Recent Developments in LS-DYNA – I

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Livermore Software Technology Corporation - LSTC

Recent Developments in LS-DYNA®

6th LS-DYNA Forum
Frankenthal, Germany

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October 11 - 12, 2007

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Outline of talk

- Introduction
- LSTC dummy development
- New features in version 971 release 3
- New features in version 971 release 4
- Version 980
- Conclusions

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LS-DYNA development

- Our developments are concentrated on four products:
  - LS-Dyna
  - LS-Opt
  - LS-PrePost
  - Dummies and barriers
- LS-PrePost and LS-Opt are part of the LS-Dyna distribution and do not require license keys.

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Current status of LS-Prepost

- LS-Prepost 2.1 has been frozen and released
- LS-Prepost 2.2 is available and is in Beta test
- LS-Prepost 2.1 and 2.2 can be freely download from ftp://ftp.lstc.com/outgoing2/lsprepost2_1 ftp://ftp.lstc.com/outgoing2/lsprepost2_2
- 64bit version is available for both Unix, Linux, Win64 and Vista
- Up-to-date online documentation is available at http://www.lstc.com/lspp
  - There are 17 online tutorials that give step-by-step instructions on how to create model. More tutorials will be added over time
  - Frequently Asked Questions (FAQ) is also available online

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Current status of LS-Prepost

- Meshing capabilities
  - Line/Surfaces creation and editing
  - Simple geometry creation like Box/sphere/cylinder both for shell or solid element
  - Automatic shell surface meshing
  - Automatic tetrahedral meshing
  - 3D solid block meshing using index space scheme
  - Multiple lines surface meshing
  - Line sweep into Shells or surface sweep into Solids along a given line

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New Features in LS-Prepost

- Special application interface for Metal forming
- A new SPH mesh generation for fuel tank sloshing analysis
- Spot weld generation using weld file
- Comprehensive LS-DYNA Keyword data check
- Extensive model checking including contact and penetration
- SCRIPTO – A scripting language allow users to modify LS-Prepost interface and access either Keyword data or d3plot data

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Development goals

- Combine multi-physics capabilities in a scalable code for solving highly nonlinear transient problems to enable the solution of coupled multi-physics and multi-stage problems in one run
  - Full 2D & 3D capabilities
  - Explicit Solver
  - Implicit Solver
  - Heat Transfer
  - ALE, EFG, SPH, particle methods
  - Navier-Stokes Fluids (version 980)
  - Radiation transport (version 980)
  - Electromagnetics (version 980)
  - Acoustics
  - Interfaces for users, i.e., elements, materials, loads, etc.
  - Interfaces with other software, Madymo, USA, etc.

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LS-DYNA development

- Advantages of the one code strategy
  - A combined explicit-implicit solver for multi-physics applications focuses all development on one comprehensive analysis code.
  - A large cost savings relative to developing an array of uncoupled multi-physics solvers and then coupling them.
  - Large and diverse user base covering many industries means lower licensing costs
  - Features needed for implicit applications are available for explicit
    - » Double precision, 2nd order stress update, Global constraint matrix, etc.

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LS-DYNA development

- Advantages of the one code strategy
  - Implicit MPP utilizes all prior efforts for explicit solver
  - Implicit options are built on explicit options with little effort
  - LS-PrePost/LS-Opt software development supports one interface.
  - QA is performed on one code
  - No costly add-ons for customers who require multi-physics solutions.

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LS-DYNA development

- We recognize that no single method is superior in all applications
- New developments and methodologies take time before gaining general acceptance and robustness
- Requests for developments from users are given the highest development priority
- Accuracy, speed, and scalability are the critical considerations for large scale simulations
- New releases must accept and run all input files from all previous releases without translation

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Parallel computing

- In less than one decade from 1998-2006 the use of explicit codes has undergone a radical transformation
  - From 100% serial and SMP licensed CPU's for crash to 90% MPP with the remaining 10% of CPU's typically running smaller models on 1-8 processors
  - Today serial and SMP explicit codes are becoming obsolete and will eventually be phased out
- What about implicit?
  - More difficult to create an MPP version
  - Requires more expensive hardware so there is less customer pressure to create MPP versions
  - SMP implicit solvers *used in large scale nonlinear simulations* will also become obsolete within the next 5 years
- Our goal is to ensure that LS-Dyna is the fastest, scalable implicit code available

