Current and future developments of LS-DYNA I

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LS-DYNA User's Meeting
4th European LS-DYNA Conference

LSTC Livermore Software Technology Corp.

Outline of talk

- LSTC's Perspective on the future
- Version 970 status
- Recent developments for crash
- Arbitrary Lagrangian-Eulerian Developments
- Implicit Developments
- EFG (Mesh-free) Developments
- MPP
- Outlook

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Perspective on the future

LSTC's major goal is to develop within one explicit finite element program capabilities to seamlessly solve problems that require:

- Multi-physics
- Multiple stages
- Multiple formulations
- Multi-processing

Multi-physics

- Multi-physics problems require solution methods from more than one discipline.
  - Fluid-Structure interaction
    - tire hydroplaning
    - airbag deployment
  - Thermo-mechanical problems (hot forging).
  - Bird strike on engine and its effect on the overall structural dynamics of the aircraft (impact + linear response)

Multiple stages

- Multi-stage problems require sequential simulations.
  - Manufacturing-stamping.
    1. Binderwrap (implicit dynamics)
    2. Sheet metal stamping (explicit with mass scaling)
    3. Spring back (dies removed-implicit static).
  - Manufacturing simulation imported into performance simulation.
    1. Crash simulation accounts for effects of manufacturing processing
  - Static initialization of dynamic simulation.

Multiple formulations

- No single solution method is suitable for all applications.
  - Solid mechanics:
    - Degree of deformation:
      - Nonlinear elements for large deformations.
      - Linear elements for eigenvalues, superelements, and linear structural analyses.
    - Dynamics:
      - Explicit methods for short duration transient problems.
      - Implicit methods for static and long duration problems.
      - Instantaneously switch between methods

Multi-processing

- Massively Parallel Processing (MPP) is here to stay.
  - MPP is moving downscale: Desktop MPP under Unix, Windows, and Linux environments
  - Heterogeneous processing.
    - Processing across high speed networks.
  - Large MPP machines have many parallel jobs running simultaneously on subsets of processors.
    - 12-32 are preferred for LS-DYNA
  - Stamping analysis with adaptivity is ideally suited to MPP machines due to the simplicity of contact.

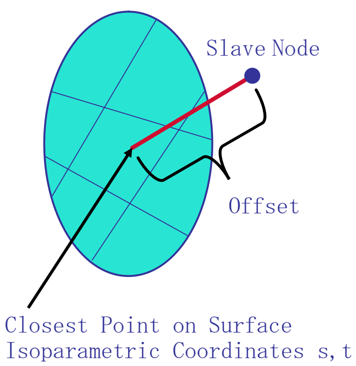
Version 970 status

- Now used at many customer sites. Advantages over version 960:
  - The implicit capabilities are greatly expanded
  - The ALE airbag deployment for out-of-position occupants is nearing production level
  - The MPP version is more scalable and, therefore, faster
- 970 will become the production code at many customer sites after the updated user's manual is published
  - An updated theory manual is ready for release.

Recent crash developments

- Spotwelds
- Segment based contact
- Mesh coarsening
- Binary options for database
- Model documentation in database
- Element technology
- Constitutive models
- Rigid body related developments
- MADYMO coupling

Tied contact with offsets



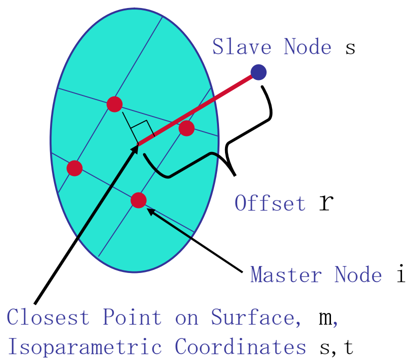
- The offset distance is fixed.
- Implemented with both constraints and penalties.
- Two algorithms are needed
  - Structural element formulation, includes rotational degrees-of-freedom
  - Continuum element formulation, no rotational degrees-of-freedom
- MPP support
- Implicit implementation for constraint method in version 970

Tied contact with offsets

- Available for contact types:
  - TIED_NODES_TO_SURFACE_{OPTION}
  - TIED_SHELL_EDGE_TO_SURFACE_{OPTION}
  - TIED_SURFACE_TO_SURFACE_{OPTION}
- Options:
  - OFFSET
    - Normal and tangential springs, old method which may not be orthogonal to rigid body motion
  - BEAM_OFFSET
    - Beam like penalty functions
      - Orthogonal to rigid body rotations
      - Can be numerically sensitive
  - CONSTRAINED_OFFSET
    - Exact method based on rigid body kinematics

Tied contact with offsets

Structural formulation



$$F^m = F^s$$

$$F_i^m = F^m N_i(s,t) + F_i^m$$

$$M^m = r \times F^m$$

$$M_i^m = M^m N_i(s,t) + M_i^m$$

$$V^m = \sum V_i^m N_i(s,t)$$

$$\omega^m = \sum \omega_i^m N_i(s,t)$$

$$A^m = \sum A_i^m N_i(s,t)$$

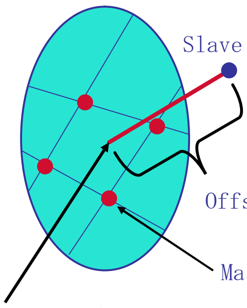
$$\dot{\omega}^m = \sum \dot{\omega}_i^m N_i(s,t)$$

$$V^s = V^m + \omega^m \times r$$

$$A^s = A^m + \dot{\omega}^m \times r + \omega^m \times (\omega^m \times r)$$

Tied contact with offsets

Solid formulation



Virtual Work

$$P = M^T \omega = F^T V$$

$$\omega \times r = R\omega$$

$$R = \begin{bmatrix} 0 & z & -y \\ -z & 0 & x \\ y & -x & 0 \end{bmatrix}$$

Least Squares Relation Between w and V

$$J = \tfrac{1}{2} \sum (R_i\omega - \delta V_i^m) \cdot (R_i\omega - \delta V_i^m)$$

