Recent developments in LS-DYNA

German LS-DYNA Forum
10/13/2011

Presented by
John O. Hallquist
Outline of talk

• Introduction
  • Version 980

• Current Developments
  • LSTC dummy/barrier
  • Implicit update
  • Frequency domain
  • Isogeometric elements
  • LS-DYNA 971 R5 & R6

• Conclusions
LSTC Products

- LS-PrePost
- LS-DYNA
- LS-OPT
- LS-TaSC

No additional license cost

USA
LS-DYNA Applications

Automotive
- Crash and safety
- NVH
- Durability

Aerospace
- Bird strike
- Containment
- Crash

Manufacturing
- Stamping
- Forging

Consumer Products

Structural
- Earthquake safety
- Concrete structures
- Homeland security

Electronics
- Drop analysis
- Package analysis
- Thermal

Defense
- Weapons design
- Blast response
- Penetration
- Underwater Shock Analysis
Development goals

• Reduce customer costs to encourage and enable massively parallel processing for large scale numerical simulations

• Approaches used by LSTC to help reduce costs

  4 jobs/1 core = 1 job/4 core

  Flexibility with 4 core license
  1 job running 4 cores or 4 jobs running 1 core

  Unlimited Site wide license

  Steeply reduced license costs
  As # of cores increase

• Expand analysis capabilities in all areas of physics to provide scalable, accurate, and robust solutions to the coupled multi-physics problems faced every day by development engineers worldwide
One code strategy

“Combine the multi-physics capabilities into one scalable code for solving highly nonlinear transient problems to enable the solution of coupled multi-physics and multi-stage problems”

<table>
<thead>
<tr>
<th>Explicit/Implicit</th>
<th>✓</th>
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</thead>
<tbody>
<tr>
<td>Heat Transfer</td>
<td>✓</td>
</tr>
<tr>
<td>Mesh Free</td>
<td>✓</td>
</tr>
<tr>
<td>EFG, SPH, Airbag Particle</td>
<td>✓</td>
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<tr>
<td>User Interface</td>
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<tr>
<td>Elements, Materials, Loads</td>
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<tr>
<td>Acoustics Frequency Response, Modal Methods</td>
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<td>Discrete Element Method</td>
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<td>Incompressible Fluids</td>
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<td>CESE Compressible Fluid Solver</td>
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<tr>
<td>Electromagnetism</td>
<td>980</td>
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</table>
Extensions in LS-DYNA 980

- EM solver involves an eddy-current approximation to the electromagnetics equations and couples to both the thermal and structural solvers.
- iCFD incompressible CFD solver handles low Mach number single and two-fluid flows; it also couples with both the structural and thermal solvers for FSI and conjugate heat transfer.
- CESE compressible CFD solver performs high-accuracy explicit space-time solutions to the Euler and Navier-Stokes equations, with coupling to a chemical reactions module and a stochastic particle capability for sprays and other applications. It also solves for FSI coupling.
Different solvers can be used in one model:

\[ \Delta t_{EM} = 10\Delta t_{Mechanical} \]

\[ \text{Often: } \Delta t_{Thermal} = \Delta t_{EM} \]

**Thermal**
- Implicit
- Double precision

**Mechanical**
- Implicit Dynamics
- Explicit
- Double precision

**EM**
- BEM (Air)
- FEM (Conductors)
- Implicit
- Double precision

**Temperature**
- Joule Heating
- Plastic Work
- Temperature
- Force

**Node Positions**
Wind Turbine Simulation

- Horizontal wind turbine.
- Blade span: 44.5m.
- Wind speed: 11.4 m/sec.
- Rotation speed: 1.26 rad/sec.
- Fluid mesh: 15.2M tet elements
- Solid mesh: 67.4K tri shells.
- Parallel run: 20 CPUs.

Fluid pressure field
Free Surface Simulation

- The free surface is implemented using a Level Set.
- It allows the simulation of free surface flows using a single phase model.
- The Level Set allows large time steps with CFL=>1.
Streamlines Visualization

- New feature in LSPP. Under the “Trace” button.
- It allows the user to easily identify fluid features.
- The example shows an FSI problem where the green dots are the source for the streamlines. The recirculation areas on the flag are shown.
Compressible CFD solver

Water Spray Jet (coupled to CESE)
Spray Particles Injected into a Supersonic flow (CESE)
Dummies
Dummies & barriers

• For licensed LS-DYNA users
  – No separate licensing from LS-DYNA.

