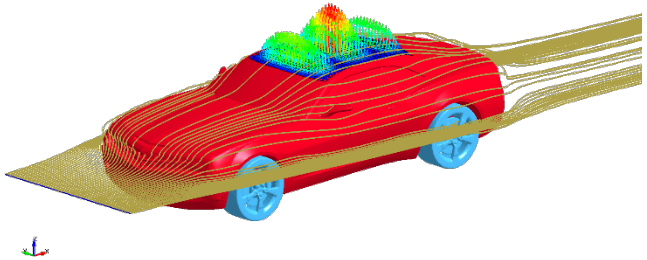
Author(s)
Session ID

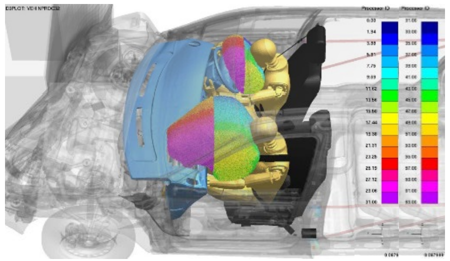
Recent Developments in LS-DYNA – Part I

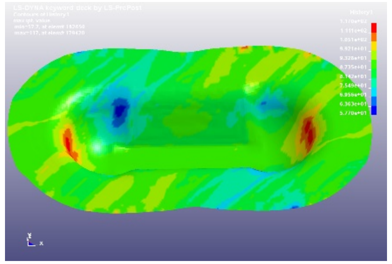
LSTC
Livermore Software Technology Corp.

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**

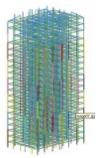
Multi-Physics, Multi-formulations, Multi-scale, Multi-stage

- **SPH/CPM Methods, Thermal Radiation, NVH and Fatigue**
- **Electromagnetics**
- **ICFD**

LS-DYNA | Applications

Development costs are spread across many industries

Automotive
Crash and safety
NVH & Durability
FSI

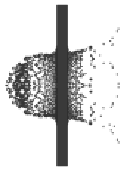


Structural
Earthquake safety
Concrete and composite structures
Homeland security

Aerospace
Bird strike
Containment
Crash

Electronics
Drop analysis
Package analysis
Thermal

Manufacturing
Stamping
Forging
Welding



Defense
Weapons design
Blast and penetration
Underwater Shock Analysis

Consumer Products

Biosciences

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

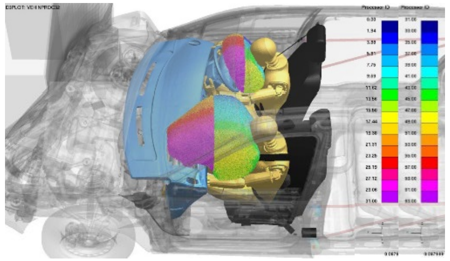
Implicit + Explicit ….

Multi-Scale

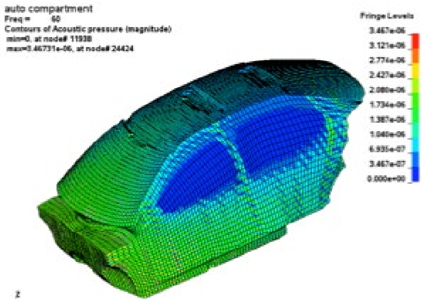
Failure predictions, i.e., spot welds

Multi-Formulations

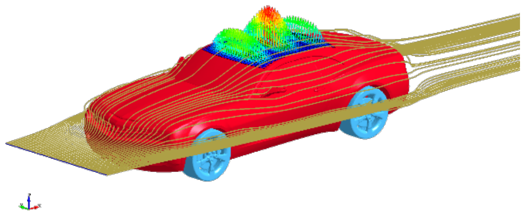
Linear + Non-Linear + Peridynamics + …



Safety



NVH



Structure + Fluid

The neon crash model is courtesy of FHWA/NHTSA National Crash Analysis Center

LSTC Organizational Structure

John O. Hallquist

Nathan Hallquist

Dilip Bhalsod
Global Business Manager

LS-DYNA
Functional groups

- Explicit
- Implicit
- ICFD
- CONTROLS
- CESE
- Chemistry
- EM
- Metal Forming
- Composites
- Particle Methods
- Thermal
- Additive Manufacturing
- NVH/Acoustics
- IGA

LS-PrePost
All LS-Dyna Pre & Post Processing

LS-Opt
Optimization Robustness

LS-TaSC
Shape, Topology Optimization

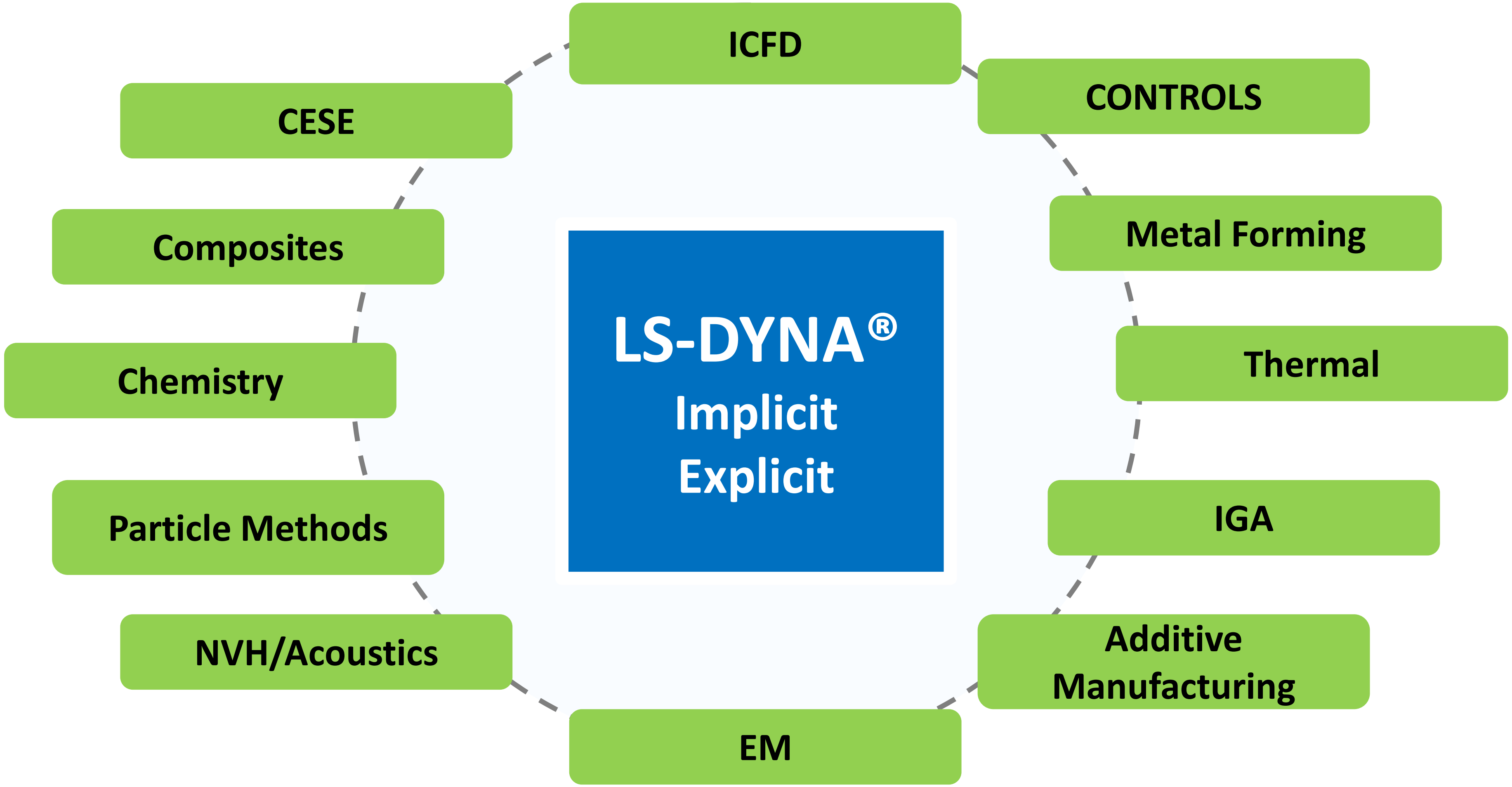
Barriers **Occupant**
Validated barriers and Occupants

Support

LS-DYNA | Strong Coupled Multi-Physics Solver

Computers capable of multi-physics simulations are becoming affordable.

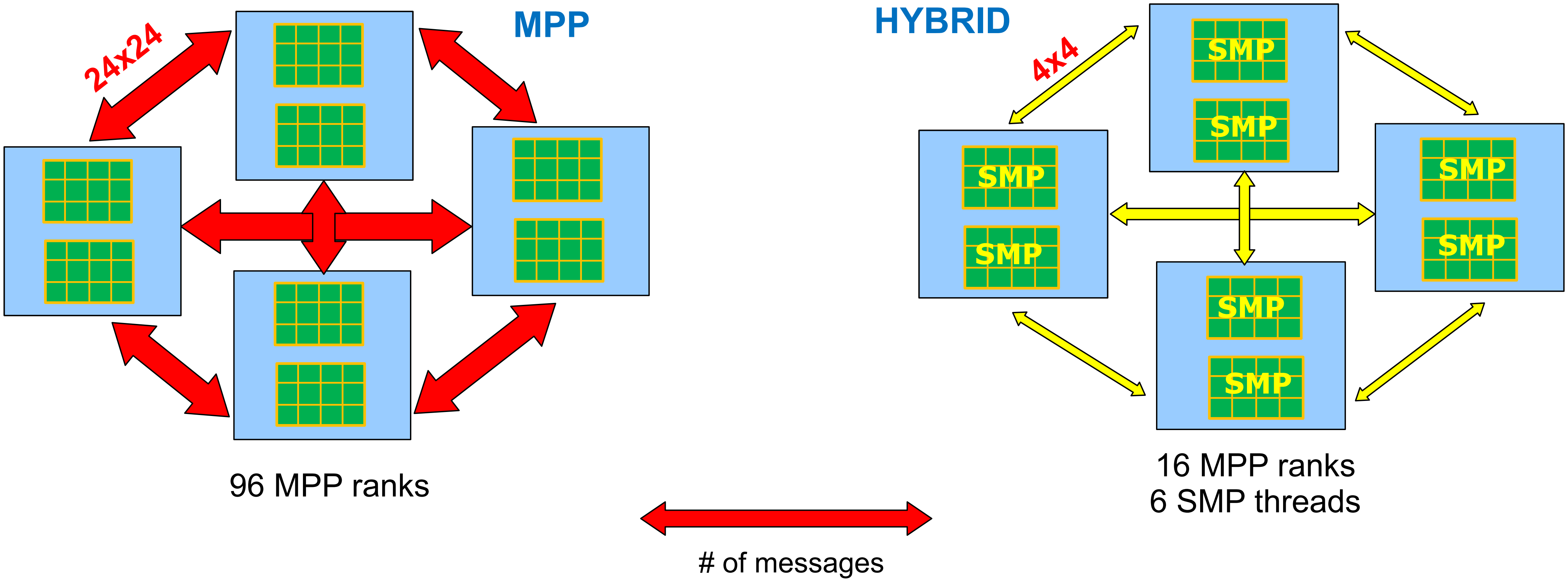
Scalability is rapidly improving for solving multi-physics problem.



SMP and MPP – HYBRID

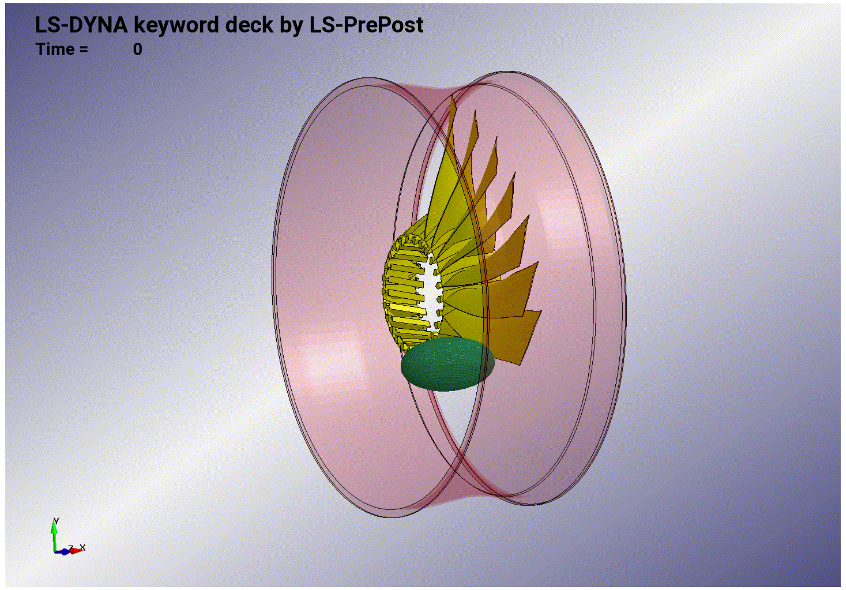
Meng
Session E7-3

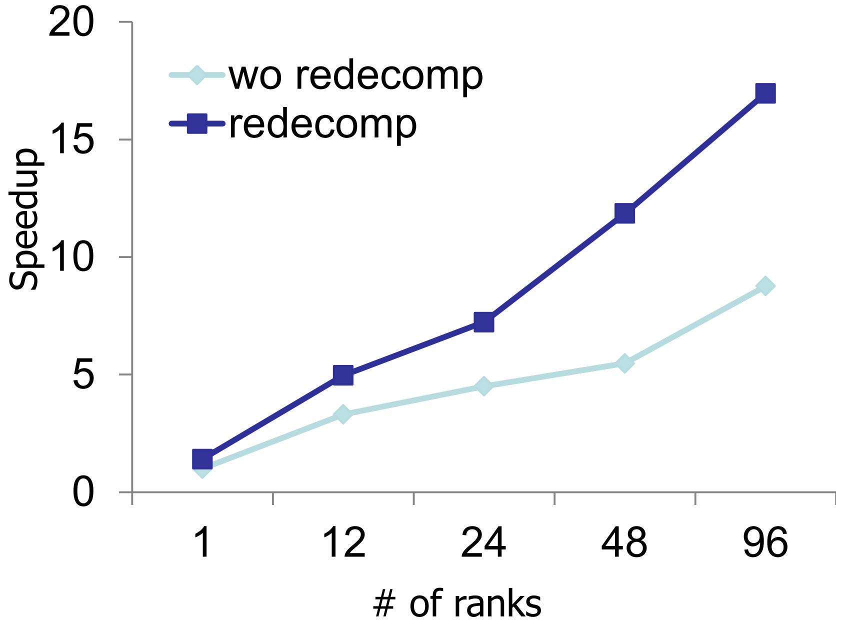
12core/2socket 4 nodes clusters

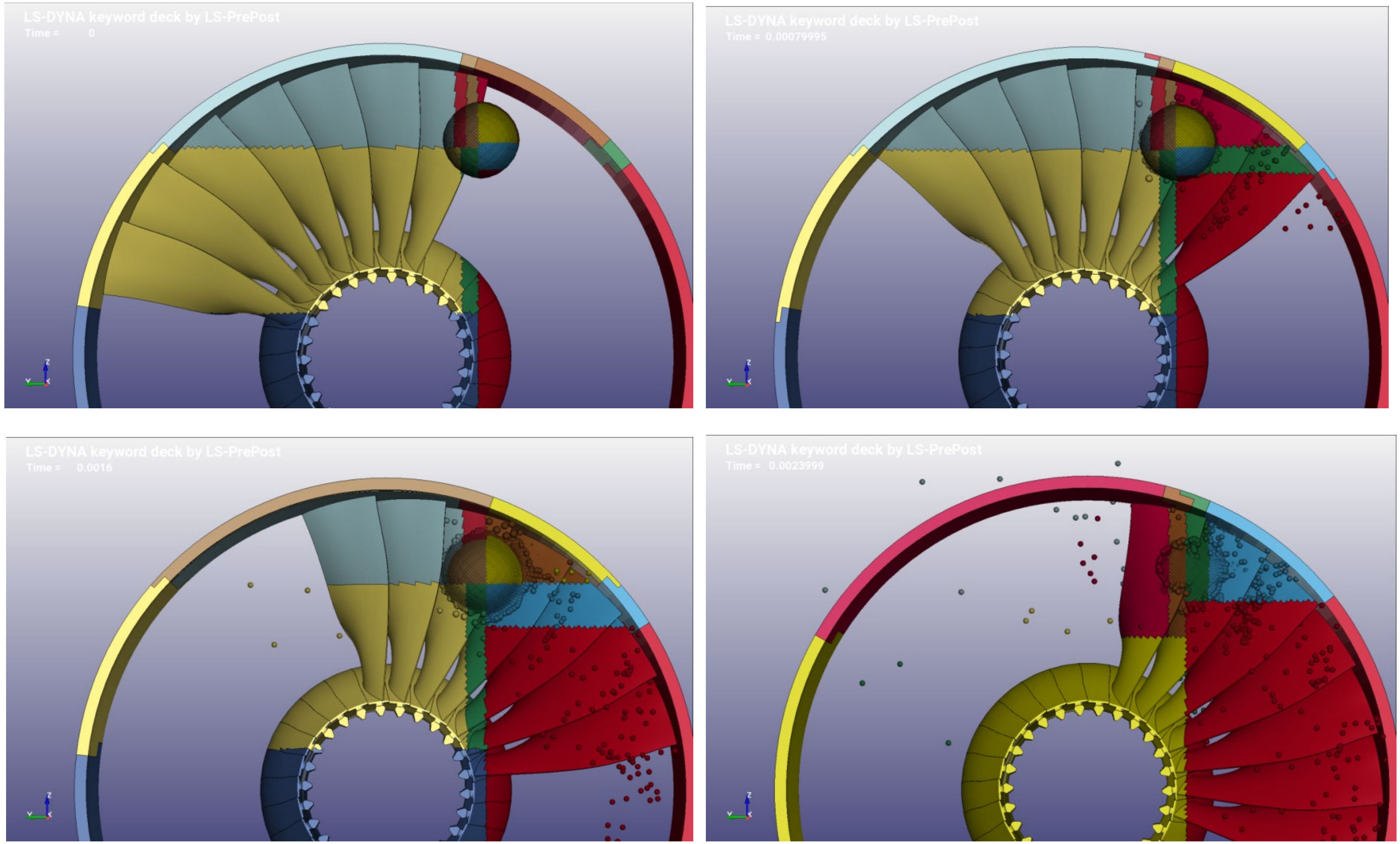


Enhance efficiency – DECOMPOSITION_REDECOMP

Yreux, Tsay, Wang
Session E7-2





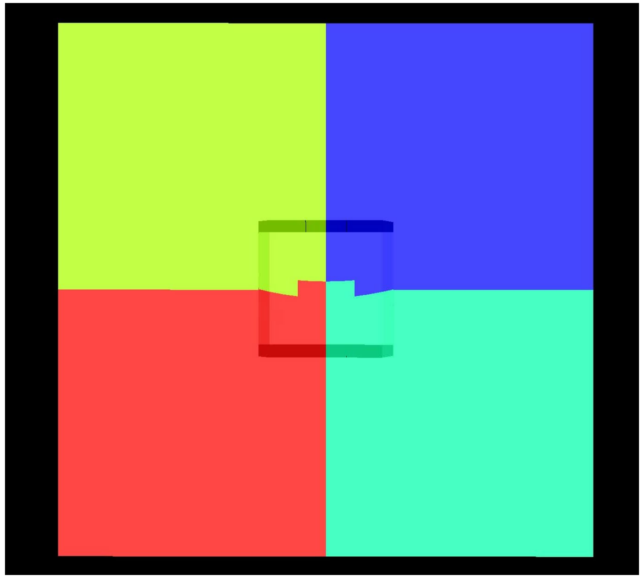


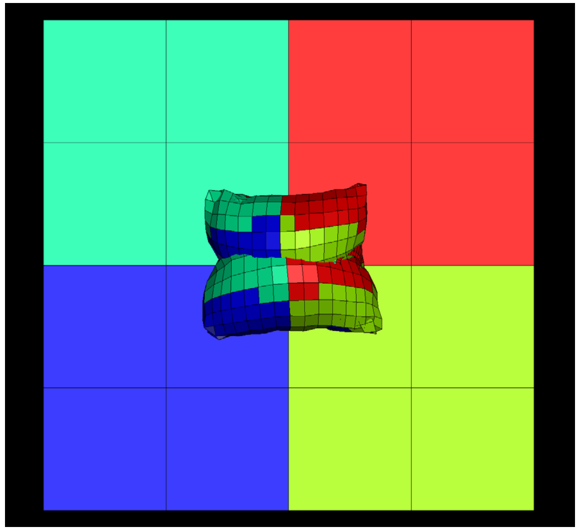
1. *SPH particles contact with structure in local*
2. *SPH particles are rearranged into same core*

