Recent developments in LS-DYNA

Part I

3rd LS-DYNA Forum 2004

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LSTC Livermore Software Technology Corp.

Outline of talk-Part 1

- Introduction
- Recent developments for the next 970 release
  - Universal restart
  - Stress initialization option
  - ALE airbag deployment
  - Metalforming
  - Spotwelds
- Developments in next 970 release

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Michigan office for support, training, and development

Development goals LS-DYNA

- Combine multi-physics capabilities in a scalable code for solving highly nonlinear transient problems
  - Full 2D & 3D capabilities
  - Explicit Solver
  - Implicit Solver
  - Coupled Heat Transfer
  - ALE, EFG, SPH
  - Navier-Stokes Fluids, Radiation transport, Electromagnetics
- Enable the solution of coupled multi-physics and multi-stage problems in one run
- Full compatibility with Linear NVH and durability models

Development goals LS-PrePost

- Provide Pre- and Post-processing for LS-DYNA
  - Full LS-DYNA 970/971 keyword support
    - All LS-DYNA keywords can be read, modified and output
    - Keyword data modified by form with field name definitions and descriptions shown interactively
  - Extensive model manipulation features
    - Mesh generation including Tool Mesher for Metal stamping and Topology Mesher for crash and other applications
    - Mesh quality check and repair
    - LS-DYNA data creation, setup and display
    - Multiple models can be merged into a single model

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Development goals LS-PrePost

- Provide Pre- and Post-processing for LS-DYNA
  - Full post-processing support for all LS-DYNA analyses
    - State results animation
    - Fringe component plots
    - ALE fluid data processing and visualization
    - Extensive model visualization and time history plotting
    - History data manipulation using command file without graphics
    - Use command macro for repeated operations

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Development goals LS-PrePost

- Special applications
  - Metal forming process setup and post-processing
  - Airbag folding with mesh generation
  - Occupant positioning
  - 201 Head impact positioning and data setup
  - IIHS intrusion computation
  - ALE mesh generation
  - SPH element generation
- No extra cost with LS-DYNA
- Can be downloaded from
  - ftp://ftp.lstc.com/outgoing/lsprepost

Development goals LS-Opt

- Provide optimization technology for LS-DYNA
  - Response Surface Methodology, Neural Networks
  - Multidisciplinary Optimization
- Tight LS-DYNA integration
  - Import Parameters from DYNA Keyword files
  - Dedicated LS-DYNA result interface
  - Interfaces for shape optimization
  - Job distribution – Queuing

Development goals LS-Opt

- Robust Design
  - Reliability
  - Bifurcation/Outlier Analysis
  - Reliability-Based Design Optimization (Future Versions)
  - No extra cost with LS-DYNA
- Version 2.2 released April, 2004

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Version 980

- Version 980 introduces a new code framework to accommodate fluid-structure coupling with embedded, scalable CFD solvers.
- New physics:
  - An explicit compressible flow solver based upon the Conservation Element/Solution Element (CE/SE) Method
  - Radiative heat transport through participating media, as well as using exchange factors initially coupled to the incompressible flow solver
  - Solid-fluid heat flow coupling for the incompressible flow solver
- Release anticipated in 2006

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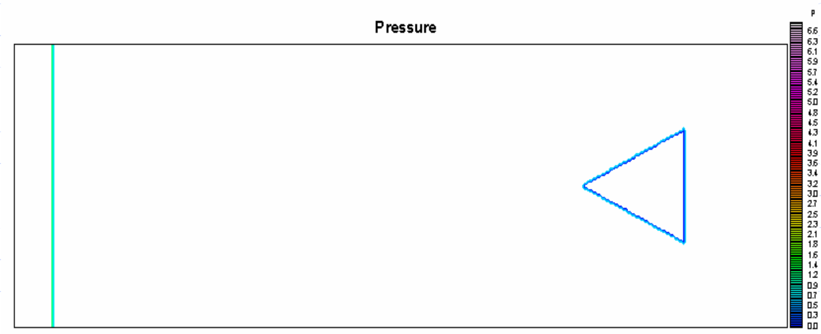
Version 980

Compressible flow solver with structural coupling:



Recent Developments in Version 970

August Release

*Keyword

***KEYWORD**_*OPTION*

- An option, *ID*, is available to assign a prefix to all output and scratch filenames, i.e., the file name for D3PLOT becomes:

  File_name_prefix.D3PLOT

- The prefix can also be assigned by the command option, jobid on the execute line:

  ls970 I=input.k jobid=*File_name_prefix*

- Multiple jobs can now be executed in the same directory

Universal restart

- With the universal restart, the restart of an SMP/MPP job is independent of the computing platform. For example,

  HP/PA8000 → Linux/IA32 → SGI/Origin

- LS-DYNA will detect the chosen vector length (NLQ) and the binary file format from the restarted job automatically for the next run

Universal restart (binary)

- Most Unix systems write binary file output in big-endian format. All IA32 and IA64 systems write binary file output in small-endian format.
- The LS-DYNA restart run will detect the file format of the previous run and use it. All LS-DYNA binary file output such as, D3PLOT, D3DUMP##, …etc, will use the same format as the first run.

