LS-DYNA Development Plan

2012 LS-DYNA German Forum
10/09 – 10/10

DYNA MORE Finite Element Solutions

Presented by
Isheng Yeh
John Hallquist

LSTC Livermore Software Technology Corp.

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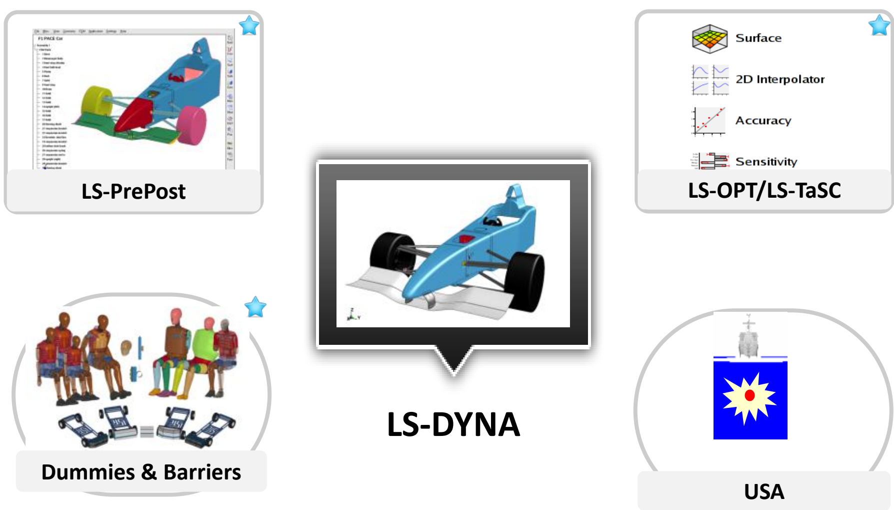
LSTC Products



No additional license cost

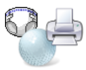
LS-DYNA Applications

Development costs are spread across many industries

Automotive
- Crash and safety
- NVH
- Durability

Aerospace
- Bird strike
- Containment
- Crash

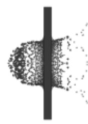
Manufacturing
- Stamping
- Forging



Consumer Products

Structural
- Earthquake safety
- Concrete structures
- Homeland security

Electronics
- Drop analysis
- Package analysis
- Thermal



Defense
- Weapons design
- Blast response
- Penetration
- Underwater Shock Analysis

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One Code for Multiple solutions

One Model

+

LS-DYNA

Multi-physics
- Structure + Fluid, ..

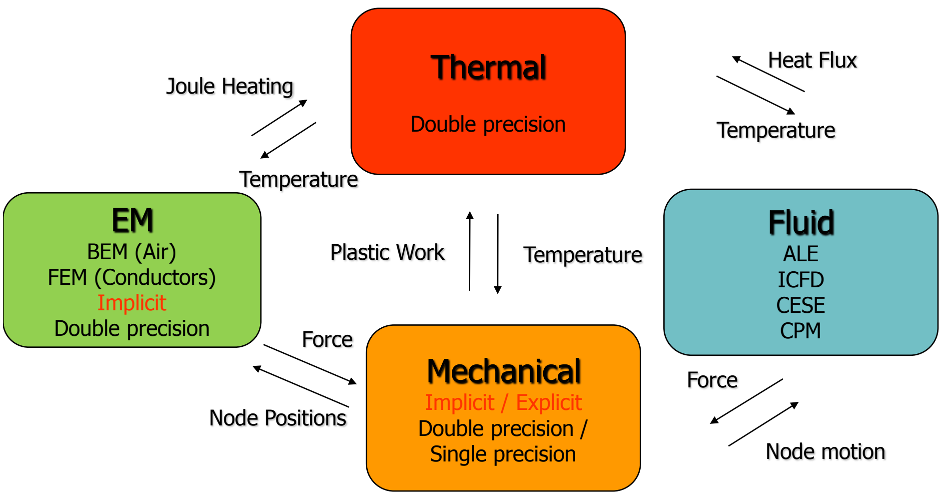
Multi-stage
- Implicit + Explicit ....

Multi-formulations
- linear + nonlinear +

Many Results

Manufacturing, Durability, NVH, Crash

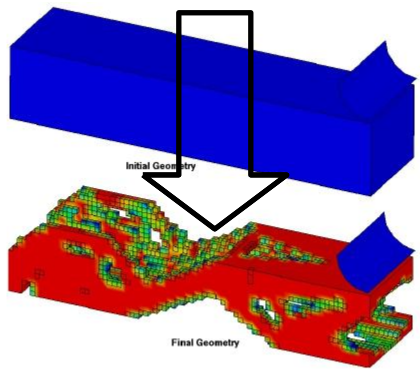
One Code for Multi-physics solutions



LS-TaSC

LS-TaSC V2.1

- Was LS-OPT/Topology for V1; renamed as LS-TaSC, Topology and Shape Computation, since V2.
- For the topology optimization of non-linear problems involving dynamic loads and contact conditions.
- Can be used to find a concept design for most structures analyzed using LS-DYNA.



LS-TaSC

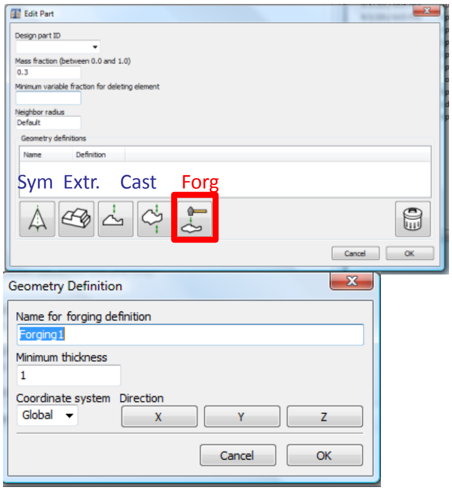
- **General capabilities**
  - Solid design using first-order hexahedrons, tetrahedral, and pentahedral elements
  - Shell thickness design using first-order quadrilateral and triangular elements
  - Global constraints
  - Multiple load cases, including **dynamic load case weighing**
- **Geometry definitions**
  - Extrusions
  - Symmetry
  - Casting, one sided or two-sided
  - **Forging**
- **Postprocessing**
  - Design histories
  - LS-PREPOST plots of the geometry evolution and the final design

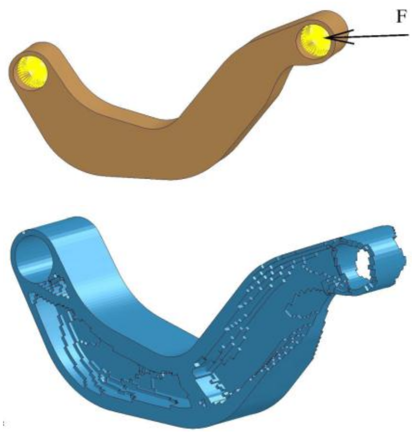
LS-TaSC

New Features in V2.1

- ***Forging geometry definitions***

  This geometry definition is set to obtain a part that can be manufactured using a forging process.

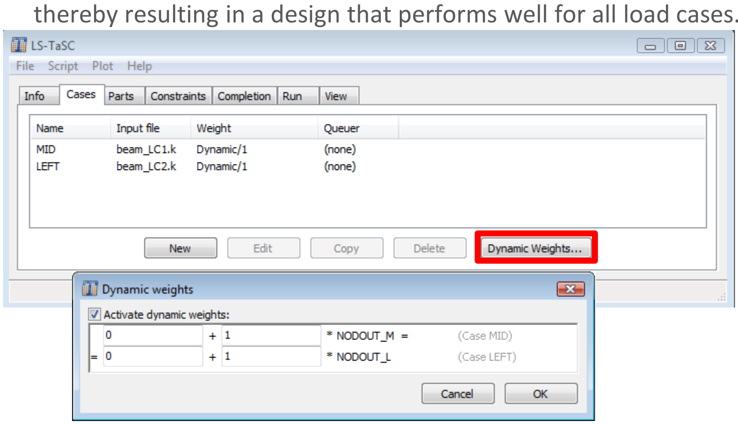




LS-TaSC

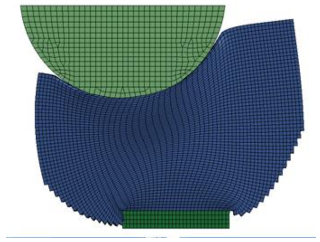
New Features in V2.1

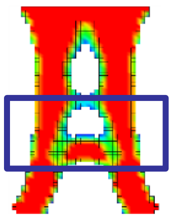
- ***Dynamic load scaling***
  - It can happen that a single load case dominates the topology of the final design making the structure perform badly for other load cases.
  - Dynamic weighing of the load cases is used to select the load case weights based on the responses of the structure as the design evolves, thereby resulting in a design that performs well for all load cases.

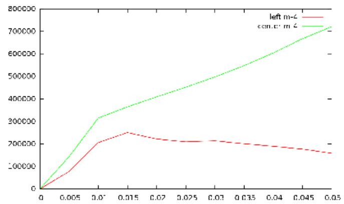


LS-TaSC

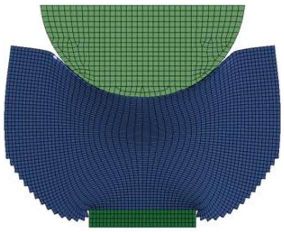
New Features in V2.1

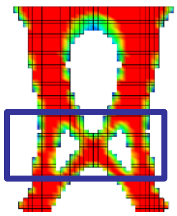


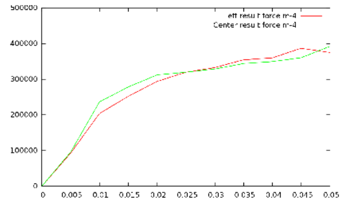




Offset Load | Design of static equal weighing | Reaction force of static weighing

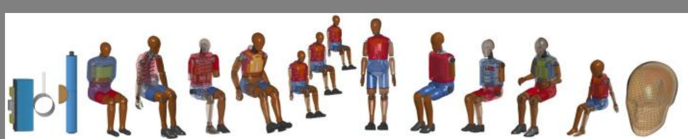






Center Load | Design of dynamic equal weighing | Reaction force of dynamic weighing

