# Recent Developments in LS-DYNA – II

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# LS-DYNA®-Development

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# Implicit update

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# MPP implicit

- MPP Implicit is working well.
  - Time for factorization and solves are scaling very well
  - There are scalar memory bottlenecks in MPP Implicit that are not in explicit. They show up on problems with millions of nodes and hundreds of cores. We are working to reduce them.
  - Hybrid parallel implementation is working

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# GPU for sparse solver

- LSTC has been monitoring GPUs for six years. A study in 2007 showed potential benefits but
  - Small memory made the GPU hard to use
  - Slow communication to and from the GPU made it appear unsuitable for explicit computations
  - Double Precision IEEE arithmetic was not available making it unsuited for Implicit Mechanics
- However, the study showed there was a potential substantial benefit for implicit mechanics
- We have been waiting for the C2050 Fermi GPU
- Nvidia made 2 Fermi boards available to LSTC in 2Q2010

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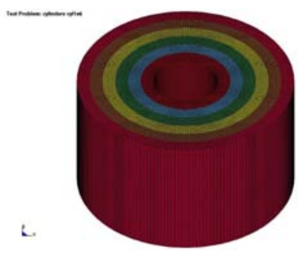
# GPU for sparse solver

- The dominant cost for large Implicit Mechanic problems is the numeric factorization of the global stiffness matrix.
- A direct factorization based on the Multifrontal method is used in LS-DYNA
  - Iterative methods are unreliable on shell element problems
- We have implemented this core computational unit
  - Rewrote the production Fortran to CUDA
- The implicit GPU capability is planned for a later release. LS-DYNA will detect the GPU and use it automatically when a speed advantage is obtainable

# AWE benchmark test problem



- Result
  - 154K solid elements
  - 173K nodes
  - 1 factor, 1 solve
  - CPU (1 core) time was 656 seconds
  - CPU + GPU time was 300 seconds
- Factor of 2+ speed up

# *Control_implicit_linear_parts

- A new implicit capability where parts are represented by a linear model based on
  - Constraint modes
  - Attachment modes
  - Eigen modes
- An extension to implicit of the explicit *PART_ MODES capability

his feature can reduce computational cost ssociated with large implicit models.

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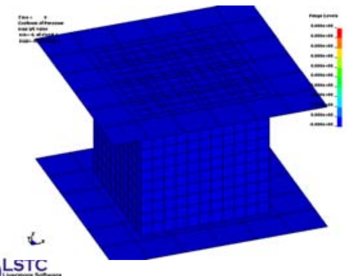
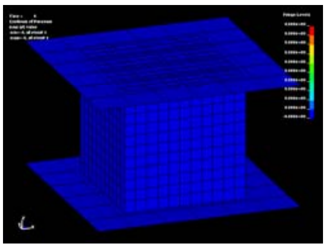
# *Control_implicit_explicit_hybrid

- Implicit-explicit hybrid capability recently implemented
- One time step size for entire model based on explicit elements
  - Use implicit solver on highly refined parts that drastically lower the explicit time step size
  - Equilibrium iterations each time step are used to ensure convergence

Explicit



Implicit Solid



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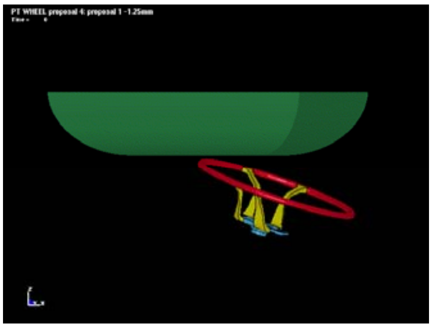
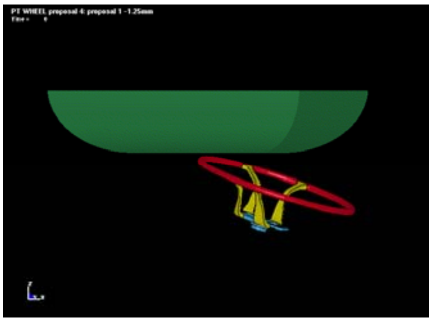
# *Control_implicit_explicit_hybrid

Body block impact using Mortar contact option for IEH

**SMS Explicit**



**Explicit with implicit steering wheel**



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# *Control_implicit_forming

**Application to roof crush**

- One step – gravity loading applications
- Multiple steps – roof crush etc
- Contact influences the time step size to improve convergence
- Internal logic scales inertia forces without altering static solution

