Recent Developments in LS-DYNA®

DYNAmore Update Forum

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November 12, 2009
Outline of talk

• Introduction
• LSTC dummy developments
• LSTC barrier developments
• Consistency/Hybrid LS-DYNA
• Implicit update
• Version 971 release 4
• Version 971 release 5
• Conclusions
LSTC

• Five products:
  – LS-DYNA
  – LS-OPT, LS-OPT/Topology
  – LS-PrePost
  – FE Models: Dummies, barriers, head forms
  – USA (Underwater Shock Analysis)

• LS-PrePost®, LS-OPT®, the FE models and are part of the LS-DYNA® distribution and do not require license keys.
Applications of LS-DYNA

• Automotive
  – Crash and safety
  – Durability
  – NVH
• Aerospace
  – Bird strike
  – Containment
  – Crash
• Manufacturing
  – Stamping
  – Forging
• Structural
  – Earthquake safety
  – Concrete structures
  – Homeland security
• Electronics
  – Drop analysis
  – Package design
  – Thermal
• Defense
  – Weapon design
  – Blast response
  – Penetration
  – Underwater shock analysis
• Consumer products
One code strategy

Combine the multi-physics capabilities

- Explicit/Implicit solve
- Heat Transfer
- ALE
- EFG, SPH, Airbag particle method
- Incompressible fluids (version 980)
- CESE compressible fluid solver (version 980)
- Electromagnetics (version 980)
- Acoustics
- Interfaces for users, i.e., elements, materials, loads

into one scalable code for solving highly nonlinear transient problems to enable the solution of coupled multi-physics and multi-stage problems.
Development goals

• Reduce customer costs to encourage and enable massively parallel processing for large scale numerical simulations
  – Multicore processors have resulted in a drastic reduction in computer hardware costs and a huge increase in LS-DYNA licenses worldwide
  – Approaches used by LSTC to help reduce costs:
    • Flexibility: 4 core license allows 4 one core jobs or one 4 core job.
    • Unlimited core site license
    • Steeply decreasing licensing fees per core as the number of processors increase
Development goals

• Quickly update code to accommodate new features needed by users
• Reduce customer costs by increasing computational speed and improving scalability
  – By continuously recoding existing algorithms and developing new more efficient methodologies
  – Ensuring that LS-DYNA is fast, accurate, robust, and the most scalable software available
• And help reduce costs by providing at no add-on costs, FEA models and necessary peripheral software
  – LS-DYNA dummy, head form, leg form, and barrier models
  – LS-DYNA dedicated pre and post processing software
  – LS-DYNA specific optimization software
Dummies and barriers
Dummy/barrier distribution

• For licensed LS-DYNA users
  – No separate licensing from LS-DYNA.
• No encryption
• Continuous updates and support are provided by LSTC and LS-DYNA distributors
• The models generated by LSTC use TrueGrid® parametric meshing
Dummy/barrier distribution

- Feedback to LSTC on model performance is encouraged
- Companies may improve models and keep their improvements proprietary
- Companies may distribute their improved models to their suppliers and subsidiaries without restrictions.
- **Restriction:** LSTC models may not be used with competitor’s products
LSTC Dummy Models

Update on the development of the LSTC dummy models
Available LSTC Dummy Models

- SID-IIs D
- Hybrid III 50\textsuperscript{th} percentile
- Hybrid III Rigid-FE Adults
- USSID
- Free Motion Headform
- Pedestrian Legform

The recent deformable dummies average 230,000 elements with a target time step size > 0.50 microseconds.

All available models can be obtained through LSTC’s ftp site: http://ftp.lstc.com/user/
Update SID-lls D

• Initial customer feedback incorporated
• Released to all customers
• 215,000 elements

Ongoing:
• Incorporation of customer feedback from OEM
• Release of updated version in November 2009

Coming soon:
• Incorporation of material test results into model
Update Hybrid III 50th

Joint Development with NCAC under LSTC funding

- Validation of initial model with adjusted material properties completed
- Model stability and response improved
- Alpha Version released to all customers
- 255,000 elements

Coming soon:
- Additional validation and revalidation tests
- Incorporation of material test results into model
Update Hybrid III Rigid-FE Adults

- Model stability and response improved
- Customer feedback incorporated
- Further improvements planned
Update USSID

Originally developed based on NHTSA public domain version of USSID

Major enhancements include:
• Improved discretization for jacket, arm and pelvic foam
• Improved material data for foams
• One global contact
• Positioning tree for LS-PrePost
• 47,200 elements
Update Free Motion Headform

Model of the Free Motion Headform to simulate upper interior head impact tests

Coming soon:
• Different way of modeling head skin – skull interaction
• Incorporation of materials from physical material tests
Update Pedestrian Legform

• Originally developed in 2001 based on EEVC WG17 recommendations.