• Continuous updates and support from LSTC and distributors

• Companies may improve models and keep the improvements proprietary

• Companies may redistribute their improved models to their suppliers and subsidiaries for LS-DYNA simulations

• Dummy development partners include DYNAmore, NCAC, a major automotive supplier, and several OEM’s.
## LSTC Hybrid III Adult Release Dates

<table>
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<th>Fast</th>
<th>Standing</th>
<th>Detailed</th>
<th>NCAC</th>
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</table>

- 5%: Fast - Released
- 50%: Fast - Released
- 95%: Released
- NCAC: Released
LSTC Hybrid III Adult Element Count

Detailed: 397,490
Fast: 4,295
## LSTC Hybrid III Child Models

<table>
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<tr>
<th>Status</th>
<th>Next Steps</th>
<th>Release Date</th>
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<td>3yr Old Calibration tests</td>
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<tr>
<td>EuroSID 2</td>
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<td>EuroSID 2re</td>
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<tr>
<td>USSID</td>
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LSTC Side Impact Dummies Release Dates
## LSTC LegForm and Headform

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<td>THOR-NT</td>
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<td>Meshing</td>
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LSTC Barrier Models Update
LSTC family of barriers

Solid barriers were sponsored by Honda USA
Shell barriers were first pioneered by Toyota
Implicit Update
Implicit update

• MPP implicit and hybrid implicit are scaling to hundreds of processors.

• The global stiffness matrix, not an issue for explicit, is necessary for implicit
  – Processing time is dominated by the numeric factorization
  – Memory and disk storage is dominated by storing the factorization

• Memory management is very important.

• Symbolic Processing is the current bottleneck.
  – Improvements are being researched at LSTC
Advantage
• Cheap, fast, and scalable with multiple CPU’s

Limitation
• Less memory than CPU side
• Communication between the CPU and GPU is slow
• Currently Fortran does not port to the GPU.
• GPU’s hundreds of cores only work at the promised speed for specialized applications with carefully programmed software.

Current implementation uses one GPU per processor, which will be automatically detected and applied without special licensing or pricing
GPU Performance in Implicit

- Test Environment
  - PC with a dual quad core Xeon 5560 processors and 2 Nvidia Tesla boards. The host has 96 Gbytes of memory while each GPU has 2 Gbytes of memory.

- Benchmark problem: AWE 1M nodes

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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.

Frequency Domain Developments
Frequency domain analysis

- Random vibration
- Random fatigue
- Frequency response function
- Steady state dynamics
- Response spectrum analysis
- BEM Acoustics
- FEM Acoustics
Applications

- NVH of automotive and air plane
- Golf club design
- Defense industry
- Fatigue of mechanical structures
- Civil Engineering
• **Keyword**
  - *FREQUENCY_DOMAIN_ACOUSTIC_BEM*

• **A wide choice of methods**
  - Rayleigh method
  - Kirchhoff method
  - Indirect variational BEM
  - Collocation BEM
  - Dual BEM with Burton-Miller formulation

• **Boundary conditions given by**
  - Direct load curve input
  - Time domain dynamic analysis followed by FFT conversion
  - Frequency domain steady state dynamic analysis

• **Acoustic panel contribution analysis**
Radiated noise by a car

Harmonic nodal force applied at the top

\[ f = 21 \text{ hz} \]

\[ f = 101 \text{ hz} \]
FEM acoustics

• **Keyword**
  – *FREQUENCY_DOMAIN_ACOUSTIC_FEM*

• Solve interior acoustic problem

• Tetrahedron and Hexahedron elements are available

• Very fast since only 1 unknown at each node

A simplified compartment example
New database files

- **Keyword**
  - *DATABASE_FREQUENCY_BINARY_OPTION*

Available options
D3ACS, D3FTG, D3PSD, D3RMS, D3SPCM and D3SSD

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<th>Card 1</th>
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<th>3</th>
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<td></td>
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</table>

FMIN → FMAX

Mode n

FMAX → FMIN

Mode n+1

(Linear spacing)

Mode n+2

(Logarithmic spacing)

Mode n

(Linear spacing)

Mode n+1

(Linear spacing)

Mode n+2

(Linear spacing)

(Linear spacing)
Isogeometric analysis
NURBS-based finite elements

- ISOGEOMETRIC-Analysis
  - research since 2003
  - many promising features (CAD-to-FEA, accuracy, …)

