Current and future developments of LS-DYNA II

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

LSTC Livermore Software Technology Corp.

Implicit development

- The combined solver for explicit and implicit applications focuses the entire development efforts on one comprehensive analysis code.
  - Large cost savings relative to developing separate implicit and explicit solvers that couple.
    - The stiffness matrix calculation is the main difference between implicit and explicit
    - Implicit MPP uses the explicit domain decomposition
      - *A second domain decomposition is needed by the equation solver.*
  - All developers work on explicit and implicit methodology
  - QA is performed on one code.

Current implicit capabilities

- Statics and dynamics with Newmark-β time integration
- Eigenvalues
- Linear buckling
- Newton, quasi-Newton and Arc-Length iteration schemes-line searches + rank one or two stiffness updates
    - BFGS (Default)
    - Broyden's first method
    - Davidon
    - DFP
- Contact, all types
- Constraints

Implicit rigidwalls

- The penalty method has now been implemented for all rigid walls options to support the implicit solver. (The penalty method can optionally be used for explicit calculations.)
    - RIGIDWALL_GEOMETRIC_FLAT
    - RIGIDWALL_GEOMETRIC_PRISM
    - RIGIDWALL_GEOMETRIC_CYLINDER
    - RIGIDWALL_GEOMETRIC_SPHERE
    - RIGIDWALL_PLANAR
    - RIGIDWALL_PLANAR _ORTHO
    - RIGIDWALL_PLANAR _FINITE
    - RIGIDWALL_PLANAR _MOVING
    - RIGIDWALL_PLANAR _FORCES

Combined implicit-explicit

- Dependable spring back for sheet metal stamping
- Initialization of static loads prior to transient calculations
- A reliable linear capability to automatically solve for normal modes, attachment modes, and constraint modes
  - To include infinitesimal motions superimposed on rigid bodies
- Check the rigid body modes in the crash models by running an eigenvalue problem
  - To identify inadvertent constraints or missing constraints

Combined implicit-explicit

- Perform nonlinear, seamless, spring back simulations on a vehicle after a crash simulation
  - To provide reliable measurements between numerical and physical results can be more easily obtained
- Generate superelements to use as boundary conditions for transient dynamics.
- Automatically switch between running implicitly and explicitly
- Mix implicit and explicit in the same analysis
  - Run parts of the model which control the time step, such as the steering well meshed with solid elements, implicitly.

Sparse linear equation solvers

- Distributed Multifrontal
  - LS-DYNA unique distributed memory solver
    - Now 2 domain decompositions, one for solver and one for elements.
- BCSLIB-EXT, Boeing's Solver
  - Software Package used throughout the FEA world.
  - SMP
  - Has extensive capabilities for solving very large problems by using disk to overcome memory limits
- Block Shift and Invert Lanczos eigensolver from BCSLIB-EXT
  - LSTC is developing the distributed memory version for release in 2003

Singularity controls for implicit

- Due to the unconstrained rotational degrees-of-freedom normal to the shell surface in the large deformation shell theories, singularity control is needed to obtain implicit solutions
- We have 3 ways to control matrix singularities in implicit problems:
  – Add a drilling stiffness matrix
  – Include 6 degrees-of-freedom per node (Costly for nonlinear)
  – Automatically scan the assembled stiffness matrix searching for rank deficient sets of columns

Implicit constraints

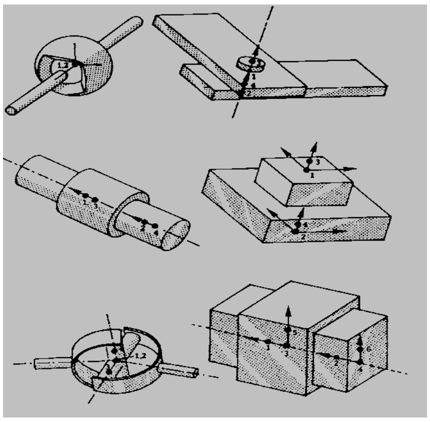
- Requires a matrix assembly and constraint application package
  - Significantly speeds up development of implicit solver since it allows us to
    - Quickly add explicit constraints to implicit solver
    - Efficiently apply constraints throughout the solution process.
    - Correctly apply complicated chains of constraints
      - Dependent nodes in one constraint can be independent nodes in another. (implicit only)
      - Four rigid bar linkage
- Explicit joints are treated by penalties. Implicit joints are treated *exactly* using constraint equations.

Explicit constraints for implicit

- BOUNDARY_
  - CYCLIC
  - NON_REFLECTING
  - NON_REFLECTING_2D
  - PRESCRIBED_MOTION (all options)
  - SLIDING_PLANE
  - SPC (global and local)
  - SYMMETRY_FAILURE
- ELEMENT_BEAM end release conditions
- MAT_RIGID global and local SPC
- CONSTRAINED_
  - ADAPTIVITY
  - EXTRA_NODES
  - GENERALIZED_WELD
  - GLOBAL
  - INTERPOLATION
  - JOINTS (all options)
  - LINEAR CONSTRAINTS
  - NODAL_RIGID_BODY
  - NODE_SET
  - POINTS
  - RIGID_BODIES
  - RIVET
  - SHELL_TO_SOLID
  - SPOTWELD
  - TIE-BREAK
  - TIED_NODES_FAILURE
  - JOINT_DISCRETE_BEAM