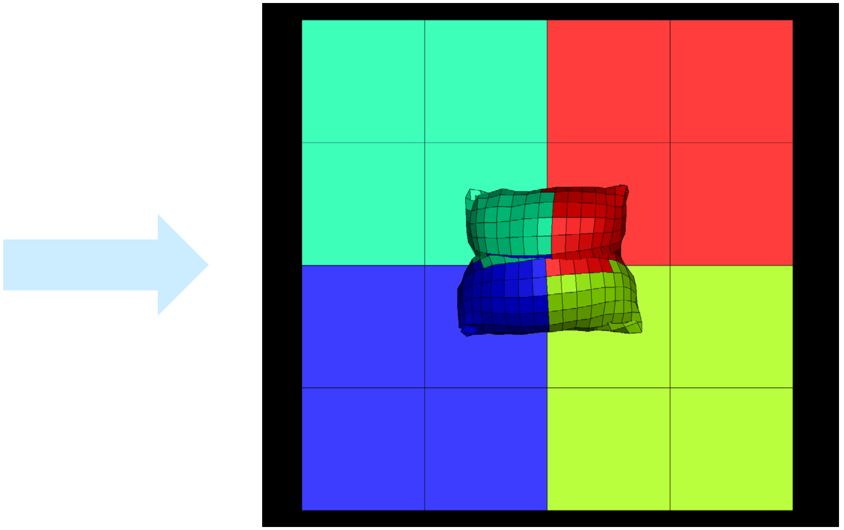
Enhance efficiency - Dynamic Load Balancing

Wainscott
Session E7-1

- 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







SPH

Yreux
Session D3-1

MLS-Based formulation 12

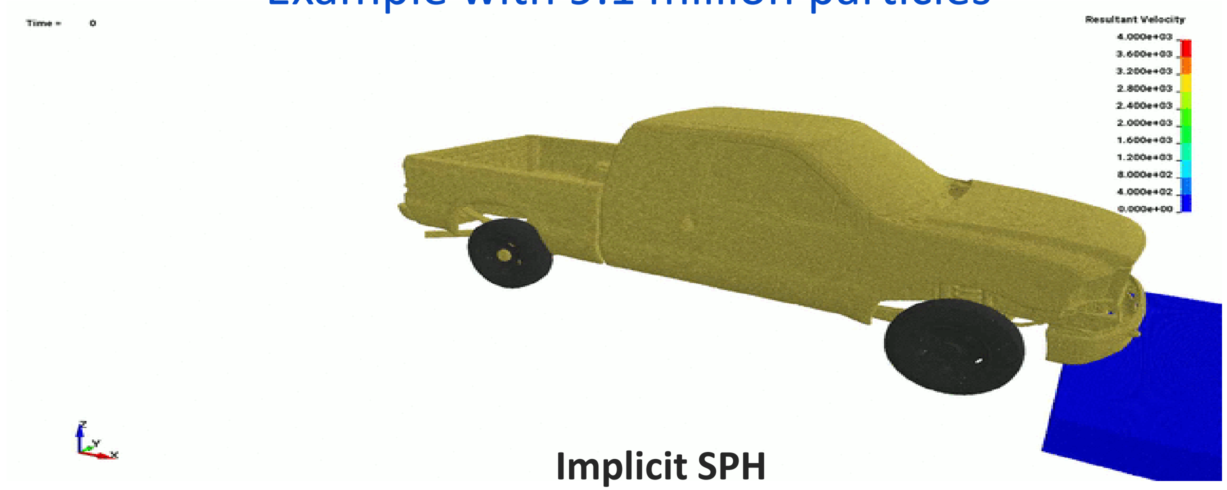
- Quasi-Linear Moving Least-Squares formulation for accuracy and consistency
- Stabilized nodal integration for better stability
- More CPU-Intensive than regular SPH

Fluid Formulation 15

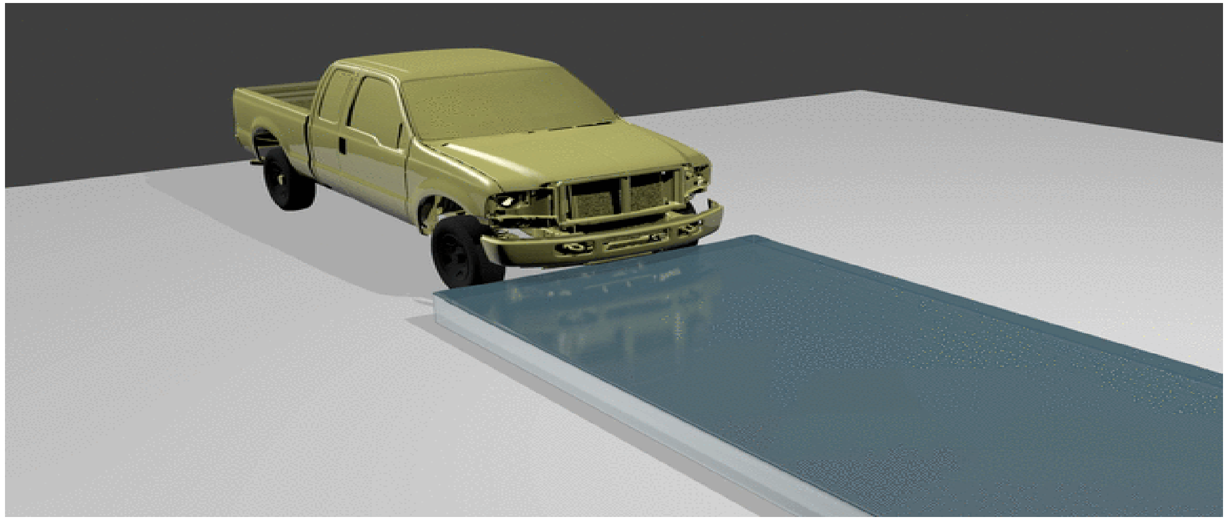
- Density smoothing
- Murnaghan Equation of State for weakly compressible modeling
- Low artificial viscosity

Implicit Formulation 13

- Implicit, incompressible SPH formulation allows larger time step size
- Tailored for wading-type problems
- Example with 9.1 million particles

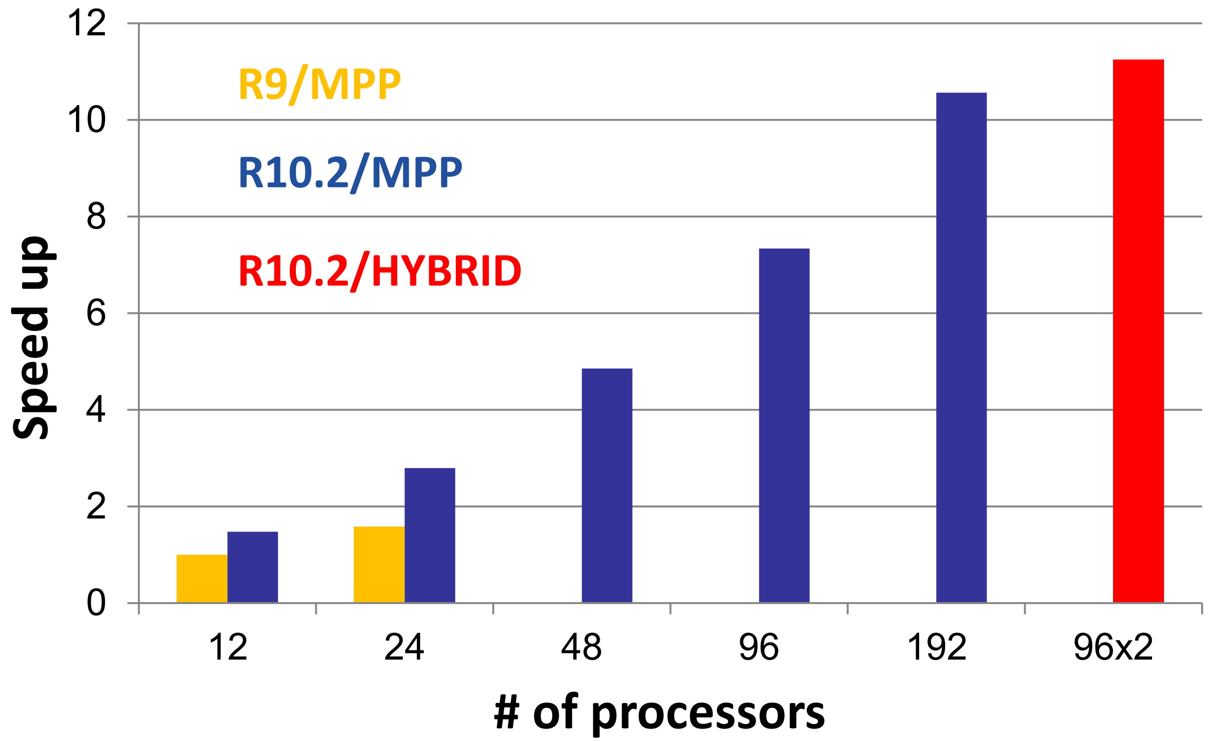


Implicit SPH
Color-coded by velocity

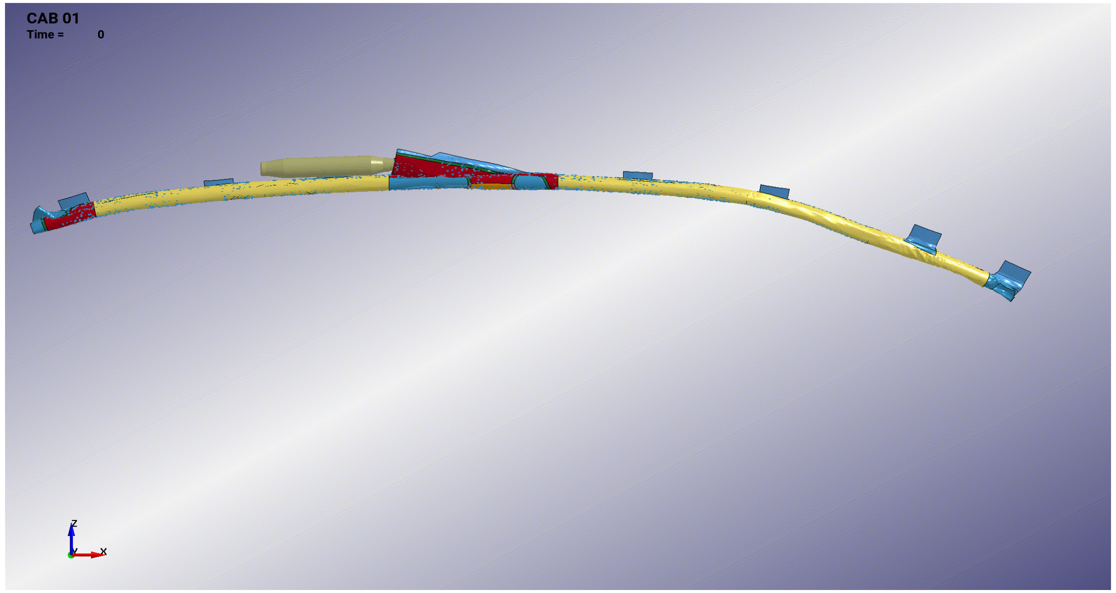


Blender rendering

CPM | CAB Performance Improvement



CAB



Courtesy of: Richard Taylor, Arup

- 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

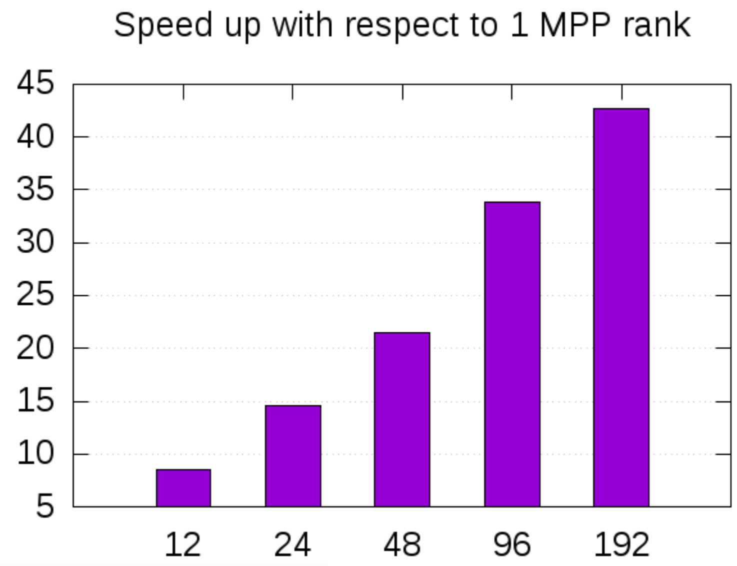
Thermal Radiation (MPP)

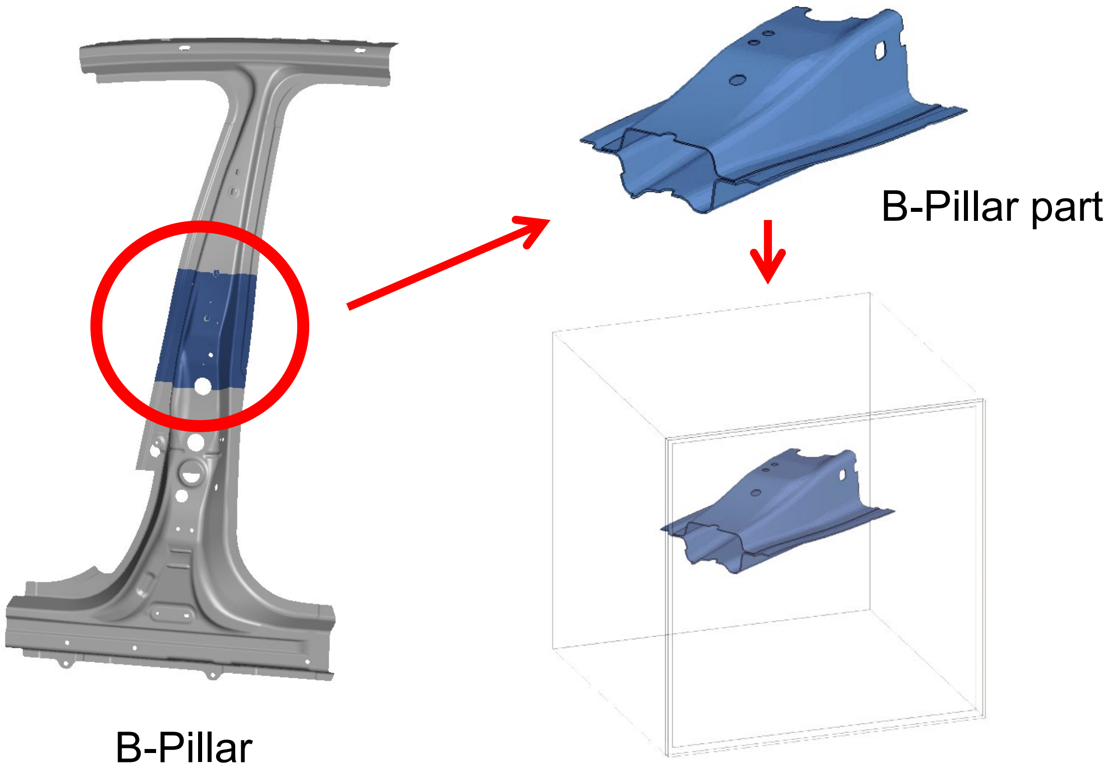
Blankenhorn, Grimes, Rouet, Gandikota, Gysei, Malcom
Session H2-1, H2-3

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.