Stress initialization

- Many user request for simple procedure for stress initialization in fasteners such as bolts
- Uses existing capabilities in LS-DYNA with the addition of 1 new keyword

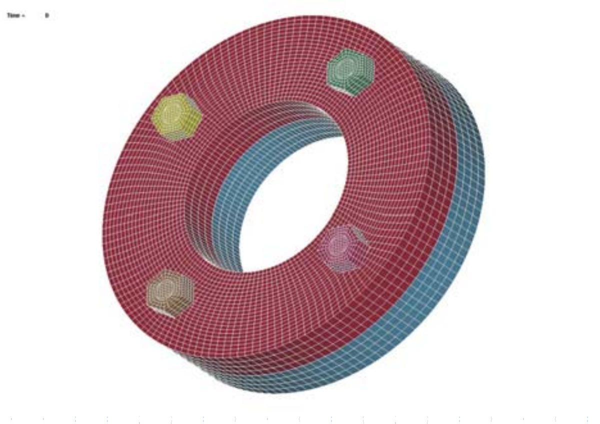
  *INTIAL_STRESS_SECTION
- Equilibrium is obtained by ramping up to the desired stress level at the start of the analysis or during the dynamic relaxation phase.

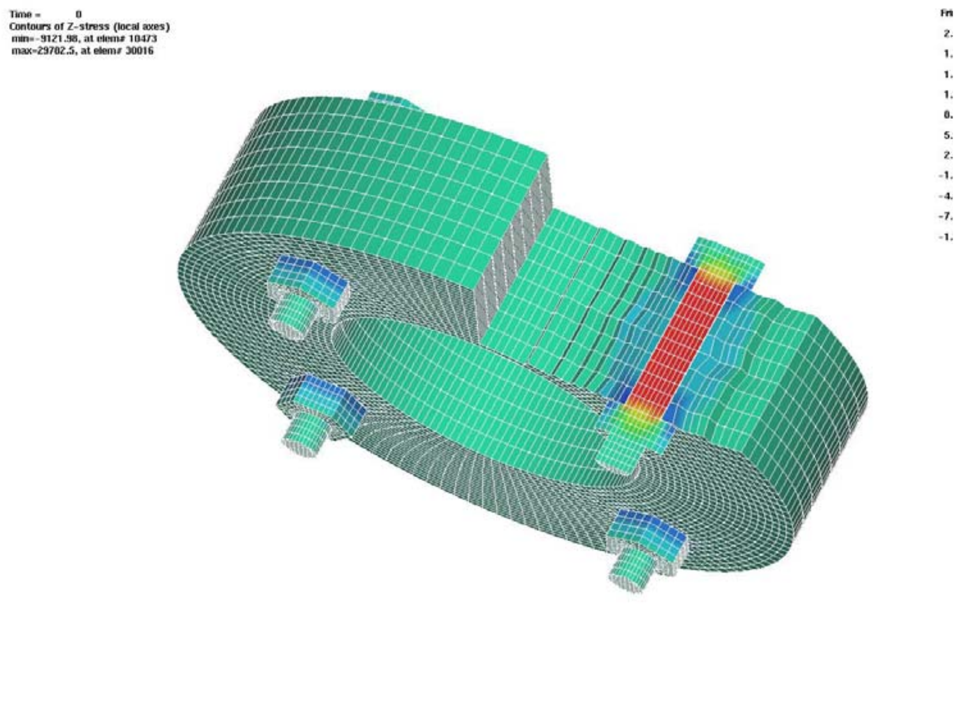
Stress initialization

- Works with a subset of materials including elastic and plastic models.
  - Does not apply to materials with equations of state or rubber like materials.
    - For rubber materials, the reference geometry can be used.
- Works with most solid elements and beam elements.

Stress initialization

- Bolts are initialized to 20000 psi stress.

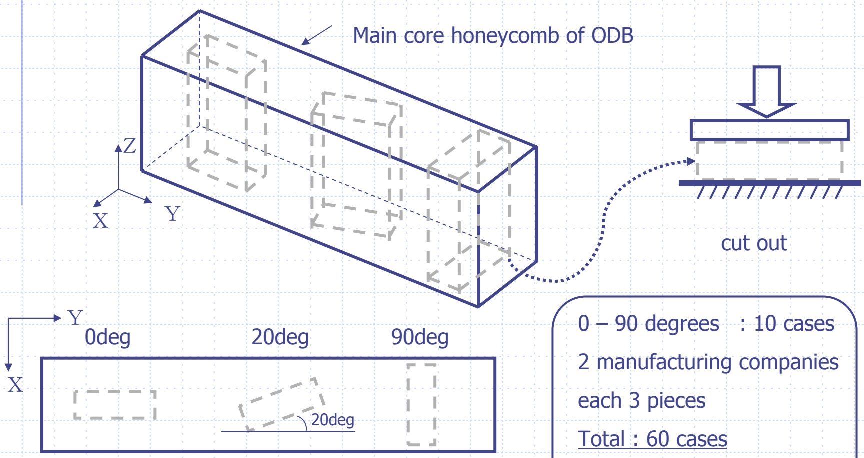




*Mat_modified_honeycomb

- Used to model aluminum honeycomb barriers
  - Frontal
  - Side
- Off-axis loading response is nonphysical
  - Excessive deformation of vehicle is predicted in oblique side impacts
  - Related to this same problem, the transversely_anisotropic_ crushable_foam was developed first. This model was not to work well for aluminum honeycomb.
  - Ove Arup Ltd has developed widely used barrier models that tie solid elements together with discrete beam elements that fail
    - Greatly improves off-axis loading behavior but expensive.
- A new yield surface that corrects problems with off-axis loading has been developed as a result of tests on aluminum honeycombs at Toyota Motor Corporation

