Recent Developments in LS-DYNA – II

J. O. Hallquist

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Particle method

- Very similar input as Control volume input
- Venting and Porosity supported
  - Blocked and unblocked
- Internal baffles can be defined and flow through the baffles can be monitored
- Multiple inflators
- Switching between Particle method and the control volume approach
- 3 unit systems currently supported for ease of input.

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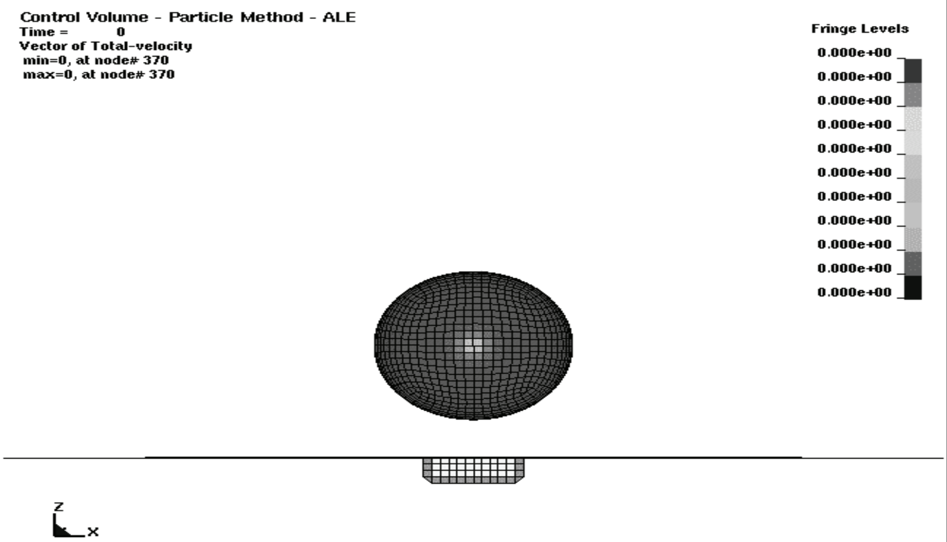
Control Volume – Particle Method - ALE



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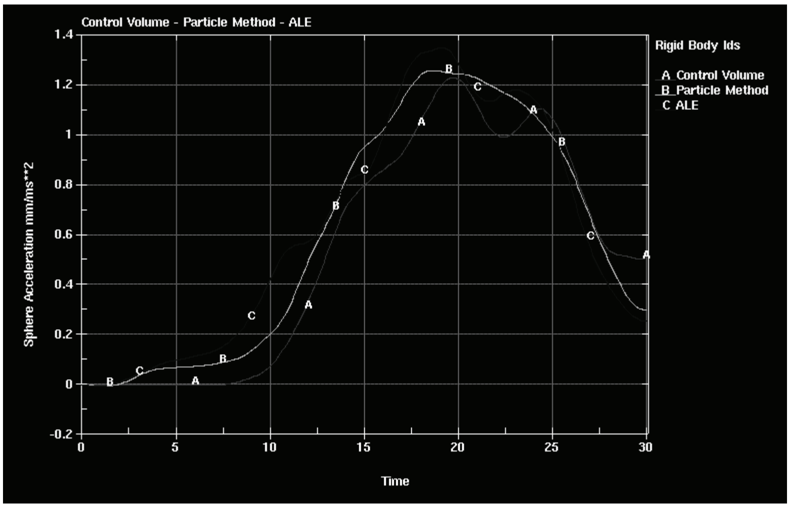
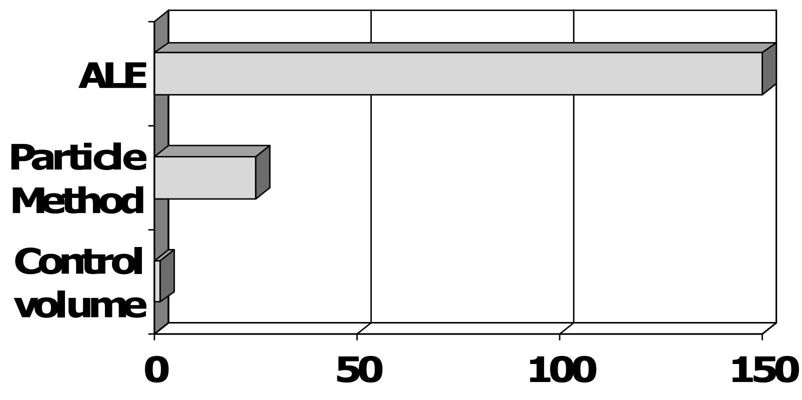
Control Volume – Particle Method - ALE



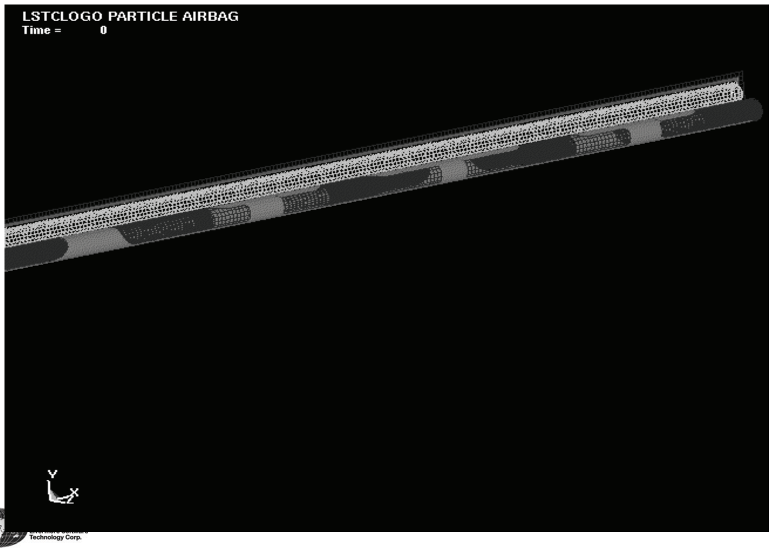
76

CPU minutes for 3 methods



77

Particle method curtain bag



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

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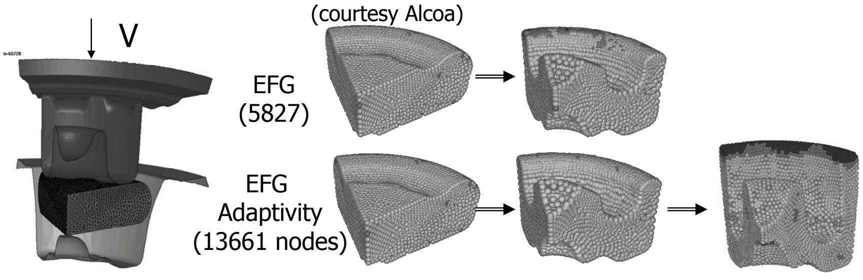
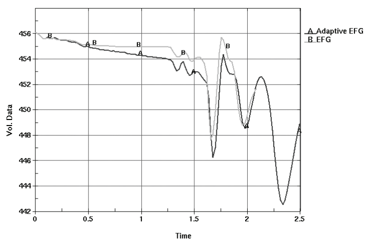
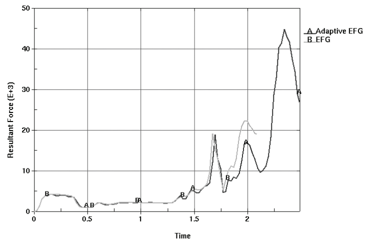
3D EFG adaptivity