$$\delta V_i^m = V_i^m - V^m$$

$$\omega = \left[\sum_i R_i^T R_i \right]^{-1} \sum_j R_j^T \delta V_j^m$$

Exact for Rigid Body Motion

Tied contact with offsets

Solid formulation

$$F_i^m = F^s N_i(s,t)$$

$$M^m = r \times F^s$$

$$\tilde{F}_i^m = R_i [\sum_j R_j^T R_j]^{-T} M^m$$

Forces on Master Segment

$\tilde{F}_i^m$ equivalent forces due to slave force offset

$$\omega = \left[\sum_i R_i^T R_i \right] \sum_j R_j \delta V_j^m$$

$$\dot{\omega} = \left[\sum_i R_i^T R_i \right] \sum_j R_j \delta A_j^m$$

$$\delta A_j^m = A_j^m - A^m - \omega \times (\omega \times r_j)$$

$$V^s = V^m + \omega \times r$$

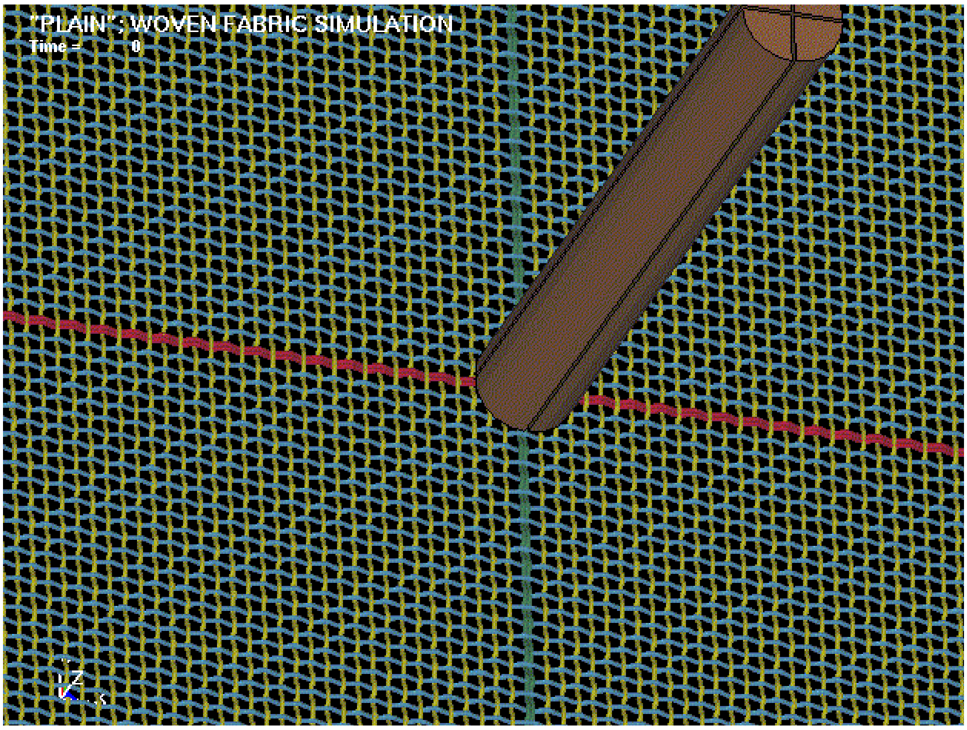
$$A^s = A^m + \dot{\omega} \times r + \omega \times (\omega \times r)$$

Update of Slave Node

Exact for Rigid Body Motion

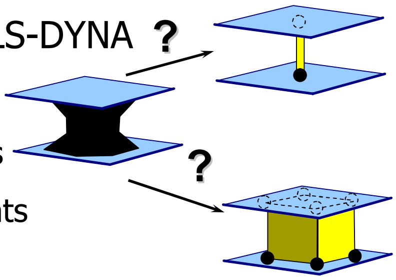
Frictional beam contact

- Recently improvements have been made in beam-to-beam contact
  - Post contact searching to reduce the number of required global searches
  - Soft constraint option is added to improve reliability
  - Interface friction between beams
  - Implicit implementation



Spotweld modeling

- Connection of shell surfaces
- Spotweld models in LS-DYNA ?
  - Nodal rigid bodies
  - Deformable beams
  - Continuum elements



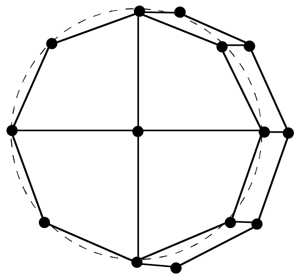
Spotweld modeling (bricks)

- Advantages
  - Contact nodes on both surfaces
  - Axial, bending, and torsional stiffness
  - Size is independent of surface mesh
  - Real width of spotweld is modeled
- Disadvantages
  - Mass scaling is needed
  - Orientation required for resultant based failure

Spotweld modeling (4-bricks)

Compared to 1 brick

- Mass scaling is similar and overall problem cost increase is insignificant.
- Interface forces are realistically distributed



Spotweld modeling (mat_100)

- To avoid time step size problems, the desired time step size is defined for *MAT_SPOTWELD:
  - LS-DYNA prints out the added mass for Δt.
- Failure can be based on plastic strain, resultants, or a combination of plastic strain and resultants:

$$\left(\frac{N_{rr}}{N_{rr_F}}\right)^2+\left(\frac{N_{rs}}{N_{rs_F}}\right)^2+\left(\frac{N_{rt}}{N_{rt_F}}\right)^2+\left(\frac{M_{ss}}{M_{ss_F}}\right)^2+\left(\frac{M_{tt}}{M_{tt_F}}\right)^2+\left(\frac{T_{rr}}{T_{rr_F}}\right)^2-1=0$$

  - The resultants are computed from the nodal point forces.
    - Currently limited to one brick per spot weld

New spotweld failure criterion

The stress based failure model for beam and solid spot welds, developed at Toyota Motor Corporation, is based on the peak axial and transverse shear stresses, fails the entire weld if the stresses are outside of the failure surface defined by

$$\left(\frac{\sigma_{rr}}{\sigma_{rr}^F}\right)^2 + \left(\frac{\tau}{\tau^F}\right)^2 - 1 = 0$$

The peak stresses are calculated from the resultants using simple beam theory.

$$\sigma_{rr} = \frac{N_{rr}}{A} + \frac{\sqrt{M_{rs}^2 + M_{rt}^2}}{Z} \qquad \tau = \frac{M_{rr}}{2Z} + \frac{\sqrt{N_{rs}^2 + N_{rt}^2}}{A}$$

$$A = \pi \frac{d^2}{4} \qquad Z = \pi \frac{d^3}{32}$$

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New spotweld failure criterion

- Three additional failure calculations have been implemented for beam spot welds
  - Notch stress
  - Stress intensity factor
  - Structural stress

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MPP segment based contact

The name, "Segment Based Contact"

is motivated by the most fundamental difference between segment-based contact and the standard LS-DYNA penalty contact:

Standard Contact*

detects penetration of nodes into segments and applies penalty forces to the penetrating node and the segment nodes.

The name, "Segment Based Contact"

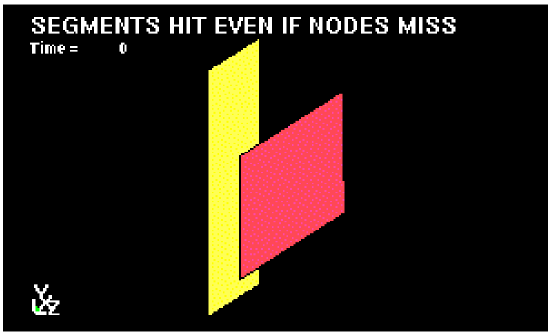
is motivated by the most fundamental difference between segment-based contact and the standard LS-DYNA penalty contact:

*standard contact refers collectively to these 9 contact types: 3, a3, 10, a10, 4, 13, a13, 14, and 15 with soft=0 or soft=1.

Segment-based vs. standard

Segments hit even if nodes miss

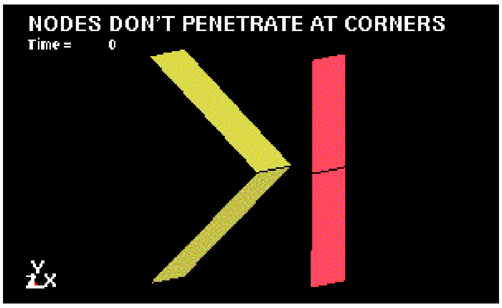
- Because penetration of segments by segments is checked rather than penetration of segments by nodes.



Segment-based vs. standard

Sharp corners are easily handled

Because contact is detected between segments, individual nodes cannot go undetected and slip into spaces between segments at corners



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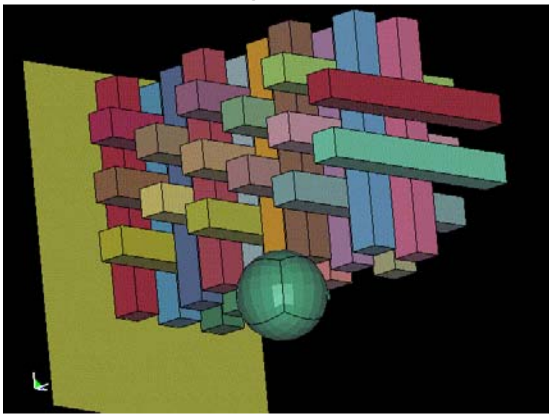
Falling blocks-segment based

One brick element defines each block. Nodes do not make contact with contact segments.