Honeycomb test at Toyota



0 – 90 degrees : 10 cases

2 manufacturing companies

each 3 pieces

Total : 60 cases

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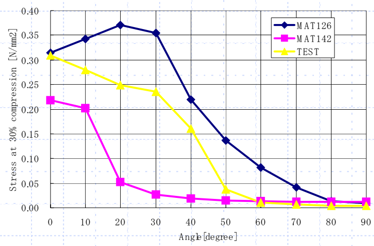
Calculation results



30% compression

The stress values agree at 0 and 90 degree.

Material model 142, developed for interior foams, does not apply to aluminum.

Material model 126, developed for aluminum, shows that the stress is over predicted at 10, 20, and 30 degrees.

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Mat_modified_honeycomb

- A modification to the modified honeycomb material has added a transversely anisotropic yield surface

$$\sigma^y\left(\varphi,\varepsilon^{vol}\right)=\sigma^b\left(\varphi\right)+\left(\cos\varphi\right)^2\sigma^s\left(\varepsilon^{vol}\right)+\left(\sin\varphi\right)^2\sigma^w\left(\varepsilon^{vol}\right)$$

φ = angle with the strong axis

$\sigma^b\left(\varphi\right)$ = yield stress as a tabulated function of φ

$\sigma^{s/w}\left(\varepsilon^{vol}\right)$ = stiffening as a tabulated function of ε^{vol}

that can match the uniaxial experimental data

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Mat_modified_honeycomb

- A drawback of this new yield surface is that the material can collapse in a shear mode due to the weak shear resistance.
- A third option is now available in the August release of version 970, the material behavior has been modified so that the shear and hydrostatic resistance can be prescribed without affecting the uniaxial behavior.

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Simplified_rubber/foam

- **Now available for shell elements.**
- 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 and foam like behavior can be approximately simulated.
- For compressible foams a constant poisson's ratio is defined. This option is in the August release.

Simplified_rubber/foam

- The response is based on Hill's strain energy functional,

$$W=\sum_{j=1}^{m}\frac{C_j}{b_j}\left[\lambda_1^{b_j}+\lambda_2^{b_j}+\lambda_3^{b_j}-3+\frac{1}{n}\left(J^{-nb_j}-1\right)\right]$$

which include compressibility. The Cauchy principle stresses are:

$$t_i=\sum_{j=1}^{m}\frac{C_j}{J}\left[\lambda_i^{b_j}-J^{-nb_j}\right]\quad i=1,2,3$$

*Mat_piecewise_linear_plas…

- Viscoplastic option with table lookup has been reformulated.
  - The secant iterations for the viscoplastic strain rate may not converge in current release of ls-dyna
    - A new iteration scheme (Ritter's method) now replaces the secant iterations
      - Runs all test problems that previously failed.
      - More validation work is underway
  - Modifications are available in the August release
    - Constitutive models for solid and shell elements are updated

*Mat_plasticity_comp.._tens..

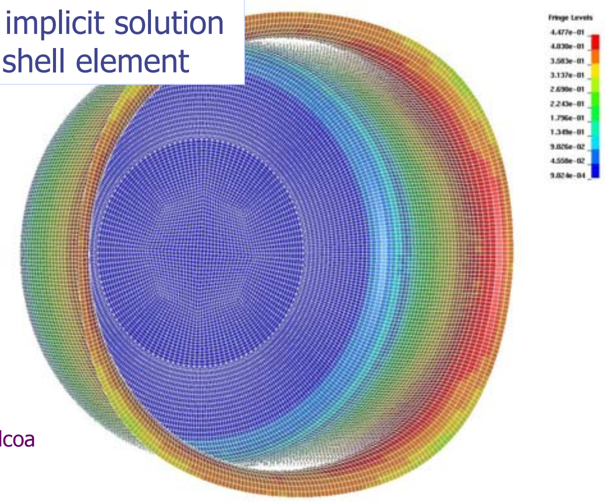
- An isotropic elastic-plastic material where unique yield stress versus plastic strain curves can be defined for compression and tension.
- Extended to rate sensitive plastic materials by a superposition of viscous stress terms from linear viscoelasticity. This model is effectively a Maxwell fluid which consists of a dampers and springs in series.
- Requires fitting of material parameters.