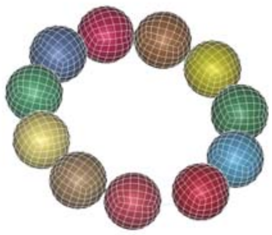
Implicit joints

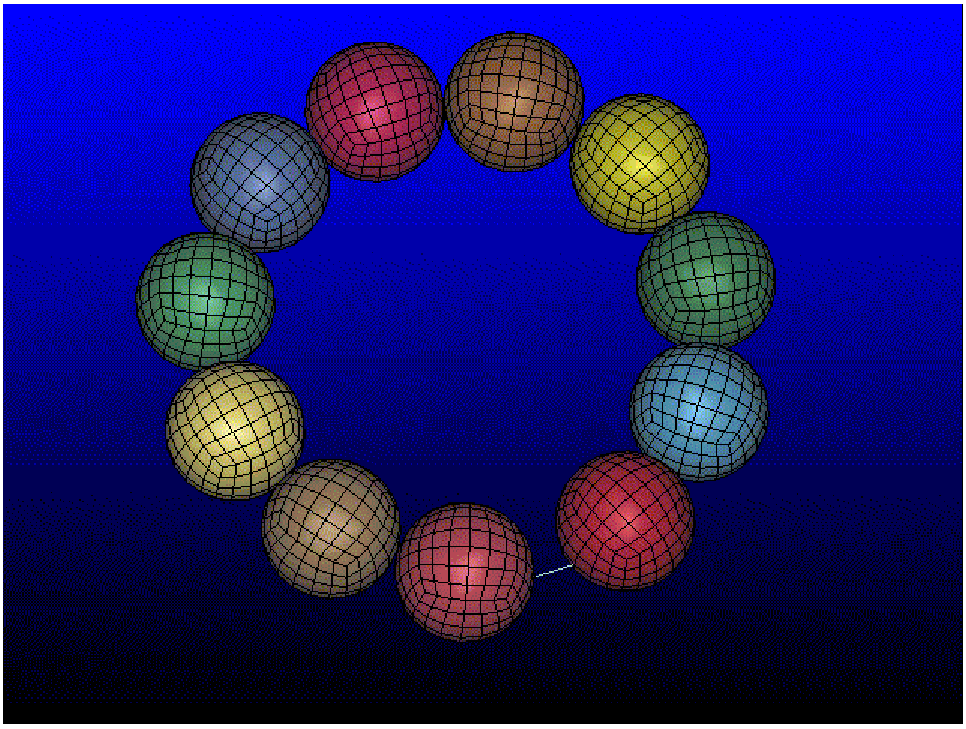
- Joint types for implicit with constraint equations.
  - spherical
  - revolute
  - cylindrical
  - planar
  - universal
  - translational
  - locking
  - translational_motor
  - rotational_motor
  - gears
  - rack_and_pinion
  - constant_velocity
  - pulley
  - screw

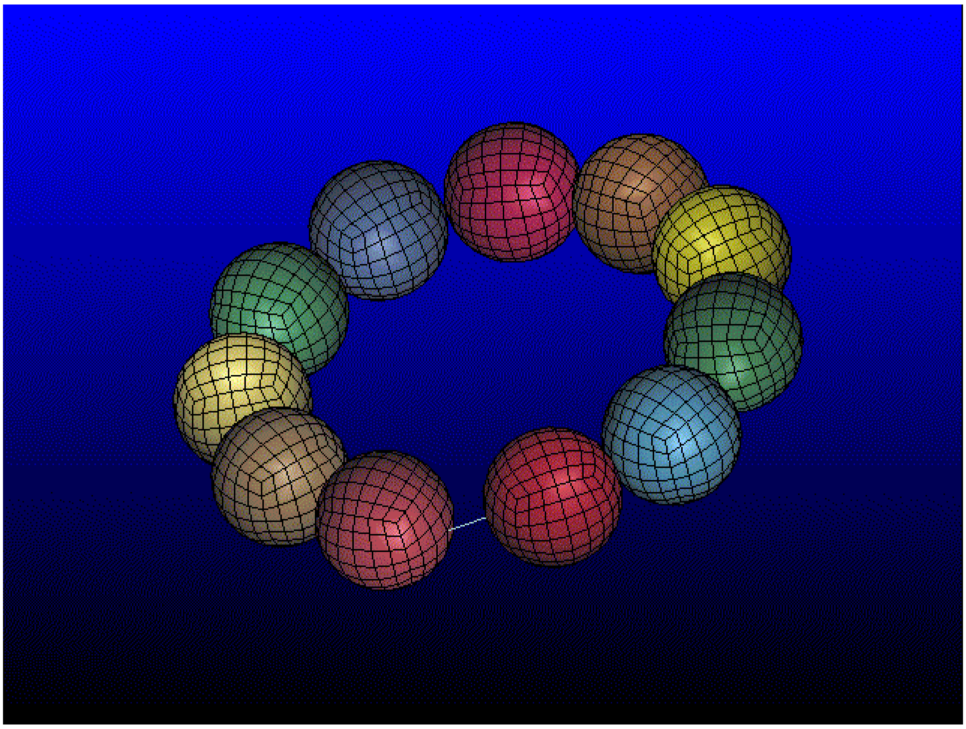


Chained rigid bodies

Example of 11 rigid spheres and 1 rigid beam that are joined together by spherical joints, which are represented by constraint equations, *(no penalties)* to form a bracelet, i.e., a closed chain. Null stiffness matrix, i.e., all eigenvalues are zero!







Implicit constraints for explicit

- It is very difficult to use a NASTRAN file in an explicit run. Note that the constraints reduce the number of degrees-of-freedom:

$$M\ddot{u}_f + Ku_f = F$$

$$u_f = Tu_r$$

$$T^t MT\ddot{u}_r + T^t KTu_r = T^t F$$

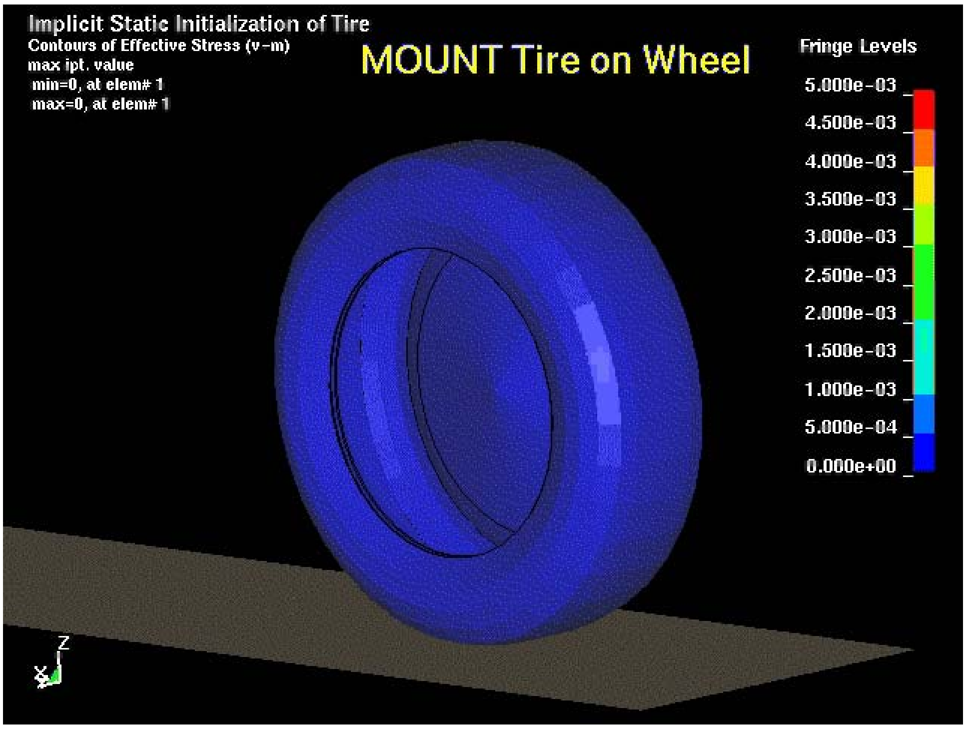
$$M_r\ddot{u}_r + K_r u_r = F_r$$

- But the mass matrix, M_r, is no longer diagonal. Sparse equation solvers must be used to invert the mass matrix hurting efficiency.

Static initialization of tire

- Use static implicit analysis to initialize tire
  - Mount tire on wheel
    - one wheel-half rigid
    - one wheel-half deformable, prescribed motion to squeeze bead
    - deformable-to-rigid switch after mounting, merge into one RB
  - Inflate tire
    - apply internal pressure
  - Apply vehicle weight

    problem: no contact -> rigid body mode is present
    - prescribe motion of road surface to establish contact
    - use death time to kill prescribed motion constraint
    - apply vehicle weight
- Switch to explicit analysis for rolling impact, etc…



Automated mode generation

- *PART_MODES is the keyword to include flexibility in rigid bodies. Currently implemented for penalty joint constraint method.
- Input can now be generated by LS-DYNA. Required:
  - Normal modes
  - Constraint and attachment modes
  - Optional list of attachment nodes
  - Modal damping coefficients

Automated mode generation

- New keyword, *CONTROL_IMPLICIT_MODES, reads nodal sets for constraint and attachment modes and then generates these mode sets automatically
- LS-DYNA modifies the constraint/attachment modes to ensure that they are orthogonal to the normal modes.
- Potential Applications
  - NVH, durability, and crash simulations

Shell elements for implicit

Nonlinear shells

- Belytschko-Tsay with warping stiffness [2]
- Belytschko-Wong-Chang [10]
- C0 triangle [3]
- Hughes-Liu [6]
- Assumed Strain [16]
- DKT Triangle [17]

Linear shells

- Discrete Kirchhoff with 6 dof/node (R.L. Taylor) [18]
- Quadrilateral shell with 6 dof/node (E.L. Wilson) [20]
- Triangular shell with 6 dof/node (E.L. Wilson) [auto sorting]
- Quadrilateral plate with 5 dof/node (E.L. Wilson), with Pian-Sumihara membrane [21]

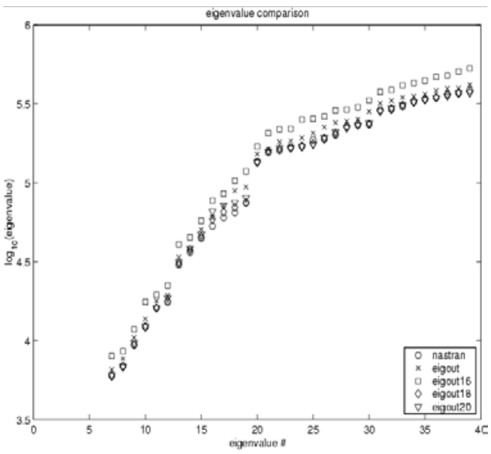
Eigenvalue comparisons

NASTRAN input file

- Component with approximately 60,000 equations
- Spotwelds use brick elements with RBE3 constraints
  - 2022 RBE3's (*CONSTRAINED_INTERPOLATION)
  - 12 RBE2's(*CONSTRAINED_NODAL_RIGID_BODY)
- Eigenvalue solution for free-free modes
  - 6 rigid body modes
- Solved eigenvalue problem with types 18 and 20 linear elements and types 6 and 16 nonlinear elements
  - Shell elements types 18 and 20 were within 2% of NASTRAN, CQUAD4, eigenvalues—some slightly smaller others larger, but generally larger.

Eigenvalue comparisons

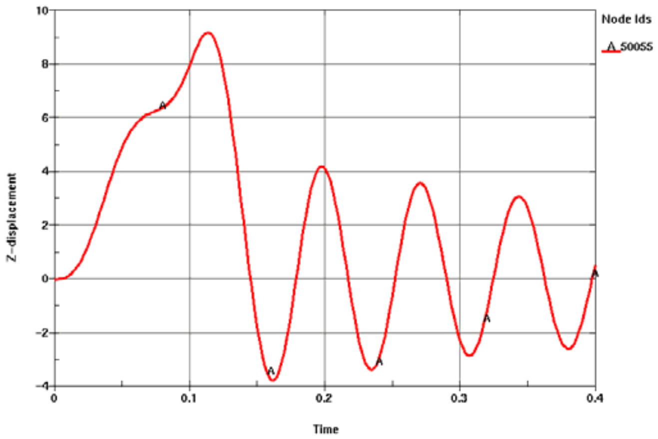
- O Nastran
- X Type 6
- Type 16
- Type 18
- Type 20



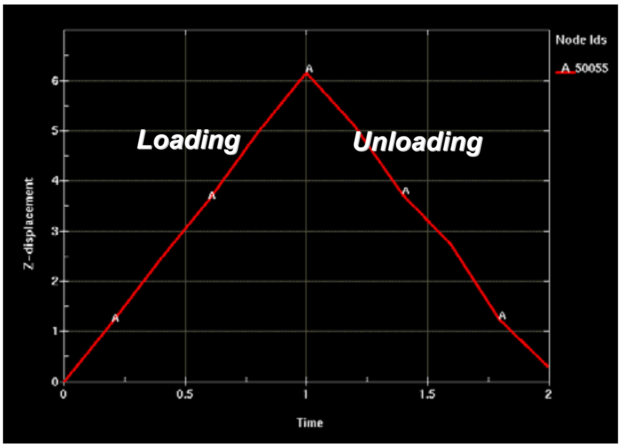
Door sag - explicit

- Door sag test is essentially applying a downward load/unload while monitoring the permanent set
- Explicit shows higher vertical displacement while loading coupled with oscillations after unloading making
- It difficult to determine the true springback
- Implicit shows a more accurate maximum vertical displacement and true springback
- This model has contact at the the hinge area and in some BIW locations
- Loading in explicit was done over 0-200 ms and unloading over 200-400ms.
- Loading in Implicit was done over 0-1sec and unloading over 1-2 sec