(courtesy Alcoa)





Volume change (1.7%)



Force

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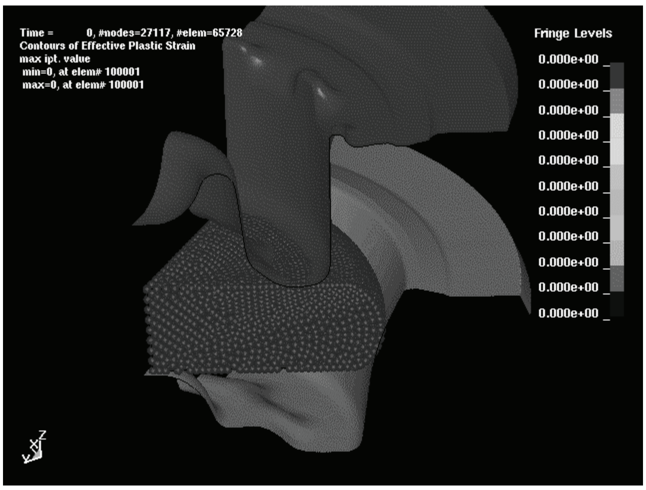
80

3D EFG adaptivity



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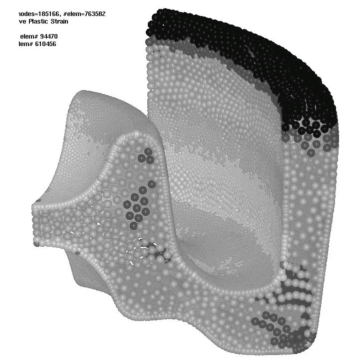
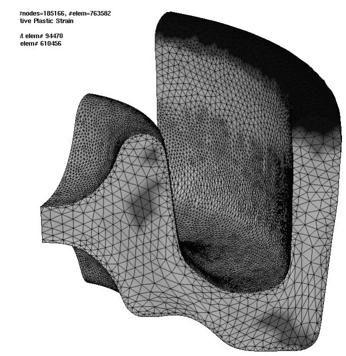
Wheel Forging Simulation



Final Nodes Distribution



Final Background Mesh

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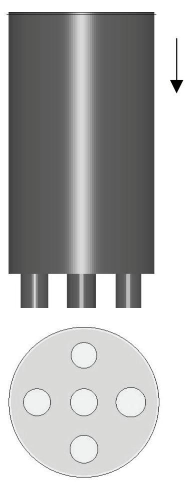
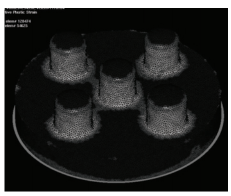
EFG extrusion simulation



Direct extrusion, Punch speed 4mm/s

Billet: Aluminum AA6082 $\phi = 137mm$

$\phi_{holes} = 24.66mm -- 28.48mm$



http://www.ivp.ethz.ch/Extrusion05/index.htm

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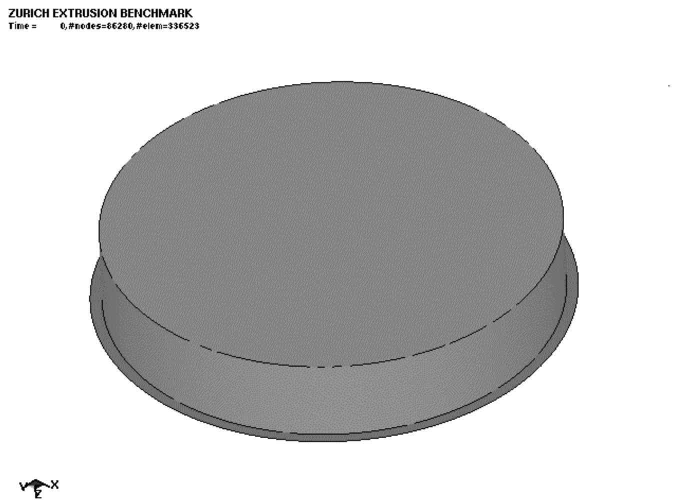
EFG extrusion simulation



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EFG with equations-of-state

- Based on the Partition of Unity approximation and Eulerian kernel formulation
  - With Stress Point Method (Dyka et al.1997) to avoid rank deficiency
  - With adjustable supports to prevent *tensile instability* in the Eulerian kernel
  - Consider convective velocity in the Eulerian kernel
- Read Finite Element mesh and mesh can be highly irregular
- Currently limited to the 4-noded background mesh

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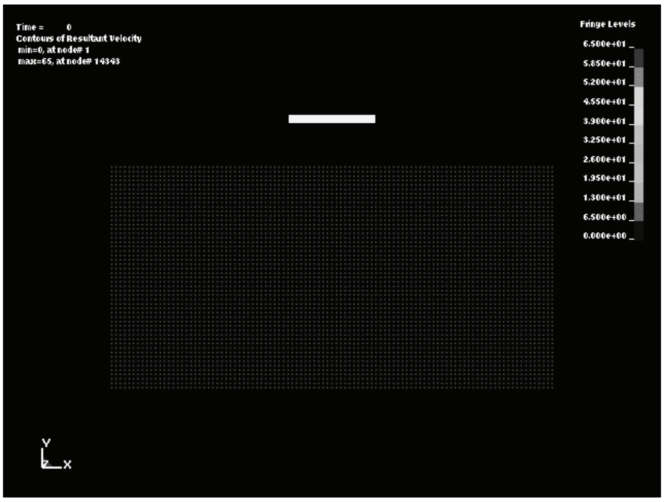
EFG with equations-of-state



