N-scale Multiscale Design System

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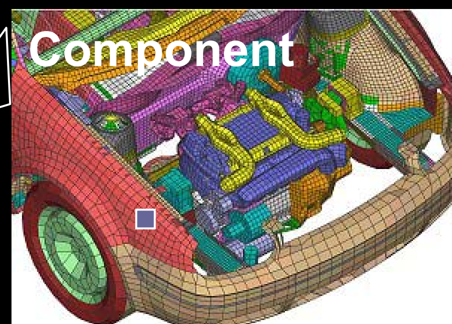
Sponsored by ONR, AFRL, NSF, Rolls-Royce and ACC

Information-Passing Approaches

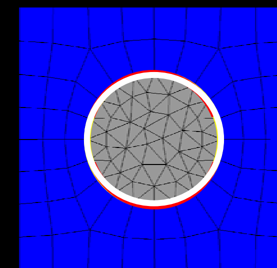
Phenomenological

Material Point

- Advantages
  - Fast
- Disadvantages
  - Reliability
  - Experiments architecture dependent

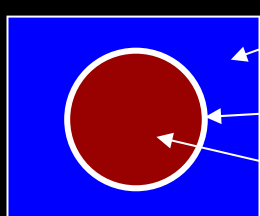


Direct Homogenization



- Advantages
  - Reliability
  - Architecture independent Exp.
- Disadvantages
  - Computationally formidable

Reduced Order Homogenization



- Engineering Accuracy
- Fast
- Architecture independent Experiments

Reduced Order Multiscale Modeling

→J. Fish and K. L. Shek, "Finite Deformation Plasticity of Composite Structures: Computational Models and Adaptive Strategies," Comp. Meth. Appl. Mech. Eng., Vol. 172, pp. 145-174, (1999).

→J. Fish, Q. Yu and K. L. Shek, "Computational Damage Mechanics for Composite Materials Based on Mathematical Homogenization," International Journal for Numerical Methods in Engineering, Vol. 45, pp. 1657-1679, (1999).

→J. Fish and K.L. Shek, "Multiscale Analysis Of Large Scale Nonlinear Structures and Materials," International Journal for Computational Civil and Structural Engineer-ing, Vol. 1, No. 1, pp. 79-80, (2000).

→J. Fish and Q. Yu, "Multiscale Damage Modeling for Composite Materials: Theory and Computational Framework," International Journal for Numerical Methods in Engi-neering, Vol. 52, pp. 161-191, (2001).

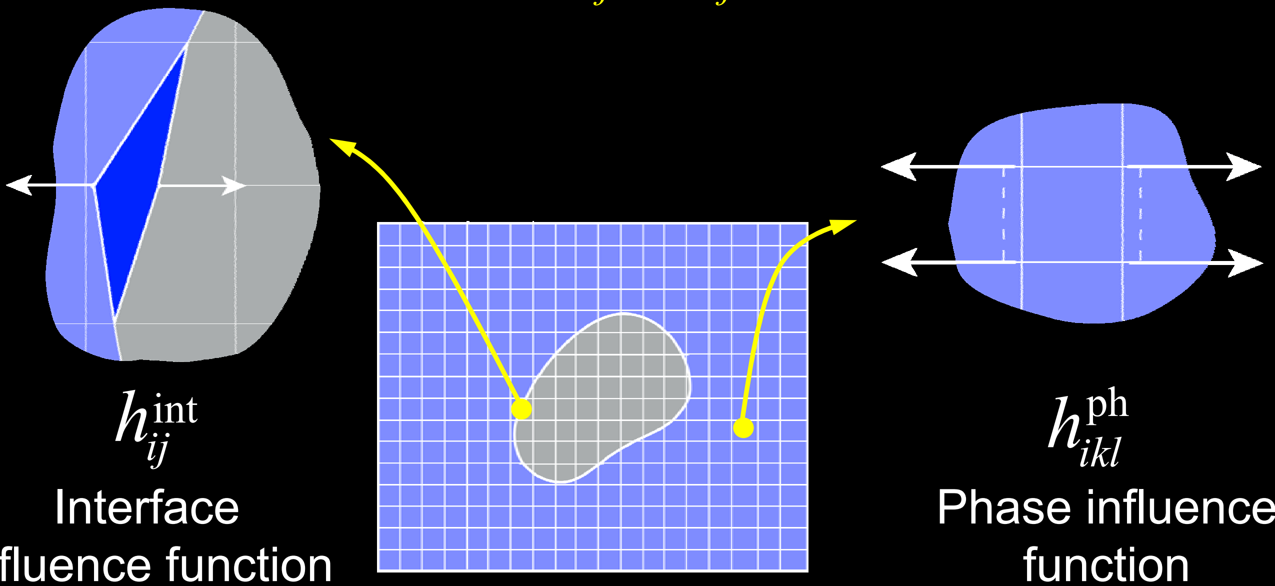
→Z. Yuan and J. Fish, "Towards Realization of Computational Homogenization in Practice," International Journal for Numerical Methods in Engineering, in print (2007)

→C. Oskay and J. Fish, "Eigendeformation-Based Reduced Order Homogenization," Comp. Meth. Appl. Mech. Engng., Vol. 196, pp. 1216-1243, (2007).

→ J. Fish and Z. Yuan, "N-scale Model Reduction Theory," in Bridging the Scales in Science and Engineering, Fish, J., ed. 2008, Oxford University Press.

