Recent Developments in LS-DYNA®

DYNAmore Update Forum

John O. Hallquist

November 12, 2009

LSTC
Livermore Software
Technology Corp.

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

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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.

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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 is 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

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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 50th 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-IIs D
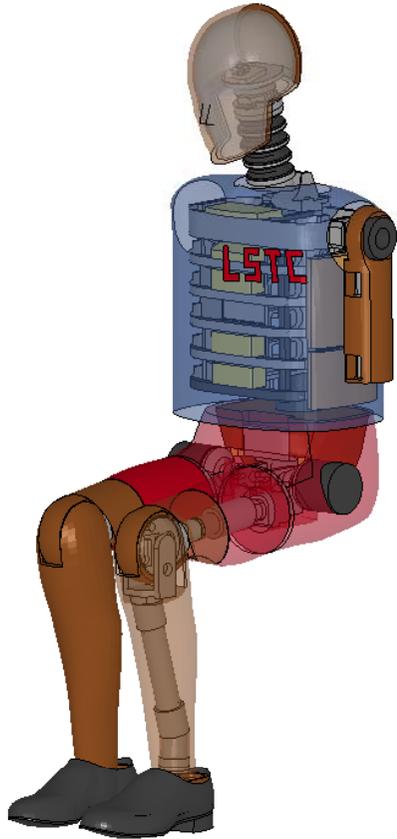
- Initial customer feedback incorporated
- Released to all customers
- 215,000 elements

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
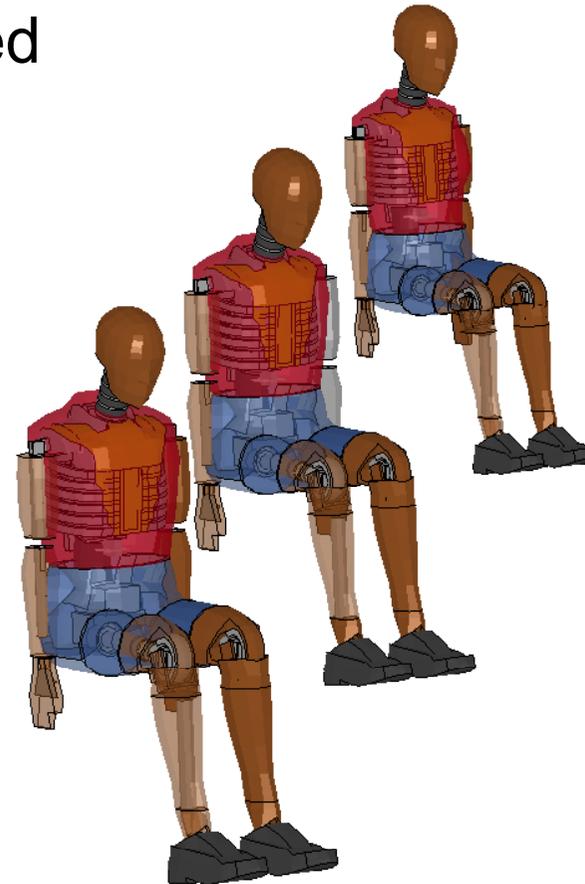
Update USSID

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
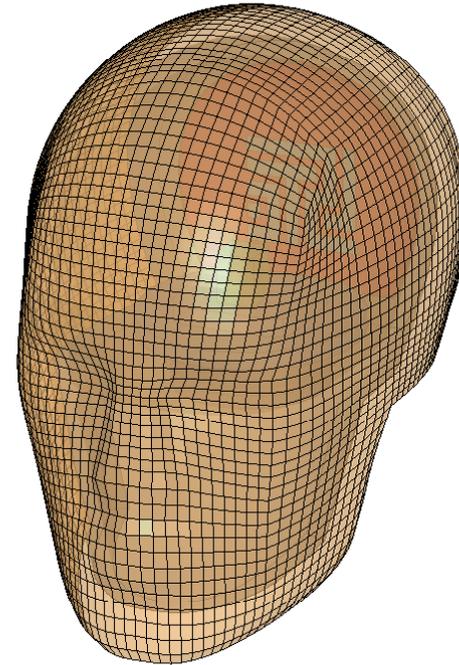
Update Pedestrian Legform

- 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

18
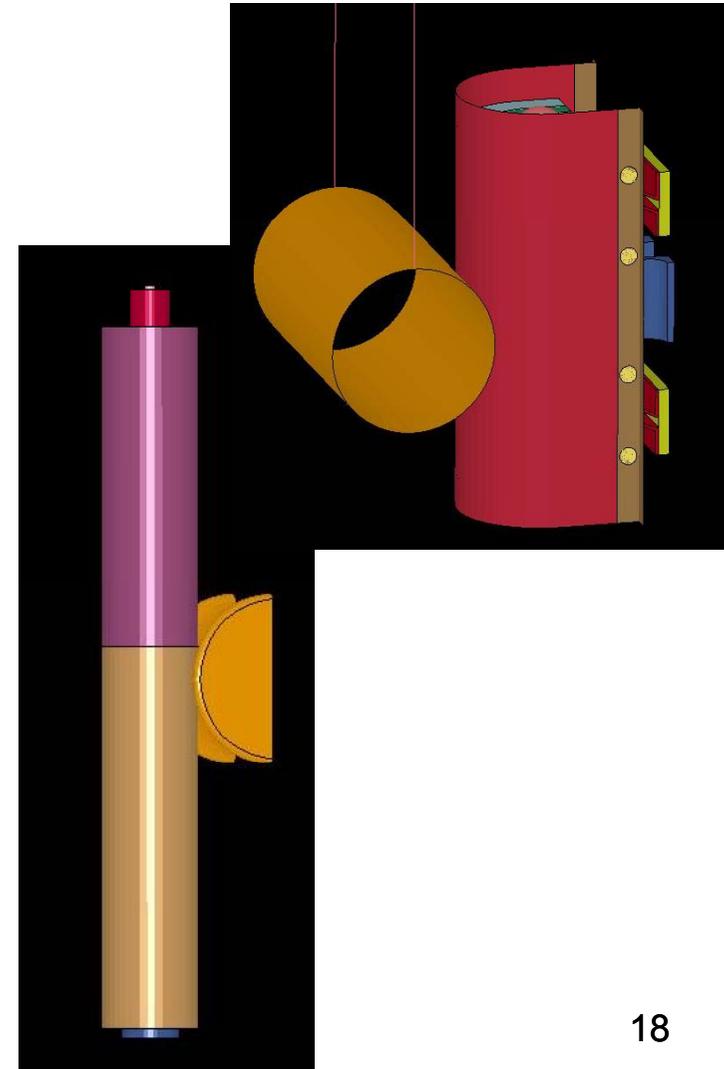
Dummy Models we are working on:

- EuroSID 2re
- EuroSID 2
- Hybrid III 3-year old
- Hybrid III 6-year old
- SID-IIs D Rigid-FE
- Hybrid III 5th percentile female
- Hybrid III 95th 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
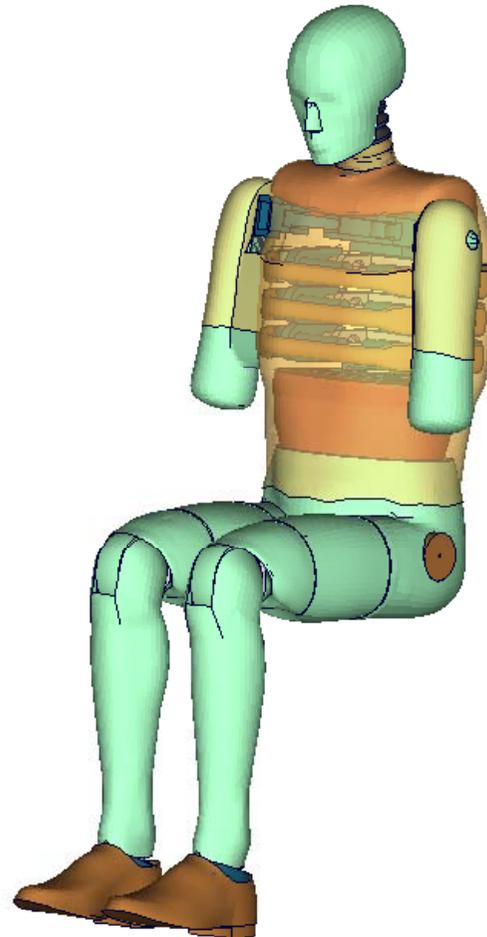
Update EuroSID 2re

Joint Development with DYNAmore

Test used for validation:
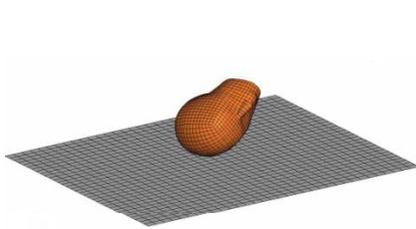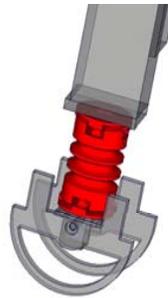
head drop test   neck test   lumbar spine test   rip drop test
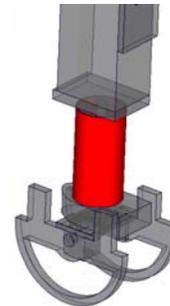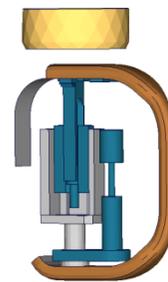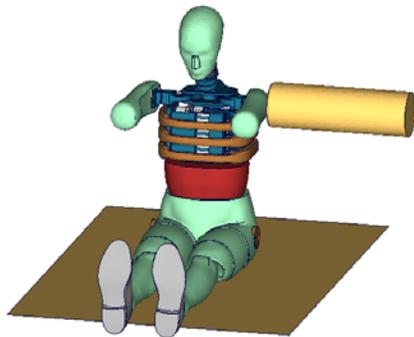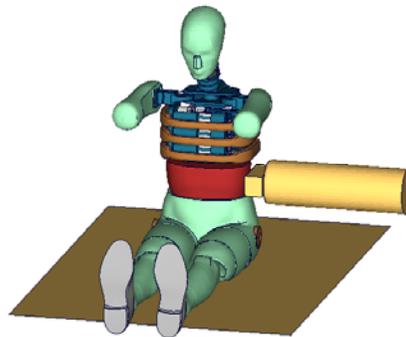
shoulder test   abdomen test   pelvis test
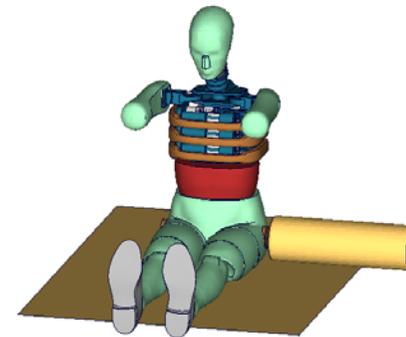
Update Hybrid III 3-year-old
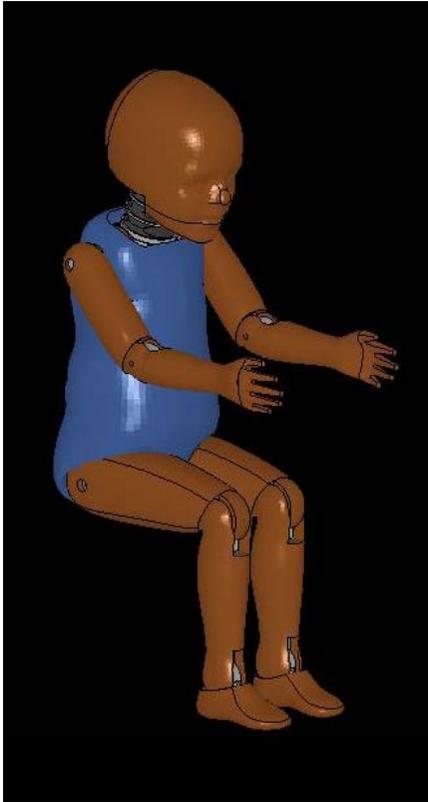
- Mesh completed

Ongoing:
- Build-up of the model

Coming soon:
- Material adjustments
- Certification test setup

Update Hybrid III 6-year-old
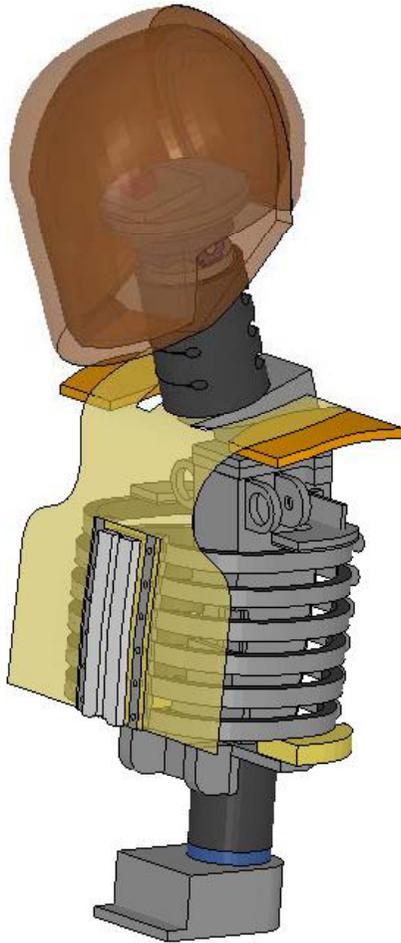
- Meshing of mechanical and interior components initialized

Ongoing:

- Meshing

Update SID-IIs D Rigid-FE

Fast version of the SID-IIs

- Meshing completed

- Model buildup completed

Ongoing:

- Material and part response adjustments

- Validation tests

Update Hybrid III 5th 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 95th 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
~125,000 elem.

Solid 214
~150,000 elem.

Shell 214
~500,000 elem.

Shell IIHS
~575,000 elem.

Shell ODB
~375,000 elem.

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LSTC Family of Barriers

AE-MDB
shell

214
shell/solid

ODB
shell/hybrid

IIHS
shell/solid

ECER95
shell
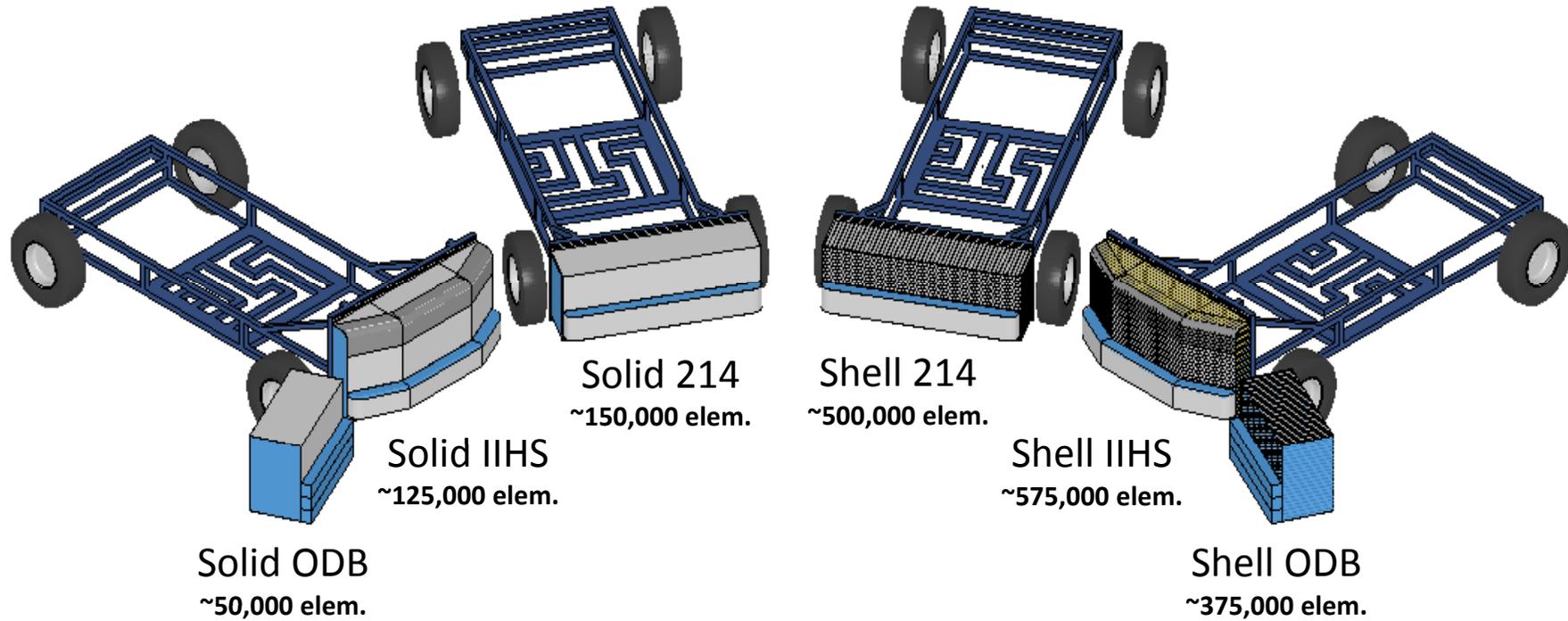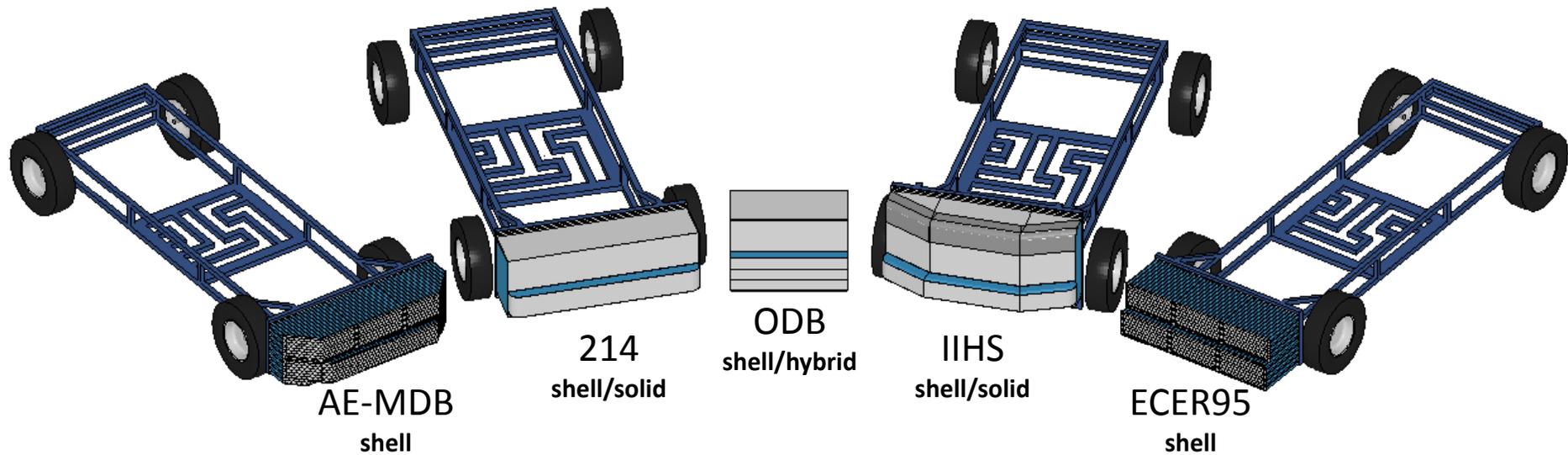
LSTC ODB Status Update

- 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 MSError compared to test
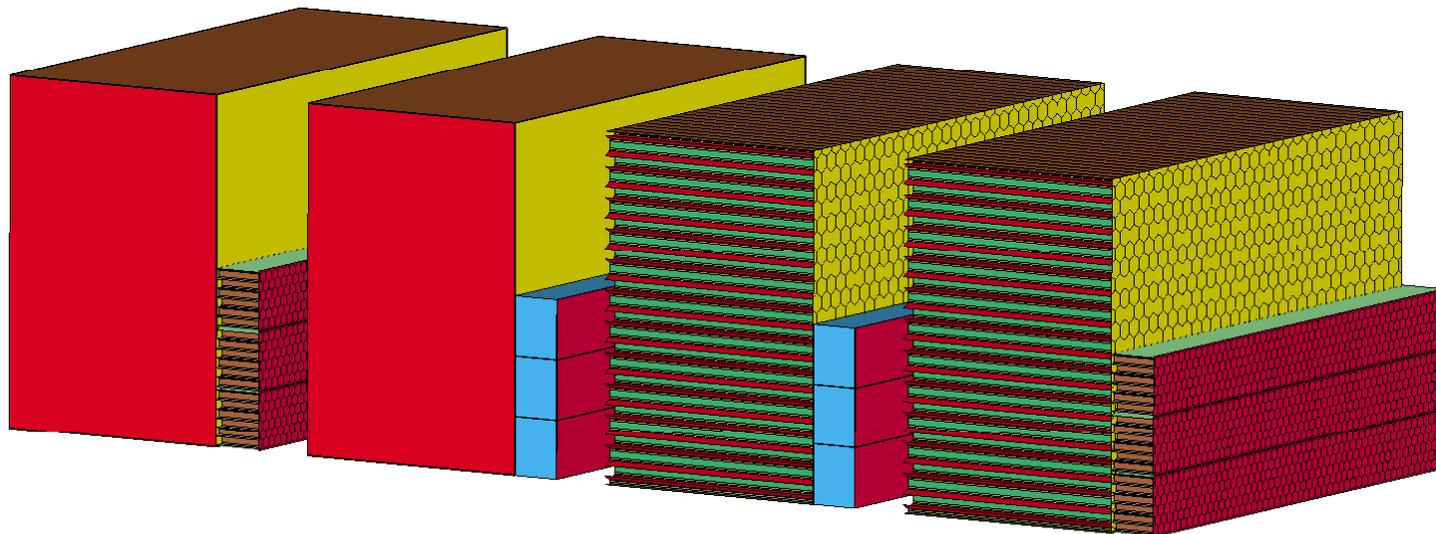
Solid Results
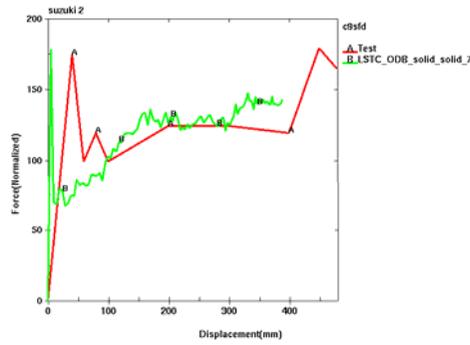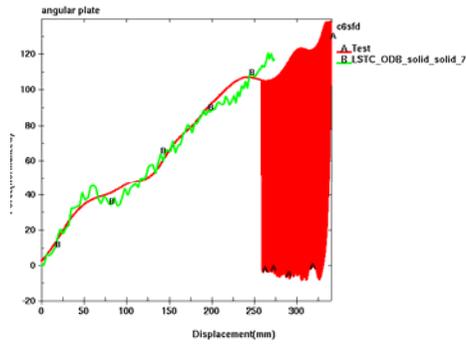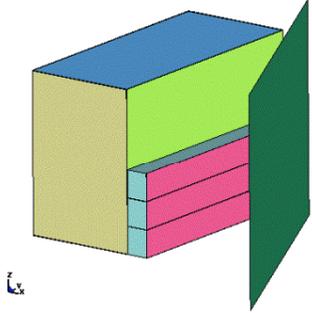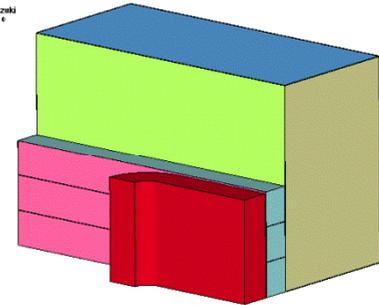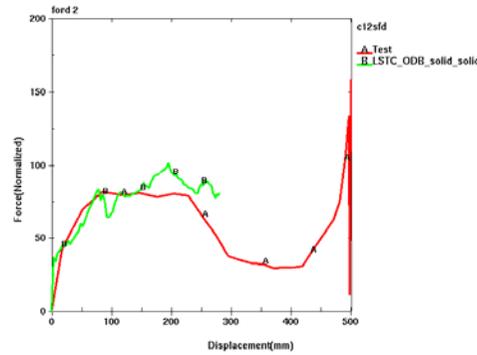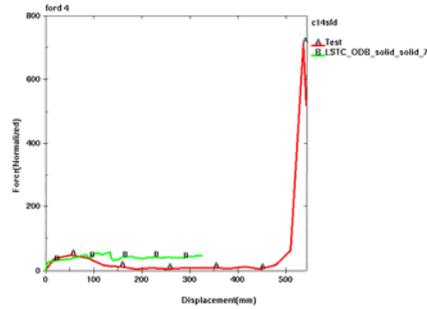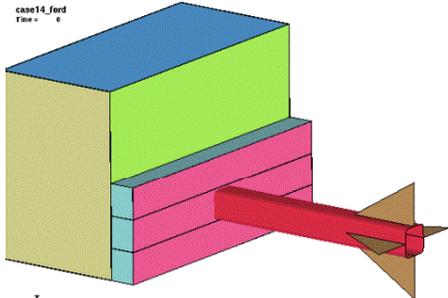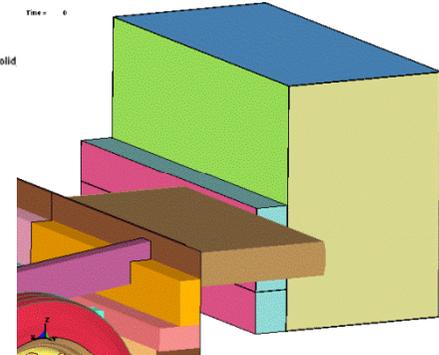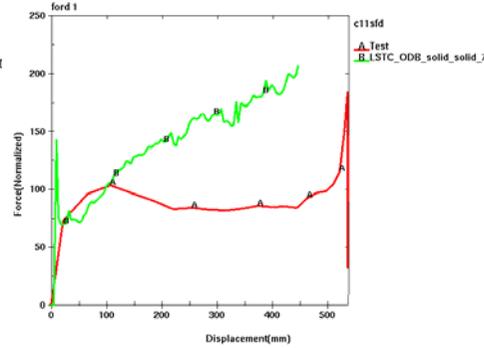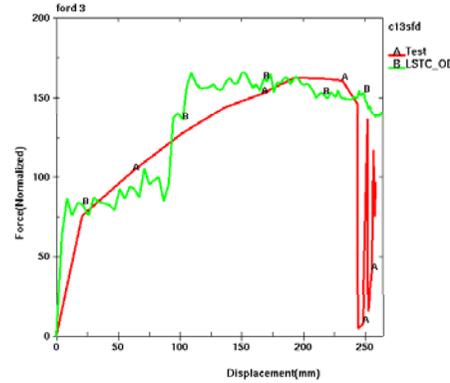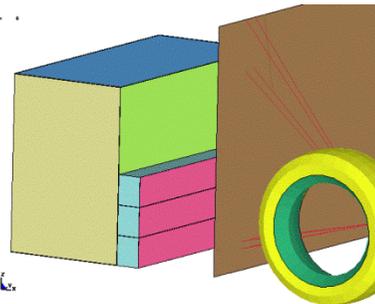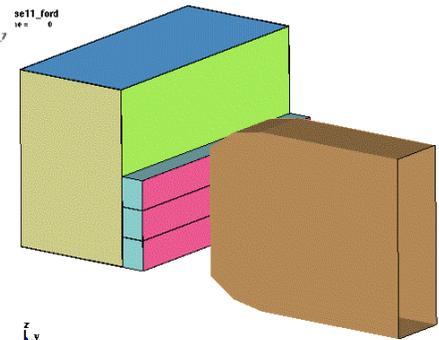
Shell Results
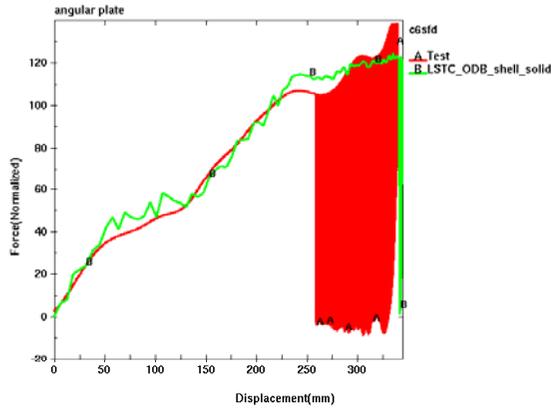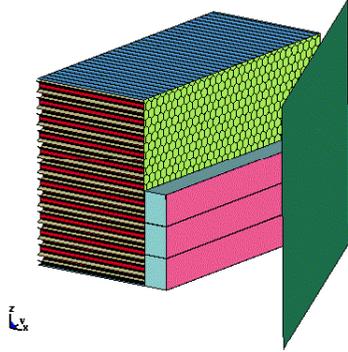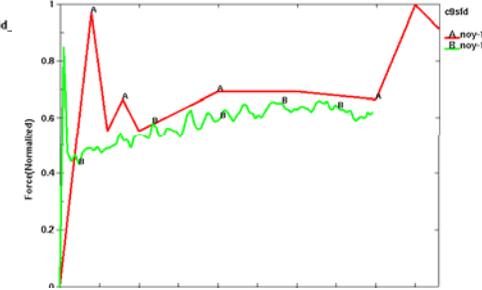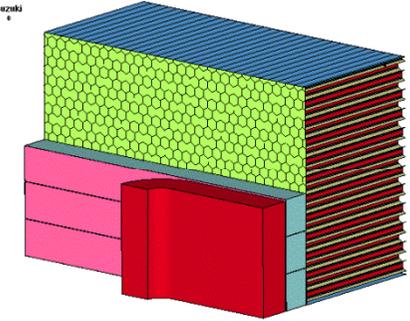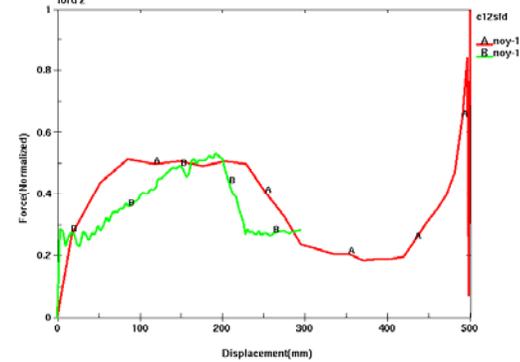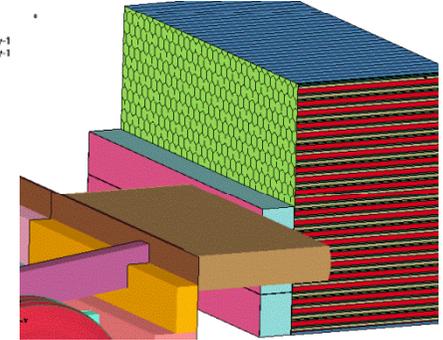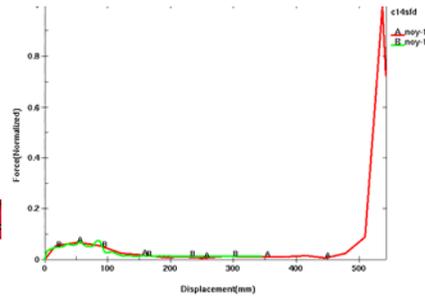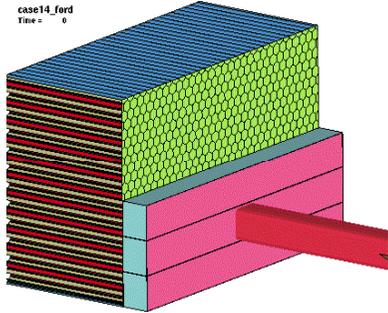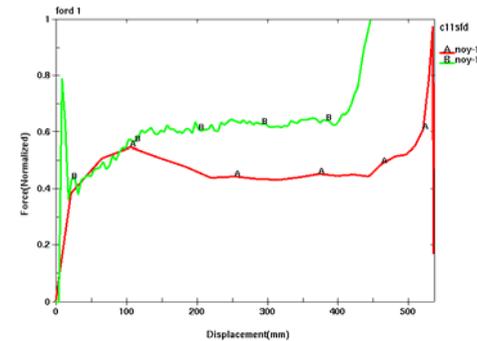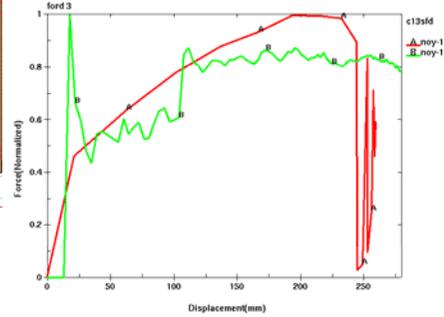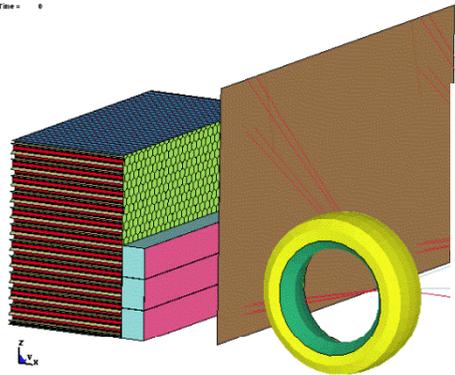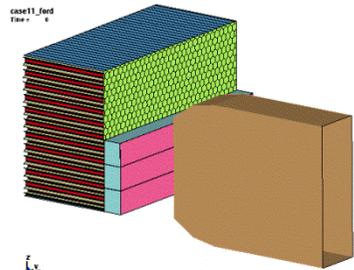
Remarks