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EFG with equations-of-state

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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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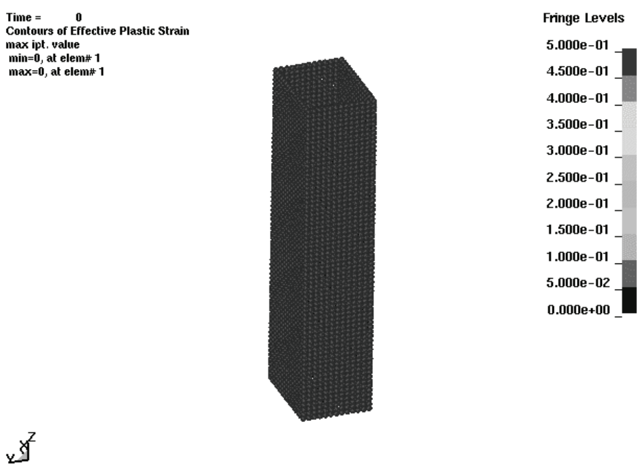
Explicit mesh-free shell formulation



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Gravity Loading

- Settling of blank into the die using gravity.
- Use to be a difficult problem due to rigid body motion of blank.
- Required Implicit Dynamics with death and burial time, slow to converge.
- New Keyword in v. 971 R3
  *CONTROL_IMPLICIT_FORMING
  1