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Dummy developments

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Dummy development

- Why is LSTC considering the development and support of dummy models:
  - Customer say:
    - Available dummy models are too coarse for finely meshed structural models
    - Data encryption hides important information and limits workarounds if model fails to run or correlate.
    - Dummies are too expensive
  - Opportunity to use advanced LSTC materials models and element technology that competitors lack
    - Improved robustness
    - Improved accuracy

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Dummy development overview

- Rigid body 5th, 50th, 95th validated rigid Hybrid III dummies are being prepared for release.
- LSTC is presently funding NCAC for the development of the 5th and 50th percentile Hybrid III dummies.
  - LSTC will do additional validation of the NCAC dummies prior to release to customers
  - Ultimate quality will depend on availability of validation data from automotive customers

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Background

- LSTC's current Hybrid III dummies are nearly 10 yrs old:
  - Rigid 5th Percentile Female and 50th & 95th Percentile Male
  - Deformable 5th Percentile Female and 50th & 95th Percentile Male
- Over time several deficiencies have been identified:
  - Difficulty in positioning
  - Difficulty in injury/response extraction
  - Lack of documentation

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Objectives

- Update dummies to take advantage of improvements in LS-DYNA and LS-PrePost.
- Generate proper documentation to improve usability.
- Update and release rigid dummies, and then proceed to work on deformable set.
- Ultimate goal is to produce relatively fast and robust dummies for early stage airbag/restraint system development.

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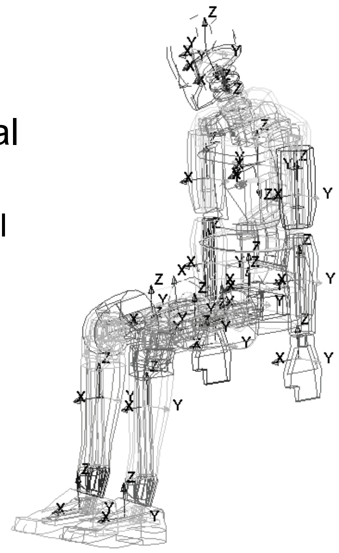
Recent Improvements (Dummies)

- Added "Rigid Markers" & Local Coordinate Systems
  - Located at H-Point and CG of all rigid parts
  - LCSs ease understanding of injury response directions



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Recent Improvements (Dummies)

- Updated all *PART_INERTIAs
  - Now defined with respect to ***Local*** rather than ***Global*** axes
  - This greatly simplifies positioning in a pre-processor
- Updated *CONSTRAINED_JOINTs
  - "Signs" agree with standard dummy conventions
  - All limb "stop angles" are correctly defined
  - Node pairs perfectly coincident for maximum robustness

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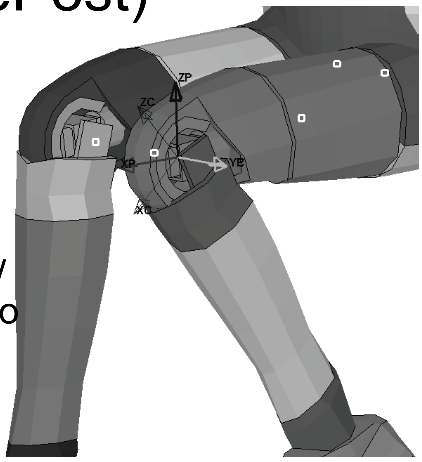
Recent Improvements (LS-PrePost)

- "Parent and child" joint coordinate systems now clearly visible for all limb rotations.
- Pelvic and limb angles now reported correctly relative to upright sitting position.



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Recent Improvements (LS-PrePost)

- Redundant (and potentially conflicting) data removed from Tree Files.
- Pre-Processor role has been minimized. (dummy can be repositioned without recalculating inertias - replacement of the "nodal block" is all that is required)

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Current Status

- Rigid 50th Percentile Dummy has been updated with all previously stated improvements.
- Rigid 50th has also been successfully calibrated based on Thorax, Neck-Flexion, and Neck-Extension tests.
- Essential documentation for usage and data extraction is being prepared.
- Beta version of Rigid 50th scheduled for limited release by end May. Assuming favorable response, final release will follow shortly thereafter.

