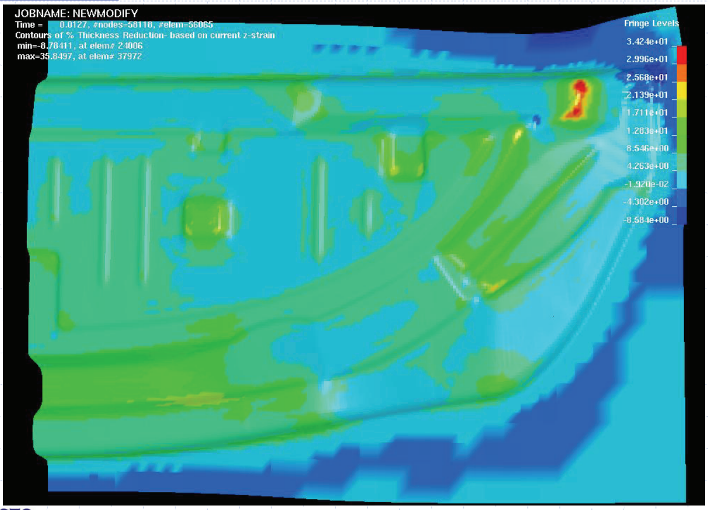
## Type 16 shell thinning

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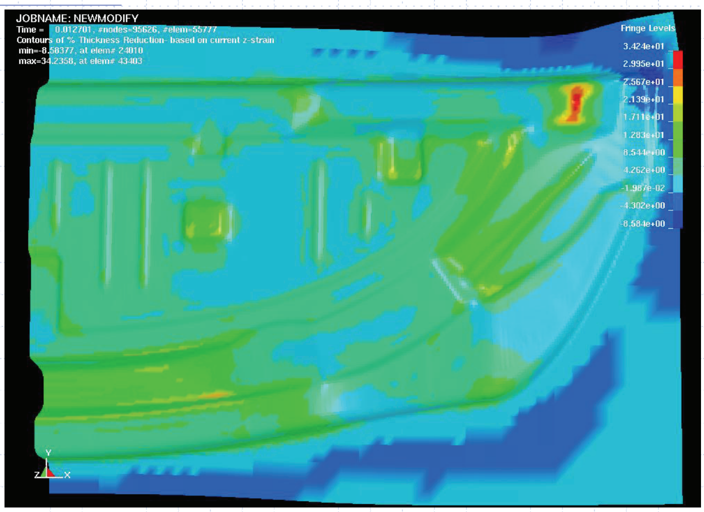
## Type 26 shell thinning

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## Example forming problem

- CPU Cost
  - Type 16 - 25.16 minutes
  - Type 26 - 37.25 minutes
- Results are nearly identical with slightly less thinning with the type 26 shell.

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## *Element_shell_..._offset

- "Offset" option has been added for all shell elements in version 971.
- The offset is included when defining the connectivity of the shell element
- The mid-surface is projected along its normal vector
  - Offsets greater than the shell thickness are permitted
  - Overrides the offset specified in the *SECTION_SHELL input
- Nodal inertia is modified to account of the offset and provide a stable time step of explicit computations

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## *Element_shell_..._offset and contact

- In the R3 release, shell thickness offsets are accounted for in the single-surface and surface-to-surface contact options.
- Shells can be generated on CAD surfaces and then offset
- Contact now accounts for the offsets during the analysis

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## *Element_shell_source_sink

- Simulation of roll forming
- Elements are created at the source
  - Force boundary conditions
- Elements are deleted at the sink
  - Displacement boundary
- Fewer elements required since elements are created and deleted as required
  - Decease in CPU time requirements

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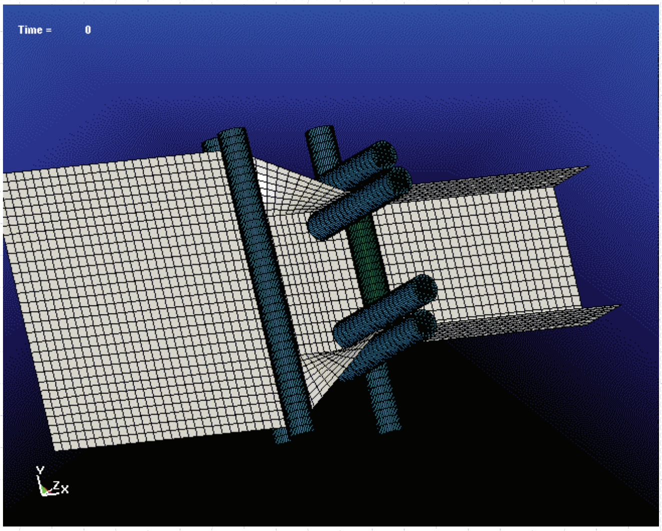
# *Element_shell_source_sink

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# Discretization of load curves

- LS-DYNA uses internally discretized curves to improve efficiency in the constitutive models.
  - Huge decrease in run times possible
  - Historically fixed at 100 equally spaced points
    - Recent customer complaint: too coarse for some applications where a very smooth response is required
- The number of points in the discretization is now an input parameter. The default remains = 100.
- All load curve use the same number of points