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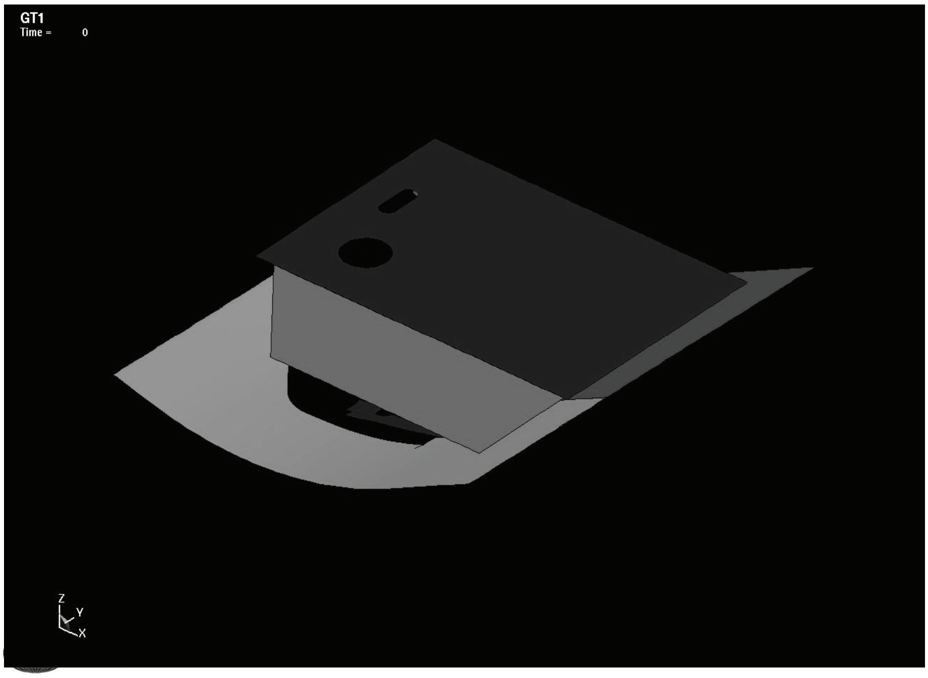
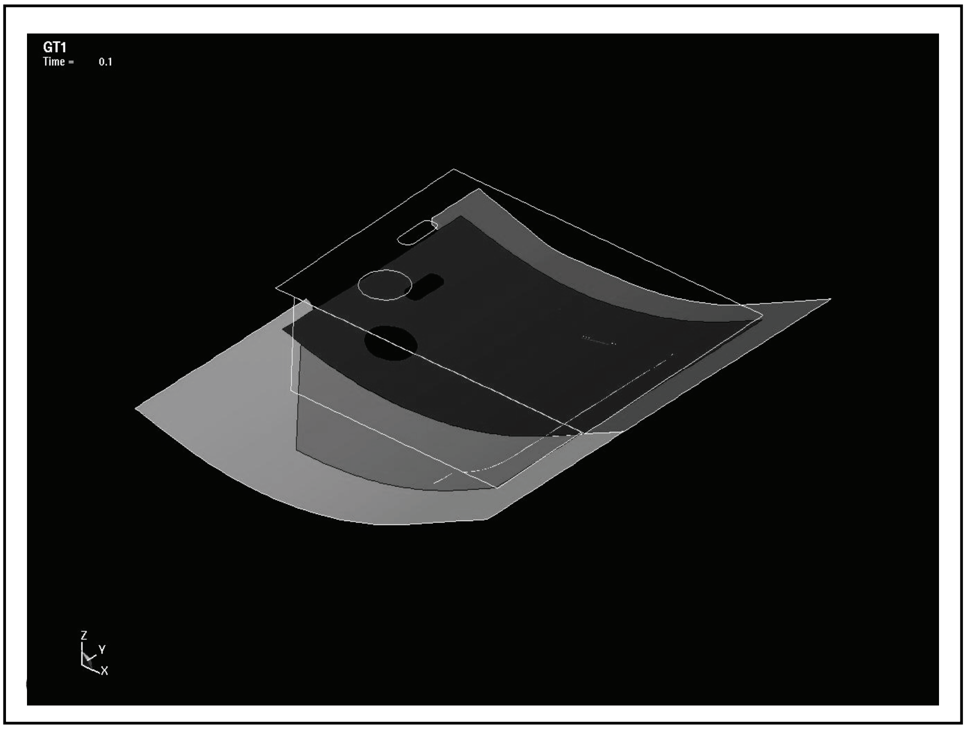
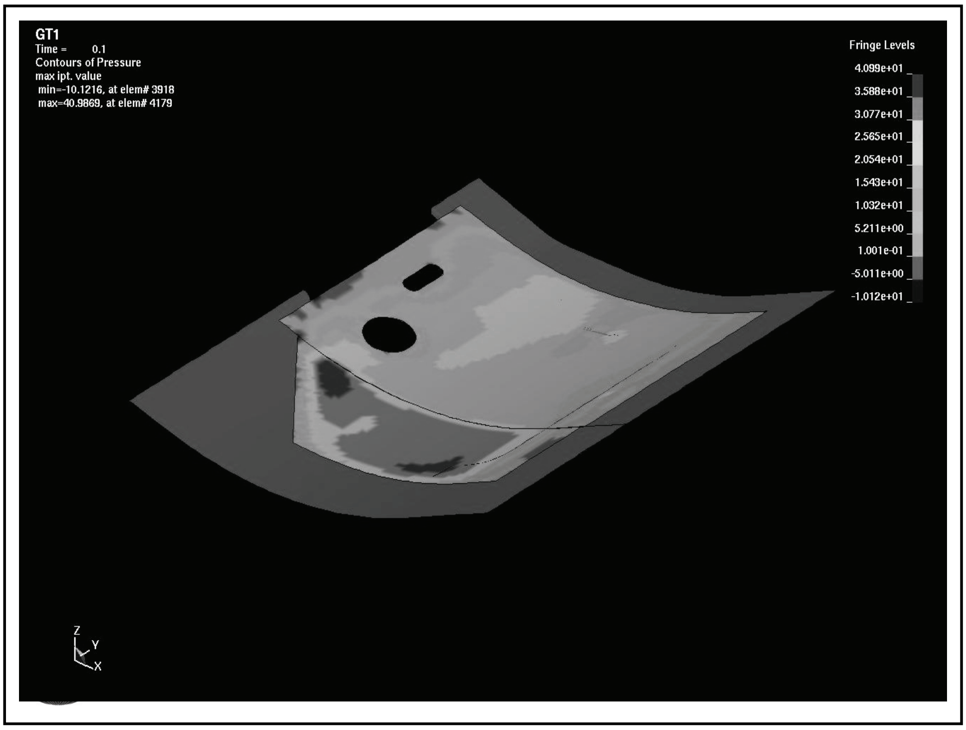
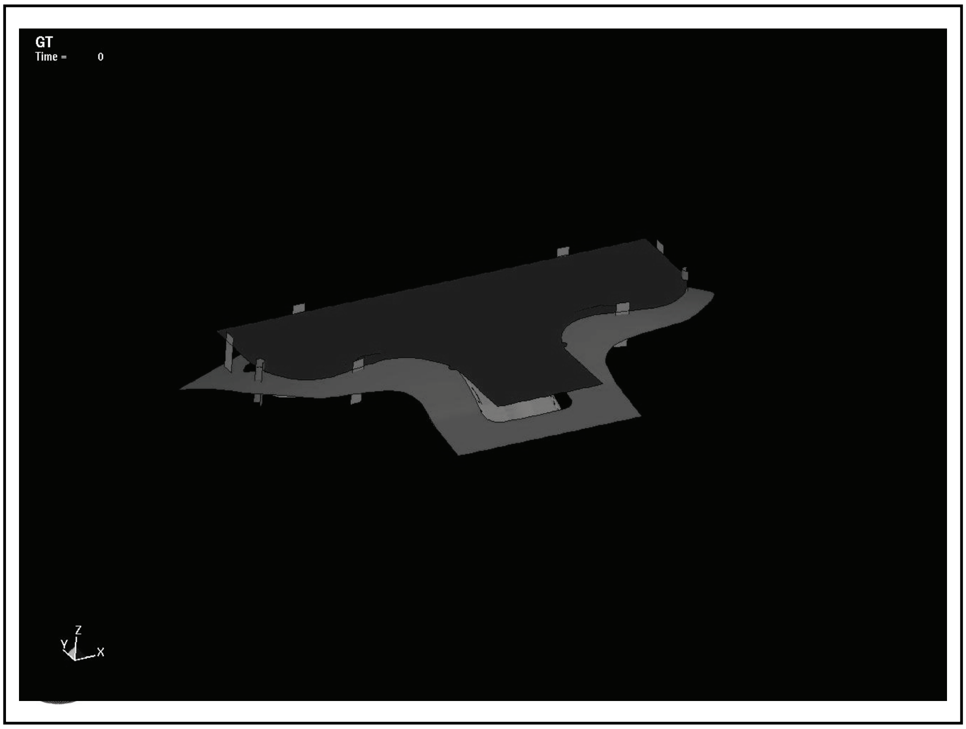
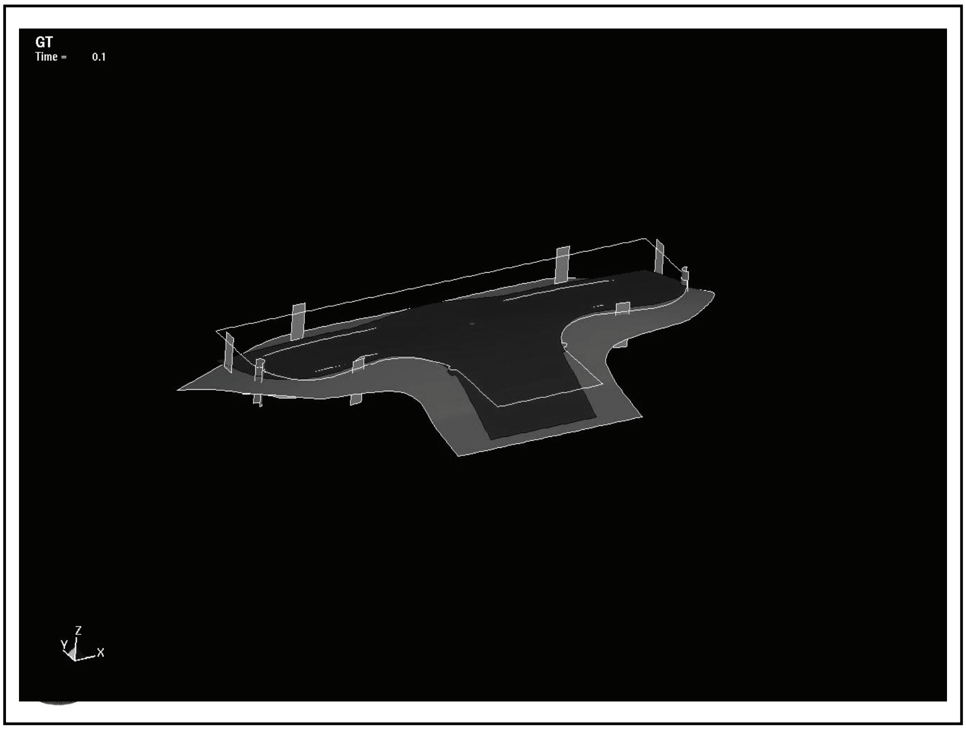
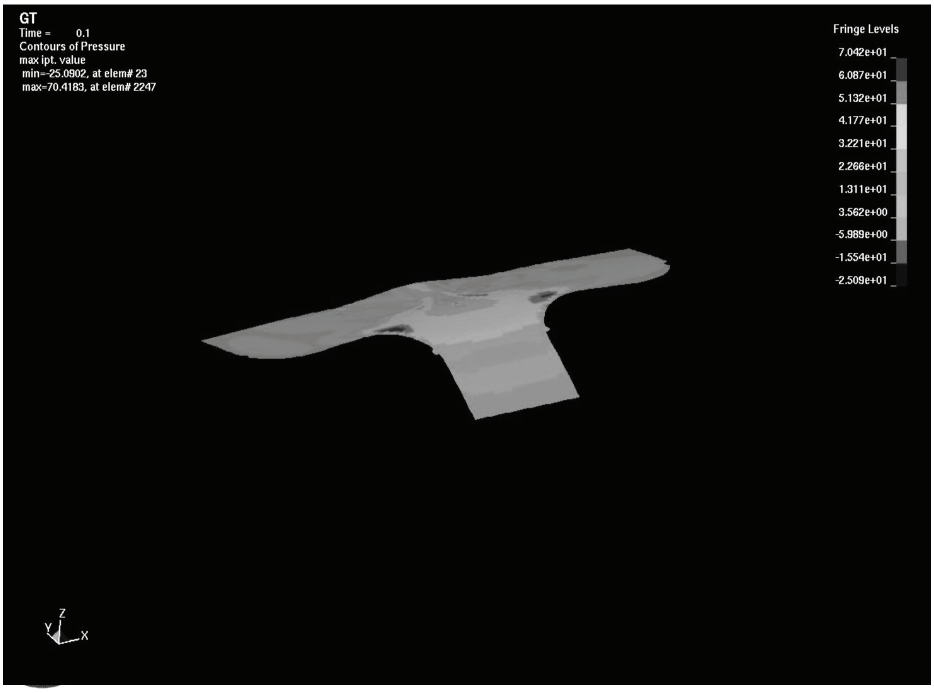