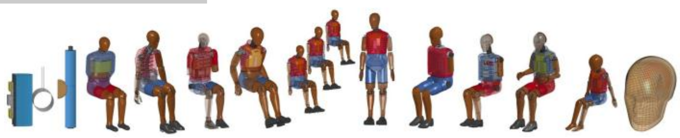
Dummies & Barriers



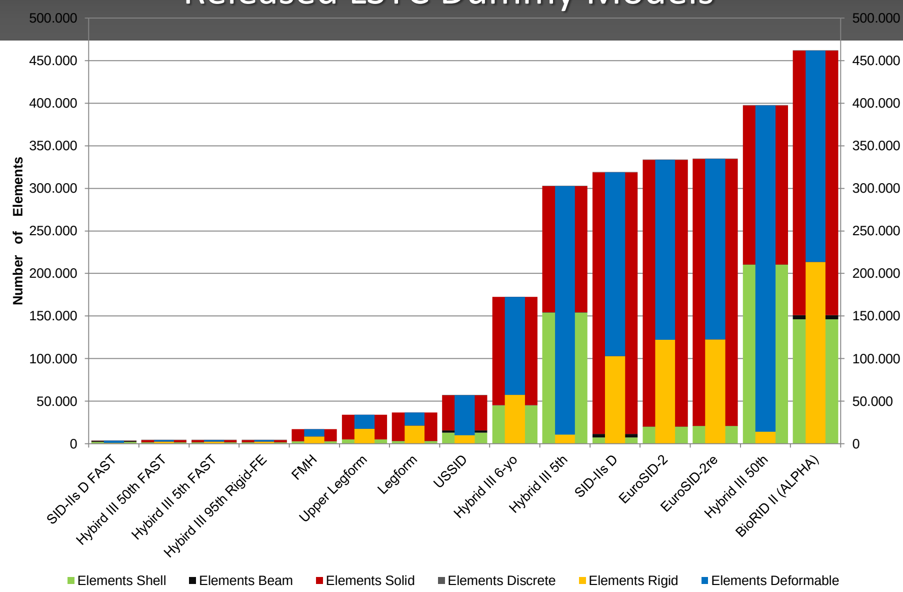
Released LSTC Dummy Models

Detailed Models
HYBRID III 5th
HYBRID III 50th
HYBRID III 95th (scaled)
SID IIs D
EuroSID 2
EuroSID 2re
USSID
HYBRID III 6-year-old
Free Motion Headform
Pedestrian Legforms
BioRID II (ALPHA)

FAST Models
HYBRID III 5th
HYBRID III 50th
HYBRID III 95th
SID IIs D
HYBRID III 5th Lower Body
HYBRID III 50th Lower Body
HYBRID III 50th standing



Released LSTC Dummy Models



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LSTC Dummy Models in Development

Model	Status
HYBRID III 3-year-old	Material Optimization
HYBRID III 95th	Model Improvements and Material Optimization
HYBRID III 95th FAST	Model Calibration and Sled Verification
BioRID II	Model Improvements and Material Optimization
WorldSID 50th	Model Build-up
THOR NT	Meshing
Ejection Mitigation Headform	Material Optimization
HYBRID II	Meshing

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Planned LSTC Dummy Models

- Pedestrian Headforms
- FAST versions of EuroSID 2 and EuroSID 2re
- Q-series child dummies
- Flex PLI
- WorldSID 5th percentile female

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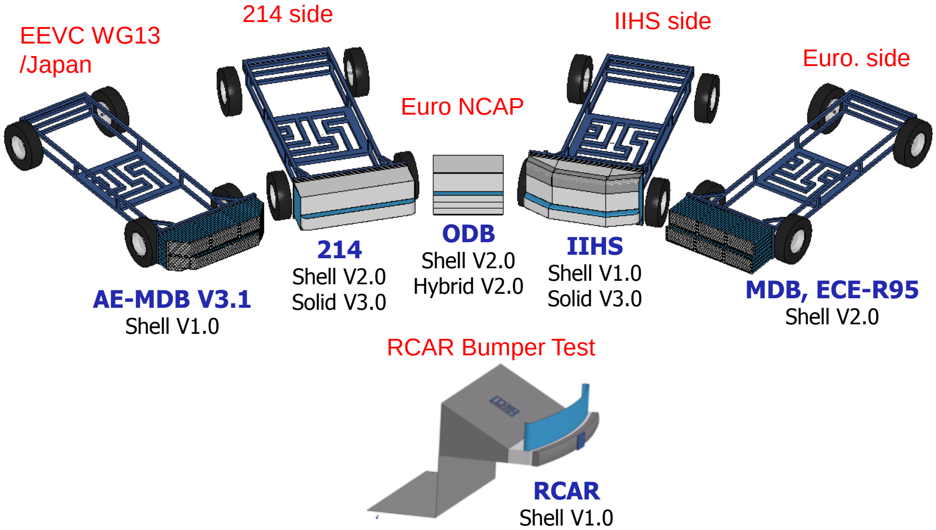
LSTC family of barriers



Solid barriers were sponsored by Honda USA
Shell barriers were first pioneered by Toyota

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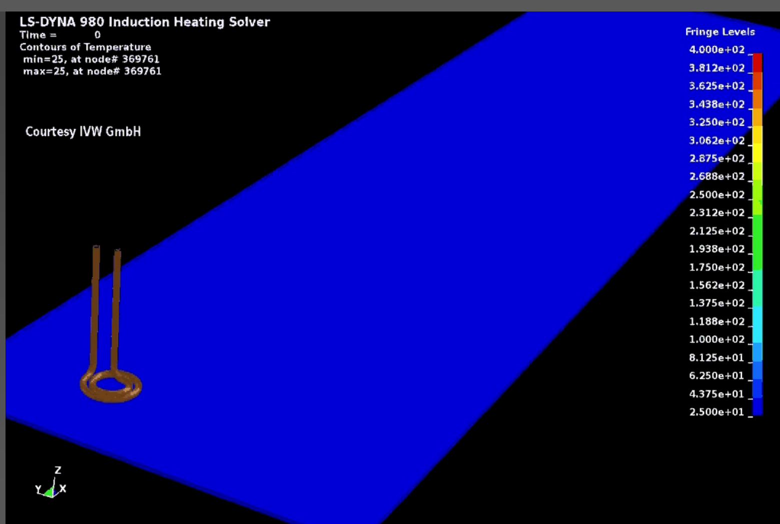
New solvers in LS-980



Video: courtesy of M. Duhovic, Institut für Verbundwerkstoffe, Kaiserslautern, Germany

Electromagnetism, EM

EM Analysis in LS-DYNA

- EM solves Maxwell's Eq. Using FEM and BEM

Ampere's Law
$$\nabla \times \frac{\vec{B}}{\mu} = \vec{j} + \varepsilon \frac{\partial \vec{E}}{\partial t}$$

Faraday's Law
$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \bullet \vec{B} = 0$$

$$\nabla \bullet \vec{E} = 0$$

Continuity
$$\nabla \bullet \vec{j} = 0$$

Material properties
$$\vec{j} = \sigma \vec{E} + \vec{j}_s$$

, where
E is the electric field,
B the magnetic flux density,
j the total current density
j_s is a source current density,
ε, μ, and σ are material electrical properties

Node Positions ↑ ↓ Lorentz Forces $\vec{F} = q(\vec{E} + \vec{V} \times \vec{B})$

Mechanical solvers

Temperature ↑ ↓ Joule heating $p = \frac{dQ}{dt} = I^2 R$

Thermal solvers

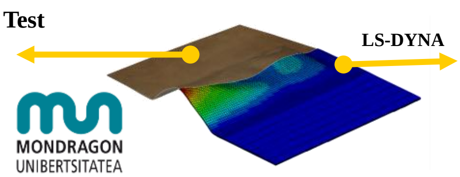
LSTC Livermore Software Technology Corp.

Current EM Status

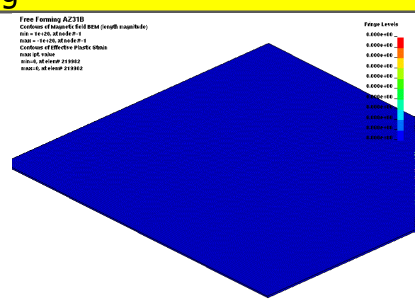
- All EM solvers work on solid elements (hexahedral, tetrahedral, wedges) for conductors.
- Shells can be used for insulator materials.
- Available in both SMP and MPP.
- 2D axi-symmetric available.
- The EM fields as well as EM force and Joule heating can be visualized in LS-PREPOST :
  - Fringe components
  - Vector fields
  - Element histories

EM Applications

EM Forming



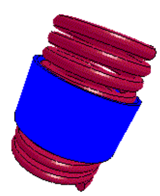
MONDRAGON UNIBERTSITATEA



THE OHIO STATE UNIVERSITY

EWI We Manufacture Innovation

Ring expansions experiments.
Various Collaborations
- **G. Daehn, Ohio State U.**
- **H. Kim, Edison Welding Institute, USA.**
- **D. Chernikov, Samara State Aerospace University, Russia.**



Ring expansion

EM Applications

Induction Heating

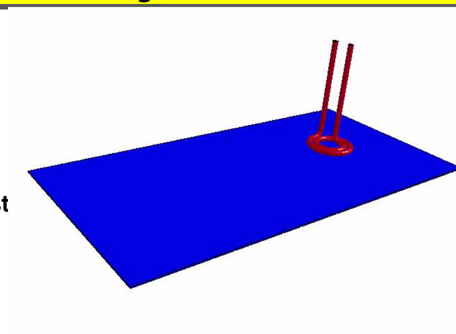
Institut für Verbundwerkstoffe

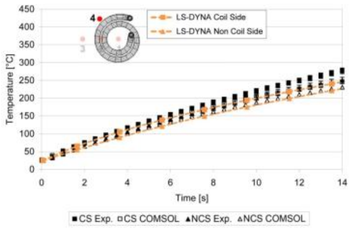
Heating of a steel plate by induction

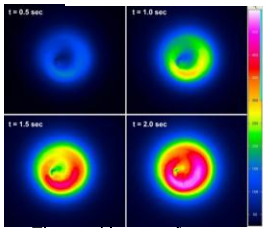
In collaboration with:

M. Duhovic, Institut für Verbundwerkst

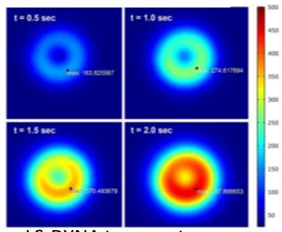
Kaiserslautern, Germany







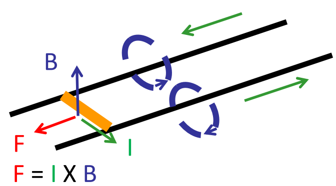
Thermal images from experiment

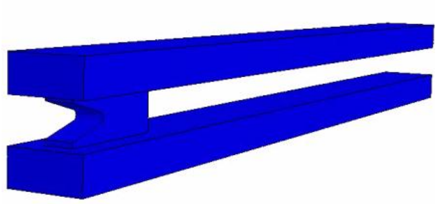


LS-DYNA temperature fringes

EM Applications

Rail Gun

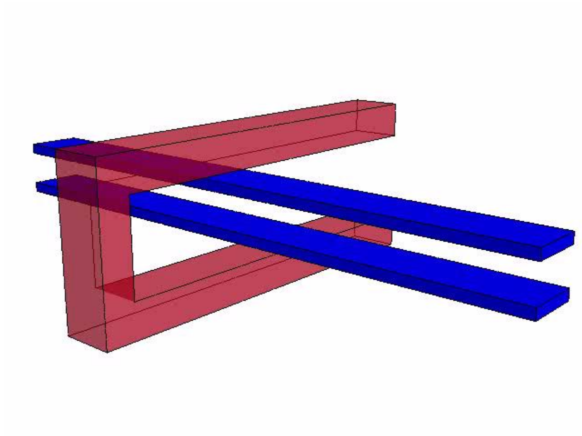




EM Applications

Magnetic Metal Welding

Magnetic Metal Welding in collaboration with
M. Worswick and J. Imbert,
University of Waterloo, Canada