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Mesh coarsening for crash

- The current coarsening capability in LSDYNA for metalforming has now been extended to provide seamless mesh coarsening for crash applications
- Process Outline
  - Define elements to be coarsened (default=ALL)
  - Perform Internal Coarsening
    - Respect existing constraints
    - Establish new adaptive constraints
  - Initialize new mesh
  - Perform calculations

Applications for coarsening

- Process Allows Seamless Transition From One-Detailed Model to Various Impact Scenarios Saving Multi-Model Maintenance and CPU Costs
  - Front Impact
  - Rear Impact
  - Side Impact
  - Head-Impact
  - Pedestrian Impact

Binary option for ascii files

- What it is not
  - A file format
  - Proprietary
- What it is
  - I/O library developed by LSTC
    - Portable
    - Robust
    - Flexible
- Source code is available on ftp site

Binary option for ascii files

- Flexibility
  - Acts like a file system
    - Directories
    - Variables, Name, Type, Length
  - New data won't break old applications
  - Easy to use
- Efficiency and portability
  - Binary files
  - Library handles size/format conversions

Binary option for ascii files

- "ASCII" output files
  - All can be output in this format today.
  - Serial and MPP codes
  - ASCII (Default on SMP and serial machines)
  - Binary (Default on MPP machines)
  - Both ASCII and Binary possible
- LS-POST is able to read and post-process the binary database

Model documentation

- ID's with descriptor information are now available for:
  - Airbags
  - Contact
  - Cross-section definitions
  - Joints
  - Parts
  - Rigid Walls
  - Nodes
  - Elements
  - SPC's
  - Displacement boundary conditions

Model documentation

- To keep upwards compatibility, _ID causes ID and heading information to be read.

- This additional information is written into the ASCII files, and their binary counterpart, to help in post-processing

Model documentation

- The ASCII files which now include model documentation information are:
  - NODOUT, nodal information
  - ELOUT, element information
  - JNTFORC, joint forces
  - MATSUM, part statistics
  - SECFORC, section forces
  - RCFORC, contact reaction forces
  - ABSTAT, airbag statistics file
  - RWFORC, rigid wall force file
  - SPCFORC, single point constraint reaction forces
  - BNDOUT, reaction forces due to applied displacements

Abnormal termination-shells

- An abnormal termination will occur if a zero or negative Jacobian develops in a shell element.
  - More severe in fully integrated elements
- Such terminations can be hard to debug to make appropriate model changes.
- Special checking is now available to identify "bad" elements and either, cleanly terminate, or delete the element and continue running.
  - Two flags control the checking, one for 1 point elements and the other for fully integrated elements

Thermal shell

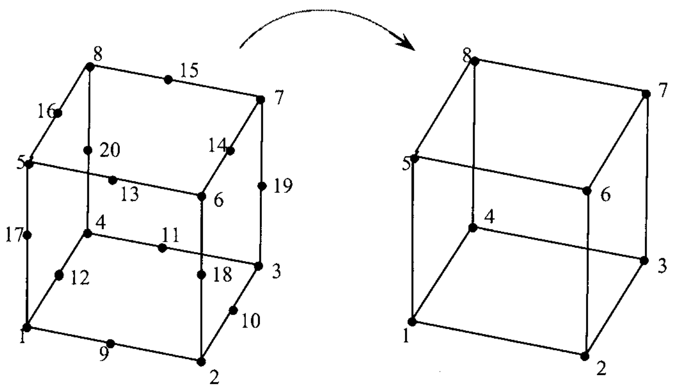
A single input flag activates the thermal shell.

- 8 fictitious nodes are created automatically to represent the upper and lower shell surfaces.
- A quadratic temperature variation is obtained through the shell thickness.
- A stiffness matrix is created for implicit solution method used in LS-DYNA for heat transfer
  - Element stiffness is based on 12-node brick element.
  - The conjugate gradient solution method is used for speed.
- Thermal contact possible through projected surfaces

Beam element enhancements

- Offsets of the beam nodes to enable a beam to be used as a shell stiffener
  1. Added as an option for all beam formulations in version 970 for both implicit and explicit applications
- Orientation vectors to position beam
  1. Added as an option for all beam formulations that use the third orientation node
- Cross sectional warping
  - Implicit applications only-being added
    - Introduces 1 additional degree-of-freedom per node so scalar nodes are being added to handle the additional DOF.

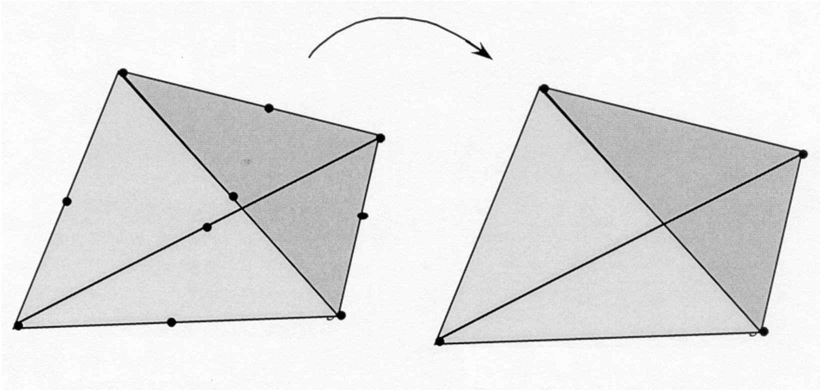
Implicit hexahedron element



DOF u_i, v_i, w_i

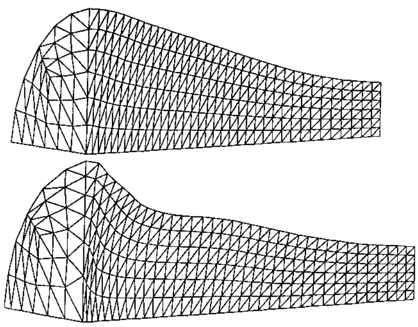
DOF $u_i, v_i, w_i, \theta_{xi}, \theta_{yi}, \theta_{zi}$

Implicit tetrahedron element



24-dof tetrahedron

A comparison of the 12 and 24 degree-of-freedom tetrahedron elements is shown.



10-node tetrahedron element

- Implemented for MPP and SMP
- Same cost per element cycle as SRI solid element. Δt is small due to high frequencies
- Contact treated automatically by 4 triangles for each face
- Available for both implicit and explicit calculations
- 4 or 5 integration points, constant pressure

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Element_direct_matrix_input

- Option for reading and using superelements in explicit computations is now extended to implicit applications
- Required input is a file in Real*8 NASTRAN format containing:
  - Mass Matrix (must be positive definite)
  - Stiffness Matrix
  - Damping Matrix (optional)
- The matrices share degrees of freedom with model boundaries and also introduce additional degrees of freedom with nodes and generalized coordinates.

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Material definitions

- Materials in version 970 can be defined by a "long" name or a short name, i.e.,
  - *MAT_TRANSVERSLY_ANISOTROPIC_CRUSHABLE_FOAM or simply, *MAT_142
  - Applies to all material models.

Orthotropic viscoplastic

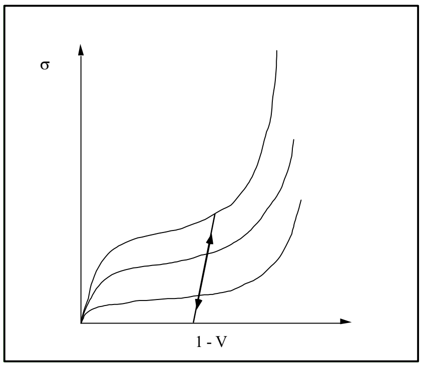
- Available for material models:
  - *MAT_SIMPLIFIED_JOHNSON_COOK
  - *MAT_PLASTICITY_WITH_DAMAGE
- Viscoplasticity is optional
  - 40% more costly due to iterative algorithm
- Damage evolves monotonically in principle strain directions in tension only. Orthotropic behavior after failure.
    - Better correlation with experimental data
    - Consistent results with minor input changes

Transversely_anisotropic_crushable_foam

- For modeling low density extruded foam with anisotropic behavior, typically with high strength in the extruded direction
  - Used in energy absorbing structures to enhance automotive safety in low and medium velocity impacts
  - Zero Poisson's ratio under longitudinal loads
  - A smooth anisotropic yield surface produces physically correct behavior, i.e. weaker in off-axis loading
  - Variable coefficients are used which depend on volumetric strain
- Accurate off-axis loading provides better results than MAT_HONEYCOMB

Modified_crushable_foam

- Rate effects are available in the extension to the isotropic crushable foam model. (*MAT_163)



Quasilinear_viscoelastic

- A new model for biological tissues.

$$\dot{\varepsilon}_1 < \dot{\varepsilon}_2 < \dot{\varepsilon}_3$$

$$G(t) = \sum_{i=1}^{NT} G_i \exp(-\beta_i t)$$

$$\sigma^{(\varepsilon)}(\varepsilon) = \sum_{i=1}^{6} \sigma_i \varepsilon^i$$

- Up to 12 terms may be include in the Prony series
  - Built in lease squares fit optional
- Implemented for solid elements-explicit only.