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# *BOUNDARY_PRESCRIBED_ ORIENTATION_RIGID_*OPTION*

- Allows the orientation of a rigid body to be prescribed as a function of time.
- Uses a total formulation which is more precise than the incrementally based: *BOUNDARY_PRESCRIBED_MOTION_RIGID
- Options:
  - **_ANGLES**: Specify a sequence of rotations about either body or space fixed axes and the associated orientation angles $q_i(t)$ ($i$=1,2,3) as time histories using *DEFINE_CURVE.
  - **_DIRCOS**: Nine elements of the direction cosine matrix are input as functions of time, $C_{ij}(t)$ ($i,j$=1,2,3)
  - **_EULERP**: Provide as functions of time four Euler parameters, $\varepsilon_i(t)$ ($i$=1,..,4)

# Conventional mass scaling

- Lumped nodal masses are scaled (increased) to increase stable time step in explicit finite element analysis
- Severe scaling unavoidably introduces unwanted, non-physical, inertia effects in the structure under consideration – this will in practice limit the amount by which the time step can be increased
- Crash models are often forced to run at small step sizes due to critical components where mass scaling will lead to wrong results, i.e.,
  - Dummy interacting with steering wheel finely meshed with solid elements

## Selective mass scaling

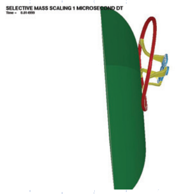
- Mass is increased under the constraint that the rigid body translational behavior is preserved
- Lowers the high frequencies which allows for a larger stable time step, but leaves the low frequency domain relatively unaffected – severe mass scaling can be performed without deteriorating the accuracy of results

## Selective mass scaling - usage

- Selective mass scaling can be performed on the entire model or a subset of parts
- Selective mass scaling and conventional mass scaling can run together in the same model
- Selective mass scaling is activated using a single parameter on *CONTROL_TIME STEP

# Steering wheel example

- Steering wheel impacted by body block
  - Solid elements dt< 0.1 microseconds
- Simulation times to 50 ms
  - 5.5 hours with mass scaled such that dt=1.e-07
  - 0.7 hours with selective mass scaling dt=1.e-06



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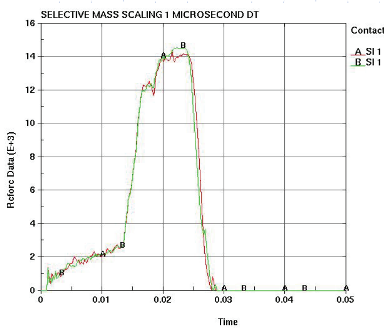
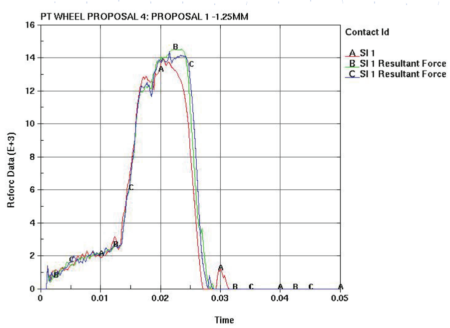
# Steering wheel example

- Comparisons between runs

Red: dt=1.e-06 SMS
Green: dt=1.e-07 CMS




Red: dt=2.e-06 SMS
Blue: dt=1.e-06
Green: dt=1.e-07 CMS

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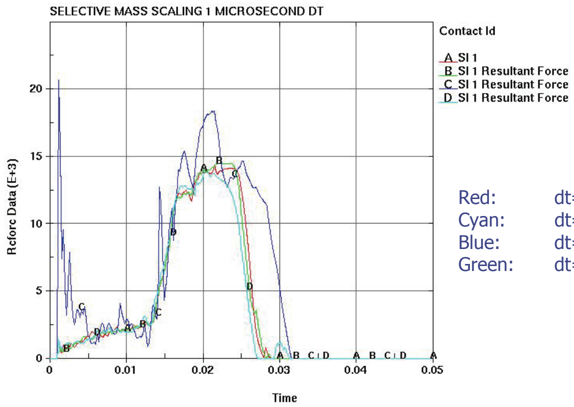
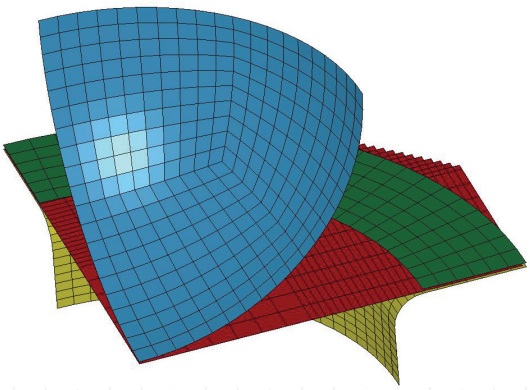
# Steering wheel example

◆ Conventional mass scaling with dt=2.e-06

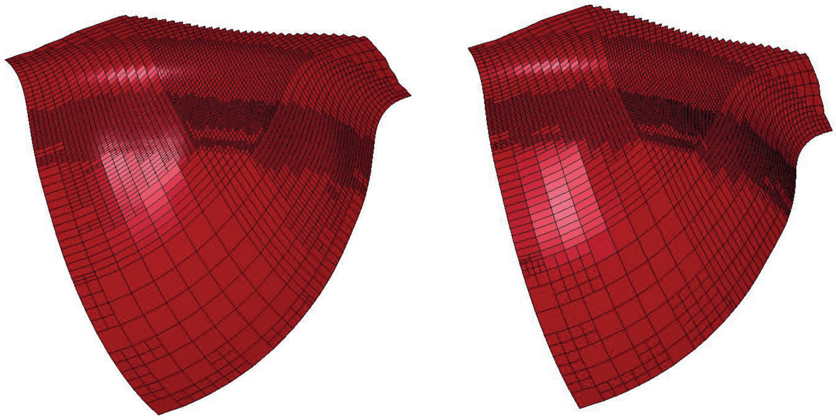



Red: dt=1.e-06 SMS
Cyan: dt=2.e-06 SMS
Blue: dt=2.e-06 CMS
Green: dt=1.e-07 CMS

# Example: Deep drawing



Illustrate efficiency improvement and preservation of accuracy and reliability of results