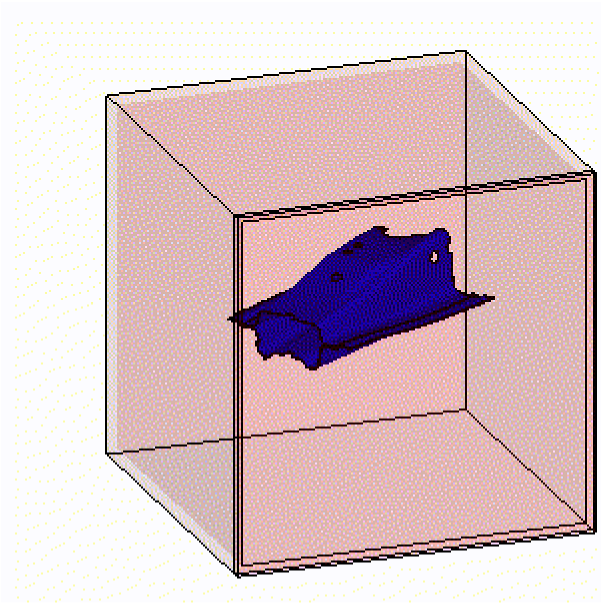
Example: B-pillar part gets heated up in an oven



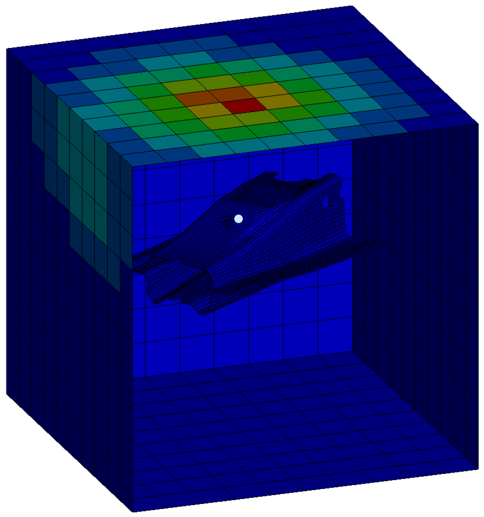


B-Pillar

B-Pillar part in oven



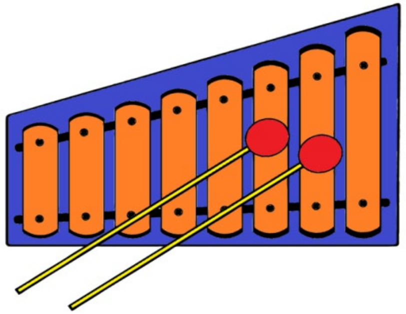
Animation (temperature)



View factor visualization

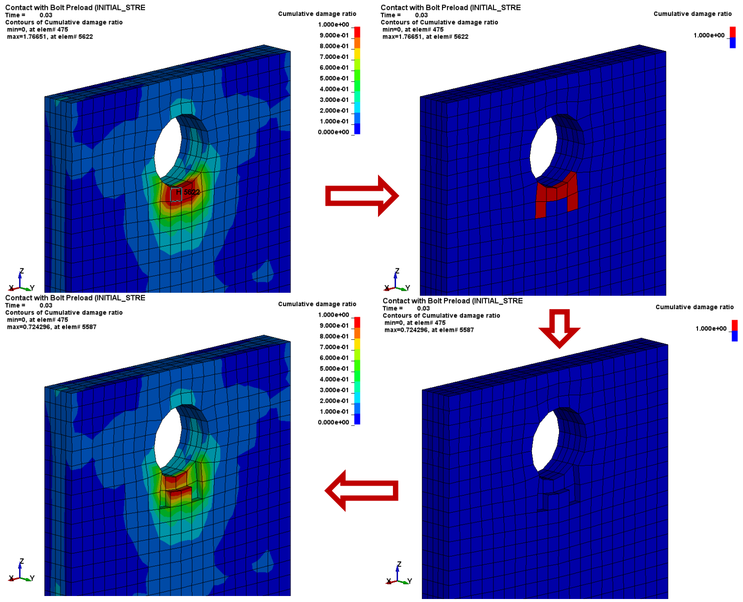
NVH and Fatigue solvers

Huang, Cui
Session H7-1, H7-3



Press_Pa_t

sound1.wav



Vibration solvers

- **F**requency **R**esponse **F**unction
- **S**teady **S**tate **D**ynamics
- **R**andom **V**ibration
- **R**esponse **S**pectrum **A**nalysis
  - *DDAM*

Fatigue solvers

- **R**andom **V**ibration **F**atigue
- **SSD** fatigue
- Time domain fatigue
  - *Stress based*
  - *Strain based*

Acoustic solvers

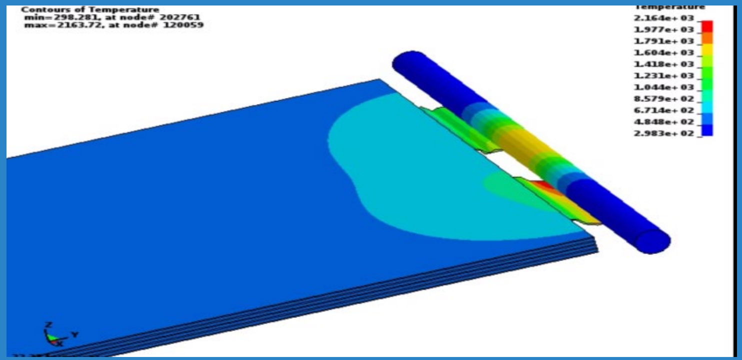
- **B**oundary **E**lement **M**ethod
  - *Collocation*
  - *Indirect*
  - *Rayleigh Method*
  - *Kirchhoff Method*
- **F**inite **E**lement **M**ethod
- **A**coustic **E**igenvalue **A**nalysis
- **S**tatistical **E**nergy **A**nalysis

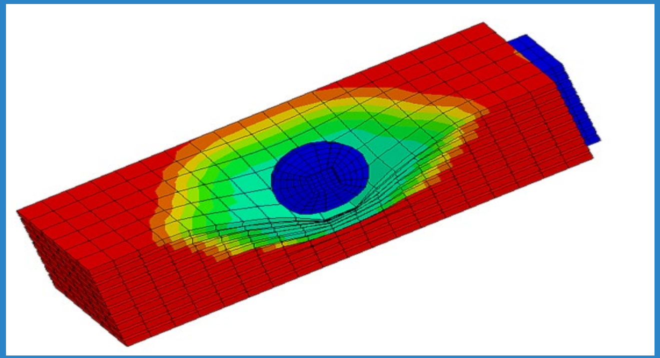
Applications

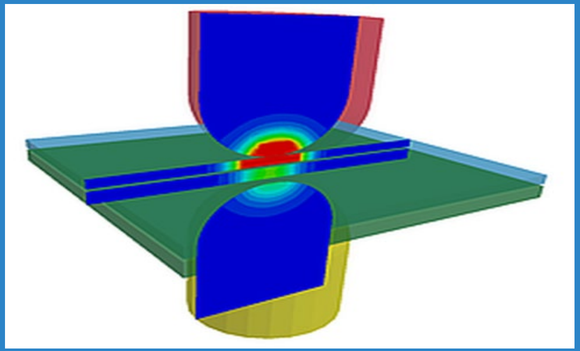
- NVH analysis of automotives and airplanes
- Civil and hydraulic Engineering
- Earthquake engineering
- Acoustic simulation
- Fatigue and durability

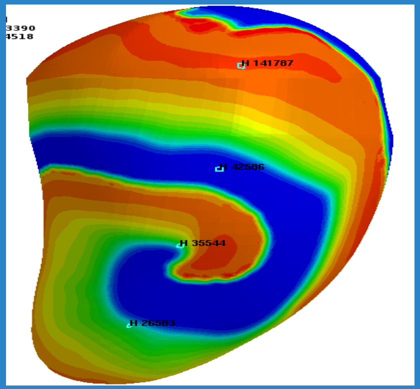
Electromagnetics

Pierre L'Eplattenier, Iñaki Çaldichoury









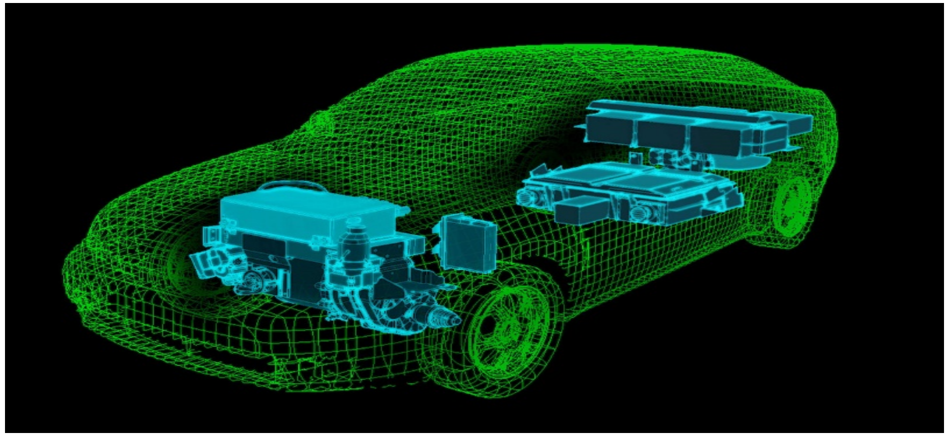
Outline

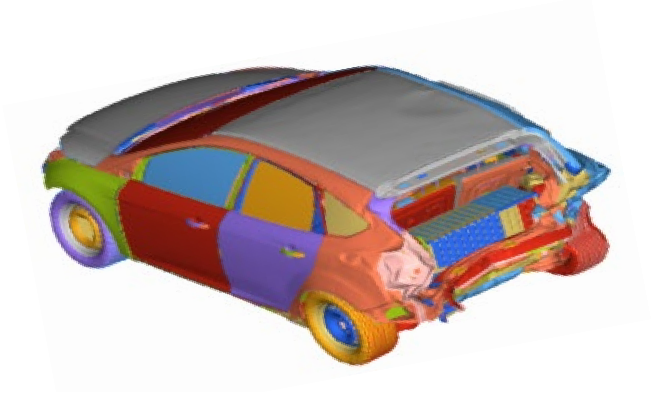
- Battery abuse
- Resistive heating - Resistive spot welding
- Cardiac simulations

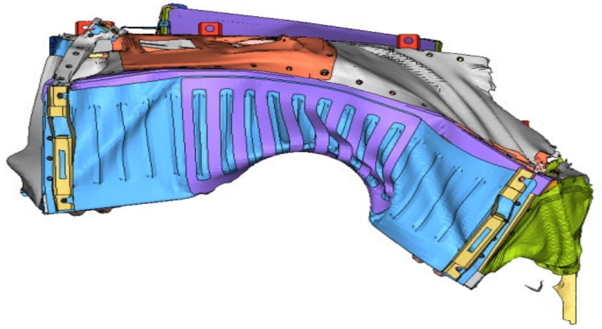
Battery abuse

Battery – Introduction

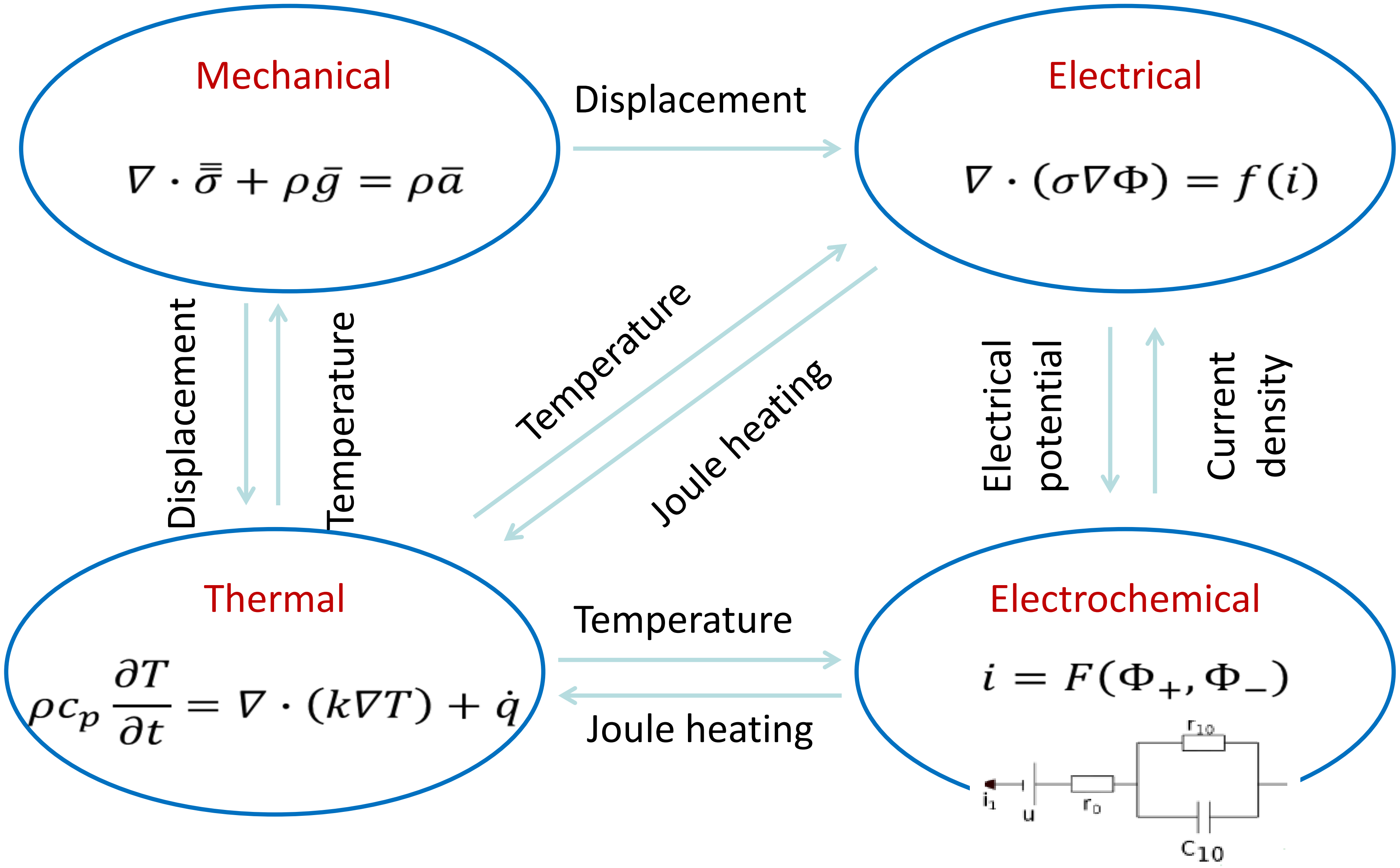
- Battery safety has been a key focus in design of electrified vehicle as battery size continues to increase.
- Understanding battery behaviors under abuse conditions is important to optimize the battery design.
- Computational modeling provides a tool to reveal the root causes of battery failure and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







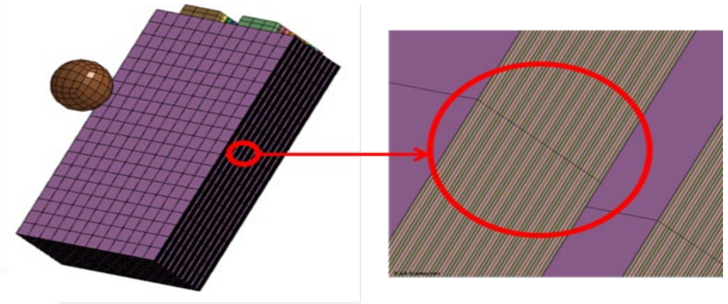
Battery – physics



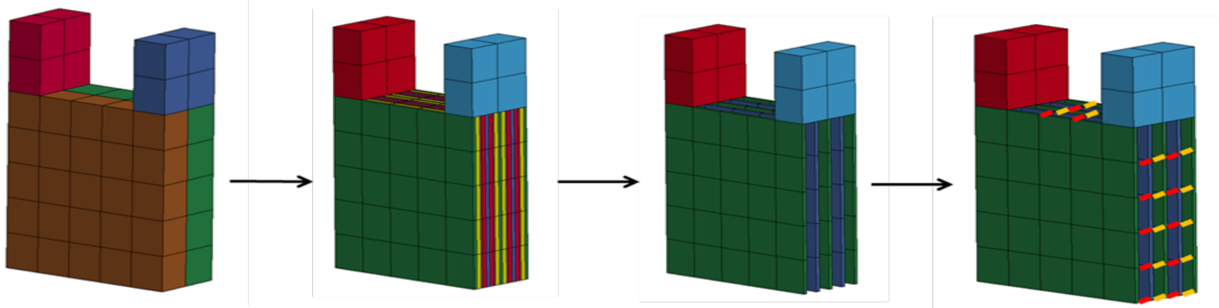
Whole range of length (10’s µm to 10’s cm) and time (ms to mn-hours) scales

Battery : 4 models depending on the scale / detail

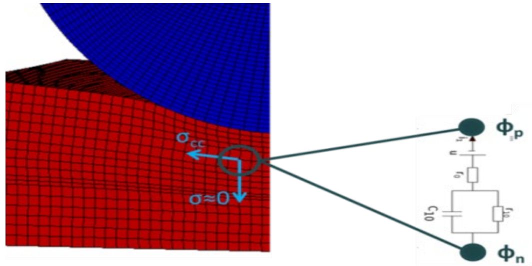
- Solid elements: cell, internal/external shorts
  - All the layers are meshed using solid elements
  - Same mesh used for mechanics, thermal and EM
  - Cautious with mechanics (element formulation, large aspect ratio, small time step)



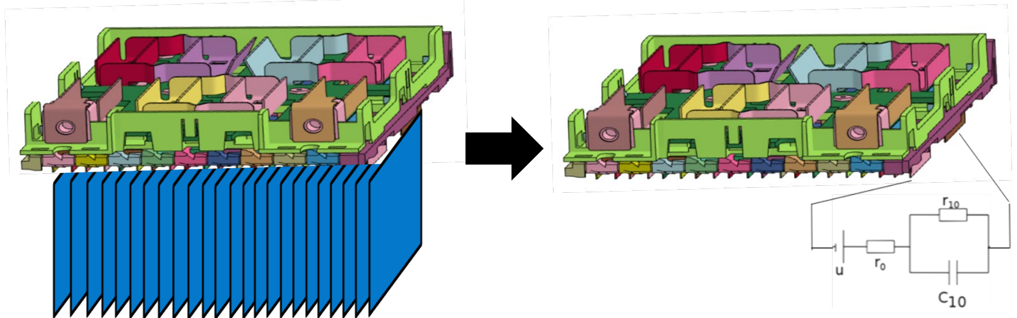
- Composite Tshells: cell/module, internal/external
  - Mechanics modeled using composite Tshells
  - EM and thermal use underlying solid mesh
  - More accurate detailed deformations
  - Faster runs (less elements, larger time step)



- 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)



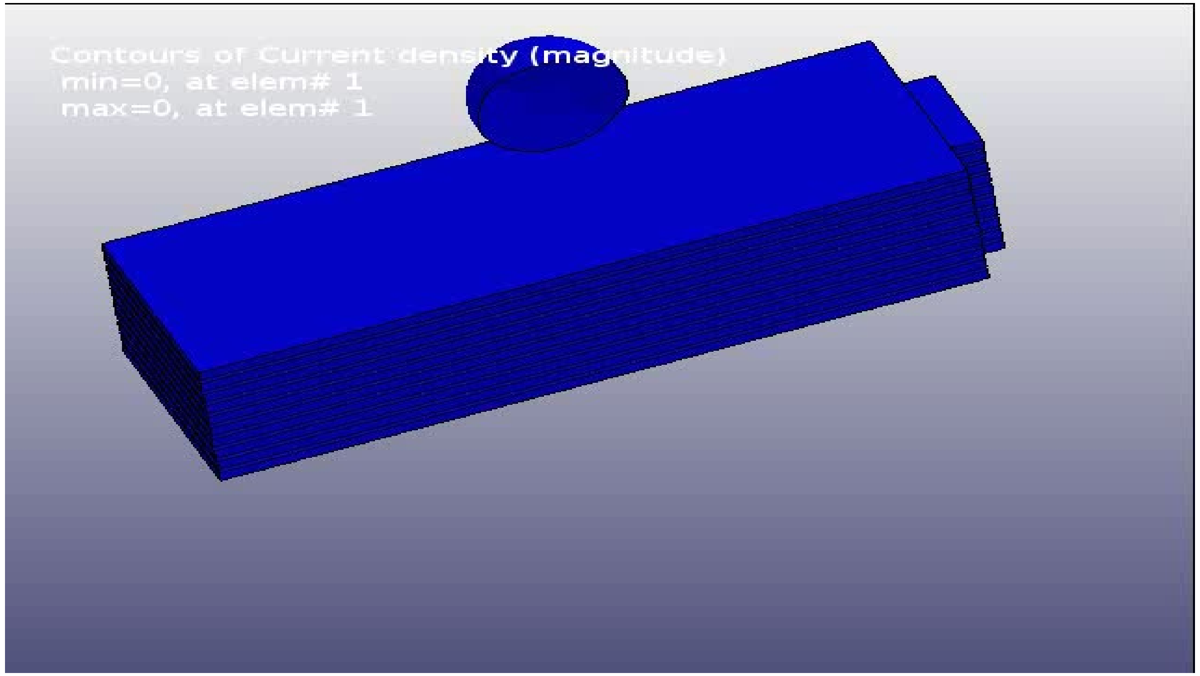
- Meshless model: module/pack/battery, external
  - One single equivalent circuit for the whole cell (lumped model)