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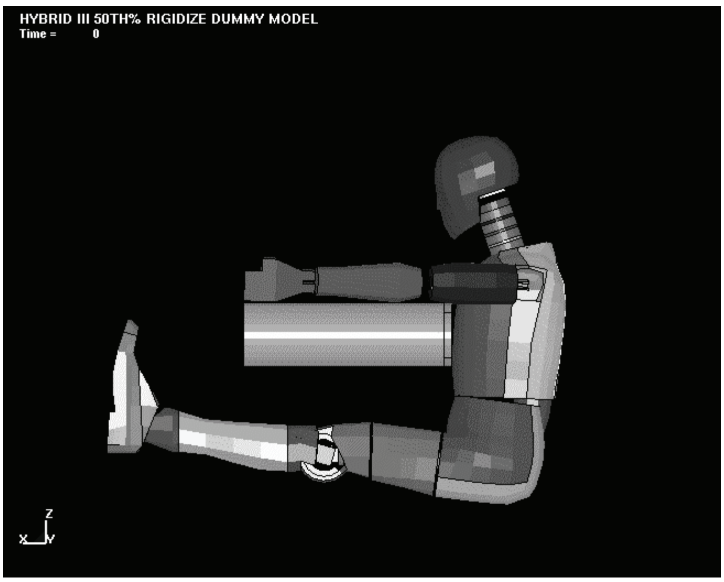
Rigid Hybrid III 50th



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Future Work

- Repeat previously mentioned tasks for Rigid 5th and 95th.
- Proceed with work on Deformable dummies.
- If possible, perform correlation studies of the following OOP simulations using the deformable 5th: “Chin-on-Rim”, “Chin-on-Module”, and “Chest-on-Module”.

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NCAC dummy modeling plan

- Develop H3 50th Percentile Model
  - Digitizing and meshing will be completed and sent to LSTC in June
- Develop H3 5th Percentile Model
  - Start in June
  - Expected completion - 9 months
- Develop SID_IIS Model
- Develop Child Dummy Model

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NCAC FHWA/NHTSA NATIONAL CRASH ANALYSIS CENTER

NCAC H3 50th percentile model

- Two models are being developed
  - 6mm mesh size (~300K elements)
  - 4mm mesh size (~1M elements)
- Digitizing and meshing process started – expected completion end of May
- Validation started in parallel to digitizing and meshing (Head and Neck)

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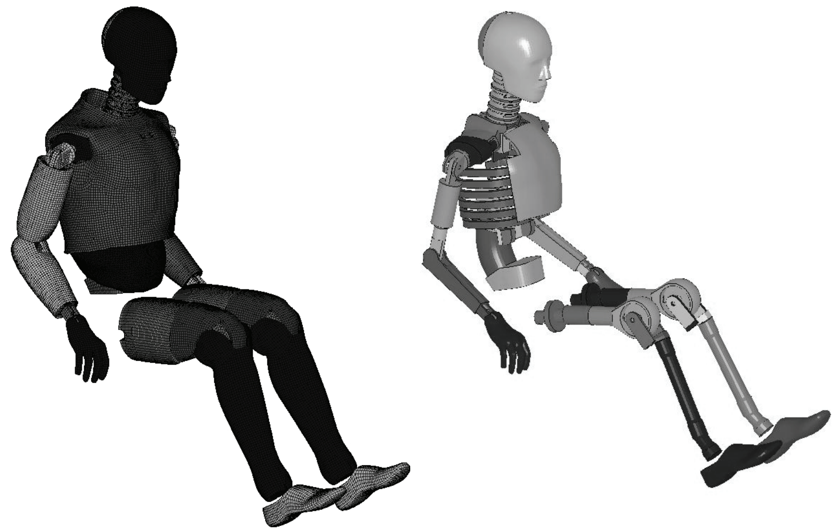
NCAC FHWA/NHTSA NATIONAL CRASH ANALYSIS CENTER

NCAC H3 50th percentile model



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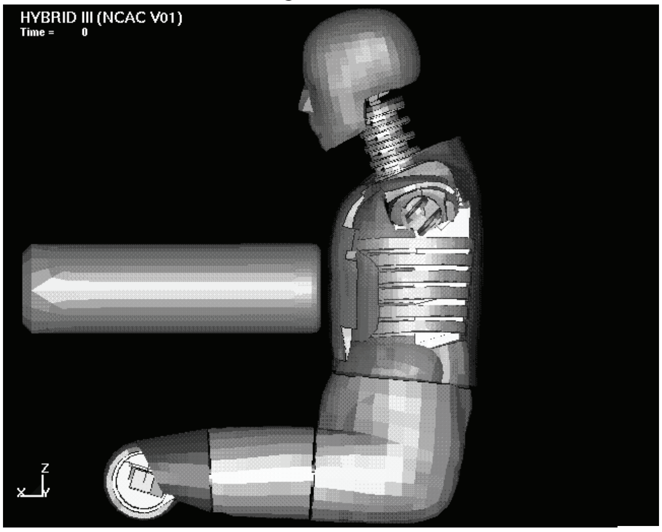
NCAC FHWA/NHTSA NATIONAL CRASH ANALYSIS CENTER