No mass scaling

22 min 6 sec

Selective mass scaling

1 min 50 sec

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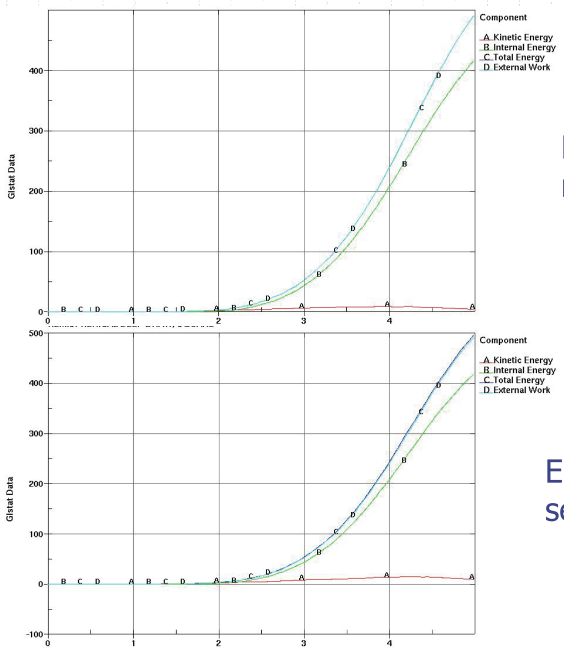


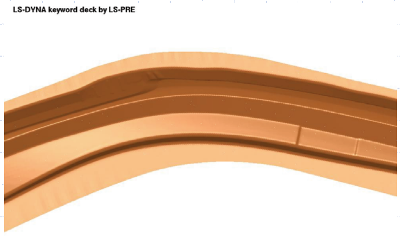

Energy balance – no mass scaling

Energy balance – selective mass scaling

# Selective mass scaling

- Example: Complex Rail
- Final Element #: 350k




| | Case1 | Case2 |
|---|---|---|
| CPU Time | 35 hours | 16 hours |

Case1: Conventional mass scaling, dt=-0.6E-06
Case2: Selective mass scaling, dt=-0.6E-05

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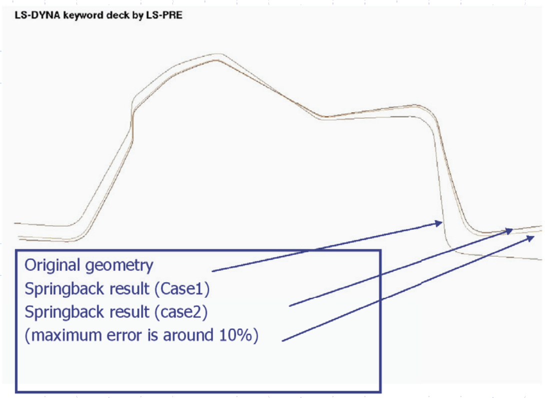
# Selective mass scaling

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## Selective mass scaling - MPP

- Selective mass scaling requires the assembly of a consistent mass matrix
- Either a direct or iterative solver can be used to solve for the accelerations
- For best efficiency this solution must be performed in parallel.
  - A parallel solution is implemented and is now working

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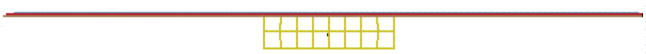
## Particle method for airbag deployment simulations

Complementing the uniform pressure and Eulerian/ALE methods



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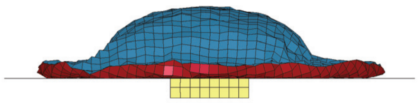
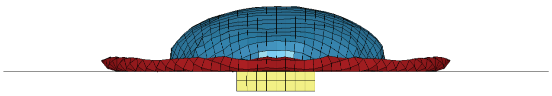
## Particle method for airbag deployment simulations

Example: flat bag after 5ms compared to results from Eulerian and uniform pressure models

particle method



multi-material Eulerian and fluid-structure interaction



uniform pressure

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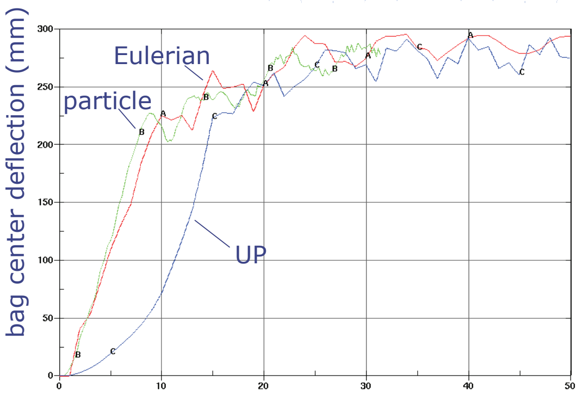
## Particle method for airbag deployment simulations

Example: airbag center deflection compared to results from Eulerian and uniform pressure models