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Hill_foam

A new hyperelastic compressible foam model, which captures Poisson's ratio effects. The Cauchy stresses are defined in terms of J and the principal stretches as:

$$t_i = \frac{1}{J}\left\{ \sum_{j=1}^{m} C_j \left(\lambda_i^{b_j} - J^{-nb_j} \right) \right\}$$

where i=1,2,3

A least squares fit is available for C_j and b_j if uniaxial or biaxial tension and compression test data is available.

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Viscoelastic_hill_foam

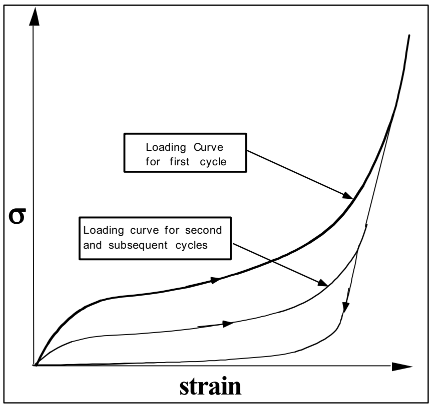
- Rate effects are taken into account through linear viscoelasticity by a convolution integral of the form:

$$\sigma_{ij} = \int_0^t g_{ijkl}(t-\tau)\frac{\partial \varepsilon_{kl}}{\partial \tau}\,d\tau$$

- The viscoelastic stresses are added to the stress tensor determined from the strain energy functional.
- A least squares fit is available to determine the viscoelastic constants

Low_density_synthetic_foam

- For modeling rate independent low density foams, which have the property that the hysteresis in the loading-unloading curve is considerably reduced after the first loading cycle.
- After the first loading cycle the loading-unloading curve is identical
- If orthotropic behavior develops after the first loading cycle where the material behavior in the orthogonal directions are unaffected then the _ORTHO option should be used



Simplified_rubber

- Uses uniaxial data given by a load curve which is defined for the entire range of expected behavior
  - Force versus change in gauge length, i.e., nominal stress versus engineering strain can be used
- Table may be used to include strain rate effects
  - Models hysterisis
  - Engineering strain rates are optional
- No fitting of material parameters means that nearly all rubber like behavior can be approximately simulated

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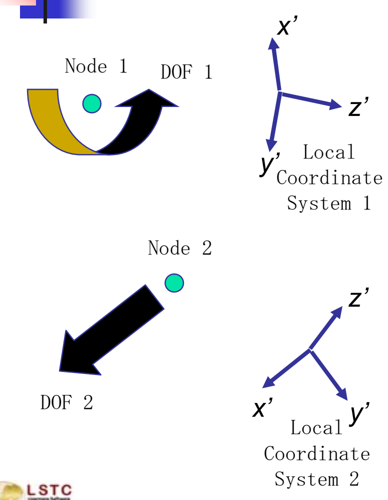
1dof_generalized_spring



Couples arbitrary degrees of freedom between nodes with springs and dampers.

$$\begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix} = -K\begin{bmatrix} a_1^2 & -a_1a_2 \\ -a_1a_2 & a_2^2 \end{bmatrix}\begin{Bmatrix} q_1 \\ q_2 \end{Bmatrix} - C\begin{bmatrix} a_1^2 & -a_1a_2 \\ -a_1a_2 & a_2^2 \end{bmatrix}\begin{Bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{Bmatrix}$$

- Fi = Generalized force for node i.
- qi = Displacement for node i.
- qi = Velocity for node i.
- ai = Scale factor for node i.
- K = Stiffness.
- C = Damping.

Available in both explicit and implicit.

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Nodal rigid bodies

Two new features are implemented for *CONSTRAINED_NODAL_RIGID_BODY

- Release flags for nodal degrees-of-freedom that allow the translation of the RBE2 constraints in NASTRAN into the nodal rigid body option
  - Either local or global system
  - Can simulate joints between deformable bodies
  - Implicit implementation allows the chaining of rigid bodies
- Center of mass constraint with _SPC option
  - Either local or global system

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Constrained_interpolation

- The motion of a single independent node is interpolated from the motion of a set in independent nodes.
- Can now be applied in either a <u>local</u> or a global coordinate system.
- <u>Implicit</u> and explicit implementations
- Some applications
  - Tie beam or shell elements to solid elements.
  - Distribute mass and inertia from the dependent node to the surrounding independent nodes
  - Distribute forces and moments from dependent node to independent nodes

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Joint failure

- OBJECTIVE: Model mechanical failures in joints without the cost of a finite element model of the joints.
  - Requested by Federal Highway Administration
- Failure criteria are based on forces and moments.
  - Failure criteria when force and moment failure are uncoupled:

$$\left(\frac{\max(N_{xx},0)}{N_{xx_F}}\right)^2+\left(\frac{N_{yy}}{N_{yy_F}}\right)^2+\left(\frac{N_{zz}}{N_{zz_F}}\right)^2-1=0 \qquad \left(\frac{M_{xx}}{M_{xx_F}}\right)^2+\left(\frac{M_{yy}}{M_{yy_F}}\right)^2+\left(\frac{M_{zz}}{M_{zz_F}}\right)^2-1=0$$

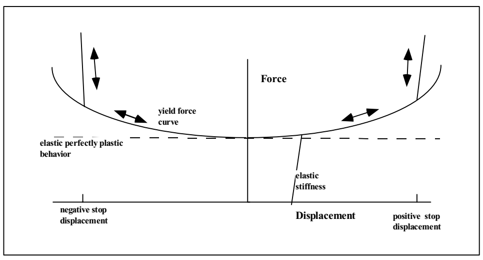
  - Failure criteria when force and moment failure are coupled.

$$\left(\frac{\max(N_{xx},0)}{N_{xx_F}}\right)^2+\left(\frac{N_{yy}}{N_{yy_F}}\right)^2+\left(\frac{N_{zz}}{N_{zz_F}}\right)^2+\left(\frac{M_{xx}}{M_{xx_F}}\right)^2+\left(\frac{M_{yy}}{M_{yy_F}}\right)^2+\left(\frac{M_{zz}}{M_{zz_F}}\right)^2-1=0$$

  - If the value of a failure constant is zero, the corresponding force or moment isn't considering in the failure criteria.
- Failure constants can be specified in either a local or the global coordinate system.

*..._Joint_stiffness_translational

- Translational stiffness has been added to joints for joint types
  - Cylindrical Joint
  - Translational joint
  - Planar joint



Madymo coupling

- Extended coupling allows users to link most MADYMO geometric entities with LS-DYNA FEM simulations.
  - FEM element/nodes.
  - FACET surfaces.
  - Ellipsoids/Planes.
  - This gives LS-DYNA Users access to the most advanced MADYMO Dummy & Human models.
- The MADYMO contact algorithm will be used to calculate loading between the two models.
  - User can access elastic loading with hysteresis/damping/friction.
  - MADYMO FEM Element Groups will be assigned to an LS-DYNA Material, allowing these entities to be defined in contacts with other LS-DYNA materials.