Reduced Order Model

- Influence functions: $H_{ijkl}, h_{ij}^{\text{int}}, h_{ikl}^{\text{ph}}$

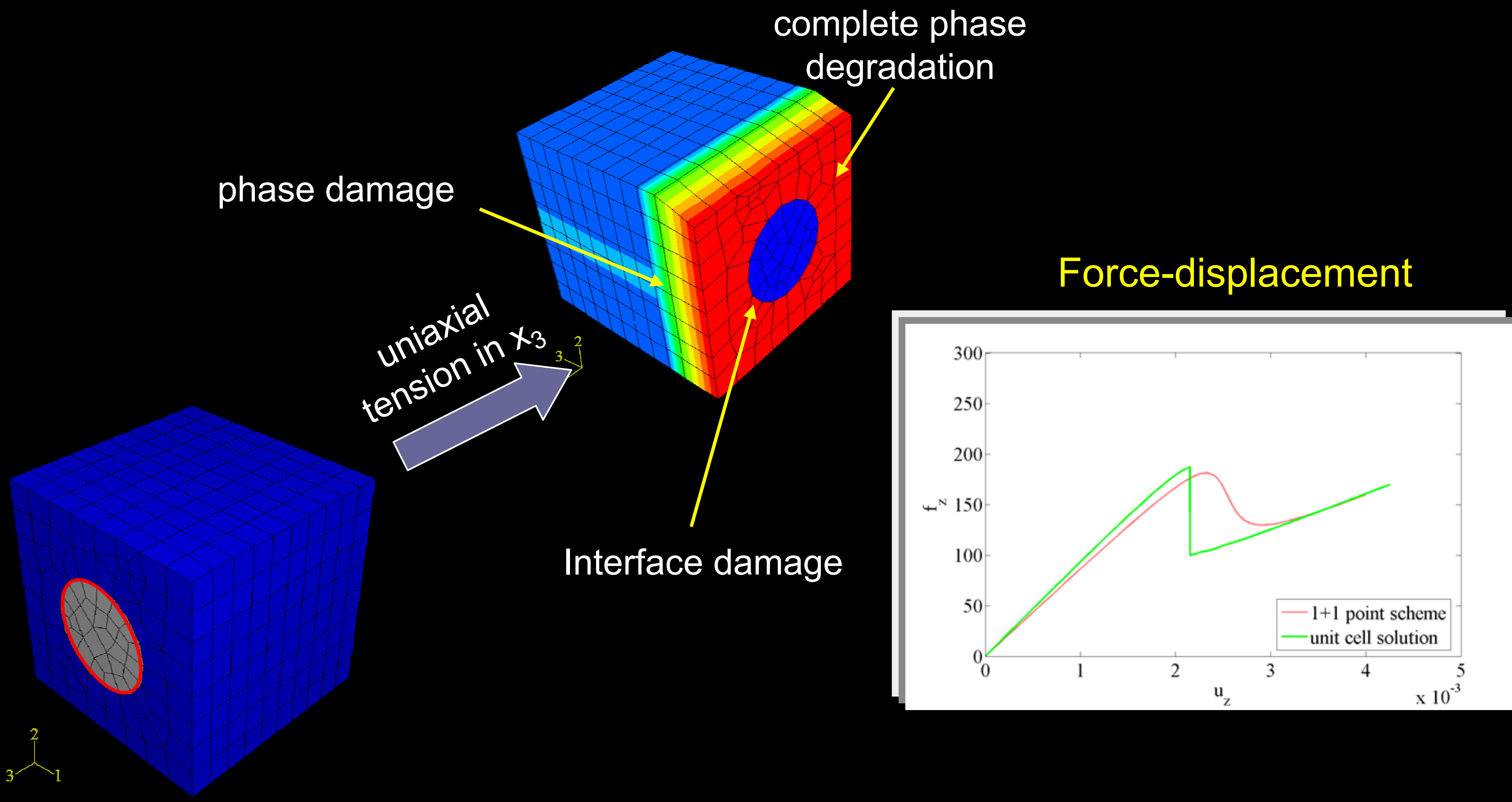


- Coefficient tensors: $\bar{L}_{ijkl}, \bar{R}_{ijk}^{(\beta)}, \bar{M}_{ijkl}^{(\eta)}$
  - In the form of integrals
  - Function of influence functions;
- Macro constitutive equation:

$$\bar{\sigma}_{ij}(\mathbf{x},t) = \bar{L}_{ijkl}\bar{\varepsilon}_{kl}(\mathbf{x},t) + \sum_{\beta=1}^{m} \bar{R}_{ijk}^{(\beta)} \delta_k^{(\beta)}(\mathbf{x},t) + \sum_{\eta=1}^{n} \bar{M}_{ijkl}^{(\eta)} \mu_{kl}^{(\eta)}(\mathbf{x},t)$$

Verification –A single Unit Cell

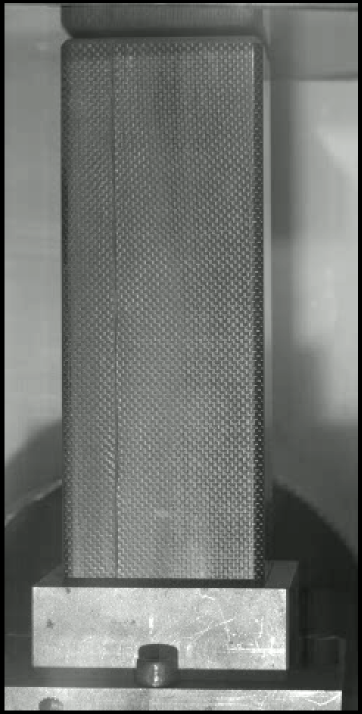
Phase and Interface damage - axial loading

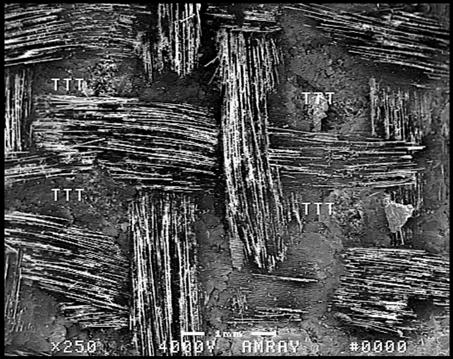


Technology Transfer

- Crash predictions of composite cars (General Motors, Ford, Chrysler)
- Life prediction of JSF ceramic composites engine (Rolls-Royce, Northrop-Grumman)
- Manufacturing of composite fan blades (General Electric)
- Energy absorption of ship structures (ONR)
- Multiscale Modeling Munitions Systems (AFRL)
- Multiscale analysis of nanostructures (ARL, Sandia, DOE, NSF)