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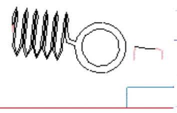
## Particle method for airbag deployment simulations

straightforward handling of folded bags



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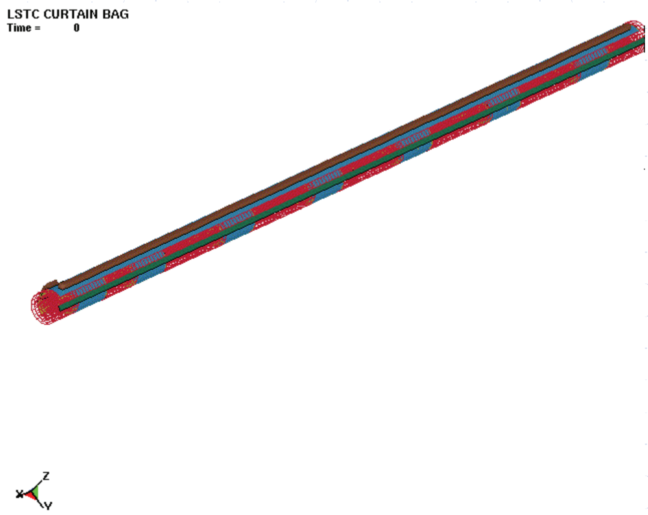
## Particle method with curtain bag

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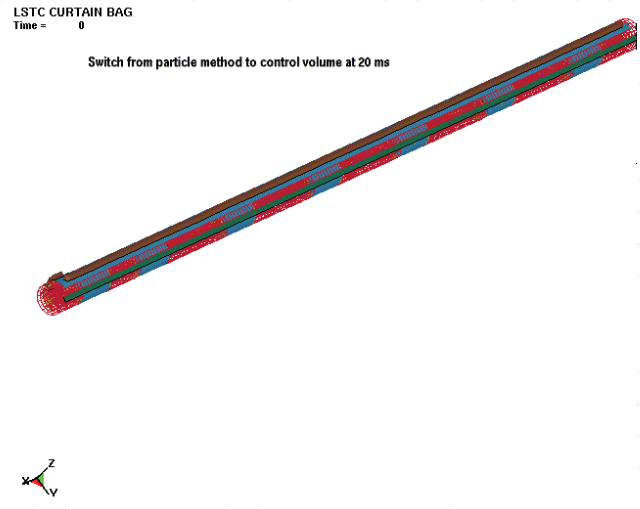
## Particle method with curtain bag with switch to cv at 20ms




## Extended formats

- Customer requests for extended formats are increasing since 8 character IDs are too restrictive
  - All keyword formats are being optionally extended
    - 2 cards will be read for each existing card
    - I10 > I20, I8 > I16, E10.0 > E20.0
    - Mixed default and extended formats will be read
    - Structured input will uniformly go to I20 and E20.0
  - Current formats are being kept and all changes will be backwards compatible.
    - All old input files, both structured and keyword, will be read.
  - New formats are being added to 971_R3 for early release since preprocessors need to be updated. A 2-5 year lead time is expected.

# EFG developments

1. EFG Mixed Transformation Method and Fast Transformation Method
2. 3D EFG Adaptivity
3. Lagrangian-Eulerian Kernel Switch
4. EFG E.O.S. Materials
5. Explicit EFG Shell Formulation
6. EFG MPP Version

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# EFG Transformation Method

- Two methods were implemented to improve the EFG efficiency
  - Mixed Transformation Method is equivalent to the original EFG Full Transformation Method in ls970 with improved efficiency
  - Fast Transformation Method does not require the inversion and multiplication of the transformation matrix in the nonlinear problems
- Both methods generate similar results
- Available for 4/6/8-noded background elements
- General efficiency performance

| Method | FEM | EFGls970 | Mixed Transformation | Fast Transformation |
|---|---|---|---|---|
| Normalized CPU | 1.0 | 7~20 | 5~10 | 3~5 |

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# 3D EFG adaptivity

- Motivation
  - To improve the large deformation analysis with a controlled accuracy
- A second-order accurate remap algorithm
  - Is Meshless
  - Is monotonic
- 3-5 times slower than FEM
- Allows to coupling with the thermal solver
- Implicit analysis is under testing
- Current Practice
  - Solving forging and extrusion problems

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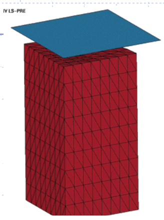
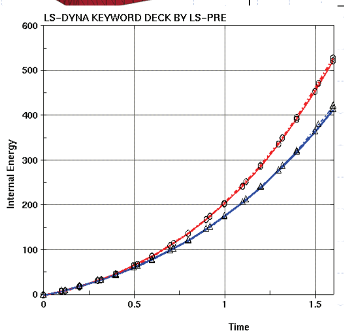
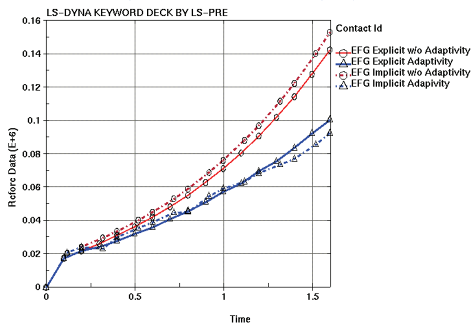
# 3D EFG adaptivity