*Mat_barlat_yld2000

- Barlat's YLD2000 is an 8-parameter elastic-plastic material model for shells
- Developed for modeling sheet metal with anisotropic material properties, especially aluminum alloys
- An automatic material parameter identification scheme is implemented
- Nonlinear isotropic, kinematic, or mixed hardening can be used
- Includes strain rate effects
- Explicit and implicit implementation

*Mat_barlat_yld2000

1.2 hr. CPU fully implicit solution
Belytschko-Tsay shell element



Courtesy of Robert Dick, Alcoa

*Hourglass

- A new hourglass control option has been added to the type 6 hourglass control for hyperelastic materials
  - Implemented in the Belytschko-Bindeman solid element
    - Uses an exact elastic hourglass stiffness if the hourglass coefficient is unity.
  - Combines hourglass viscous and stiffness forces together for tire applications
    - Hyperelastic materials frequently require additional damping for stability

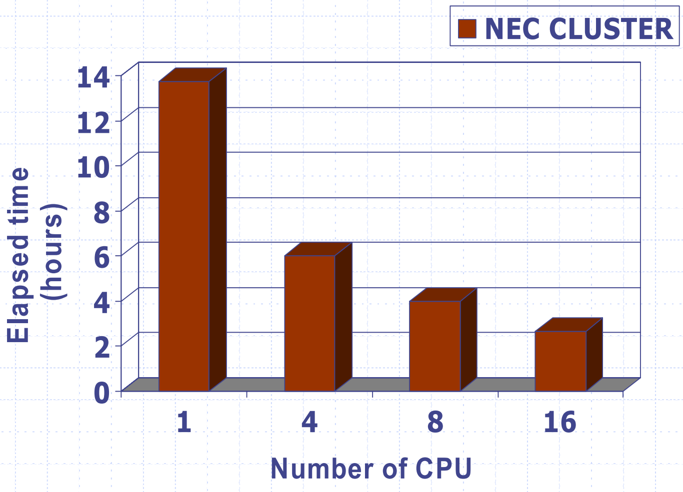
OOPS capabilities

- Modeling out-of-position occupants requires the ability to compute the early time evolution of the airbag deployment before the uniform pressure, control volume, approach is valid. An approach using Arbitrary Lagrangian Eulerian techniques, ALE, is used in LS-DYNA.

OOPS Capabilities

- Gas mixture
- Moving point sources
- Automatic expansion of the ALE mesh
- Moving ALE mesh with vehicle
- Robust contact algorithm for mulit-layer airbags
- Fabric porosity for ALE
- Discrete venting for ALE
- Blockage considered for porosity and venting
- ALE supported in Serial, SMP, and MPP

MPI scalability for ALE model



*AIRBAG_ALE

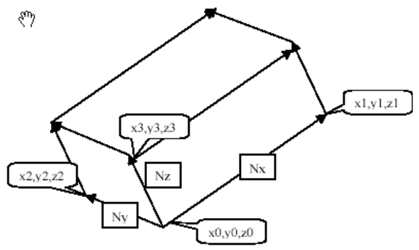
- In current 970 release
  - Simplified input
  - Smooth transition from control volume to ale for users currently using control volume method
  - Options
    - Run control volume only
    - Run ALE only
    - Start with ALE and switch to control volume

*AIRBAG_ALE

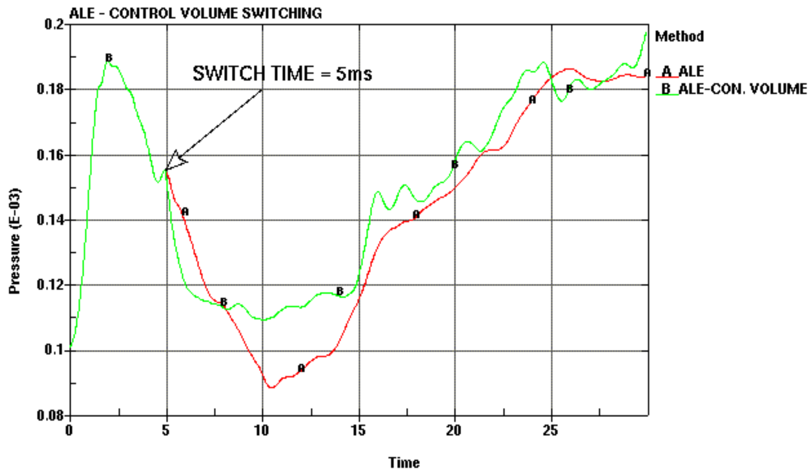
- Fabric porosity in ALE and CV phase
- Venting in ALE and CV phase
- Blockage considered for porosity and vents during ALE and CV phase
- ALE mesh movement with vehicle
- ALE mesh automatic expansion for folded airbags

*AIRBAG_ALE

- The ALE mesh is trivially defined,
  - x0,y0,z0 to x3,y3,z3 define the ale mesh position and nx, ny, nz define the number of element to generate in x, y, and z direction



