Recent Developments in LS-DYNA – Part I

Presented by
Jason Wang, Pierre L’Eplattenier, Facundo Del Pin

12th European LS-DYNA Conference 2019
14-16 May 2019 in Koblenz, Germany
Outline

Introduction

Scalable Technologies
  • HYBRID
  • Rebalancing

Multi-Physics, Multi-formulations, Multi-scale, Multi-stage
  • SPH/CPM Methods, Thermal Radiation, NVH and Fatigue
  • Electromagnetics
  • ICFD
Development costs are spread across many industries

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LS-DYNA | One Code, One Model

Single Model for Multiple Disciplines – Manufacturing, Durability, NVH, Crash, and FSI

Multi-Physics and Multi-Stage
Structure + Fluid + EM + Heat Transfer
Implicit + Explicit ....

Multi-Scale
Failure predictions, i.e., spot welds

Multi-Formulations
Linear + Non-Linear + Peridynamics + ...

Safety

NVH

Structure + Fluid

The neon crash model is courtesy of FHWA/NHTSA National Crash Analysis Center
Computers capable of multi-physics simulations are becoming affordable. Scalability is rapidly improving for solving multi-physics problems.
SMP and MPP – HYBRID

12core/2socket 4 nodes clusters

MPP

- 24x24
- 96 MPP ranks

HYBRID

- 4x4
- 16 MPP ranks
- 6 SMP threads

# of messages
Enhance efficiency – DECOMPOSITION_REDECOMP

1. SPH particles contact with structure in local

2. SPH particles are rearranged into same core
Enhance efficiency - Dynamic Load Balancing

- Modifies decomposition during execution based on actual element timings
- Transfers elements and model features between processors directly via MPI
- Still in early stages of development
MLS-Based formulation 12
- Quasi-Linear Moving Least-Squares formulation for accuracy and consistency
- Stabilized nodal integration for better stability
- More CPU-Intensive than regular SPH

Fluid Formulation 15
- Density smoothing
- Murnaghan Equation of State for weakly compressible modeling
- Low artificial viscosity

Implicit Formulation 13
- Implicit, incompressible SPH formulation allows larger time step size
- Tailored for wading-type problems
- Example with 9.1 million particles
OpenMP (HYBRID) enabled
Reduced amount of data transferring between processors for better scaling
More efficient particle to fabric contact algorithm
Same input faster turn around time
Thermal Radiation (MPP)

Extended MPP implementation to reduce wall clock time and memory requirements and to couple with fluid and other solvers.

Applications are, for example, drying and curing processes.

Example: B-pillar part gets heated up in an oven.
NVH and Fatigue solvers

Vibration solvers
- Frequency Response Function
- Steady State Dynamics
- Random Vibration
- Response Spectrum Analysis
  - DDAM

Fatigue solvers
- Random Vibration Fatigue
- SSD fatigue
- Time domain fatigue
  - Stress based
  - Strain based

Acoustic solvers
- Boundary Element Method
  - Collocation
  - Indirect
  - Rayleigh Method
  - Kirchhoff Method
- Finite Element Method
- Acoustic Eigenvalue Analysis
- Statistical Energy Analysis

Applications
- NVH analysis of automotives and airplanes
- Civil and hydraulic Engineering
- Earthquake engineering
- Acoustic simulation
- Fatigue and durability
Electromagnetics

Pierre L’Eplattenier, Iñaki Çaldichoury
• Battery abuse
• Resistive heating - Resistive spot welding
• Cardiac simulations
Battery abuse
Battery – Introduction

- Battery safety has been a key focus in design of electrified vehicle as battery size continues to increase.
- Understanding battery behaviors under abuse conditions is important to optimize the battery design.
- Computational modeling provides a tool to reveal the root causes of battery failure and evaluate its safety metrics.
- The models can also be used to check battery behavior in different “normal” operating conditions (Charge/discharge cycles, heating, ...).
Battery – physics

Mechanical

\[ \nabla \cdot \bar{\sigma} + \rho \bar{g} = \rho \bar{a} \]

Electrical

\[ \nabla \cdot (\sigma \nabla \Phi) = f(i) \]

Thermal

\[ \rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + \dot{q} \]

Electrochemical

\[ i = F(\Phi_+, \Phi_-) \]

Whole range of length (10’s μm to 10’s cm) and time (ms to mn-hours) scales
Battery: 4 models depending on the scale / detail

- **Solid elements:** cell, internal/external shorts
  - All the layers are meshed using solid elements
  - Same mesh used for mechanics, thermal and EM
  - Cautious with mechanics (element formulation, large aspect ratio, small time step)

- **Composite Tshells:** cell/module, internal/external
  - Mechanics modeled using composite Tshells
  - EM and thermal use underlying solid mesh
  - More accurate detailed deformations
  - Faster runs (less elements, larger time step)

- **Battery Macro model (BatMac):** pack/battery, internal/external
  - One (or a few) solid elements through thickness for mechanics, EM and thermal
  - 2 fields at each node (positive and negative current collectors)

- **Meshless model:** module/pack/battery, external
  - One single equivalent circuit for the whole cell (lumped model)
Battery: BatMac example (1)

New “BatMac” solver for large number of cells, up to full battery in a car crash, internal/external shorts