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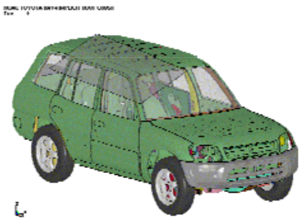
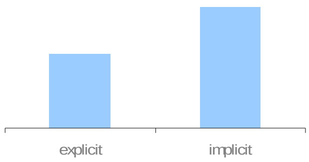
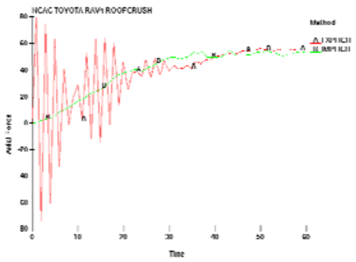
## Roof crush Rav4



| | |
|---|---|
| 478K | elements |
| 478k | nodes |
| 1 | contact |

16CPU




## Version 971_R5

# Adaptive EFG in forging

- Use 4-noded integration cell.
- Multiple meshfree formulations are available.
- Interactive adaptivity for efficiency as well as accuracy.
- A second-order interpolation scheme for state variables
- Pressure projection to improve accuracy.
- Includes global/local adaptive refinements.
- Including thermal solver.
- Available in SMP and MPP.

# New features in R5 adaptive EFG

Meshfree Interactive Adaptive Method

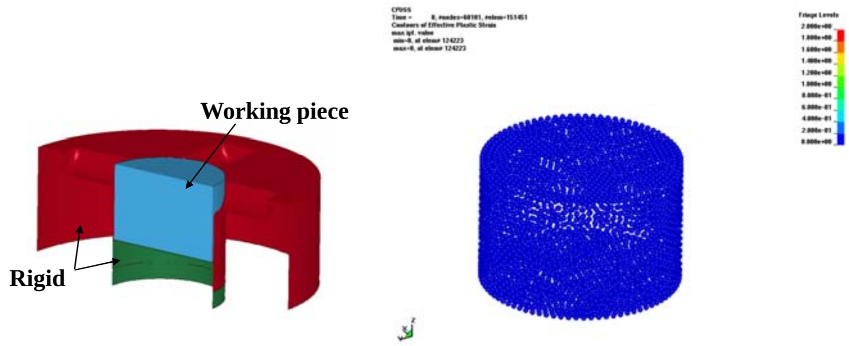
Dynamically detect distortion and maintain the quality of EFG discretization.

Three indicators were implemented to detect distortion including shear deformation, nodal distributions, and volume change.

More efficient than non-interactive adaptivity using constant interval method.

More robust than non-interactive adaptivity in large strain analysis.

# Cross joint extrusion




Interactive adaptivity is triggered only when distortion is detected by indicators.

**( Courtesy of JSOL)**

| Method | Conventional adaptivity | Interactive adaptivity |
|---|---|---|
| **Normalized CPU time** | 1.0 | 0.61 |
| **# of adaptive steps** | 40 | 22 |

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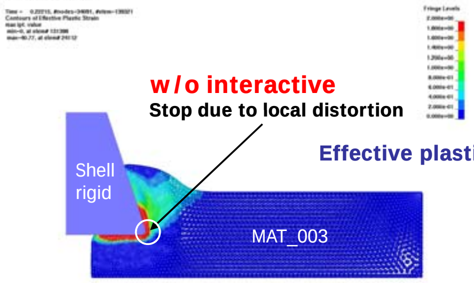
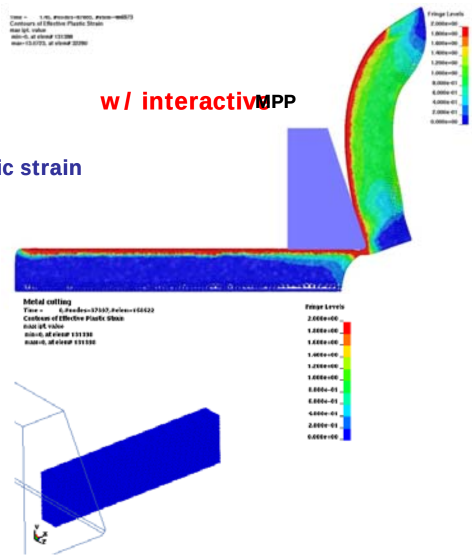
# Metal cutting simulation




A special surface reconstruction algorithm is developed for metal cutting analysis.

Interactive adaptivity is able to detect distortion that occurs frequently and irregularly in metal cutting analysis.

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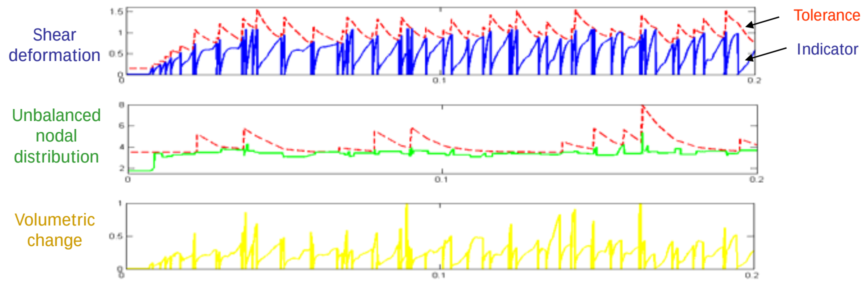
# Metal cutting simulation