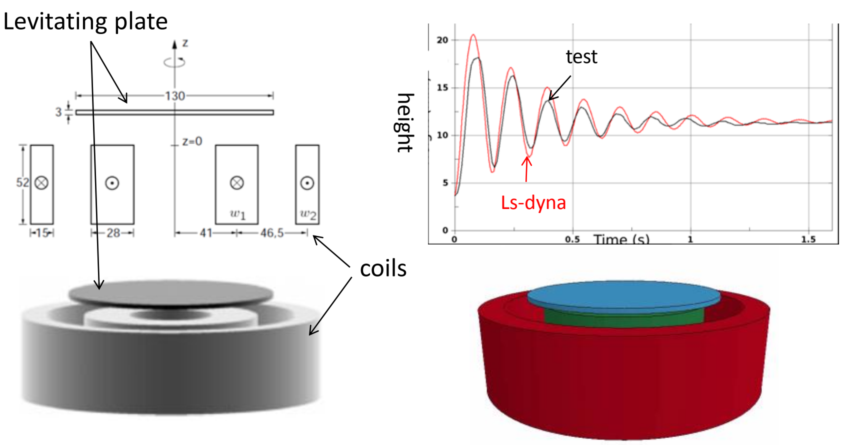


Current density Fringe

EM Applications

Magnetic Levitation

- Some TEAM, Testing Electromagnetic Analysis Methods, test cases have been used to validate LS-DYNA/EM accuracy and demonstrate its features and applications



Incompressible CFD, ICFD

ICFD in LS-DYNA

- ICFD solves Navier-Stokes equations using FEM

Navier-Stokes $$-\nabla p + \mu(\nabla^2 \vec{v}) + \rho \vec{b} = \rho \frac{D\vec{v}}{Dt}$$

Incompressibility $$\nabla \bullet \vec{v} = 0$$

Heat $$\frac{\partial T}{\partial t} + \vec{v} \bullet \nabla T - \alpha \nabla^2 T = f$$

, where
μ is the viscosity,
p the pressure,
v the fluid velocity,
b the body force
ρ the density,
T temperature,
α diffusivity

- ALE is used for to trace mesh movement and FSI

Node motion ↑ ↓ Forces, p

Temperature ↑ ↓ Temperature

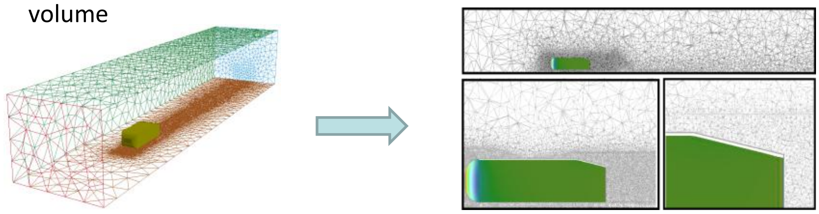
Mechanical solvers
- Double Precision
- Explicit for weak coupling
- Implicit for strong coupling

Thermal solvers
- Double Precision
- Implicit

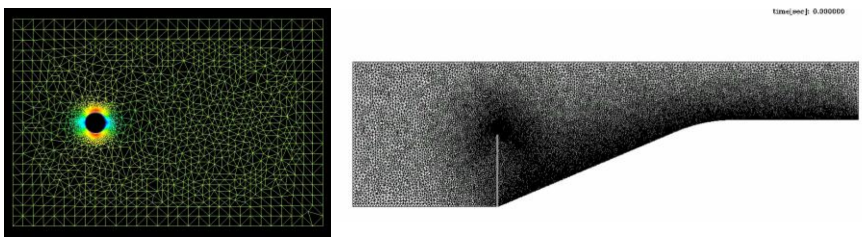
Current ICFD Status

Mesh generation and remeshing

- Automatic Volume mesher, *MESH in LS-DYNA
  - Volume mesh can be created using the automatic volume mesher, together with input surfaces and specified local mesh size inside the volume



- Error Control and Adaptive Re-Meshing

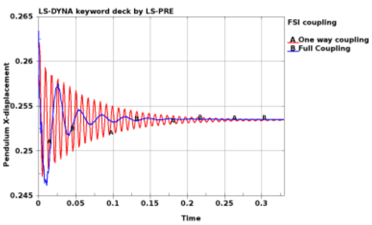


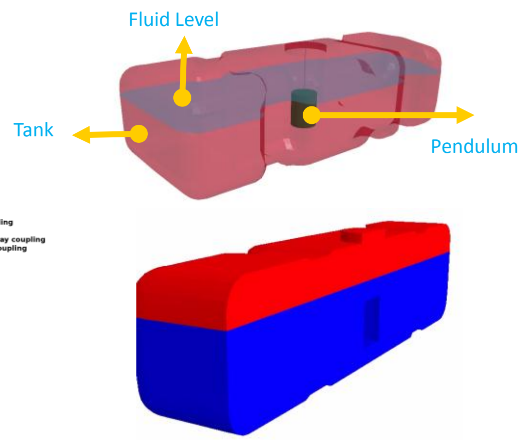
Current ICFD Status

Coupling

- Both explicit and Implicit coupling available
  – Loose coupling for explicit mechanics. Less robust and less costly. Suitable for simpler couplings. e.g. aeroelasticity analysis,
  – Strong coupling is available for implicit mechanics. More robust but more costly

Water Tank example :
Moving Water Tank coming to a brutal halt,
Sloshing occurring,
Study of pendulum oscillations.

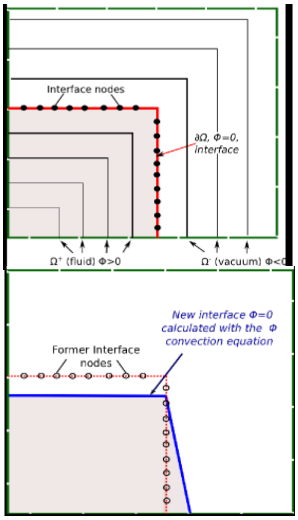


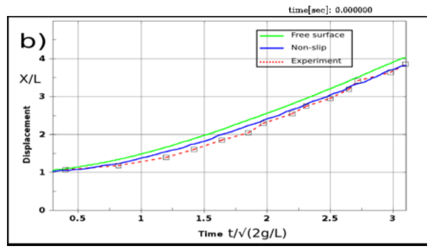


Current ICFD Status

Level Set Function for Free Surface Problems

– An implicit distance function called the level set function is used to define the interface. At the interface with changing signs on the two sides of the boundary, its absolute value increases with the distance to the interface



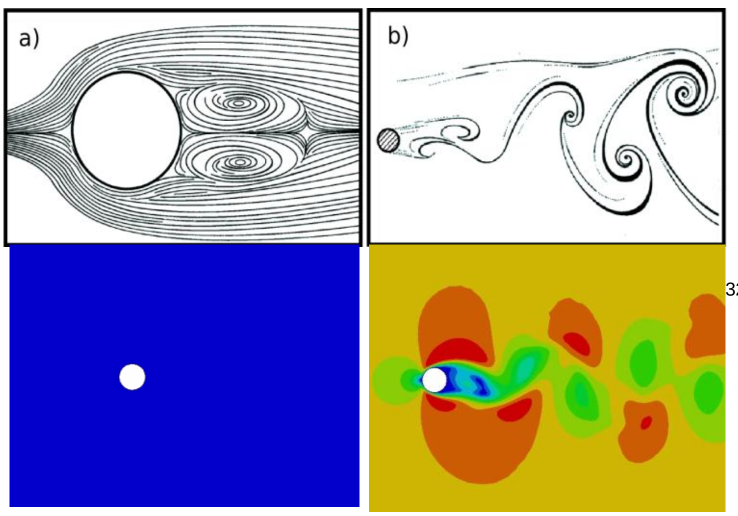


ICFD Validations

External Aerodynamics

Cylinder Test Cases

a) Re=40, Symmetric flow separation b) Re=100, Von Karman Vortex Street



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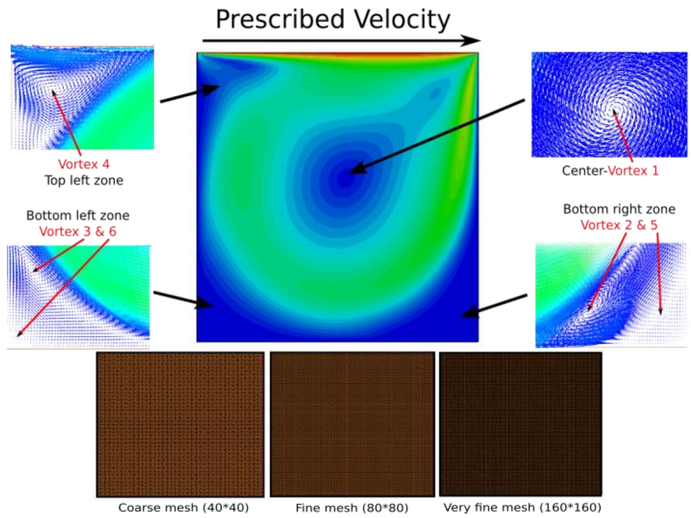
ICFD Validations

Internal Aerodynamics

The driven cavity

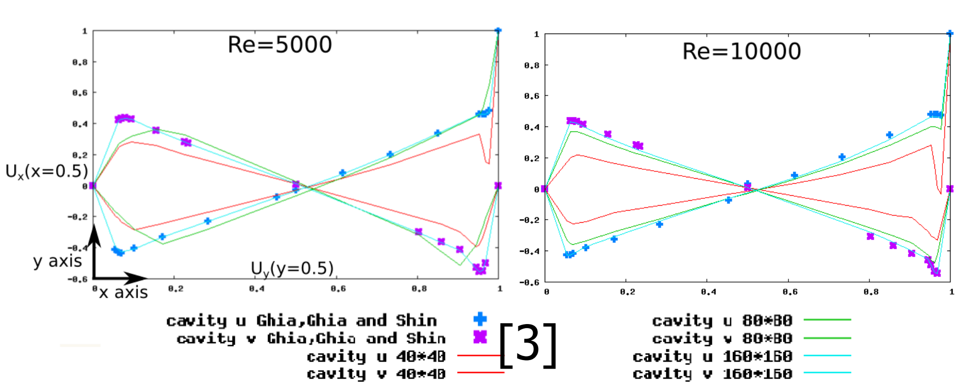


ICFD Validations

Internal Aerodynamics

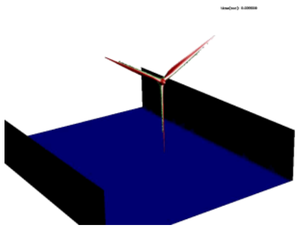
The Driven Cavity

Mesh Convergence Analysis

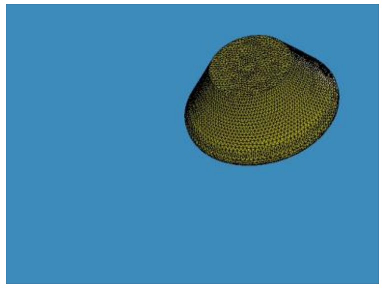


ICFD Applications

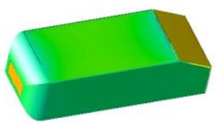
Wind Turbine



Space Capsule impact on water

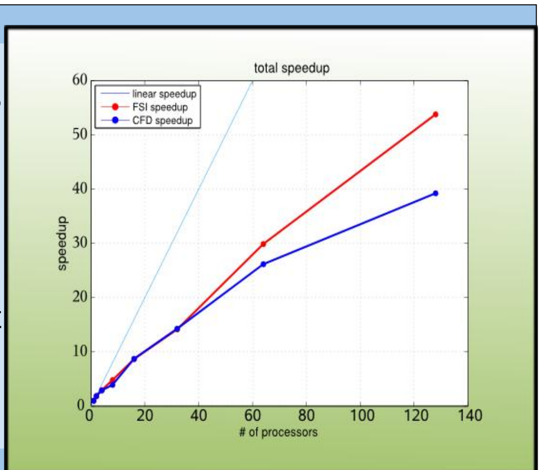


Drag Analysis



MPP Scalability

The results show a **speedup of 40 for 128 cpus in the CFD** only case (2.1 M elements) and a **speedup of 55 for 128 cpus in the case of FSI** (3.6 M elements). For the next development cycle further improvments will be implemented.