GM, Ford, Chrysler
Light-weight fuel-efficient vehicles

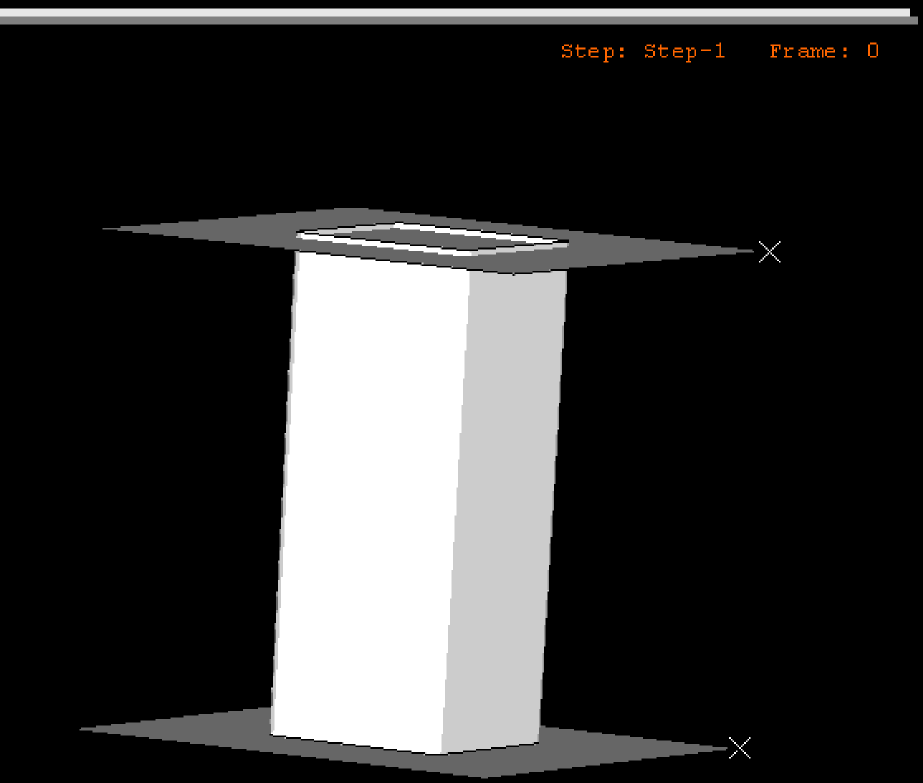


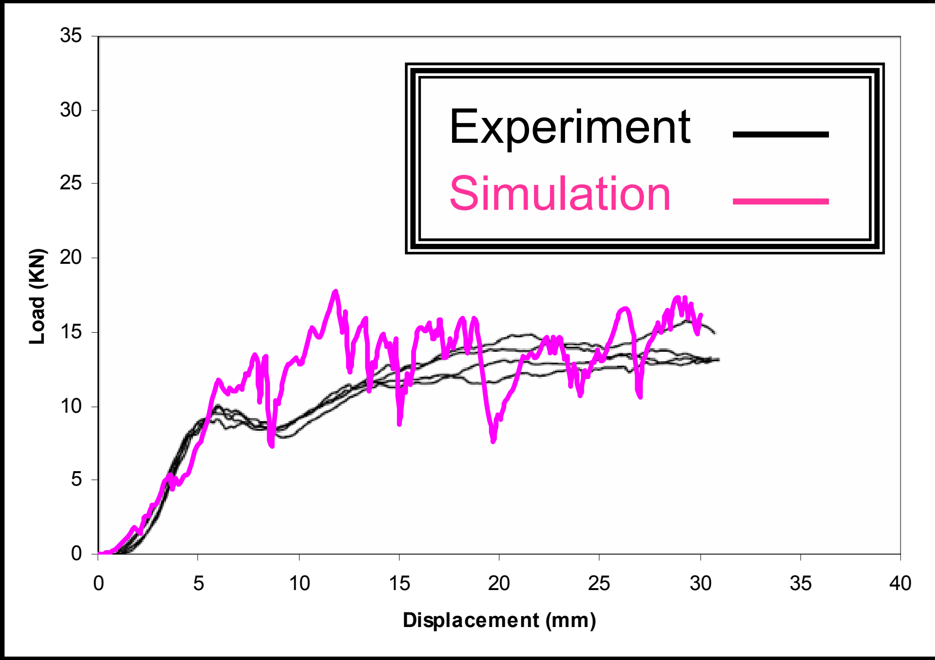


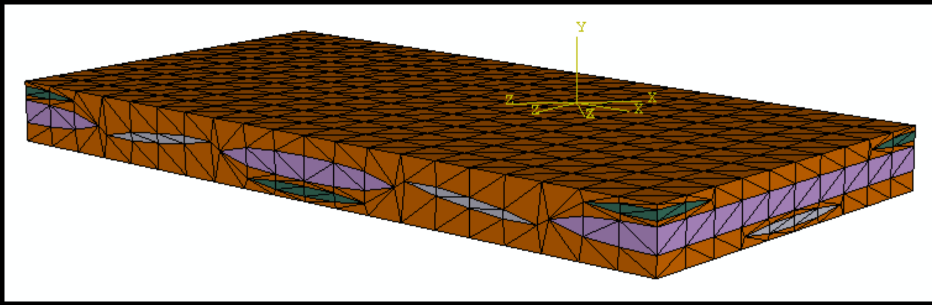
Experiment: Oak Ridge

National Laboratory, DOE

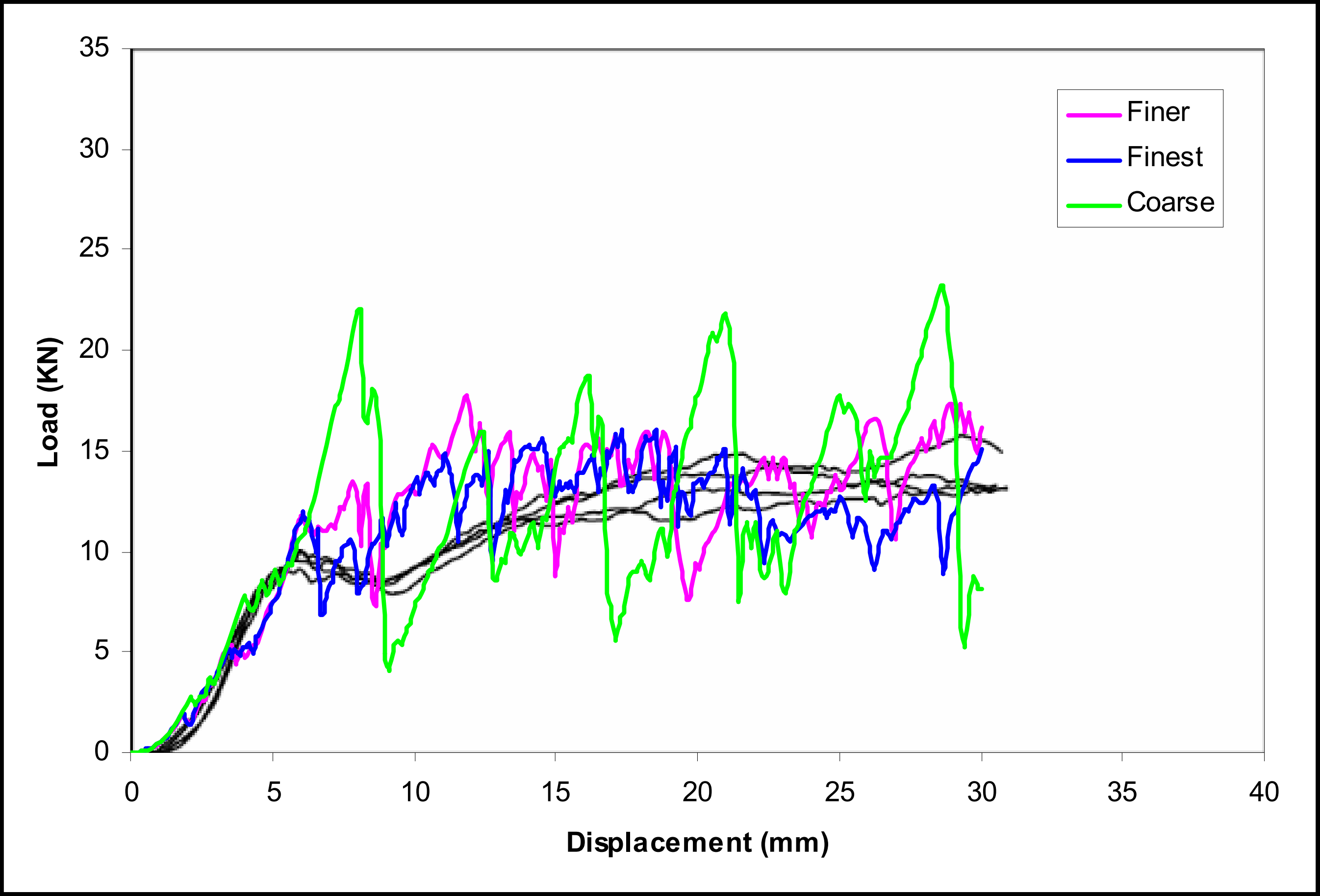
Model Validation



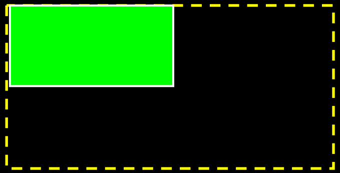




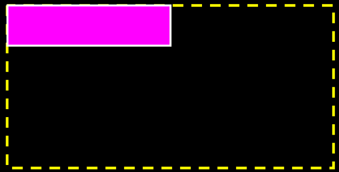
Tube Crush Simulation
Mesh Dependence (C45 °)