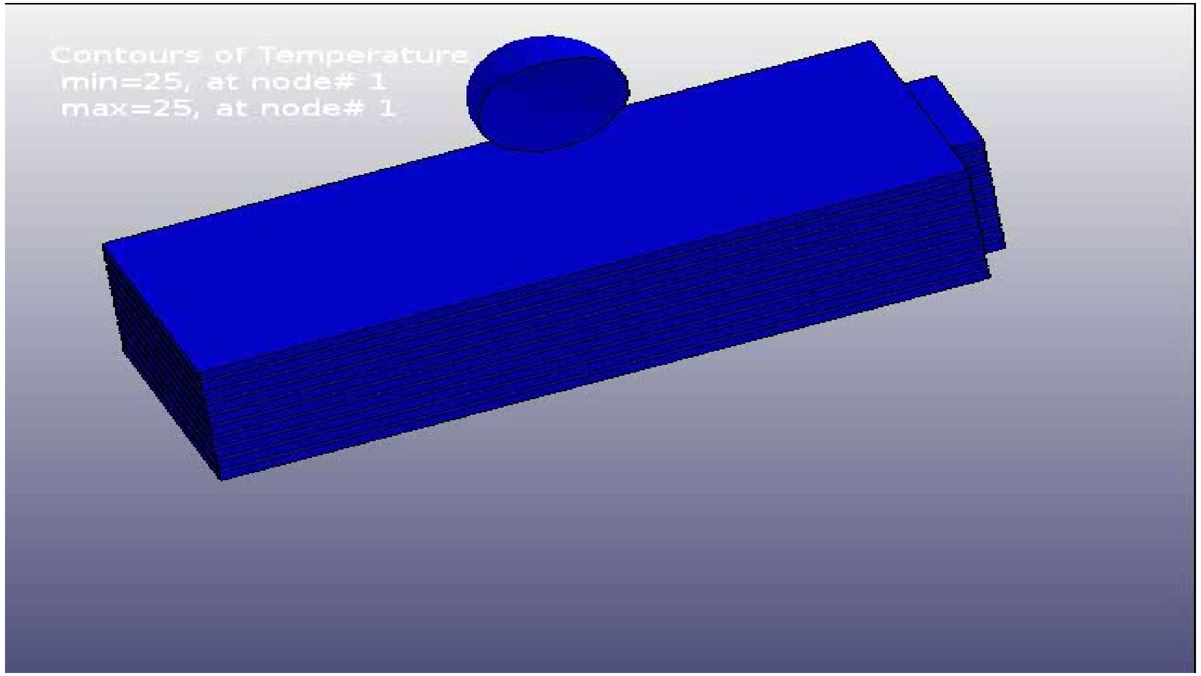
Battery: BatMac example (1)

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



Current density

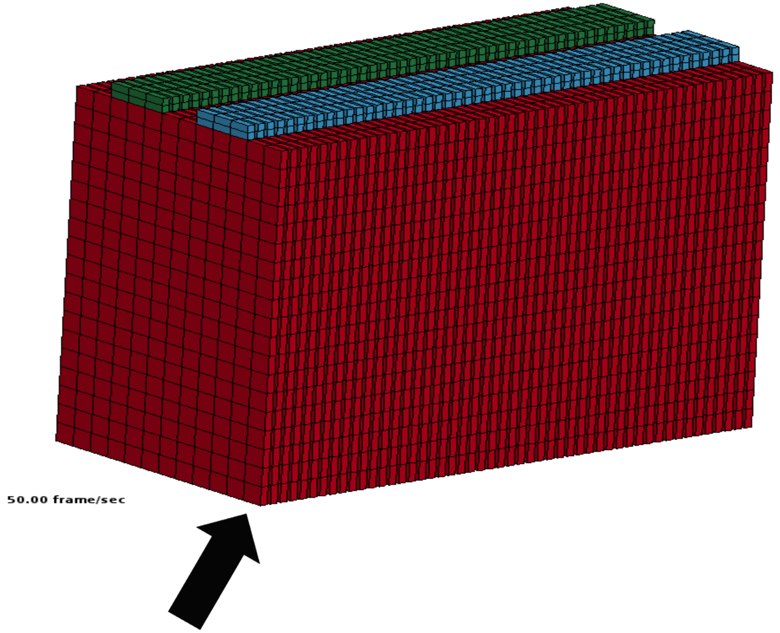


Temperature

Battery: BatMac – Example (2)

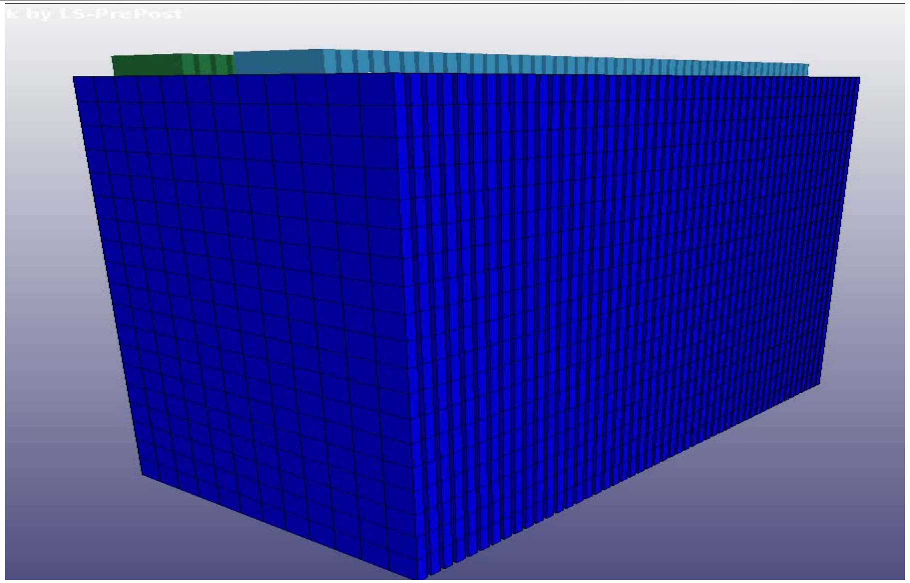
50 cells module impacted by a plane

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

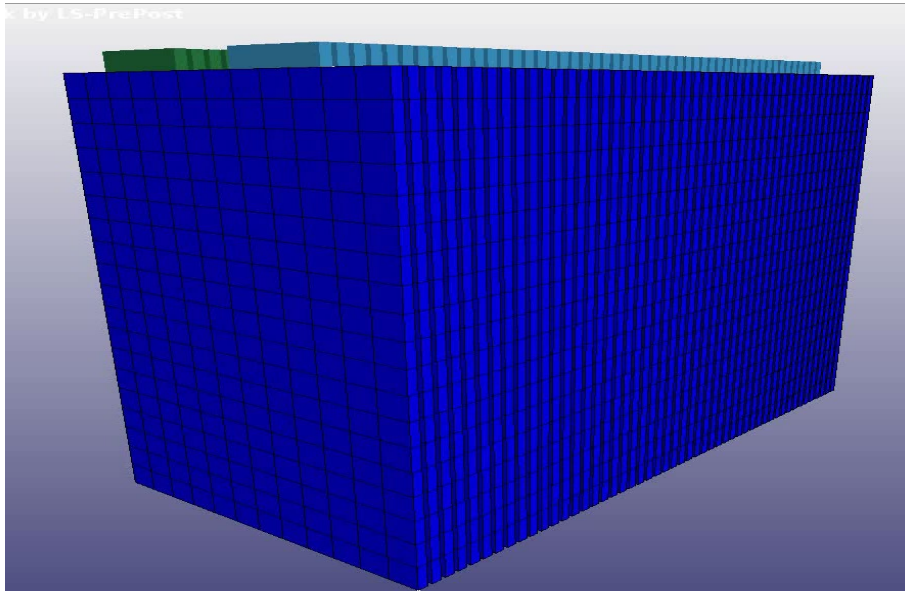


Impact by a moving plane

Internal short



Internal short + exotherm. reaction



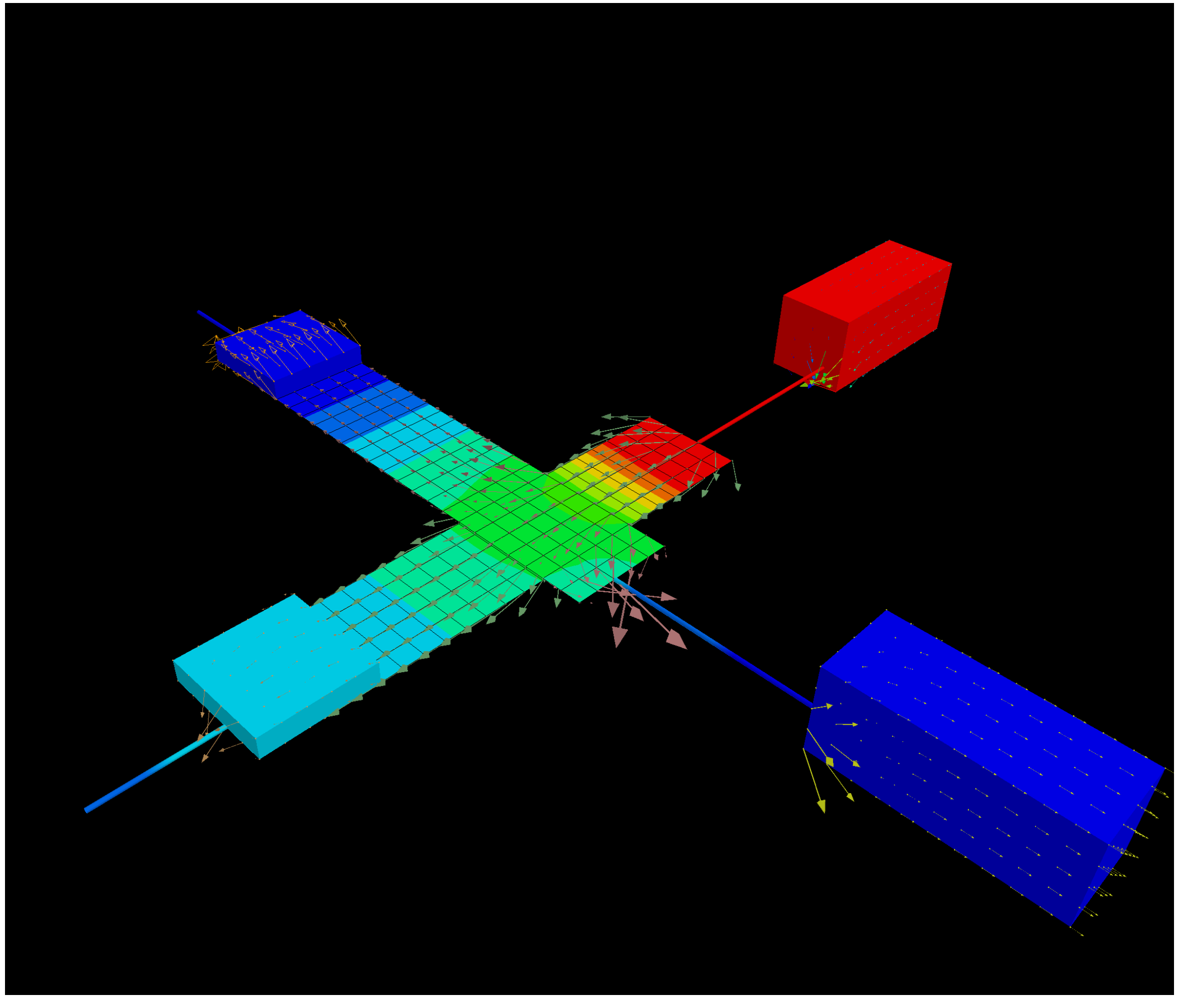
Temperature + current density

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

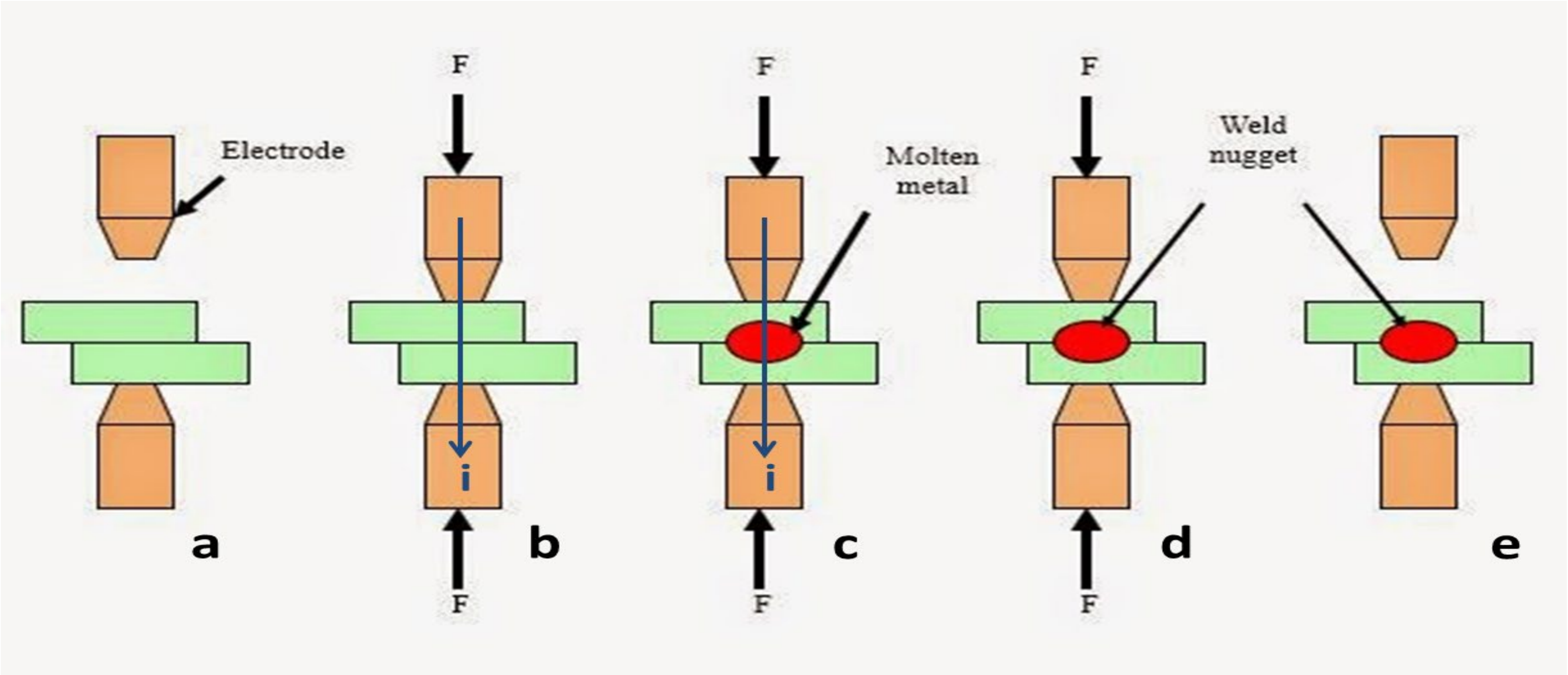


Resistive spot welding

Electrodes on each sides of 2 sheets to be welded :

- Pressure
- Current flow => Joule heating => formation of a molten weld nugget

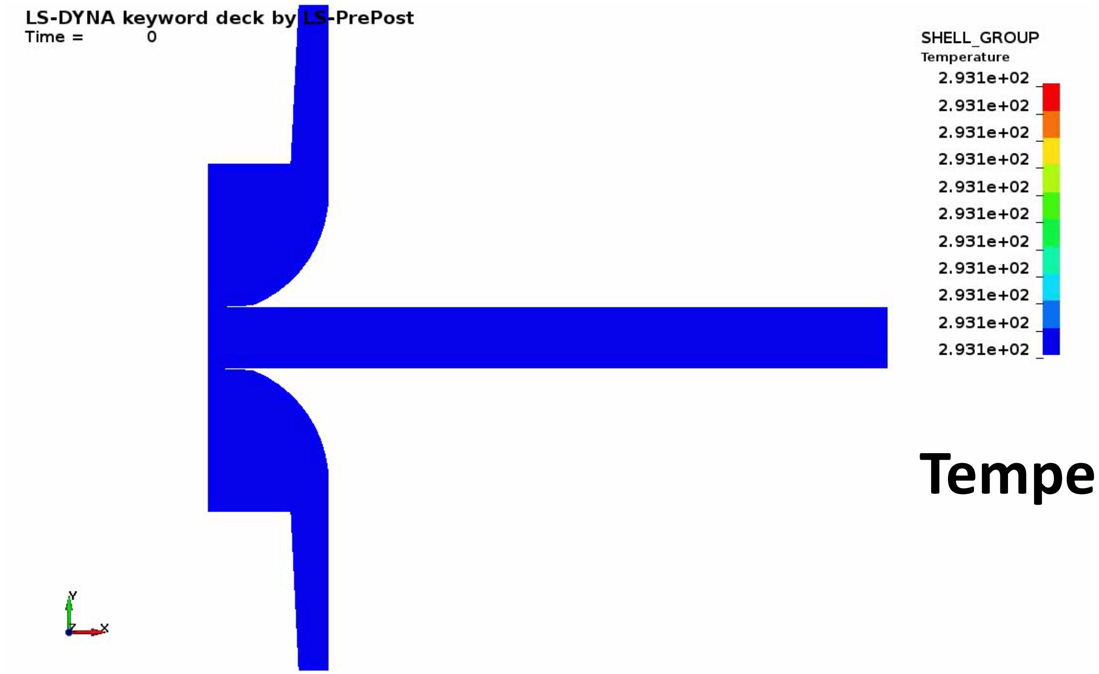
Coupled mechanical/EM/thermal simulations in **3D or 2D (axi/planar)**



Resistive spot welding

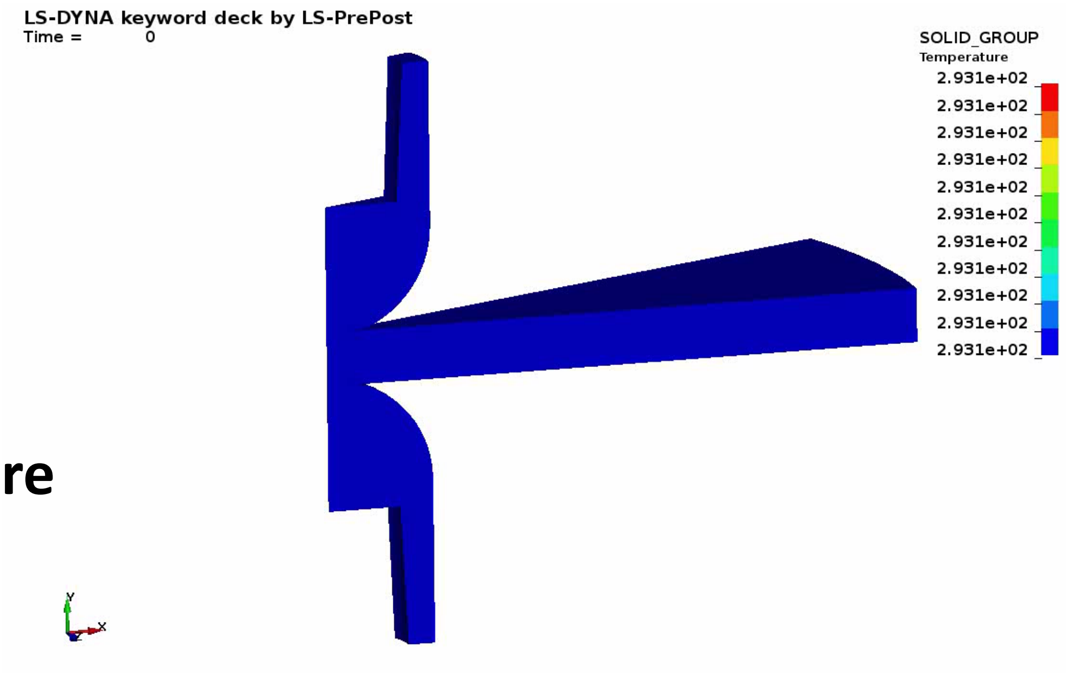
New model in LS-DYNA for local contact resistance depending on local parameters, using *DEFINE_FUNCTION, e.g. Jonny-Kaars model :

$$r(T,P) = r_0 \left(\frac{p - p_k}{p_0 - p_k} \right)^{\varepsilon_p} \cdot \left(\frac{T - T_{\lim} + (293{,}15\ K - T) \cdot 2^{-\frac{1}{\varepsilon_T}}}{293{,}15\,K - T_{\lim}} \right)^{\varepsilon_T}$$