- 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
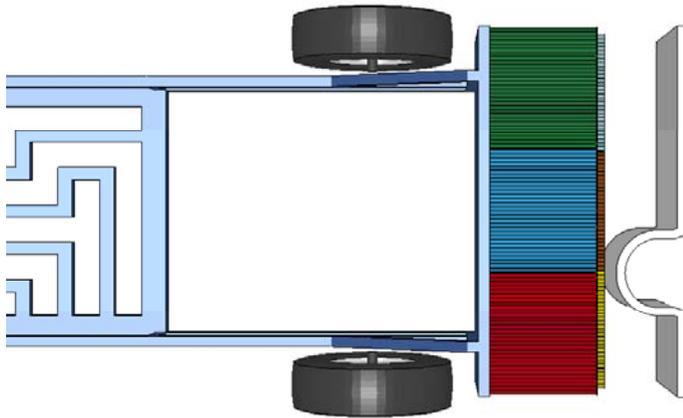
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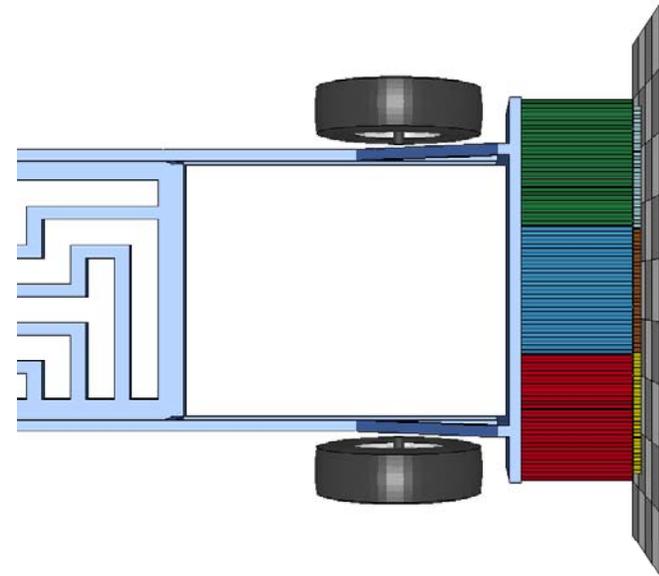
Flat wall Impact Setup

ECE Rev 95 version 1
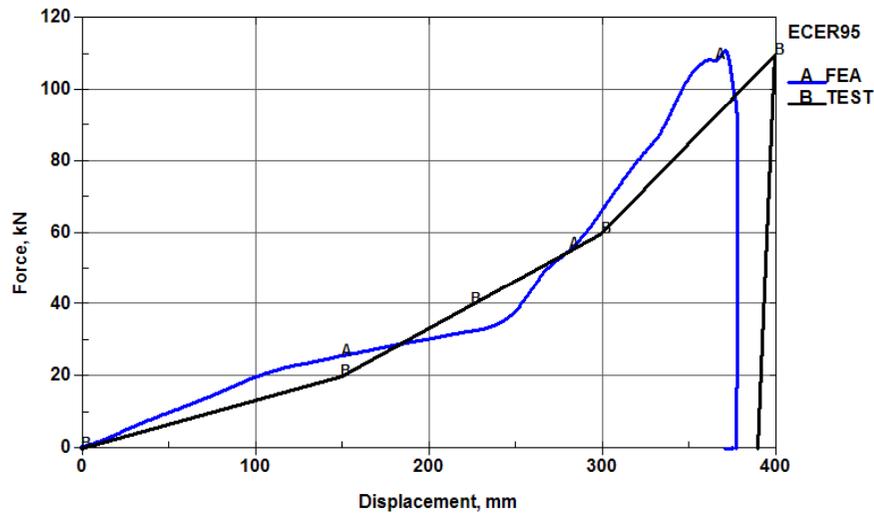
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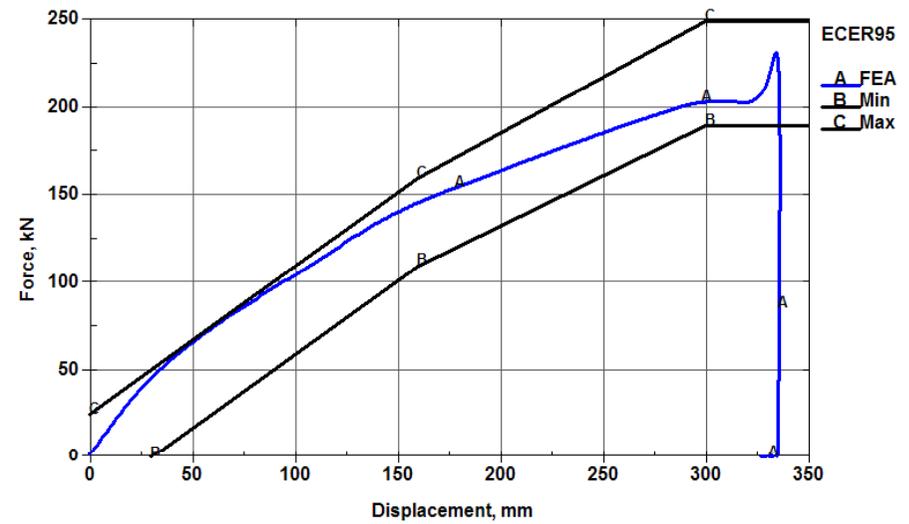
Flat wall impact

ECE Rev 95 version 2
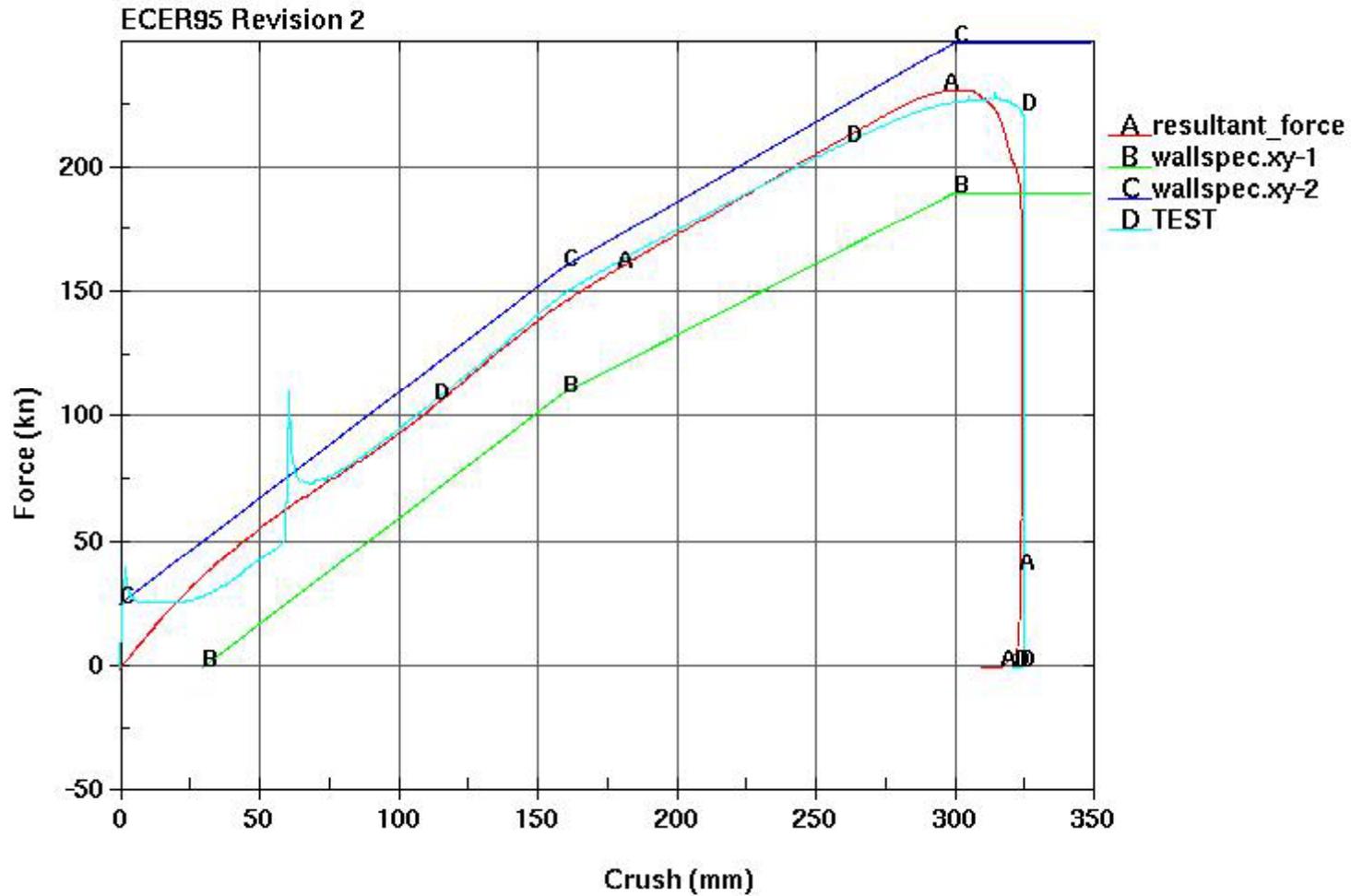
AEMDB V3.10

- 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
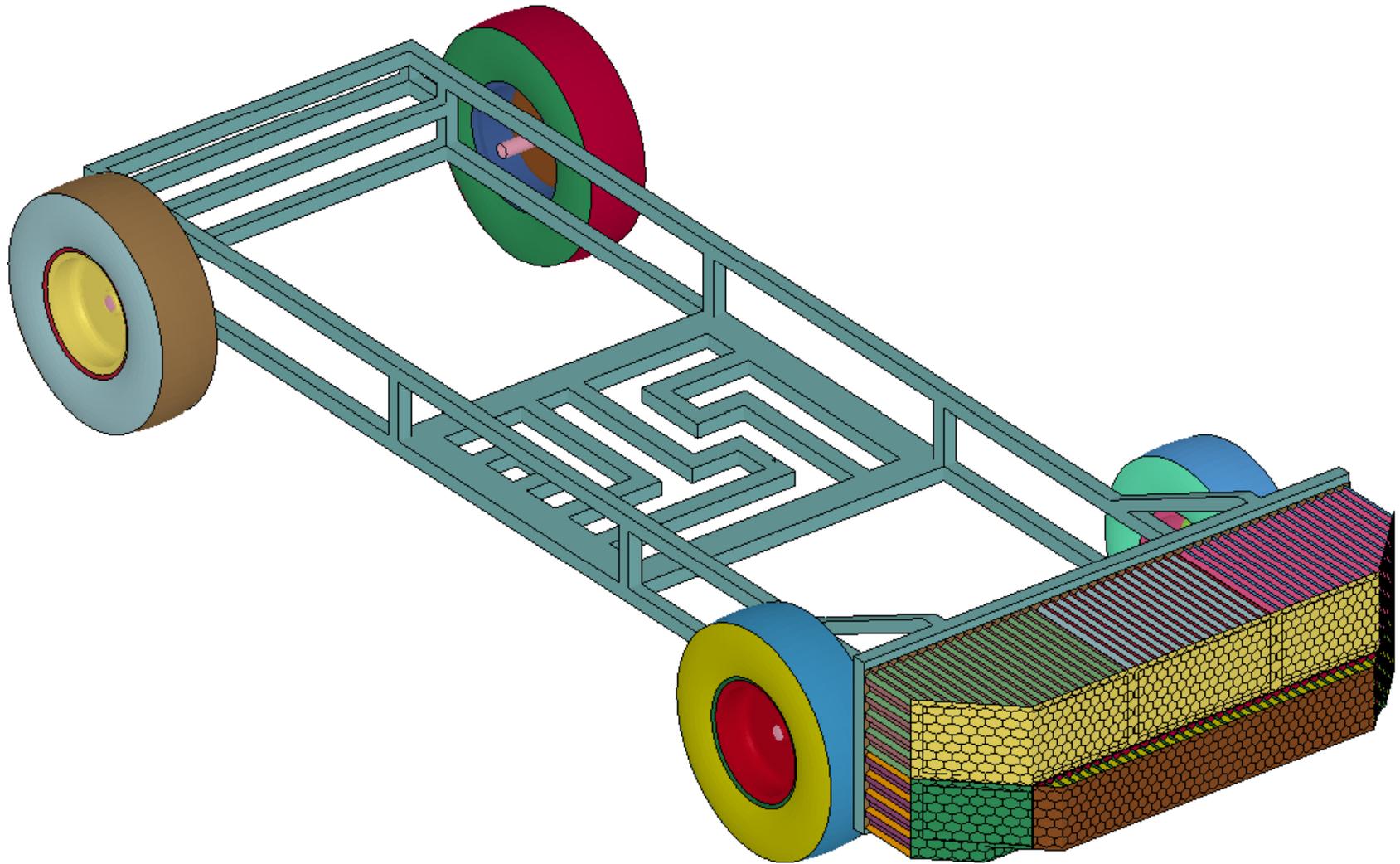
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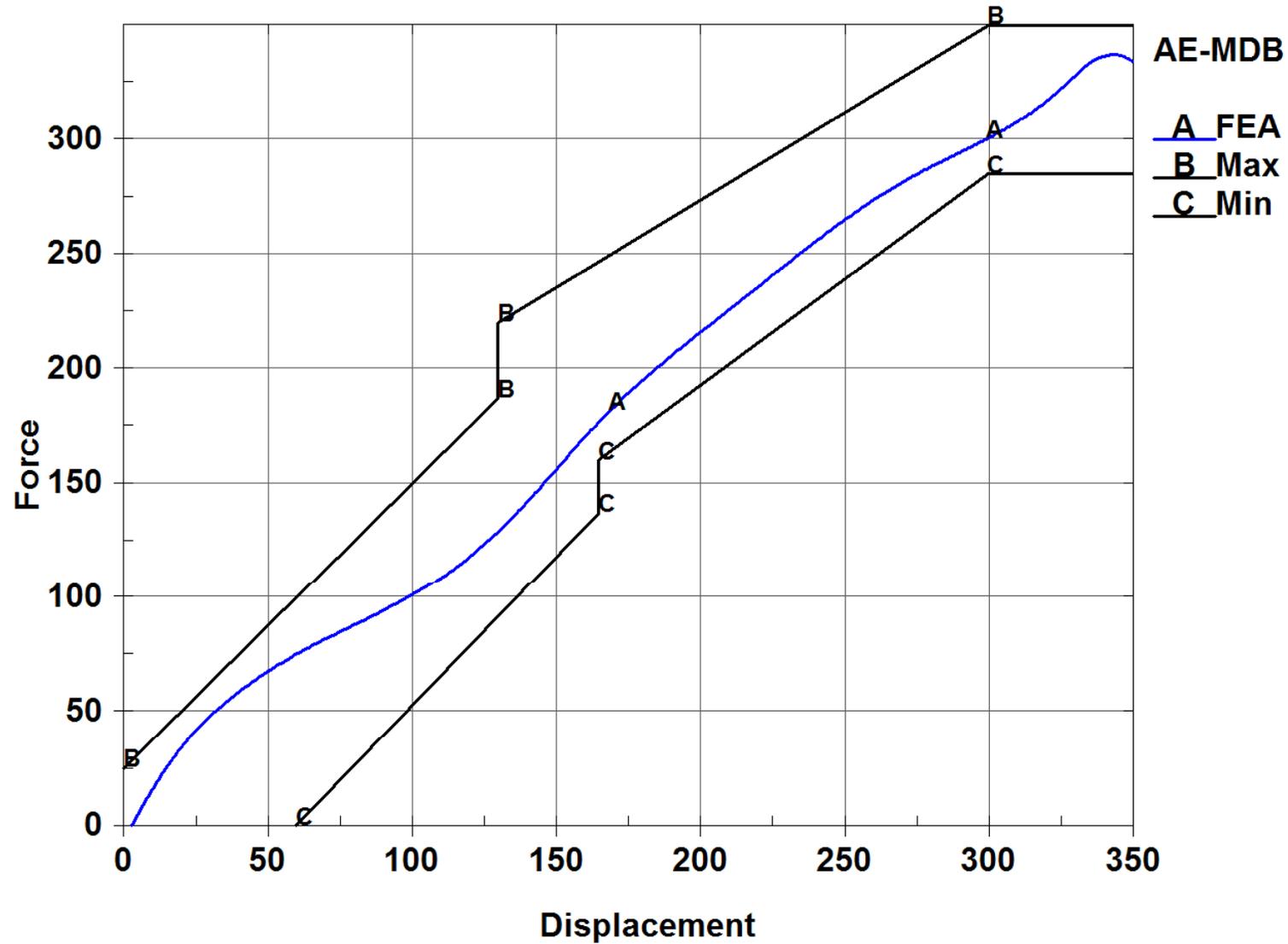
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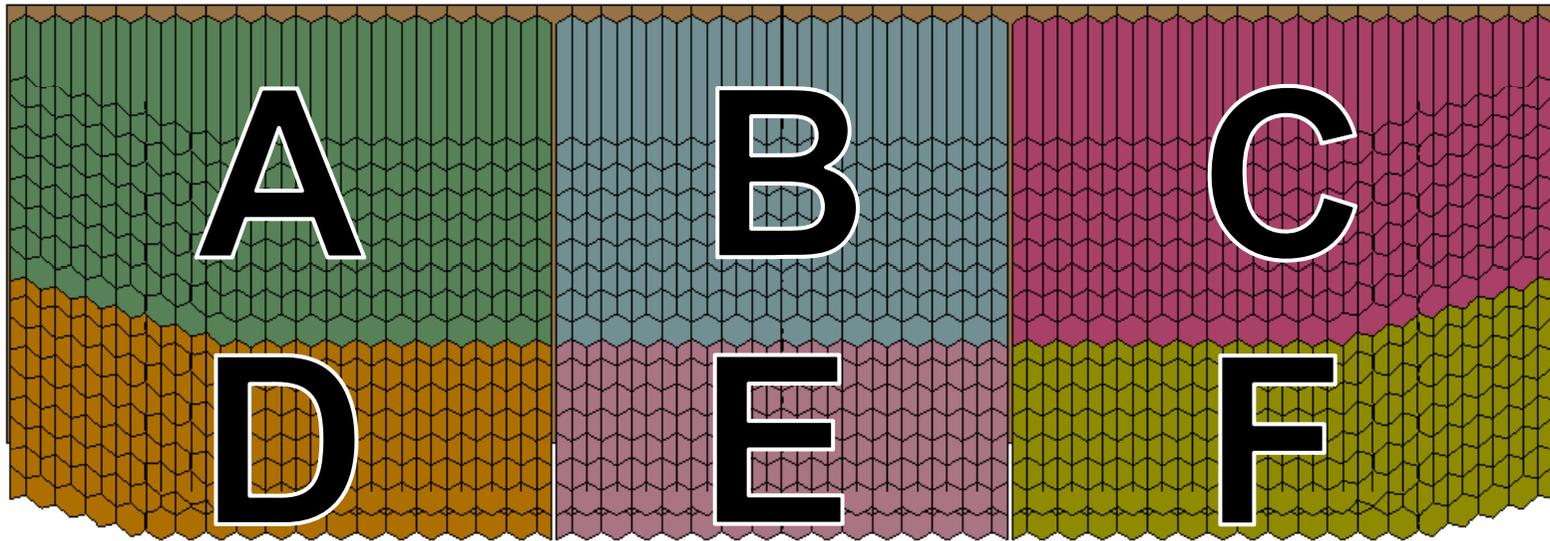
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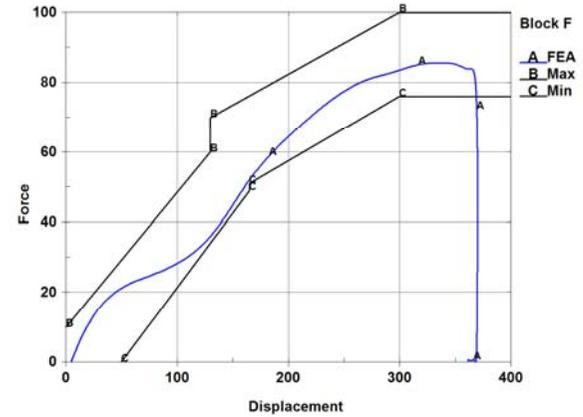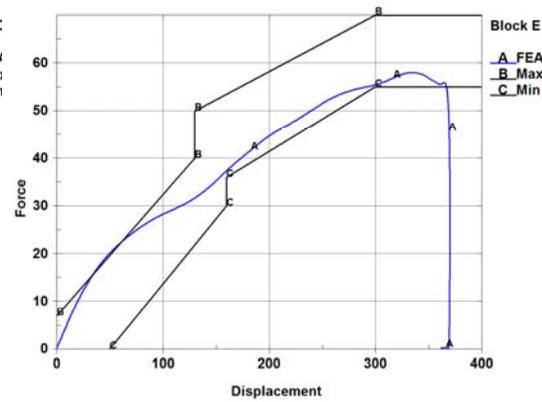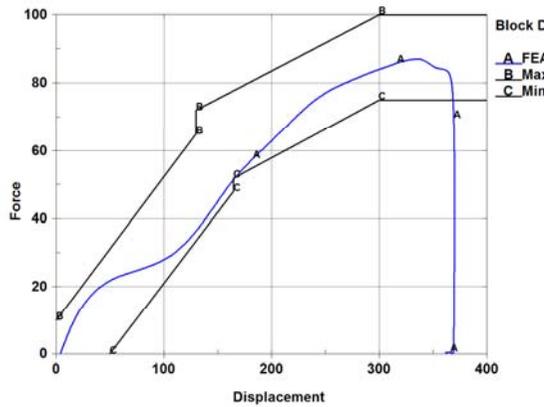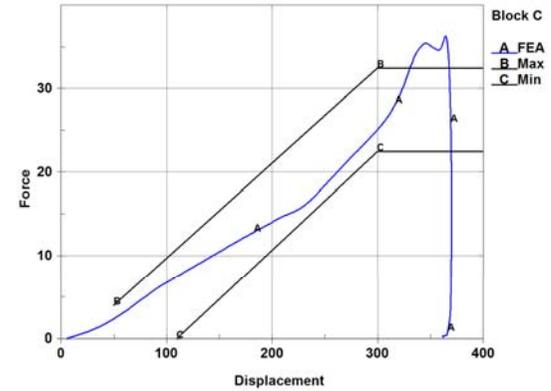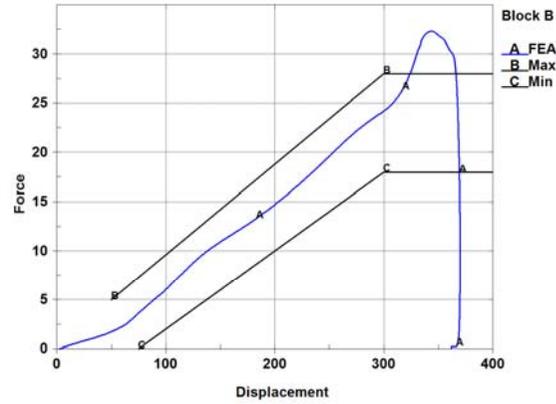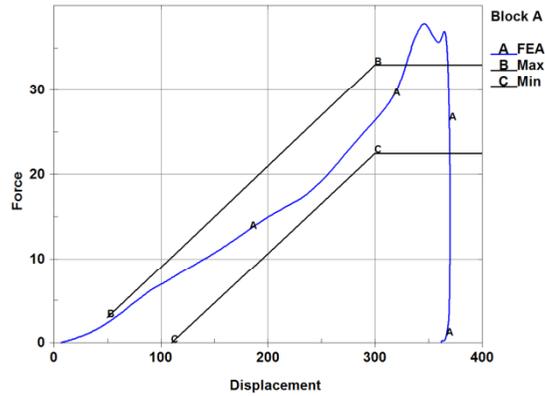
214 SIDE IMPACT BARRIER