- GENERALIZED-Elements in LS-DYNA (User defined)
  - possible to try different shape functions …
  - good results (accuracy, …)
  - difficult to use, huge input-decks with lots of data † slow to read …

- Decision to implement NURBS-based finite elements in LS-DYNA
  - NURBS: most widely used geometric description
  - first step into ISOGEOMETRIC-Analysis

- Very first implementations …
  - 2D-NURBS for shell analysis
  - Boundary conditions (contact) with interpolation nodes/elements
New Keyword: *ELEMENT_NURBS_PATCH_2D
- definition of NURBS-surfaces
- 4 different shell formulations with/without rotational degrees-of-freedom

Preprocessing
- work in progress for LS-PrePost … current status (lspp3.1beta)
  † Visualization of 2D-NURBS-Patches
  † import IGES-format and construct *ELEMENT_NURBS_PATCH_2D
  † Modification of 2D-NURBS geometry

Postprocessing and boundary conditions (i.e. contact) currently with
- Interpolation nodes
- Interpolation elements

Analysis capabilities
- implicit and explicit time integration
- eigenvalue analysis
- other capabilities (e.g. geometric stiffness for buckling) implemented but not yet tested

LS-DYNA material library available (including umats)
**NURBS-based finite elements**

*ELEMENT_NURBS_PATCH_2D

$---+--EID----+--PID----+--NPR----+---PR----+--NPS----+---PS----+----7----+----8
11 12  4  2  5  2

$---+--WFL----+-FORM----+--INT----+-NISR----+-NISS----+IMASS----+----7----+----8
0  0  1  2  2  0

$rk----1------2-------3-------4-------5-------6-------7-------8
0.0 0.0 0.0 1.0 2.0 2.0 2.0

$sk----1------2-------3-------4-------5-------6-------7-------8
0.0 0.0 0.0 1.0 2.0 3.0 3.0 3.0

$net+---N1----+---N2----+---N3----+---N4----+---N5----+---N6----+---N7----+---N8
1  2  3  4
5  6  7  8
9 10 11 12
13 14 15 16
17 18 19 20

**Control Points**

**Control Net**
NURBS based elements are stable

Code optimization necessary to make it faster but already competitive. MPP enabled.

Further implementation
- (selective) mass scaling
- thickness update of shells
- use NURBS for contact (instead of interpolation elements)
- make pre- and post-processing more user-friendly
- introduce 3D NURBS elements
- ... much more

Perform a lot more studies in different fields

Encourage customers to test these elements

Summary & Future Directions
LS-DYNA Version 971
recent developments
LS971R5 & R6
To define elements for a general composite shell part where the shells within the part can have an arbitrary number of layers.

The material ID, thickness, and material angle are specified for the thickness integration points for each shell in the part.

\[ \theta_i = \beta + \beta_i \]

THICKi, of MAT i
Node-to-node contact for SPH

*DEFINE_SPH_TO_SPH_COUPLING to define penalty-based SPH-to-SPH particle contact
Hybrid element couples SPH to solid

*DEFINE_ADAPTIVE_SOLID_TO_SPH
ICPL=1 creates hybrid elements as transit layers between SPH elements and Solid elements. Solid elements constrain SPH nodal locations. SPH elements provide "penalty force" against solid nodal motion.
Adaptive solid to SPH

*DEFINE_ADAPTIVE_SOLID_TO_SPH

The SPH particles replacing the failed element inherit all of the properties of failed solid element, e.g. mass, kinematic variables, and constitutive properties. Hybrid transition elements are automatically created.
A new explicit thermal conduction solver is implemented for SPH analysis.

Following keywords are supported:
- *INITIAL_TEMPERATURE_OPTION*
- *BOUNDARY_TEMPERATURE_OPTION*
- *BOUNDARY_FLUX_OPTION*

Thermal coupling with SPH is implemented.
**SPH thermal conduction**

*INITIAL_TEMPERATURE_OPTION*

**Lagrangian thermal solver**

Time step: \( \Delta t = m\Delta t^2 \rho c / k \quad m = 1/12 \)

**explicit SPH thermal solver**

Time step: \( \Delta t = \zeta \rho c_v h^2 / k \quad \zeta = .1 \)
Boundary_temperature

*BOUNDARY_TEMPERATURE_OPTION

Solids

SPH
Boundary temperature

*BOUNDARY_FLUX_OPTION

Solids

**Heat flow is negative in the direction of surface normal vector (left hand rule)**
Thermal coupling with SPH

Control_thermal_solver: \( (eqheat)(fwork)w = \rho c \Delta T \)

Conversion of mechanical work to heat
A single rigid material is defined which contains multiple disjoint pieces. Each rigid piece can contain an arbitrary number of solid elements that are arranged in an arbitrary shape. Reduction in memory and wall clock time over separate rigid bodies. Can be used to model granular material.
For cases where the particles can be modeled with geometric shapes, meshing of particles are not needed for solving contact and analytical contact can be used.