EFG Fast Transformation Method
Mesh-free interpolation for data transfer

Initial Temperature 20 $^0$C
Low carbon steel Ck105

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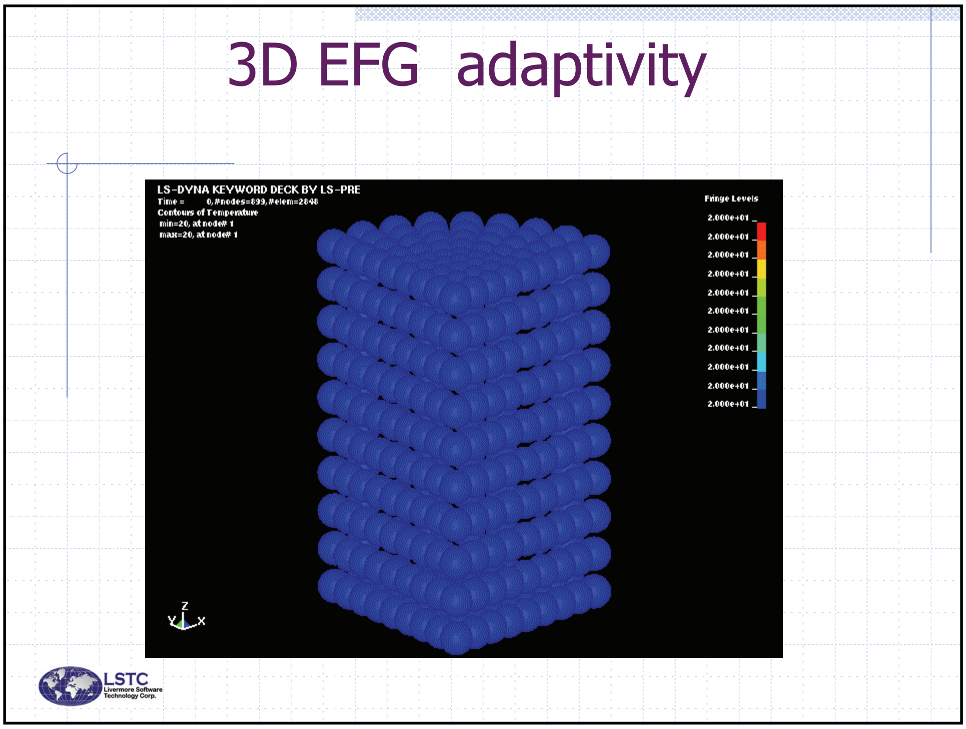
3D EFG adaptivity
LS-DYNA KEYWORD DECK BY LS-PRE
Contours of Temperature
Fringe Levels
LSTC
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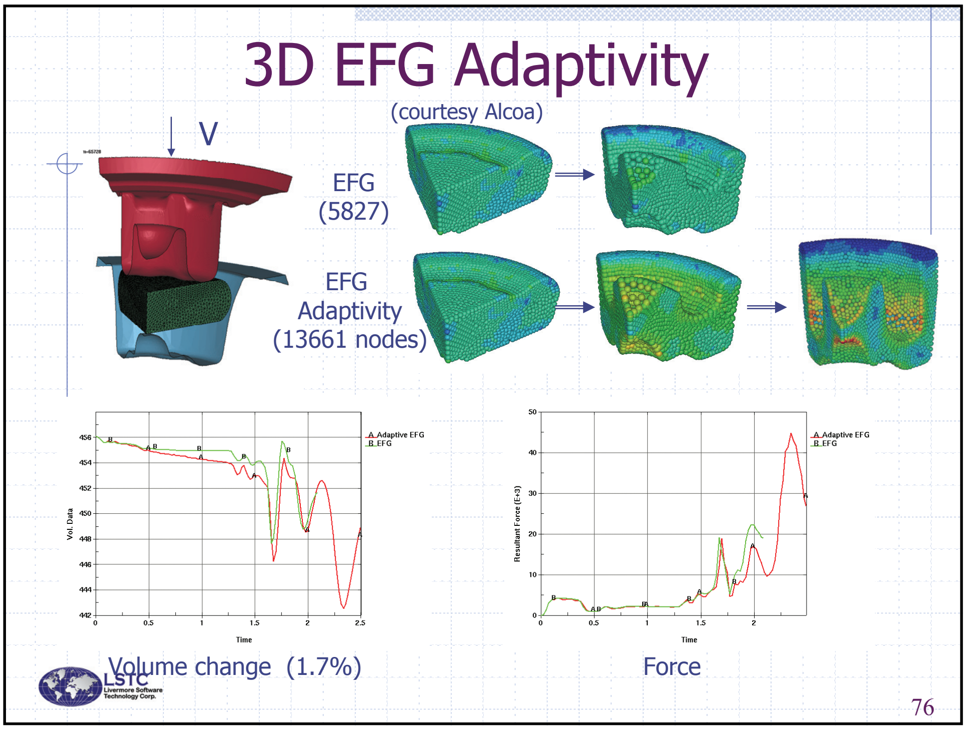
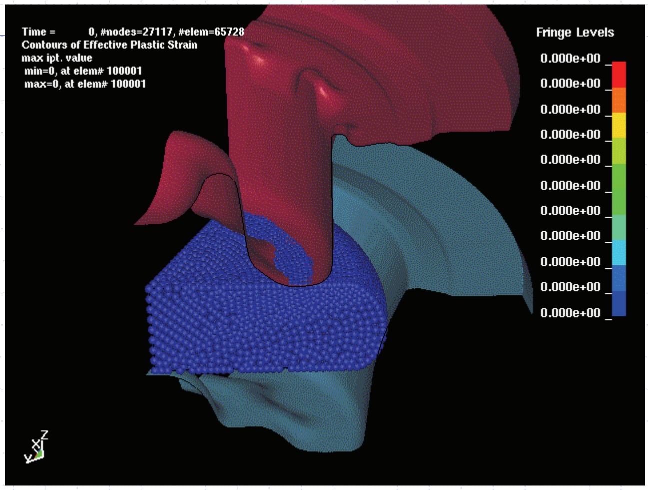