Extended MADYMO coupling

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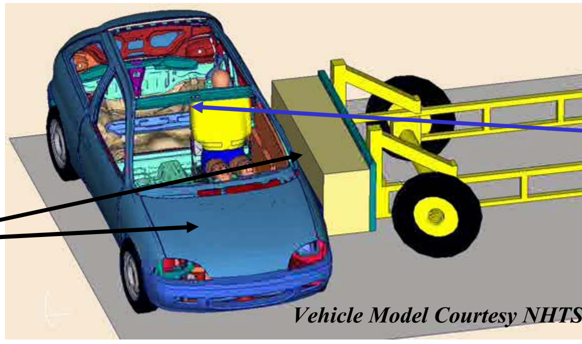
Example: us-sid & es2 in lincap

- Vehicle/barrier/seat are LS-DYNA models.
- FEM Dummies are MADYMO models.
- Side Inner Panel + Side Trim Panels are the coupled entities.



Vehicle Model Courtesy NHTSA.

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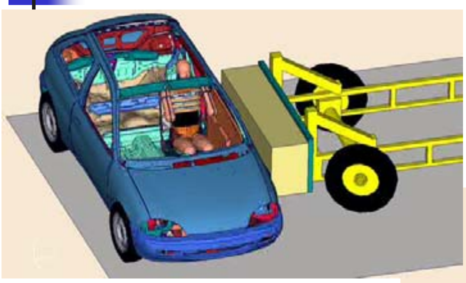
Lincap with fem es2



•Beta release of v6.0/v970 available at the end of May, 2002.

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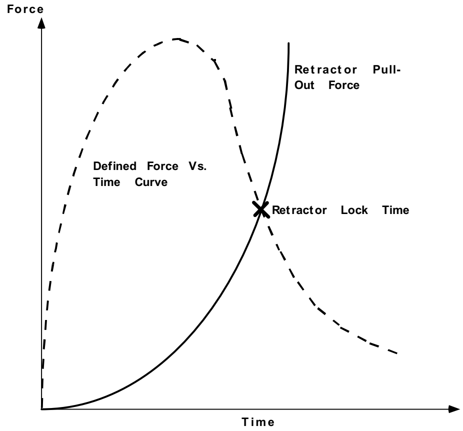
Seatbelt pretensioner option

Force versus time can now be defined:



Nastran interface

- A NASTRAN reader, developed for Superwhams by KBS2 Inc., is now embedded in LS-DYNA version 970 to allow NASTRAN input decks to run directly in LS-DYNA without translation.
  - Advantages:
    - Many production problems setup in NASTRAN format exist for normal modes, statics, and buckling that can be used for verification of linear capabilities and constraint equations
    - Nastran input can be augmented by LS-DYNA input to allow one model for NVH and crash.
    - First line in the input file: *NASTRAN or, alternatively, *INCLUDE_ NASTRAN followed by the file name
      - Allows change of element formulations
      - Mix LS-DYNA input with NASTRAN input.

Normal trimming

- Normal (or 3D) trimming has been implemented, the new features include
  - No vector is required
  - Trimming curves are projected to the element based on its normal
  - Trimming curve could include several segments
  - Both digitized and IGES data are supported
- Availability:
  - It is available in LS970
  - The Keyword is *DEFINE_CURVE_TRIM_3D

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Normal trimming

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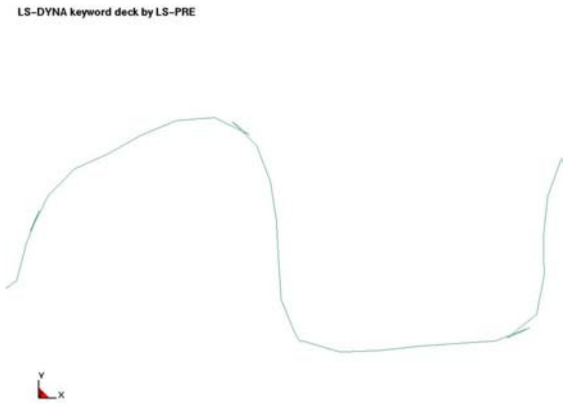
Normal trimming

This method allow distorted Trimming curve



Cam trimming

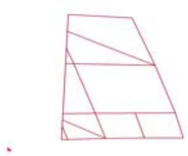
- One more feature available for cam trimming:
  - Trimming curve can be defined in global coordinate
  - In *DEFINE_CURVE_TRIM, one more parameter is added
    - The seventh parameter, iglobal=1, will activate this feature

Trimming improvements

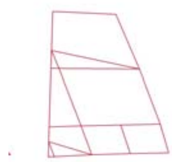
- Trimming causes
  - Poor aspect ratios
  - Large internal angles
  - Element size is too small
- Side effect
  - Poor convergence for the implicit springback prediction
  - Poor mesh for next forming stage

Element quality check

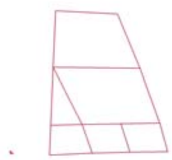
- After trimming, elements are checked for
  - Size
  - Distortion
  - Aspect ratio
  - Internal angles
  - Adaptivity patterns
- After checking any deficiencies are removed



Original result



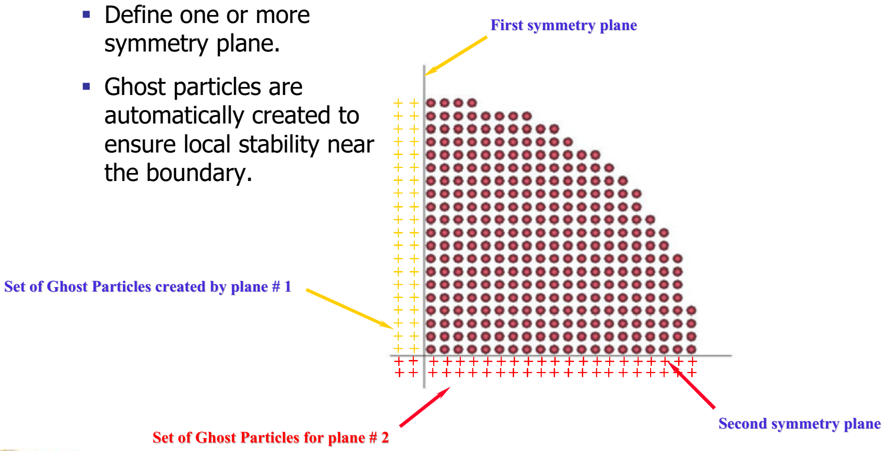
New trimming



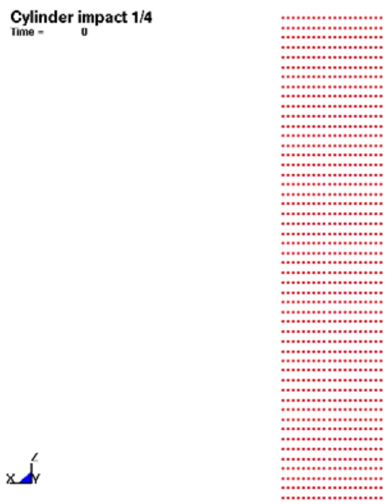
Element Checking/Fixing

Symmetry plane with SPH

- Define one or more symmetry plane.
- Ghost particles are automatically created to ensure local stability near the boundary.



Symmetry Plane with SPH



New ALE developments

- MPP
- Improved fluid-structure interaction
- Fluid-structure interaction output
- Point sources for gases
- *EOS_IDEAL_GAS and *MAT_GAS_MIXTURE
- *MAT_VACUUM for MMALE simulations
- New mesh smoothing algorithm for high explosive simulations
- *INITIAL_VOLUME_FRACTION_GEOMETRY, volume fraction distribution for simple and complex geometries.