Door sag - explicit



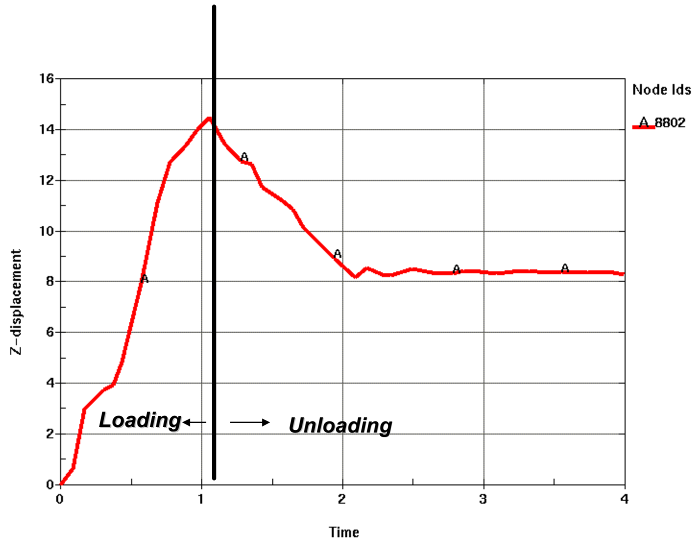
Door sag - implicit



Door check

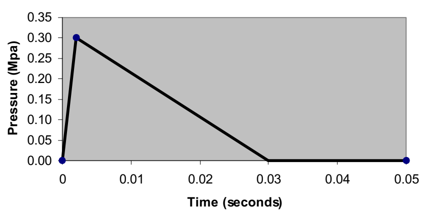
- Door check test is applying a load to simulate the over-opening of the door while monitoring the z-displacement
- Explicit run does not reach equilibrium (at least when run from 0-100ms and unloading over 100-200 ms). Consequently, solving this problem explicitly is impractical
- Implicit shows a more accurate maximum vertical displacement and true springback
- This model has contact at the the hinge area and in some BIW locations
- Loading in Implicit was done over 0-1sec and unloading over 1-2 sec

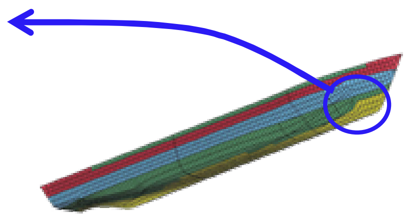
Door check - implicit



Test problem - dry ship

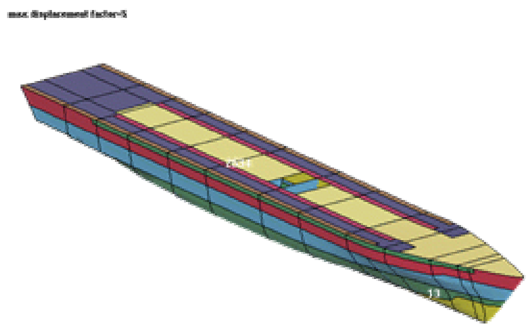
- Loading Simulates Mine Attack
  - pressure spike applied to forward hull section
  - simulate response at isolation deck for one second





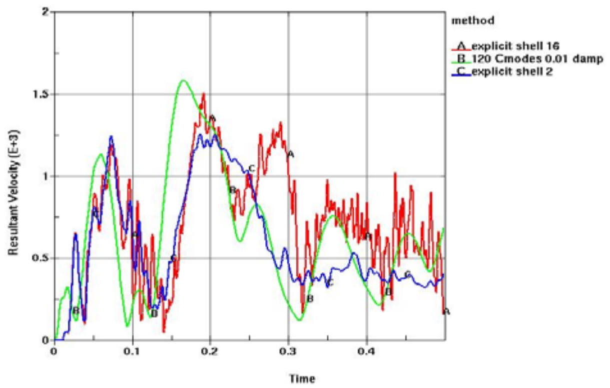
Test problem - dry ship

- Ship response (5x displacement scale factor)



Test problem - full ship

- Velocity response at isolation deck



Example - dry ship

- Timing data (IBM B80, one CPU)

method	CPU seconds
explicit, shell type 2	36,586
explicit, shell type 16	129,049
modal, 120 constraint modes	430
compute 120 constraint modes	84

~300 Times Faster!

Eigenvalue extraction

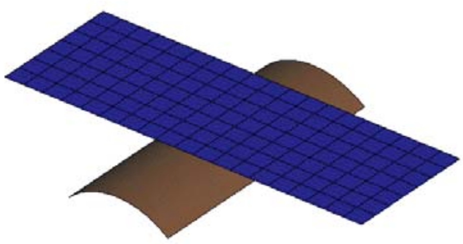
- Frequencies and Mode Shapes Change During Simulation
  - tensile stress increases natural frequency (guitar string)
  - contact with obstacles changes mode shapes
- LS-DYNA Can Extract Eigenvalues During Transient Analysis
  - curve gives time to extract eigenvalues, how many to extract
  - implicit or explicit transient analysis
  - new database family for each set of eigenvalues

Eigenvalue extraction

- Simple Input Parameters
  - *CONTROL_IMPLICIT_GENERAL
    - IMFLAG = 1: implicit with intermittent eigenvalues
    - IMFLAG = 6: explicit with intermittent eigenvalues
  - *CONTROL_IMPLICIT_EIGENVALUE
    - NEIGV = -(curve ID) on