10 cells module impacted by a sphere using BatMac:
Runs in minutes, 20 times faster than composite Tshell model
50 cells module impacted by a plane

- 12,000 elements
- runs in 30 mn on 4 CPU’s

Internal short

Impact by a moving plane

Internal short + exotherm. reaction

Temperature + current density

More details on Batmac in talk in “Electric vehicle I” session Wednesday afternoon
Resistive Spot Welding
Resistive heating solver: new features

- Solids + shells + beams
- New EM Contact (Mortar)
- Contact resistance
- Coupled with thermal solver
- MatDeath, erosion
Resistive spot welding

Electrodes on each sides of 2 sheets to be welded:
- Pressure
- Current flow $\Rightarrow$ Joule heating $\Rightarrow$ formation of a molten weld nugget

Coupled mechanical/EM/thermal simulations in 3D or 2D (axi/planar)
New model in LS-DYNA for local contact resistance depending on local parameters, using *DEFINE_FUNCTION, e.g. Jonny-Kaars model:

\[
    r(T, P) = r_0 \left( \frac{P - P_k}{P_0 - P_k} \right)^{\varepsilon \rho} \cdot \left( \frac{T - T_{\text{lim}} + (293,15 - T) \cdot 2 - \frac{1}{e_T}}{293,15 - T_{\text{lim}}} \right)^{e_T}
\]

Temperature

2D axi-symmetric

3D (small slice of the full model)
Cardiac electro-physiology
Heart simulation

The heart is a complex bio-mechanical pump:
• Electrical impulses create wave of excitation, which propagates through the heart: ElectroPhysiology (EP).
• It initiates the contraction of the cardiac cells: Mechanics
• Which pumps the blood to the body: FSI

Our goal: coupled EP-Mechanical-Fluid heart simulations in LS-DYNA
Heart Modeling: EP+Mechanics+FSI

Ventricle with EP+Mechanical+ICFD:

- Help diagnostic (ECG)
- Understand abnormal heart beat, arrhythmia
- Assist therapy planning (medicine, pacemaker, surgery, ...)
- Shear stresses on the valve walls
- Hydrodynamic loads on medical devices like pacemakers
- Flow rate in and out of heart cavities
- Recirculation areas

Blood flow through artery from FSI
External Flow
Internal Flow

LS-DYNA: Internal flow.

FDA Benchmarks
Free Surface and Sloshing

LS-DYNA: Dam Break Impact Simulation

Reza ISSA and Damien VIOLEAU. SPH European Research Interest Community. Test-case 2, 3D dam breaking. Electricité de France.
Fluid Structure Interaction (FSI)

LS-DYNA: Fluid Structure Interaction of Prosthetic Heart Valves
Thermal Analysis

Conjugate Heat Transfer Analysis for Cooling in Metal Stamping and an Electromagnetic Coil
New Features
Sliding mesh
Periodic Boundary Conditions

Horizontal Wind Turbine.
Periodic Boundary Conditions

Model the full domain near the turbine. Results in a large mesh but most accurate. Use sliding mesh or non-inertial reference frame.
Periodic Boundary Conditions

Model a cylinder that contains the turbine. Results in a smaller mesh but less environment effects. Use sliding mesh or non-inertial reference frame.
Model a third of the cylinder that contains the turbine. Even a smaller mesh. Take advantage of repeating pattern in the flow. Use non-inertial ref. frame with periodic boundary conditions.
Model a third of the cylinder that contains the turbine. Even a smaller mesh. Take advantage of repeating pattern in the flow. Use non-inertial ref. frame with periodic boundary conditions.
Porous Parachutes and Membranes modeling: an FSI approach.

- 2D and 3D FSI porous/permeable parachutes and membranes modeling,
- Pressure drop through the fabric thickness is modeled as \( \frac{\partial p}{\partial n} = \alpha (u \cdot n) + \beta |u|(u \cdot n) \).
- \( \alpha = f(\mu, \kappa) \) and \( \beta = f(\rho, \epsilon, \kappa, F) \). Where \( \mu, \rho, \epsilon, F \) is the fluid dynamic visc., the fluid density, the fabric porosity and the Forchheimer Factor, respectively.
- A flexible user interface to define the porous parameters through *ICFD_MODEL_POROUS keyword and Porous Model IDs = 8, 10 and 11.
Wave Generator for Free-Surface Flows

- A complete set of 2D and 3D Regular and Irregular wave shapes for deep/intermediate/shallow water flows:
  - 1st, 2nd and 5th Stokes waves,
  - Solitons (Tsunami-like waves),
  - Irregular Ocean waves (JONSWAP spectrum).
- Wave absorption/damping and FSI capabilities.

Irregular Ocean waves

FSI capability

Soliton

Time: 0.00 (secs)

2nd Order Stokes

2nd Order Stokes + wave damping.
LSPP \textbf{pre}-processor Multi-Solver menu
LSPP post-processor Multi-Solver menu
• For models and examples visit: www.dynaexamples.com/icfd
• For movies showing more capabilities visit: https://www.youtube.com/user/980LsDyna

More details: tomorrow Wednesday at 8:30 session
Fluid Structure Interaction

Thank You
Recent Developments in LS-DYNA – Part II

Presented by
Tobias Erhart, Thomas Borrval

Thank you!
Thank you!