NCAC Hybrid III 50th



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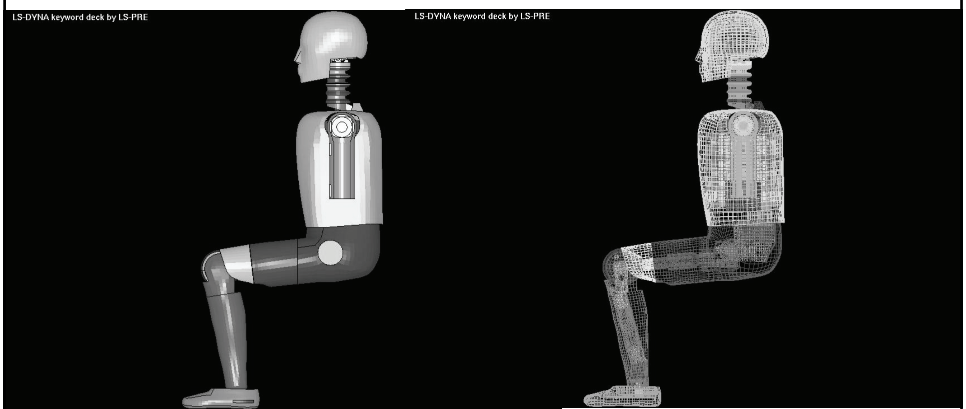
NCAC FHWA/NHTSA NATIONAL CRASH ANALYSIS CENTER

Sid IIs meshing has started

- ~300k nodes and elements



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Dummy development

- What about the future with NCAC?
  - Future work with NCAC may include:
    - All remaining frontal dummies
    - SID IIs
    - DOT-SID
    - All other dummies
  - However, LSTC future efforts and funding depend on several factors:
    - Cost and quality of available 3rd party dummies
    - Customer interest is supporting the development
    - NCAC interest in continuing the work

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Version 971_R3 developments

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Release of version 971_R3

- Version 971_R1 was released during the 4th quarter of 2005
  - Multiple customers requested additional capabilities before switching from version 970
- Version 971_R2 was released during the 3th quarter of 2006 and includes nearly all additional requested capabilities. The final release is now available
- Version 971_R3 will be frozen by the end of June and released in September
- Manual is available as a pdf file and the printed version will be available soon.

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*Part_duplicate

- Provides a method of duplicating parts or part sets without the need to use the *Include_transform option
- Keyword format

Card1	PTYPE	TYPEID	IDPOFF	IDEOFF	IDNOFF	TRANID		
Type	A	I	I	I	I	I		
Default	none	none	0	0	0	0		

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*Part_duplicate

– PTYPE = “PART” to duplicate a single part
  PTYPE = “PSET” to duplicate a part set
– TYPEID = ID of part or part set to be duplicated.
– IDPOFF = ID offset of newly created parts
– IDEOFF = ID offset of newly created elements
– IDNOFF = ID offset of newly created nodes
– TRANID = ID of *Define_transformation to transform the existing nodes in a part or part set

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*B…_prescribed_accelerometer

- Prescribes rigid body motion based on experimentally obtained accelerometer data
- Required input includes x, y and z sensor acceleration traces and local coordinate system of each sensor
  - Accepts data from any number of sensors (a minimum of three is required)
  - Redundancy from the plurality of data is addressed automatically – information from only the most well conditioned signals is used
  - Filtered or unfiltered data can be handled

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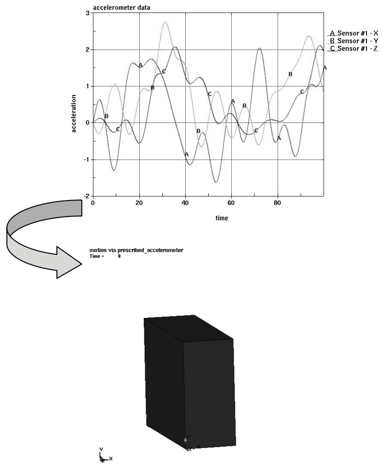
Example *B…_prescribed_accelerometer

- Experimental acceleration data

- Resulting prescribed motion



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*Control_contact

- Parameters SPOTSTP and SPOTDEL now apply to both beam and solid element spot welds.
  - SPOTSTP has a new option, 2, to delete the weld element and continue the calculation
  - Solid elements are deleted when elements constraining the nodes on either the upper or lower contact surface are deleted
- ITHOFF is a flag for offsetting thermal contact surfaces for thick thermal shells
  - EQ.0: No offset, the heat will be transferred between the mid-surfaces of the corresponding contact segments (shells).
  - EQ.1: Offsets are applied so that contact heat transfer is always between the outer surfaces of the contact segments (shells).