Speed is considerably faster than with arbitrarily shaped particles and general single surface contact

Spherical particles with arbitrary radii have been implemented for

- Elastic impact
- Inelastic impact
- Combination of elastic and inelastic impacts
CPU time and porosity comparison between DES and discrete elements based on Mat_220 and Mat_20
Effects of viscosity on the mechanical response of a liquid bridge is considered.
Discrete element sphere particle filling algorithm

- Linear Packing Speed
  ~8,500 sphere/second, single CPU, including sphere regularization
- Packing Density: ~56.7%
- Direct implementation into LS-PrePost and generate the LS-DYNA keyword input
Bounding Surfaces and Triangulation
Phase III: Filling the volume

Particle filling algorithm
Mesh refinement along a curve

- **DEFINE_CURVE_TRIM_NEW**
  - Used together with *CONTROL_ADAPTIVE_CURVE*

```plaintext
*DEFINE_CURVE_TRIM_3D
$    TCID    TCTYPE    TFLG    TDIR    TCTOL    TRDIS
 1   2   0   0   0.500   2.000
adpcurves.iges
*CONTROL_ADAPTIVE_CURVE
 1  2  4  0.3
```

- **Purpose**
  - Refine elements along curve
  - No further refinement in later simulation
  - Flanging and hemming simulating become more efficient
Mesh refinement along a curve

- New method – Allow specifying distance from the curve to the edge of refinement
• Adaptive meshing allows stress concentrations to be automatically resolved in linear static calculations.

• Implementation in LS-DYNA:
  – If 4 levels of adaptive remeshing are specified, then 4 load steps are performed holding the load constant. Error norms are computed each step to determine which elements are refined.
  – Super-convergent Patch Recovery, SPR, is now the default for error estimate.
Time = 0, #nodes=708, #elem=625
Contours of Effective Stress (v-m)
max ipt. value
min=0, at elem# 1
max=0, at elem# 1
Superconvergence Patch Recovery (SPR) has been extended for shells and plates.

The element-centered element patch is used for the SPR with the weighted lease square, to support T-joints and feature lines natively.

Support various error estimators, within the element, including the energy norm, maximum tension or shear, von Mises stress, etc.

All error estimation procedures are carried out locally, which is MPP friendly.
General framework for pulley mechanism:
- rope / cable / belt / chain runs over a wheel
- beam elements run over pulley node

Adopted from slipring mechanism for belts

Available for truss beam elements

Available for *MAT_ELASTIC and *MAT_MUSCLE, more materials could be implemented
Smooth transition of beam material from one side to the other

Swapping of beam elements if elements get too short

Static and dynamic friction coefficients can be defined
Simplified Table Definitions

*DEFINE_TABLE_2D
Unlike the *DEFINE_TABLE keyword, a curve ID is specified for each abscissa value defined in the table. The same curve ID to be referenced by multiple tables, and the curves may be defined anywhere in the input file.

*DEFINE_TABLE_3D
A table ID is specified for each abscissa value defined for the 3d table
Consider a thermal material model. For each temperature, $T$, we have a table of hardening curves of stress versus strain at 3 strain rates, i.e., $s = f(\varepsilon, \dot{\varepsilon}, T)$.
For each temperature, we specify a table with 3 strain rates

For each strain rate, we specify a curve of $s$ vs $e$
New failure criteria added

EPSEFF – Effective in-plane strain for cohesive elements
LCFLD – Forming Limit Diagram curve for shell elements
EPSTHIN – Thinning strain to failure for shell elements