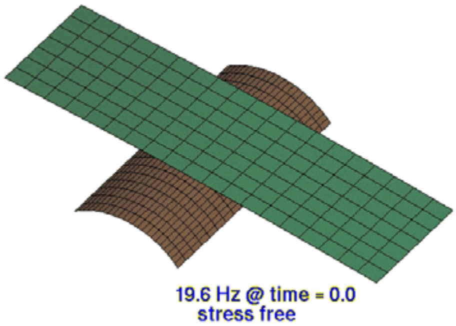
Tensile strip with indentor

Transient Analysis: stretch, then indent



Tensile strip with indentor

Eigenvalues after each loading phase

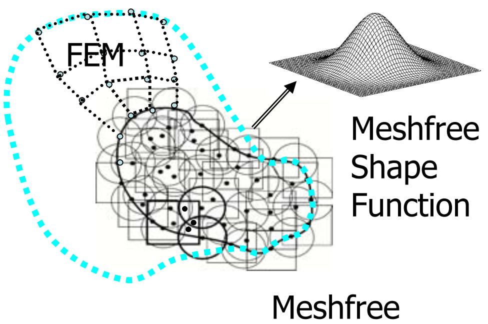


FEM/mesh-free

A Lagrangian Galerkin method

Less mesh distortion problems

Currently applies to solids



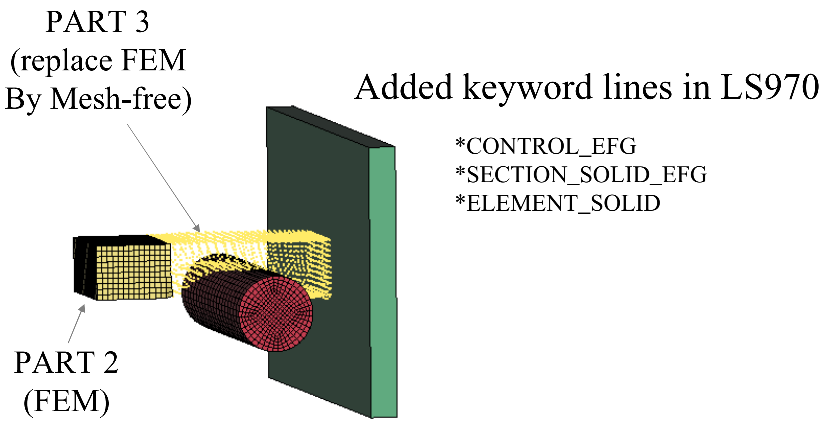
Basic features

- No conforming problems across the coupled boundaries
- Passes patch test
- Multiple FEM/Mesh-free and Mesh-free/Mesh-free coupling
- Applicable for essential and natural boundary conditions
- Available for most types of contact
- Available for most material models including incompressible, foam and damage materials
- CPU cost is 4~5 times expensive than FEM for 3D explicit version

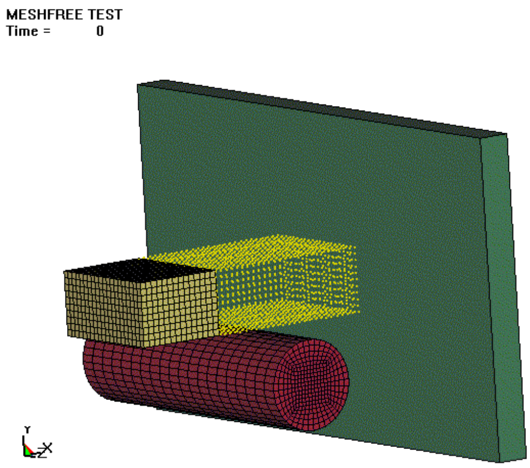
EFG applications

- Any nonlinear large deformation stress analysis problem involving large distortions
  - Crushable barriers
  - Hyperelastic foams
  - Forming problems
    - Forging
    - Extrusion