ALE-control volume switching

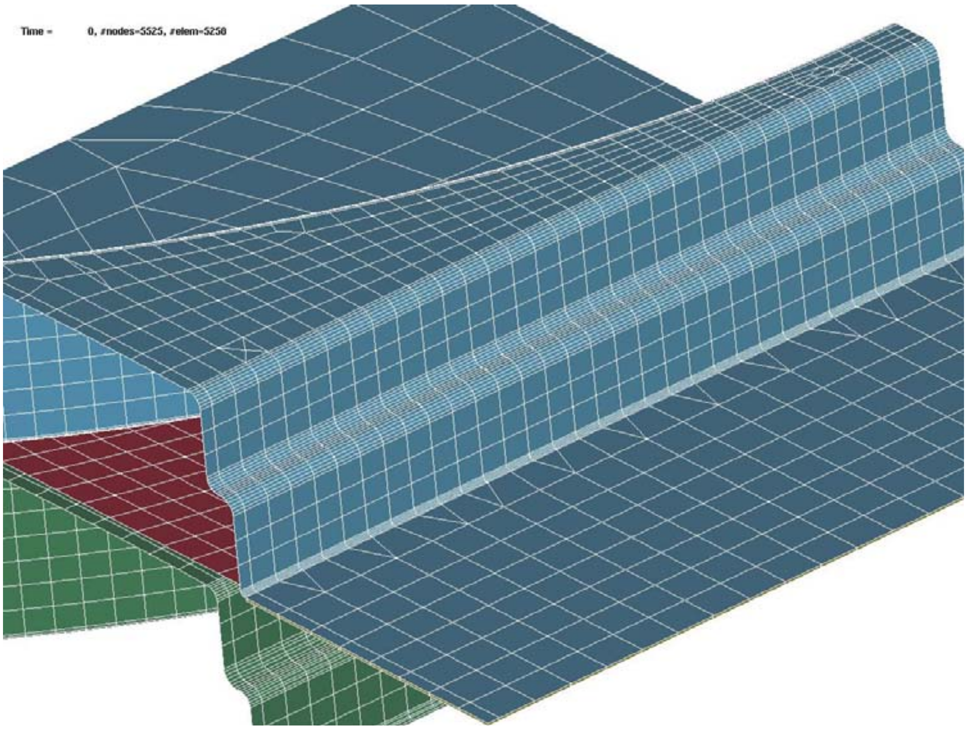


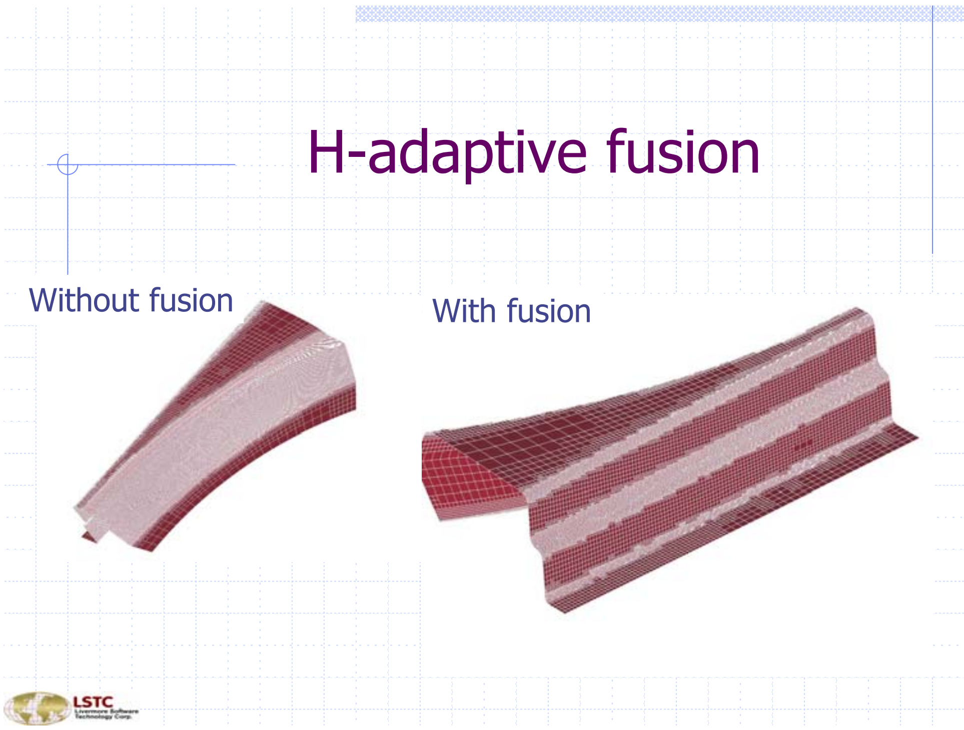
H-adaptive fusion

- LS-DYNA currently allows fission in adaptive remeshing
  - Number of elements monotonically increase
  - Many more element than necessary are created in deep drawing simulations
  - CPU time is a strong function of the number of elements
- In the August release of version 970 fusion is available

H-adaptive fusion

- In LS-DYNA fission is based on one or more of the following:
  - Tooling curvature (standard approach)
    - Refine before contact
    - Referred to as look-ahead adaptivity
    - Calculation is not repeated after refinement
  - Angle change or incremental angle change between elements
    - same criteria for fusion
  - Element thickness change
- Until now, fusion was possible only after the simulation completes, prior to implicit springback.