- 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
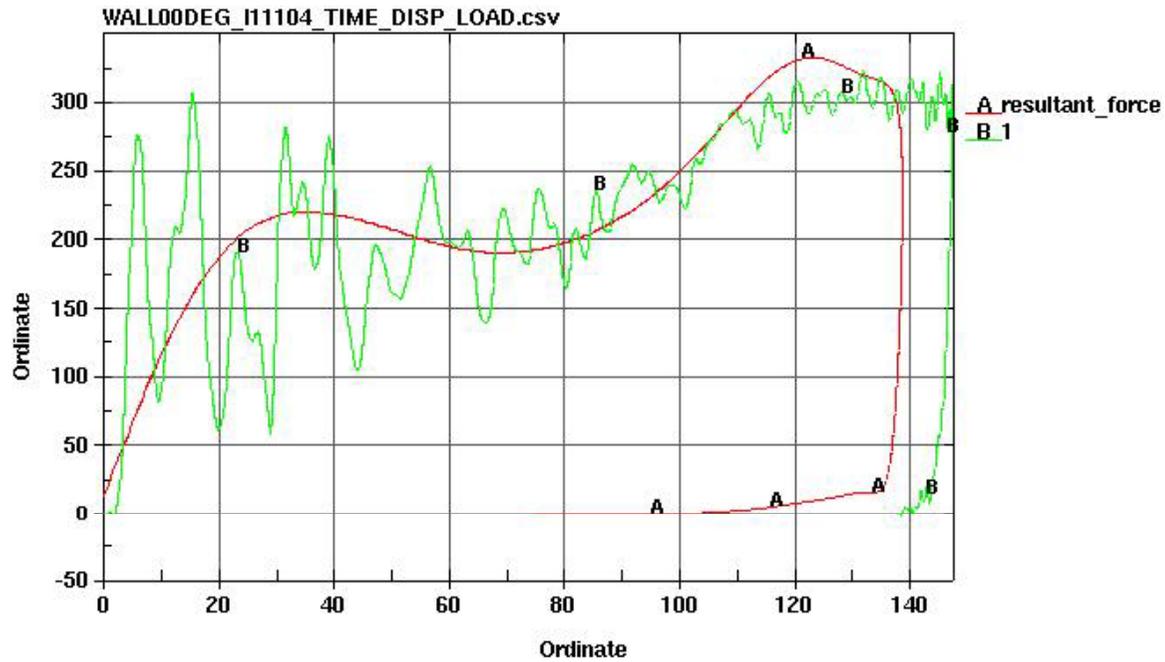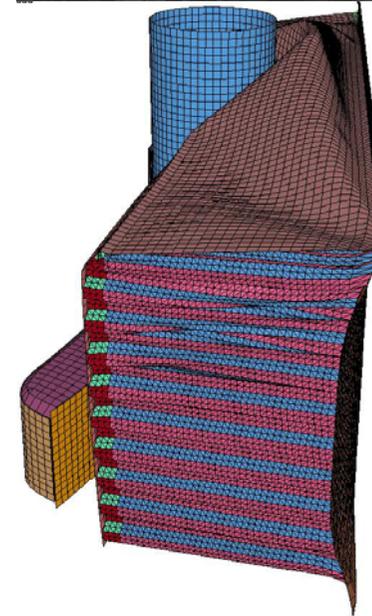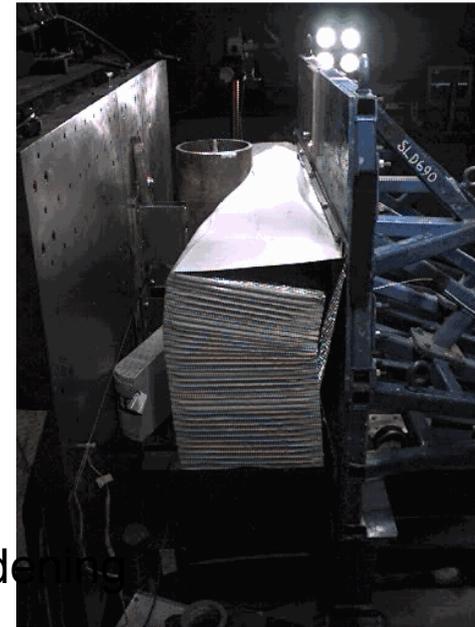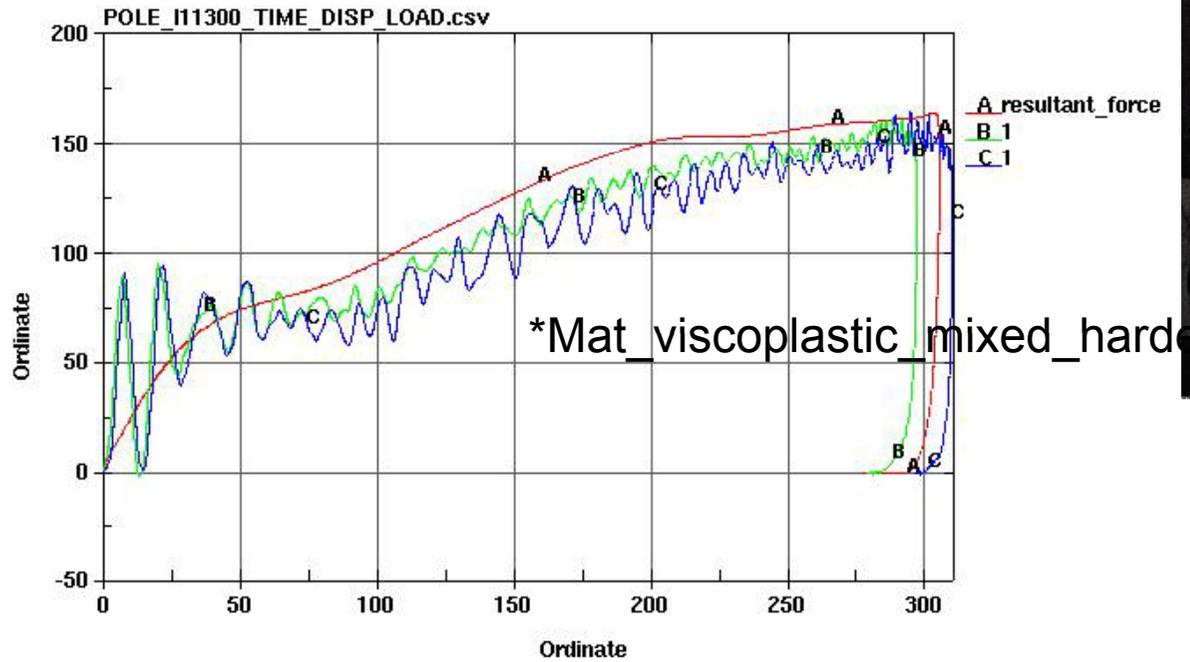
Test Case 4 Results
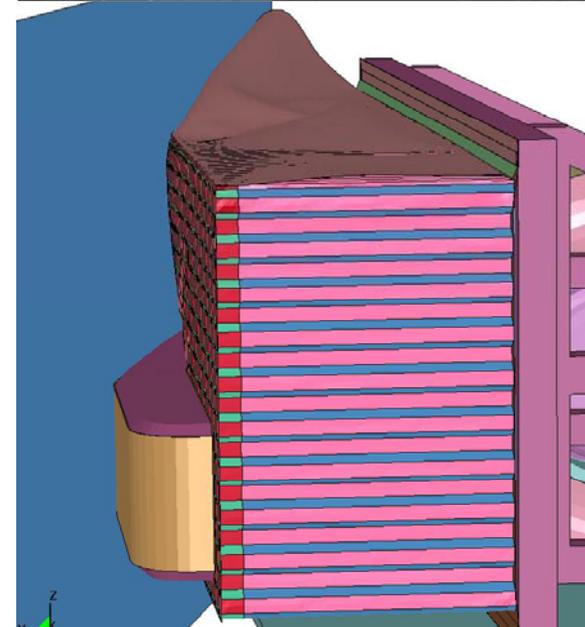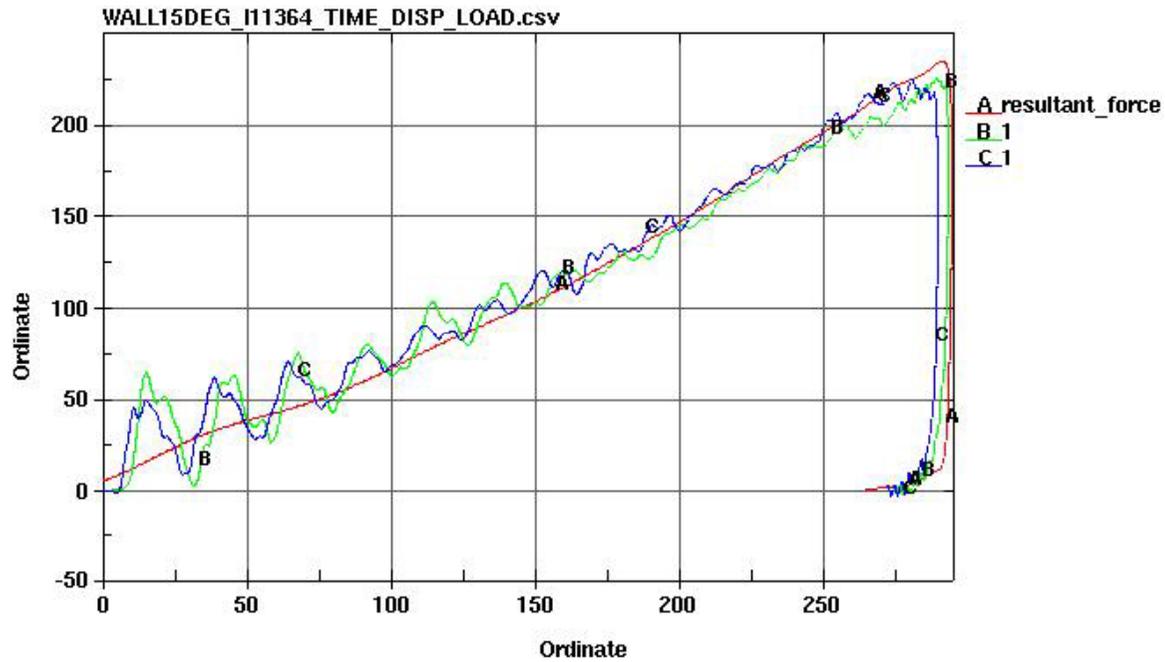
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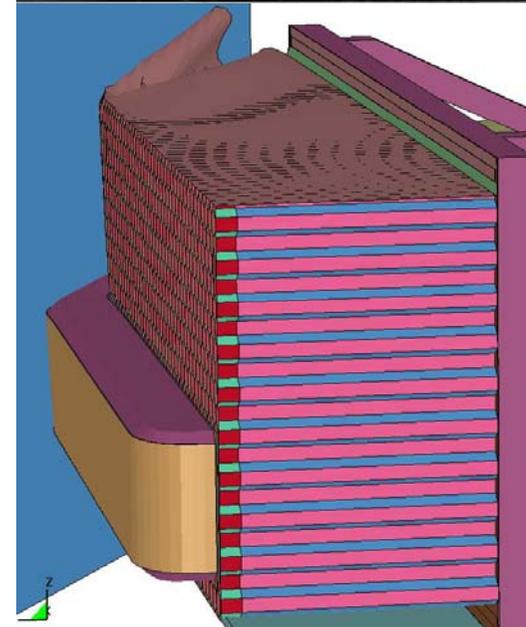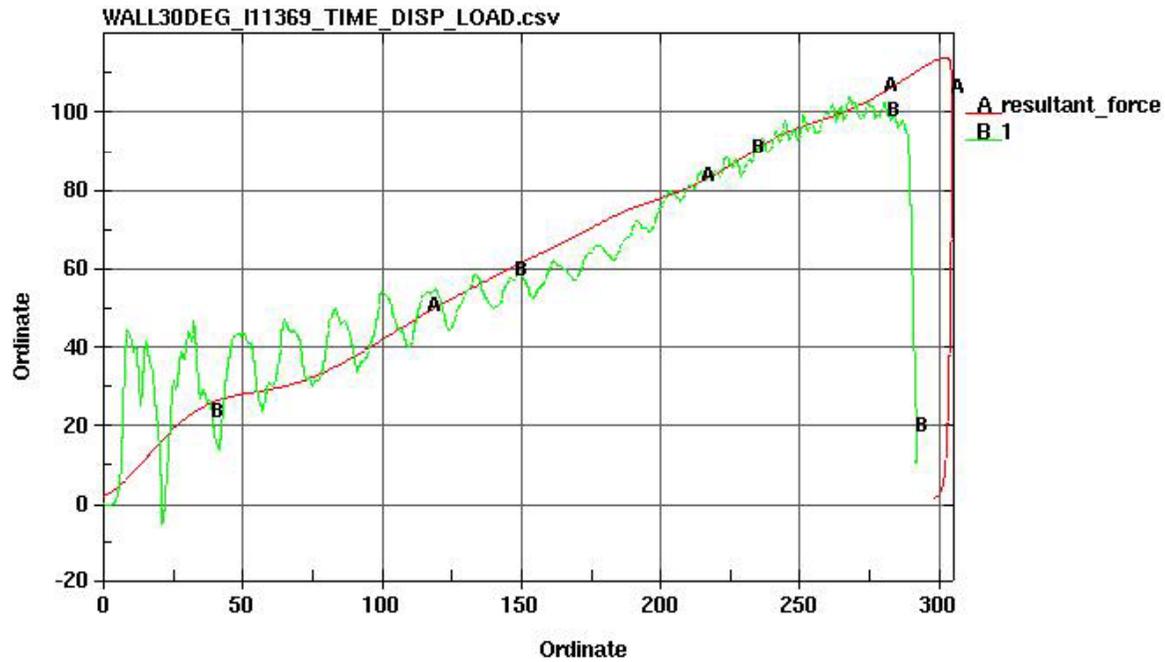
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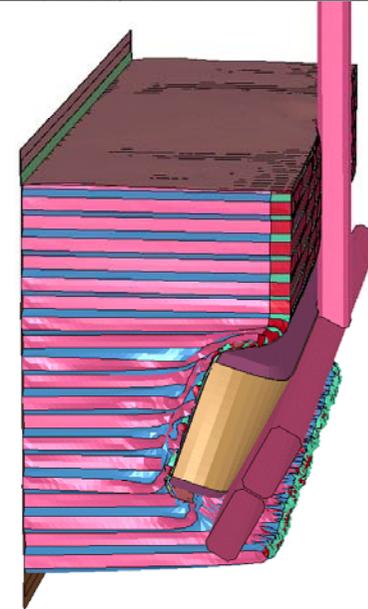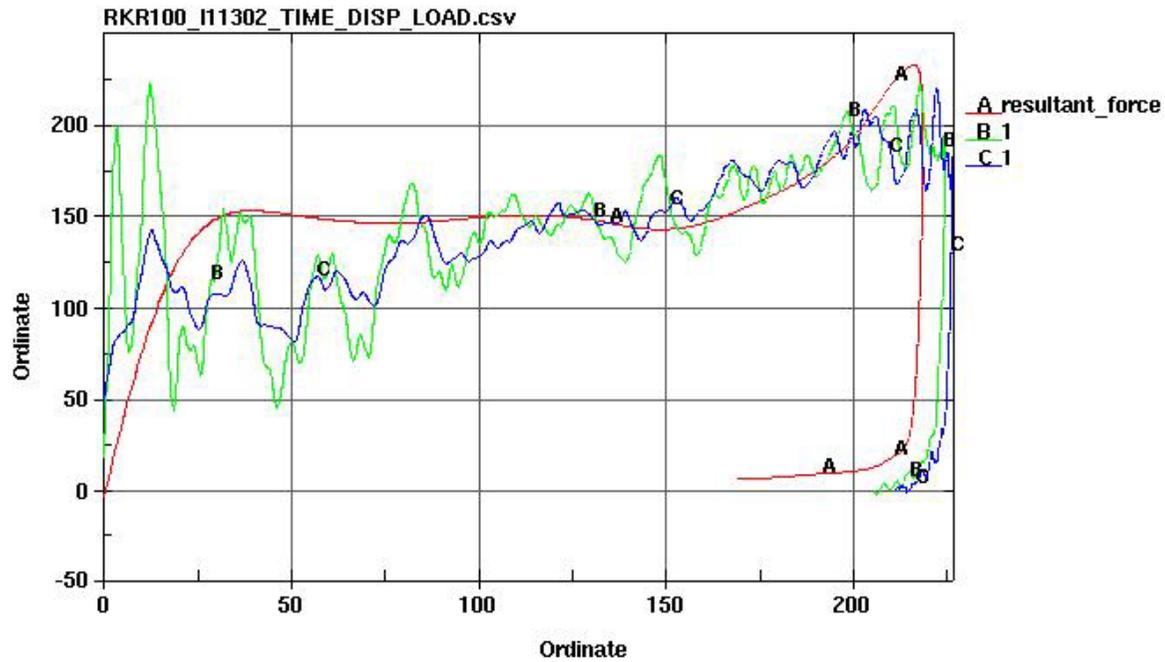
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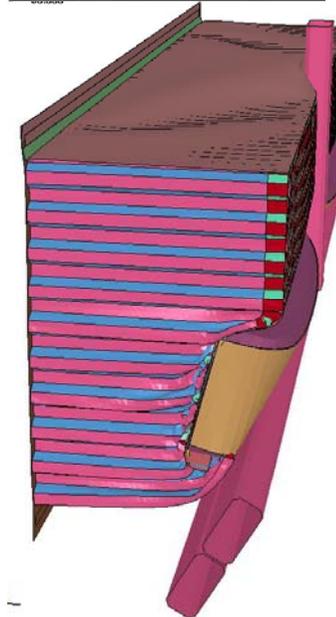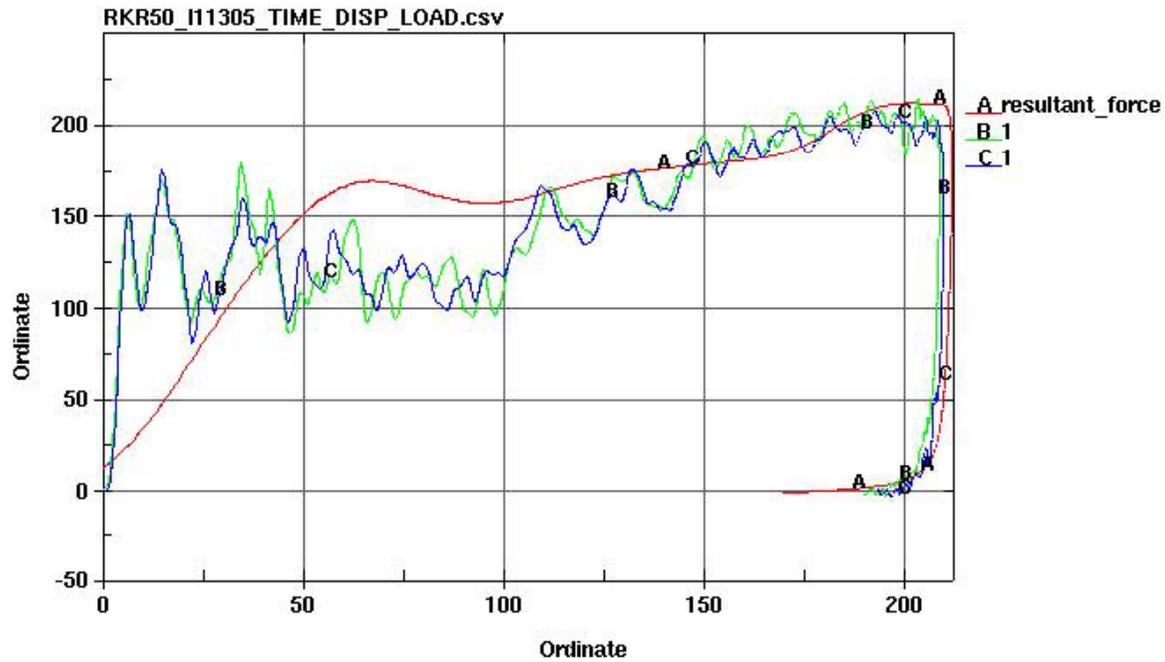
Test Case 8 Results
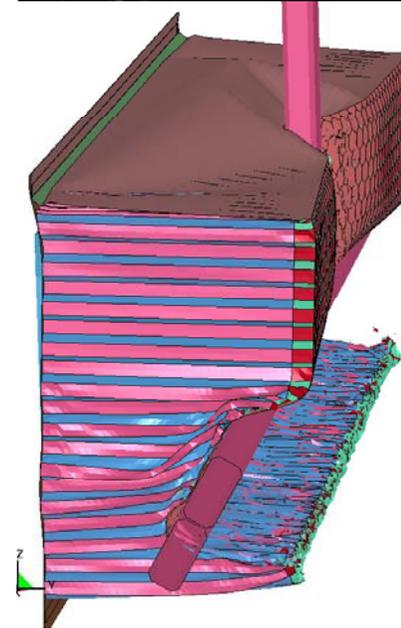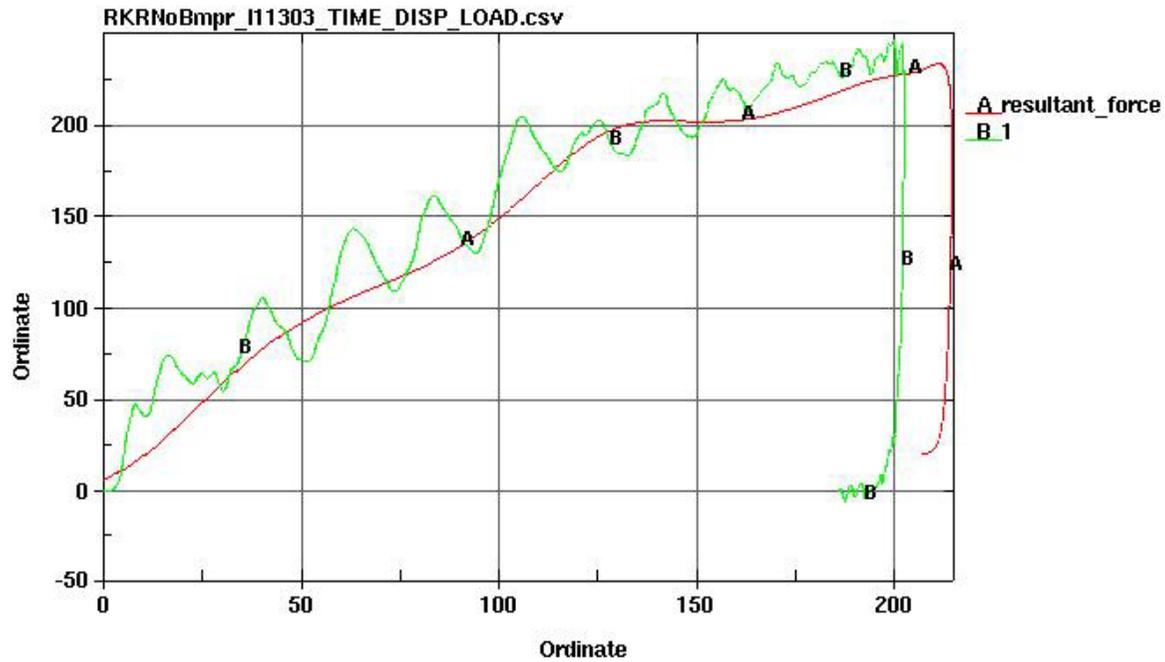
Side impact barrier status

- LSTC_214_SOLID_BARRIER.102408_V3.0
- LSTC_IIHS_SOLID_BARRIER.102408_V3.0
  - Honeycomb material coordinate system defined using –AOPT for easy positionin.
- 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

pfile:
   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_THREAD=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
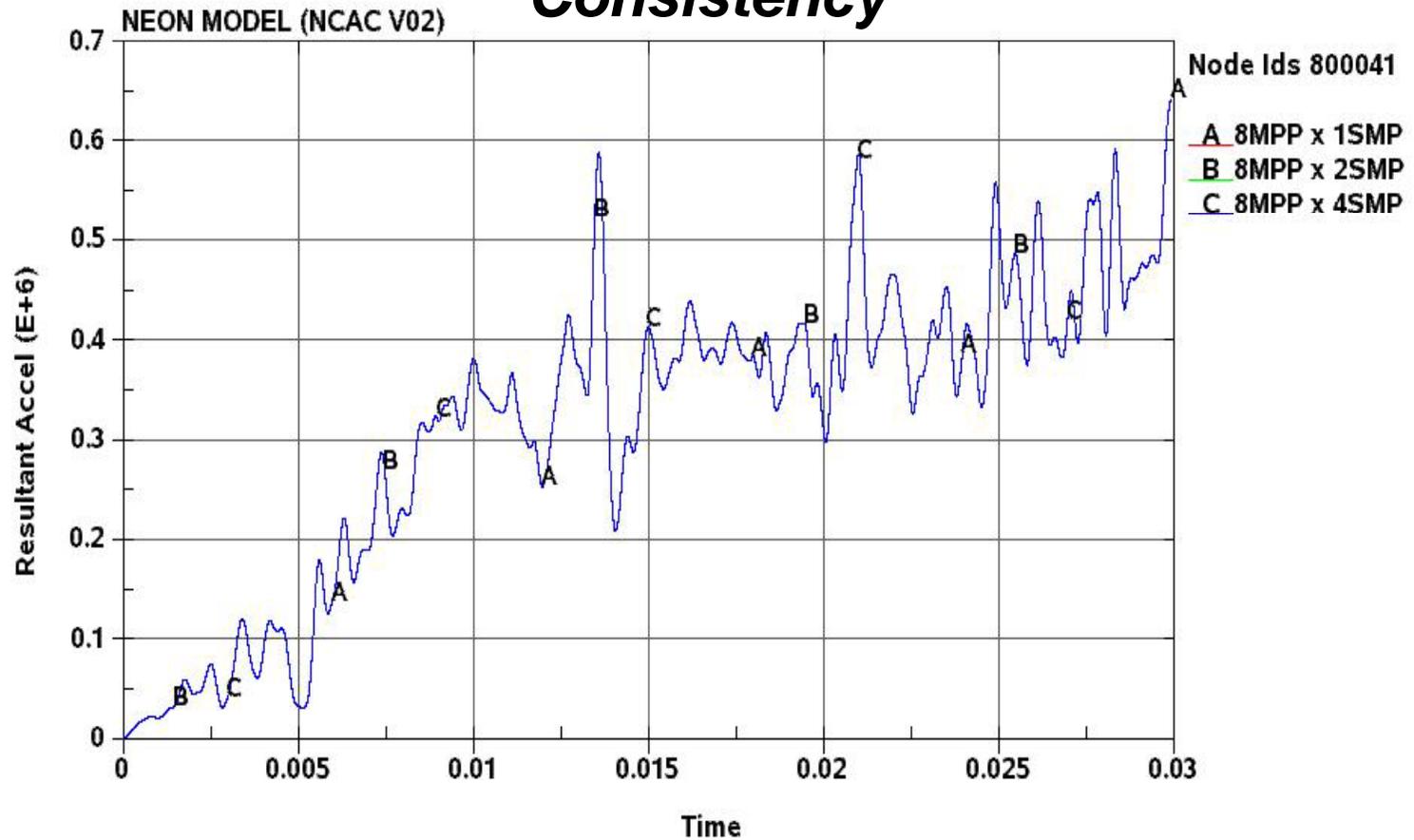
- Consistent results are obtained with fix decomposition and changing number of SMP threads