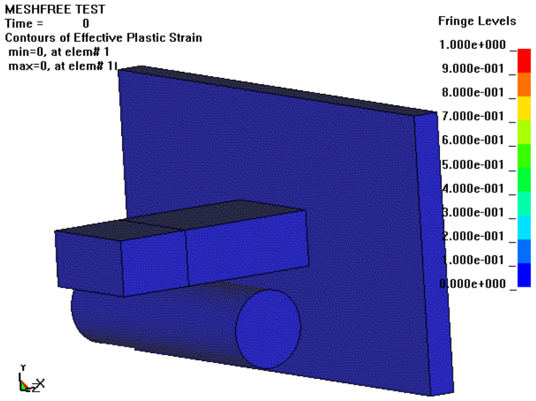
Problem definition



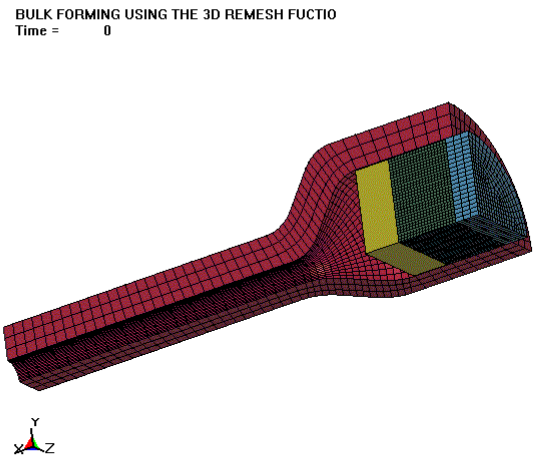
Cold rolling simulation



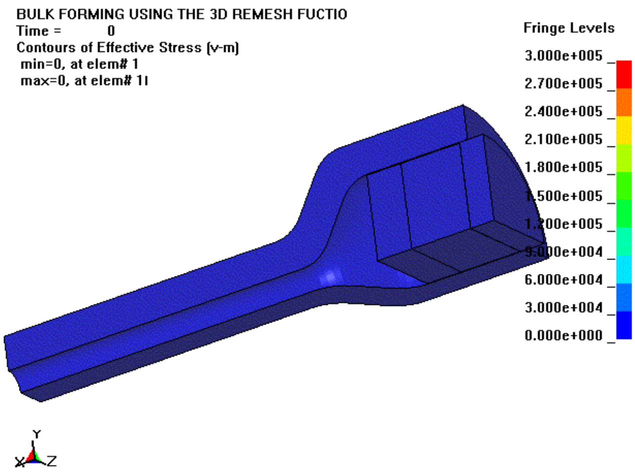
Cold rolling simulation



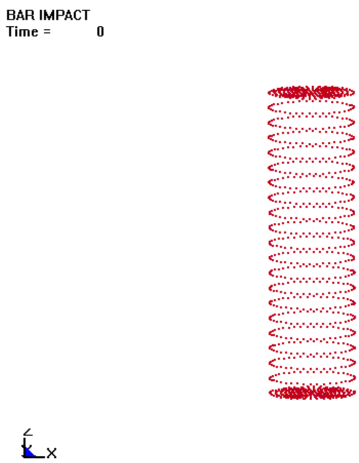
Bulk forming simulation



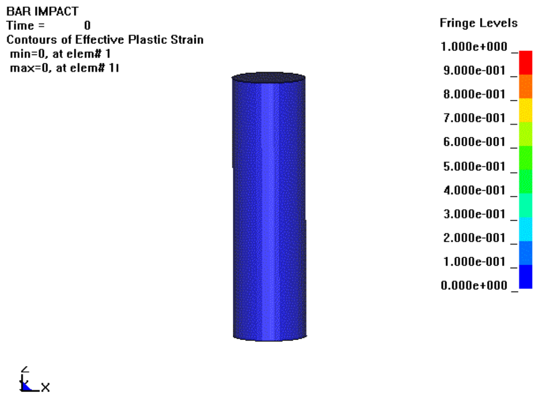
Bulk forming simulation



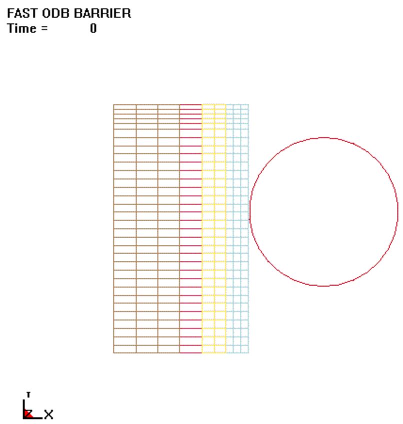
Bar impact simulation



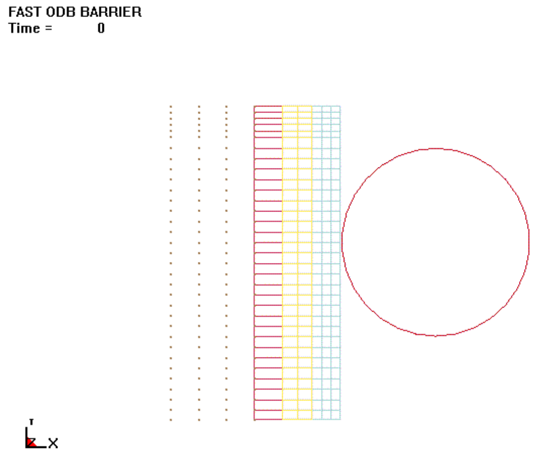
Bar impact simulation



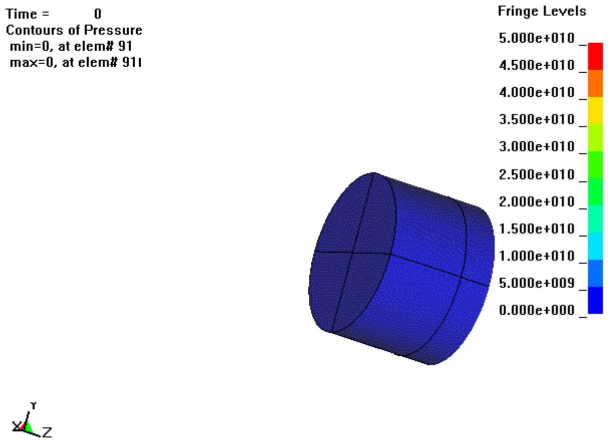
Form material simulation-fem



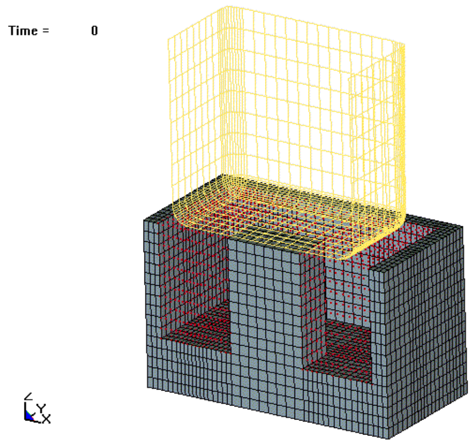
Form material simulation–efg



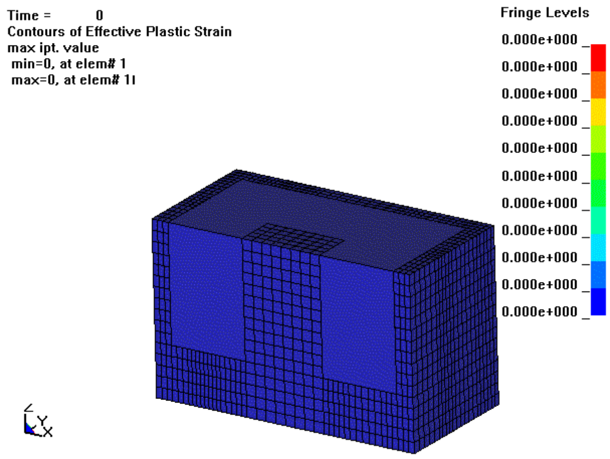
Extrusion simulation



Frictional forging simulation



Frictional forging simulation



Future plans for efg

2002

2D/3D solid formulation will available in the coming LS970

2004

Implicit version will be available
Start to implement MPP version

2005

Coupled FEM/Mesh-free shell formulation will be available

Others

Adaptivity
Fluid and Gas formulations

Massively parallel processing

The porting of LS-DYNA to MPP architectures started in 1992 and is ongoing.