• Adjustment and Revalidation of Upper Leg Impactor and Legform Impactor according to European regulation 631/2009
Dummy Models we are working on:

- EuroSID 2re
- EuroSID 2
- Hybrid III 3-year old
- Hybrid III 6-year old
- SID-lls D Rigid-FE
- Hybrid III 5\textsuperscript{th} percentile female
- Hybrid III 95\textsuperscript{th} percentile
Update EuroSID 2re / EuroSID 2

Joint Development with DYNAmore

- 212,000 elements
- Most certification tests finished

Ongoing:
- Final certification tests
- Modifications from EuroSID 2re model to EuroSID 2

LSTC
Livermore Software Technology Corp.
Update EuroSID 2re
Joint Development with DYNAmore

Test used for validation:

- head drop test
- neck test
- lumbar spine test
- rip drop test
- shoulder test
- abdomen test
- pelvis test
Update Hybrid III 3-year-old

- Mesh completed

Ongoing:
- Build-up of the model

Coming soon:
- Material adjustments
- Certification test setup
Update Hybrid III 6-year-old

- Meshing of mechanical and interior components initialized

Ongoing:
- Meshing
Update SID-IIIs D Rigid-FE

Fast version of the SID-IIIs
• Meshing completed
• Model buildup completed

Ongoing:
• Material and part response adjustments
• Validation tests
Update Hybrid III 5\textsuperscript{th} percentile female

Joint Development with NCAC under LSTC funding

- Meshing completed
- Model buildup completed
- Initial simulations completed

Ongoing:
- Test for robustness
- Validation tests
Update Hybrid III 95\textsuperscript{th} percentile

Joint Development with NCAC under LSTC funding

- Surfaces scanned by NCAC
- Meshing started

Ongoing:
- Meshing
Estimated Release Dates*

- EuroSID 2re: November 2009
- EuroSID 2: November 2009
- Hybrid III 3-year old: Spring 2010
- Hybrid III 6-year old: Fall 2010
- SID-IIs D Rigid-FE: November 2009
- Hybrid III 5th percentile female: Fall/Winter 2009

*Estimated release dates cannot be guaranteed and may be delayed due to various circumstances.
Planned Dummy Models

- BioRID II
- Q-series child dummies
- Future Pedestrian Legform Impactors
LSTC Barrier Models

Update on the development of the LSTC barrier models
LSTC family of barriers

- Frontal offset barrier
  - Solid
  - Meshless (EFG)
  - Shells
- MDB (FMVSS 214)
  - Solid
  - Shell
- SICE (IIHS)
  - Solid
  - Shell
- ECE Rev 95
  - Shell
- AEMDB V3.10
LSTC family of barriers

Solid ODB
~50,000 elem.

Solid IIHS
~150,000 elem.

Solid 214
~125,000 elem.

Shell 214
~500,000 elem.

Shell IIHS
~575,000 elem.

Shell ODB
~375,000 elem.
LSTC Family of Barriers

AE-MDB
shell

214
shell/solid

ODB
shell/hybrid

IIHS
shell/solid

ECER95
shell
LSTC ODB Status Update

• Development based on 16 available OEM Tests
• Both Shell and Solid Version show promising results
• Solid version used to perform DOE (200+ runs) to study sensitivity of some important variables such as honeycomb shear damage, adhesive failure strength, cladding failure, etc.
• Verification runs made to reduce overall MSE error compared to test
Solid Results
Shell Results
Remarks

• Current shell and solid ODB barriers are production ready and are available with documentation
• Solid barrier takes roughly 10 minutes while the shell barrier takes 4 hours
• Future planned development includes but not limited to:
  • Fine-tuning correlation for certain load-cases
  • Adhesive area is better represented in shells. This approach will be incorporated in solids by using shells to model honeycomb at the cladding interface
  • Improve Predictive Robustness using LS-OPT to eliminate sensitivity on intrusion numbers
• We thank all the OEMs who provided us with the test data and helped us in “beta” evaluation
ECE Rev 95

Pole Impact Setup

Flat wall Impact Setup
ECE Rev 95 version 1

Pole impact

Flat wall impact
ECE Rev 95 version 2

ECER95 Revision 2

- A resulted_force
- B_wallspec_xy-1
- C_wallspec_xy-2
- D_TEST

Force (kN)