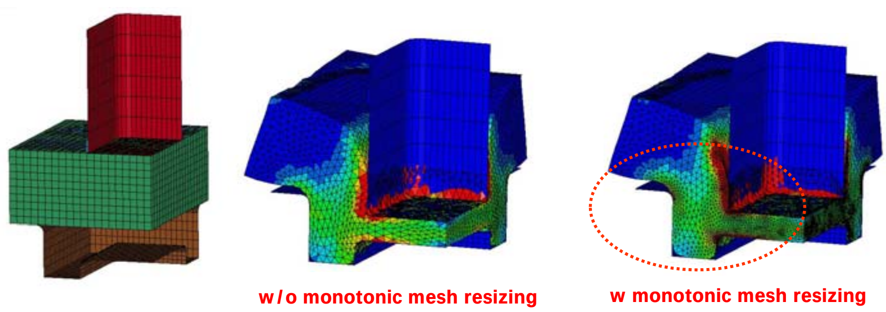
History of error indicators in cutting simulation




# New features in R5 adaptive EFG

## Monotonic Mesh Resizing

- No mesh coarsing effect
- Do not depend on the contact curvature
- Capture high gradient and maintain high density grids in local areas



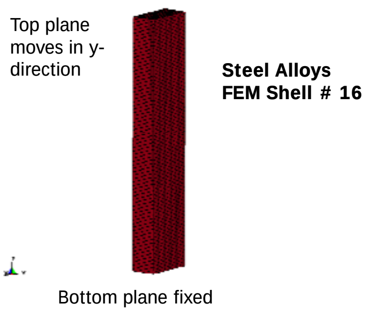

Contour Effective Plastic Strain 0 ~ 3.5

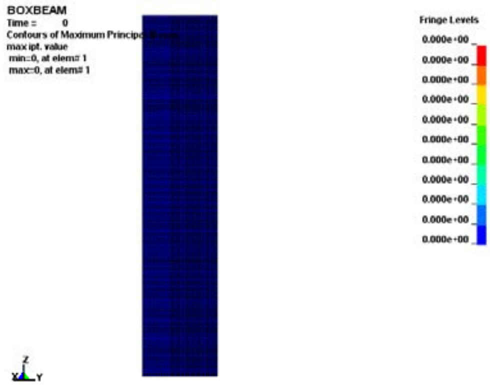
 

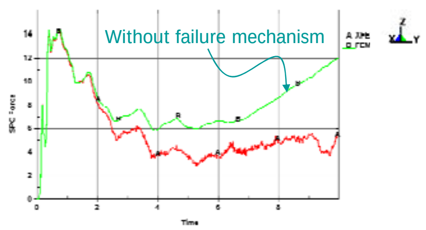
# XFEM in fracture analysis

- Uses strong discontinuity approach (discontinuity in displacement).
- Crack initiation and propagation are governed by cohesive law.
- Crack is defined by level set.
- Implemented for FEM shell #16.
- Minimized mesh sensitivity and orientation effects.

# Failure of box beam using XFEM




(Courtesy of GM)

# Airbag particle developments

- *Initial_airbag_particle
  - Initialize pressure in a closed volume
    - Airbags
    - Door cavity for pressure sensing studies
    - Tires
- Multi-chamber airbags
- Joule-Thomson effects

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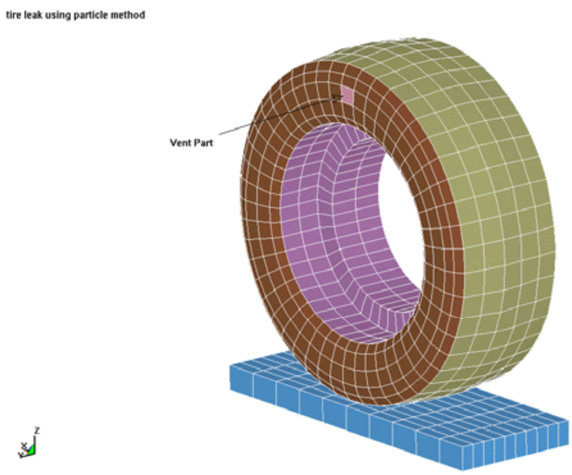
# *Initial_airbag_particle