Update of LS-DYNA Advanced CAE Tools

SPH and Thermal Coupling

- Thermal coupling with SPH is implemented
- Following keywords and materials are supported

*INITIAL_TEMPERATURE_OPTION
*BOUNDARY_TEMPERATURE_OPTION
*BOUNDARY_FLUX_OPTION

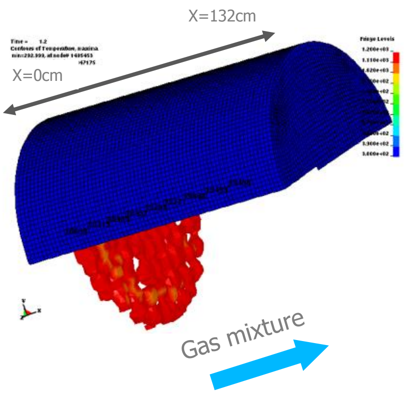
*MAT_THERMAL_ISOTROPIC
*MAT_ADD_THERMAL_EXPANSION
*MAT_VISCOELASTIC_THERMAL
*MAT_ELASTIC_VISCOPLASTIC_THERMAL
*MAT_ELASTIC_PLASTIC_THERMAL

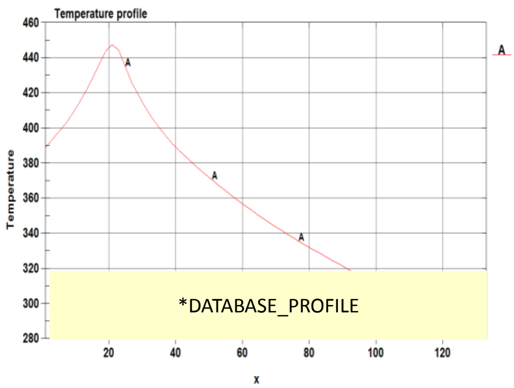
Friction stir welding

Temperature distribution

ALE and Thermal Coupling

ALE *MAT_GAS_MIXTURE coupled with shell structure using *CONSTRAINED_LAGRANGE_IN_SOLID



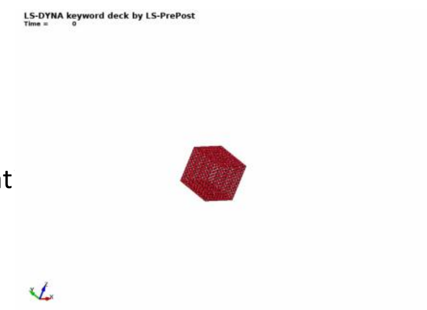


Energy is removed from gas and deposited to shell via heat convection
The energy is used as source term for thermal analysis

Particle based Blast Loading

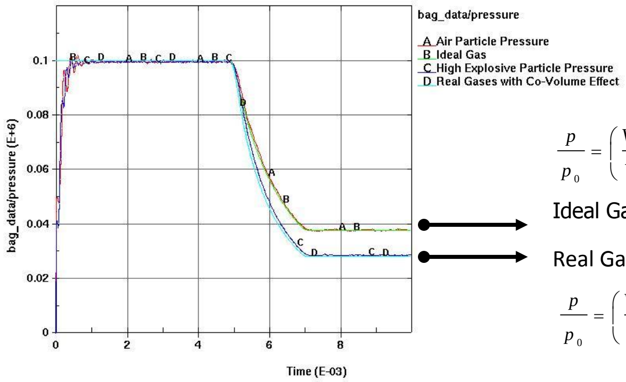
Real Gas Model of High Explosive Particle

- High Explosive Particles of *PARTICLE_BLAST
  - Modeled by real gases: $p(V-b)=nRT$
  - The co-volume effect is included
  - Works for high pressure and high temperature
  - Pressure drops sharply during adiabat expansion
- Air Particle of *AIRBAG_PARTICLE
  - Modeled by ideal gas law: $pV=nRT$
  - The volume of molecules is neglected
  - Works for low pressure and moderate temperature



Validation of Particle Blast w. Adiabatic Expansion

- An 8 liter box filled up with air particles, the box is expanded to 16 liter
- Ratio of heat capacities $\gamma = 1.4$
- The same procedure is repeated with high explosive particles with $b = 0.32\,V_0$



$$\frac{p}{p_0} = \left(\frac{V_0}{V}\right)^{\gamma}$$

Ideal Gases

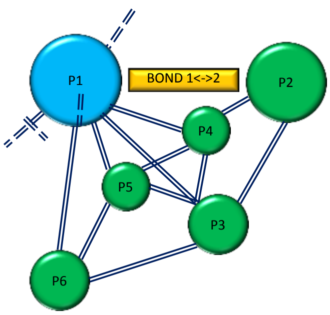
Real Gases

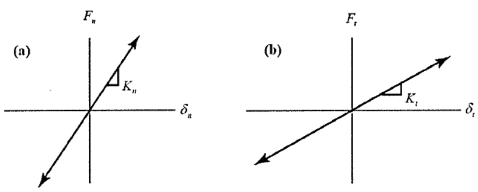
$$\frac{p}{p_0} = \left(\frac{V_0 - b}{V - b}\right)^{\gamma}$$

DES Bond Model

Emerge into Continuum Mechanics

- All particles are linked to their neighboring particles through Bonds.
- The properties of the bonds represent the complete mechanical behavior of Solid Mechanics.
- The bonds are independent from the DES model.
- They are calculated from Bulk Modulus and Shear Modulus of materials.

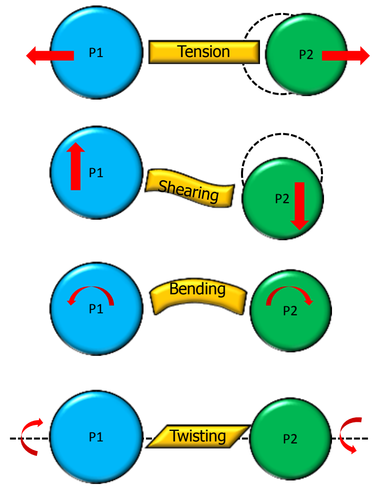




DES Mechanical Behaviors

LSTC Bond Model

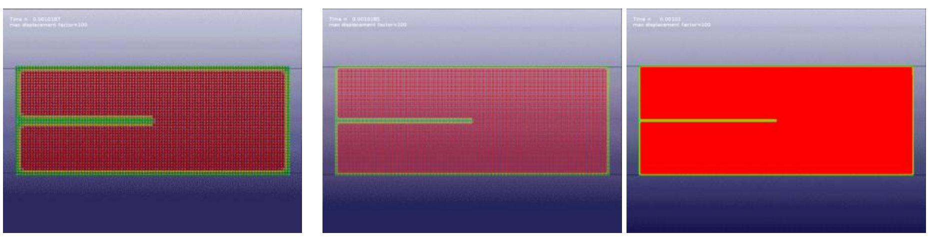
- Every bond is subjected to:
  - Stretching
  - Shearing
  - Bending
  - Twisting
- The breakage of a bond results in Micro-Damage which is controlled by the critical fracture energy value J_{IC}.
- Application includes:
  - Simulation of granular media involving large deformation and solid phase change
  - Material separation and progressive failure phenomena like concrete failure, rock blasting



DES for Fracture Analysis

Pre-notched plate under tension

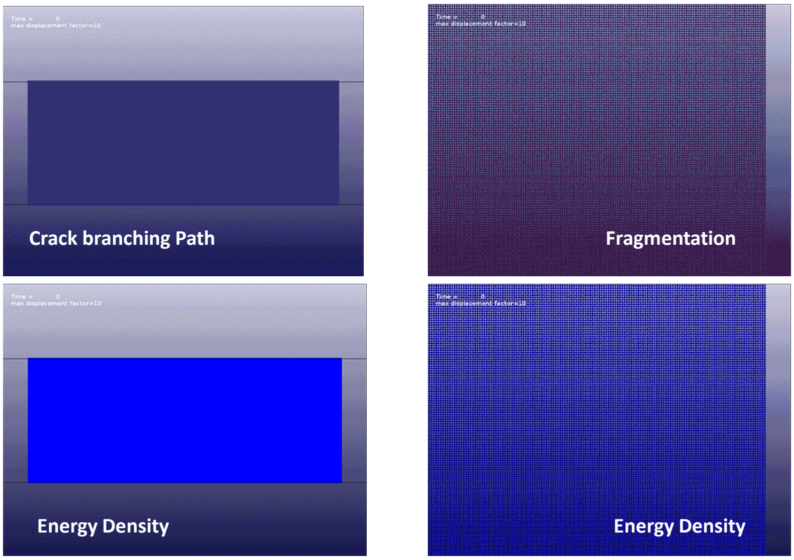
Quasi-static Loading
Young's Modulus: 65GPa
Material: Duran 50 Glass
Poisson Ratio: 0.2
Density: 2235kg/m^3
Fracture Energy Release Rate: 204 J/m^2



Case 1:		Case 2:		Case 3:	
Sphere Radius:	0.5 mm	Sphere Radius:	0.25 mm	Sphere Radius:	0.125 mm
N. of spheres:	4000	N. of spheres:	16000	N. of spheres:	64000
Crk Growth Spd:	2012 m/s	Crk Growth Spd:	2058 m/s	Crk Growth Spd:	2028 m/s
Fracture Energy:	10.2 mJ	Fracture Energy:	10.7 mJ	Fracture Energy:	11.1 mJ

DES for Fracture Analysis

Fragmentation Analysis



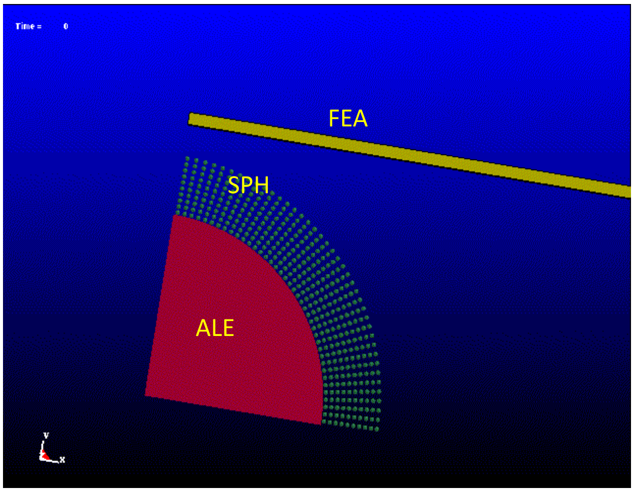
Coupling among various LS-DYNA modules

	ALE	SPH	DES	PGas
ALE		▲	▲	
SPH			■	
DES				●
Pgas				

△ *ALE_COUPLING_NODAL
□ *DEFINE_SPH_TO_SPH_COUPLING
○ *PARTICLE_BLAST
● testing ● developing