GT1
Time = 0.1
Z
Y
X


GT1
Time = 0.1
Contours of Pressure
max ipt. value
min=-10.1216, at elem# 3918
max=40.9869, at elem# 4179
Fringe Levels
4.099e+01
3.588e+01
3.077e+01
2.565e+01
2.054e+01
1.543e+01
1.032e+01
5.211e+00
1.001e-01
-5.011e+00
-1.012e+01
Z
Y
X


GT
Time = 0
Z
Y
X


GT
Time = 0.1
Z
Y
X



Gravity Loading

- Gravity Loading problems are now solved in one implicit time step and a small number of nonlinear steps.
- Faster and more robust than using Implicit Dynamics.
- Accurate answers.

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Binder Wrap

- Act of clamping the blank to the die.
- Use to be a difficult problem due to rigid body motion and contact issues.
- Use new Keyword in v. 971 R3
  *CONTROL_IMPLICIT_FORMING
  2

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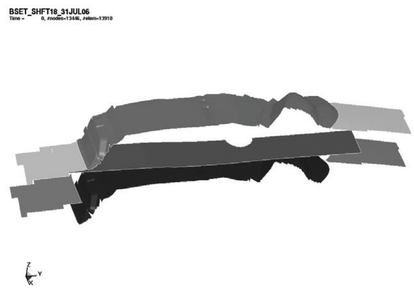
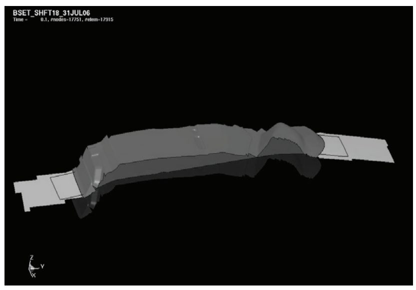
Implicit Binder Wrap





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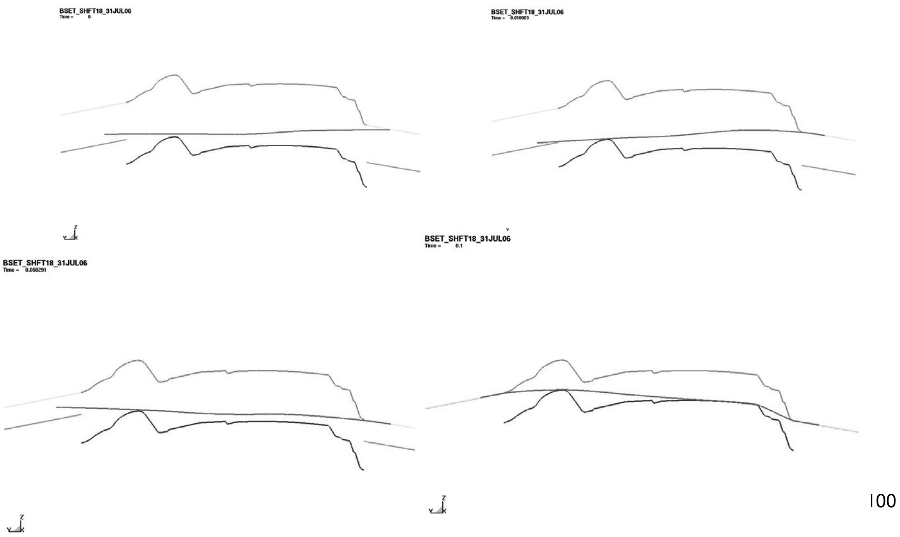
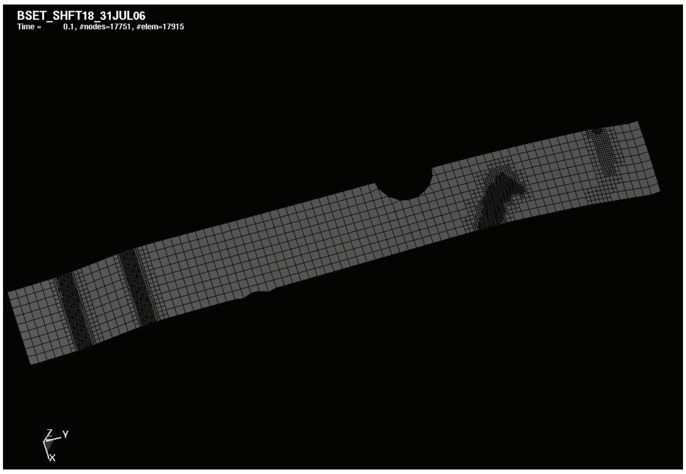
Implicit Binder Wrap



100

Implicit Binder Wrap
Mesh Refinement



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Binder Wrap

- Binder Wrap problems are now solved with a small number of implicit time steps (O(10)).
- Faster and more robust than old approach using implicit dynamics.
- Accurate answers.

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Version 971_R4 developments

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Wave absorbing layer

- Required for modeling wave propagation on unbounded domains, e.g. in geophysics
- Use perfectly matched layer (PML) for near-perfect absorption of all elastic waves
- Available as new material: *MAT_PML_ELASTIC
- Define layer of PML material adjoining truncated domain to simulate unboundedness
- Depth: 5-10 elements (maintain mesh density)

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Wave absorbing layer

- Layers must adjoin planar boundary surfaces of the truncated domain
- Each layer must be perpendicular to one of the coordinate axes
- Material in truncated domain near layer must behave as a linear, isotropic elastic solid, i.e. problem is linear in the far-field
- Entire PML layer is automatically partitioned to facilitate definition of absorption coefficients