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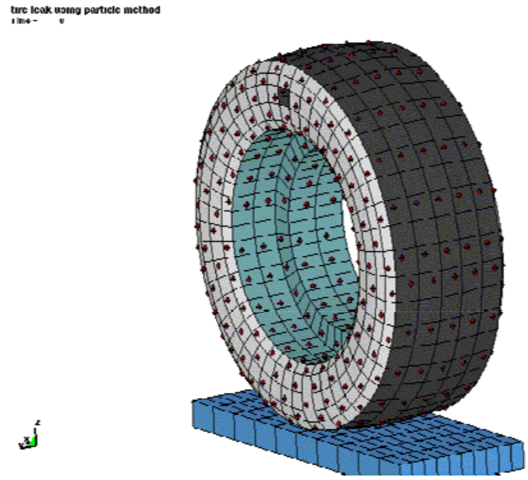
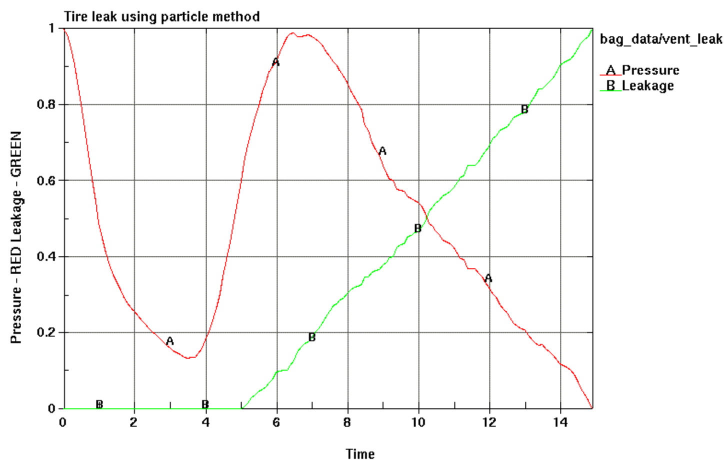
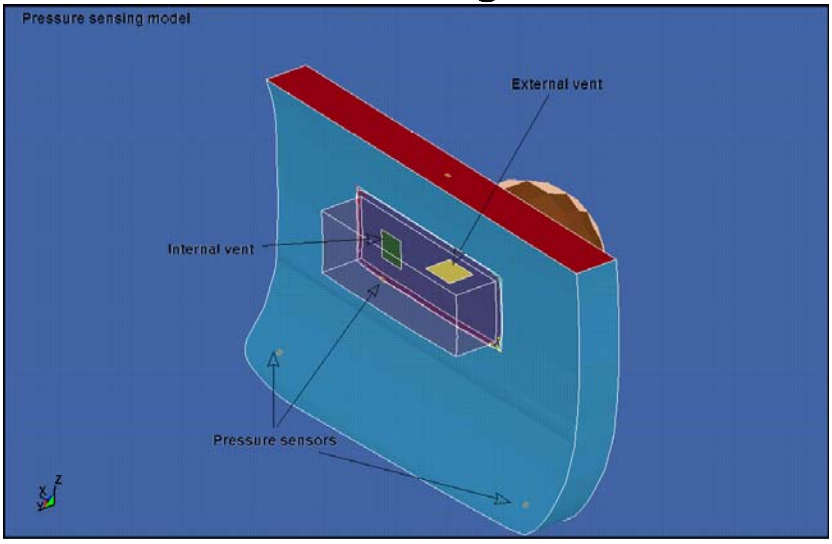
# *Initial_airbag_particle



# *Initial_airbag_particle



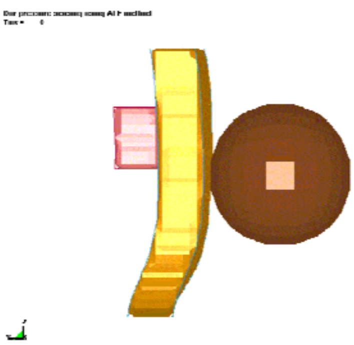
# Pressure sensing - sensors

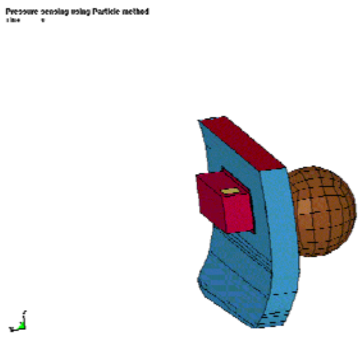



# Pressure sensing - sensors

ALE
195360 ALE elements
16 cpus 33 minutes

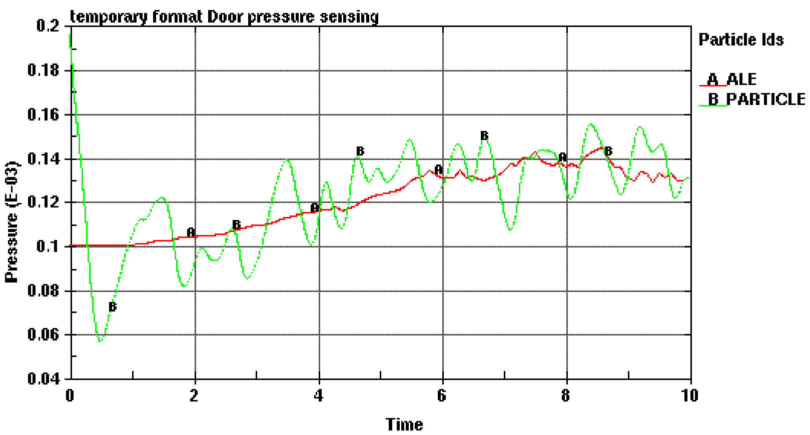
PARTICLE
50000 particles
16 cpus 4 minutes