Scalability

Multi-core/Multi-socket clusters
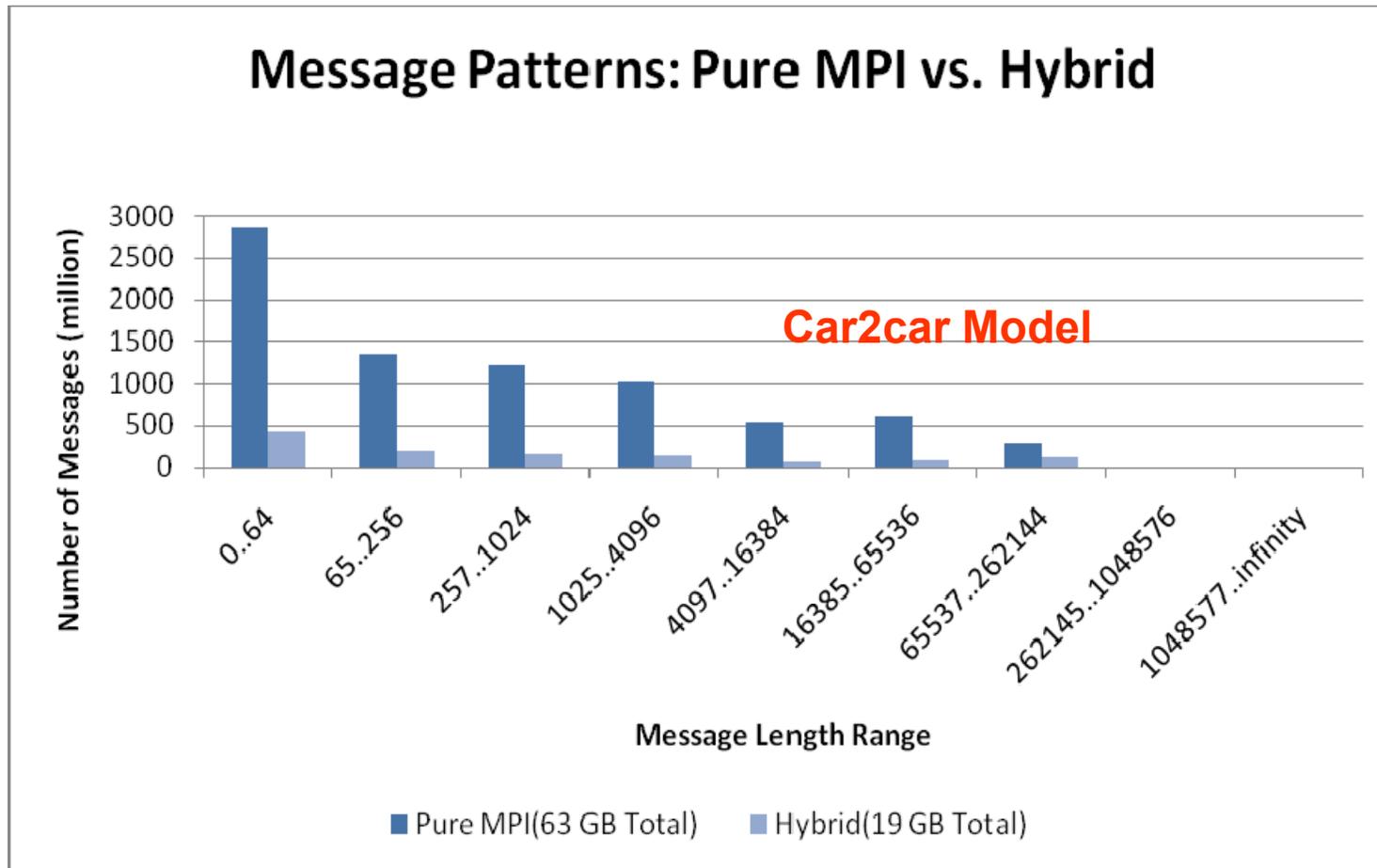
- Hybrid greatly reduces the amount of data through network and provide better scaling to large number of processors

60

Scalability

Multi-core/Multi-socket clusters

Performance Comparison on Windows Server 2008
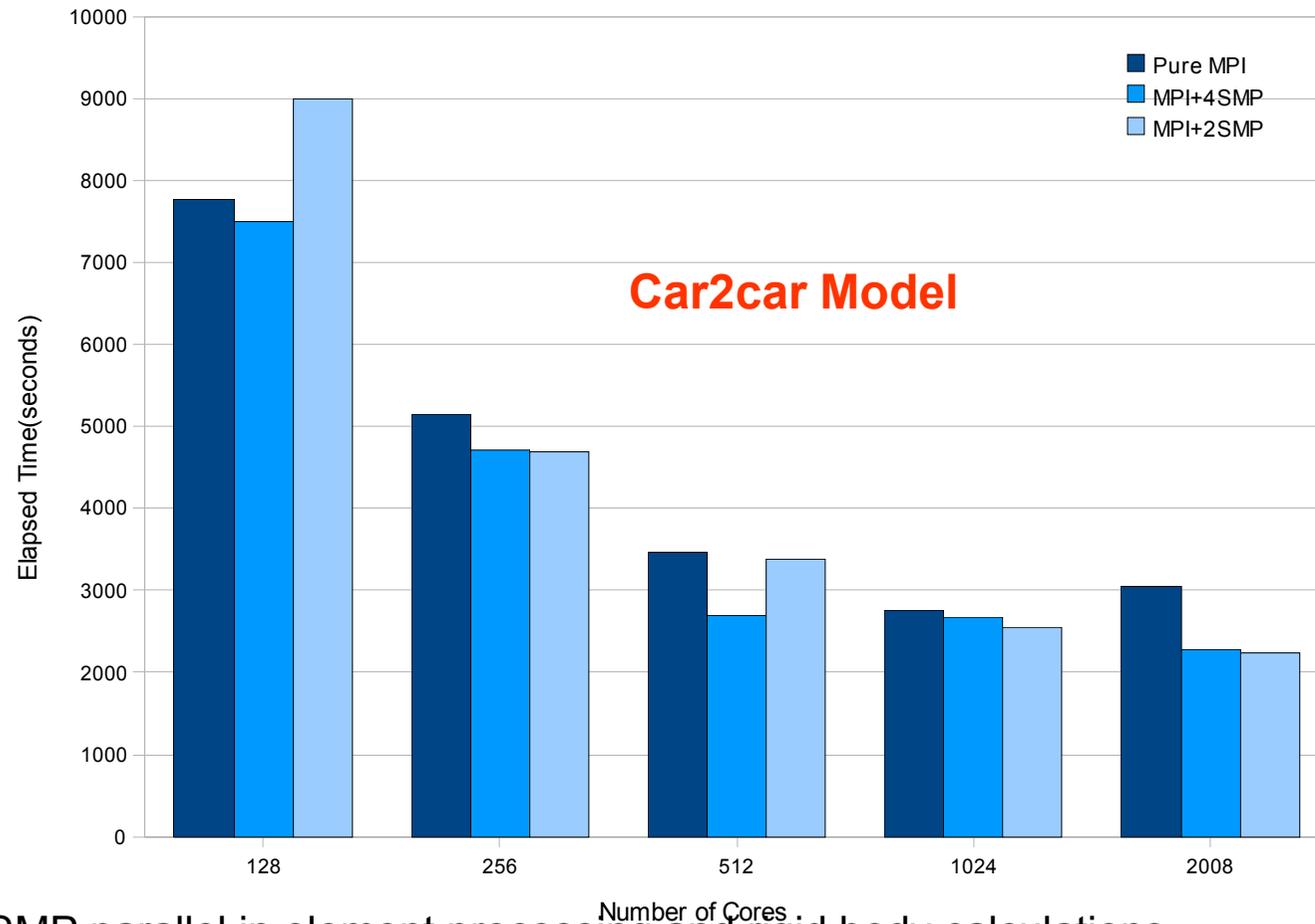
- SMP parallel in element processing and rigid body calculations
- SMP directives are now added to the MPP Contact---not reflected above

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

LS-DYNA keyword deck by LS-Prepost
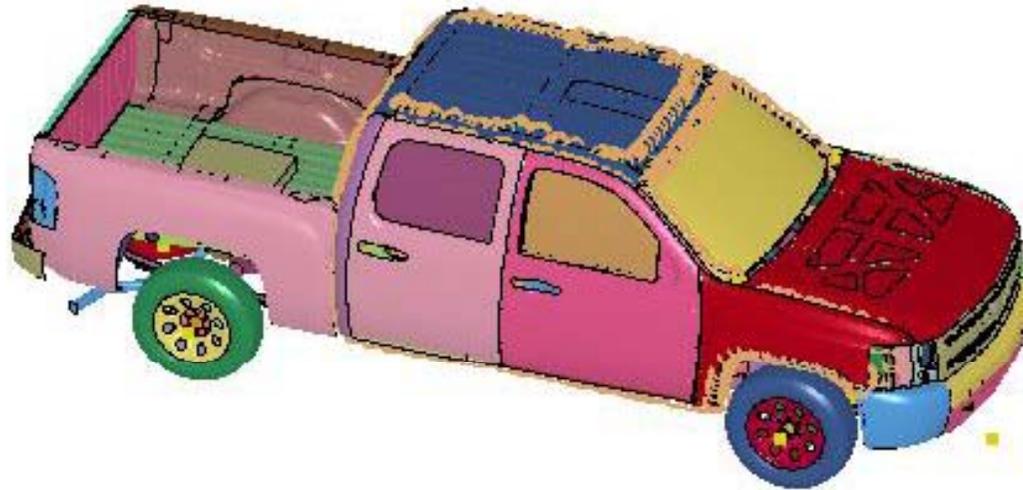
- Original from NCAC with .90M nodes
- Refined to have 1.8M and 3.6M nodes

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

MPI

No. of cores/node	Factor WCT	Solve WCT
1 (4 cores)	123.0	3.5
2 (8 cores)	68.4	2.1
4 (16 cores)	44.6	1.7
8 (32 cores)	27.3	1.3

MPI+OPENMP

No. of cores/node	Factor WCT	Solve WCT
1 (4 cores)	127.1	3.5
2 (8 cores)	79.9	2.1
4 (16 cores)	51.4	1.7
8 (32 cores)	37.6	1.3

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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

No. of cores/node	Factor WCT	Solve WCT
1 (8 cores)	68.5	1.9
2 (16 cores)	44.8	1.4
4 (32 cores)	26.5	0.9
8 (64 cores)	19.8	0.9

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*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

68

*Control_implicit_explicit

Body block impact using Mortar contact option

SMS Explicit

Explicit with implicit steering wheel

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

NCAC TOYOTA RAV4 IMPLICIT ROOF CRUSH
Time =   0
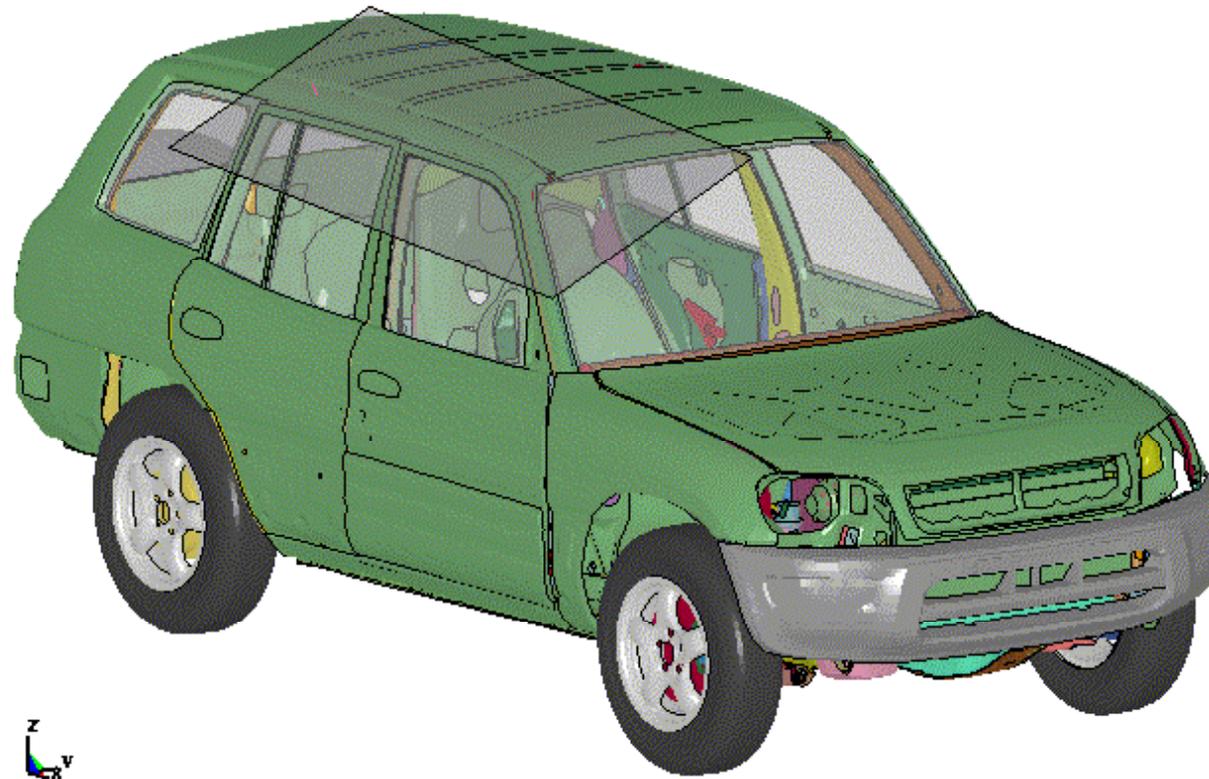
*Control_implicit_forming
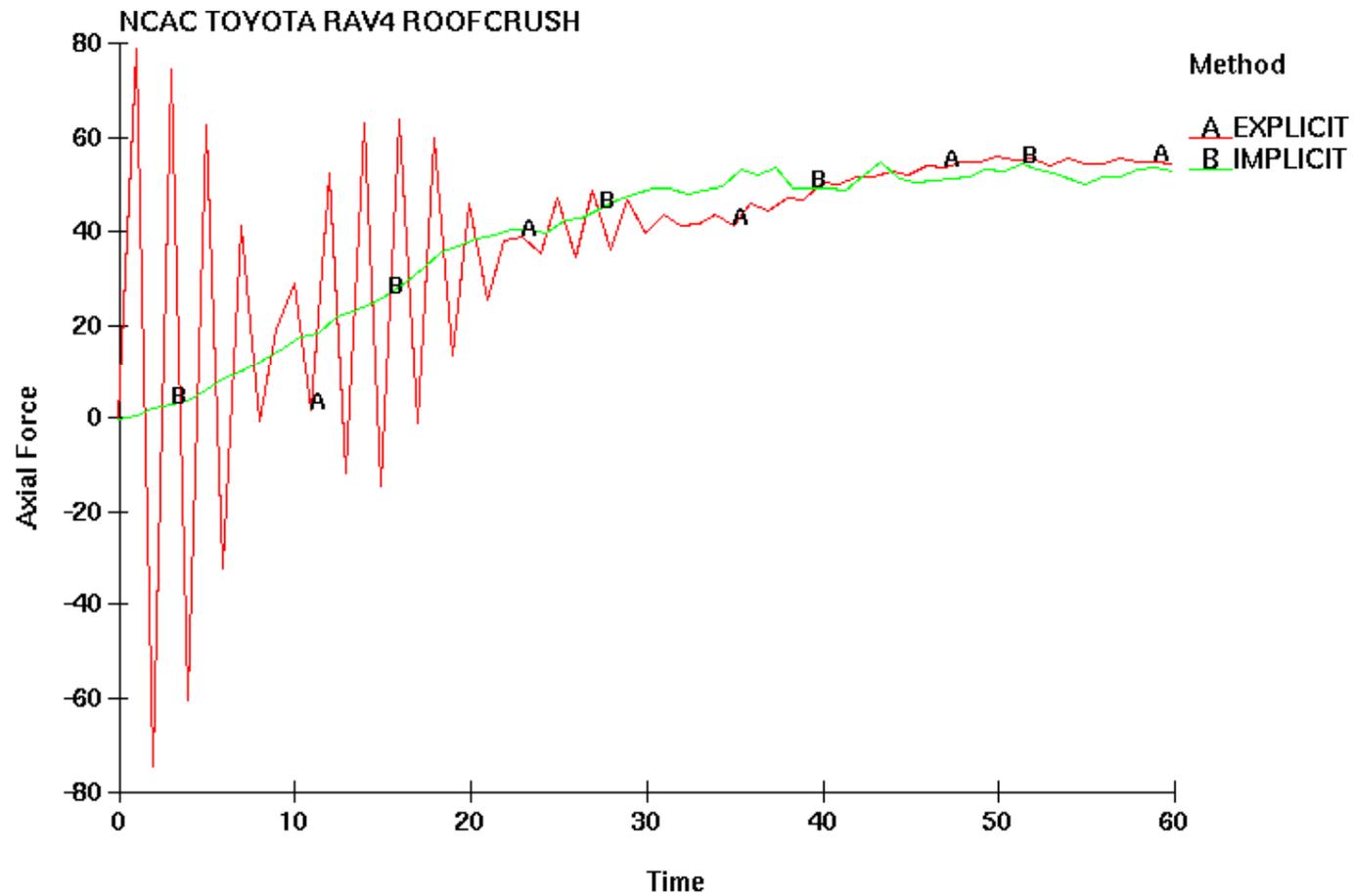
*Control_implicit_forming
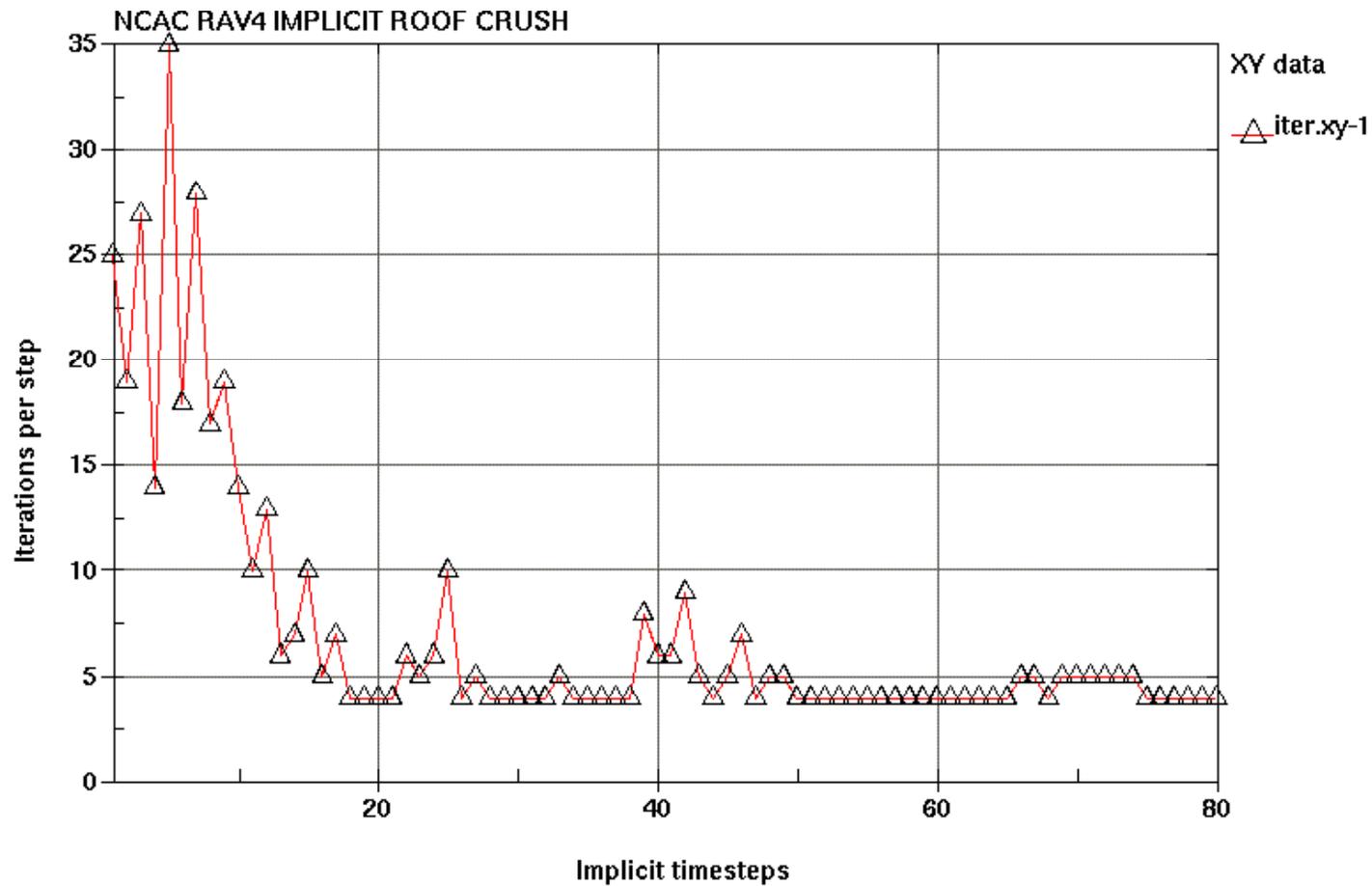
Version 971_R4

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.
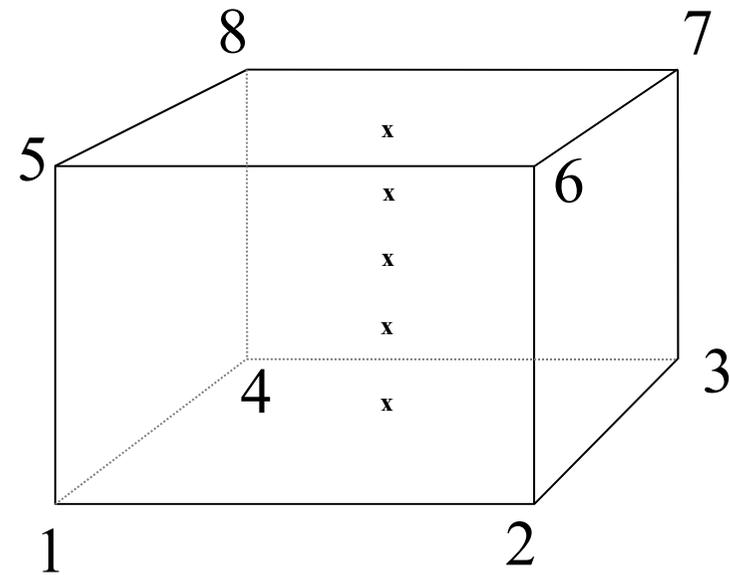
Thick shell formulation 5

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 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

Contact_beam_to_surface

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

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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
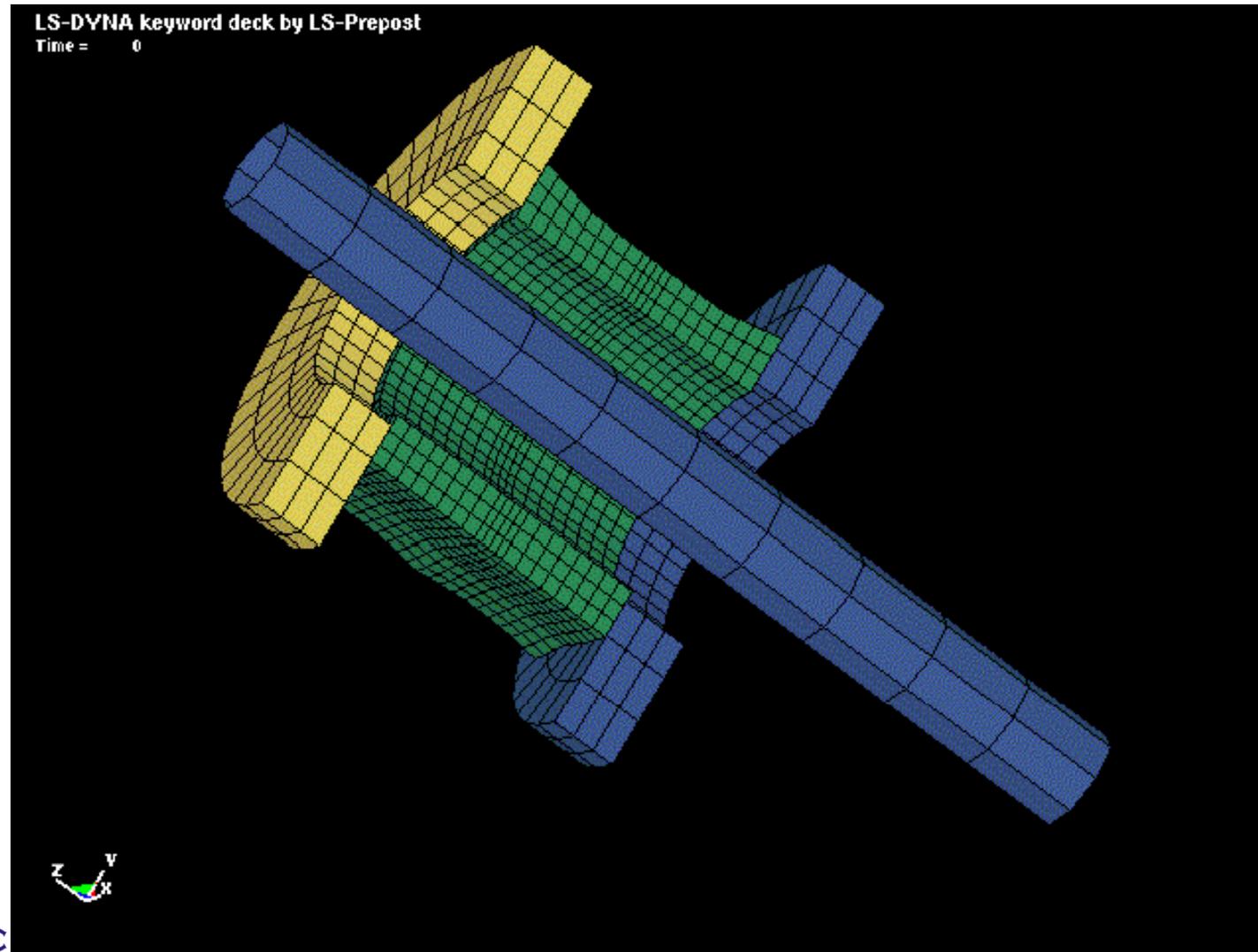
Slow speed impact

- 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
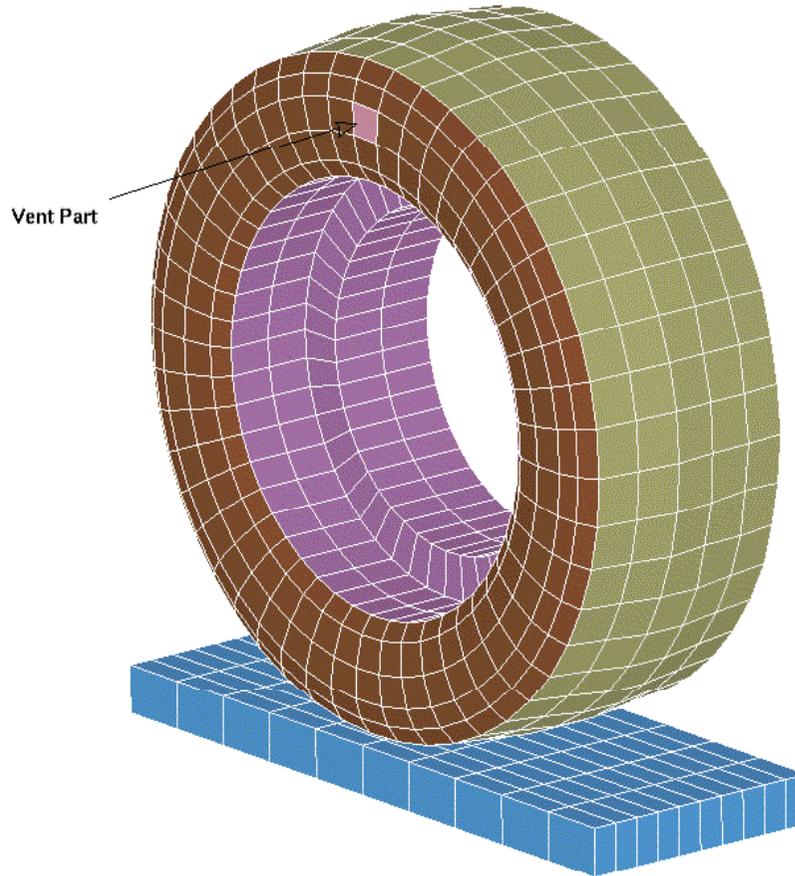
tire leak using particle method