2D axi-symmetric

Temperature



3D (small slice of the full model)

Cardiac electro-physiology

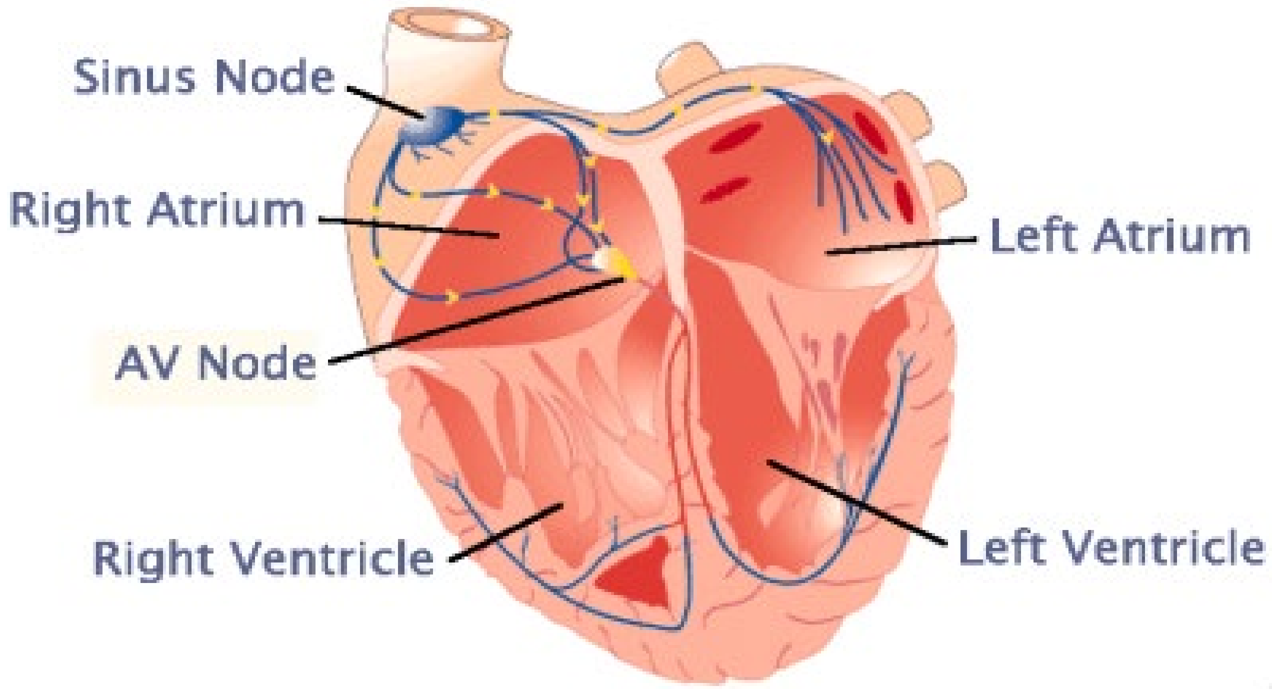
Heart simulation

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

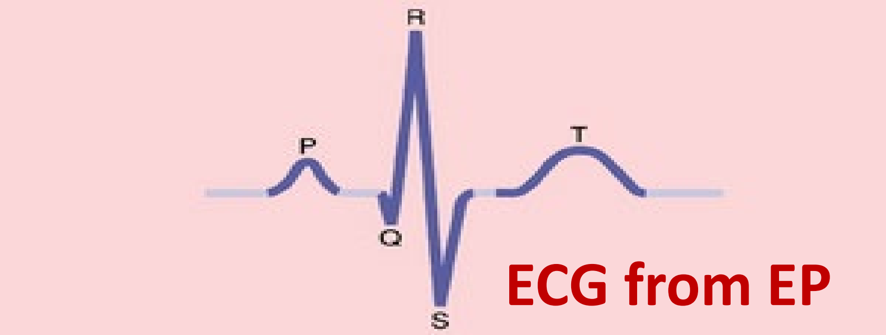


Heart electrical system

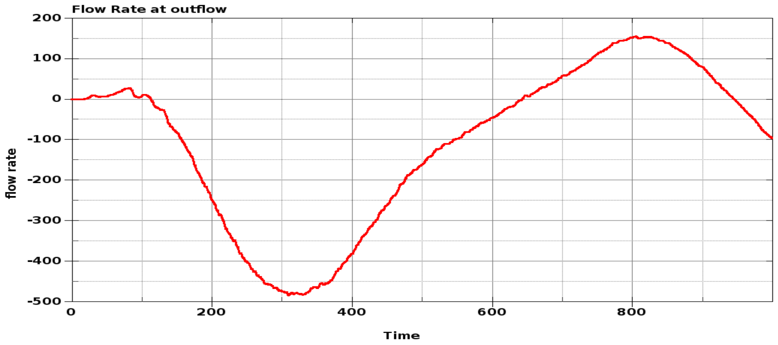
Heart Modeling: EP+Mechanics+FSI

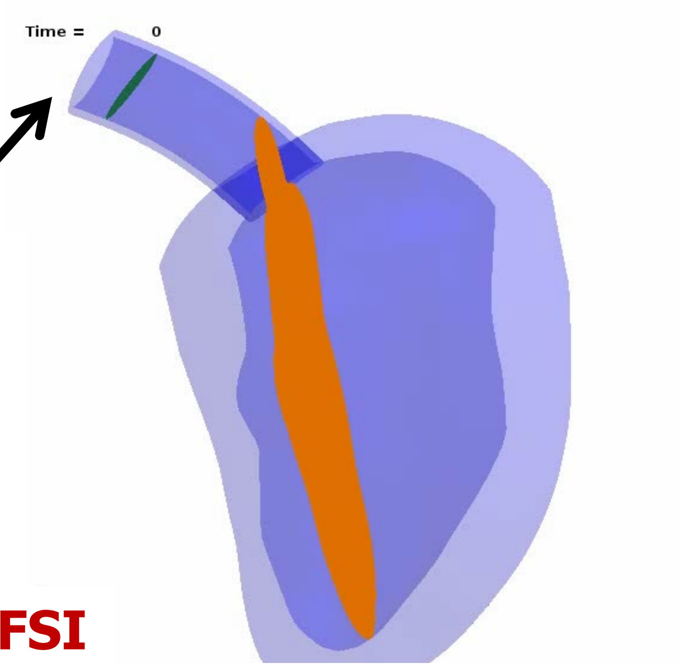
Ventricle with EP+Mechanical+ICFD:

- 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



ECG from EP

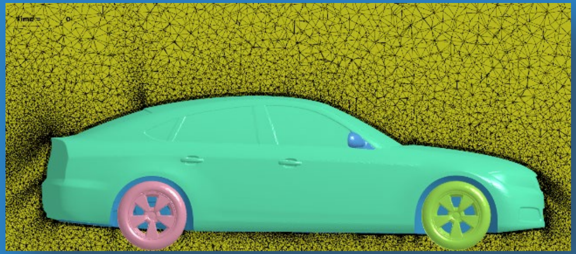


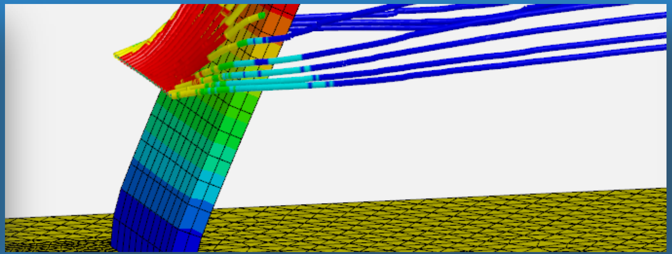


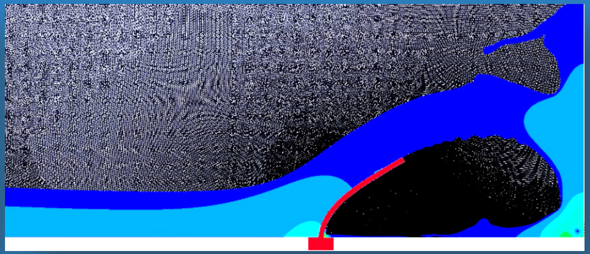
Blood flow through artery from FSI

ICFD
Recent Developments

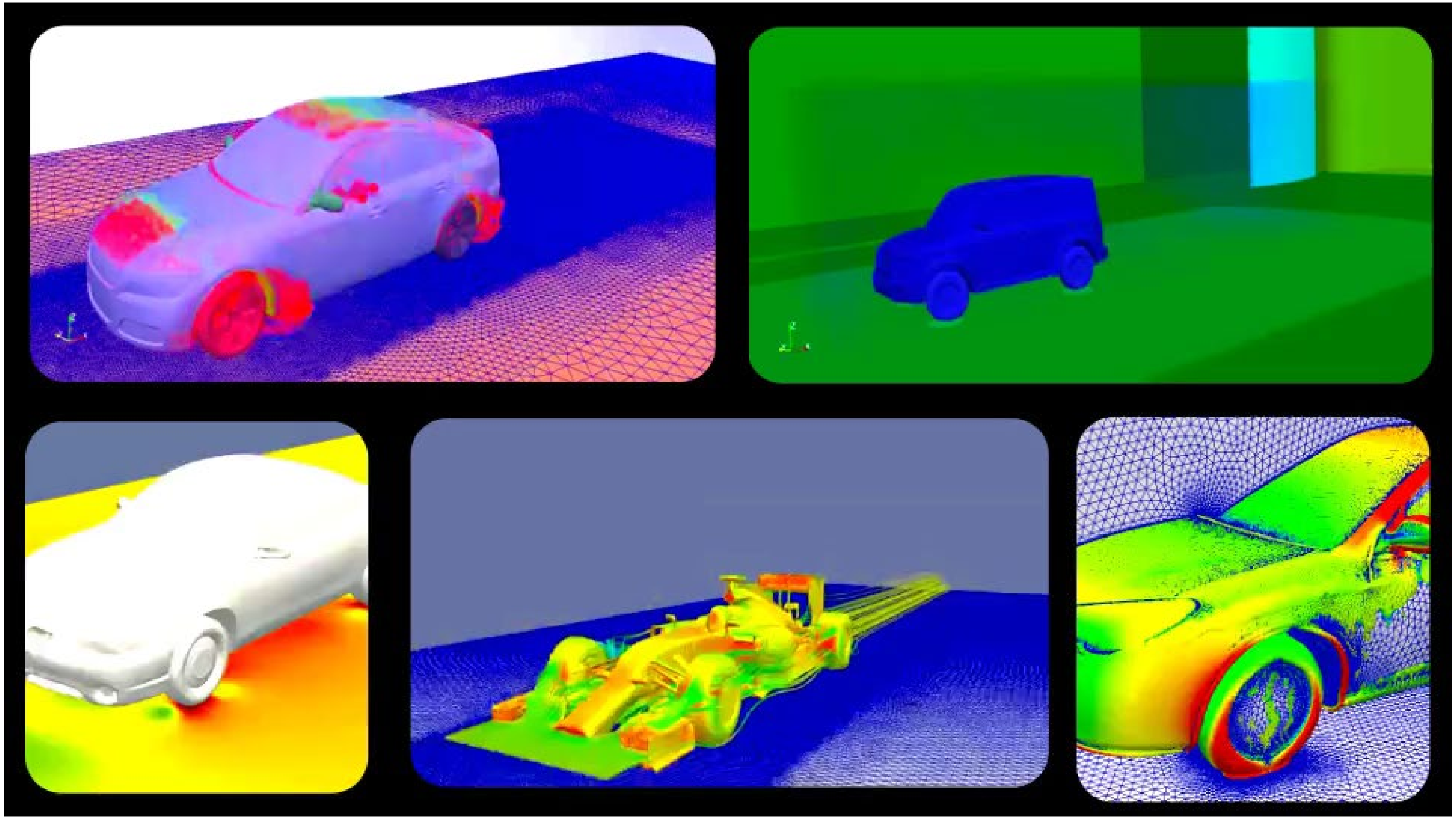
Facundo Del Pin
Iñaki Çaldichoury
Rodrigo R. Paz
Chien-Jung Huang