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Mpp ALE capability

- Design of airbags for out-of-position occupants has created huge interest in ALE capabilities in automotive design
  - Control volume approach for airbag inflation predicts bag pressures that are unrealistically high and cannot be used for design purposes
- 1 processor requires 2 weeks per calculation. 32 processors < 12 hours
- Much effort is being spent in ALE development for airbag deployment

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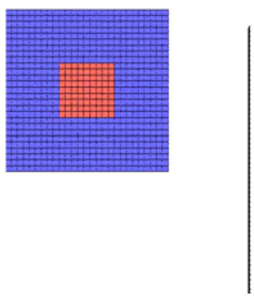
Fluid structure interaction

Keyword: *CONSTRAINED_LAGRANGE_IN_SOLID

- Leakage control
- Viscous damping
- Alternative penalty stiffness definition for better numerical stability
- Automatic time step adjustment at high penalty stiffness

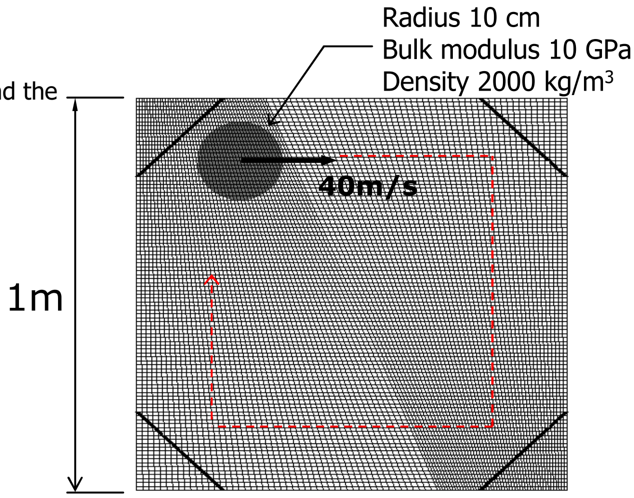
ALE structural coupling

- Prescribed motion of nodes following user defined load curves, and rigid body translation of mesh following mass flow



Bouncing ball

Evaluation:
check the path and the shape of the ball



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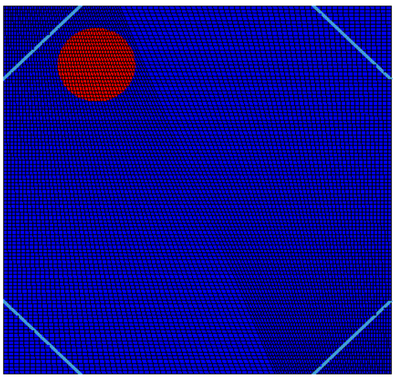
Bouncing ball

Second order accurate advection with interface reconstruction preserves shape of rubber ball.



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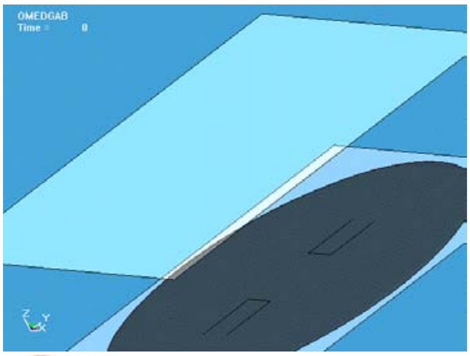
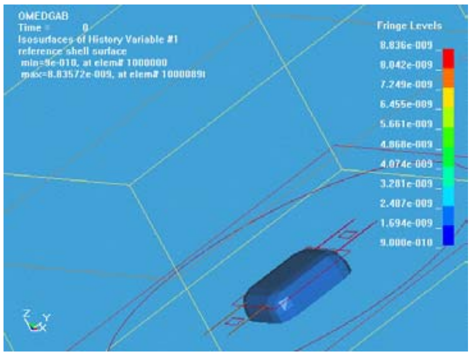
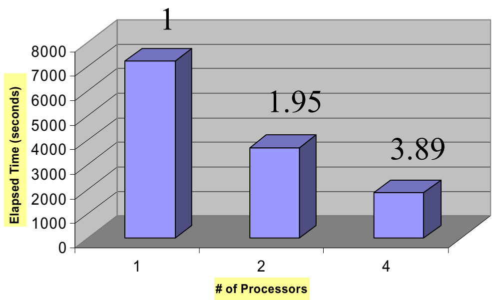
Flat airbag deployed with ALE

- Shells – 2752
- ALE Solids - 43200





Speed-up



FSI output

Keyword: *DATABASE_FSI

pressure x-force y-force z-force porous leakage mass flux through surface

```
Fluid-structure interaction output
Number of surfaces:  2

id     p            fx           fy           fz           pleak        mflux

   time=  0.00000E+00
 1     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
 2     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00

   time=  0.10200E-03
 1     0.1632E+05   0.4091E+01  -0.3215E+01   0.2546E+01   0.0000E+00  -0.1284E-04
 2     0.1947E+05  -0.4878E+01  -0.4174E+01   0.2548E+01   0.0000E+00  -0.7193E-05
```

New EOS for gases

Keyword: *EOS_IDEAL_GAS

$$p = \rho(\gamma - 1)C_V T$$

$$\gamma = C_P / C_V$$

$$C_V = C_{V0} + C_L T + C_L T^2$$

$$C_P = C_{P0} + C_L T + C_L T^2$$

New gas mixture model

Keyword: *MAT_GAS_MIXTURE

The model is designed for the treatment of hybrid inflators in coupled ALE-airbag models. ***MAT_GAS_MIXTURE** handles the mixing of up to eight different ideal gases.

Special action is taken to conserve the total energy in the Eulerian advection step. Dissipated kinetic energy is automatically transformed into heat.

up to eight different gases

$$p = \sum_{i=1}^{N} \rho_i (C_{Pi} - C_{Vi}) T$$

density and heat capacities of the different gas species

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Point sources

Keyword: *SECTION_POINT_SOURCE_MIXTURE

The command is used to model hybrid inflators for coupled ALE-airbag simulations.

```
*SECTION_POINT_SOURCE_MIXTURE
SID     LCT     .       LCV     NIDL1   NIDL2   NIDL3
LCM1    LCM2    LCM3    LCM4    LCM5    LCM6    LCM7    LCM8
NID1    VID1    AREA1
NID2    VID2    AREA2
.
NIDn    VIDn    AREAn
```

- SID: section ID
- LCT: dynamic inlet temperature
- LCV: inlet gas flow velocity
- LCM1 … LCM8: mass flow rates of the different gas species
- NID1 … NIDn, VID1 … VIDn, AREA1 … AREAn: *n* point sources
- AREAn: point source inlet areas
- VIDn: vectors defining the initial flow direction
- NIDn: nodes defining the initial location of the point sources

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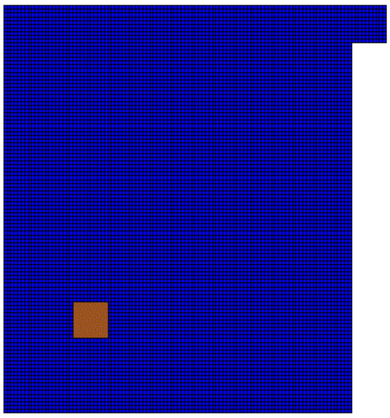
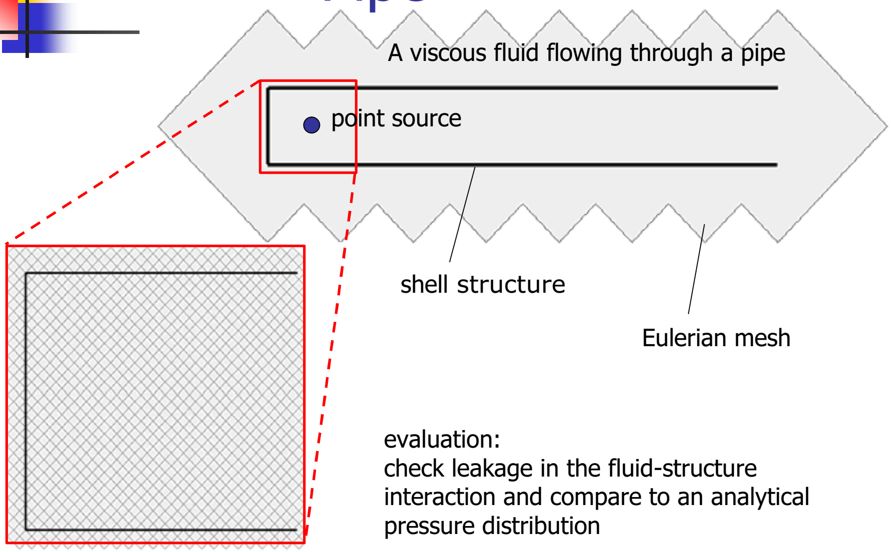
Point sources-airbag inflators