MPP machines have replaced vector supercomputers at customer sites in the U.S., Japan, and Europe

There is now a significant demand for the MPI implementation

MPP machines offer the fast turnaround time -- 98% of crash jobs will finish overnight on 8-32 processors

LS-DYNA was the fastest Lagrangian code in a benchmark with DOE ASCI codes on the LLNL ASCI computers

Massively parallel processing

Recent Development:

- LS-DYNA is available under Windows
  - Commercial version of MPI provides better scaling on several test examples
    - 2 dual processor PCs (1.4 GHz AMD)
    - 100 mbit switched ethernet
    - Speed-up about 3 on public domain MPI and 3.8 on commercial version of MPI
  - Excellent performance, equivalent to Linux and Unix

Network performance on mpp

- Algorithmic Overhead
  - Independent of the system
  - Can be minimized through careful software design
  - Increases moderately with number of processors
- Load Imbalance (improvements made in 970)
  - Elemental calculations
  - Contact calculations
  - Constraints and other items
- Communication Overhead
  - Hardware and system dependent
  - Can increase substantially with number of processors

Outlook

LS-DYNA developments are leading to the ultimate goal of including within one explicit finite element program capabilities to seamlessly solve problems that include:

– Multi-Physics

and require:

– Multiple-Stages

with

– Multi-Processing

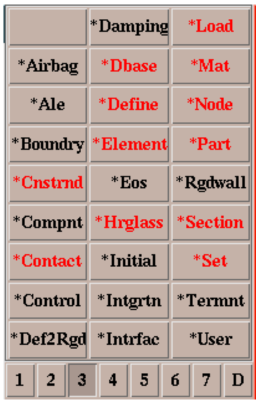
to reduce run times.

LS-PREPOST Features

- Full LS-DYNA 970 keyword support
- Subsystem concept is introduced for include files and imported model
- Extensive mesh manipulation features
- Metal forming related features
- Occupant positioning – improved capabilities
- Airbag Folding
- 201 Head impact positioning
- SPH element generation

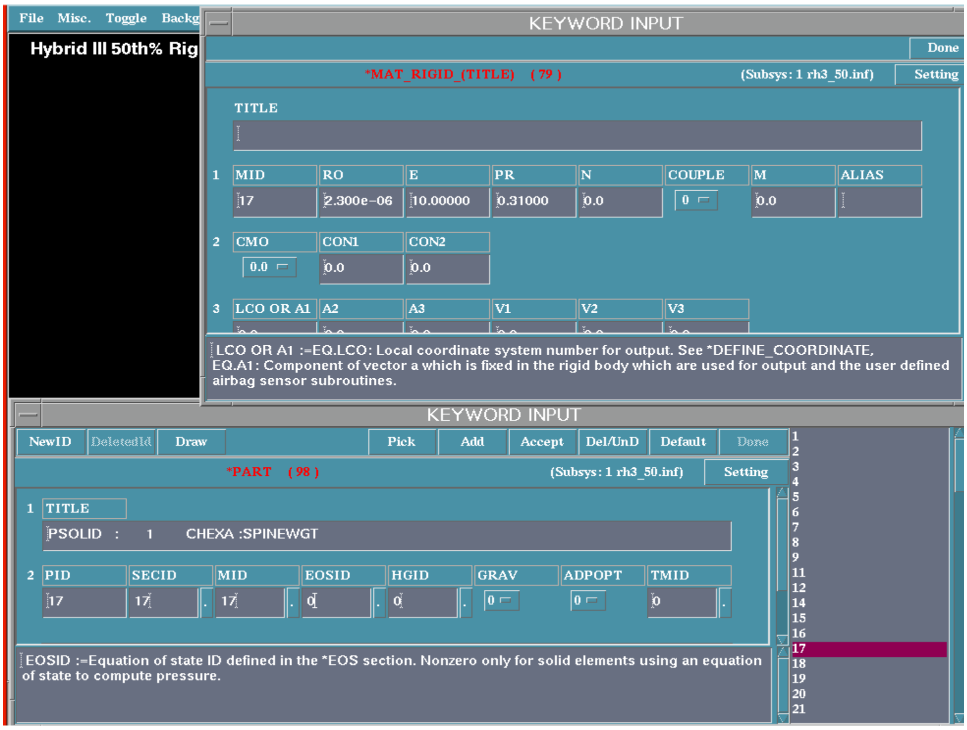
LS-PREPOST – Keyword input

- Each keyword has its own form for input and editing
- Keyword data that is present in the model will be highlighted with red color
- There are over 800 keyword entities
- Comment card is available for each keyword input



Keyword Input Form

- Keyword input forms match LS-DYNA manual
- Each data field is identified by its name
- An explanation of the field is shown with a simple click in the field or the field name
- Simple selection button is used for the data field with pre-defined values
- A popup table can be used as an aid to transfer data to the selected field
- Link data can be viewed with a click on the name



LS-PREPOST - Subsystem

- The subsystem concept gives user better control over the a model with many imported files
- A subsystem can consist of any keyword data
- Each include file will be treated as one subsystem
- All subsystems can be output as one single files or individual files
- A subsystem can be deleted

Model Manipulation

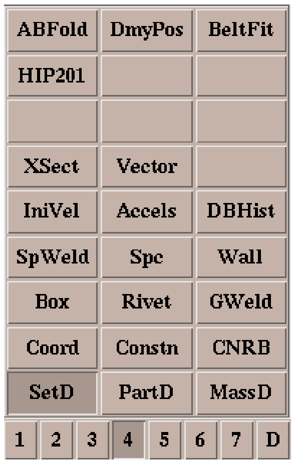
- A whole or portion of the model can be translated, rotated, scaled, transformed, reflected or projected
- New elements can also be created with each of these operations
- Shell element/segment normal check and reverse, auto reverse with seed element
- Move or copy elements from one part to another part
- Extensive element quality check
  - Feature angle, Warping, Aspect ratio, Characteristic length ,Internal angles

Model Manipulation

- Duplicated grid elimination (grids have the same coordinates)
- Free edges detection
- Element deletion and creation (mesh cleaning)
- Nodes deletion ,creation, replacement and alignment
- Element splitting