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*Control_shell

- Automatic sorting of degenerate quadrilateral shells to treat them as triangular shells is extended. The ESORT flag now permits 3 values:
  - EQ.0: no sorting required
  - EQ.1: full sorting to C0 triangular shells
  - EQ.2: full sorting to DKT triangular shells
- The bulk viscosity for shell elements now applies to the C0 and DKT triangular shells

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*Control_shell

- PSNFAILOptional shell part set ID specifying which part ID's are checked for negative Jacobians. If zero, all shell part ID's are included.
- |PSSTUPD| is the optional shell part set ID specifying which part ID's have or do not have their thickness updated.
  - LT.0: shells in part set are excluded from updates
  - EQ.0: all shells have their thickness updated
  - GT.0: shell in part set are included in updates

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*Database_history

- New options include
  - To limit output for the DEFORC file:
    - DISCRETE
    - DISCRETE_ID
    - DISCRETE_SET
  - To limit output for the SBTOUT file:
    - SEATBELT
    - SEATBELT_ID

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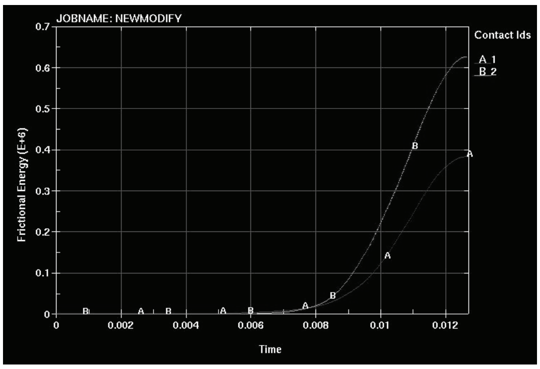
Database_sleout

- Frictional energy dissipation is now computed and output for each contact interface.



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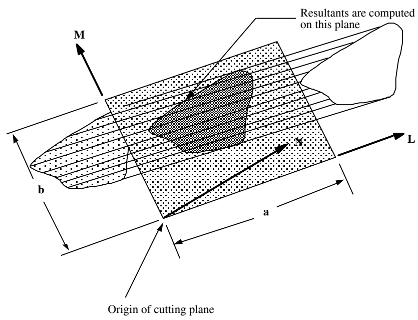
*Database_cross_section

- Cross-sectional forces can now be output do a coordinate systems defined by *Define_coordinate_nodes



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Encrypted input

- Encryption is now available to protect proprietary material input data
  - Uses openPGP standard format, so data can be encrypted with widely available tools such as gpg
  - Public key encryption with 1024 bit DSA key and 128 bit AES
  - Any subset of input lines may be encrypted except *INCLUDE statements, and initial *KEYWORD
  - Multiple encrypted sections allowed, without limitation
  - Material properties defined in encrypted blocks will not be echoed to d3hsp or other output files.

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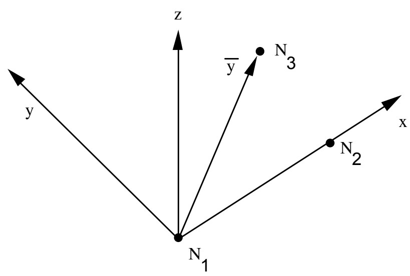
*Define_coordinate_nodes

- Define a local coordinate system with three node ID′s
- New option allows nodes N1 and N2 to define the local x (default), y, or z axis.