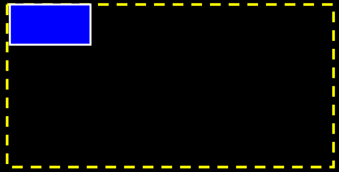
Coarse

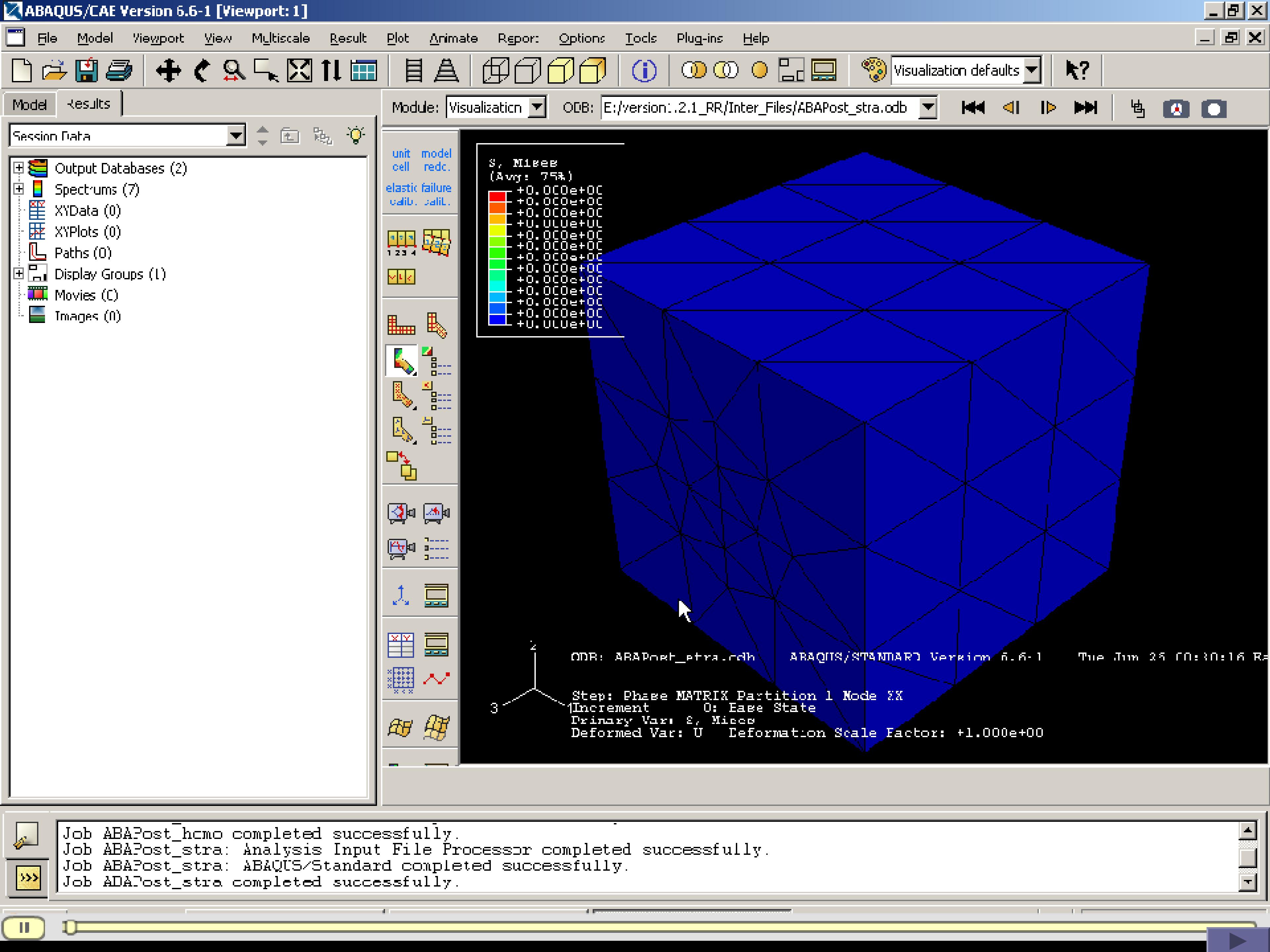


Finer



Finest

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File Model Viewport View Multiscale Result Plot Animate Report Options Tools Plug-ins Help
Visualization defaults
Model Results
Module: Visualization
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Session Data
Output Databases (2)
Spectrums (7)
XYData (0)
XYPlots (0)
Paths (0)
Display Groups (1)
Movies (0)
Images (0)
unit cell
model redc.
elastic calib.
failure calib.
S, Mises
(Avg: 75%)
+0.000e+00
ODB: ABAPost_stra.odb ABAQUS/STANDARD Version 6.6-1
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Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +1.000e+00
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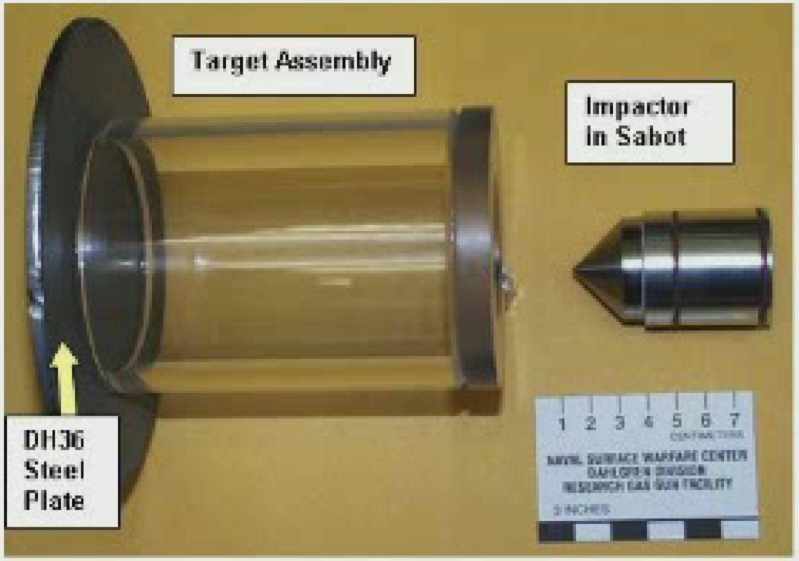
Job ABAPost_stra: Analysis Input File Processor completed successfully.
Job ABAPost_stra: ABAQUS/Standard completed successfully.
Job ABAPost_stra completed successfully.