Vent Part

*Initial_airbag_particle

tire leak using particle method
Time =   0
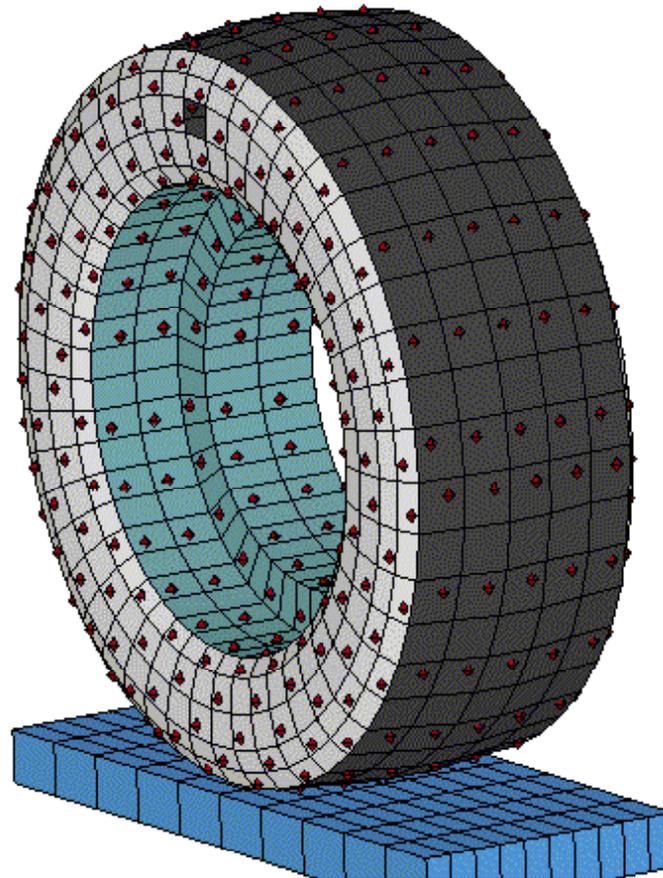
*Initial_airbag_particle

tire leak using particle method
Time =   0
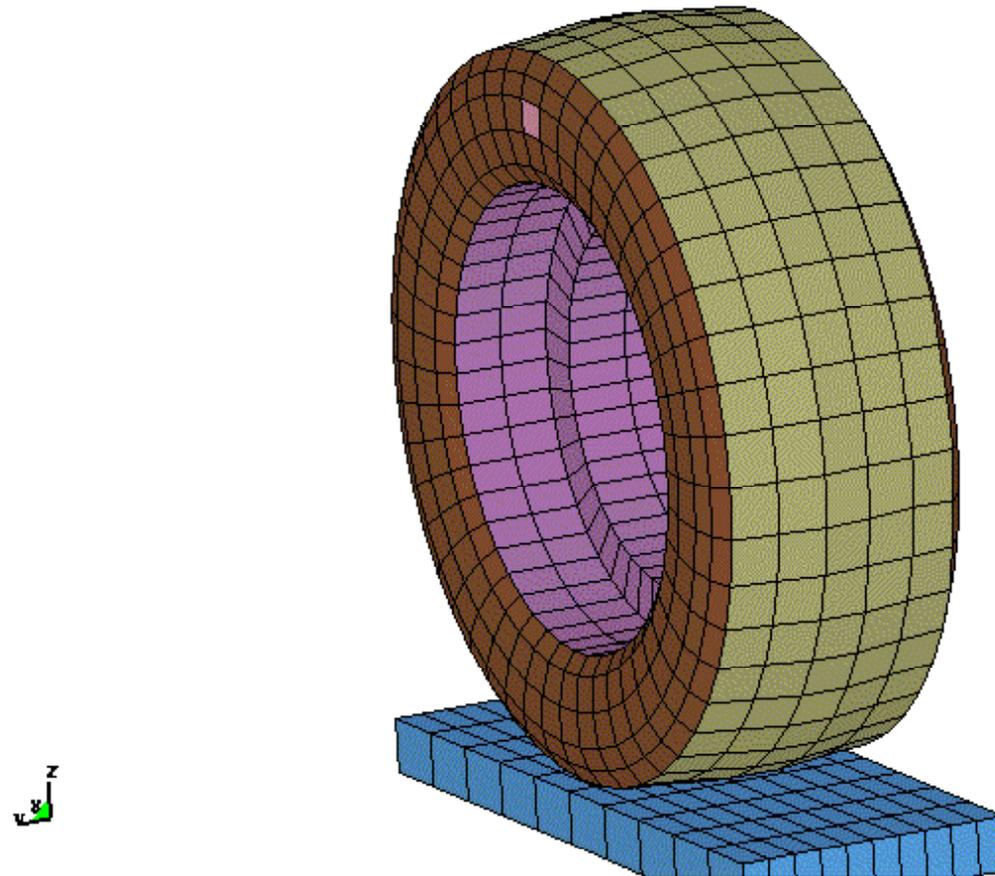
*Initial_airbag_particle
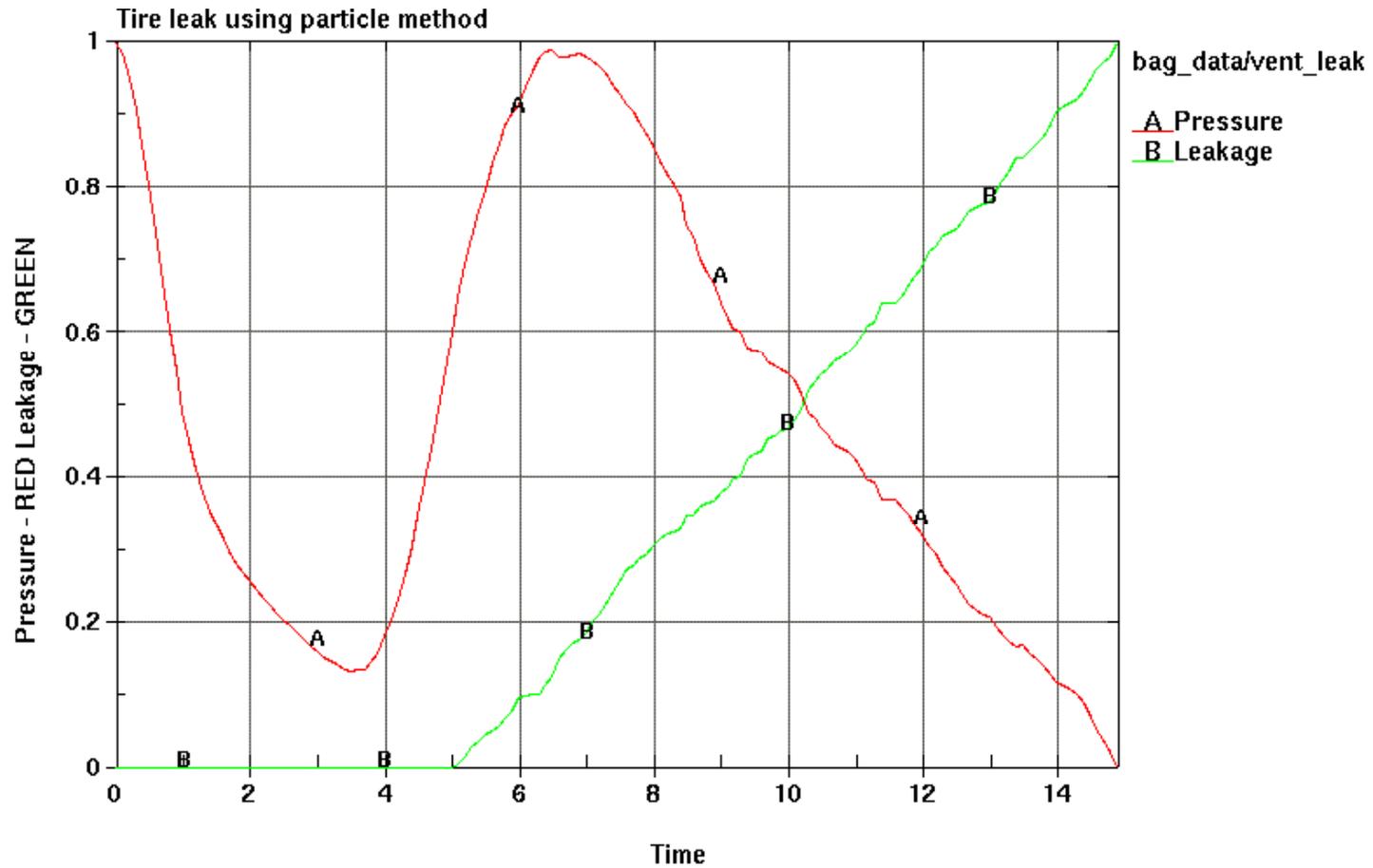
Pressure sensing - sensors

ALE

195360 ALE elements

16 cpus 33 minutes

PARTICLE

50000 particles

16 cpus 4 minutes

Dor pressure sensing using ALE method
Time = 0
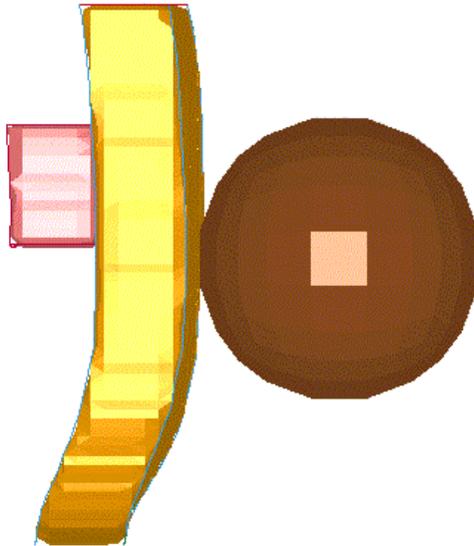
Pressure sensing using Particle method
Time = 0
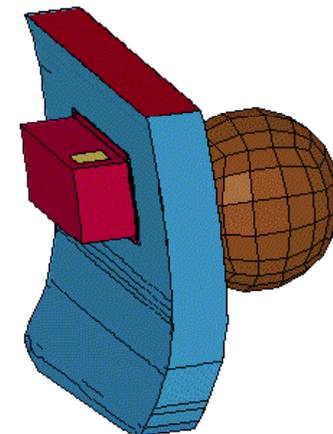
*Node_merge

- 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.

Time =   0
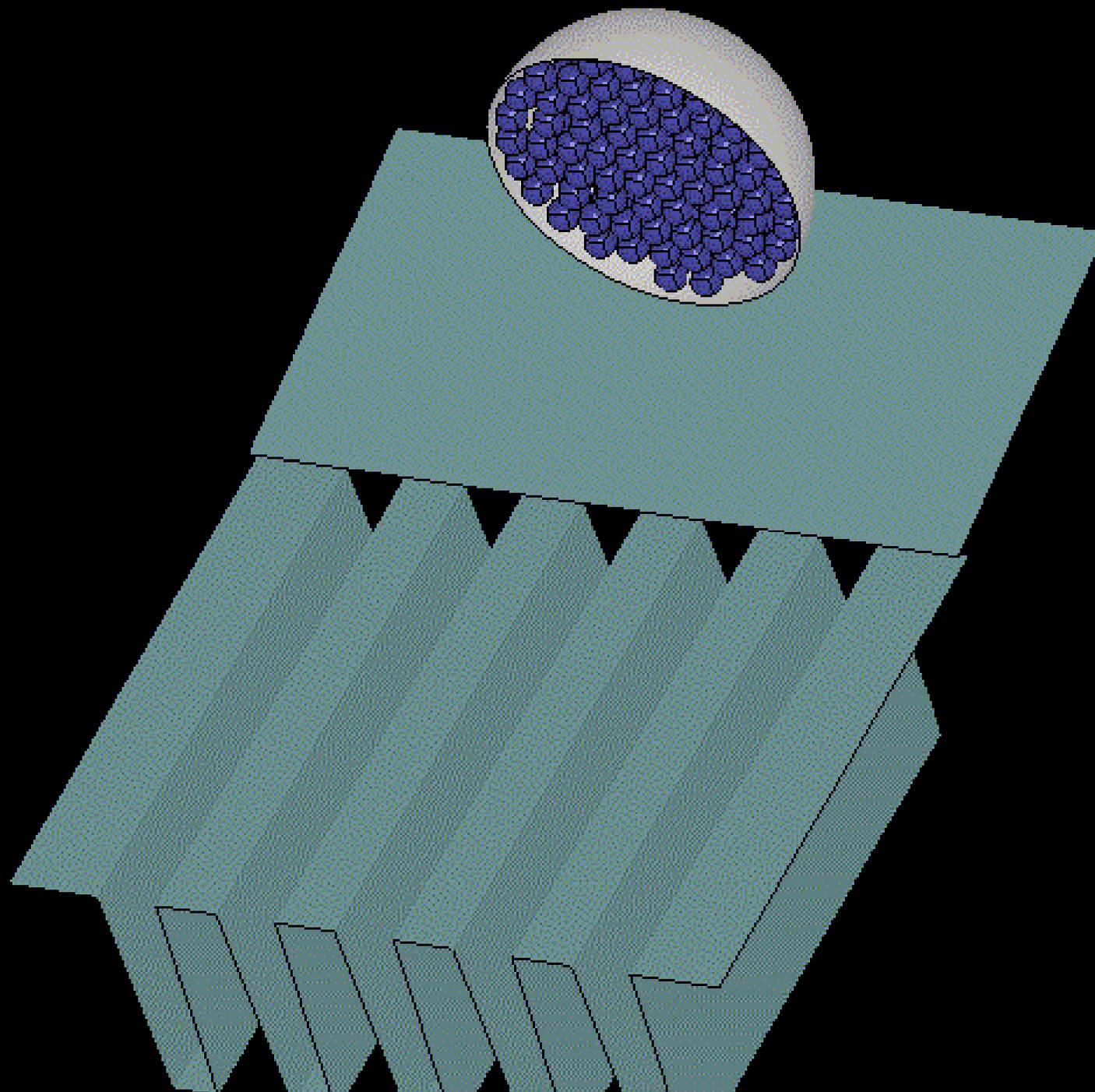
*Mat_viscoplastic_mixed_hardening

- *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)
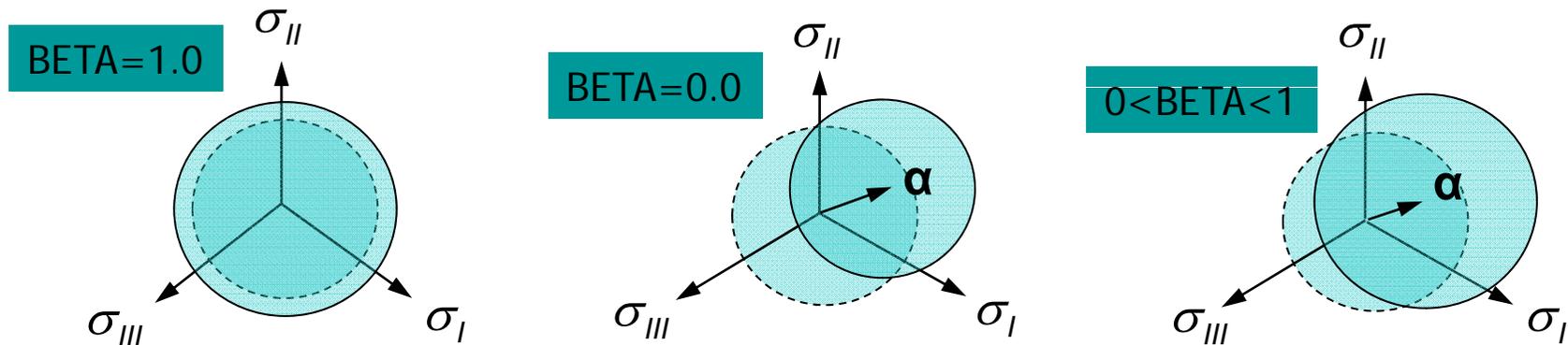
$$f(\boldsymbol{\sigma}) = \sqrt{\tfrac{3}{2}(\mathbf{s} - \beta\boldsymbol{\alpha}):(\mathbf{s} - \beta\boldsymbol{\alpha})} - (1-\beta)\overline{\sigma}_y(\overline{\varepsilon}^{pl}) = 0$$

*Mat_viscoplastic_mixed_hardening

- Suited for cyclic loading cases (Bauschinger effect)

<div>

pure isotropic hardening
(*MAT_024 or *MAT_225 with BETA=1.0)
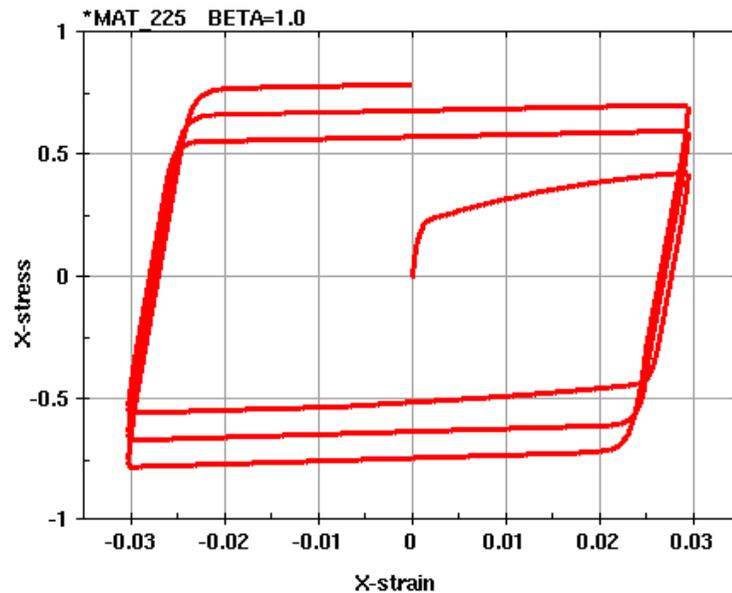
mixed hardening
(*MAT_225 with BETA=0.3)

</div>
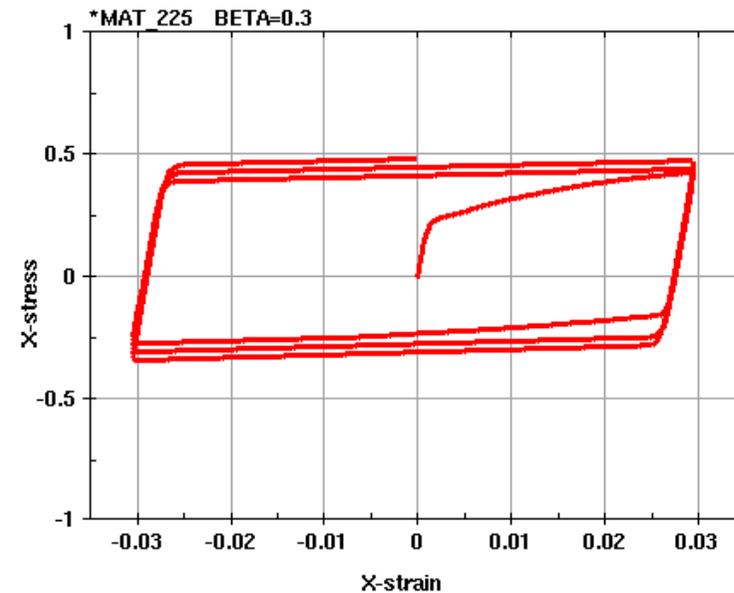
more realistic

*Mat_fabric:new reloading option

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

Loading

Unloading
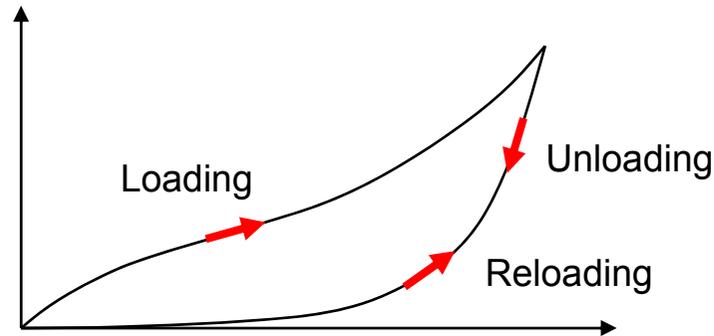
Reloading

- Not realistic for **cyclic loading**

experimental result: force-displacement loops

cyclic loading (displacement)
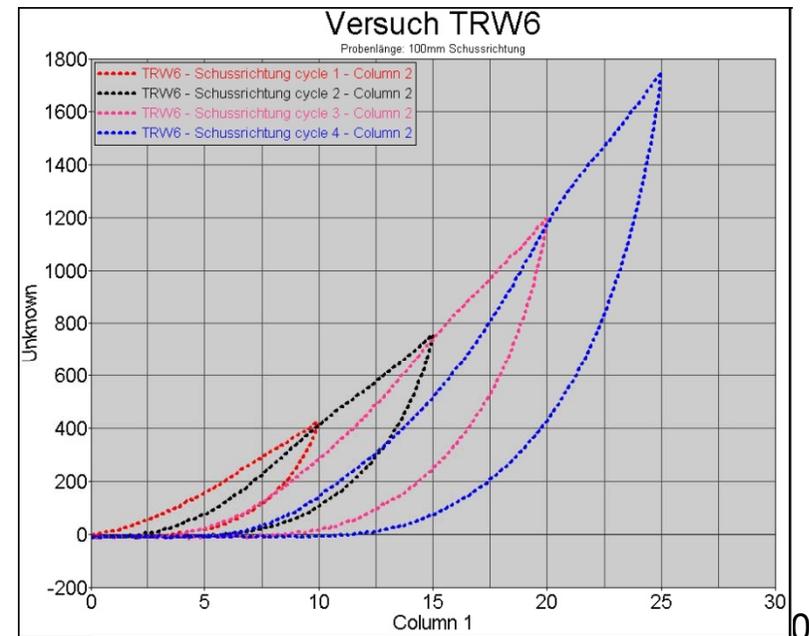
*Mat_fabric:new reloading option

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

model: straight line

Loading

Reloading

Unloading
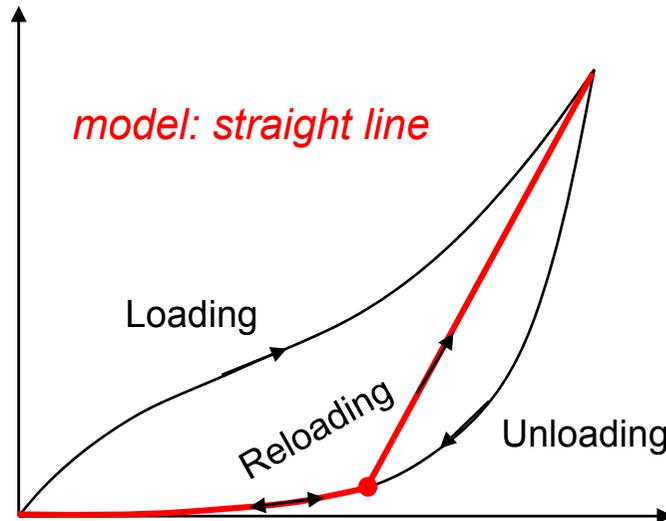
- A new parameter governs slope of straight line
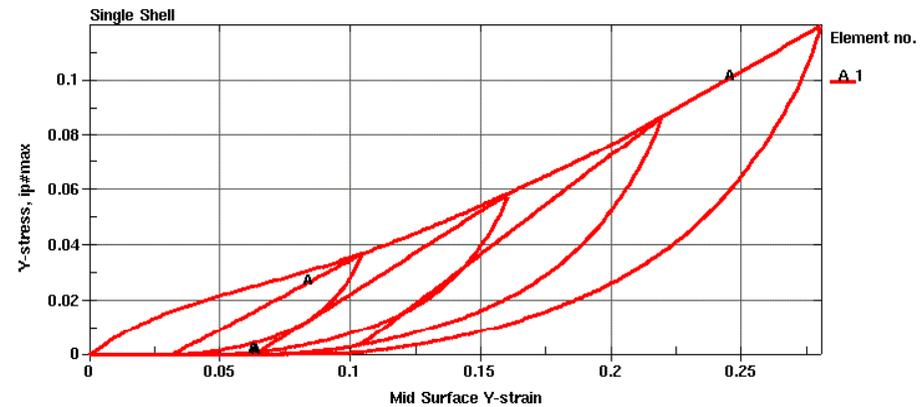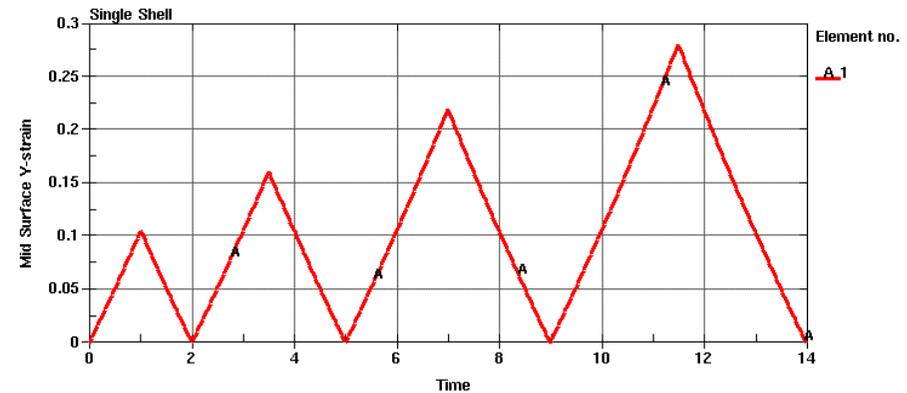
*Mat_add_thermal_expansion

- Orthotropic thermal expansion for anisotropic materials

shells

solids
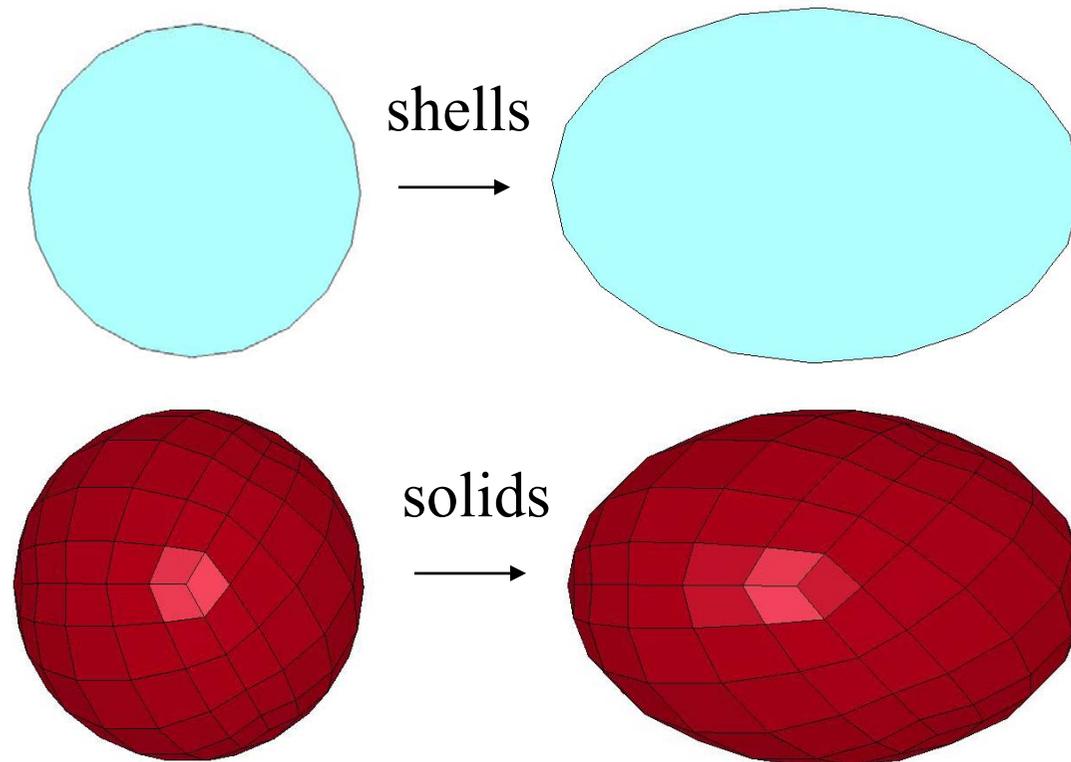
*Mat_add_erosion

- New option developed at Daimler:
  GISSMO - Generalized Incremental Stress State dependent damage MOdel
  - GISSMO allows for:
    - The use of existing Material models
    - Constitutitve 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

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*Mat_add_erosion

Damage Evolution

$$\dot{D}_f = \frac{n}{\varepsilon_f} D_f^{(1-\frac{1}{n})} \dot{\varepsilon}_p$$
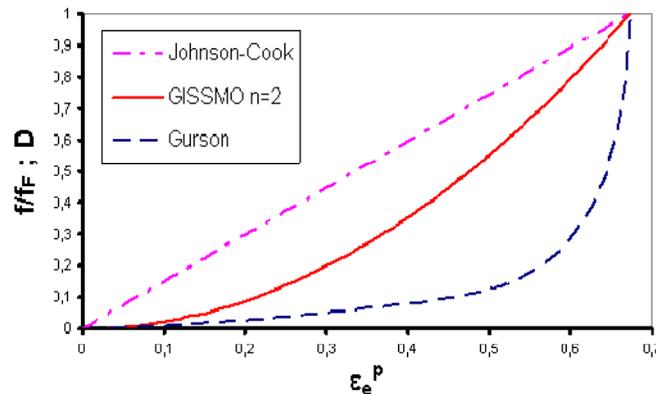
Damage depends on:
- stress state (triaxiality)
- load path
- element size (regularization)