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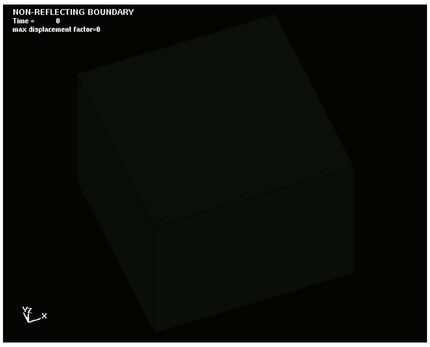
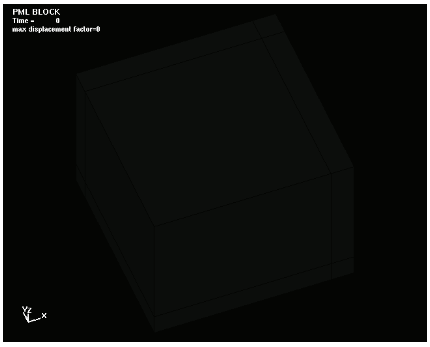
Wave absorbing layer

Compare older and newer approaches on quarter-mesh of half-space





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Soil-structure interaction

- Interaction - under earthquake excitation - of non-linear structure (and nearby soil) with unbounded linear soil or rock
- Adding earthquake excitation to a soil-structure model by exciting the base of the soil is highly heuristic!
- Rational method: compute effective forces at soil-structure interface
- Implemented using new cards:
  *BOUNDARY_SPECIFIED_GROUND_MOTION
  *DEFINE_GROUND_MOTION

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Soil-structure interaction

- Define one or more soil-structure interfaces as segment sets
- Define each earthquake ground motion as a set of a ground acceleration and a velocity history, using *DEFINE_GROUND_MOTION
- Assign the defined ground motions as free-field ground motions at specific locations on the defined interfaces, using *BOUNDARY_SPECIFIED_GROUND_MOTION
- LS-DYNA does the rest!

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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.

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Explicit constraints

- Historically, LS-DYNA Explicit has applied constraints each time step by constraint type.
  - Multi-point constraints
  - Tied constrained contacts
  - Joint constraint
  - Rigid bodies
- In explicit calculations constraints involving the same node but different constraint types may not be properly applied.
  - A node cannot be both a dependent node in one constraint and an independent node in another

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Consistent constraint explicit

- LS-DYNA Implicit uses a global view of constraints so multiple constraints are consistently applied.
  - Constraints can form closed chains
- LSTC has started a project entitled *Consistent Constraint Explicit, CCE,* where we will apply this Implicit technology to explicit problems.

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Consistent constraint explicit

- Build a global constraint matrix C and associated right hand side g.

$$\begin{array}{ll} Solve & Ma = f \\ Subject\ to & Ca = g \end{array}$$

- We are looking at using an iterative solver on the null space of the constraints.

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Consistent constraint explicit

- Results will be a consistent application of constraints for explicit models.
- It is expected that CPU time and computer memory requirements will be increased for explicit simulations.
  - Approach will be optional
  - No input changes

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CCE summary

- A new approach for explicit time integration
- Allows identical constraint treatment for NVH, durability, and crash models
- If we are successful, MD Nastran implicit models will run explicitly in solution 700 with no changes in the constraints

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Version 980 developments

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CESE Method

- New compressible fluid solver

  CESE —— Conservation Element & Solution Element
- Some features of CESE method:
  - *Flux* conservations in *space and time* (locally & globally)
  - Accurate
    - 2nd order (for flow variables & their spatial derivatives)
  - Novel & simple shock-capturing strategy
    - Just simple weighting average or relaxation technique is used
  - Both strong shocks and small disturbances can be handled very well simultaneously
  - Boundary conditions can be implemented easily & accurately

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Applications of CESE method

- Some applications:
  - All speed compressible flows
    - Low speed → High speed flows (subsonic → hypersonic)
    - Especially for high speed flows with complex shock patterns
  - Acoustics (noise)
    - Reasons:
      - Fluid solution is accurate
      - Can handle both strong and small disturbances very well at the same time
    - Far field solver is still needed (not yet in current version)
  - Chemical reaction flows (not yet in current version)
  - Cavitating flows (not yet in current version)

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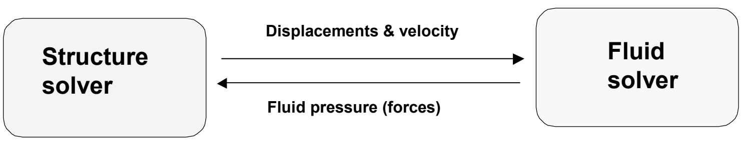
Fluid - Structure Coupling

– **Structure and fluid solvers**
- Structure solver —— **FEM** (Explicit Lagrangian)
- Fluid solver —— **CESE** (Explicit Eulerian)
- Both meshes —— Independent of each other

– **Interface treatment**
- Quasi-constraint method



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Current status

– **CESE fluid solver:**

- **Codes**: Serial & MPP modes
  (fluid solver input deck setup is very simple)
- **Flows**: Inviscid & viscous flows
- **Meshes:** Hexahedra, wedges, tetrahedra or a mixture of them
- **BCs**: • Regular boundary conditions
  (solid, open, inflow, outflow, symmetric)
  • Moving or rotating solid boundaries for viscous flows
  (in tangential directions)
- **2D option:** Triggered when the mesh and BCs are properly defined for 2d problems

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Current status

– **Fluid / structure coupling (3D** Serial & MPP modes**):**

- structures can be shell and/or solid volume elements
- Fluid mesh is independent of the structures
  (*Requirements*: fluid domain must covers all the active structures during the process)
- For some applications (e.g. airbag), users have the option to only calculate the inside of the bag or both sides (using the same fluid material or different ones)

Note: This new solver (**ls980** β-version) is already ready for users to try.

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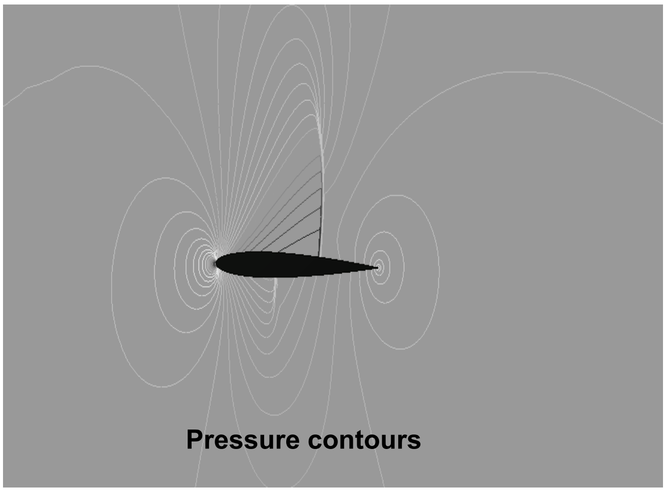
Inviscid flow example