Multiscale in time for impact simulation

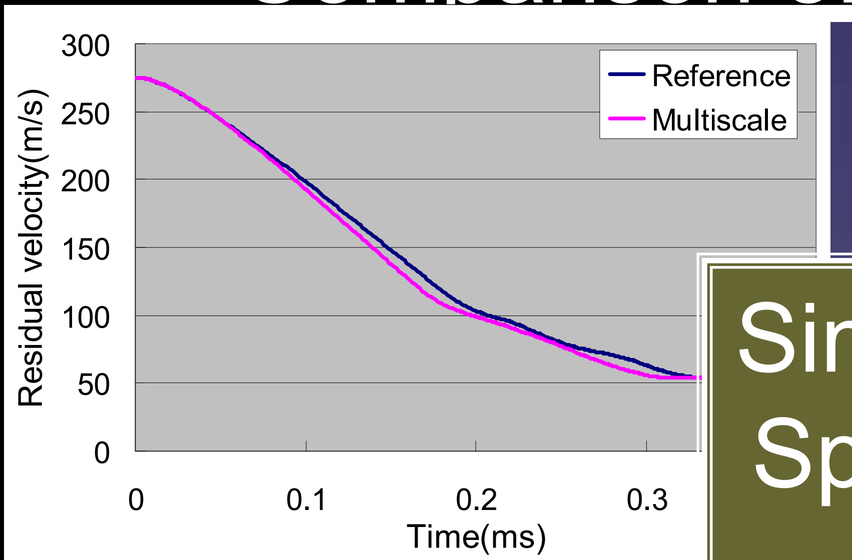
Impact of DH36-Polyurea plates

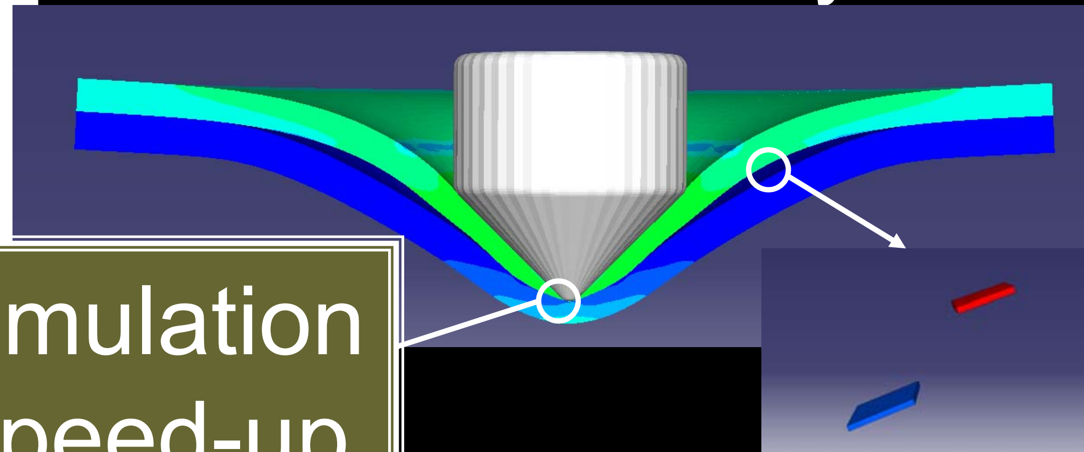


DH36/Polyurea Model – Nemat Nasser
Interface Model – Liechti and Wu
Impact Experiments – Bill Mock
Multiscale Model – Fish and Fan