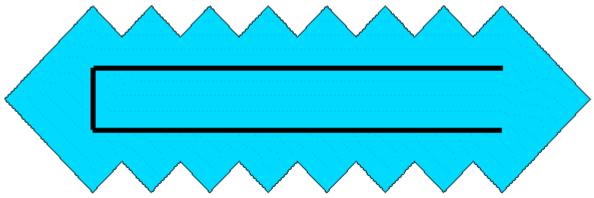


Pipe



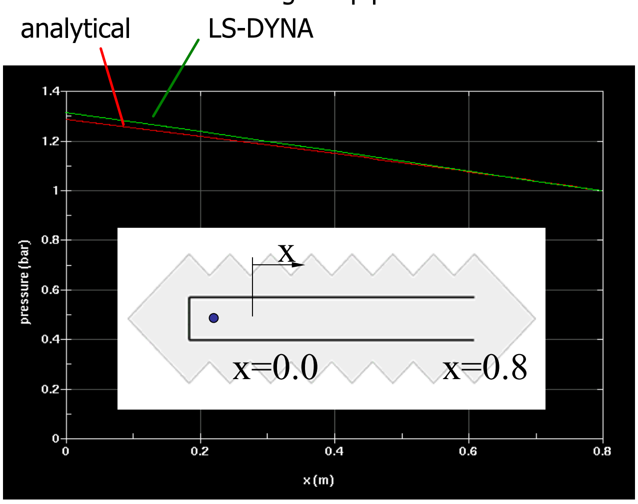
Pipe

A viscous fluid flowing through a pipe



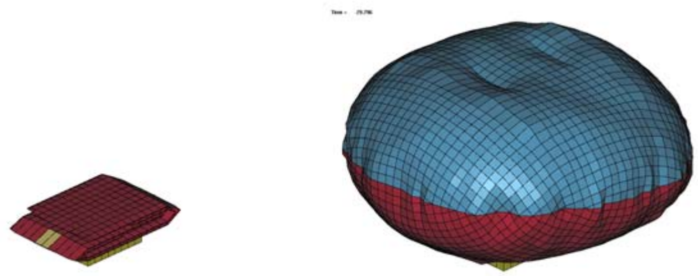
Pipe

Pressure distribution along the pipe



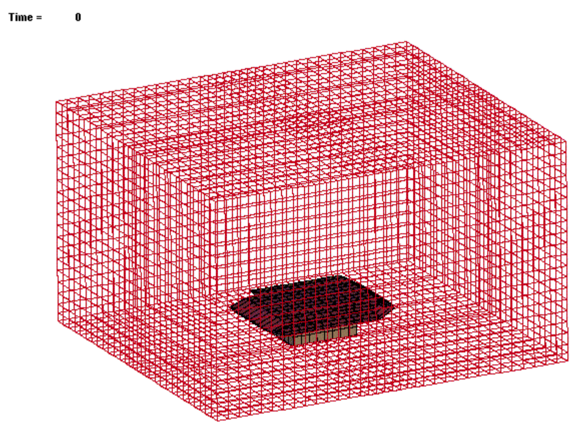
Airbag model

We have tested a small airbag, deployed with a hybrid inflator, in both a uniform pressure model and in a fully coupled Eulerian model. The inflator and the gas mixture are modeled with *SECTION_POINT_SOURCE_MIXTURE and with *MAT_GAS_MIXTURE.



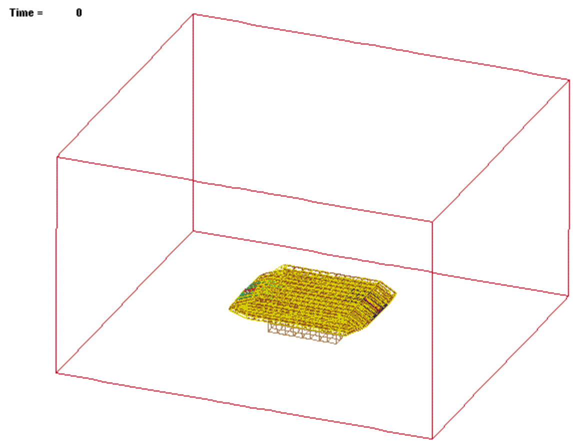
Airbag model

Airbag inside fluid mesh



Airbag model

Gases inside bag



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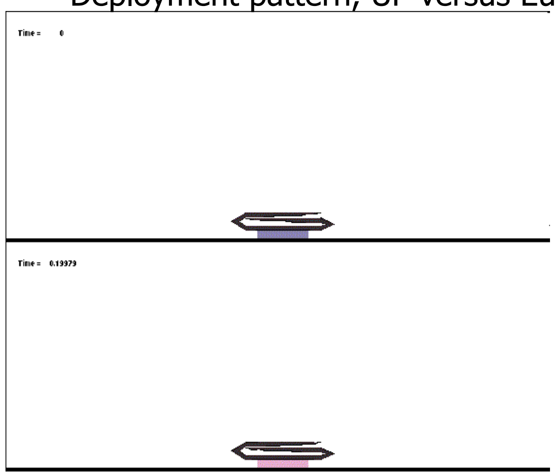
Airbag model

Deployment pattern, UP versus Euler



Uniform pressure

Euler

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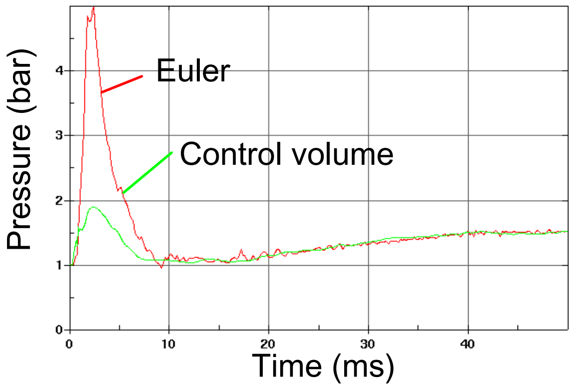
Airbag model

Gas pressure inside airbag



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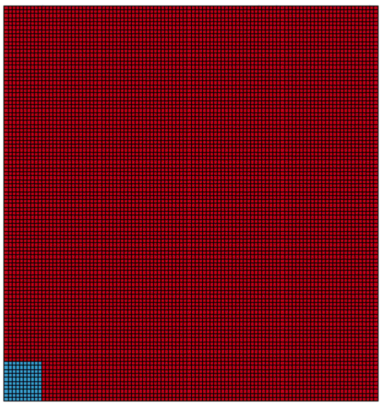
ALE smoothing for shock fronts