- Flow over NACA 0012 Airfoil



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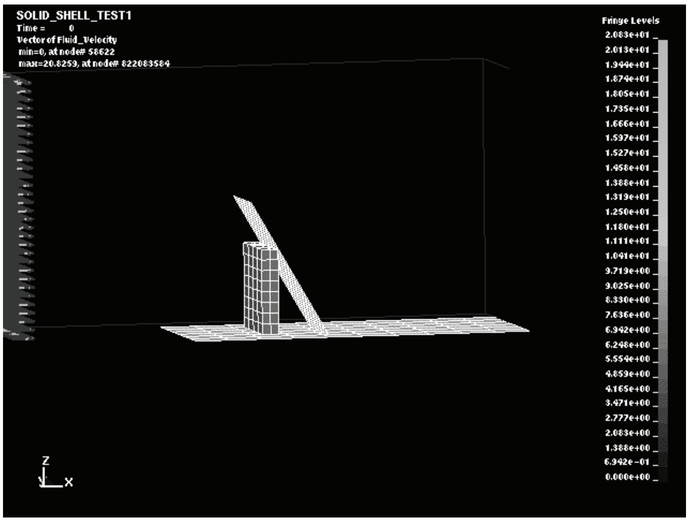
Fluid / Structures Interaction



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Incompressible flow (980)

- Explicit-implicit solver
- Lagrangian treatment of most interfaces
- Automatic meshing and adaptive remeshing (error control)
- FSI with large deformations
- MPP implementation

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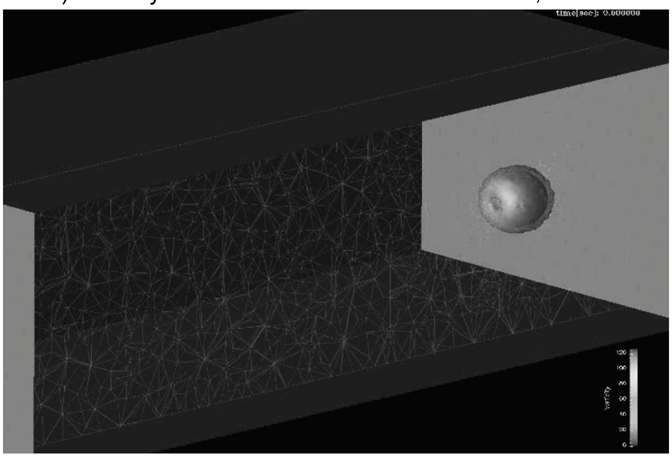
Flow Past a Sphere (Re=400)

Volume Adaptivity Based on Velocity Gradient Reconstruction (Prescribed error = 5%) Vorticity Field. Initial mesh size: 120K Elem, final: 1.2M Elem.



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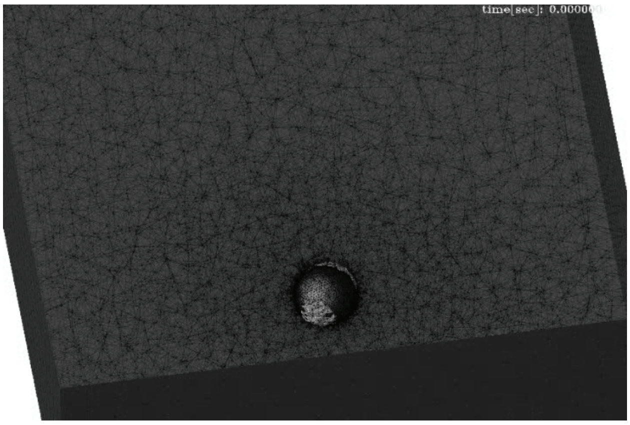
Flow Past a Moving Sphere (Re=800)

Volume Adaptivity Based on Velocity Gradient Reconstruction
(Prescribed error = 5%) Green Mesh: Error > 2%



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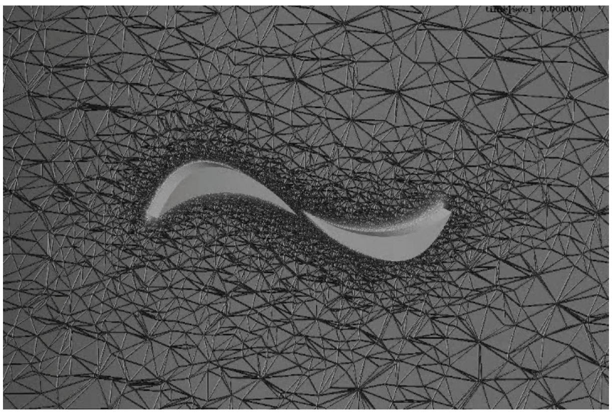
Flow Past Rotating Blades (Re=4e6)

Volume Adaptivity Based on Velocity Gradient Reconstruction
(Prescribed error = 8%) mesh: Velocity field, Structure: pressure



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LS-DYNA electromagnetism

- Introduction of electrical currents in solid conductors.
- These currents generate magnetic fields, electric fields, as well as induced currents.
- The magnetic fields coupled with the currents generate Lorentz forces on the conductors.
- The forces induce motion and deformation of the conductors.
- This motion has an effect on the fields and the currents.
- The currents generate Joule heating in the conductors, changing the temperature, and thus some mechanical as well as electromagnetic properties (conductivity for example).

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LS-DYNA electromagnetism (2)

• The EM fields are solved using FEM in the conductors and BEM in the surrounding air/insulators.

• Advantage: no air mesh (thus much easier to have motion of the conductors).

• Drawback: the “BEM” system is dense:

•Relatively long matrices assembly time.

•A priori big memory requirement.

• Block decomposition as well as low rank approximation method have been introduced to reduce the memory requirement and CPU time.

These methods have allowed to

•reduce the memory requirement by a factors around 20-50,

•and increase the sizes of typical cases from 10,000 to 100,000 elements.

• Other methods will be introduced to decrease cpu time.

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Electromagnetism: plans for the future

- **Near term**
  - planar and axi-symmetric 2D, coupled with 3D (in progress).
  - Increase computational speed.
  - Add electromagnetism capability on tetrahedra, wedges, and triangular faces.
- **Medium term**
  - Parallelization of the EM module.
  - Work on FEM+FEM method with automatic remeshing of the air mesh.
  - Introduce adaptivity.
- **Long term**
  - Introduce magnetic materials.
  - Work on a magnetostatics solver.