Program Monitor – Roshdy Barsoum

Comparison of stress and velocity

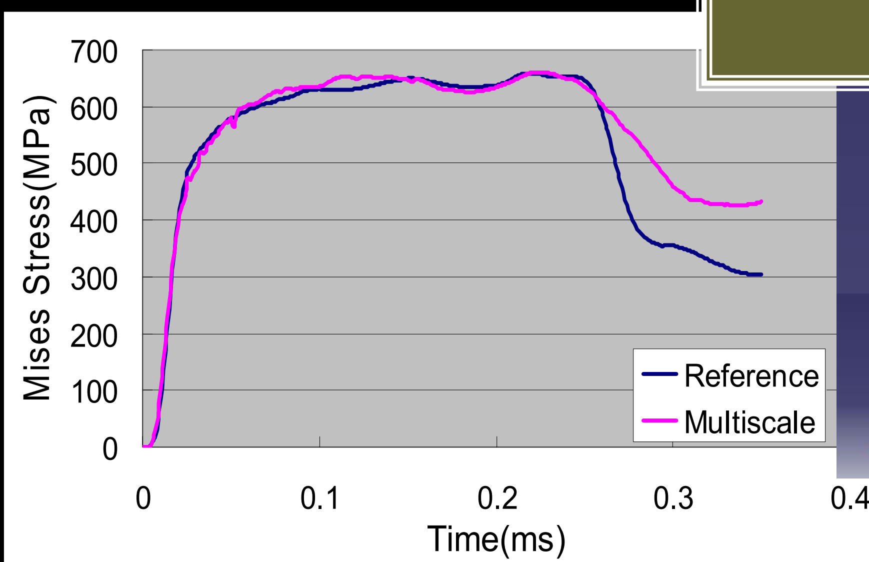


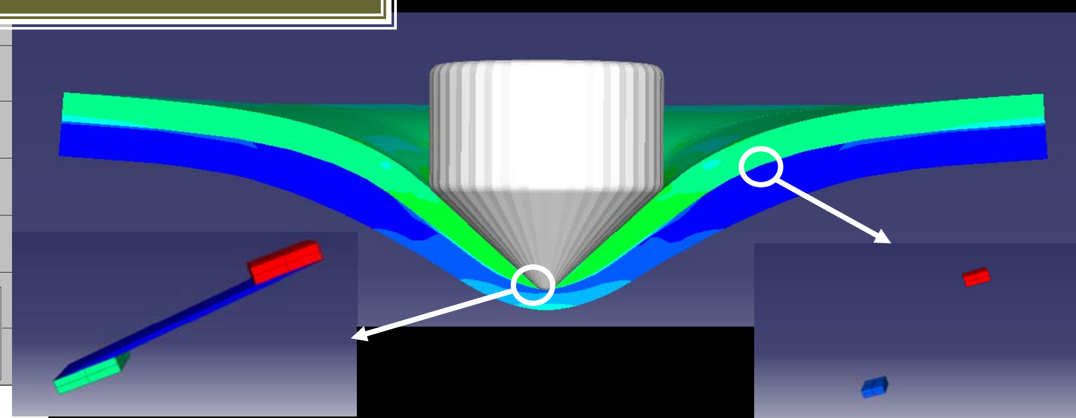


Reference t=15ms

Simulation Speed-up

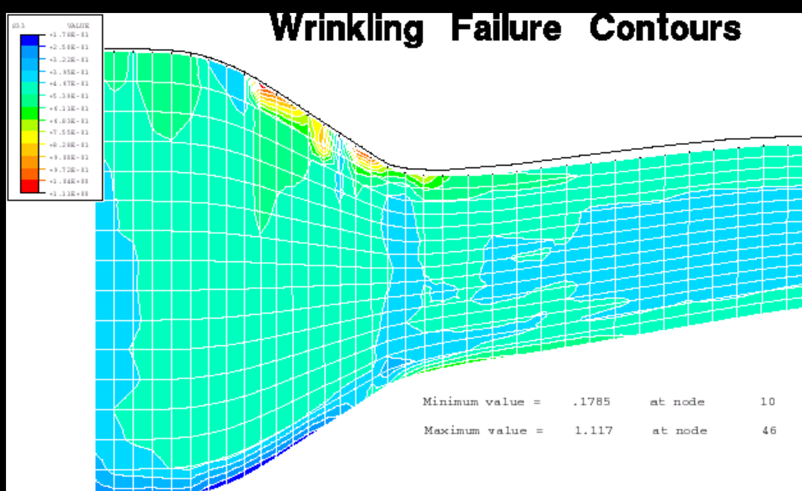
30

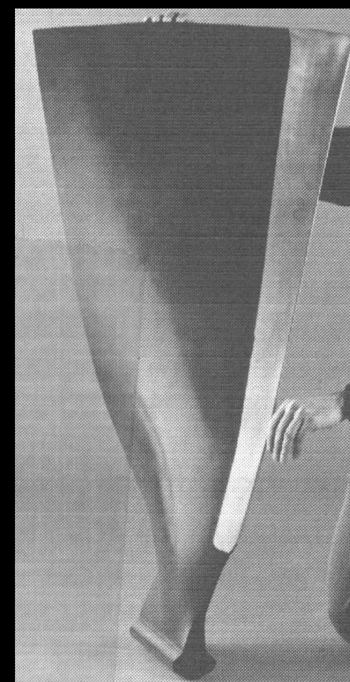




Multiscale t=15ms

General Electric



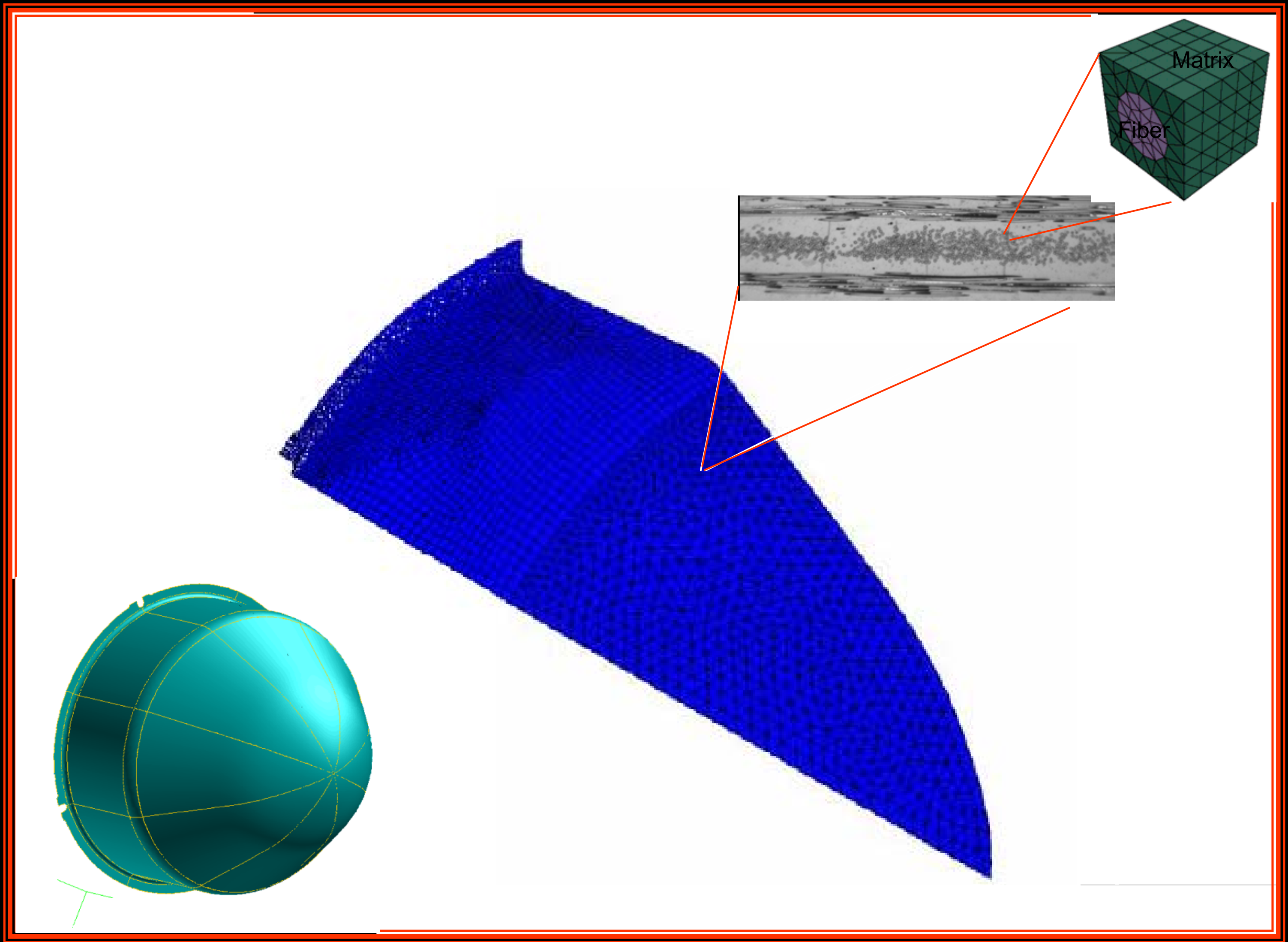


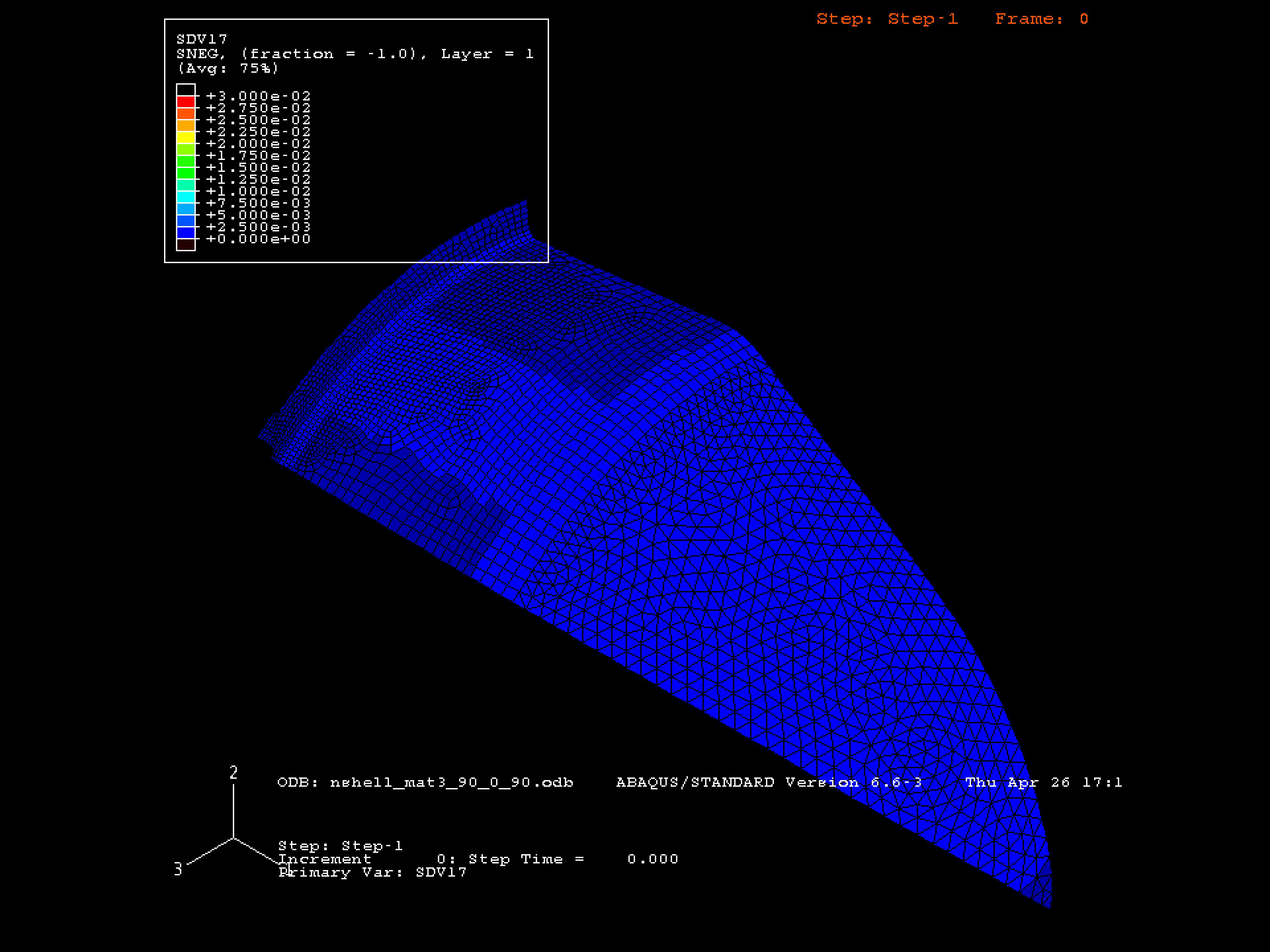
Comments

Multiscale computational technology has been applied to predict wrinkling (on micro-mechanical level) in compression molding process. The model yielded the time of the onset of wrinkling which agreed