Crush (mm)
AEMDB V3.10

- Advanced European Moving Deformable Barrier
- Shell element version was developed at the request of an OEM
- Validated according to Version 3.10
LSTC AE-MDB v3.10
Full Barrier Results

[Graph showing force vs. displacement with different lines labeled AE-MDB, A FEA, B Max, and C Min]
Block Layout
Block Results
214 SIDE IMPACT BARRIER

• Shell version has been validated with 7 additional test cases
  – Case2 - 0 degree Flat wall
  – Case3 - Pole impact
  – Case4 - 15 degree angle
  – Case5 - 30 degree angle
  – Case6 - 100 % rocker
  – Case7 - 50 % rocker
  – Case8 - 100 % no bumper

• Version2 expected to be released Fall 2009
Test Case 2 Results
Test Case 3 Results

*Mat_viscoplastic_mixed_hardening*
Test Case 4 Results
Test Case 5 Results
Test Case 6 Results
Test Case 7 Results
Test Case 8 Results
Side impact barrier status

- LSTC_214_SOLID_BARRIER.102408_V3.0
- LSTC_IHHS_SOLID_BARRIER.102408_V3.0
  - Honeycomb material coordinate system defined using –AOPT for easy positioning.
- LSTC_ECER95_SHELL_BARRIER.090625_V2.0
  - Addition of airbags and venting of trapped air
    - Improved match with experimental results
- LSTC_214_SHELL_BARRIER version 2 will be released soon
  - 7 additional tests cases are added for barrier validation
- LSTC_AEMDB_V3.10_SHELL_BARRIER will be released soon
- UNITS
  - All LSTC barriers use the mm-ms-kg-kN unit system. Unit system conversion can be done by the *INCLUDE_TRANSFORM keyword.

- Contact Dilip at dilip@lstc.com for more information
Improved consistency & Hybrid LS-DYNA
Features to improve consistency

Problem:
Different MPI environments may use different algorithms to sum up data between cores within a node and across nodes. This changing summation order will cause different numerical truncation errors even using same number of MPP processors while changing from a dual core to a quad core system.

LSTC_REDUCE Option solves this problem.

Keyword:
*CONTROL_MPP_IO_LSTC_REDUCE

file:
    general { lstc_reduce }

LS-DYNA then uses a fixed order to get consistent answers
Features to Improve Consistency

Problem:
MPP decomposition is based on averaging the computational cost across the processors. If a model has been modified or refined, the cost profile will change and model will decompose in different way. This may change numerical results.

RCBLOG
keyword:
*CONTROL_MPP_DECOMPOSITION_RCBLOG
pfile:
decomposition { rcblog file_rcblog}

In the first run, LS-DYNA will store all the cut information and also retain all other options in the pfile into “file_rcblog”. In the subsequent runs, replace p=pfile to p=file_rcblog and LS-DYNA will decompose the model base on the preserved cut lines.
Scalability

Multi-core/Multi-socket clusters

- Scaling for a large number of processors, typically larger than 128, is not always good.
- A new approach is available in the upcoming R5 release and is currently being tested, it runs SMP within each processor and MPP between the processors.
- It is named **Hybrid LS-DYNA**.
- If the number of SMP threads is increased, results remain identical.
- To run the Hybrid option both SMP and MPP variables are set.
Scalability

Multi-core/Multi-socket clusters

• Setting variables
  – If e.g. the set-up is a system with 16 nodes, dual socket quad core system the variable is:
    • Set OMP_NUM_THREADS=4 (max four cores in each SMP)
    • The system is a 128 core system
  – mpirun –np 32 mpp971_hybrid i=input ncpu=-1
    • 32 MPP Processors (green circle) and 1 core in each which then is a total of 32 cores.
  – mpirun –np 32 mpp971_hybrid i=input ncpu=-2
    • 32 Processors and 2 cores in each = 64 cores
  – mpirun –np 32 mpp971_hybrid i=input ncpu=-4
    • Total of 128 cores is used
Scalability

Multi-core/Multi-socket clusters

Consistency

- Consistent results are obtained with fix decomposition and changing number of SMP threads
Scalability

*Multi-core/Multi-socket clusters*

- Hybrid greatly reduces the amount of data through network and provide better scaling to large number of processors
Scalability