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
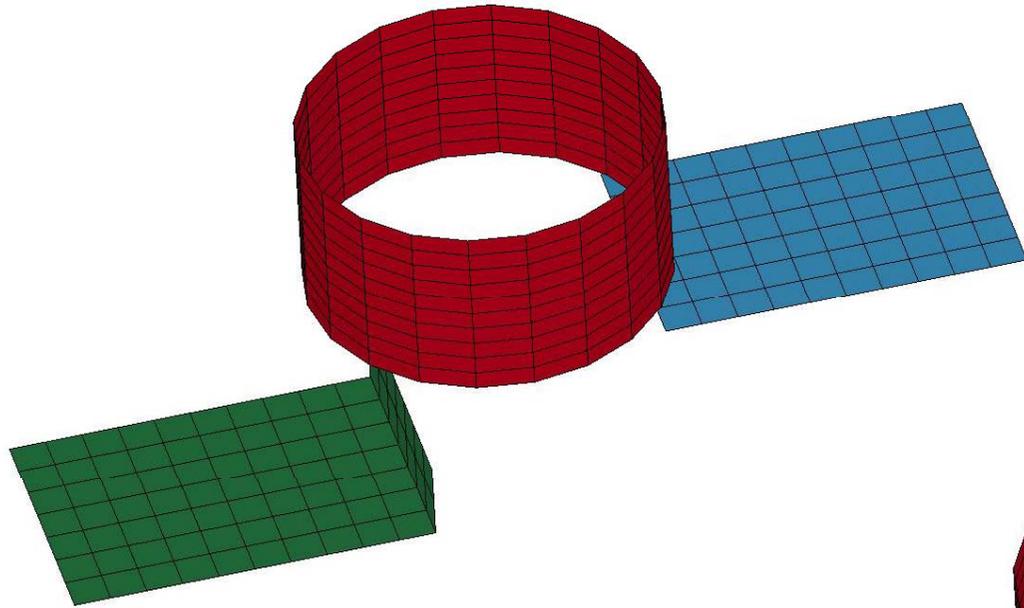
Edge contact in
automatic mortar
contact

Supported with no
extra option
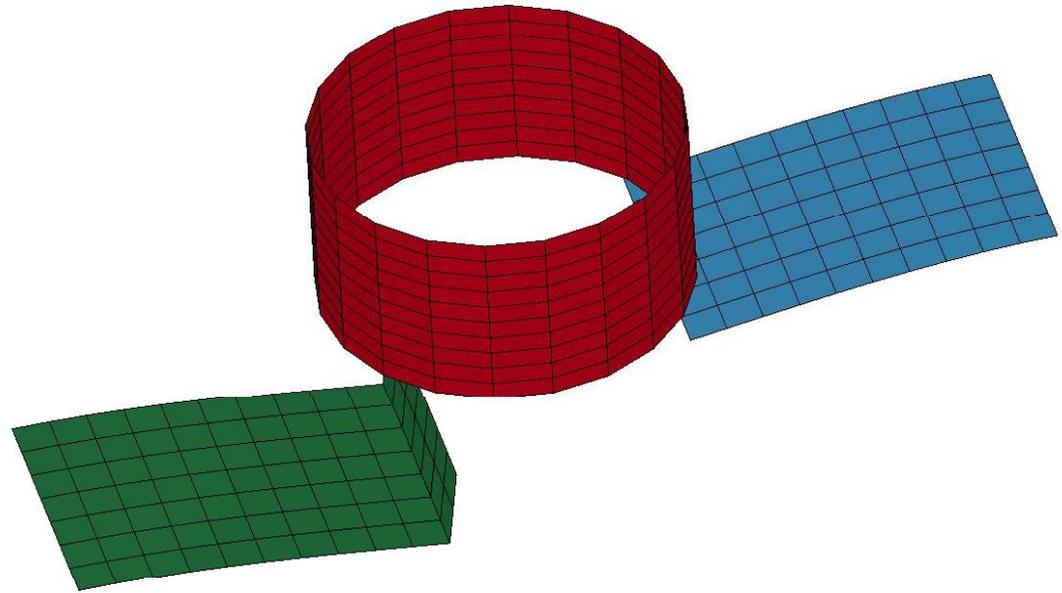
Mortar contact
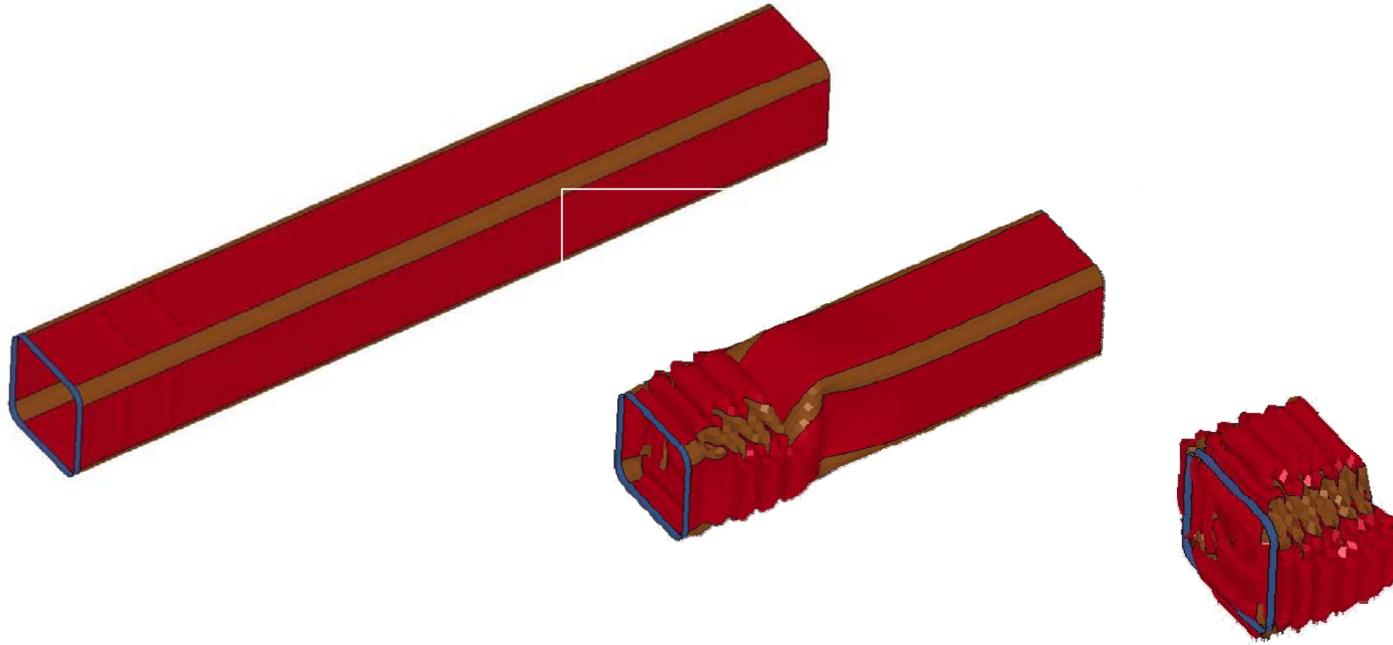
Crashbox utilizing automatic single surface mortar contact

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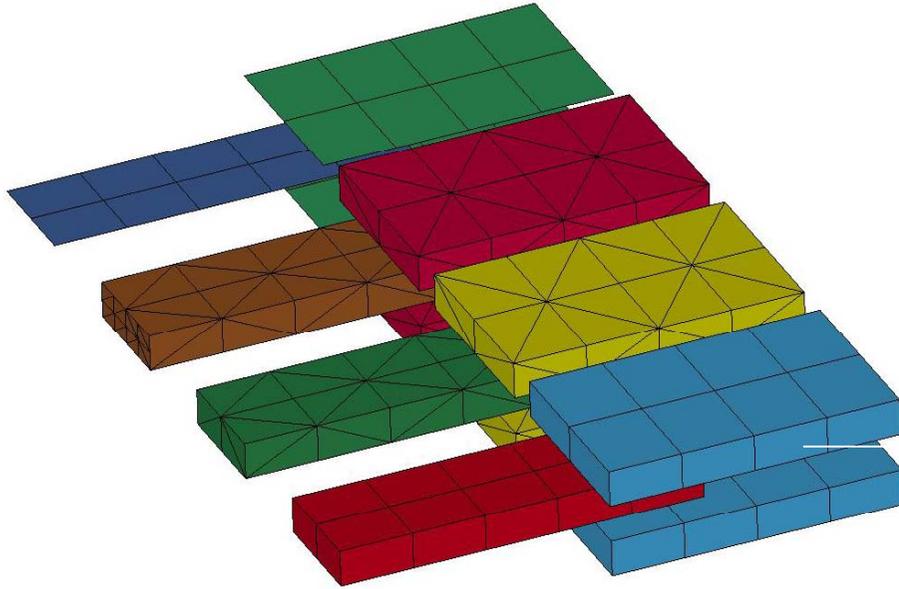
Tied mortar contact for some
supported element types
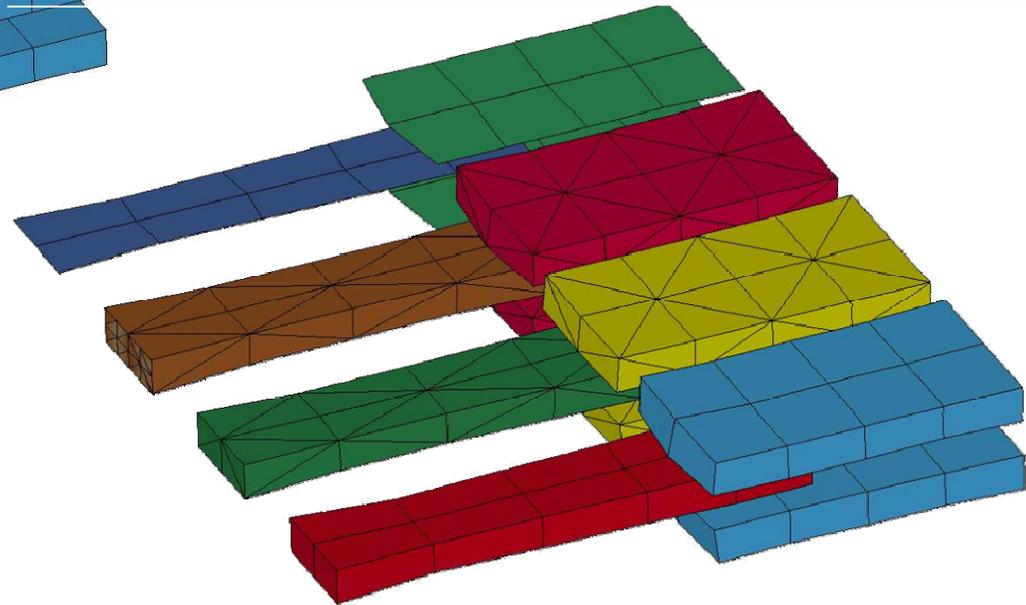
Molar fraction mass flow input

- 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

2d belt   1d belt
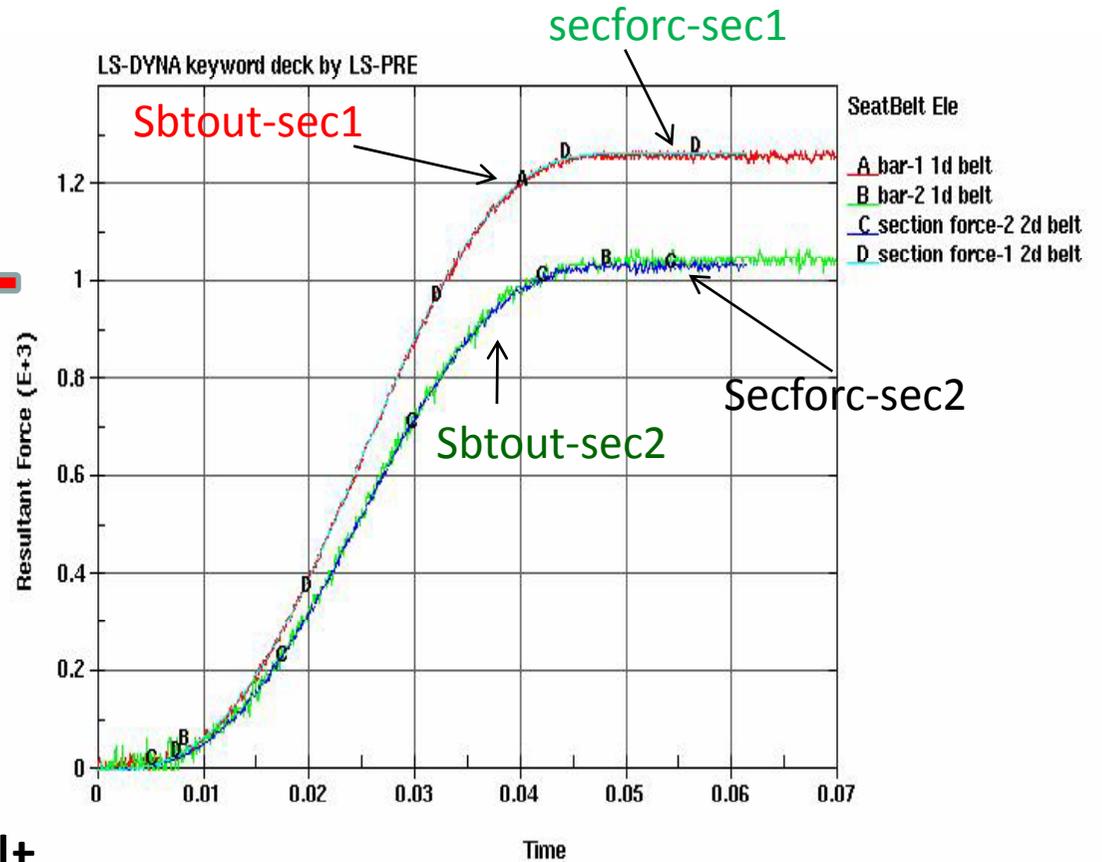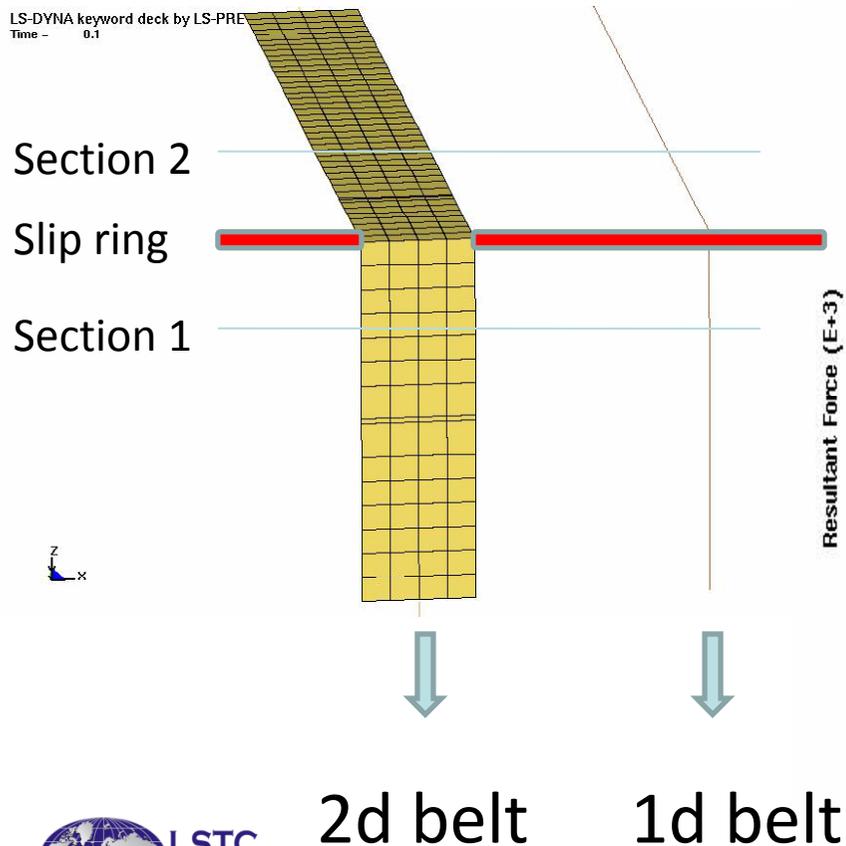
Improvement to 2d-belts

- 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

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Improvement to 2d-belts

Head Acceleration

Chest Acceleration
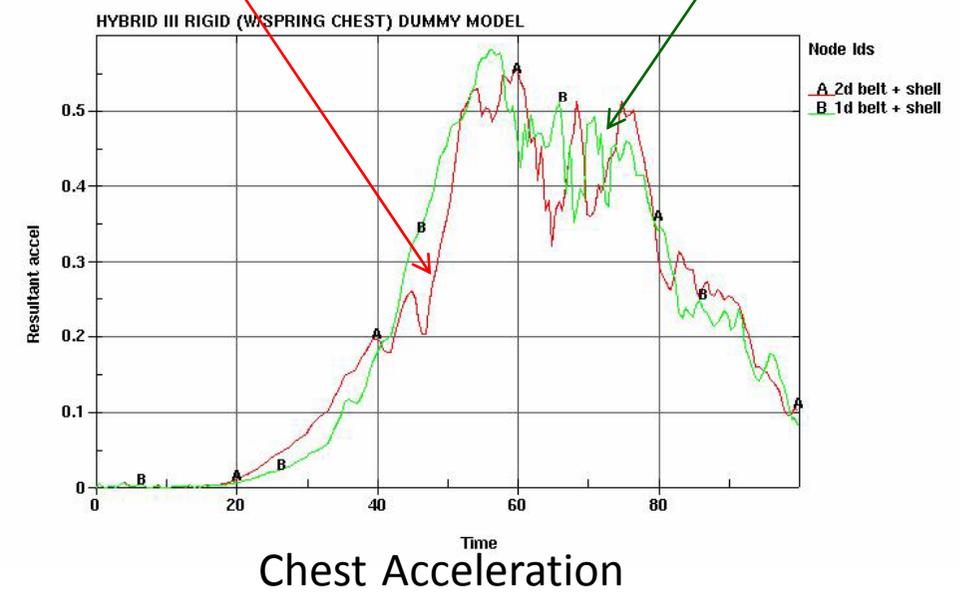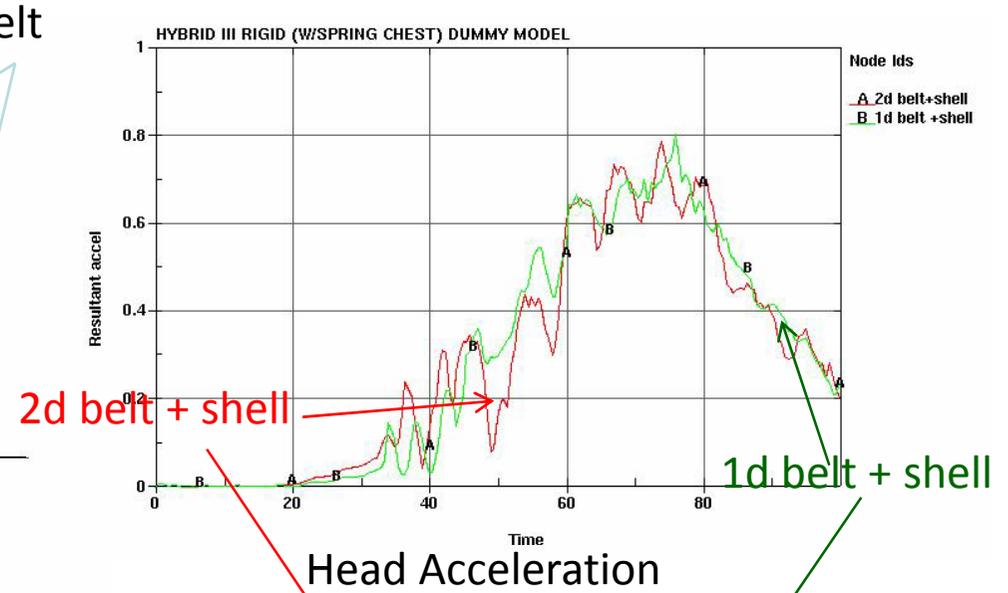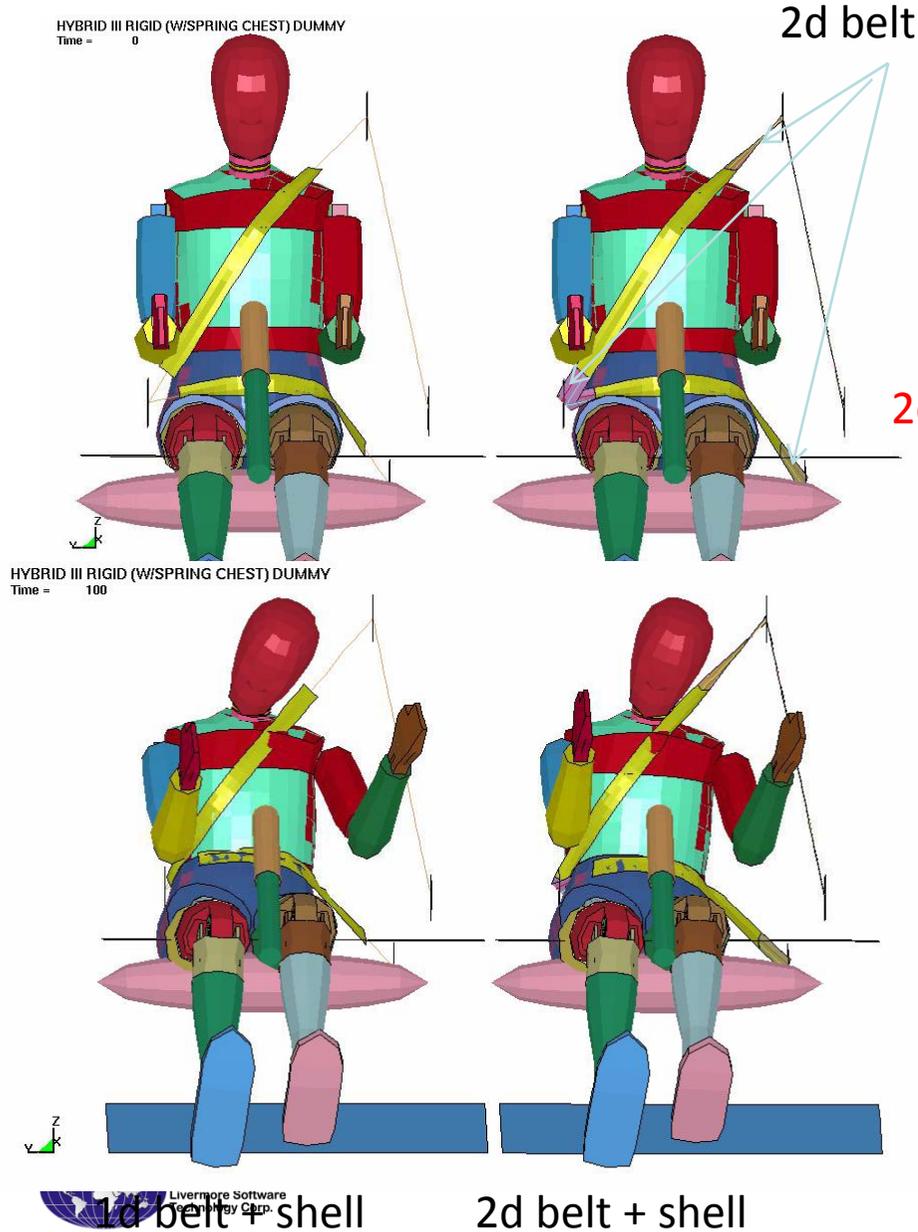
Improvement to belt analysis

- 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 forumulation 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 polynmials.

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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 <u>without</u> 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.

$$v_i(\xi) = \sum_{A=1}^{n} N_A(\xi) \left(v_{Ai} + \frac{h\xi_3}{2} e_{ijk}\omega_{Aj}n_k(\xi) \right)$$

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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
max ipt. value
min=0, at elem# 1001
max=0, at elem# 1001
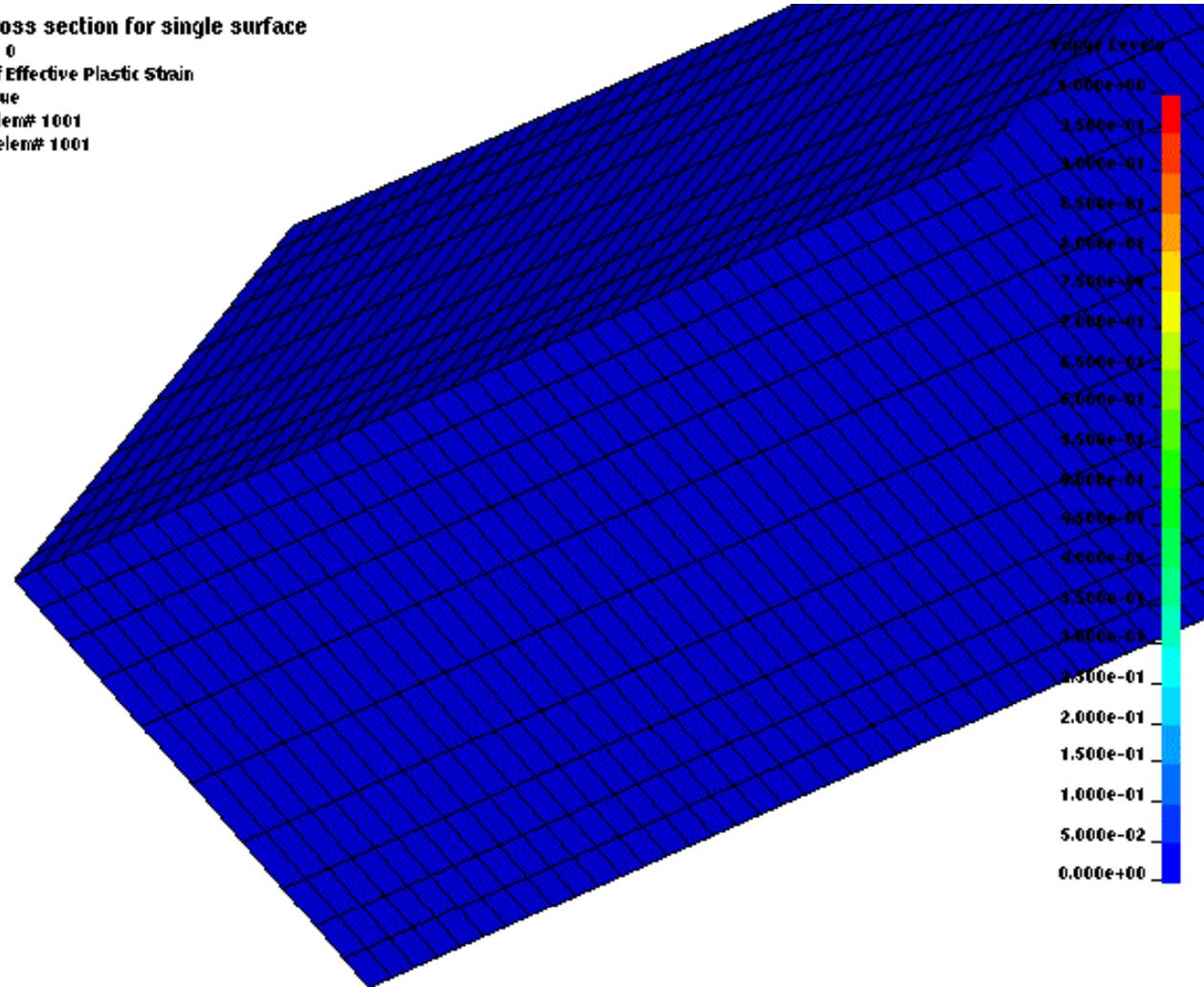
Square tube buckling
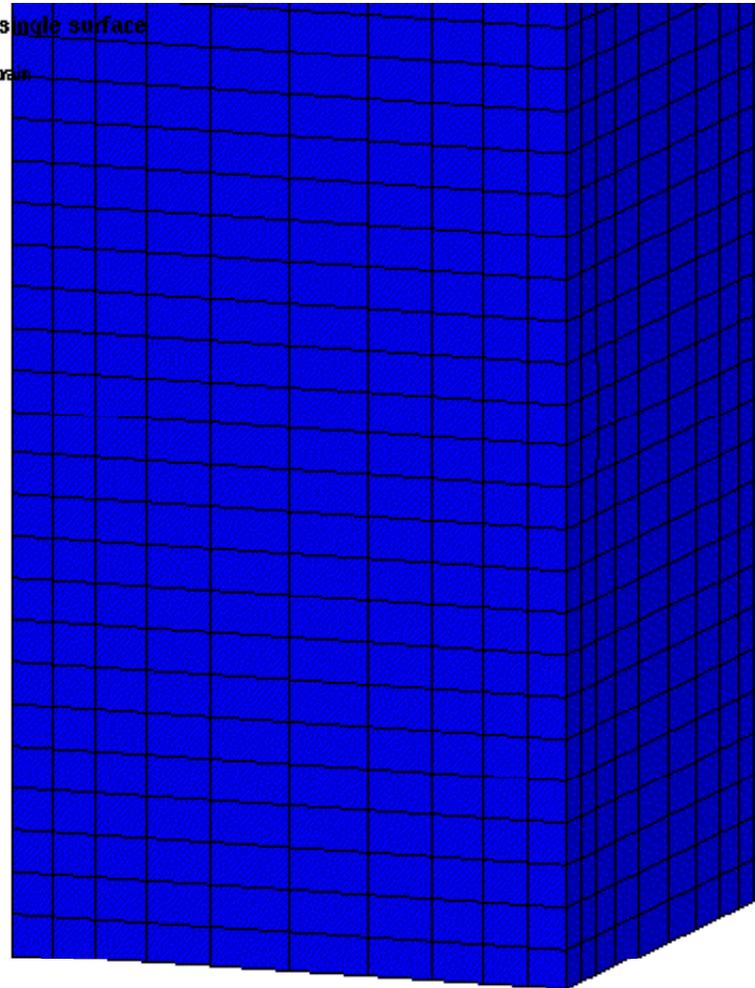
Quartic (P=4) NURBS Shell Elements
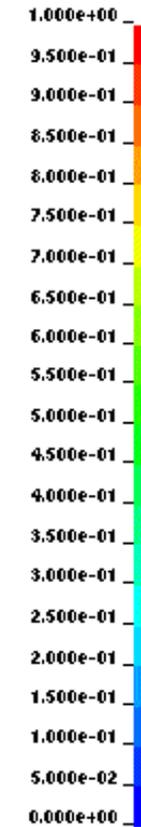
Acoustic solvers in LS-DYNA