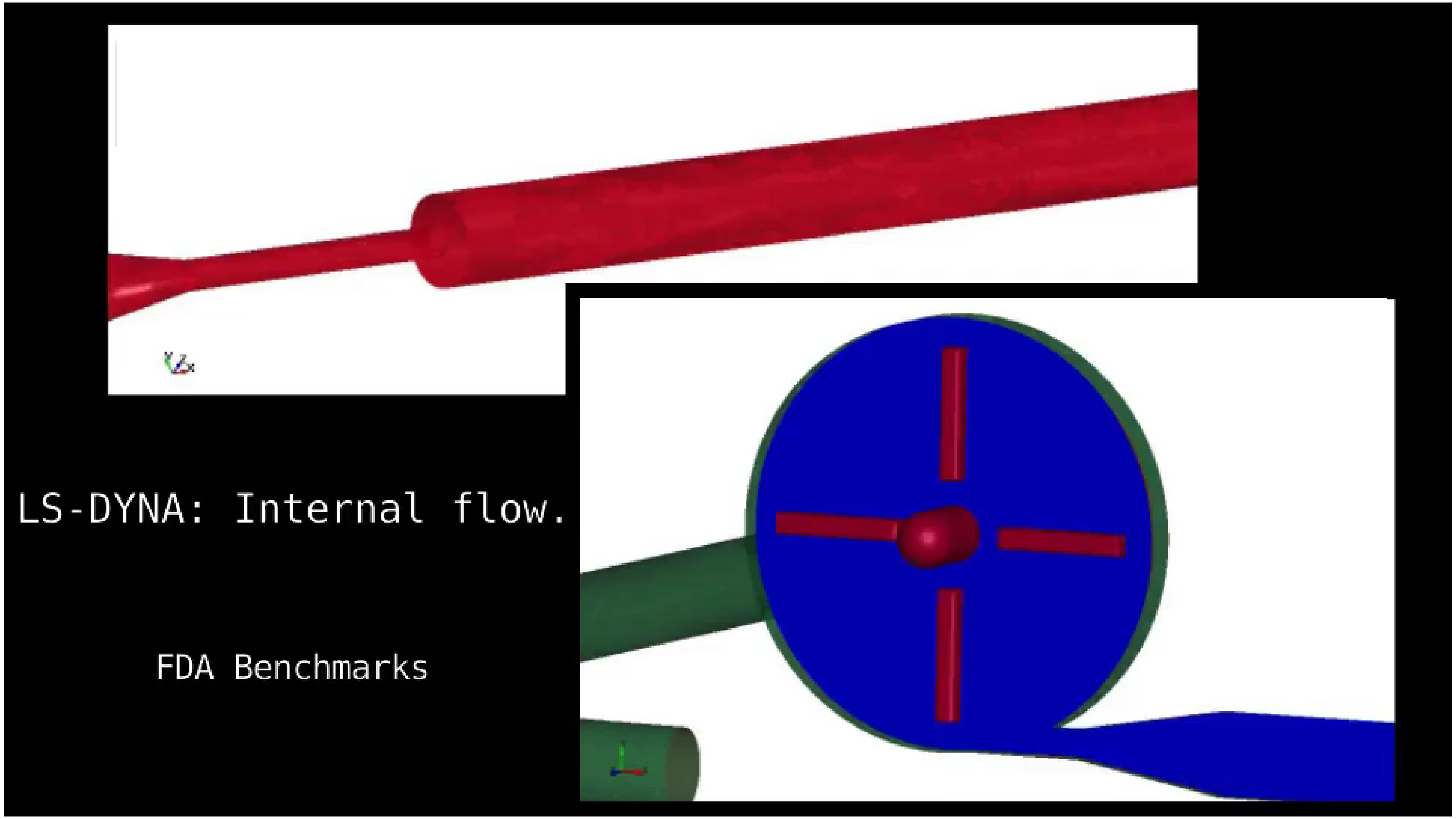




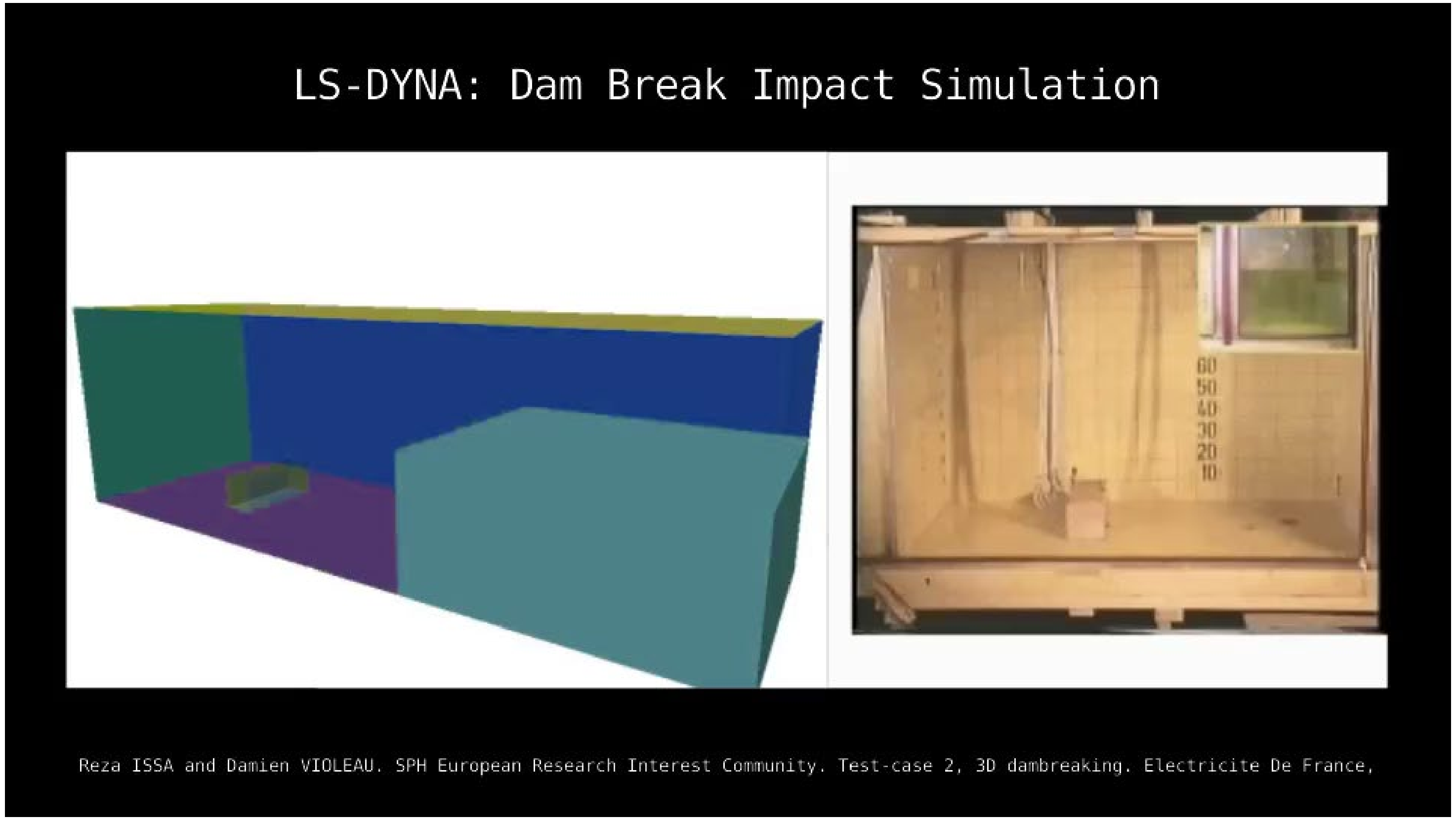
External Flow

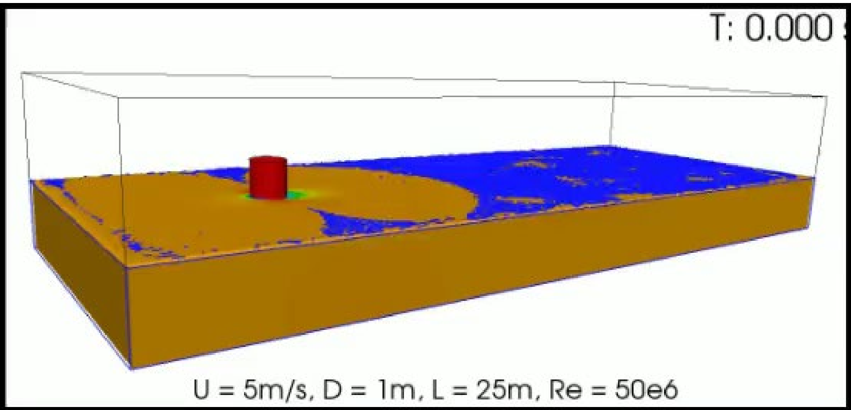


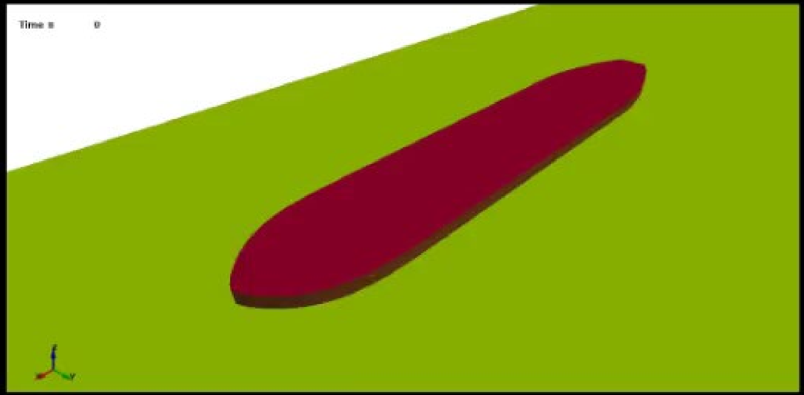
Internal Flow



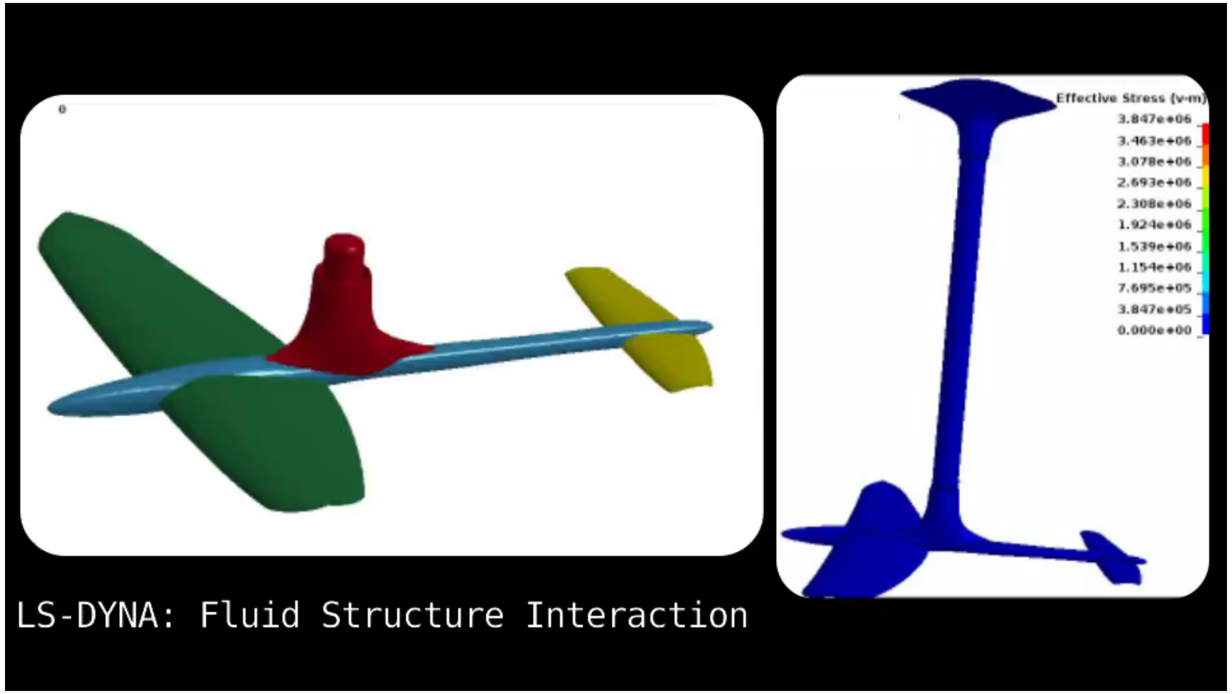
Free Surface and Sloshing

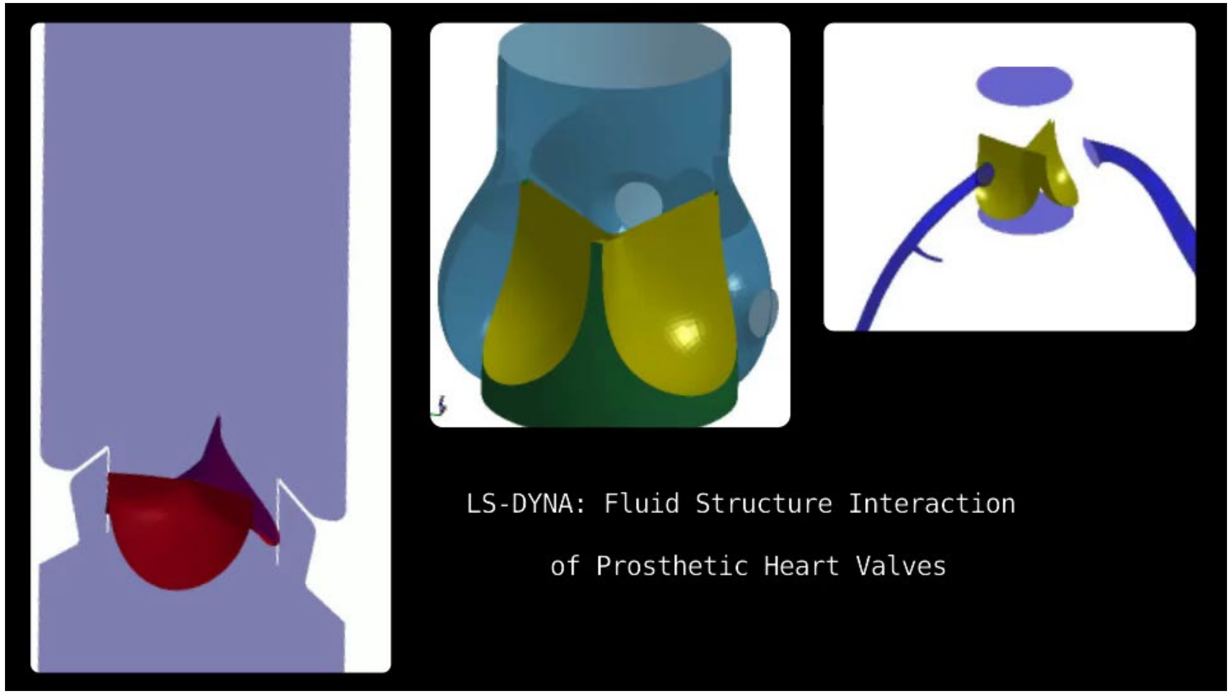




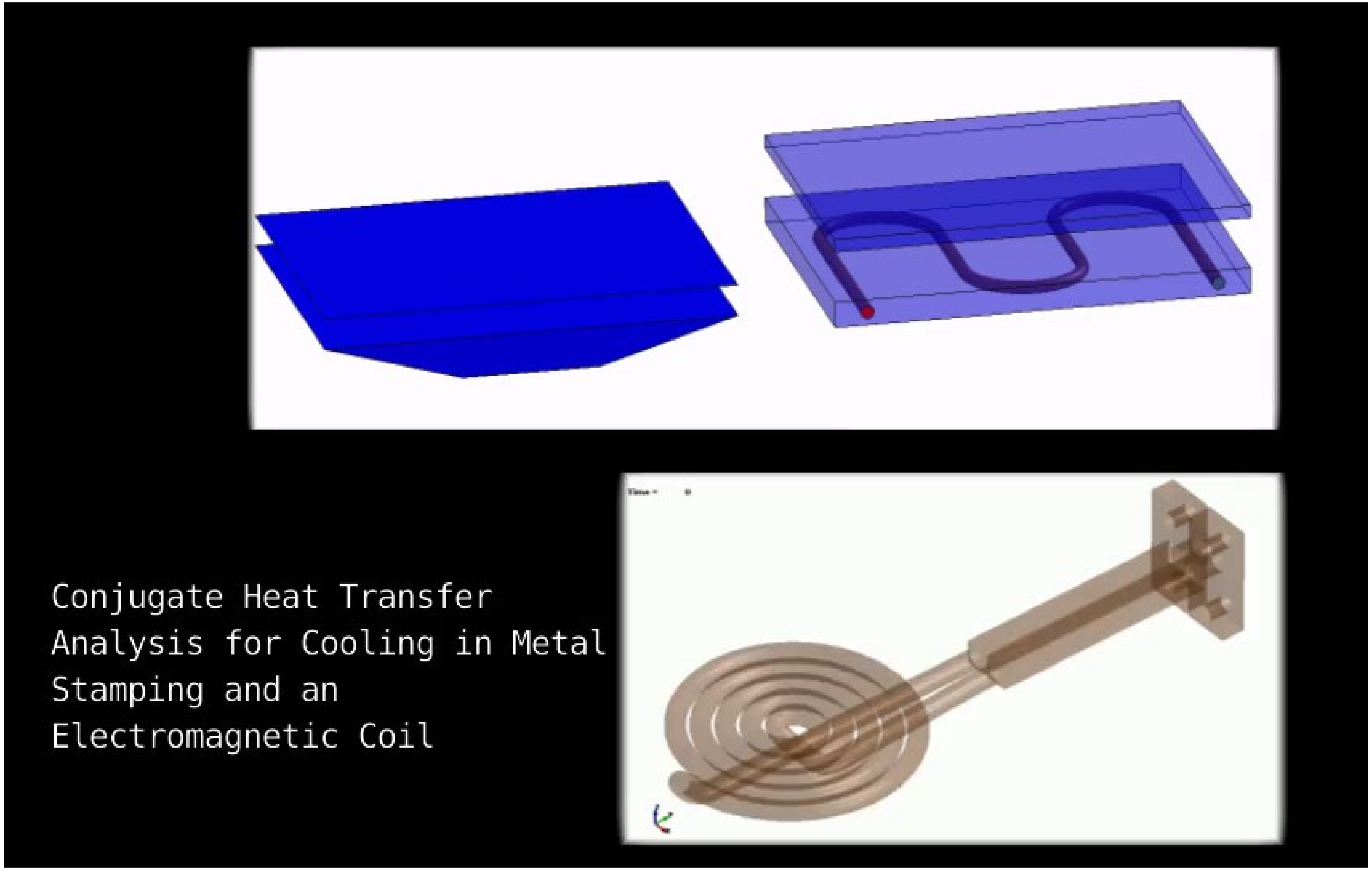


Fluid Structure Interaction (FSI)