Multi-core/Multi-socket clusters
Performance Comparison on Windows Server 2008

- SMP parallel in element processing and rigid body calculations
- SMP directives are now added to the MPP Contact---not reflected above

Car2car Model
Implicit update
MPP implicit

• MPP Implicit is working well.
  – Time for factorization and solves are scaling very well
  – There are scalar memory bottlenecks in MPP Implicit that are not in explicit. They show up on problems with millions of nodes and hundreds of cores. We are working to reduce them.
  – We are testing the *hybrid* parallel implementation.
Silverado

- Original from NCAC with .90M nodes
- Refined to have 1.8M and 3.6M nodes
MPP/Hybrid performance – 4 nodes

- Using 4 nodes and 1, 2, 4, and 8 cores/threads per node, all available memory the wall clock time results

<table>
<thead>
<tr>
<th>No. of cores/node</th>
<th>Factor WCT</th>
<th>Solve WCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (4 cores)</td>
<td>123.0</td>
<td>3.5</td>
</tr>
<tr>
<td>2 (8 cores)</td>
<td>68.4</td>
<td>2.1</td>
</tr>
<tr>
<td>4 (16 cores)</td>
<td>44.6</td>
<td>1.7</td>
</tr>
<tr>
<td>8 (32 cores)</td>
<td>27.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

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<tbody>
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<td>127.1</td>
<td>3.5</td>
</tr>
<tr>
<td>2 (8 cores)</td>
<td>79.9</td>
<td>2.1</td>
</tr>
<tr>
<td>4 (16 cores)</td>
<td>51.4</td>
<td>1.7</td>
</tr>
<tr>
<td>8 (32 cores)</td>
<td>37.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>
MPP performance – 8 nodes

- Using 8 nodes and 1, 2, 4, and 8 cores per node, all available memory the wall clock time results for Silverado 85M node / 5.3M row model

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<td>1.4</td>
</tr>
<tr>
<td>4 (32 cores)</td>
<td>26.5</td>
<td>0.9</td>
</tr>
<tr>
<td>8 (64 cores)</td>
<td>19.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>
*Control_implicit_linear_parts*

- A new implicit capability where parts are represented by a linear model based on
  - Constraint modes
  - Attachment modes
  - Eigen modes
- An extension to implicit of the explicit *PART_MODES* capability
- This feature can reduce computational cost associated with large implicit models.
*Control_implicit_explicit*

- Implicit-explicit capability **under development**
- One time step size for entire model
  - Use implicit solver on highly refined parts that drastically lower the explicit time step
  - The explicit elements determine the time step size
  - Equilibrium iterations necessary for implicit nonlinear

**Explicit**

**Implicit Solid**
*Control_implicit_explicit*

Body block impact using Mortar contact option
Implicit

*CONTROL_IMPLICIT_FORMING
1
One step – gravity loading applications

*CONTROL_IMPLICIT_FORMING
2,40,60
Multiple steps – roof crash etc
Roof crush

- 478332 elements
- 478624 nodes
- 1 contact including the ram

**Explicit**
- 16 cpus
- 2 hours 33 mins

**Implicit**
- 16 cpus
- 8 hours 5 mins
*Control_implicit_forming*
*Control_implicit_forming*

![Graph showing axial force over time with explicit and implicit methods.](image-url)
*Control_implicit_forming*
Version 971_R4
Thick shell formulation 5

- Layered brick element element or 3D shell
- 1 integration point in-plane
- Uses 3D stress
- Materials types may be mixed between layers
- Uses custom hourglass control that is orthogonal to bending modes and some torsional modes.
Thick shell formulation 5

Assumed strain formulation:

• Prevents shear locking and volumetric locking

• Modified z-strain accounts for layers with different stiffness in the thickness direction

• Modified z-strain accounts for layers with different Poisson's affect due to anisotropic properties (composites)

• Laminated shell theory
Thick shell formulation 5

Advantages

- 3D stress field (includes thickness stress)

- Bending stiffness accuracy of a thin shell due to multiple integration points through thickness

- Matches shell results in plane stress problems including composite tests

- Matches results with stack bricks to represent layers
Enhanced-strain solids

• Solid element type 2 shear locks when the aspect ratio are poor
  – Based on selective reduced integration
    • Avoids volumetric locking

• Two new fully integrated solid elements are implemented that overcomes shear locking
  – Type -2 which is approximately 2.9 times more costly
  – Type -1 which is approximately 1.5 times more costly
  – Implicitly
  – Works for linear and nonlinear large deformation problems
The need for simple and efficient beam to surface contact:

- Analysis of cables contained within a conduit or cables adjacent to a structural surface subjected to static and dynamic loading
- Human body modeling of muscles and tendons interacting with skeleton
- Interaction of woven fabrics on discretized surfaces
  - Beam to beam contact treats the fiber contact in the woven fabric
Contact_beam_to_surface

New keyword:

- *CONTACT_AUTOMATIC_BEAMS_TO_SURFACE
- Compatible with the beam-to-beam contact type, AUTOMATIC_GENERAL, which allows both contact types to function together in analyzing woven fabric interacting with surfaces
- Speed advantage over current methods
  - Avoids beam to beam contact checking of the GENERAL option
- Accuracy over node to surface contact types
  - Provides continuous force distribution due to beam contact
Neck-cable interaction
Slow speed impact

• Slow speed impact can be noisy due to single precision
• Double precision eliminates problem but runs significantly slower
  – Arithmetic operations are more costly
  – Message length of communicated data under MPI doubles
• By keeping all arrays related to the global coordinates in double precision the problem is now solved
  – Only small slowdown relative to R3 due to additional double precision arithmetic and message lengths
• We are now confident that single precision can continue to be used for crash analysis for the next decade
Version 971_R5
*Initial_airbag_particle

• Applications
  – Initialize pressure in a closed volume
    • Airbags
    • Door cavity for pressure sensing studies
    • Tires
*Initial_airbag_particle

- SID1 – External and internal parts
- SID2 – Internal parts
- Ambient pressure and temperature
- Initially filled gas properties, pressure and temperature.
- Number of vents
- BAGID - *airbag_particle to be filled.
  – To be implemented soon
*Initial_airbag_particle

Tire leak using particle method
*Initial_airbag_particle
*Initial_airbag_particle
*Initial_airbag_particle*

Tire leak using particle method

- A: Pressure
- B: Leakage

---

Initial airbag particle

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LSTC
Livermore Software Technology Corp.
Pressure sensing - sensors

ALE
195360 ALE elements
16 cpus 33 minutes

PARTICLE
50000 particles
16 cpus 4 minutes
*Node_merge

- The MERGE option in the *NODE definition is typically applied to boundary nodes on disjoint parts and only applies to nodes defined where the merge option is invoked.
- With this option, nodes with identical coordinates are replaced during the input phase by the first node encountered that shares the coordinate.
- During the merging process a tolerance is used to determine whether a node should be merged.
  - This tolerance can be defined using the keyword *NODE_ MERGE_TOLERANCE
**Define_box_xxxx_LOCAL**

- _LOCAL option is now available for the box definitions:
  - Box diagonal corner coordinates are given in a local coordinate system defined by an origin and vector pair
- For the *INCLUDE_TRANSFORM options that include translations and rotations, all box options are automatically converted from *DEFINE_BOX_XXXX to *DEFINE_BOX_XXXX_LOCAL in the DYNA.INC file.
*Boundary_prescribed_final_geometry*

- Simplified input for special applications where the initial and final geometries are known.
  - Eliminates the need to define individual vectors for prescribed movement
- The final displaced geometry for a subset of nodal points is defined.
- The nodes of this subset are displaced from their initial positions specified in the *NODE input to the final geometry along a straight line trajectory.
*Mat_rigid_discrete or *Mat_220

- Eliminates the need to define a unique rigid body for each particle when modeling a large number of particles
- Big reduction in memory and wall clock time over separate rigid bodies
- A single rigid material is defined which contains multiple disjoint pieces. All disjoint rigid pieces are identified automatically during initialization.
- Each rigid piece can contain an arbitrary number of solid elements that are arranged in an arbitrary shape.
**Mat_rigid_discrete**

- Rigid body mechanics is used to update each disjoint piece of any part ID which references this material type.
- Can be used to model a granular material where the grains interact through an automatic single surface contact definition.
- Another possible use includes modeling bolts as rigid bodies where the bolts belong to the same part ID.
*Mat_viscoplastic_mixed_hardening

- *Mat_225
- Based on viscoplastic *MAT_024 (VP=1.0 and table)
  but with additional mixed hardening (isotropic/kinematic) as in *MAT_003

Hardening parameter, 0<BETA<1.