3D EFG Adaptivity
(courtesy Alcoa)
V
EFG
(5827)
EFG
Adaptivity
(13661 nodes)
Volume change (1.7%)
Force
LSTC
Livermore Software Technology Corp.
76

# 3D EFG adaptivity

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# Lagrangian-Eulerian kernel switch

- Motivation
  - To improve the large deformation analysis that is beyond the Lagrangian description
- Is a user-defined kernel switch
  - A gradient-based indicator for the switch from the Lagrangian kernel formulation to the Eulerian kernel formulation
  - Reconstruct the neighboring information based on the Moving-least-squares approximation from the current configuration
- Total number of EFG nodes are fixed
- Available for 4/6/8-noded background elements
- Current Practice
  - Highly compressible foam materials

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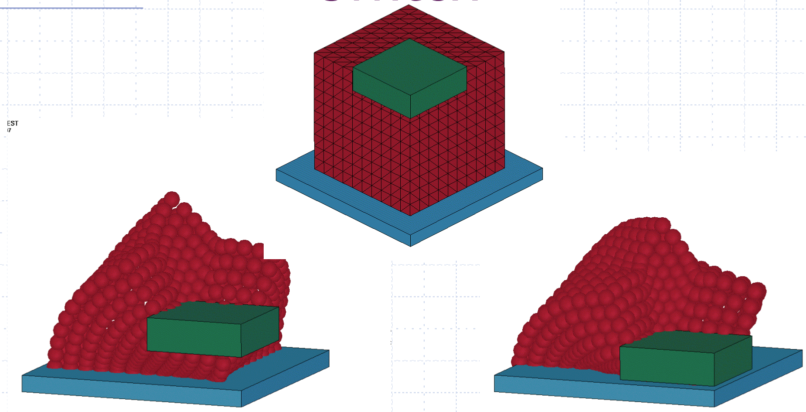
## Lagrangian-Eulerian kernel switch



Original EFG (ls970)
80% compression

EFG + Kernel Switch
95% compression

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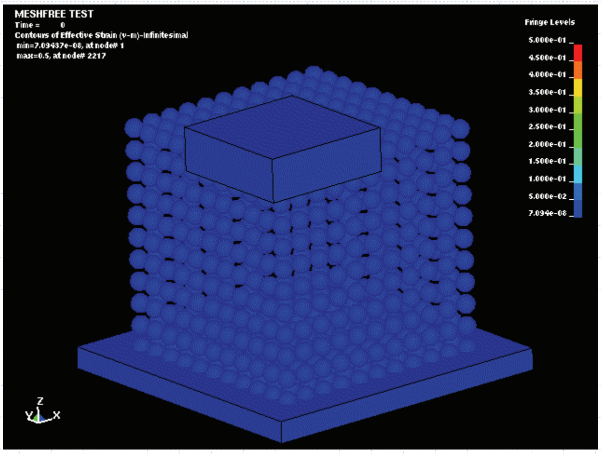
## Lagrangian-Eulerian kernel switch

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## Explicit mesh-free shell formulation

- Based on the mesh-free surface representation and the mesh-free shell formulation
  - First-order shear deformable shell theory is adopted
  - An assumed strain method is utilized
- Work well for the membrane and bending-dominant problems, and mesh can be highly irregular
- Can be applied to the composite materials
- 2-4 times slower than FEM #16

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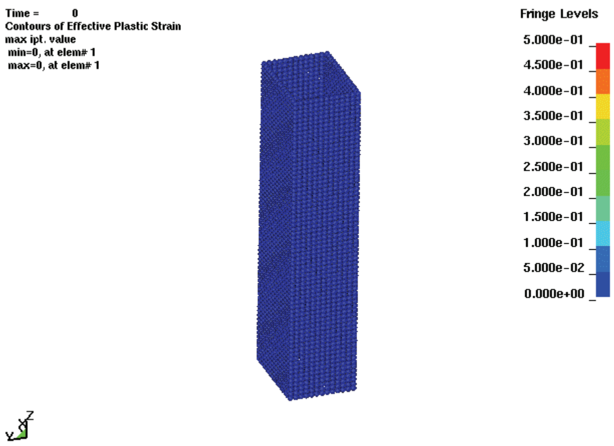
## Explicit mesh-free shell formulation

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# IMPLICIT

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# Distributed Memory Parallel Eigensolver

- Block Shift and Invert Lanczos Algorithm was developed at Boeing during the mid-1980's.
- Used throughout the FEA industry.
- LSTC uses Boeing's Lanczos software in serial and SMP in LS-DYNA.
- LS-DYNA 971 has the only distributed MPP Lanczos implementation in the FEA industry.
- Same robust results as Serial and SMP version.

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# The Eigen Problem

$$K\Phi = M\Phi\Lambda$$

$$\text{subject to} \quad C\Phi = 0$$

| | |
|---|---|
| $K$ | FEM Stiffness Matrix |
| $M$ | FEM Mass Matrix (block diagonal) |
| $\Phi$ | Eigenvectors (mode shapes) |
| $\Lambda$ | Eigenvalues (modes) |
| $C$ | Linearized constraint matrix |

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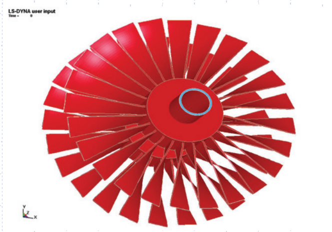
# Example

- Model of jet turbine fan blades
  - 2 sets of fan blades on a common shaft
  - 24 fan blades on each
  - Lots of eigenvalues with multiplicity 48
- Requested the smallest 100 eigenvalues.
- 700K nodes, 2.06M dofs, 70M nonzeroes in lower triangle of K.