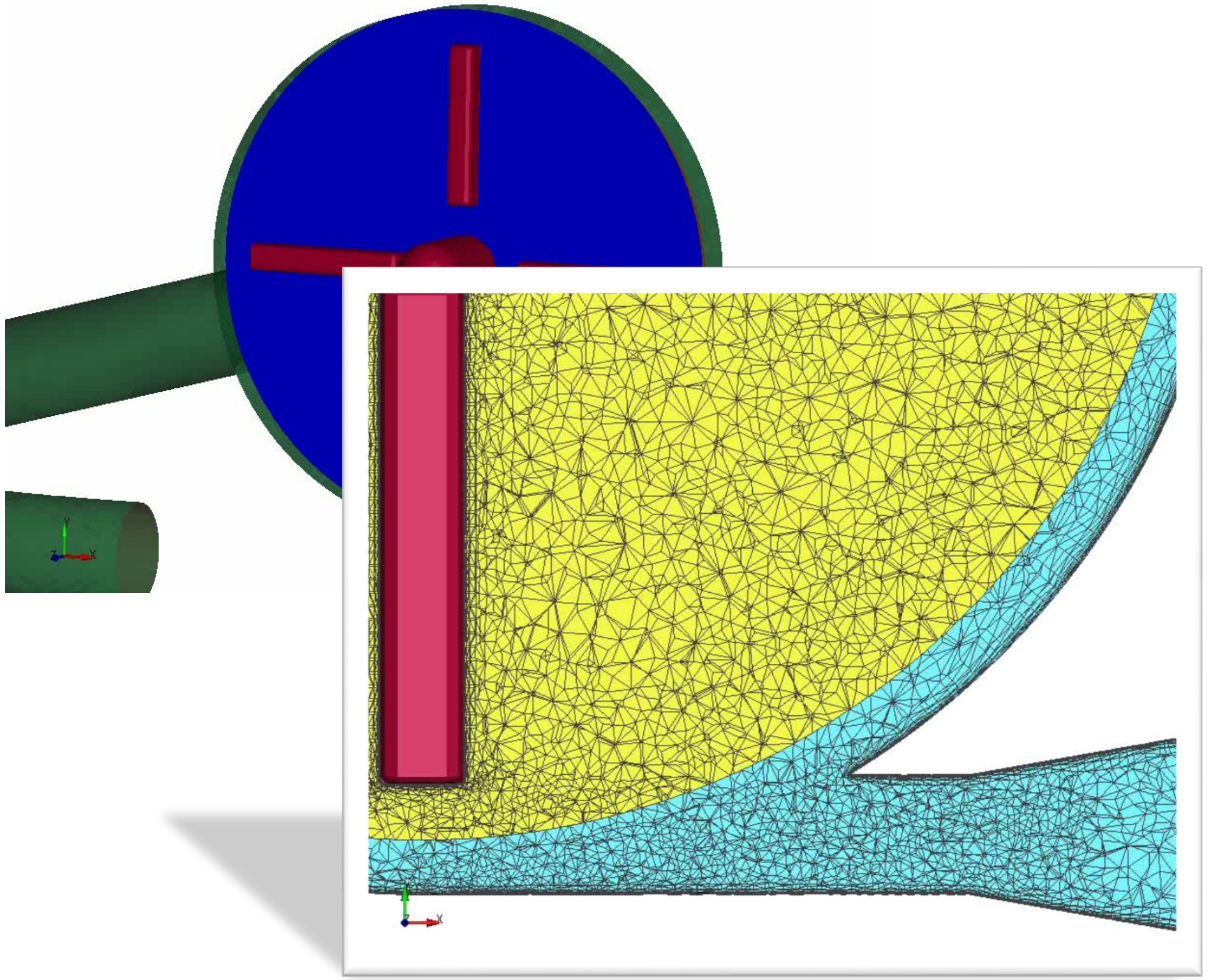


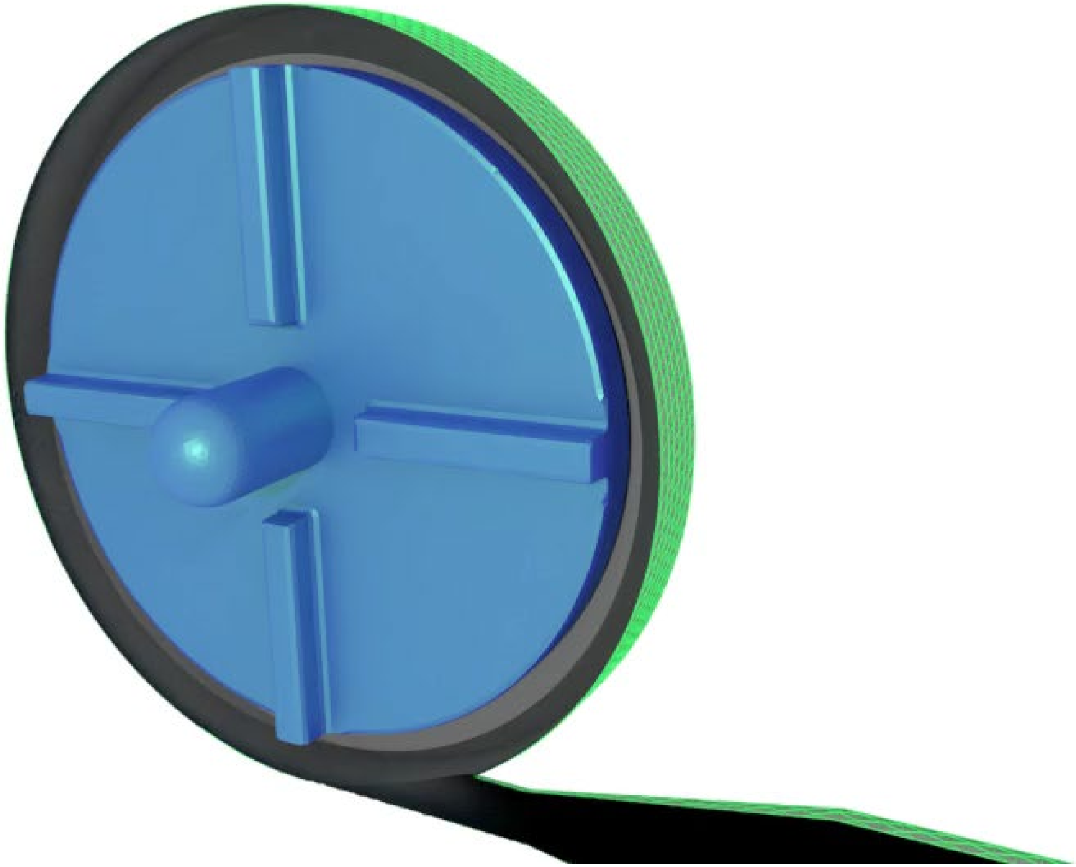
Thermal Analysis



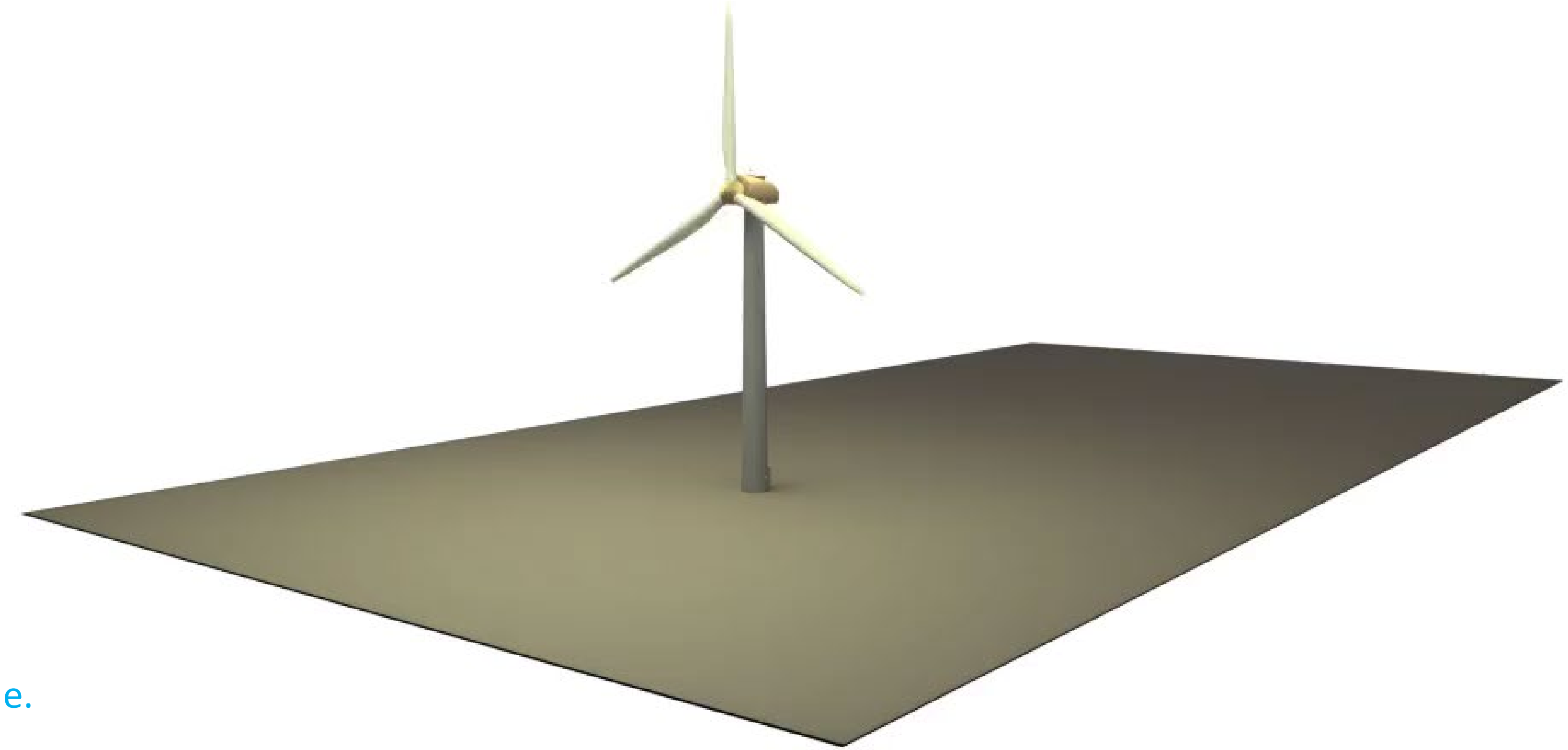
New Features

Sliding mesh



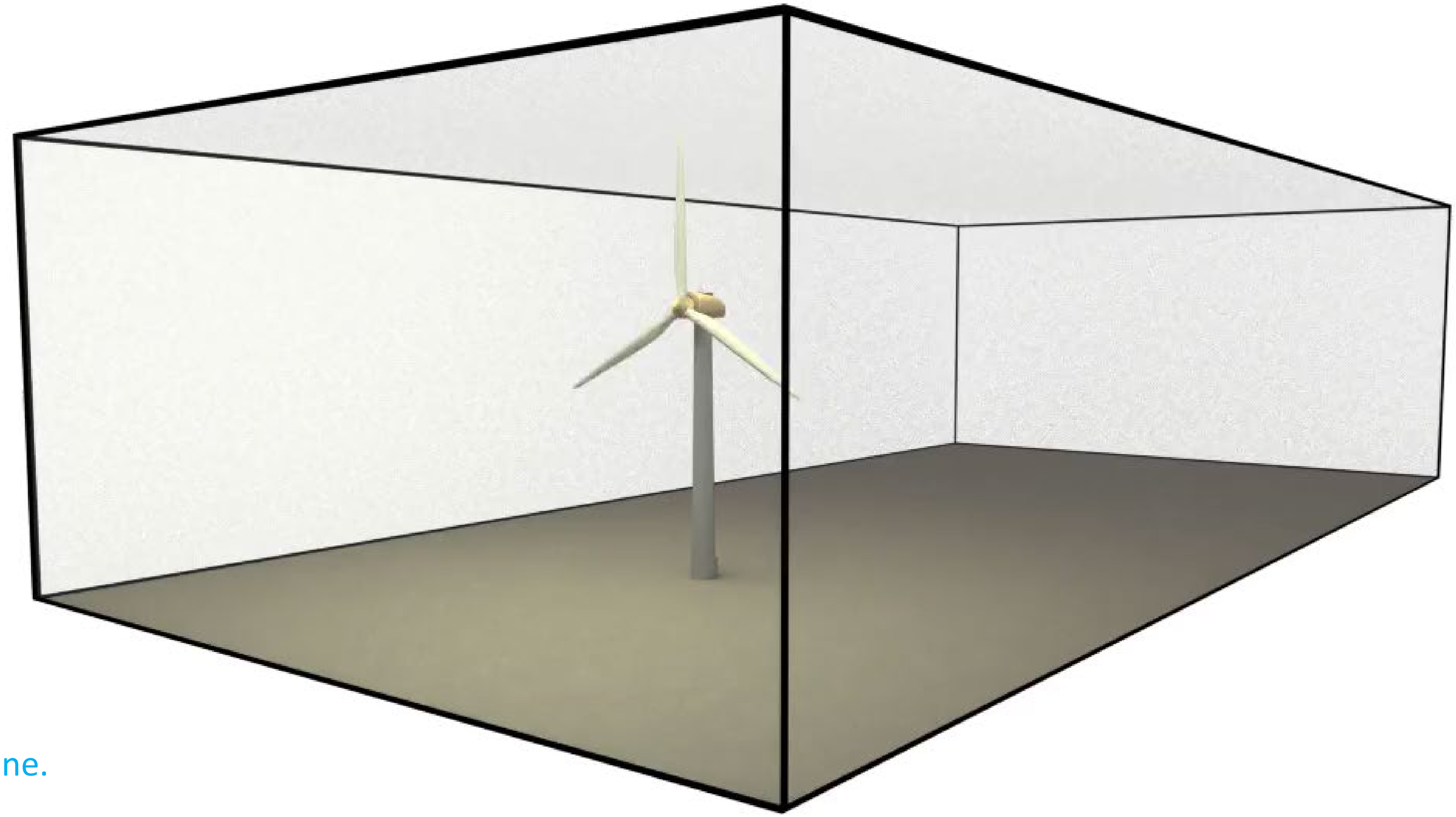


Periodic Boundary Conditions



Horizontal Wind Turbine.

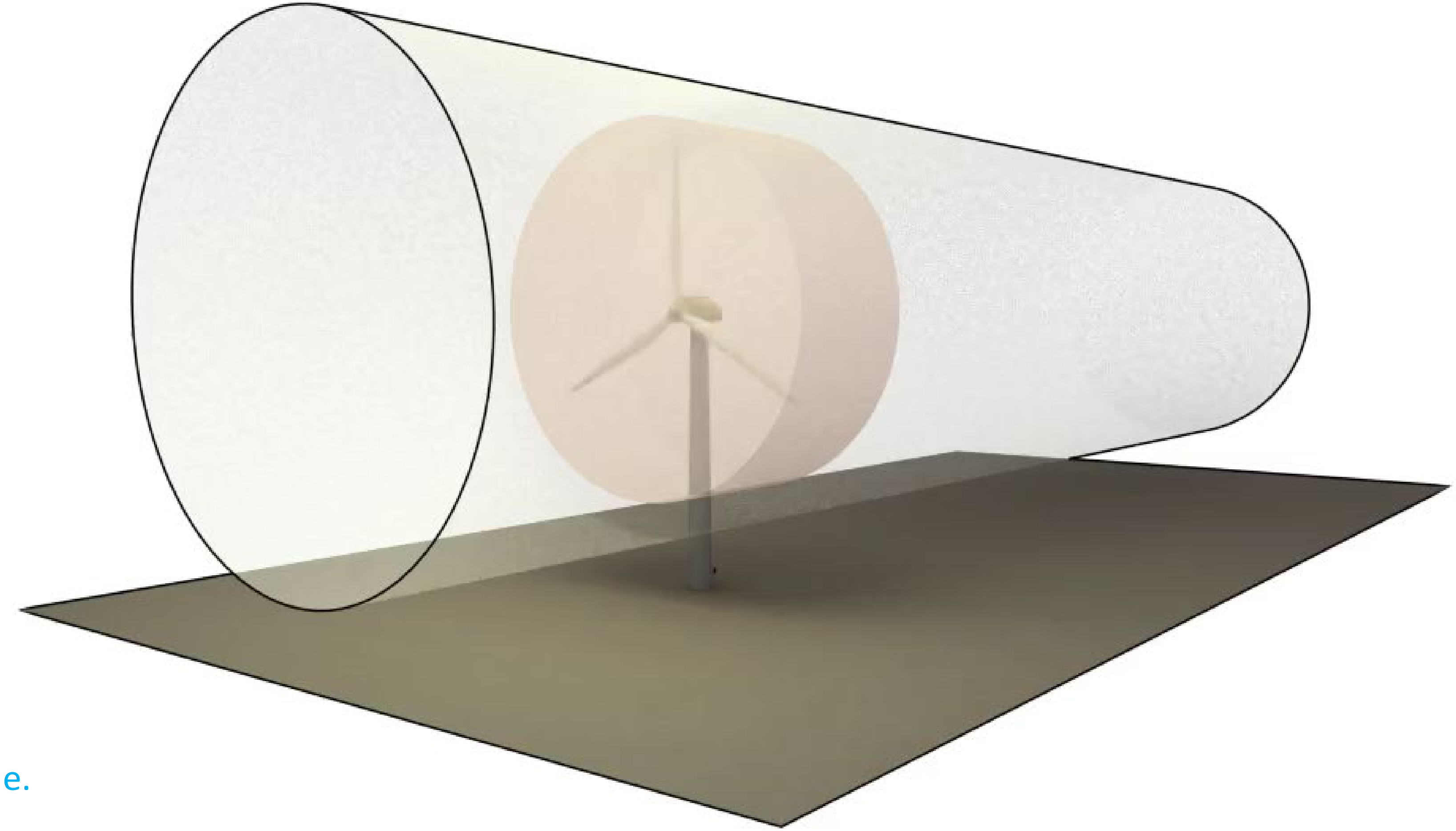
Periodic Boundary Conditions



Horizontal Wind Turbine.

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

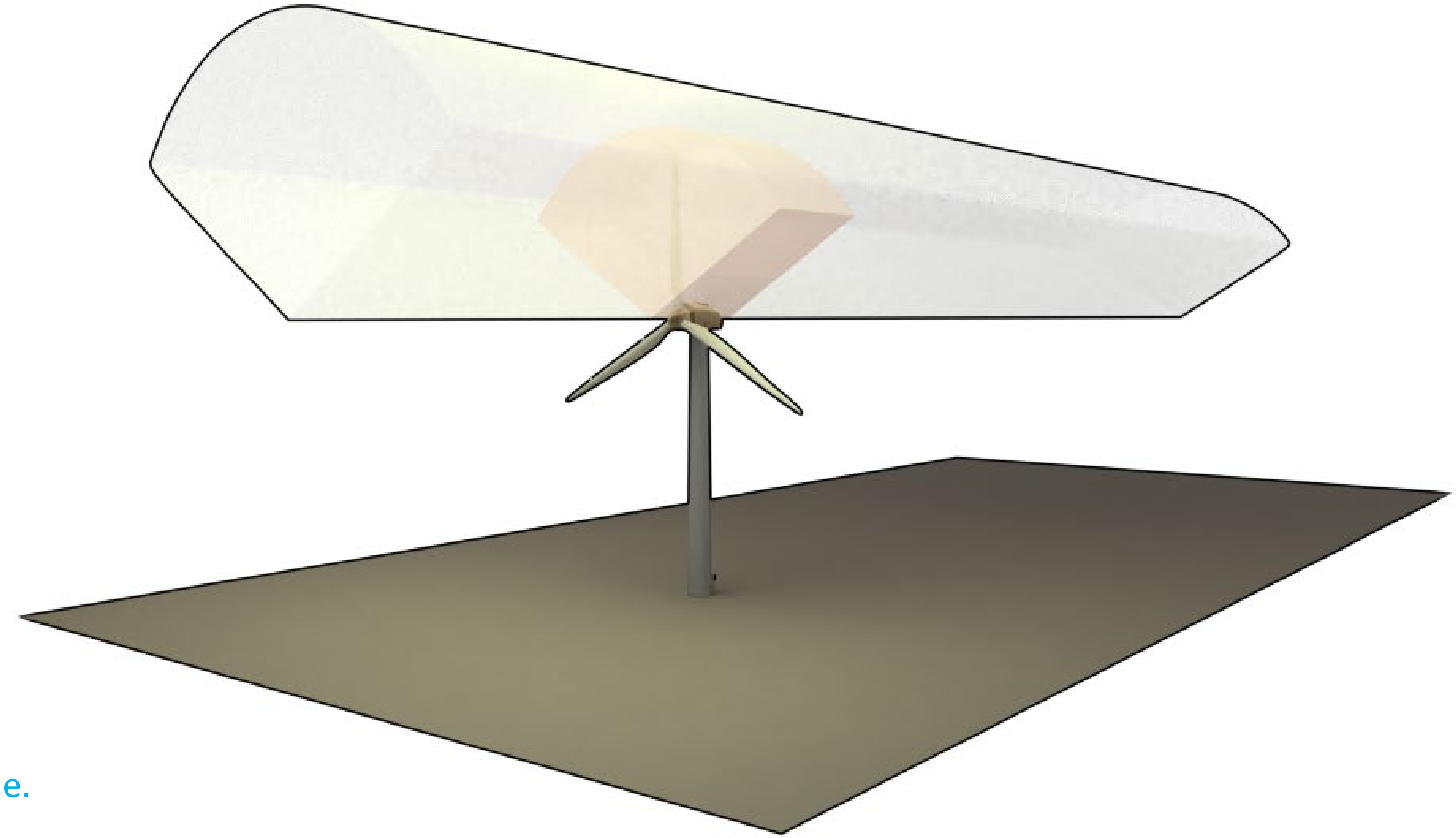
Periodic Boundary Conditions



Horizontal Wind Turbine.

Model a cylinder that contains the turbine.
Results in a smaller mesh but less environment effects. Use sliding mesh or non-inertial reference frame.

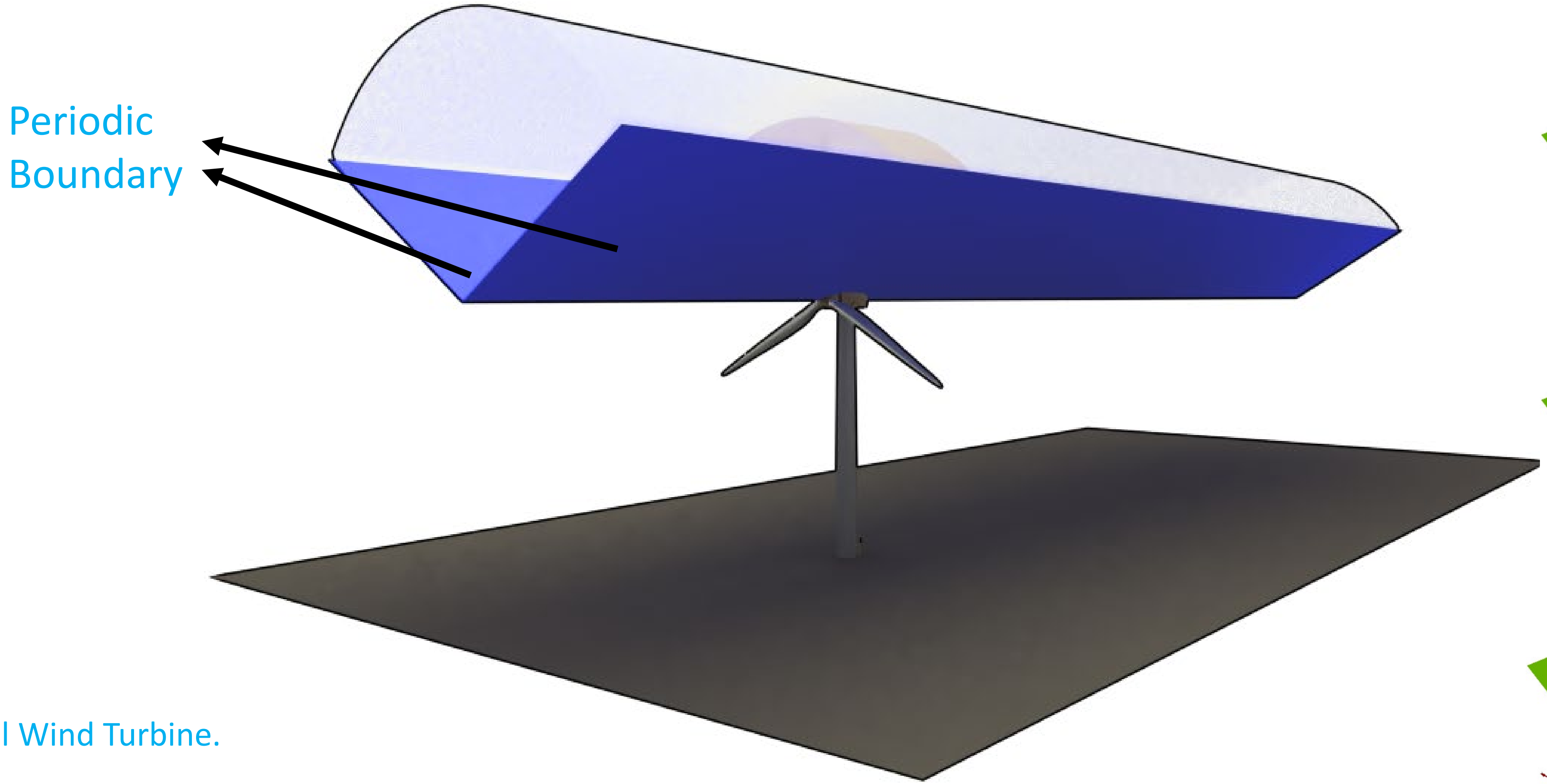
Periodic Boundary Conditions

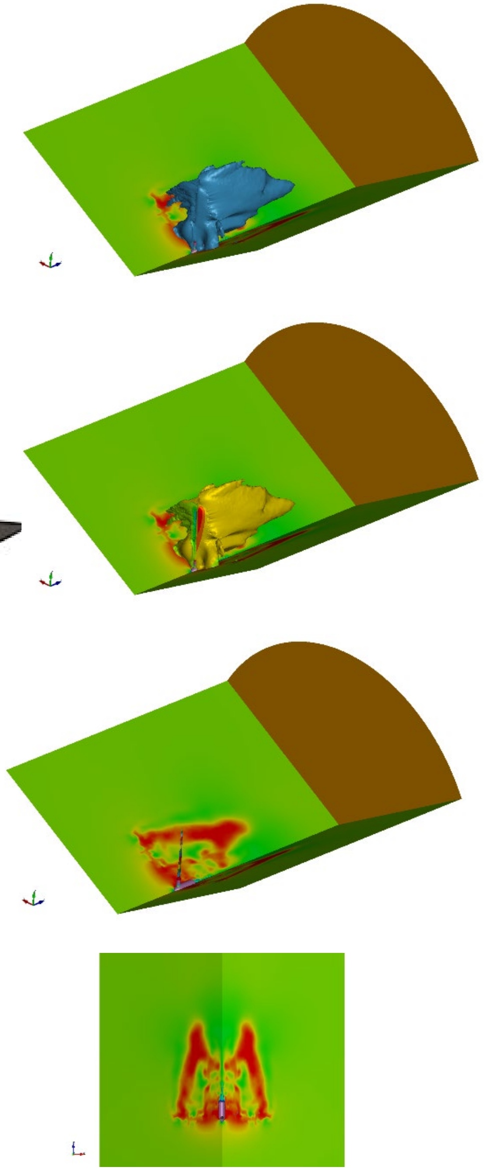


Horizontal Wind Turbine.