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*Load_body_generalized

- Current input allows specification of body forces on a range of nodes N1 to N2 inclusive
- An arbitrary number of body load definitions are possible
- Two new keyword options are available to define the active node set
  - *Load_body_generalized_set_node
  - *Load_body_generalized_set_part
- Body forces can now be applied in a local coordinate system

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*Element_mass_part_{set}

- Defines additional non-structural mass to be distributed by an area weighted distribution to all nodes of a given part or part set ID
  - The total added mass can be specified
  - The final mass of the part or part set can be specified and the added mass computed automatically
- Applies only to part ID's defined by shell elements.
- Provides an alternative method to giving the non-structural mass per unit area in the section definition

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*Load_segment_nonuniform

- Provides a method to load segments with a distributed load
  - Loading acts in direction defined by a vector
    - vector is defined in a local coordinate system
  - Birth and death time for loading
  - Scale factors are defined for each node of the segment
  - Linear and quadratic segments considered

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*Eos_tabulated

- The tabulated equation of state type 9, now allows the functions C and T to be defined by load curves

$$P = C\left(\varepsilon_V\right) + \gamma T\left(\varepsilon_V\right)E$$

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*Mat_ogden_rubber

- Twelve terms in the Prony series can now be used to treat viscoelastic damping
- Recoding has reduced storage per integration point to the minimum needed given the number of Prony series terms.
- Reliable nonlinear least square fitting of the Ogden constitutive constants is now available for up to 8 terms in the strain energy functional

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*Mat_036 enhancements

- Young's modulus as function of plastic strain (damage)
- Volume correction treatment for phase transformation effects
- Hardening curves in three directions simultaneously
- Lankford parameters as function of plastic strain

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Cohesive elements

- Used to predict interface failure.
  - Glued surfaces
- Four new constitutive models are available
  - *MAT_COHESIVE_ELASTIC
  - *MAT_COHESIVE_TH
    - Tvergaard and Hutchinson theory
- Solid element type 19 for connecting solid elements and type 20 for connecting shells at their mid-surfaces
  - Type 20 transmits moments, 19 does not
  - Four planar integration points
  - Hexahedral shape

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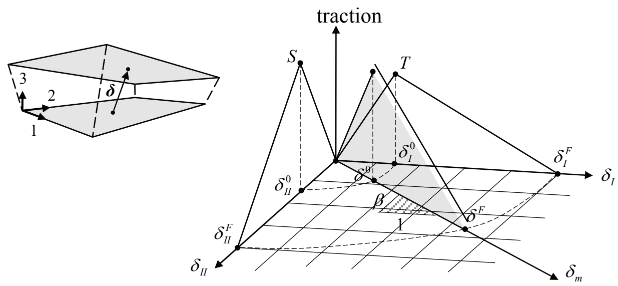
*Mat_cohesive_mixed_mode

- Bilinear traction-separation law with quadratic mixed mode delamination criterion and a damage formulation



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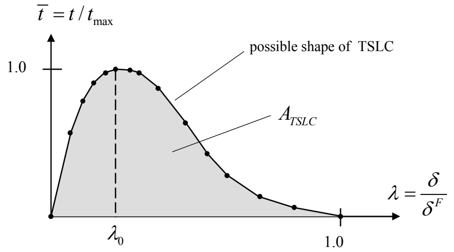
*Mat_cohesive_general

- Interaction between fracture modes I and II is considered.
- Load curve defines damage function



	mode I	mode II
t_{max}	T	S
δ^F	$\frac{G_I^c}{A_{TSLC}T}$	$\frac{G_{II}^c}{A_{TSLC}S}$
G^c	G_I^c	G_{II}^c

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Thermal development

- New thermal solid element for compatibility with mechanical counterparts
  - Consistent 4-noded tetrahedron element
  - Consistent 6-noded pentahedron element
  - 10-noded tetrahedron element
- Full integration is optional
- Flux, radiation and convection consistently applied to 6-noded segments corresponding to 10-noded tetrahedrons
- A line search option for nonlinear thermal problems

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Thermal contacts

- Complete MPP support of option *CONTACT_ …_THERMAL_FRICTION
  - Predefined expression of thermal contact heat transfer conductivity as function of interface pressure
  - Frictional coefficients as function of temperature via load curves
  - Cancelling of thermal boundary conditions for segments in thermal contact
- Thermal contact treatment for thick thermal shells
  - Heat transfer occurs on outer surfaces for rigid bodies (option on *CONTROL_CONTACT)
  - Frictional work transforms into heat on outer surfaces

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User defined contact

- Keyword *USER_INTERFACE_FRICTION supported in MPP
- New *USER_INTERFACE_CONDUCTIVITY available in SMP and MPP
  - Define contact heat transfer conductivity in a user defined function
- Frictional coefficients and conductivity can be given as functions of
  - Interface pressure
  - Temperature
  - Relative sliding velocity
  - User input parameters

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*Set_node_add_advanced

- Define a node set by combining, Node, Shell, Solid, Beam, Segment, Discrete, and Thick Shell sets.