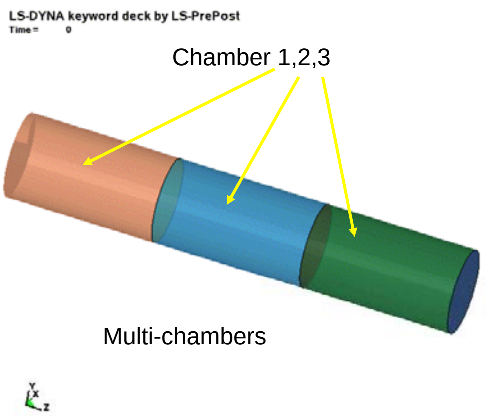
 

# Pressure sensing - sensors

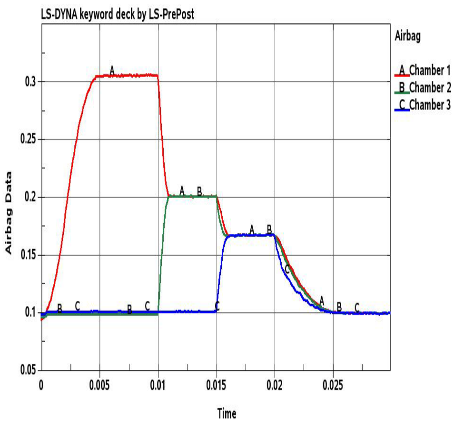



# Multi-chamber interactions

- Get pressure, temperature information from each chamber in the database: ABSTAT
- Better prediction of gas behavior and vent flow rate by analyzing chamber data



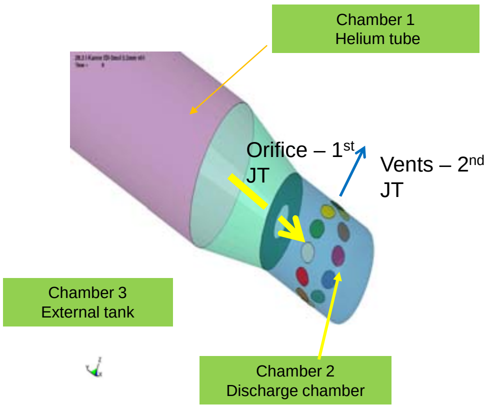

Multi-chambers



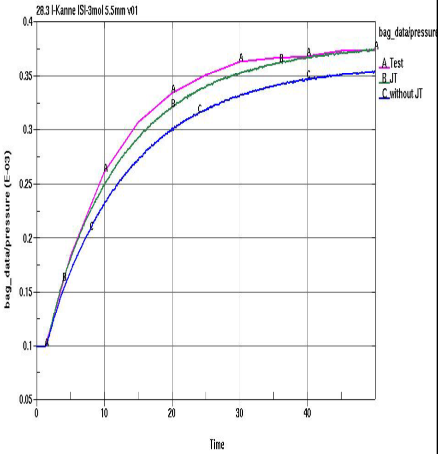

ABSTAT from each chamber

# Joule-Thomson effect

CPM can include negative Joule-Thomson effect which has significant effect for pressurized Hydrogen, Helium and Neon.(Courtesy of Andreas Hirth)



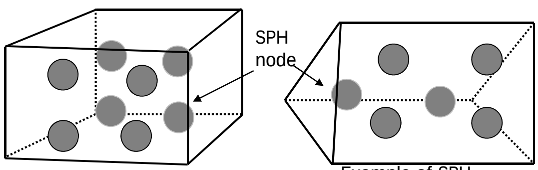

Helium Tank Test




Tank pressure compared with test

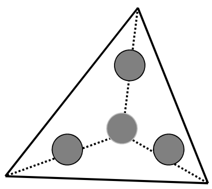
# Adaptive solid to SPH

- When solid elements fail, SPH elements replace the failed solids.
- The new SPH particles inherit the properties of failed solids.