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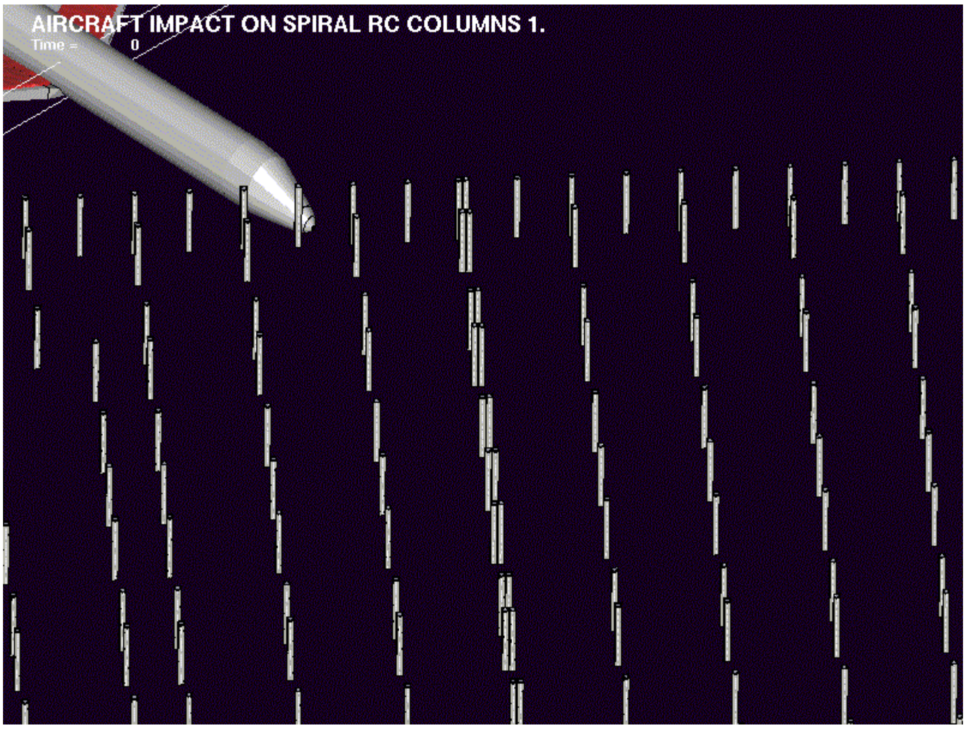
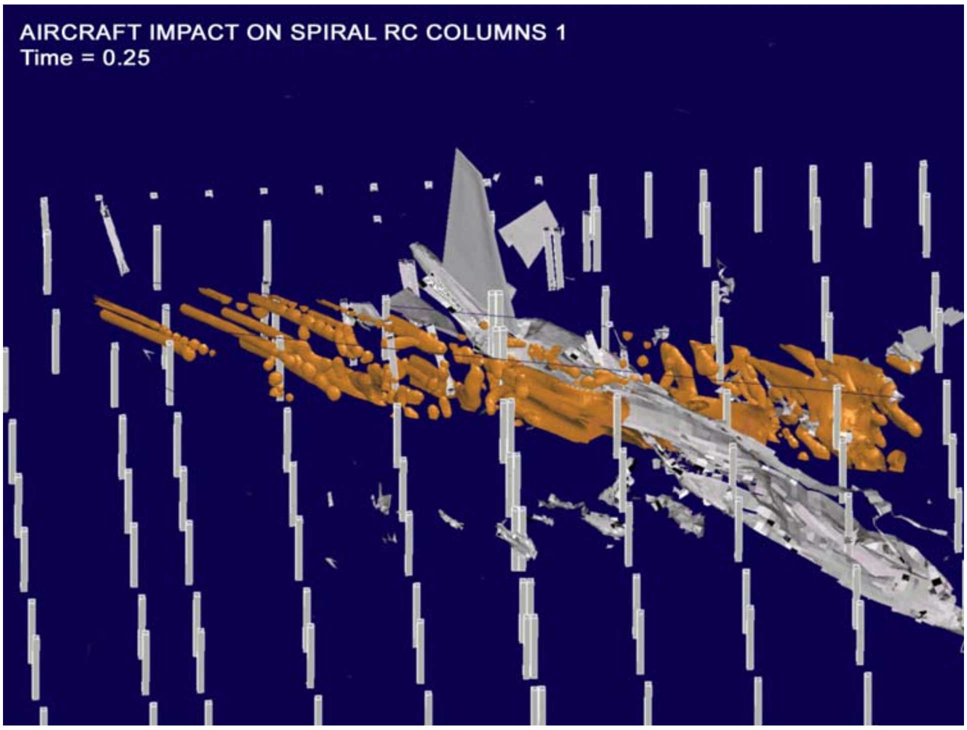
Boeing 757 pentagon impact

Courtesy of Purdue University, Department of Civil Engineering, Prof. M. Sozen.

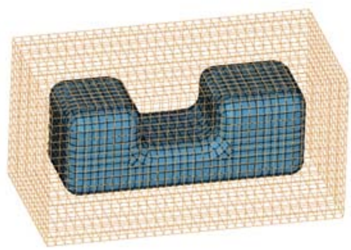
Calculations and modeling: Dr. Sami Kilic





Initialization of volume fraction

*INITIAL_VOLUME_FRACTION_GEOMETRY
Initializing the inside of the tank with fluid



LSTC

Initialization of volume fraction

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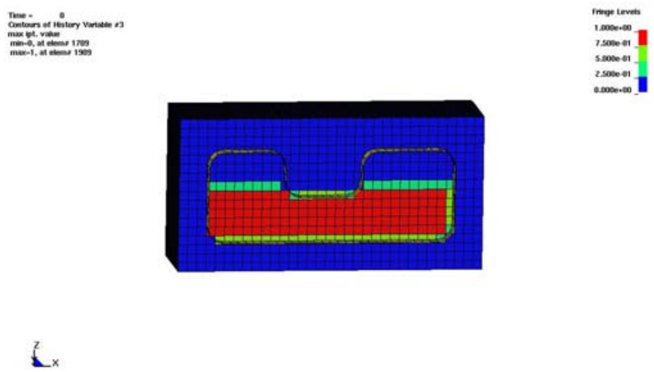
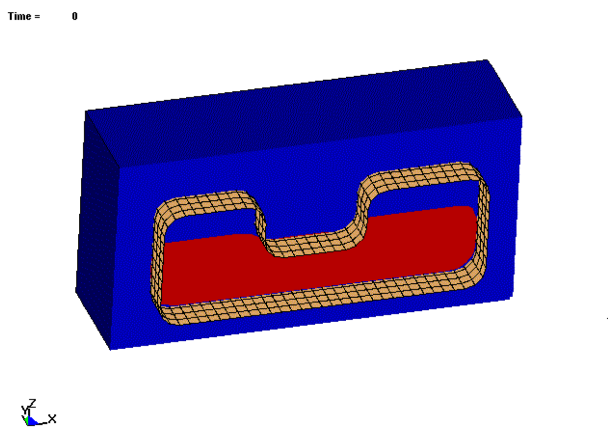


LSTC

Initialization of volume fraction

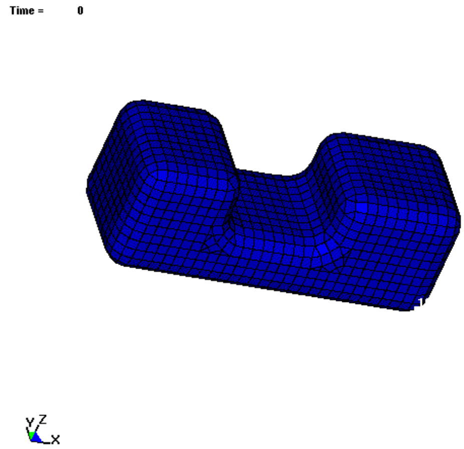
Sloshing tank, volume fraction of fluid inside deformable tank



LSTC

Initialization of volume fraction

Sloshing tank, stresses in deformable tank



Combined implicit-explicit

- Adding an implicit solution option to an explicit code can utilize the extremely efficient data structures, element formulations, and contact algorithms developed for explicit analysis.
- Use latest linear direct equation solvers
  - Sparse matrix solver
  - CG iterative solvers
- Results in improved explicit algorithms
  - second order accurate formulations required for accurate implicit calculations are automatically available for explicit applications.