Card 2, 3, 4 ... (The next "*" card terminates the input.)

	1	2	3	4	5	6	7	8
Variable	SID1	TYPE1	SID2	TYPE2	SID3	TYPE3	SID4	TYPE4
Type	I	I	I	I	I	I	I	I

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Nonlinear shell element with thickness stretch

- Includes thickness degrees-of-freedom
  - Requires 4 scalar nodes with 2 dof each
    - Generated automatically
- Calls 3D constitutive models
- Shell types available
  - Type 27 Triangle (new in R3)
  - Type 25 Quadrilateral
  - Type 26 Quadrilateral
- Can now be used in metal stamping with adaptive remeshing (new in R3)

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Nonlinear shell element with thickness stretch

- Main applications
  - Metal forming where normal loading is important, e.g., hydroforming.
  - Crash analysis
  - Composite analysis
- Forming material models implemented:
  - *Mat_3-parameter_barlat (36)
  - *Mat_transversely_anisotropic_elastic_plastic (37)
  - *Mat_barlat_yld2000 (133)

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Example forming problem

- CPU Cost
  - Type 16 - 25.16 minutes
  - Type 26 - 37.25 minutes
- Results are nearly identical with slightly less thinning with the type 26 shell.

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*Element_shell_…_offset

- “Offset” option has been added for all shell elements in version 971.
- The offset is included when defining the connectivity of the shell element
- The mid-surface is projected along its normal vector
  - Offsets greater than the shell thickness are permitted
  - Overrides the offset specified in the *SECTION_SHELL input
- Nodal inertia is modified to account of the offset and provide a stable time step of explicit computations

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*Element_shell_…_offset and contact

- In the R3 release, shell thickness offsets are accounted for in the single-surface and surface-to-surface contact options.
- Shells can be generated on CAD surfaces and then offset
- Contact now accounts for the offsets during the analysis

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*Element_shell_source_sink

- Simulation of roll forming
- Elements are created at the source
  - Force boundary conditions
- Elements are deleted at the sink
  - Displacement boundary
- Fewer elements required since elements are created and deleted as required
  - Decrease in CPU time requirements

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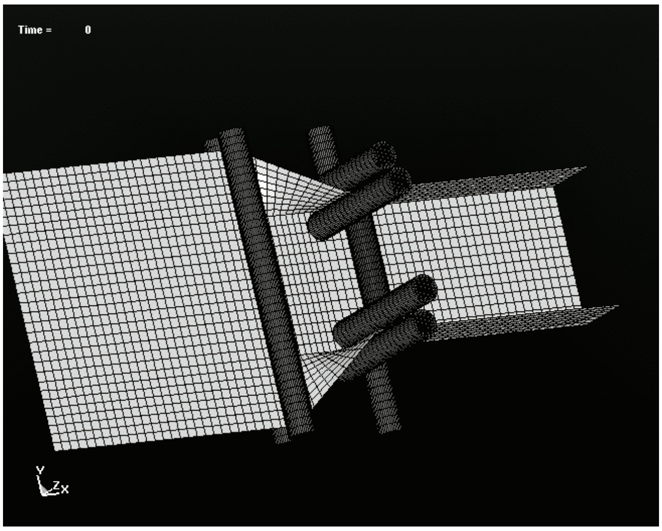
*Element_shell_source_sink



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Discretization of load curves

- LS-DYNA uses internally discretized curves to improve efficiency in the constitutive models.
  - Huge decrease in run times possible
  - Historically fixed at 100 equally spaced points
    - Recent customer complaint: too coarse for some applications where a very smooth response is required
- The number of points in the discretization is now an input parameter. The default remains = 100.
- All load curve use the same number of points

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BOUNDARY_PRESCRIBED_ ORIENTATION_RIGID_*OPTION

- Allows the orientation of a rigid body to be prescribed as a function of time.
- Uses a total formulation which is more precise than the incrementally based: *BOUNDARY_PRESCRIBED_MOTION_RIGID
- Options:
  - **_ANGLES**: Specify a sequence of rotations about either body or space fixed axes and the associated orientation angles $q_i(t)$ (i=1,2,3) as time histories using *DEFINE_CURVE.
  - **_DIRCOS**: Nine elements of the direction cosine matrix are input as functions of time, $C_{ij}(t)$ (i,j=1,2,3)
  - **_EULERP**: Provide as functions of time four Euler parameters, $\varepsilon_i(t)$ (i=1,..,4)