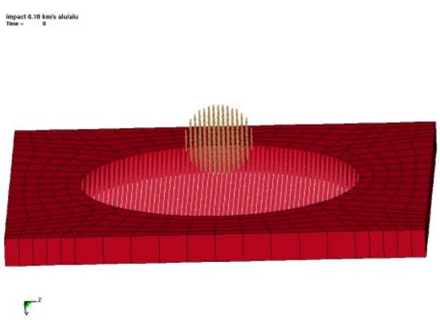
*ALE_COUPLING_NODAL

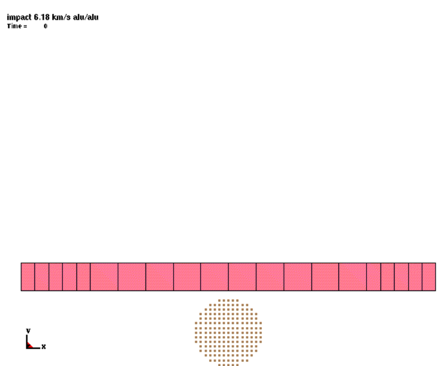
A simple test case modeling explosion driven sand grains hitting on a plate



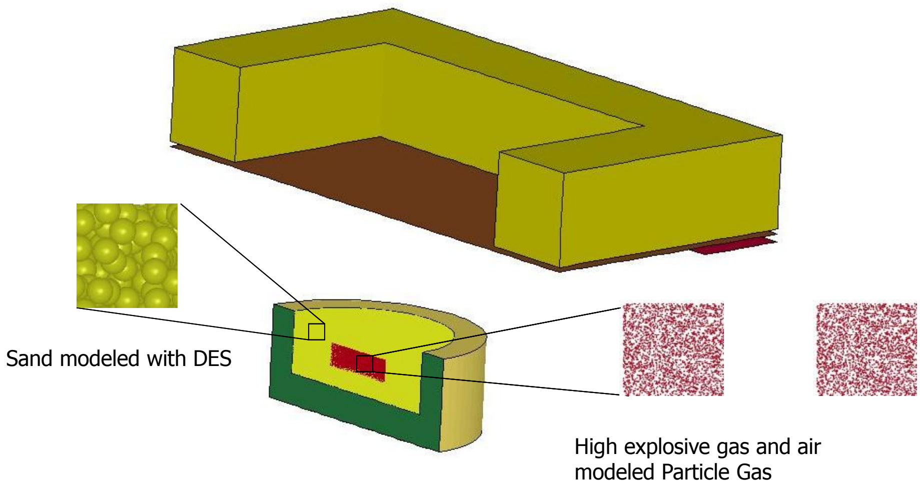
*DEFINE_SPH_TO_SPH_COUPLING

- Penalty based SPH to SPH particle contact
- Will be extended to SPH and DES coupling

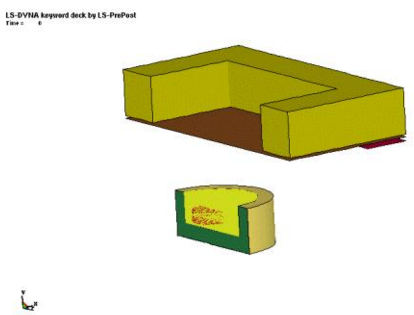




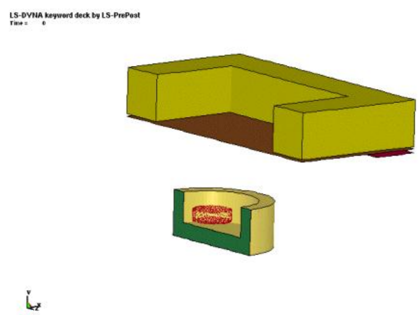
*PARTICLE_BLAST



*PARTICLE_BLAST



Blast simulation with sand

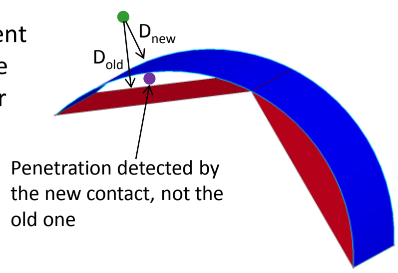


Blast simulation without sand

Isogeometric analysis

Isogeometric Analysis

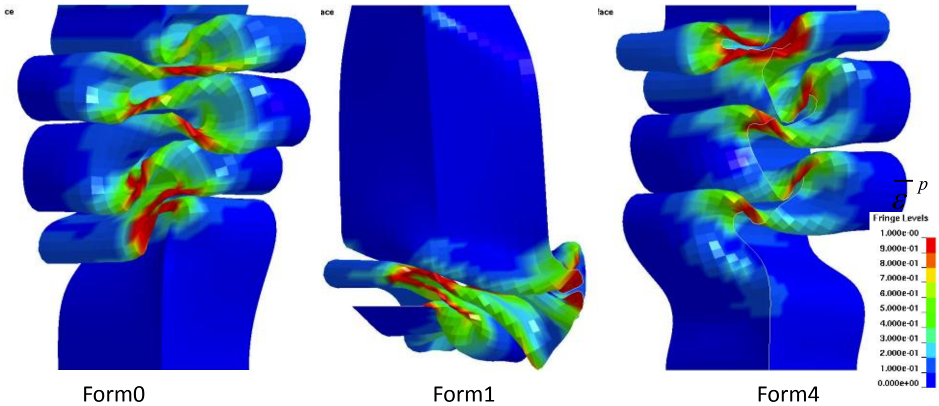
- Four formulations for NURBS shell elements,
  - EQ.0: shear deformable shell theory with rotational DOFs
  - EQ.1: shear deformable shell theory without rotational DOFs
    - Excellent eigenvalues for NVH.
    - Only 3 DOF per node, reducing implicit analysis cost
  - EQ.2: thin shell theory without rotational DOFs
  - EQ.3: thin shell theory with rotational DOFs
- Recent progress:
  - Elements now run in MPP with excellent scaling.
  - **FORM. EQ.4: combination of FORM=0 and FORM=1**
    Multi-patch analysis with thin shells by selectively adding rotational DOF at patch boundaries,
  - NURB based contact is under deployment
    Penetration happens when the distance between the slave node and the master NURBS element, D, is smaller than shell thickness



Recent progress

selectively adding rotational DOF at patch boundaries

640 Quadratic NURBS elements on Four Processors



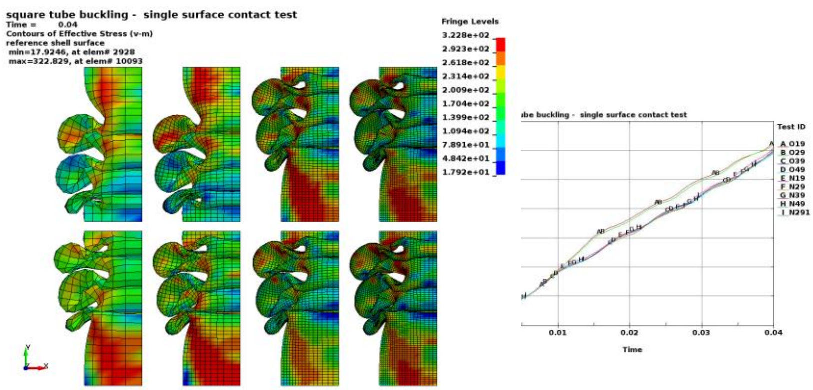
Form0 Form1 Form4

Recent progress

NURBS-based contact

Old Contact

New Contact



1x1 2x2 3x3 4x4

History of Internal Energy

Recent progress

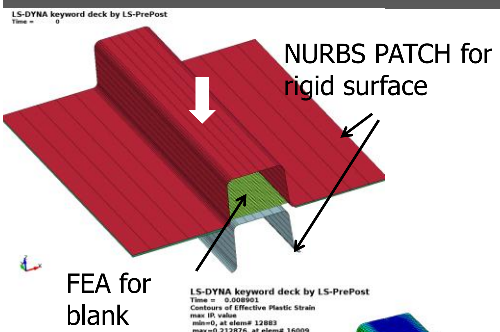
NURBS-based contact

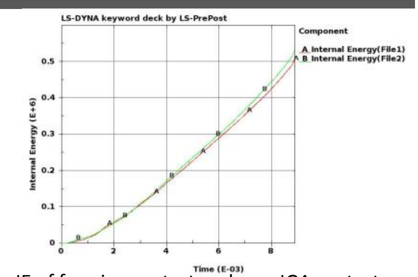
Contact algorithm	Test ID	Interpolated Ele.	Δt factor	Search depth	result	Contact time
Old	O19	1x1	0.9	2	NG	1.0
Old	O29	2x2	0.9	2	NG	2.15
Old	O25	2x2	0.5	2	Good	4.23
Old	O39	3x3	0.9	2	Good	3.74
Old	O49	3x3	0.5	2	Good	7.05
New	N19	1x1	0.9	2	Good	1.70
New	N191	1x1	0.9	1	Good	1.35
New	N29	2x2	0.9	2	Good	4.10
New	N291	2x2	0.9	1	Good	3.35
New	N39	3x3	0.9	2	Good	6.88
New	N391	3x3	0.9	1	Good	5.84
New	N49	4x4	0.9	2	Good	10.5
New	N491	4x4	0.9	1	Good	8.80

⟸ Best old contact (O39)

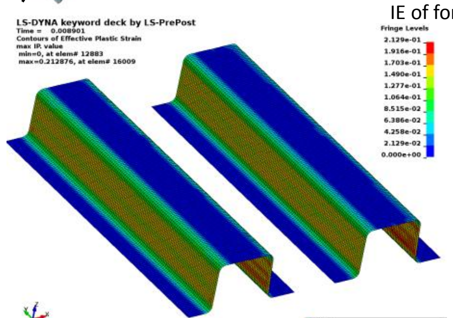
⟸ Best new contact (N191)

Contact bet. IGA and FEA





IE of forming contact and new IGA contact



FORMING_ONE_WAY_S2S CONTACT_ONE_WAY_S2S

Contact bet. IGA and FEA

Test ID	Contact algorithm	Search depth	# of contact	result	Contact cpu time
AO1	AUTO_1WAY_S2S, Old	2	3	NG (penetrate)	NA
F1	FORMING_1WAY_S2S	2	3	Good	1.0
AN1	AUTO_1WAY_S2S, New	2	3	Good	2.0
AN2	AUTO_1WAY_S2S, New	1	3	Good	1.4
AN3	AUTO_1WAY_S2S, New	2	1	Good	1.5

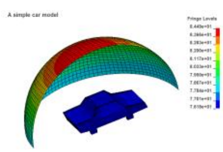
- New contact is about twice as expensive as the old contact.
- New contact is more robust and stable than old contact. It allows lower search depth, less-frequent bucket search and larger time steps. Therefore it is possible that, in some cases, new contact costs less to get the same accuracy.