Example of SPH nodes for Hex element with NQ=2

Example of SPH nodes for Wedge element with NQ=2

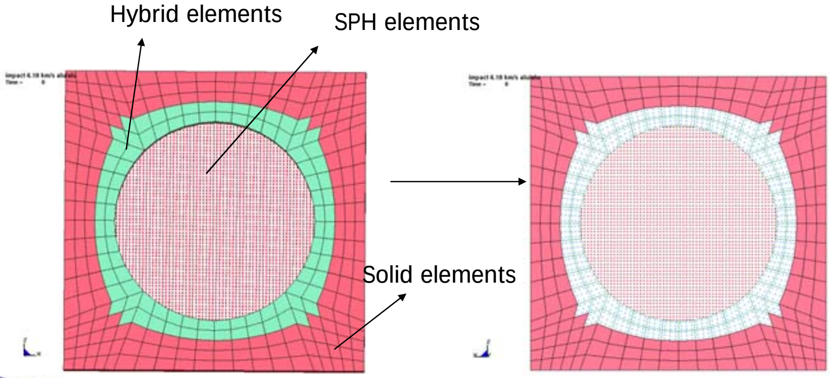


Example of SPH nodes for Tet element with NQ=2

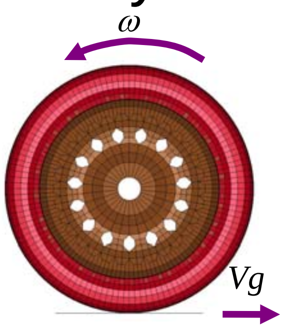
# Hybrid element couples SPH to solid

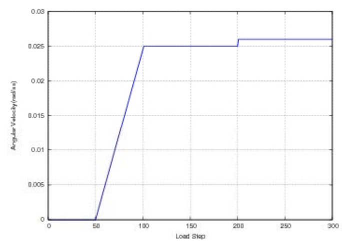
**Hybrid element**: Solid elements constrain SPH nodal locations. SPH elements provide "penalty force“ against solid nodal motion. Hybrid elements are used as transit layers between SPH elements and Solid elements.

**Advantage**: we have the SPH formulation which can endure quite large deformation and at the same time we have the Solid mesh which clearly describes the material interface.




# Steady state rolling development




**SSR**

- Load Curve are defined on *LOAD_STEADY_STATE_ROLLING card
- Elements don’t rotate

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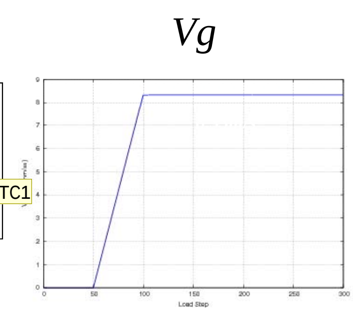
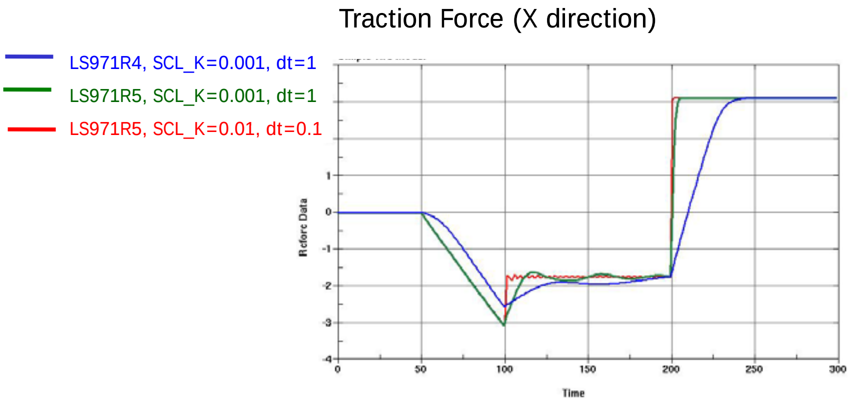


# SSR resultant contact force




- ➢LS971R4: Traction force and deformation at footprint couldn't be stable
- ➢LS971R5: If using small SCL_K , easier to converge, resultant force slightly unstable
- ➢LS971R5: If using large SCL_K, more difficult to converge, one has to use small time step to guarantee convergence, SSR can get stable result quickly.

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# *Mat_rigid_discrete or *Mat_220

- Eliminates the need to define a unique rigid body for each particle when modeling a large number of rigid particles
- Large reduction in memory and wall clock time over separate rigid bodies
- A single rigid material is defined which contains multiple disjoint pieces. Input is simple and unchanged, since all disjoint rigid pieces are identified automatically during initialization.
- Each rigid piece can contain an arbitrary number of solid elements that are arranged in an arbitrary shape.

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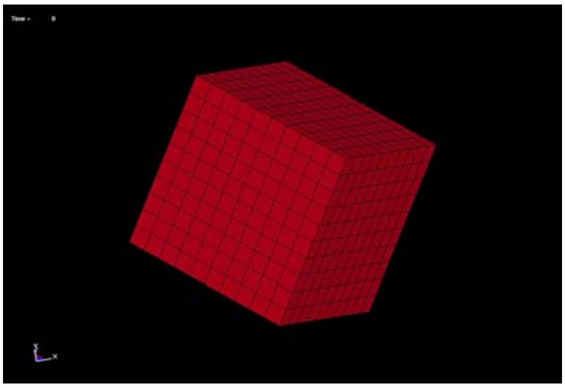
# *Mat_rigid_discrete