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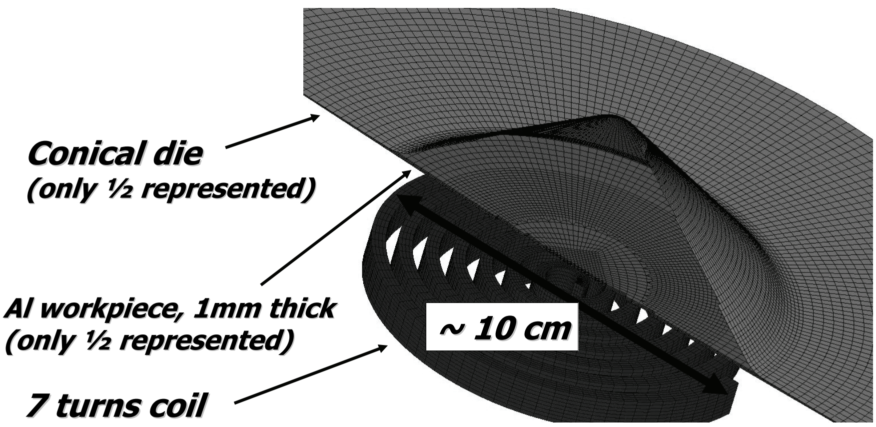
EM Sheet forming on conical die (1)

In collaboration with M. Woswick, J. Imbert,

University of Waterloo, Ontario, Canada



(around 70.000 elements)

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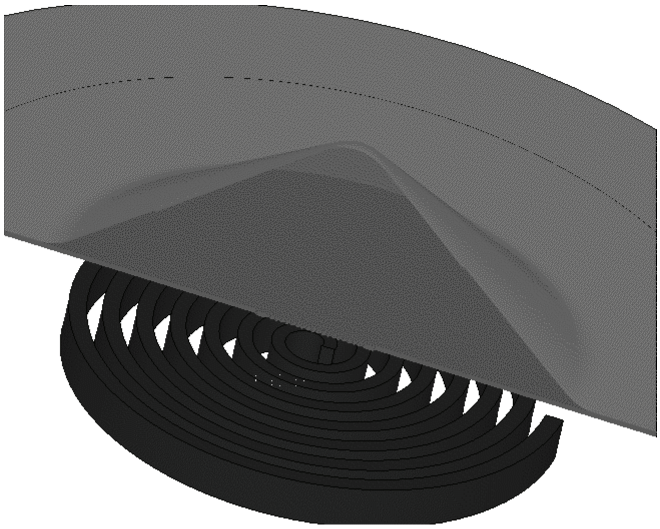
EM Sheet forming on conical die (2)



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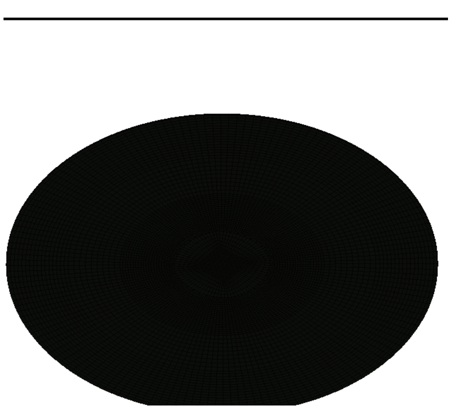
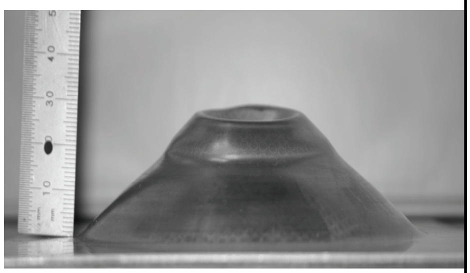
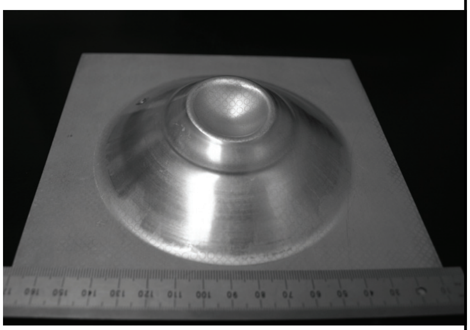
EM Sheet forming on conical die (3)
Comparisons with experiments







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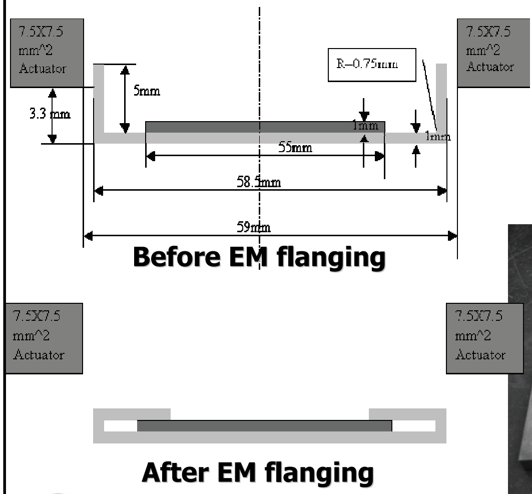
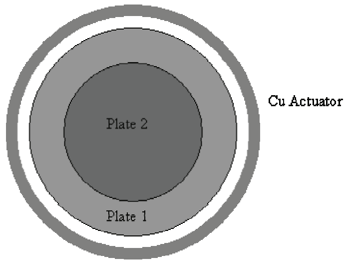
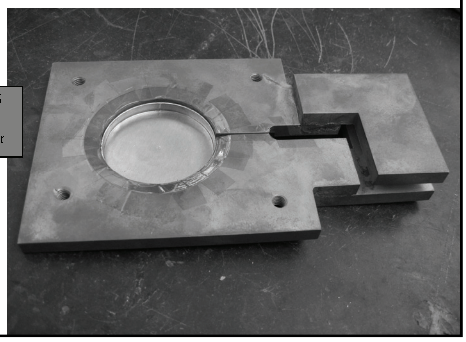
EM Hemming experiment (1)

In collaboration with G. Daehn, M. Seth, Y. Zhang,

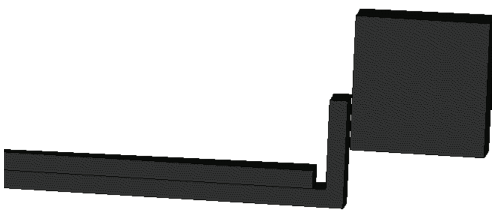
The Ohio State University, USA



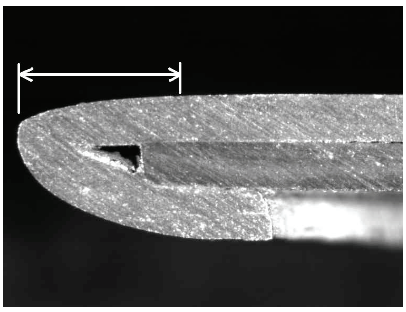




EM Hemming experiment (2)
Comparison with experiments



Current density



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Conclusions

- Rigid frontal dummies will be available soon for restraint system design.
- The R3 release will have many improvements such as selective mass scaling, the particle method for airbag deployment, and many other new feature requested by users
- The consistent constraint explicit option will be in the R4 release to eliminate the need for penalty constraints
  - Eliminates a major difference between implicit and explicit models
- 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, and running on large clusters of processors.

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THANK YOU

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