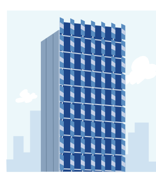
Update of LS-DYNA FEA Tools

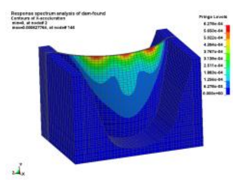
Frequency Domain Analysis

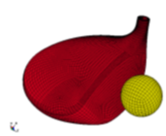
Frequency Domain Analysis

- Features:
  - Random vibration
  - Random fatigue
  - Frequency response function
  - Steady state dynamics
  - Response spectrum analysis
  - BEM Acoustics
  - FEM Acoustics
- Applications:
  - Automotive: NVH, engine, fatigue
  - Aircraft: acoustic, landing gear, fatigue
  - Earthquake engineering for offshore, structures, nuclear structures,..
  - Civil engineering, Defense industries,….









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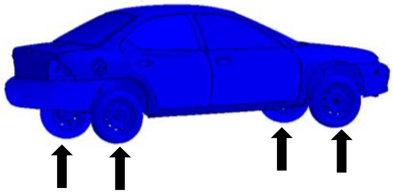
New FDA Features

- Correlated excitations in random vibration for FREQUENCY_DOMAIN_RANDOM_VIBRATION

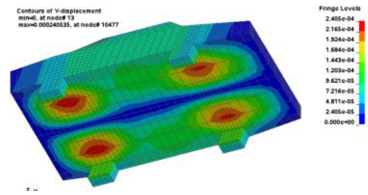
Card 5	1	2	3	4	5	6	7	8
Variable	SID	STYPE	DOF	LDPSD	LDVEL	LDFLW	LDSPN	CID
Type	I	I	I	I	I	I	I	I
Default								

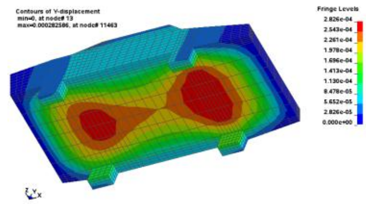
When SID and STYPE are both < 0, they give the IDs of the correlated excitations



The multiple excitations on structure can be

- uncorrelated
- correlated (cross PSD function needed)





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New FDA Features

- Nodal Force output for FREQUENCY_DOMAIN_FRF

Card 3	1	2	3	4	5	6	7	8
Variable	N2	N2TYP	DOF2	VAD2				
Type	I	I	I	I				

VAD2 Response output type:
- 0: velocity
- 1: acceleration
- 2: displacement
- 3: Nodal force (new)

- Double-sum method for modes combination of FREQUENCY_DOMAIN_RESPONSE_SPECTRUM

Card 1	1	2	3	4	5	6	7	8
Variable	MDMIN	MDMAX	FNMIN	FNMAX	RESTRT	MCOMB		
Type	I	I	F	F	I	I		

MCOMB:
- EQ.0: SRSS method,
- EQ.1: NRC Grouping method,
- EQ.2: Complete Quadratic Combination
- EQ.3: Double Sum method,
- EQ.4: NRL-SUM method.
- EQ.5: Double Sum method based on Gupta-Cordero coefficient,
- EQ.6: Double Sum method based on modified Gupta-Cordero coefficient.

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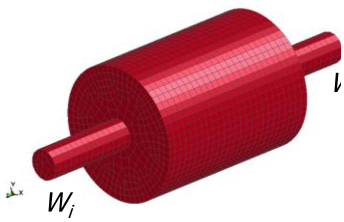
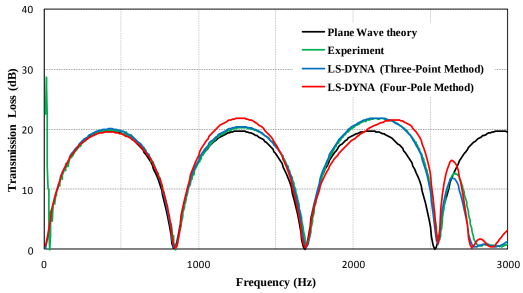
FDA application examples of FREQUENCY_DOMAIN_ACOUSTIC_BEM

•Muffler Transmission Loss





TL (Transmission loss) is the difference in the sound power level between the incident wave entering and the transmitted wave exiting the muffler when the muffler termination is anechoic.

$$TL = 10 \log_{10} \frac{W_i}{W_t}$$

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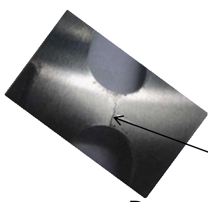
FDA application examples of FREQUENCY_DOMAIN_RANDOM_VIBRATION_FATIGUE

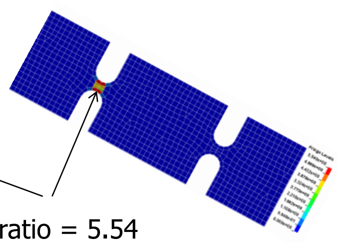
- Palmgren-Miner's rule of cumulative damage ratio

  $E(D) = \sum_i \frac{n_i}{N_i}$, where

  n_i is the number of cycles at stress level S_i*, and* N_i *is the number of cycles for failure at stress level* S_i*, given by material's S-N curve.*

- Fatigue analysis of a simple cantilever aluminum beam subjected to base accelerations is considered.





Damage ratio = 5.54

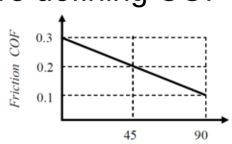
Metal Forming

Directional and pressure sensitive friction model for metal forming

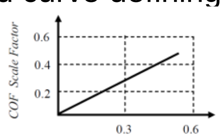
- *DEFINE_FRICTION_ORIENTATION enables definition of Coulomb frictions in any directions in the sheet plane. The friction coefficients can also be scaled based on the contact pressure.

Variable	PID	LCID	LCIDP	V1	V2	V3		

  - LCID: ID of the curve defining COF vs. orientation in degree.

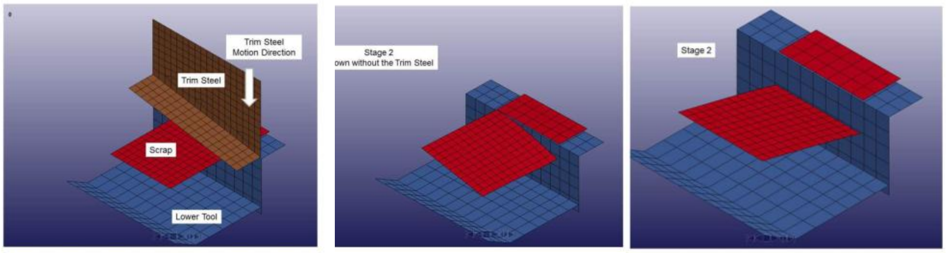


  - LCIDP: ID of the load curve defining COF scale factor vs. pressure.



A Contact-based Scrap Trimming Feature

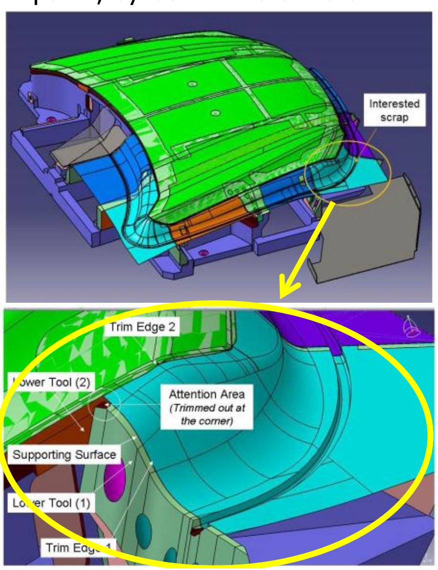
- Scrap fall failure is one of the common defects in stamping plants
- Critical characteristics needed to detect scrap fall errors
  - Broken-off scraps carry the initial kinematics and dynamics from the upper moving trim steel through contact during the trim process.
  - trimming action is not simultaneous along the trim curve
  - Contact between scrap and low trim steel and post
- CONTROL_FORMING_SCRAP_FALL is developed, together with Ford Motor, as an effective analytical tools to detect potential scrap fall failures in tool/die design stages.

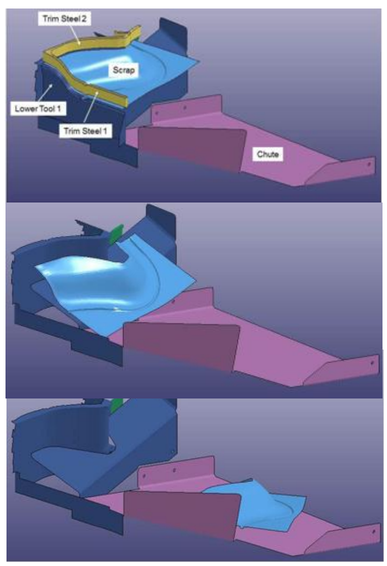


New Method Old Method

A Contact-based Scrap Trimming Feature

- CONTROL_FORMING_SCRAP_FALL application to die design for a hood outer panel, by Gu etc. Ford Motor.





Formability Index Analysis for *MAT_036

- NLP option of MAT_3-PARAMETER_BARLAT allows for prediction of sheet metal failure using the Formability Index (F.I.), which accounts for the non-linear strain path effect.
  - The F.I. information is stored in a history variable #9. Be sure to set the variable NEIPS of *DATABASE_EXTENT_BINARY to 10, and set MAXINT to NIP used in *SECTION_SHELL.
  - Necking failure starts when the F.I. across the section, viewable via history variable #9, reaches the value of 1.0.

Card 3	1	2	3	4	5	6	7	8
Variable	AOPT	C	P	VLCID		PB	**NLP**/HTA	HTB

Blank Size Development

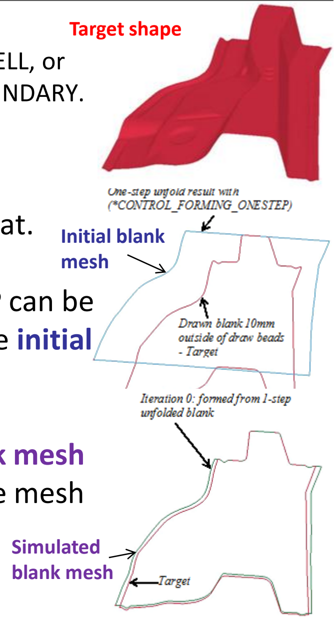
- ***INTERFACE_BLANKSIZE** is developed to
  - accurately obtain initial flat blank size
  - obtain trimming curve for flanging process
- For a single forming process, only the option **DEVELOPMENT** is needed, and three input files are needed
  - an initial estimated blank shape,
  - a formed blank shape, and,
  - a target blank shape.