well with the experiment conducted at GE. A new thermal/cure manufacturing cycle has been developed.

Program monitor: Jeff LeMonds, GE

Fatigue of Tailcone

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+2.250e-02
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+1.000e-02
+7.500e-03
+5.000e-03
+2.500e-03
+0.000e+00
2
3
ODB: nshell_mat3_90_0_90.odb ABAQUS/STANDARD Version 6.6-3 Thu Apr 26 17:1
Step: Step-1
Increment 0: Step Time = 0.000
Primary Var: SDV17

Nanotechnology applications

Generalized Mathematical Homogenization

Space-time asymptotic expansion

$$u_i(\underbrace{\mathbf{x}}_{\substack{coarse\\space}}, \underbrace{\mathbf{y}}_{\substack{fine\\space}}, \underbrace{\tau}_{\substack{fast\\time}}, t, \underbrace{s_k}_{\substack{slow\\time}}) = u_i^0(\mathbf{x}, t) + \varepsilon u_i^1(\mathbf{x}, \mathbf{y}, \tau, t, s_k) + O(\varepsilon^2)$$

Math: Scale separation — Stabilization

Fast τ | Midrange t | Slow s_i | Time →

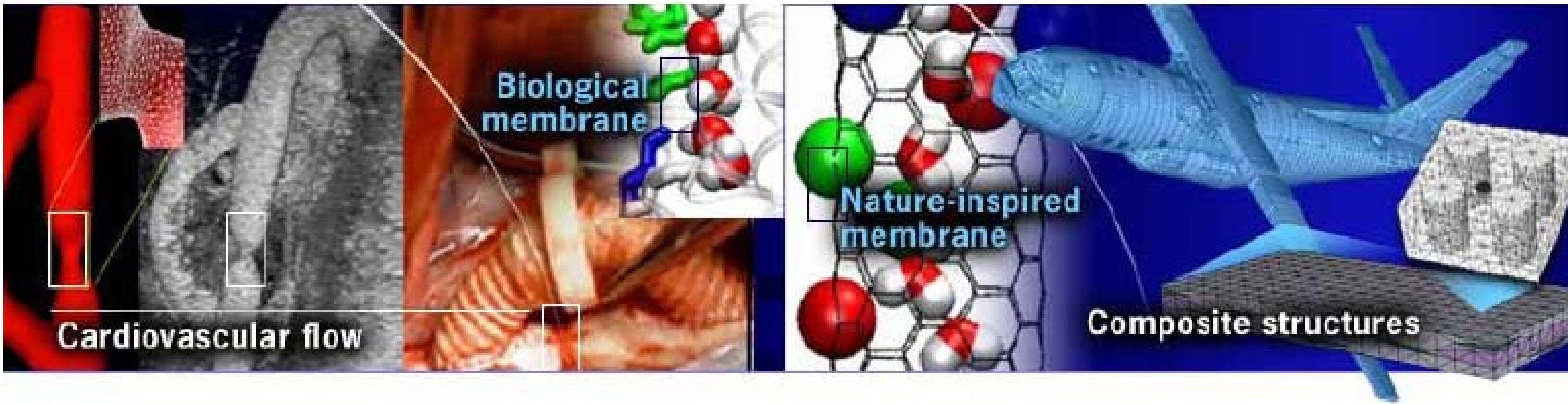
Physics: Atomistic vibration — Wave dispersion

Finite temperature

MSEC Multiscale Science & Engineering Center

at Rensselaer Polytechnic Institute

http://msec.rpi.edu



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