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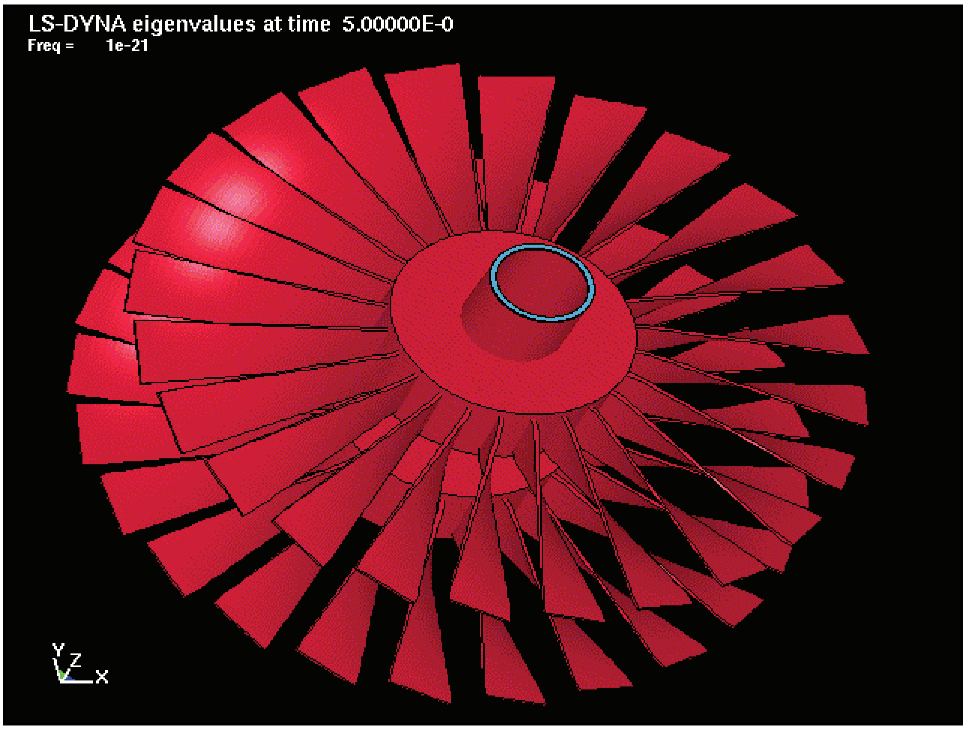
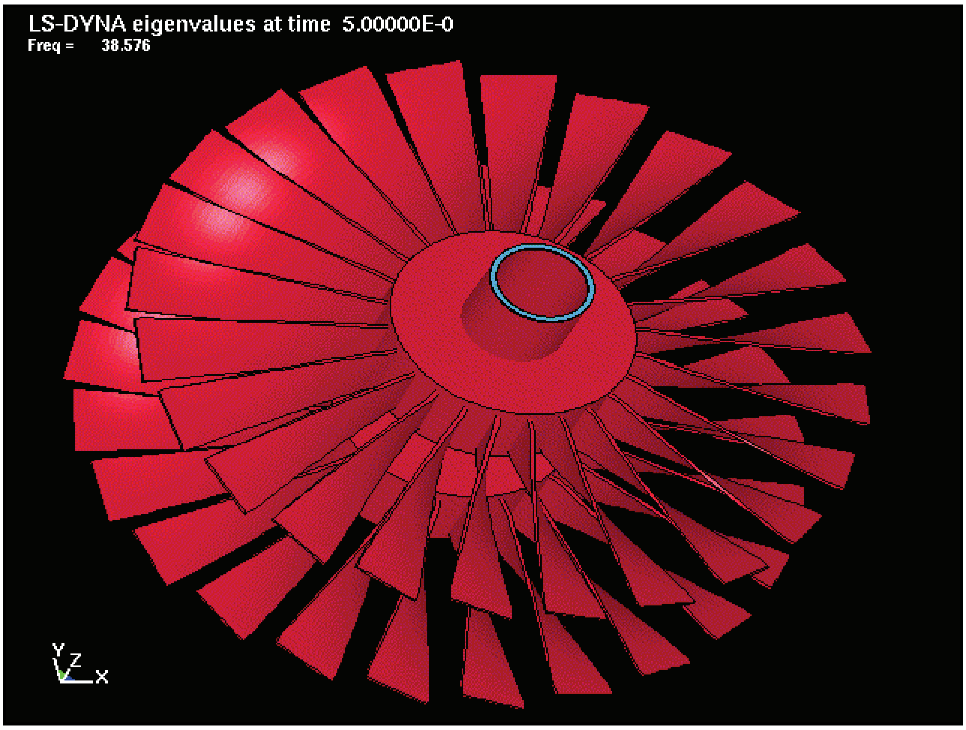

LS-DYNA eigenvalues at time 5.00000E-0
Freq = 1e-21
Y
Z
X


LS-DYNA eigenvalues at time 5.00000E-0
Freq = 38.576
Y
Z
X

# Test Environment

- Cray XD1
  - 12 nodes / 24 cpus
  - 192 Gbytes memory
- 1, 2, 4 and 8 process runs used 16 Gbytes per process and one process per node.
- 16 process runs used 8 Gbytes per process with round robin assignment of process to node.