EQ.0.0: Pure kinematic hardening
EQ.1.0: Pure isotropic hardening
0.0<BETA<1.0: Mixed hardening (linear interpolation)

\[ f(\sigma) = \sqrt{\frac{3}{2}} (s - \beta \alpha) : (s - \beta \alpha) - (1 - \beta) \bar{\sigma}_y (\bar{\varepsilon}^{pl}) = 0 \]
*Mat_viscoplastic_mixed_hardening

- Suited for cyclic loading cases (Bauschinger effect)

  pure isotropic hardening
  (*MAT_024 or *MAT_225 with BETA=1.0)

  mixed hardening
  (*MAT_225 with BETA=0.3)

more realistic
*Mat_fabric:new reloading option*

- **Current behavior:**
  - Reloading on unloading path

- Not realistic for **cyclic loading**

Experimental result: force-displacement loops
**Mat_fabric: new reloading option**

- **New option**: Reloading between loading and unloading path

- A new parameter governs slope of straight line

---

**model: straight line**

- Loading
- Reloading
- Unloading
*Mat_add_thermal_expansion*

- Orthotropic thermal expansion for anisotropic materials
**Mat_add_erosion**

- New option developed at Daimler:
  
  GISSMO - *Generalized Incremental Stress State dependent damage Model*

  - GISSMO allows for:
    
    - The use of existing Material models
    - Constitutive Model and Damage formulation are treated separately
    
    - Offers features for a comprehensive treatment of Damage in Forming Simulations
    
    - Implementation in LS-DYNA recently completed for the R5 release
Damage Evolution

\[
\dot{D}_f = \frac{n}{\varepsilon_f} D_f^{(1-\frac{1}{n})} \dot{\varepsilon}_p
\]

Damage depends on:
- stress state (triaxiality)
- load path
- element size (regularization)

Modular damage model: can be used with many different standard plasticity materials (*MAT_024, *MAT_036, ...)

Damage variable can be mapped from forming to crash ("pre-damage")
Mortar contact features

- Automatic surface-to-surface, automatic single-surface and tied surface-to-surface
- Provides contact tractions that are consistent with finite element theory, for trias/quads/tet4/pentas/hexa/tet10
- Intended for implicit analysis but works for explicit
- MPP and SMP
Mortar contact

Edge contact in automatic mortar contact

Supported with no extra option
Mortar contact

Crashbox utilizing automatic single surface mortar contact
Mortar contact

Tied mortar contact for some supported element types
Molar fraction mass flow input

• Some airbag suppliers provide inflator mass inflow rate and gas mixture composition in terms of
  – a single curve representing the combined mass flow rate of all gas components
  – For each gas component, a curve is used to represent the molar ratio as a function of time
Molar fraction mass flow input

• Input description:
  – Additional card 3 for airbag_hybrid
    
    | OPT | PVENT | NGAS | LCEFR | LCIDM0 |
    |-----|-------|------|-------|--------|
    |     |       |      |       |        |

    LCIDM0: combined gas inflow rate of all gas components
  – For each gas component
    
    | LCIDM | LCIDT | MW | INITM | A | B | C |
    |-------|-------|----|-------|---|---|---|
    |       |       |    |       |   |   |   |

    LCIDM: molar ratio curve, when LCIDM0 is defined
    INITM : initial molar ratio, when LCIDM0 is defined

• Implemented for *airbag_hybrid and *airbag_hybrid_jetting
• Available in R4.2 and after
Improvement to 2d-belts

- 2d belt, now correlated with 1d belt, has its belt load output in secforc
Improvement to 2d-belts

• Retractor and slipring output are available in sbtout

• 2d belt can work together with regular shells to complete a seatbelt; this allows users to keep regular shell they prefer, which might be needed to maintain correlation
Improvement to 2d-belts

2d belt

2d belt + shell

1d belt + shell

Head Acceleration

Chest Acceleration
Improvement to belt analysis

- Use of type 16 shell elements to complete a belt is now possible with *Mat_non-linear_orthotropic, type 40.
  - Allows modeling of nonlinear fiber behavior
  - Captures bending stiffness of belt
  - Total lagrangian formulation tracks angle changes between fibers in deformed configuration
  - Type 16 fully integrated shell element
User-Defined Elements

• Implemented for solids and shells.
• Permits new element types to be defined entirely by keyword input.
• Interpolation elements allow output to LS-Prepost.
  – Contact
  – Boundary conditions
• Intended for researchers and students.
  – Research: isogeometric elements.
  – Students: implement elements as homework.
• Analysis types possible:
  – Explicit, Implicit quasi-static and dynamic
Isogeometric Analysis