  The calculated/corrected initial blank shape will be output.
- For multi-stamping process involving drawing, trimming and flanging, additional options of **INITIAL_TRIM** and **INITIAL_ADAPTIVE** are needed to trace all the forming processes involved.
- Usually 1 ~ 3 iterations are needed to get the correct result

INTERFACE_BLANKSIZE_DEVELOPMENT

Input description

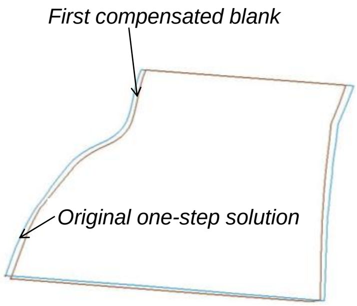
- A **target blank shape** could be either
  - a mesh file containing *NODE and *ELEMENT_SHELL, or
  - a boundary file containing *DEFINE_TARGET_BOUNDARY.
- An **initial sheet blank mesh** in keyword format. This can be the 1st state mesh from current simulation. *CONTROL_FORMING_ONESTEP can be used to unfold the **target shape** to obtain the **initial sheet blank** for iteration 0.
- **A simulated (formed or flanged) sheet blank mesh** in keyword format. This can be the final state mesh from the current simulation.



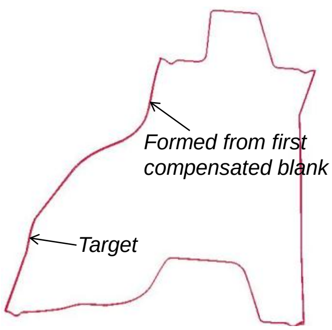
BLANKSIZE_DEVELOPMENT

Output

- Result after 1st iteration



First compensated blank superimposed with original one-step result

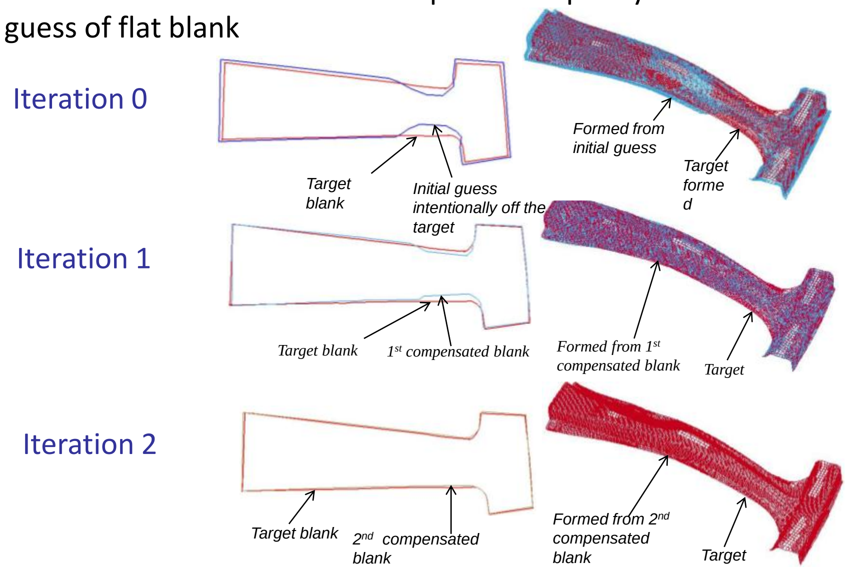


Final formed blank overlaps target

Blank Size Development

examples requiring more iterations

- Number of needed iterations depends on quality of initial guess of flat blank

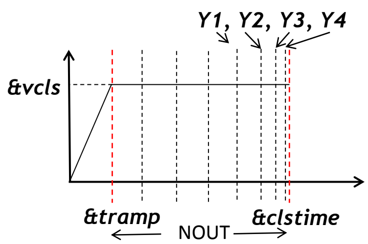


New Forming Output Control

- ***CONTROL_FORMING_OUPUT** provides more control on d3plot output of stamping simulations

Variable	CID	NOUT	TBEG	TEND	Y1	Y2	Y3	Y4

  - CID, ID of a tooling kinematics curve, as defined by *DEFINE_CURVE and used by *BOUNDARY_PRESCRIBED_MOTION_RIGID.
  - NOUT, total number of D3PLOT outputs for the tooling kinematics curve, excluding the beginning and final time.
  - TBEG (TEND), Start(END) time of the curve.
  - Yi, Distances to tooling home, where D3PLOT files will be output.



M125

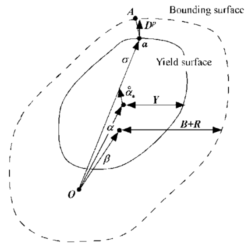
Different kinematic hardening for for. & rev. deformation

- This material model is based on Yoshida-Uemori's theory that uses two surfaces to describe the hardening rule: a yield surface *f with back stress α and* boundary surface *F with back stress β.*

- Old model assumes that shape of the stress-strain curve of forward deformation is closely related to the one of reverse deformation.

CARD 2	CB	Y	C	K	RSAT	SB	H	

$$\begin{cases} \alpha = \beta + \alpha^*, \qquad \dot{\beta} = m\left(\frac{2}{3}b\dot{\varepsilon}^P - \beta \cdot \dot{\bar{\varepsilon}}^P\right) \\ \dot{\alpha}^* = C\left[\frac{B+R-Y}{Y}(\sigma - \alpha)\dot{\bar{\varepsilon}}^P - \alpha^* \sqrt{\frac{a}{\bar{\alpha}^*}}\,\dot{\bar{\varepsilon}}^P\right] \end{cases}$$



M125

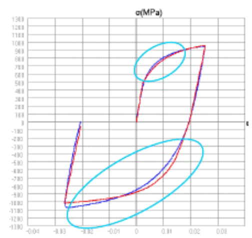
Different kinematic hardening for for. & rev. deformation

- The old model is too rough for most materials. In the new model variables SC1 and SC2 are used to describe the forward and reverse deformations of the cyclic plasticity curve, respectively, *Yoshida & Uemori, IJP 2002*

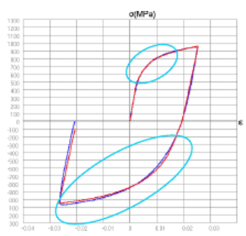
CARD 2	CB	Y	SC1	K	RSAT	SB	H	SC2

$C = SC1$, when $\text{Max}(\bar{\alpha}_*) < B - Y$, where $\bar{\alpha}_* = \sqrt{1.5\alpha_* : \alpha_*}$

$C = SC2, (SC1 > SC2)$, otherwise



With SC1 Only



With SC1 & SC2

Improvement to SENSOR

Improvements to SENSOR_DEFINE

- Add SET options to *SENSOR_DEFINE_NODE and *SENSOR_DEFINE_ELEMENT
- Positive set ID requires all elements in a set to meet the switch condition to change the switch status; If set ID is negative, switch status will change if at least one of elements in the set meets the switch condition
- This example changes the switch status if every node in set-200 has velocity larger than 100.

```
* SENSOR_DEFINE_NODE _SET
$   SNSID     NODE1    NODE2       VID     CRD    CTYPE
     100        200                 X              VEL
*SENSOR_SWITCH
$  SWITID     TYPE     SENSID    LOGIC   VALUE
     700     SENSOR      100        GT     100.
```

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Improvements to SENSOR_DEFINE

- *SENSOR_DEFINE_NODE

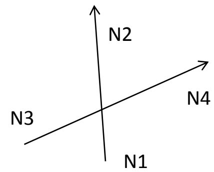
SENSID	NODE1	NODE2	VID		CTYPE		

  - Magnitude of nodal disp., vel. and acc. will be output if vector ID, VID, is “0”
  - CTYPE could be defines as “TEMP” to trace nodal temperature

- *SENSOR_DEFINE_ANGLE

SENSID	N1	N2	N3	N4			

Define an angle sensor for angular measurement. This command outputs the angle between two lines, in the same plane, 0≤ θ ≤180



Improvements to SENSOR_DEFINE

- *SENSOR_DEFINE_ELEMENT

SENSID	ETYPE	ELEMID	COMP	CTYPE	LAYER	**SF**	**N**

SF, PWR:

Optional parameters, scale factor and power, for users to adjust the resultant sensor value. The resultant sensor value is $(SF \times \text{Original Sensor Value})^N$

- This new feature allows user to simulate the spot-weld-type failure model when beam elements are used to model spot welds. $$\left(\frac{|f_n|}{S_n}\right)^n + \left(\frac{|f_s|}{S_s}\right)^m \geq 1$$

Improvement to SENSOR_CONTROL

- *SENSOR_CONTROL

CNTLID	TYPE	TYPEID	TIMEOFF				

TYPE=FUNCTION

The status of *SENSOR_CONTROL can be referred in *DEFINE_CURVE_FUNCTION. Its value is set to “1” and “TYPEID” when its status is “on” and “off” respectively.

```
* SENSOR_CONTROL
$   CTLID        TYPE     TYPEID  TIMEOFF
      100  FUNCTION            -1
*DEFINE_CURVE_FUNCTION
$     LCID
      700
$   FUNCTION
2+3*sensor(100)  -> value is 5 (=2+3) when CONTROL-100 is on
                 ->  value is -1 (=2-3) when CONTROL-100 is off
```

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Miscellaneous Features

Efficient EFG shell for crash

Card 1

Variable	SECID	ELFORM	SHRF	NIP	PROPT	…		
Type	F	F	F	I	F			
Default								

ELFORM EQ. 41: EFG shell (local projection) (recommended for crashworthiness)

Card 3

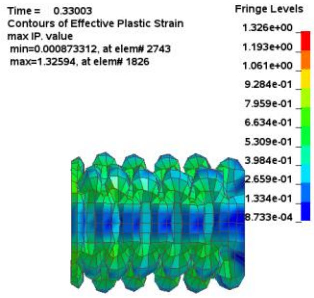
Variable	DX	DY	ISPLINE	IDILA	IEBT	IDIM
Type	F	F	I	I	I	I
Default	1.01	1.01	0	0	3	1

IEBT EQ. 3: Coupled EFG/FEM method
IDIM EQ. 1: Local boundary integration

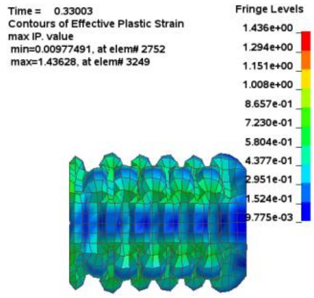
- CPU saving is about 50%~100%
- Capable of dealing large deformation
- Over all performance is close to original EFG shell formulation
- Supports for ELFORM = 41
- Available in R6.0 and after SMP and MPP

Efficient EFG shell for crash

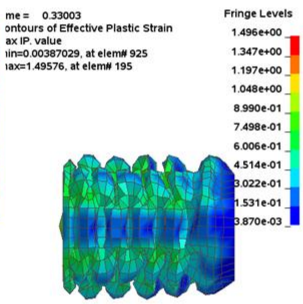
FEM shell #16



Coupled EFG/FEM shell



Original EFG shell



Methods	Original EFG shell	Coupled EFG/FEM shell	Original EFG shell
Normalized CPU	1.0	1.68	3.23

MAT_ADD_EROSION

- MAT_ADD_EROSION application is extended to MAT_34, and
  - Shell formulation 18, 20, 21 ,23 , 24 and 54
  - Beam formulation 7 and 8
- Treatment of failed elements in an airbag model

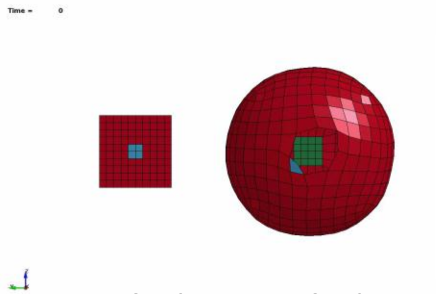
CARD 6 of *AIRBAG_HYBRID

OPT	PVENT	NGAS	LCEFR	LCIDM0	VNTOPT		

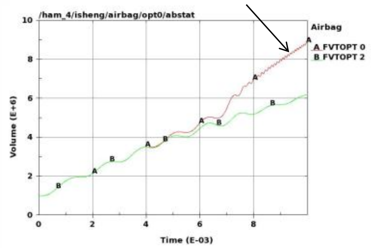
VNTOUP: bag venting option

EQ. 2: the areas of failed elements at failure times are added to the venting area defined by A23.