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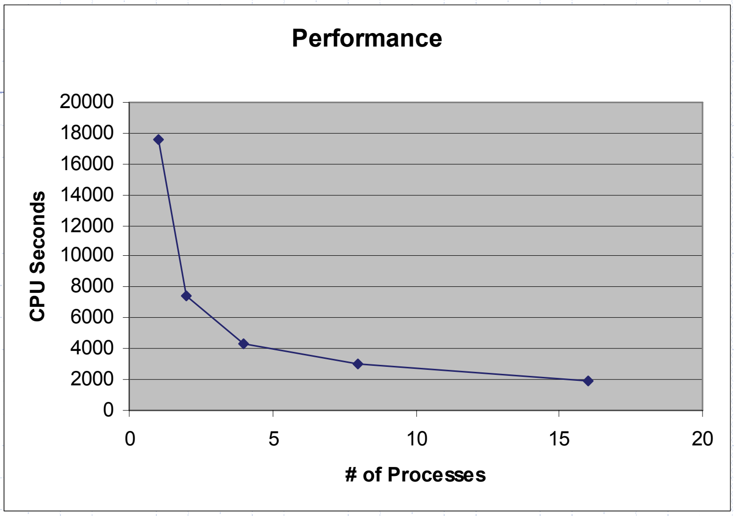


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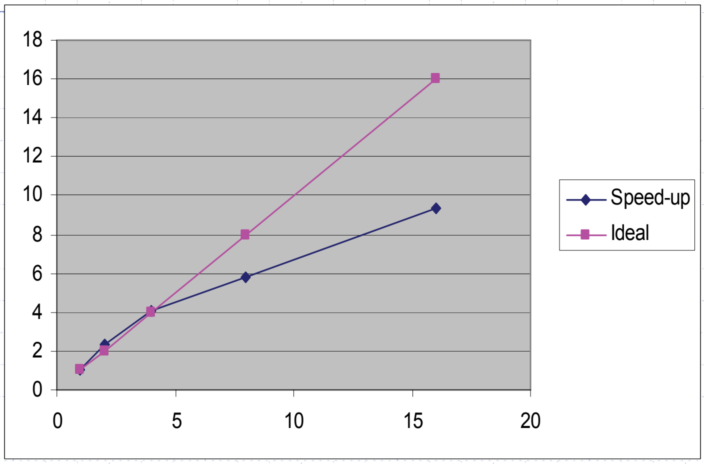
## MPP Eigensolver Speed up

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## Conclusions

- Version 971 has become a major release with many new capabilities that focus on the automotive industry
  - MPP implicit
  - ALE is at production level for out-of-position occupant analysis
  - EFG is implemented for scalable MPP applications
- Significant progress has been made to include most crash capabilities within the implicit solver
- LSTC's software development goal continues to be the implementation within one scalable code of all capabilities required to solve problems that involve, multi-physics, requiring multiple-stages, running on large clusters of processors.
- Full compatibility with linear structure models leading to a one model environment

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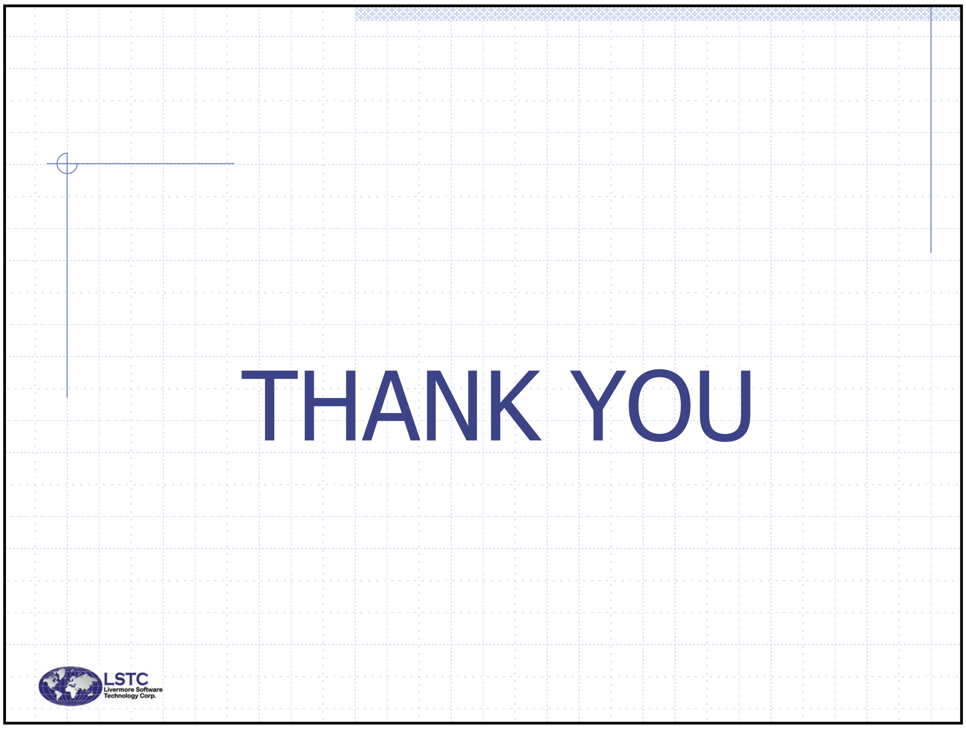
THANK YOU
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