Example of User-Defined Elements

• Isogeometric analysis uses NURBS as basis functions.
  – NURBS are the basis functions used in CAD programs.
  – Therefore: facilitates direct CAD to analysis interface.
  – NURBS are nicely behaved.
    • Improved numerical conditioning.
    • Larger time step size for higher order elements than for Lagrangian polynomials.
Shell Formulations

• 3 types currently available.
  – IFORM=0: Degenerated solid element with rotational DOF.
    \[ v_i(\xi) = \sum_{A=1}^{n} N_A(\xi) \left( v_{Ai} + \frac{h\xi_3}{2} e_{ijk}\omega_{Aj}n_{Ak} \right) \]
  – IFORM=2: Thin shell without rotational DOF.
    \[ v_i(\xi) = \sum_{A=1}^{n} N_A(\xi) v_{Ai} + \frac{h\xi_3}{2} \sum_{B,k} \frac{\partial n_i(\xi)}{\partial x_{Bk}} v_{Bk} \]
  – IFORM=3: Reissner-Mindlin with rotational DOF.
    \[ v_i(\xi) = \sum_{A=1}^{n} N_A(\xi) \left( v_{Ai} + \frac{h\xi_3}{2} e_{ijk}\omega_{Aj}n_k(\xi) \right) \]
Square tube buckling

*Quadratic (P=2) and Quartic (P=4) NURBS Elements*

- Isogeometric NURBS basis functions
  - Quadratic ($s^2$) and quartic ($s^4$) functions
  - 3 integration points through the thickness
- 858 control points (nodes)
- 640 elements
- Perturbation of control points (nodes) with amplitude of 0.05 at $y=67.5$
- *MAT_KINEMATIC_PLASTIC* with isotropic hardening
- We are starting the work to make NURBS Elements directly available
Square tube buckling

Quadratic ($P=2$) NURBS Shell Elements

square cross section for single surface
Time = 0
Contours of Effective Plastic Strain
min ip, value
min=0, at elem# 1001
max=0, at elem# 1001
Square tube buckling

Quartic ($P=4$) NURBS Shell Elements
Acoustic solvers in LS-DYNA

**BEM (accurate)**
- Indirect variational boundary element method
- Collocation boundary element method
  
  *A fast solver based on domain decomposition*
  
  *MPP version is available*

**Approximate methods**
- Rayleigh method
- Kirchhoff method
  
  *Assumptions and simplification in formulation*
  
  *Very fast since no equation system to solve*
Flow chart

- LS-DYNA nonlinear FEM analysis
- Velocity (pressure) in time domain
- Velocity (pressure) in frequency domain
  - FFT
  - Rayleigh
  - BEM
  - Kirchhoff

- Sound pressure (Pa), SPL (dB) for target points

Velocity in frequency domain given by user
Keyword

Execution line:

LSDYNA i = input.k bem=filename

Keyword

*BOUNDARY_ELEMENT_METHOD_ACOUSTIC
Golf club example

Model information

FEM part
34412 Nodes
27616 Solid elements

BEM part
6313 Nodes
6272 Shell elements
SerialMPP (8 cpu)

Elapsed time
12 hours 14 min
102 hours 32 min

MPP (8 cpu)  Serial

press field pt (dB)

freq(1Hz) (E+3)

A_BEM
B_Rayleigh
Random vibration analysis

• The loading on a structure is not known in a definite sense;
• Many vibration environments are not related to a specific driving frequency (may have input from multiple sources);
• Examples:
  ✓ Fatigue
  ✓ Wind-turbine
  ✓ Air flow over a wing or past a car body
  ✓ Acoustic input from jet engine exhaust
  ✓ Wheels running over a rough road
  ✓ Earthquake ground motion
  ✓ Ocean wave loads on offshore platforms
• Loadings: PSD or SPL (for acoustic excitation);
Random vibration analysis

**INPUT**
Structure model, acoustic or mechanical excitations (PSD or SPL), damping, temperature, etc.

**OUTPUT**
PSD and RMS of displacement, velocity, acceleration and stress (accessible by LS-PrePost)

**KEYWORDS**

*CONTROL_VIBRO_ACOUSTIC*
Purpose: Set vibro-acoustic structural analysis control options.

*LOAD_VIBRO_ACOUSTIC*
Purpose: Define acoustic spectrum load, damping, etc. as a series of load curves.

*DATABASE_POWER_SPECTRAL_DENSITY*
Purpose: Define set ID for nodes and elements for PSD output.