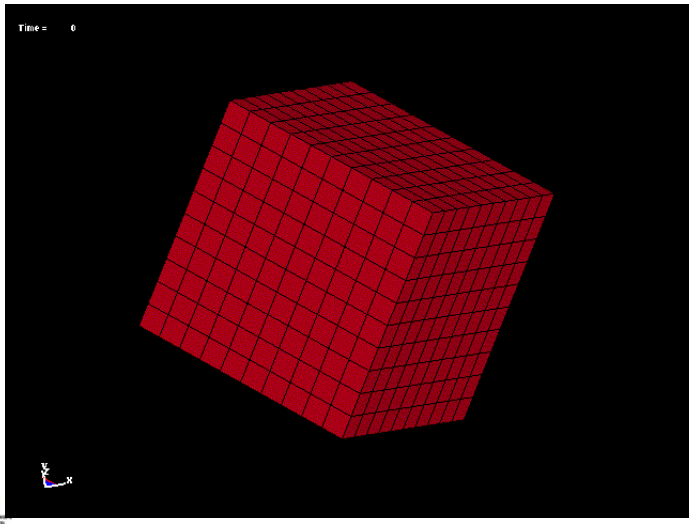
- Rigid body mechanics is used to update each disjoint piece of any part ID which references this material type.
- Can be used to model granular material where the grains interact through an automatic single surface contact definition.
- Another possible use includes modeling bolts as rigid bodies where the bolts belong to the same part ID.

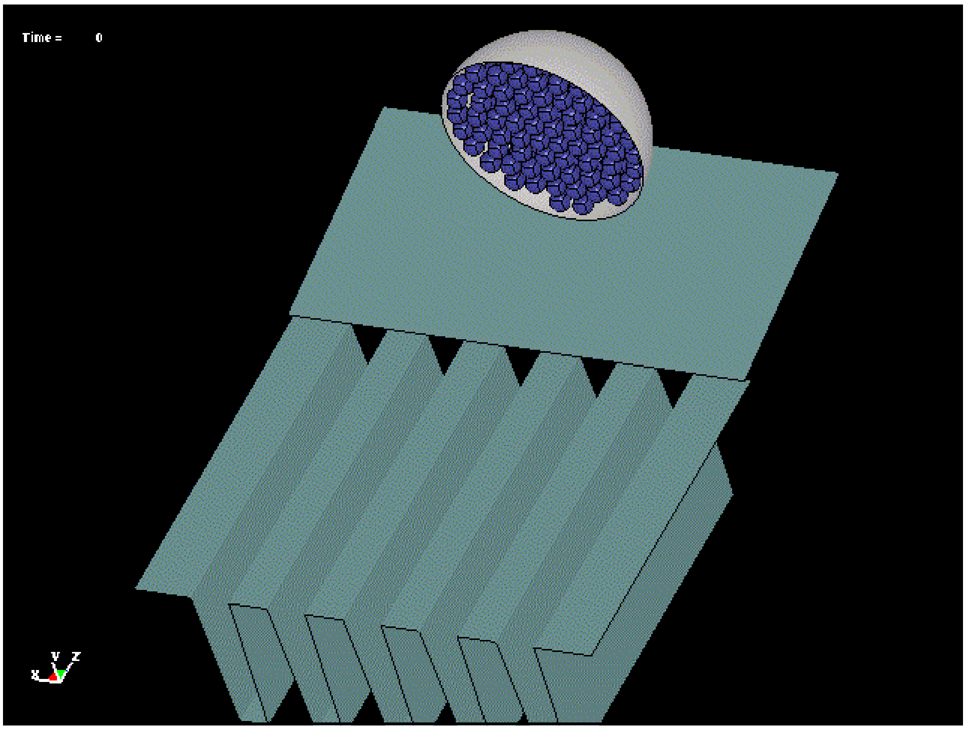
# Example, Mat_220

- Block of 1000 bricks impacted by rigid wall
- One part ID, containing 1000 rigid bodies



# Example – block of 1000 bricks





# Compression folding

- Accurate compression folding of airbags is available with segment based contact (SOFT=2).
- New options were added:
  - Quad segment splitting
  - Shell penetration reporting
  - Neighbor segment contact check

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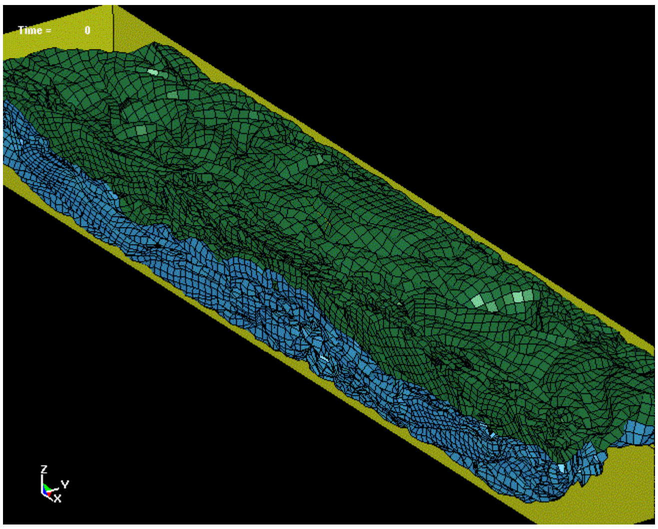
# Compression folding