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Conventional mass scaling

- Lumped nodal masses are scaled (increased) to increase stable time step in explicit finite element analysis
- Severe scaling unavoidably introduces unwanted, non-physical, inertia effects in the structure under consideration – this will in practice limit the amount by which the time step can be increased
- Crash models are often forced to run at small step sizes due to critical components where mass scaling will lead to wrong results, i.e.,
  - Dummy interacting with steering wheel finely meshed with solid elements

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Selective mass scaling

- Mass is increased under the constraint that the rigid body translational behavior is preserved
- Lowers the high frequencies which allows for a larger stable time step, but leaves the low frequency domain relatively unaffected – severe mass scaling can be performed without deteriorating the accuracy of results

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Selective mass scaling - usage

- Selective mass scaling can be performed on the entire model or a subset of parts
- Selective mass scaling and conventional mass scaling can run together in the same model
- Selective mass scaling is activated using a single parameter on *CONTROL_TIME STEP

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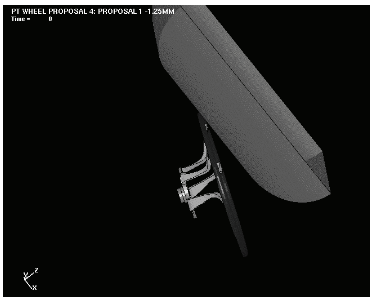
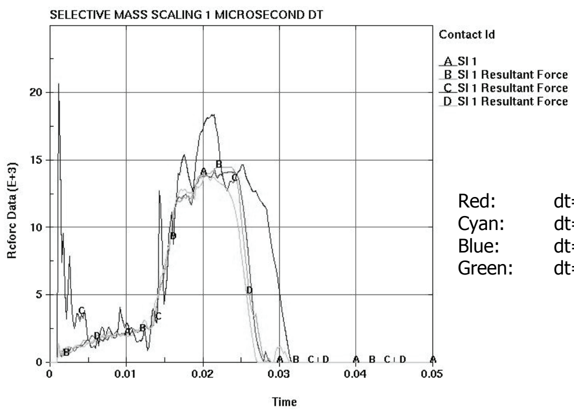
Steering wheel example

- Steering wheel impacted by body block
  - Solid elements dt< 0.1 microseconds
- Simulation times to 50 ms
  - 5.5 hours with mass scaled such that dt=1.e-07
  - 0.7 hours with selective mass scaling dt=1.e-06



Steering wheel example

- Conventional mass scaling with dt=2.e-06



Red:	dt=1.e-06	SMS
Cyan:	dt=2.e-06	SMS
Blue:	dt=2.e-06	CMS
Green:	dt=1.e-07	CMS

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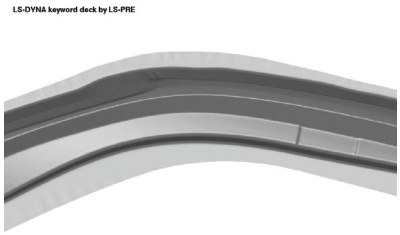
Selective mass scaling

- Example: Complex Rail
- Final Element #: 350k



	Case1	Case2
CPU Time	35 hours	16 hours

Case1: Conventional mass scaling, dt=-0.6E-06
Case2: Selective mass scaling, dt=-0.6E-05

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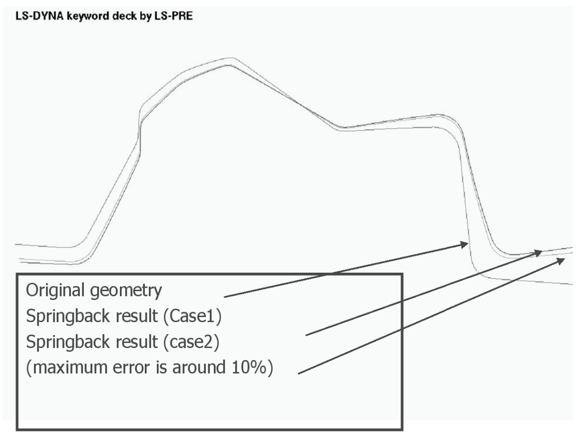
Selective mass scaling



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Selective mass scaling - MPP

- Selective mass scaling requires the assembly of a consistent mass matrix
- Either a direct or iterative solver can be used to solve for the accelerations
- For best efficiency this solution must be performed in parallel.
  - A parallel solution is implemented and is now working

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