New GISSMO features added

LCSDG – Failure as function of triaxiality and Lode parameter
LCSRS – Failure as function of plastic strain rate
SHRF, BIAXF – Reduction factors for regularization
• Background
  – Yoshida’s non-linear kinematic hardening has been found to be very important for high-strength steel and aluminum
  – Mat_125 (Yoshida’s hardening + Hill’s yield surface)
    • Is suitable for many high strength steels
    • Needs improvement for aluminum
  – Barlat 89 yield surface is more suitable for aluminum
    • It is natural to combine Barlat89 yield surface with Yoshida’s non-linear kinematic hardening
• M125 and M226 give similar predictions of thickness changes
  – NUMISHEET’05 Xmbr – AL5182
M226 gives the best springback prediction – AL5182

*Mat_kinematic_hardening_barlat89 (Mat 226)*

- Experimental data
- M226 result
- M125 result
- M37 result

M37 Comparison Y = -370.0
New material model for forming simulations, e.g. aluminum

Features anisotropic yield criterion of Hill (1990)

\[ \Phi = K_1^m + K_3 \cdot K_2^{(m/2)-1} + c^m \cdot K_4^{m/2} = \left( 1 + c^m - 2a + b \right) \sigma_Y^m \]

\[ K_1 = |\sigma_x + \sigma_y| \]

\[ K_2 = |\sigma_x^2 + \sigma_y^2 + 2\sigma_{xy}| \]

\[ K_3 = -2a\left(\sigma_x^2 - \sigma_y^2\right) + b\left(\sigma_x - \sigma_y\right)^2 \]

\[ K_4 = \left(\sigma_x - \sigma_y\right)^2 + 4\sigma_{xy}^2 \]

Available for shell elements

Supports all options of widely used *MAT_HILL_90*
Based on works of Riedel, Hiermaier and Thoma

Concrete model featuring
  - Pore crush
  - Meridian dependence
  - Strain rate effects
  - Three curve formulation
    • Yield surface
    • Failure surface
    • Residual surface
Contact detonation

- Cross sectional view of concrete block after subjected to close range detonation
- Damage fringed and compared with experiment
Heat treatment in materials 36 & 133

- Yield stress reduced but hardening increased
- Enhanced formability
- Hardening curves at different temperatures
- Component prestrained, heated and cooled

Curves are fitted and extrapolated
0% curve is extrapolated
Mullins effect in *MAT_077

• For modelling hysteresis in rubber
• Hysteresis controlled via a table $D$ giving damage as function of current and peak elastic energy

$$S = D(W_{\text{dev}}, \bar{W}_{\text{dev}}) \frac{\partial W_{\text{dev}}}{\partial E} + \frac{\partial W_{\text{vol}}}{\partial E}$$

• Damage table determined from cyclic compression tests
• Used for accurate estimation of HIC value in pedestrian impact
Eight-chain rubber model (*MAT_267)

- A new advanced rubber model is available in LS-DYNA R6.
- Based on the standard (*mat_127) model but enhanced with the following features:
  - For solids and explicit simulations only.
  - Includes general Hill plasticity, Kinematic hardening, Visco-plasticity (4 types), Visco-elasticity (2 types) and Mullin’s effect (2 types).
Visualization by beam elements

Output to SWFORC will be implemented soon
Two shell element meshes are connected via a constrained model

Free node between both parts defines center of the connection

Shell nodes inside domain of influence (e.g. spotweld radius) are involved

Relative deformation between both parts through interpolation

Plasticity-damage model with failure

Forces and moments distributed to corresponding shell nodes
One step solution

• Keyword: *CONTROL_FORMING_ONE_STEP
• Purpose:
  – For forming simulations:
    • Determine initial blank size
    • In the feasibility phase, approximately predict the formability
  – For crash simulations:
    • It can provide approximate thickness and plastic strain distributions to improve simulation accuracy
• Characteristics of the one-step solver:
  – Triangular and quadrilateral shell elements are supported
  – Complex parts are handled,
    • including parts with under-cuts
  – Friction and drawbead definitions are considered
One step solution

LS-DYNA 1-step solution (30% lock everywhere + 15% top/bottom)

Competing code 1-step solution

LS-DYNA Incremental Solution

Max: 6mm difference between LS-DYNA 1-step and AUTOFORM 1-step

Initial Blank Size Prediction
Porosity leakage for non-fabric

*MAT_ADD_AIRBAG_POROSITY_LEAKAGE*

<table>
<thead>
<tr>
<th>Variable</th>
<th>MID</th>
<th>FLC/X2</th>
<th>FAC/X3</th>
<th>ELA</th>
<th>FVOPT</th>
<th>X0</th>
<th>X1</th>
</tr>
</thead>
</table>

- Allows users to model porosity leakage through non-fabric material when such material is used as part of control volume
- Applies to both airbag_hybrid and airbag_Wang_Nefske
- Application includes pyrotechnic device design, where non-fabric material is used to model a control volume and leakage through area-dependent leakage has to be considered.
**Set_xxxx_intersect**

- Define a set as the intersection, $\cap$, of a series of specified sets. The new set, SID, contains the common elements of all named sets.