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

⇩ FFT

Velocity (pressure) in frequency domain

⇩

Velocity in frequency domain given by user ⟹

Rayleigh   BEM   Kirchhoff

⇩

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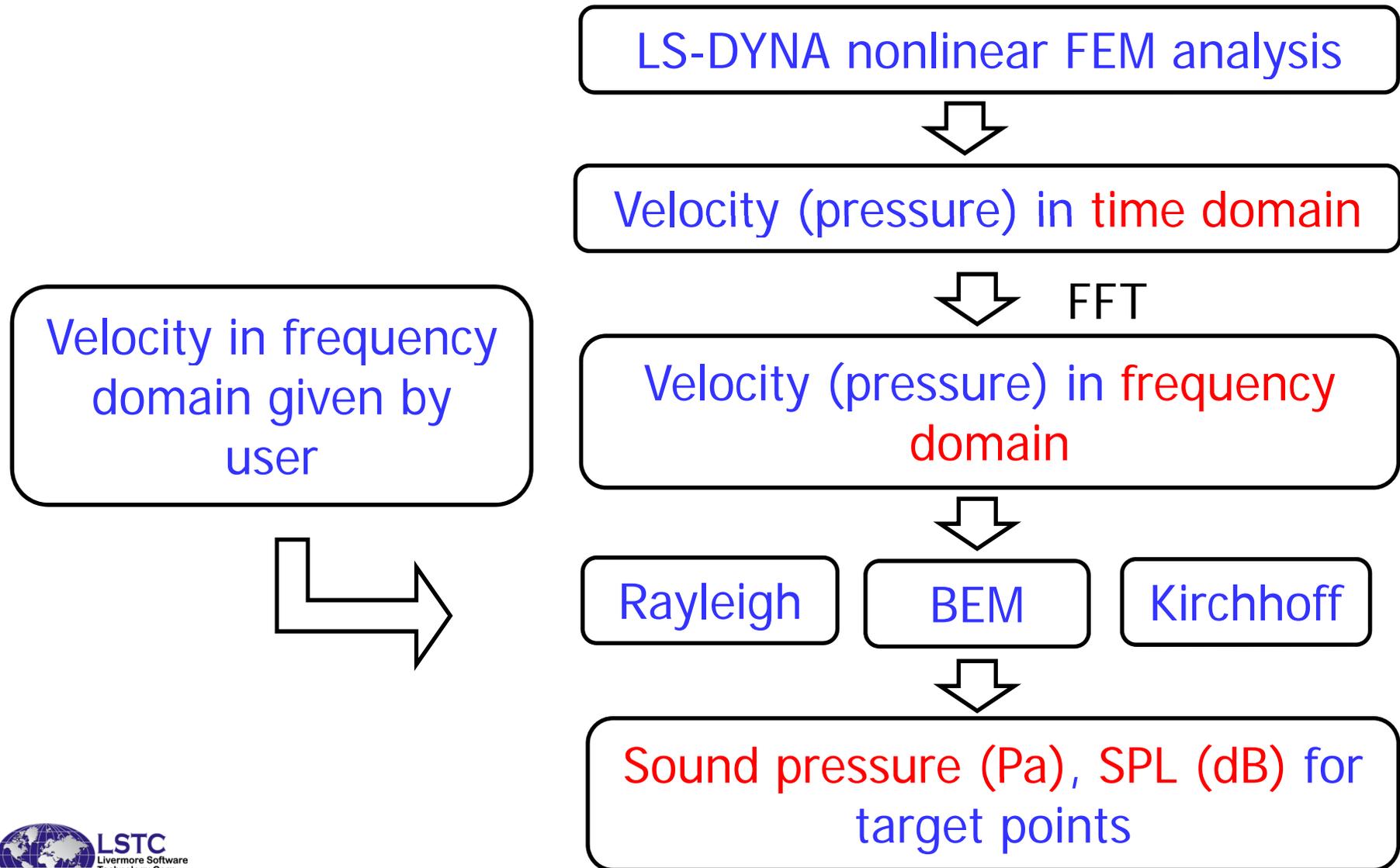
Keyword

Execution line:

LSDYNA   i = input.k   bem=filename

Keyword

*BOUNDARY_ELEMENT_METHOD_ACOUSTIC

Golf club example
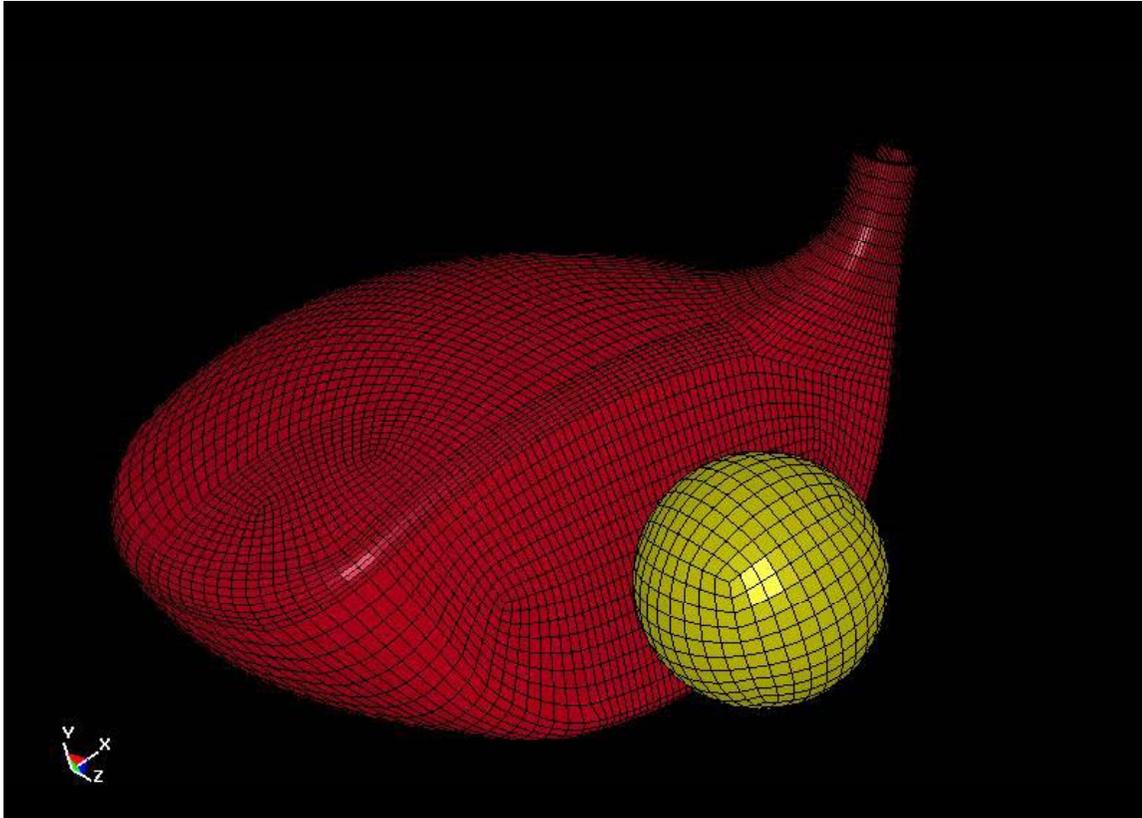
Model information

FEM part
34412 Nodes
27616 Solid elements

BEM part
6313 Nodes
6272 Shell elements
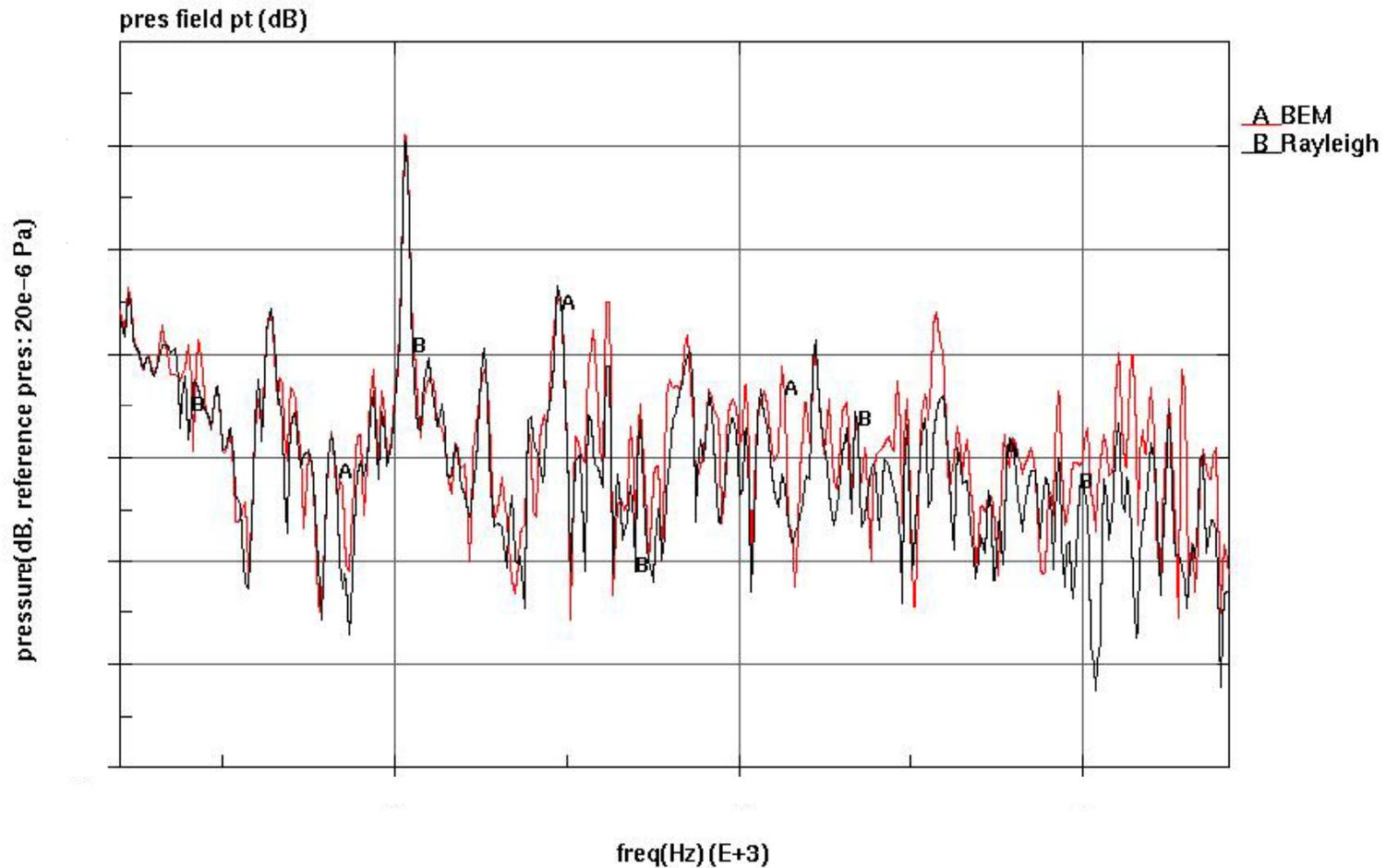
	MPP (8 cpu)	Serial
Elapsed time	12 hours 14 min	102 hours 32 min

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);
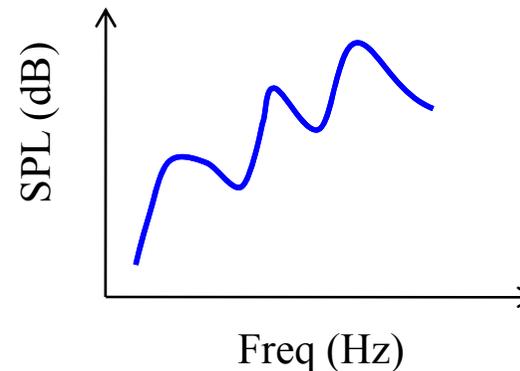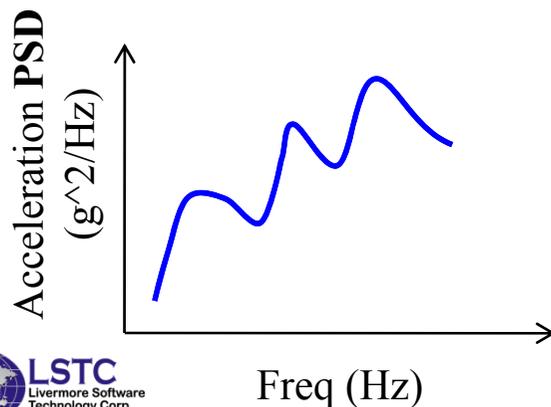
Random vibration analysis

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

RMS of Von mises stress

Reverberant acoustic wave is applied

Forward Bulkhead

7.107e+02
6.397e+02
5.686e+02
4.976e+02
4.265e+02
3.555e+02
2.844e+02
2.134e+02
1.423e+02
7.129e+01
2.455e-01
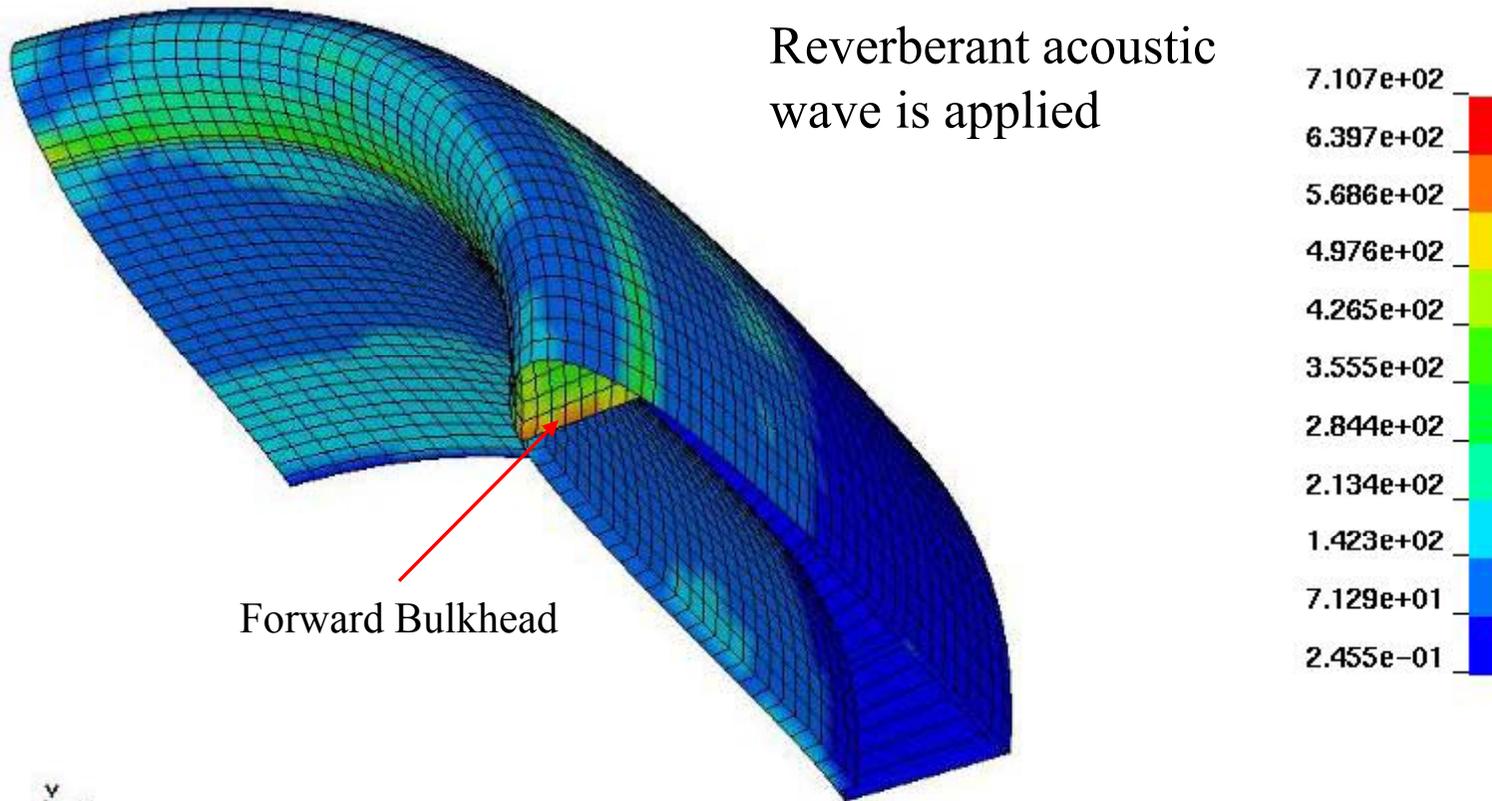
Example was provided by the Phantom Works, Boeing Company.

Frequency response functions

Input force   Transfer function   Displacement response

$F(\omega)$ $H(\omega)$ $X(\omega)$
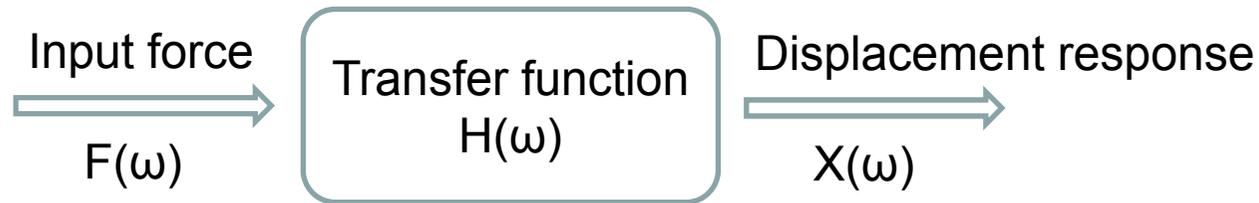
$$X(\omega) = H(\omega) \cdot F(\omega) \qquad H(\omega) = \frac{X(\omega)}{F(\omega)}$$

- 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)

Mode	Analytic	Experimental	ANSYS	LS-DYNA
1	76.29	76.12	76.84	78.62
2	82.87	83.00	81.62	81.36
3	176.81	177.65	177.11	179.61
4	190.60	201.50	189.88	188.66
5	220.58	221.70	220.37	219.69
6	255.79	261.41	254.96	255.13
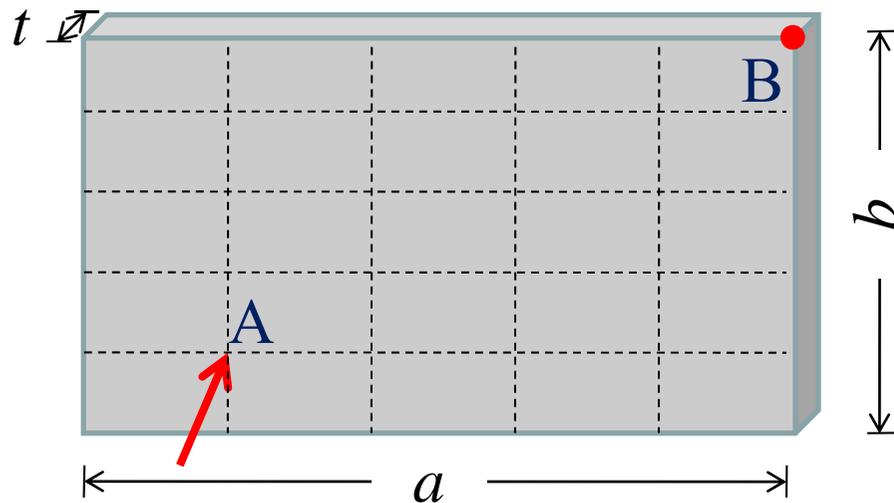
Harmonic point force excitation
F=exp(-$i\omega t$)

Reference:
Bor-Tsuen Wang, Wen-Chang Tsao. Application of FEAand EMA to Structural Model Verification, *Proceedings of the 10th CSSV conference. Taiwan, 2002; 131-138.*

Transfer FRF A->B
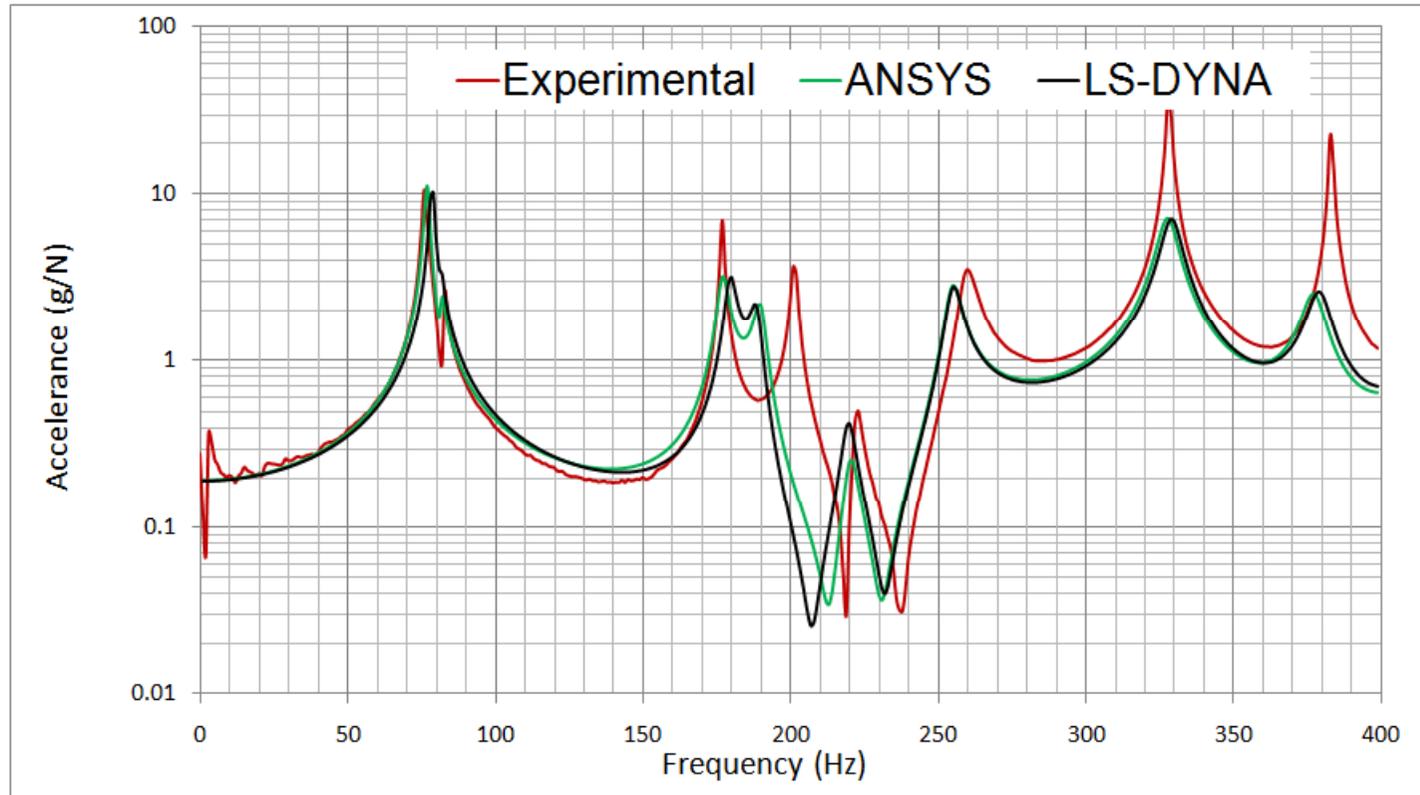
Constant modal damping ratio 0.01 is adopted in ANSYS and LS-DYNA

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.