Wrongly calculated volume results in erroneous results



VNTOPT=0 VNTOPT=2



Volume History

*MAT_ADD_PORE_AIR

- *MAT_ADD_PORE_AIR

Card 1	1	2	3	4	5	6	7	8
Variable	MID	PA_RHO	PA_PRE	PORE				
Card 2	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Variable	PERM1	PERM1	PERM3	CDARCY	CDF	LCPGD1	LCPGD2	LCPGD3

- Linear Darcy's law

  $(CDARCY+CDF||\mathbf{v}_{ai}||)*PORE*\mathbf{v}_{ai}= PERM_i *\partial P_a/\partial x_i$, i=1,2,3

- A general form of Darcy's law can be defined through

  $LCGDC_i$:

  $(CDARCY+CDF||\mathbf{v}_a||)*PORE*v_{ai}= PERM*f_i (\partial P_a/\partial x_i)$, i=1~3,

  where f_i is the function value of $LCPGD_i$, v_{ai} is the pore air flow velocity along the i'th direction, $\partial P_a/\partial x_i$ is the pore air pressure gradient along the i'th direction, and x_1=x, x_2=y, x_3=z

CVRPER for *BOUNDARY_PORE_AIR_PRESSURE

- Pore air analysis boundary condition card

*BOUNDARY_PORE_AIR_PRESSURE

Card 1	1	2	3	4	5	6	7	8
Variable	SEGID	LCID	CMULT	CVMASS	BLOCK	TBIRTH	TDEATH	CVRPER

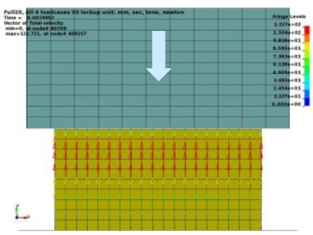
CVRPER: Permeability factor of cover material. CVRPER allows users to model the porosity properties of the cover material. If SEGID is covered by a material of very low permeability (e.g., coated fabric), it is appropriate to set CVRPER=0. In this case, P_c, the pressure calculated assuming no boundary condition, is applied to SEGID. If SEGID is not covered by any material, it is appropriate to set CVRPER=1, the default value. In this case, the applied pressure becomes P_b, the boundary pressure determined by CMULT and LCID. $0.0 \le CVRPER \le 1.0$

Low CVRPER example: leather covered seat

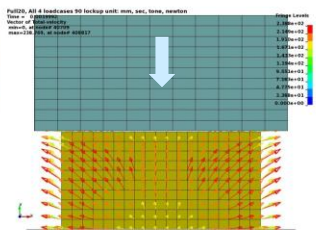
High CVRPER example: clothes covered seat

CVRPER for *BOUNDARY_PORE_AIR_PRESSURE

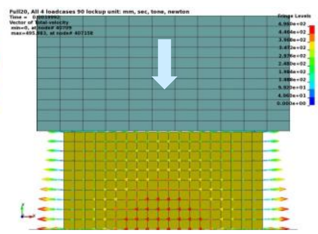
- Pore air velocity plot at time=0.02



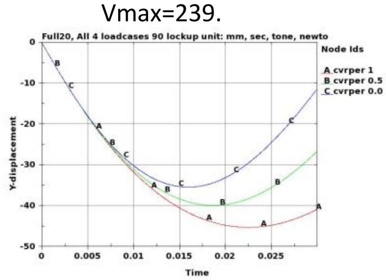
CVRPER=0.0
Vmax=122



CVRPER=0.5
Vmax=239.



CVRPER=1.0
Vmax=495



Displacement of impacting block

*BOUNDARY_PRESCRBED_MOTION_SET_BOX

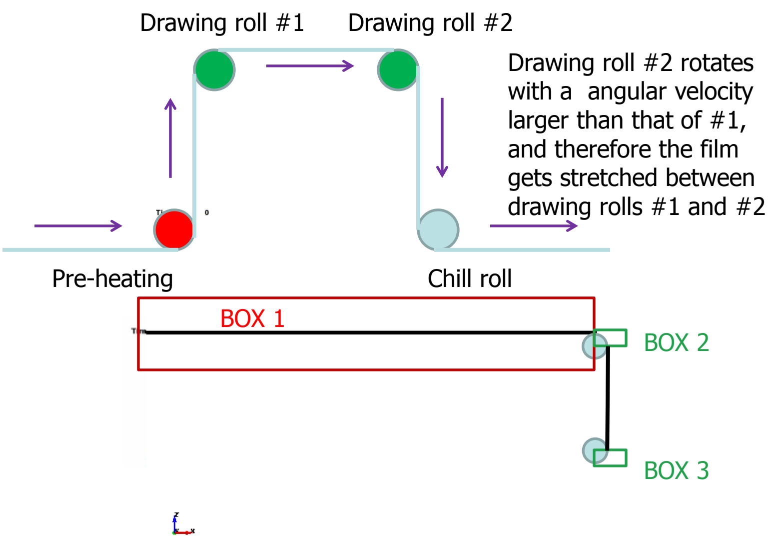
- A new option of “BOX” is added to *BOUNDARY_PRESCRBED_MOTION_SET
- Extra cards

Variable	BOXID	TOFFSET					

  - BOXID: A box ID defining a box volume in space in which the constraint is activated. Only the nodes falling inside the box volume will be applied the prescribed motion
  - TOFFSET: Time offset flag for the SET_BOX option
    - EQ.1: the time value of the load curve, LCID, will be offset by the time when the node enters the box
    - EQ.0: no time offset is applied to LCID

*BOUNDARY_PRESCRBED_MOTION_SET_BOX

- Application example: rolls-stretching



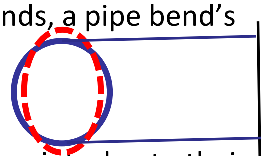
Elbow Pipe Element

- Pipe networks are part of almost every industrial setup including refineries and power plants.
- Pipes are very often used to carry substances that, by virtue of their pressure, temperature, physical and chemical characteristics, can cause serious damage to health, property and the environment, if released into the atmosphere.
- Therefore FEA analysis to guarantee the integrity of pipes in industrial contexts is of paramount importance

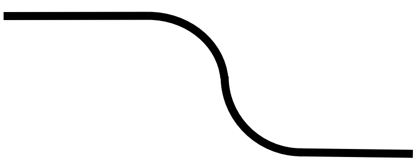
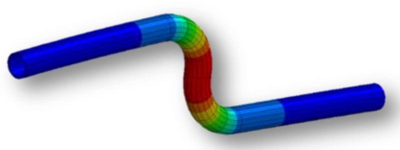


Elbow Pipe Element

- When an external load is applied to one of its ends, a pipe bend's cross-section tends to deform significantly.

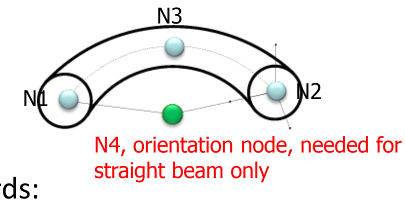



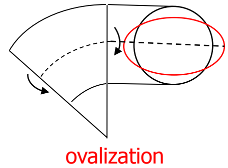
- This behavior, characteristic of pipe bends and mainly due to their curved geometry, accounts for their greater flexibility. This added flexibility is also accompanied by stresses and strains much higher than those present in a straight pipe. For this reason, pipe bends are considered the critical components of a piping system.
- A quadratic beam element has been implemented for LS-DYNA. It is based on the formulation developed by Carlos Almeida 1982.

Elbow Pipe Element

- It is a 3 node element with 36 degrees of freedom, 18 degrees of translation and rotation and 18 degrees of ovalization (each node have 6 ovalization degrees)

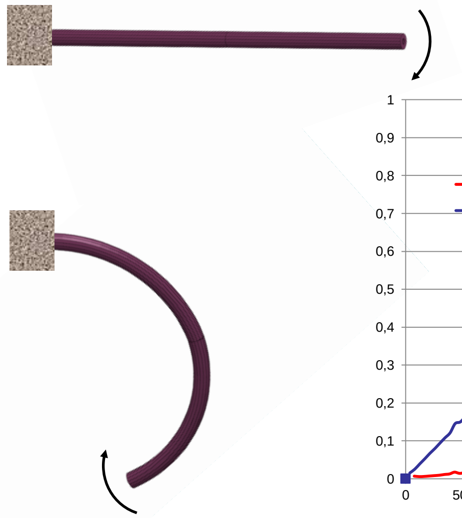


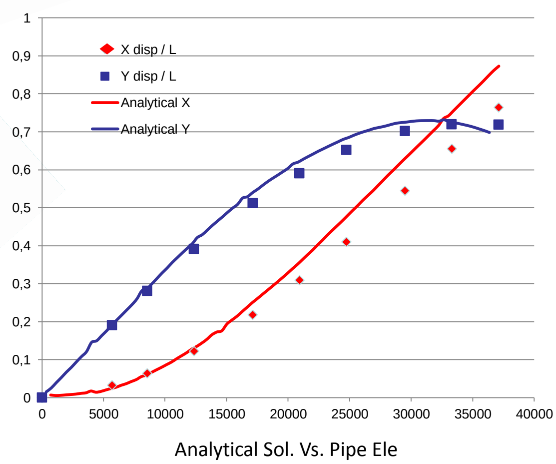


- Related Keywords:
  - *ELEMENT_BEAM_ELBOW
  - ELFORM, of *SECTION_BEAM, =14,
  - *INTEGRATION_BEAM, a user-defined integration rule with tubular cross section must be used
- Ovalization degreees can be printed to an ASCII file
- Both explicit and implicit implementations.

Validation of Elbow Pipe Element

- A cantilever beam, modelled as 2 beam elements, is subjected to an end moment





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 and Cosserat elements, contact, and related developments
  - Discrete element methodology for modeling granular materials
  - Simulation based airbag folding and THUMS dummy positioning underway
- Multi-scale capabilities are under development
  - Implementation underway (New approach which is more user friendly)
- Hybrid MPI/OPENMP developments are showing significant advantages at high number of processors for both explicit and implicit solutions

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