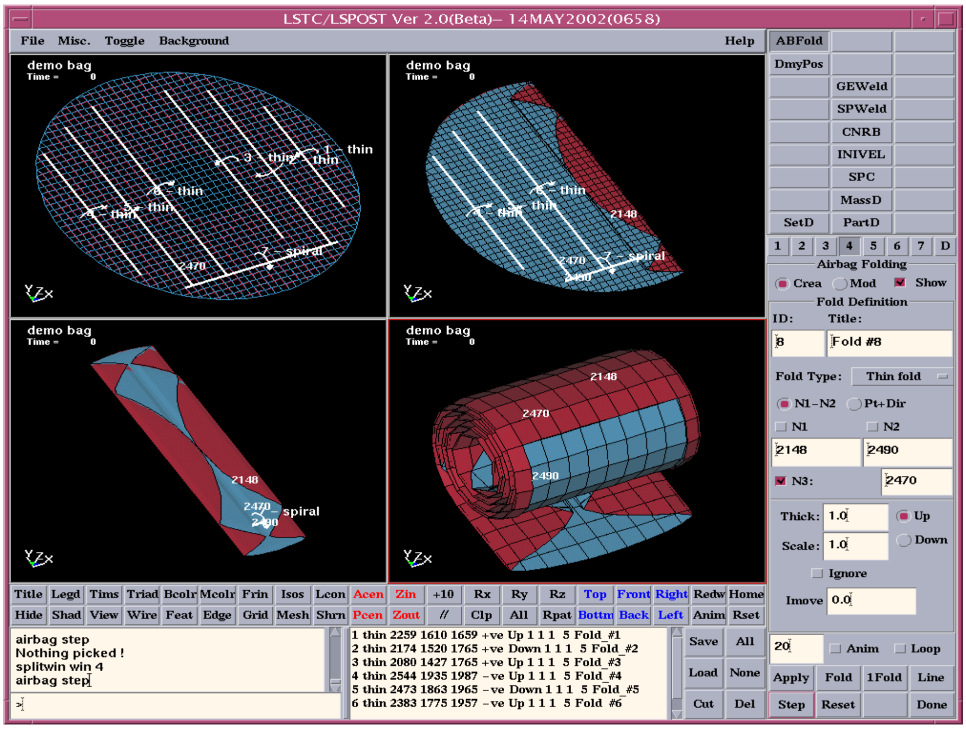
LS-DYNA data creation

- Set data (Beam, Shell, Node, Part, Segment, Discrete, etc.)
- Part data
- Mass element
- Nodal SPC data
- Initial Velocity
- Constrained Nodal Rigid Body
- Spot weld data
- General weld data
- Rigid walls



Airbag folding

- The Airbag folding menu is designed to make airbag folding simple and straight forward.
- The folding procedure leads to a list of fold instructions which can be saved and reloaded later.
- Thin, Thick, Tuck and Spiral Fold can be defined.
- Folds can be examined via the Section Plane menu for good shape and freedom from nodal intrusions.
- Whole folding procedure can be stepped through and animated



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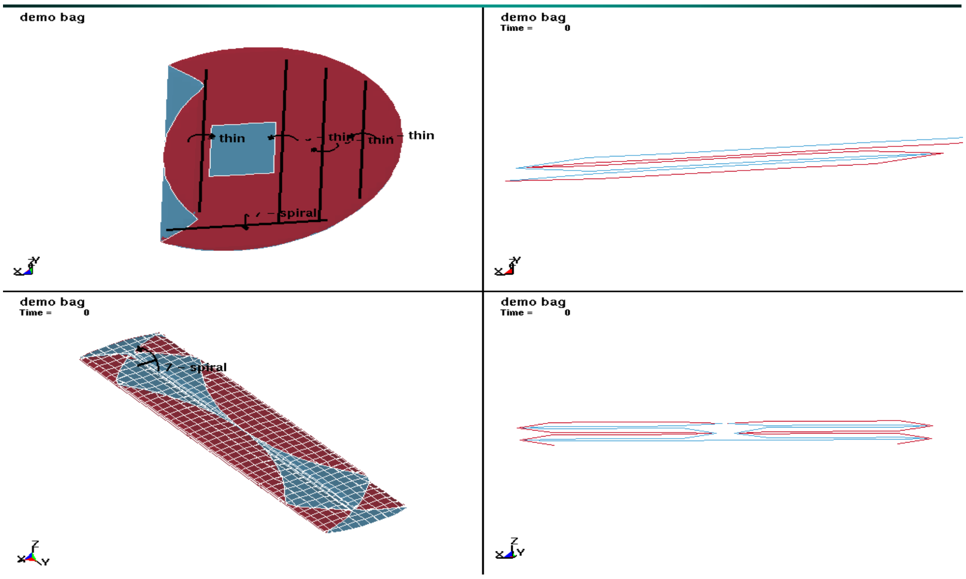
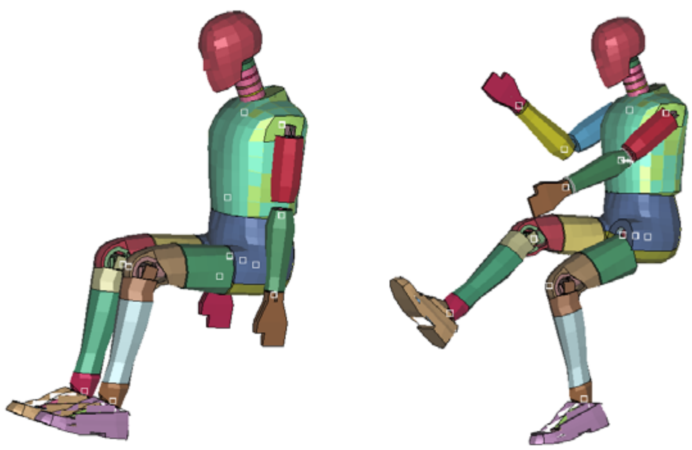
Folds and Section Cuts



Occupant Positioning

- Multiple dummies can be imported into one single model
- Move a dummy in a model to the desired location
- Use a tree file to define joints and limbs
- Rotate limbs of the dummies about their joints
- All related keyword data will be transformed
- Manipulation of the dummy model is now recorded and can be reset to its original position
- Final positioning can be saved as a LS-DYNA keyword input deck



Metal forming related features

- Creation of new parts by offsetting elements along the element normal direction
- Separation measure between parts can be displayed as fringe plot
- Part travel distance to another part before contact can be calculated
- Multiple section cuts for different states or locations

201 Head Impact Positioning

- Multiple head can be position in the same model
- Head can be tilted vertically or rotated horizontally interactively
- Configuration file can be setup to have head model loaded automatically
- Multiple LS-DYNA keyword file can be output for different head positions

SPH Element Generation

- SPH elements can be generated in simple geometries such as boxes, spheres and cylinders
- Material models for SPH can be automatically setup or can be picked by the users

Conclusions

- LSTC is committed to develop the pre- and post-processing capabilities for LS-DYNA
- LS-PREPOST beta release is available for download from ftp.lstc.com in the directory outgoing/lsprepost
- LS-PREPOST version 1.0 will be release in March, 2003
- New functionalities and enhancements will be released periodically
- Users are encouraged to give suggestions and provide ideas for the development