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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
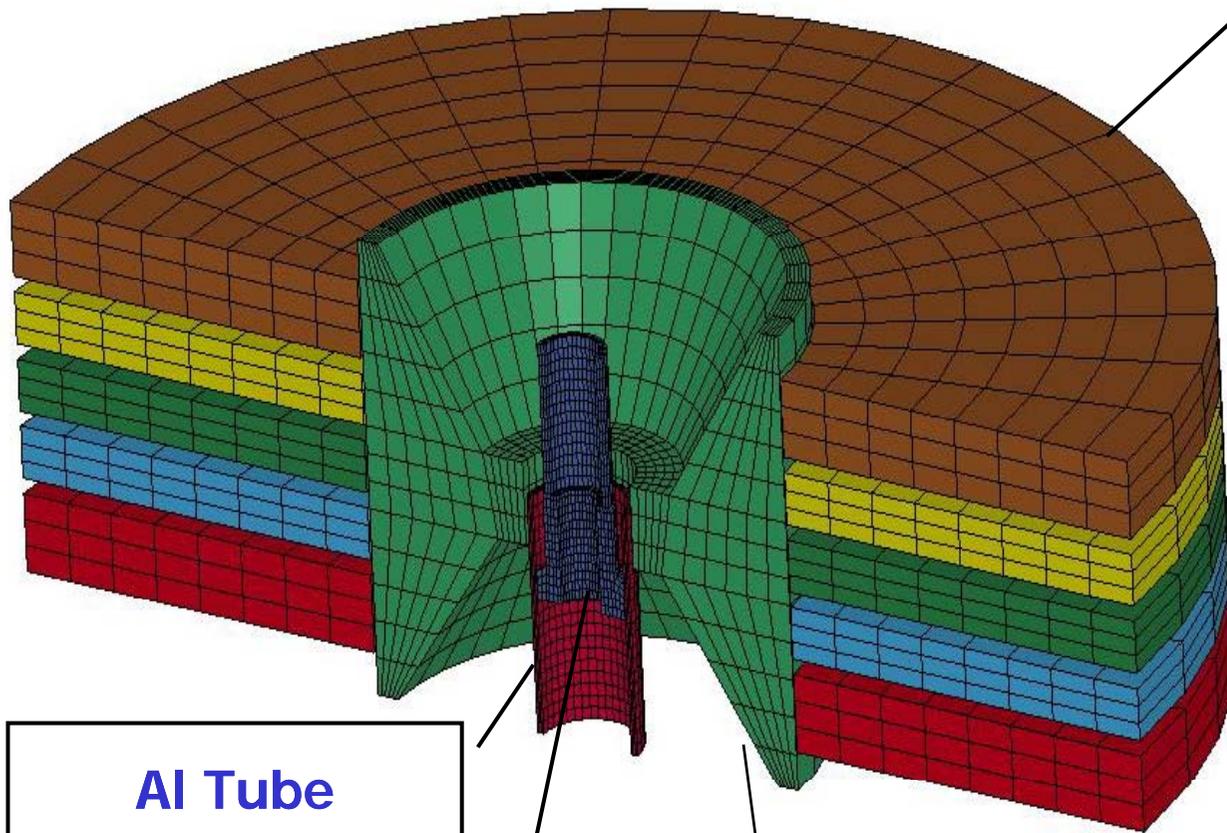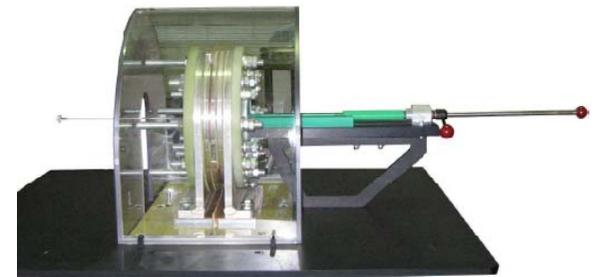
Al Tube

Cu central rod

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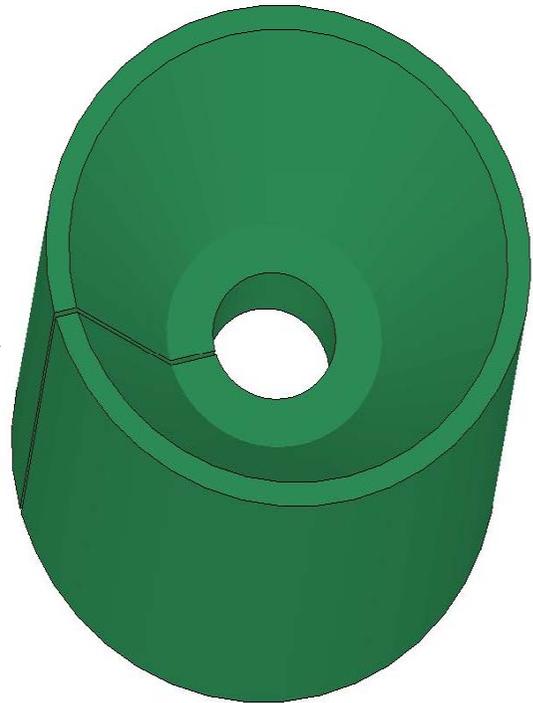
3D simulation (1/2 of the mesh shown)
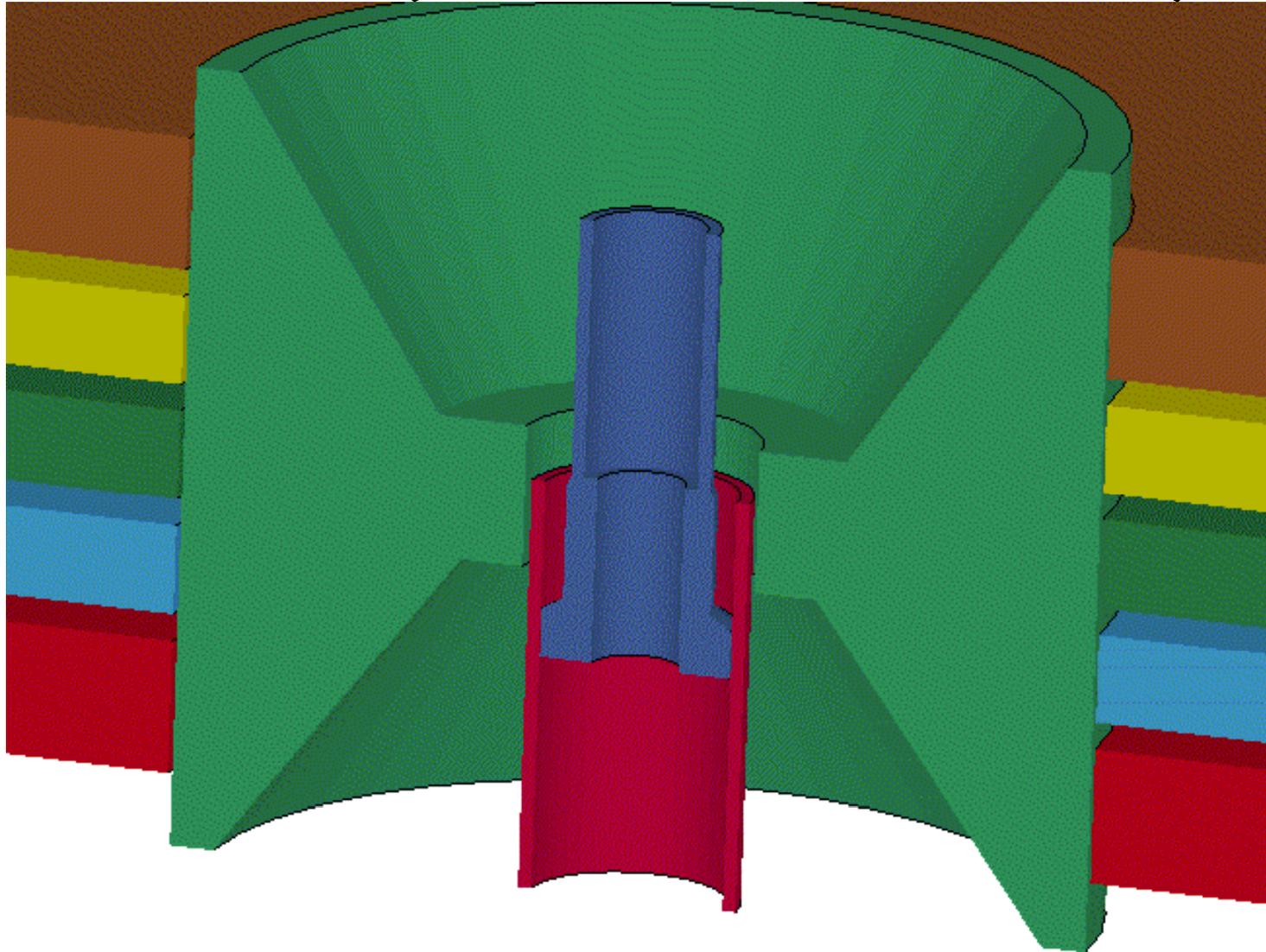
Incompressible flow solver

- 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

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Bubble Drop: High Resolution Interface Capturing and Adaptive Re-Meshing

Free Surface (P=0)

Density=0.5

Density=0.1

g = (0,0,-1)

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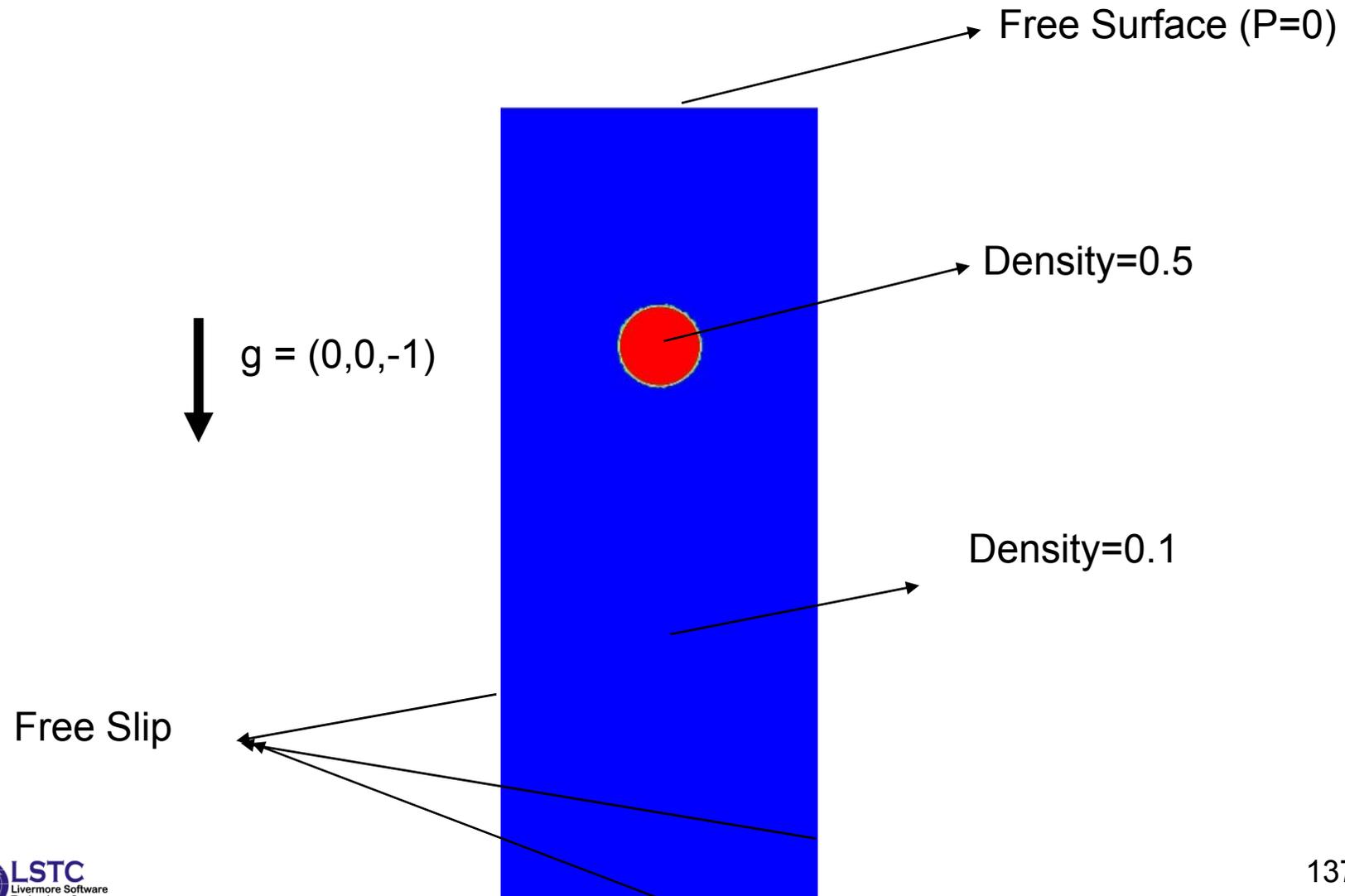
Bubble Drop: High Resolution Interface Capturing and Adaptive Re-Meshing
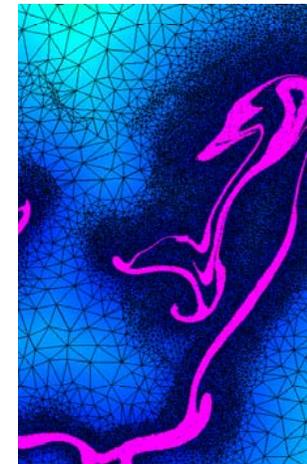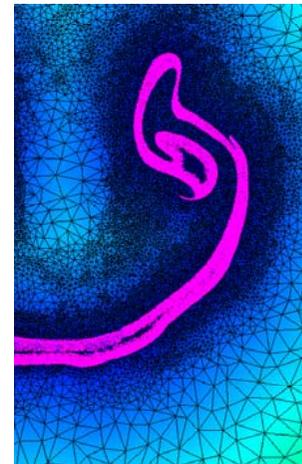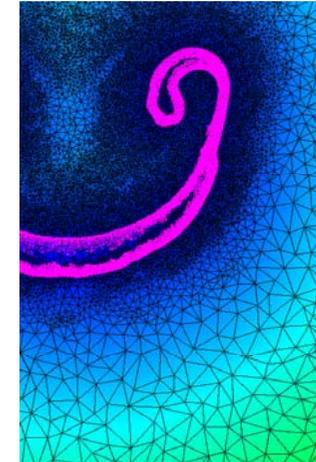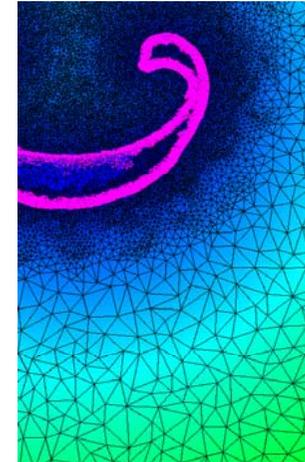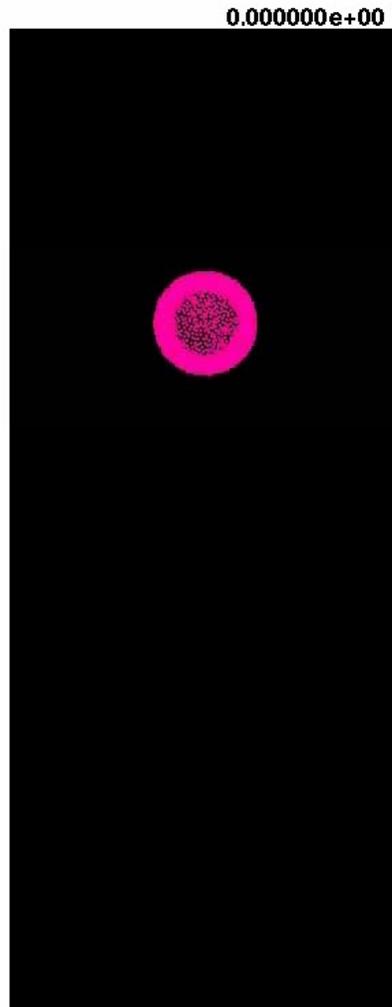
Flexible Beam With Error Control

FSI BOUND.

OUTFLOW

INFLOW

FREE SLIP
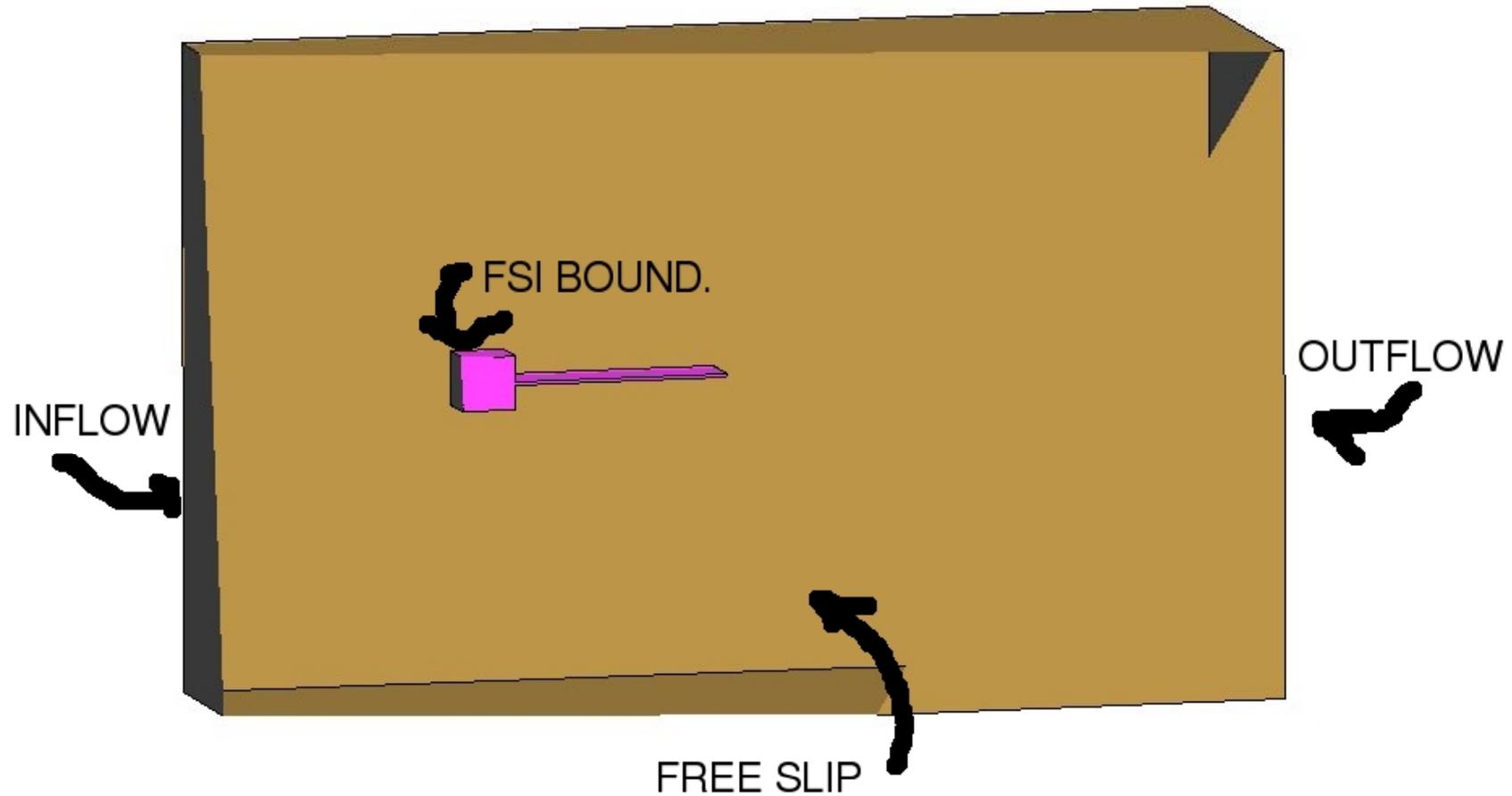
Velocity Field and Mesh
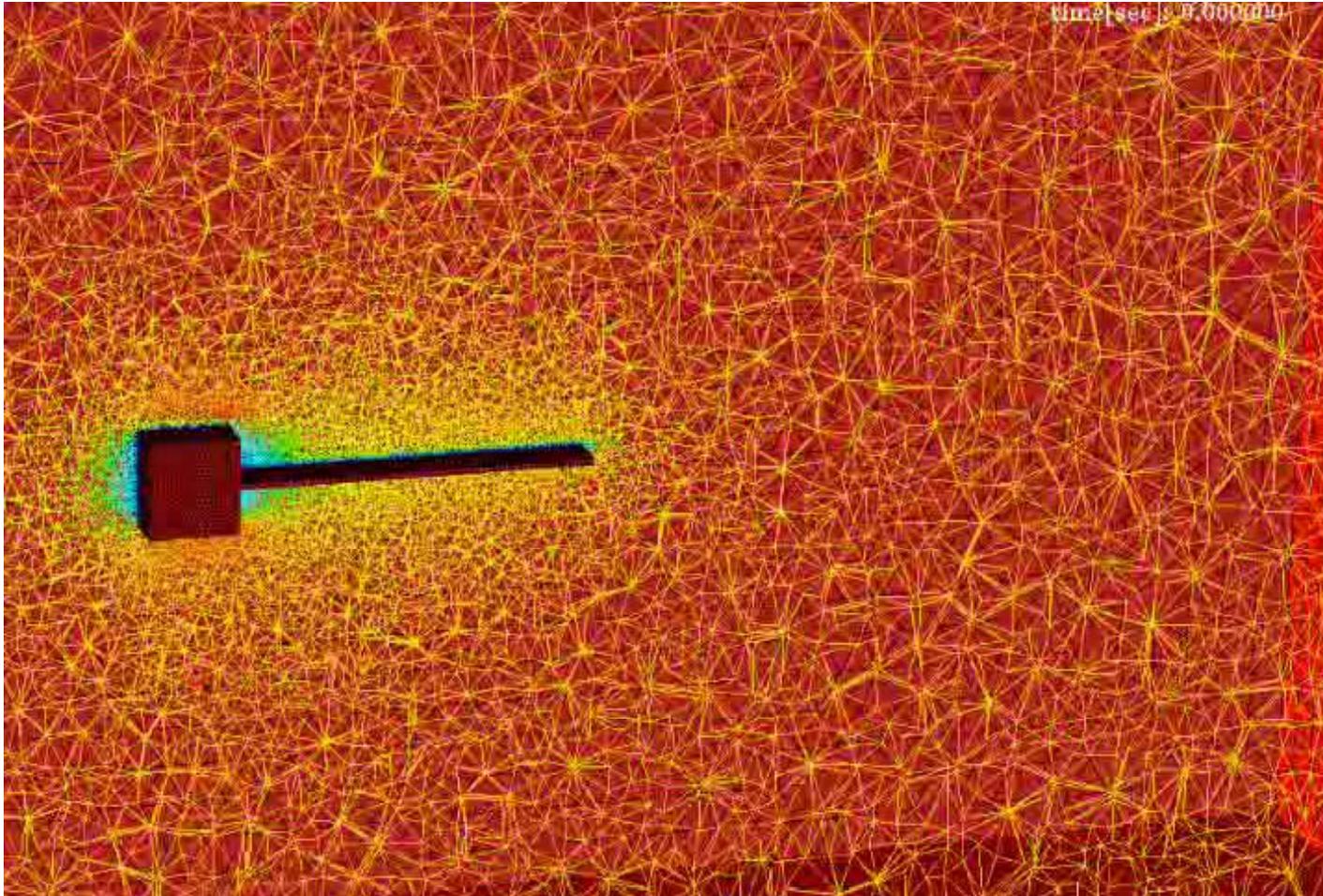
CESE Method

- Advantage of CESE method for compressible flow:

    – *Flux* conservations in *space and time* (locally & globally)

    – 2nd 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
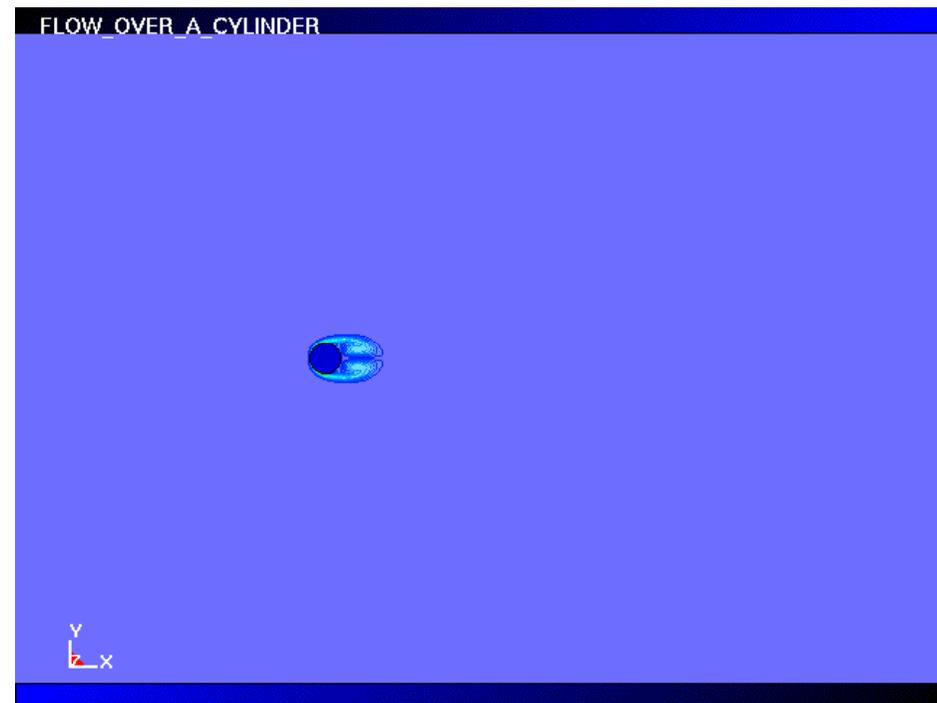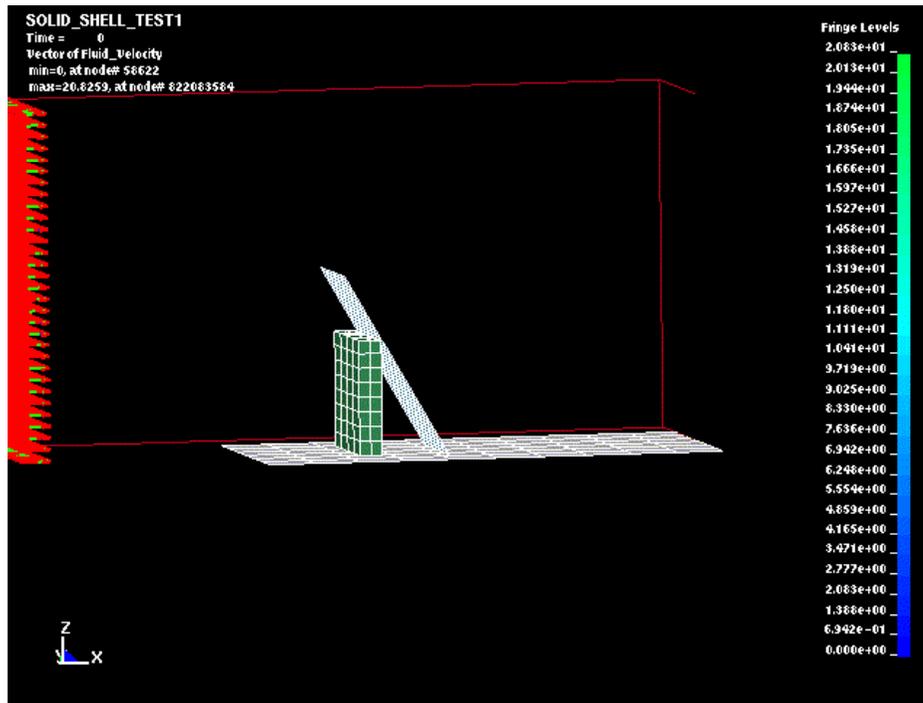
FSI with CESE
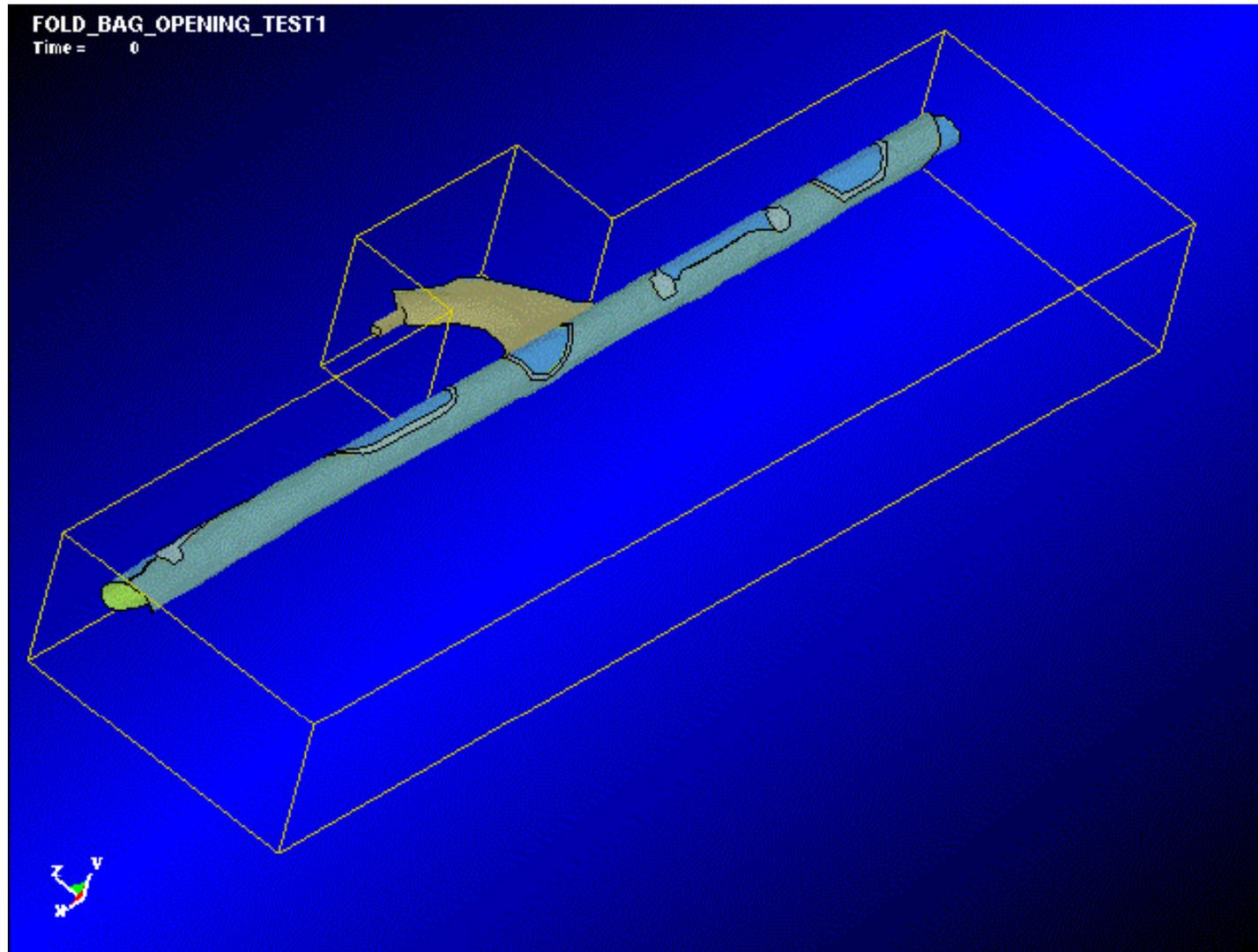
Conclusions: summary

- 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

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