- **Applies to:**
  - *SET_BEAM
  - *SET_NODE
  - *SET_SEGMENT
  - *SET SHELL
  - *SET_SOLID
Meshfree - enriched finite element formulation

- A purely displacement-based finite element formulation.
- Enriched with a meshfree node in tetrahedral element.
- Easy to be incorporated with existing finite element model

Volumetric locking-free

Isoparametric mapping in the 5-noded meshfree-enriched tetrahedral element

*New element formulation for implicit analysis of rubber-like materials*

*SECTION_SOLID*

<table>
<thead>
<tr>
<th>Variable</th>
<th>SECID</th>
<th>ELFORM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
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<td>1</td>
</tr>
</tbody>
</table>

ELFORM EQ.43: meshfree-enriched finite element formulation

Large deformation analysis of microscopic particle-reinforced rubber compound
• Brick element using Cosserat Point Theory
• Implemented as solid element type 1 with hourglass type 10
• Hourglass is based on a total strain formulation
• Hourglass constitutive coefficients determined to get correct results for
  – Coupled bending and torsion
  – High order hourglass deformation
  – Skewed elements
• **Tip loaded cantilever beam**
  - 5 mesh size levels (H=10, 5, 3.33, 2.5, 2 mm)
  - 3 distortion levels (a=-20, 0, 20 mm)
  - 2 load cases (horizontal (H) and vertical (V))

• **Analytical tip displacement 0.21310 mm**
<table>
<thead>
<tr>
<th>Cosserat</th>
<th>Belytschko-Bindeman</th>
<th>Puso</th>
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<tbody>
<tr>
<td>1.7%</td>
<td>61.8%</td>
<td>24.8%</td>
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<tr>
<td>0.8%</td>
<td>46.8%</td>
<td>14.7%</td>
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<td>0.6%</td>
<td>40.0%</td>
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<tr>
<td>0.3%</td>
<td>39.8%</td>
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<td>8.5%</td>
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<td>0.2%</td>
<td>27.0%</td>
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<tr>
<td>0.1%</td>
<td>15.4%</td>
<td>0.3%</td>
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</tbody>
</table>

- Worst errors for three hourglass formulations
Single point pentahedron

- Implemented as element type 115
- Supports Flanagan-Belytschko viscous and stiffness hourglass types
- Presumably more robust than the 2 point integrated pentahedron element
- Degenerated single point hexahedron elements are sorted to type 115
- Supported for implicit calculations
Robustness enhanced when pentahedron elements (depicted in brown) are run with element type 115 compared to element type 15.
• Selective mass scaling now supports
  – Geometric rigid walls
  – Constraint based contacts

• Hardening laws implemented in materials 36 and 133
  – Gosh and Hocket-Sherby hardening
  – TRansformation Induced Plasticity (TRIP) hardening
  – Young’s modulus as function of plastic strain in material 133

• Mortar contact supports
  – Initial penetration check
  – Ignore option
  – Proper edge to edge contact, edges treated as flat surfaces
Recent developments

• Modified *EOS_JWL to get correct cavitation effect

• Variable FSI friction based on relative interface velocity

• Implemented in 2D and 3D
  – ALE static adaptive
  – ALE dynamic adaptive
Variable FSI Friction

Friction coefficient being a function of relative velocity and pressure.

**FRIC**= -N: N the table ID
- Abscissa: Pressure
- Ordinate: A load curve ID specifies relative velocity versus friction coefficient.

```
*CONSTRAINED_LAGRANGE_IN_SOLID

<table>
<thead>
<tr>
<th>SLAVE</th>
<th>MASTER</th>
<th>SSTYP</th>
<th>MSTYP</th>
<th>NQUAD</th>
<th>CTYPE</th>
<th>DIREC</th>
<th>MCOUP</th>
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<td>PLEAK</td>
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</table>
```
Variable FSI Friction
*Courtesy of Shoji Oida, Bridgestone

FSI between Rubber tread and fluid

Rubber tread
Rigid ring
Air
Fluid

Driving motion (+X)
ALE mesh motion

Eye technology corp.
Relative interface velocity

Backward flow can be observed as expected.