*DATABASE_POWER_SPECTRAL_DENSITY_FREQUENCY*
Purpose: Define range and interval of frequencies for PSD output.
Example: an engine inlet

Reverberant acoustic wave is applied

Example was provided by the Phantom Works, Boeing Company.
Frequency response functions

- A FRF expresses the structural response to an applied force as a function of frequency. It is a transfer function.
- The response may be given in terms of displacement, velocity, or acceleration. Accordingly, they are called compliance, mobility and accelerance.
- A FRF is a complex function, with real and imaginary components. They may also be represented in terms of magnitude and phase.
- One input/Multiple output.
- These functions are used in vibration analysis and modal testing.
- Activated by keyword *CONTROL_FREQUENCY_RESPONSE_FUNCTION
Benchmark example

Natural frequencies (Hz)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Analytic</th>
<th>Experimental</th>
<th>ANSYS</th>
<th>LS-DYNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>76.12</td>
<td>76.84</td>
<td>78.62</td>
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<td>220.37</td>
<td>219.69</td>
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<tr>
<td>6</td>
<td>255.79</td>
<td>261.41</td>
<td>254.96</td>
<td>255.13</td>
</tr>
</tbody>
</table>

Harmonic point force excitation
F = \exp(-i\omega t)

Reference:
Constant modal damping ratio 0.01 is adopted in ANSYS and LS-DYNA.

For high frequency results, LS-DYNA results can approach experimental results more closely, by using a smaller damping ratio, which suggests that the damping ratio is dependent on frequency for this structure.
Version 980

• Version 980 has been under development for 6 years
• Adds to the multi-physics capabilities
  – Electromagnetics
  – Incompressible fluid solver
  – Compressible fluid solver based on CESE
• Full structural and thermal coupling between solvers
• Planned beta release in 2010
Electromagnetism module:
General presentation

Electromagnetism module for 3D eddy-current problems, coupled with mechanical and thermal solvers (typical applications: magnetic metal forming and welding).

Boundary element method in the air coupled to finite elements in the conductor is used to avoid meshing the air.

The EM fields, as well as EM force and Joule Heating can be visualized with LSPREPOST.
Electromagnetic tube welding with field shaper

~14000 elements (1/2 mesh shown)

5 turns Al coil

Al Tube

Cu central rod

Cu-Be Field shaper
3D simulation (1/2 of the mesh shown)
Incompressible flow solver

• Incompressible fluid solver.
• Error Control and adaptive re-meshing MPP implementation.
• Separate meshes for fluid and structure.
• Allows weak and strong FSI coupling depending upon the problem.
• Coupling to explicit and implicit structural solvers
• Multifluid and Free-Surface flows.
• LES and RANS turbulent models
Bubble Drop: High Resolution Interface Capturing and Adaptive Re-Meshing

\[ \mathbf{g} = (0, 0, -1) \]

Free Surface (P=0)

Density=0.5

Density=0.1

Free Slip
Bubble Drop: High Resolution Interface Capturing and Adaptive Re-Meshing
Flexible Beam With Error Control

INFLOW

FSI BOUND.

FREE SLIP

OUTFLOW
Velocity Field and Mesh
CESE Method

• Advantage of CESE method for compressible flow:
  – Flux conservations in space and time (locally & globally)
  – 2\textsuperscript{nd} order accurate
  – Both strong shocks and small disturbances can be handled very well simultaneously
  – Boundary conditions can be implemented easily & accurately
Current status

• **Codes:** Serial & MPP modes
  ( fluid solver input deck setup is very simple )

• **Flows:** Compressible inviscid & viscous flows

• **Meshes:** Hexahedra, wedges, tetrahedra

• **BCs:**
  • Regular boundary conditions (solid, open, inflow, outflow, symmetric)
  • Moving or rotating solid boundaries for viscous flows (in tangential directions)
FSI with CESE
FSI with CESE
Conclusions: summary

• LSTC is working to be the leader in large scale numerical simulations
  - LSTC is providing dummy, barrier, and head form models to reduce customer costs.
  - LS-Prepost and LS-Opt 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 implicit solver is quickly gaining market acceptance for nonlinear implicit calculations and simulations
    • Robustness, accuracy, and scalability has rapidly improved
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
  – Multiscale capabilities are now under development with initial release later this year
  – Hybrid MPI/OPENMP developments are showing significant advantages at high number of processors for both explicit and implicit solutions
JUNE 06 – 08, 2010 at the Hyatt Regency Dearborn, Detroit, MI

11th Int’l LS-DYNA Users Conference  www.ls-dynaconferences.com

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