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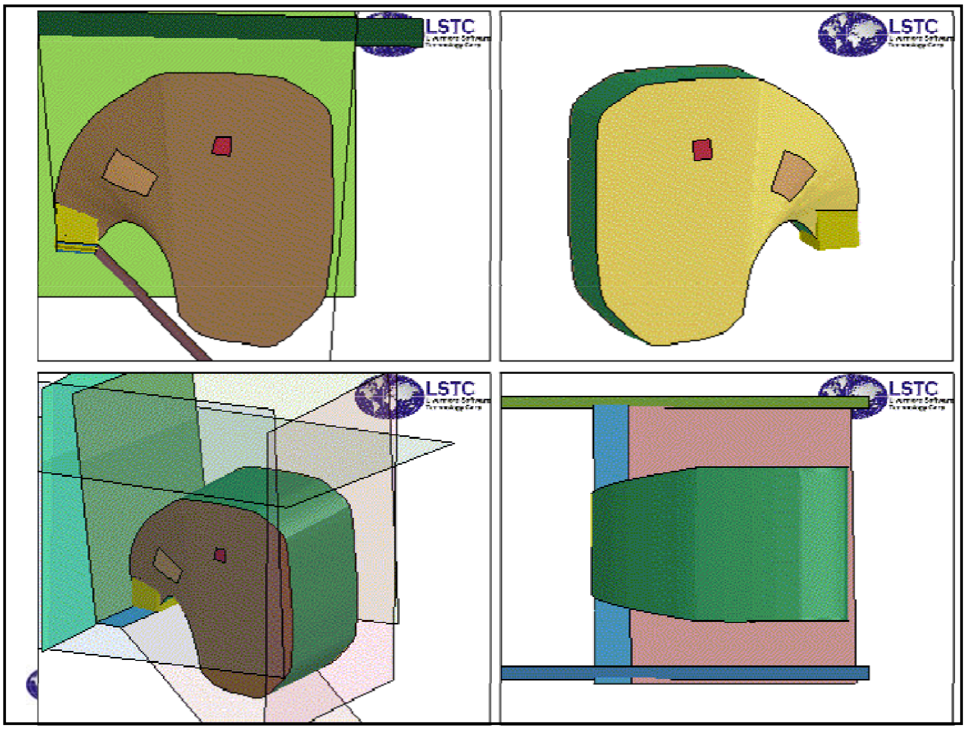

## Multiscale spotwelds

- New development requested by 3 OEM's.
- Because of the way work is distributed and communication is performed, only the MPP version of the code has the capability to support multiscale features
- In the long term, extensions to this option will encompass a wide range of multiscale applications

# Multiscale spotwelds

- Allows the users to create their own detailed models of the spotwelds and accurately compute their failure during a crash simulation.
  - All LS-DYNA material/failure models, including user defined, are available for these predictions
- The finely meshed welds are run in a separate process at a much smaller time step.
- A near perfect load balance is achieved since all processors are shared with the vehicle model

# Multiscale spotwelds

- The user creates one or more detailed models of their spotwelds, and includes these definitions in their model via the keyword:
  - *INCLUDE_MULTI-SCALE_SPOTWELD
- The user then indicates which spotwelds should be coupled to these models with a SET_....._ LIST and the new keyword:
  - *DEFINE_SPOTWELD_MULTISCALE

# Multiscale spotwelds

- When MPP-DYNA is started, a special invocation is required to run in a "multiple program" mode sharing the same processors
- The root processor of the master group, running the full model, creates solid spot welds for the slave group in the location and orientations necessary.
- Each cycle the master group communicates to the slave group the deformations of the areas surrounding the coupled spot welds.

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# Multiscale spotwelds

- The slave group imposes these deformations on the detailed models, and checks for failure
- Coupled spotwelds in the master group have their failure determined solely by the failure flags, set by the slave group.

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# Frequency domain analysis

## Continuing developments

- Random vibration
- Frequency response function
- Steady state dynamics
- BEM Acoustics
- FEM Acoustics

# Conclusions: summary

- LSTC is working to be the leader in large scale numerical simulations
  - LSTC is providing dummy, barrier, and head form models to reduce customer costs.
  - LS-Prepost and LS-Opt are continuously improving and gaining more usage within the LS-DYNA user community
  - LSTC is actively working on seamless multistage simulations in automotive crashworthiness, manufacturing, and aerospace
  - The implicit solver is quickly gaining market acceptance for nonlinear implicit calculations and simulations
    - Robustness, accuracy, and scalability has rapidly improved
    - Combined implicit and explicit running together

# Conclusions: future

- LSTC is not content with what has been achieved
  - New features and algorithms will be continuously implemented to handle new challenges and applications
    - Electromagnetics,
    - Acoustics,
    - Compressible and incompressible fluids
    - Isogeometric elements
    - Discrete elements
  - Multiscale capabilities are now under development with initial release later this year
  - Hybrid MPI/OPENMP developments are showing significant advantages at high number of processors for both explicit and implicit solutions