**Variable FSI Friction**

*Courtesy of Shoji Oida, Bridgestone*
### ALE static adaptive

#### *ALE_REFINE*

<table>
<thead>
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<th>Variable</th>
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<th>STYPE</th>
<th>MMSID</th>
<th>NLVL</th>
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<th>DESCRIPTION</th>
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<tr>
<td>SID</td>
<td>Set ID. Id of a set defined by SETTYP</td>
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<tr>
<td>STYPE</td>
<td>Set type:</td>
</tr>
<tr>
<td></td>
<td>ALE part set/ALE part/Part set coupled to ALE/ etc.</td>
</tr>
<tr>
<td>MMSID</td>
<td>Multi-Material Group Set Id</td>
</tr>
<tr>
<td></td>
<td>GT.0: Refine ALE cells having at least one of the ALE MMG</td>
</tr>
<tr>
<td></td>
<td>LT.0: Refine ALE cells only having mix of the ALE MMG</td>
</tr>
<tr>
<td>NLVL</td>
<td>Number of levels of refinement</td>
</tr>
</tbody>
</table>

**Example:**

- NLVL = 1
- NLVL = 2
Application: Underwater explosion

*S A L E  R E F I N E

Original mesh: 11 min. 16 sec.
History pressure in h2528
ALE static adaptive

*ALE_REFINE
Catch better pressure front

Globally refined mesh: 53 min. 04 sec.
History pressure in h23717

Locally refined mesh: 15 min. 52 sec.
History pressure in h6325
ALE static adaptive

*ALE_REFINE

A: Original mesh (H2528)
B: Locally refined (H6325)
C: Globally refined (H23717)

Graph showing spherical charge in water over time with pressure in E-03.
**ALE dynamic adaptive**

**Purpose:** The 2nd line allows to dynamically refine the ALE mesh

<table>
<thead>
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<table>
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<th>FREQ</th>
<th>CRITERIA</th>
<th>VALUE</th>
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<tr>
<td>Type</td>
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<td>I</td>
<td>I</td>
<td>F</td>
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</tbody>
</table>

**VARIABLE**

- **NELEM**: Number of ALE elements to refine
- **FREQ**: Number of cycles between each refinements
- **CRITERIA**: Criteria type for the refinement:
  - **EQ.1**: Pressure
  - **EQ.2**: Divergence of velocity
  - **EQ.3**: Volume fraction
- **VALUE**: Threshold value for mesh fission/fusion
Every cycle dynamically refine 300 ALE cells that:

1) coupled to the structure
2) mixed with air and water
3) volume fractions > 0.0
Problem

- Single layer to ensure the flatness around vents
- Those elements will stretch a lot from their original geometry
- Bucket sort region size will increase by $L^3$ for correct searching

Solution

- A multi-step bucketsort algorithm is implemented in the latest R5.1.1 and development code
Performance issue with null shells

Single layer of vent with null shells
Performance issue with null shells

Time/zone cycle

with null shells

without null shells

Simple CAB 12

Glstat Data

A nzc
B nzc
Performance issue with null shells
Performance issue with null shells

with null shells and new bucket sort
Performance issue with null shells

Implemented a new bucket sort algorithm to improve the performance –
Please download the latest exe from beta site
Conclusions: Summary

- LSTC is working to be the leader in cost effective large scale numerical simulations
  - LSTC is providing dummy, barrier, and head form models to reduce customer costs.
  - LS-PrePost, LS-Opt, and LS-TaSC 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 scalable implicit solver is quickly gaining market acceptance for linear/nonlinear implicit calculations and simulations
  - Robustness, speed, accuracy, and scalability have rapidly improved
  - New developments:
    - Combined implicit and explicit running together
    - Linear analysis combined with h-adaptivity
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 will be available soon
  - Discrete element methodology for modeling granular materials
  - Simulation based airbag folding and THUMS dummy positioning underway
- Multiscale capabilities are under development
  - Implementation underway (New approach which is more user friendly)
- Hybrid MPI/OPENMP developments are showing significant advantages at high number of processors for both explicit and implicit solutions
JUNE 03 - 05, 2012 at the Hyatt Regency Dearborn, Detroit, MI

12th Int’l LS-DYNA Users Conference  www.ls-dynaconferences.com

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