Time = 0, #nodes=5525, #elem=5258


H-adaptive fusion
Without fusion
With fusion
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*Control_forming_template

- Occasionally, the results of metal stamping simulations are user-dependent
  - In LS-DYNA there are parameters that need to be manually reset from their default values for crash.
  - Contact algorithms for crash are not suitable for sheet metal stamping
- Objective of new control card
  - Decrease user-dependent result by setting parameters to optimal values for forming simulations
  - Simplify input decks

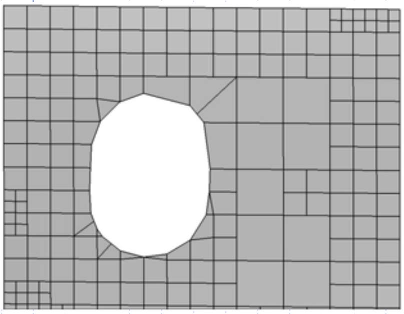
*Control_forming_template

- Supported Process include
  - Three-Piece Air Draw
  - Three-Piece Toggle Draw
  - Four-Piece Draw
  - Trimming
  - Springback
- If the process is chosen, it is possible to automatically
  - Preposition the blank and tools
  - Set up the rigid body motion
  - Set up the part, section, and material input
  - Calculate the termination time

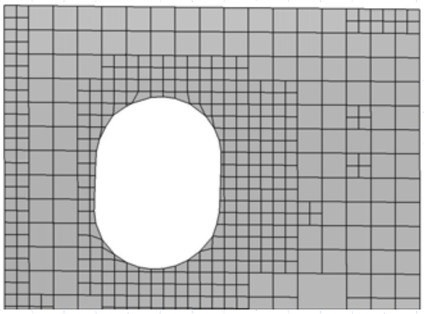
Trimming

- New adaptive mesh feature refines trimmed elements

OLD METHOD



NEW METHOD



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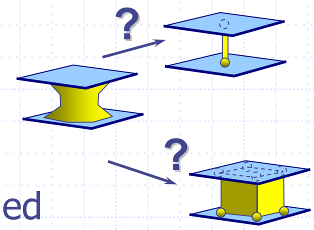
Spotweld modeling

- Arbitrary connection of shell surfaces
- Deformable spotwelds in LS-DYNA
  - Beams
  - Solids
  - Beam like springs
- Nodes of spotwelds are tied automatically by constraint equations



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Spotweld failure

- Accurate failure prediction is very important for accurate crashworthiness predictions.
- In version 970, several failure criterion are available:
  - Failure can be based on plastic strain, resultants, or a combination of plastic strain and resultants:

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

    - For solid elements the resultants are computed from the nodal point forces.

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Spotweld failure

- 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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Spotweld failure

- Failure predictions are unreliable, especially for high strength steels.
- No widely accepted approach in the treatment of failure.
- Failure is dependent on:
  - Strain rates
  - Sheet thickness
  - The yield stress and the ductility of welded sheets
  - Contact
- Many experimental studies have been completed on spotweld failure.

Spotweld failure

- In the next release of version 970 two new failure options have been added that utilize experimental test results. This data is provided by the keywords:
  - *DEFINE_SPOTWELD_RUPTURE_STRESS
    - Beam elements only
  - *DEFINE_SPOTWELD_FAILURE_RESULTANTS
    - Solid elements only

Spotweld failure-beams

- *DEFINE_SPOTWELD_RUPTURE_STRESS table containing the experimental data
- Rupture stress values are defined by part ID
- The data is used by the stress based spot weld failure model developed at *Toyota Motor Corporation*.
- In *MAT_SPOTWELD this option is activated by setting the parameter *OPT* to a value of 6

Spotweld failure-beams

- If the effects of strain rate are considered, then the failure criteria becomes:

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

- Where the rupture stresses are found by using the Cowper and Symonds model which scales the static failure stresses:

$$\sigma_{rr}^F\left(\dot{\varepsilon}^p\right)=\sigma_{rr}^F\cdot\left[1+\left(\frac{\dot{\varepsilon}^p}{C}\right)^{1/p}\right] \qquad \tau^F\left(\dot{\varepsilon}^p\right)=\tau^F\cdot\left[1+\left(\frac{\dot{\varepsilon}^p}{C}\right)^{1/p}\right]$$