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.

Periodic Boundary Conditions



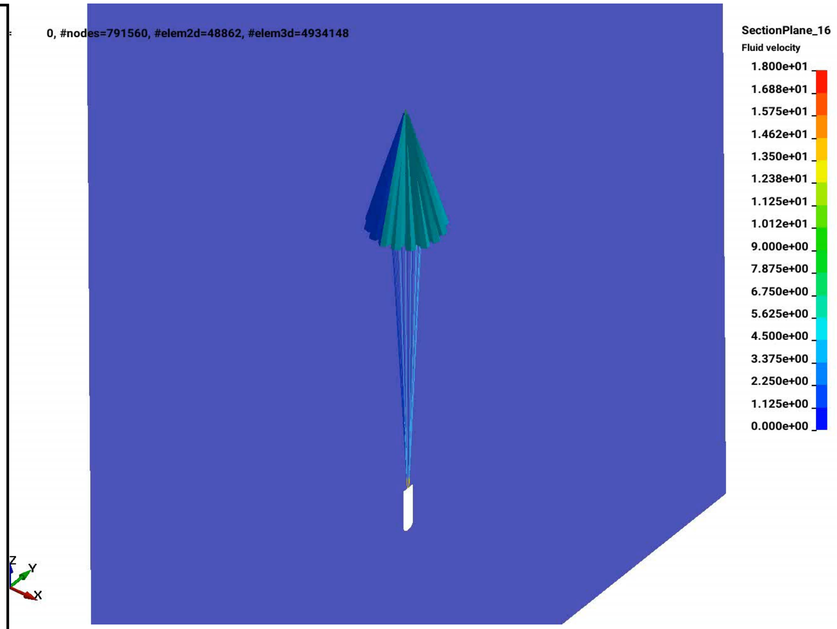


Horizontal Wind Turbine.

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.

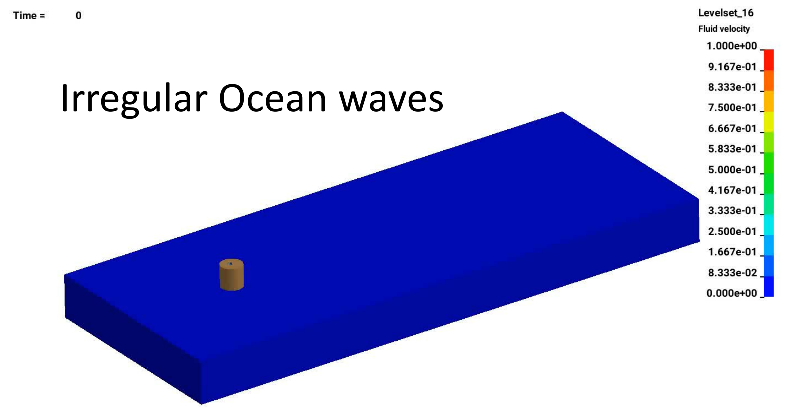
Porous Parachutes and Membranes modeling: an FSI approach.

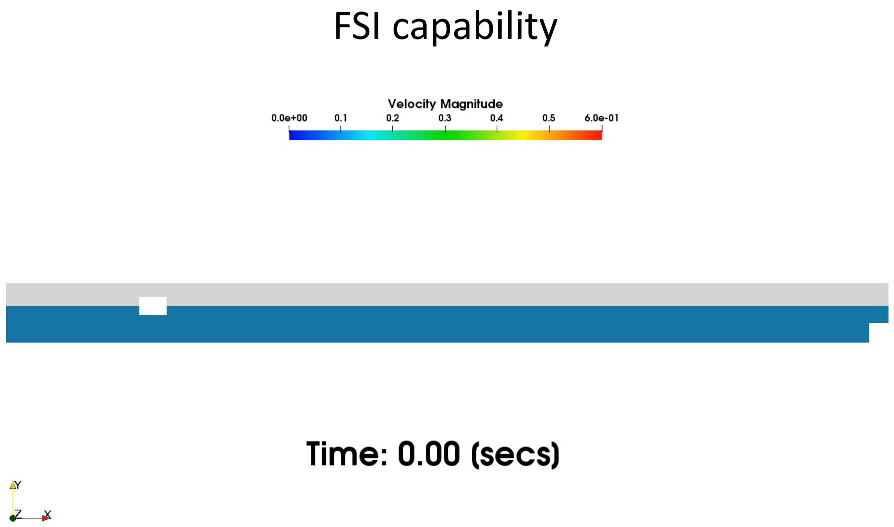
- 2D and 3D FSI porous/permeable parachutes and membranes modeling,
- Pressure drop through the fabric thickness is modeled as $\frac{\partial p}{\partial n} = \alpha\,(u * n) + \beta|u|(u * n)$.
- $\alpha = f(\mu, \kappa)$ and $\beta = f(\rho, \epsilon, \kappa, F)$. Where μ, ρ, ϵ, F is the fluid dynamic 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.

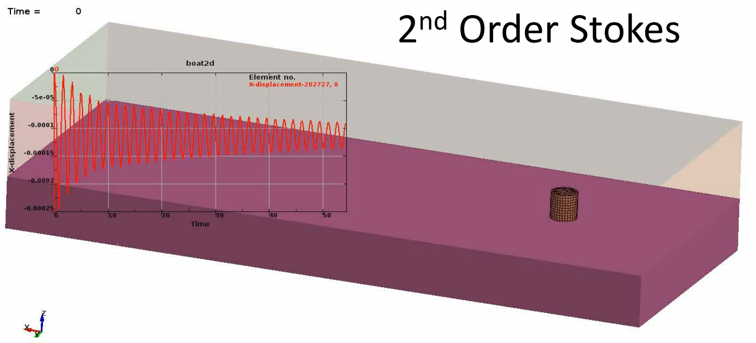


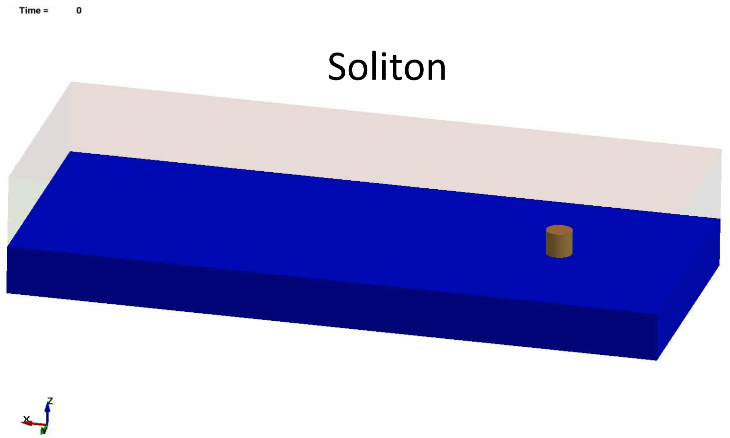
Wave Generator for Free-Surface Flows

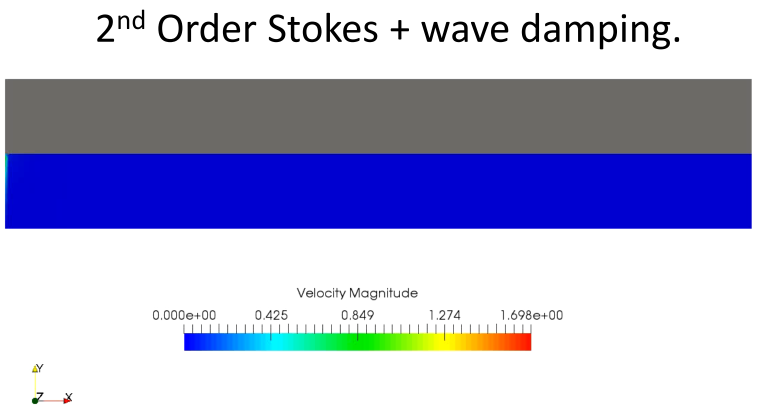
- A complete set of 2D and 3D Regular and Irregular wave shapes for deep/intermediate/shallow water flows:
- **1st, 2nd and 5th Stokes waves,**
- **Solitons (Tsunami-like waves),**
- **Irregular Ocean waves (JONSWAP spectrum).**
- **Wave absorption/damping and FSI capabilities.**



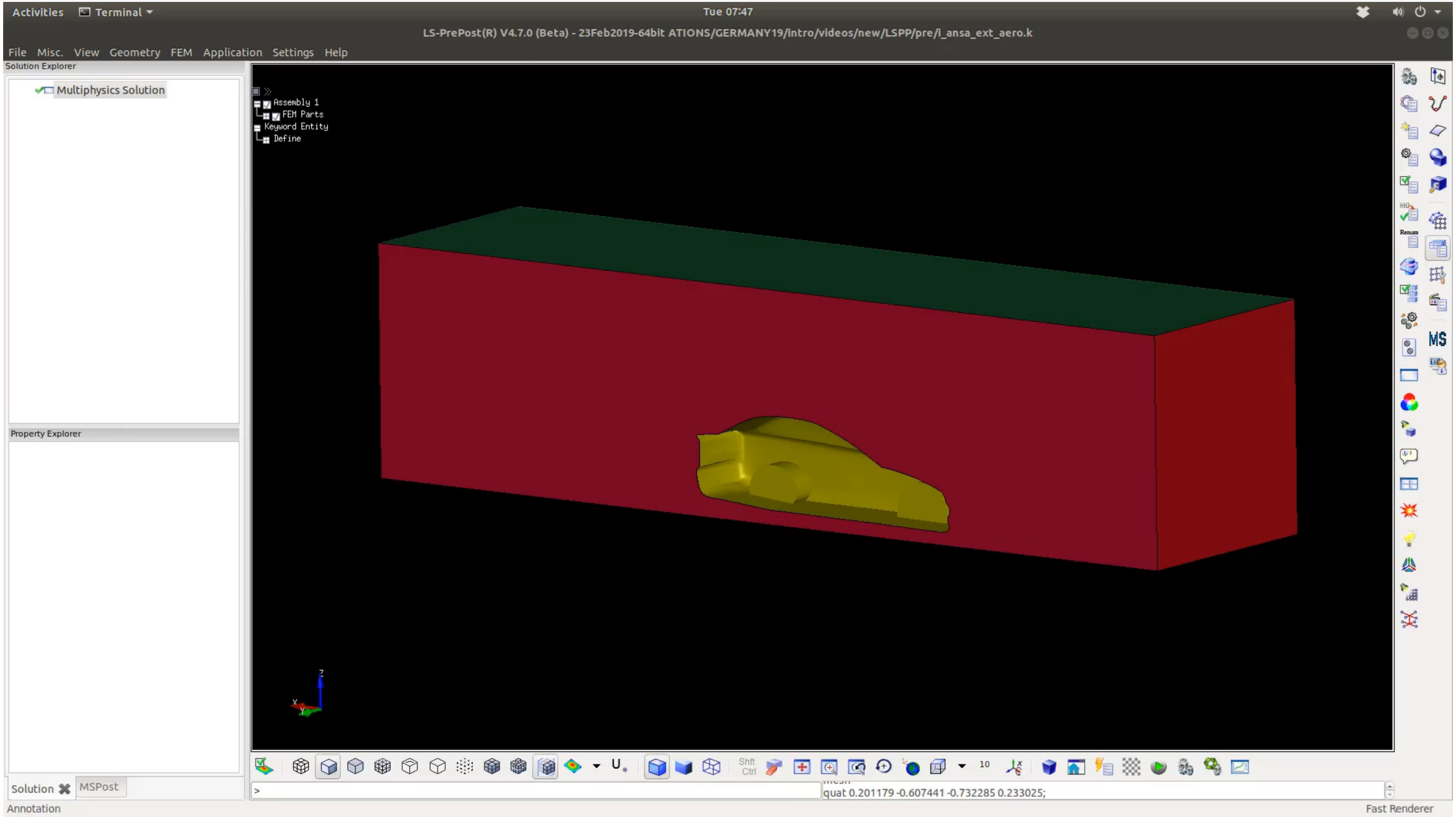




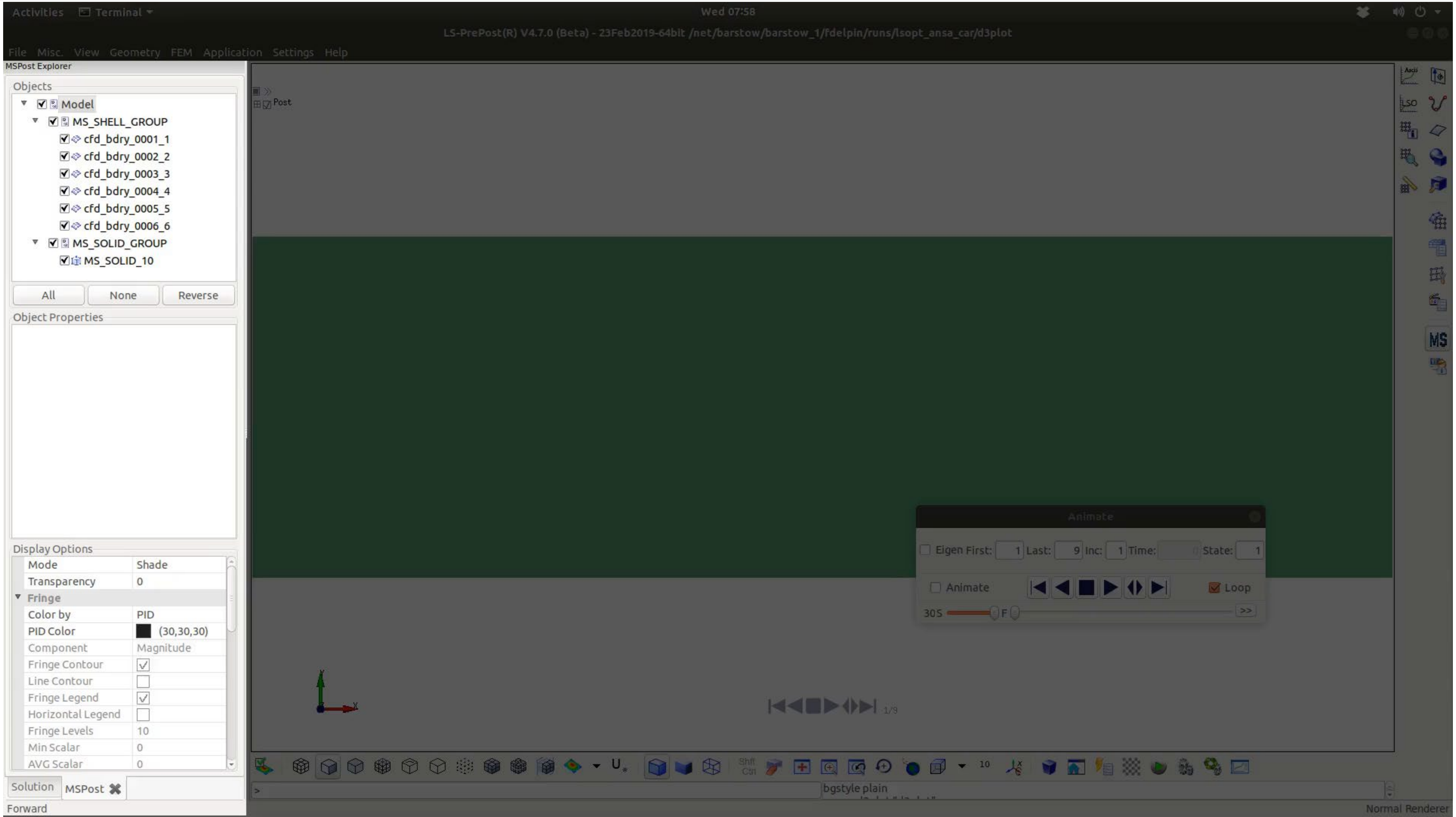




LSPP pre-processor Multi-Solver menu



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

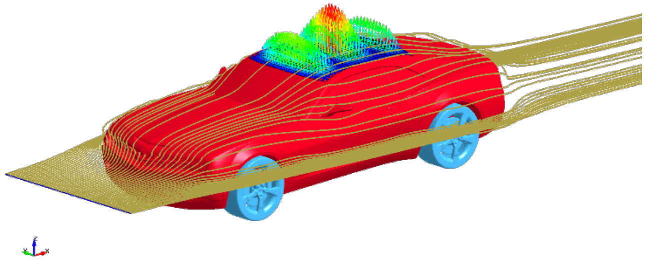
Thank You

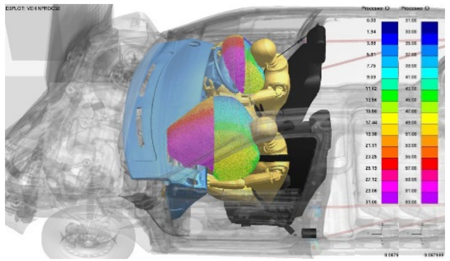
Recent Developments in LS-DYNA – Part II

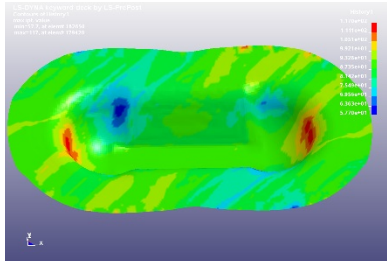
Presented by

Tobias Erhart , Thomas Borrvall

Thank you!







LSTC
Livermore Software Technology Corp.

Thank you!