Spotweld failure-beams

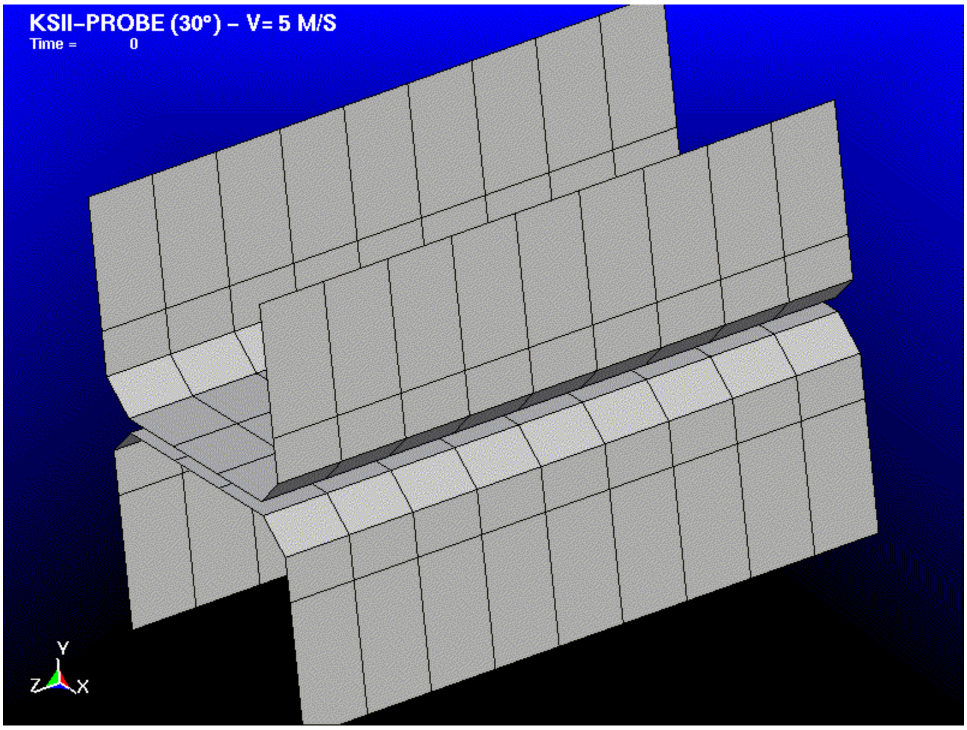
- The average plastic strain rate is integrated over the domain of the attached shell element.
- The constants *C* and *p* are taken from the constitutive data of the attached shell elements.
- The failure criteria is compute independently for each node of the beam. If failure occurs at either end of the beam, the spot weld fails

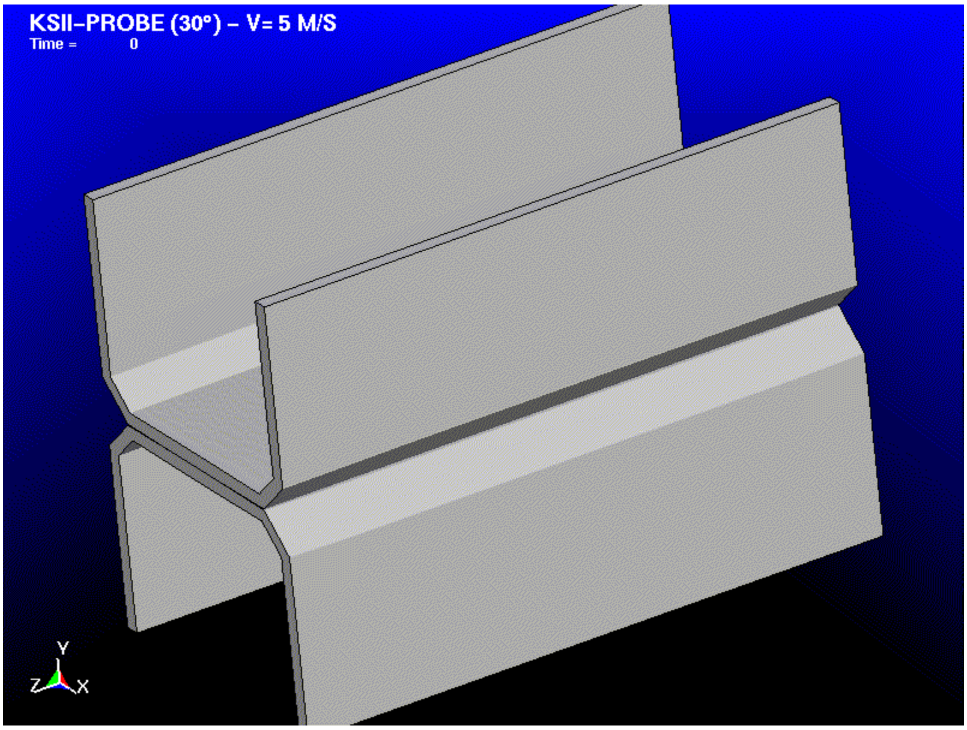
Spotweld failure-solids

- *DEFINE_SPOTWELD_FAILURE_RESULTANTS table containing the experimental data
- A unique failure criteria is defined for each pair of parts that are joined by spot welds.
- Rate effects are included by using load curve that scale the static failure resultants.
  - The strain rate are computed within the solid element spot weld where the effective strain rate is used.
- In *MAT_SPOTWELD this option is activated by setting the parameter *OPT* to a value of 7

Spotweld failure-contact

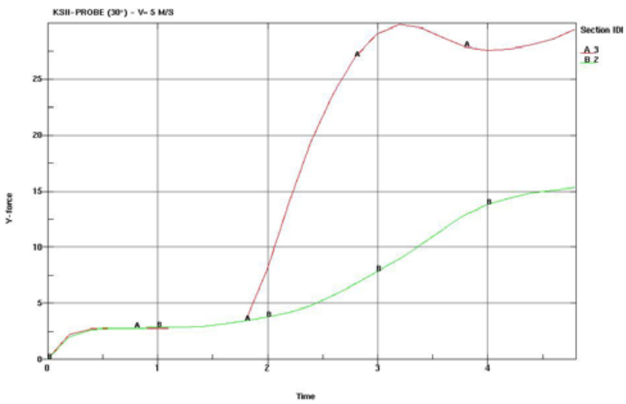
- Premature failure in welds are sometimes traced to the development of large contact forces equilibrated within the weld.
  - Experimental tests have shown that these contact forces are non-physical
  - These forces can develop in both beam and solid welds
  - These forces can develop under loading conditions where they would not be expected!





Spotweld failure-contact

Red = force in solid weld
Green = boundary reaction force



Spotweld failure-contact

Option SPOTHIN has been added to the *CONTROL_CONTACT input. SPOTHIN is a scale factor generally

.5< SPOTHIN < 1.0

With this option active, the thickness of the parts in the vicinity of the weld are automatically scaled, the contact forces do not develop, and the problem is avoided.

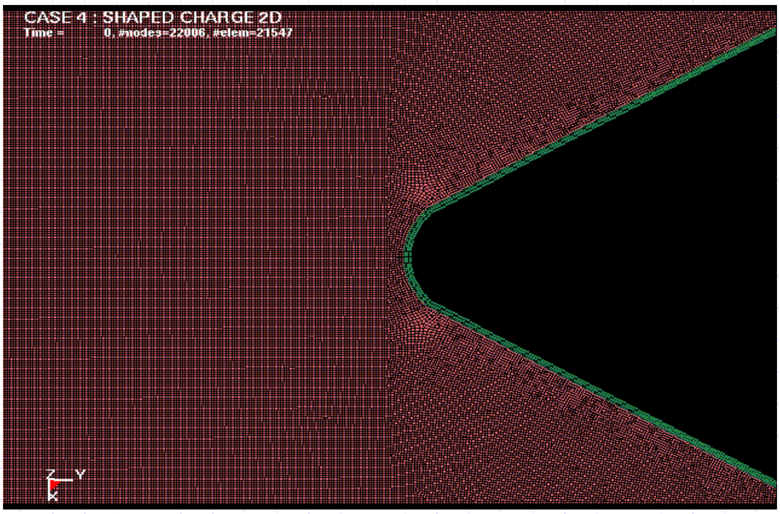
*Contact_auto…_tiebreak

- MPP implementation is underway for contact type:
  *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK
- Replaces old tiebreak option:
  *CONTACT_TIEBREAK_SURFACE_TO_SURFACE
  - Old option available by setting a flag for upwards compatibility
  - Old option is not robust if geometries are disjoint and non-smooth

2D r-adaptivity

- Option to specify the mesh size by part ID as a function of time added.
  - Next release of version 970.
- Failure option base on the part thickness added to handle in a general way failure of parts due to necking.
  - Available for constitutive model type 10 with others to be added later.

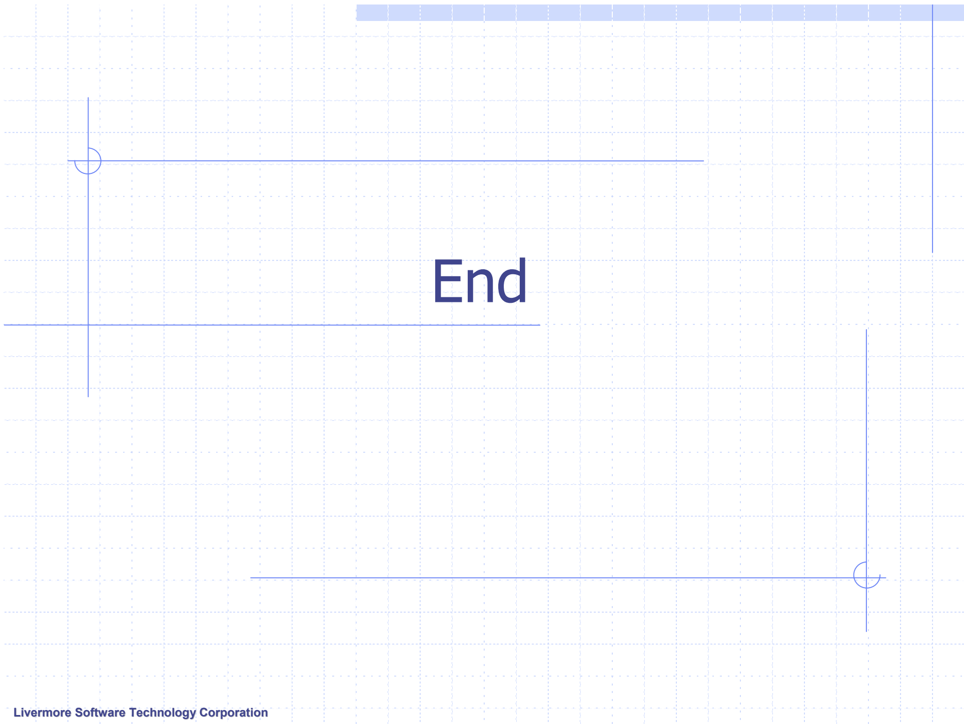
2D r-adaptive example



2D r-adaptive example

Future version 970 release

- One additional release is planned early next year.
  - New constitutive models will be included
  - MPP Automatic_..._tiebreak contact will be available
  - Improvements will be included for 2d adaptive problems
  - Will include all bug fixes for current release as they are discovered.
  - Features deemed urgent by customers will be added.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