Computationally efficient non-linear finite element framework for composite structure simulations

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Overview

Development of computationally efficient non-linear finite element framework based on Carrera Unified Formulation (CUF) to undertake

- Elasto-plastic analysis of metallic beams and matrix non-linearity modeling
- Progressive damage failure analysis of composite laminates damage with multi-scale modeling capabilities
- Node-Dependent Kinematics (NDK) based contact modeling for Impact analysis in composite structures
- Interfacing with commercial CAE software such as ABAQUS

Methodology

Carrera Unified Formulation

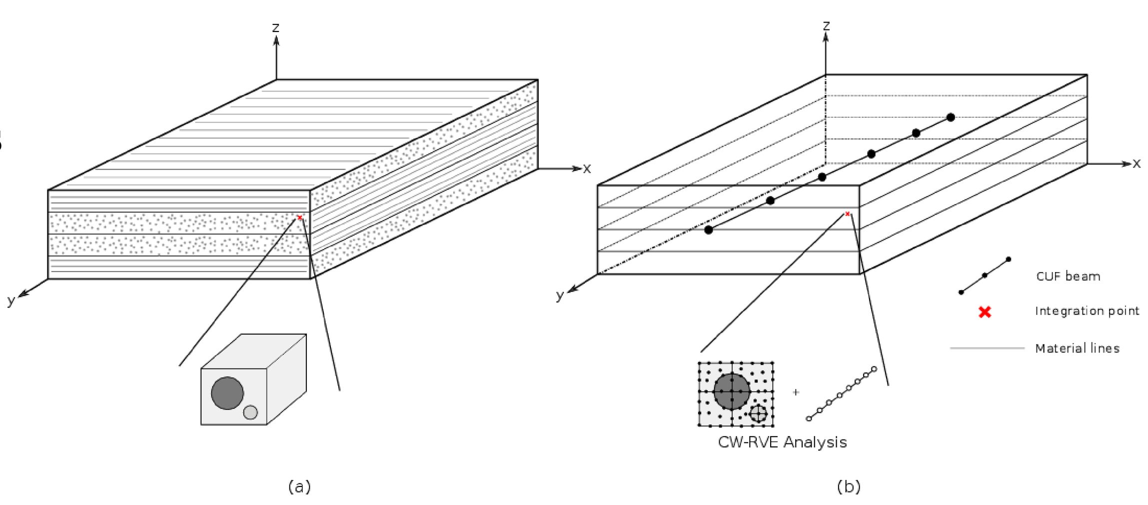
- A hierarchical formulation to generate refined structural theory through variables kinematic description

$$\boldsymbol{u}(x, y, z) = \boldsymbol{N}_i(y)\, F_\tau(x, z)\, \boldsymbol{u}_{\tau i}$$

- CUF 1D models are able to generate accurate 3D finite element like solution at reduced computational cost

Capabilities developed

- Non-linear material models : Von-Mises plasticity, Smeared crack damage models
- Multiscale analysis for high-fidelity solutions
- Interface elements for delamination/ de-bonding and contact problems
- Impact modeling (Future work)

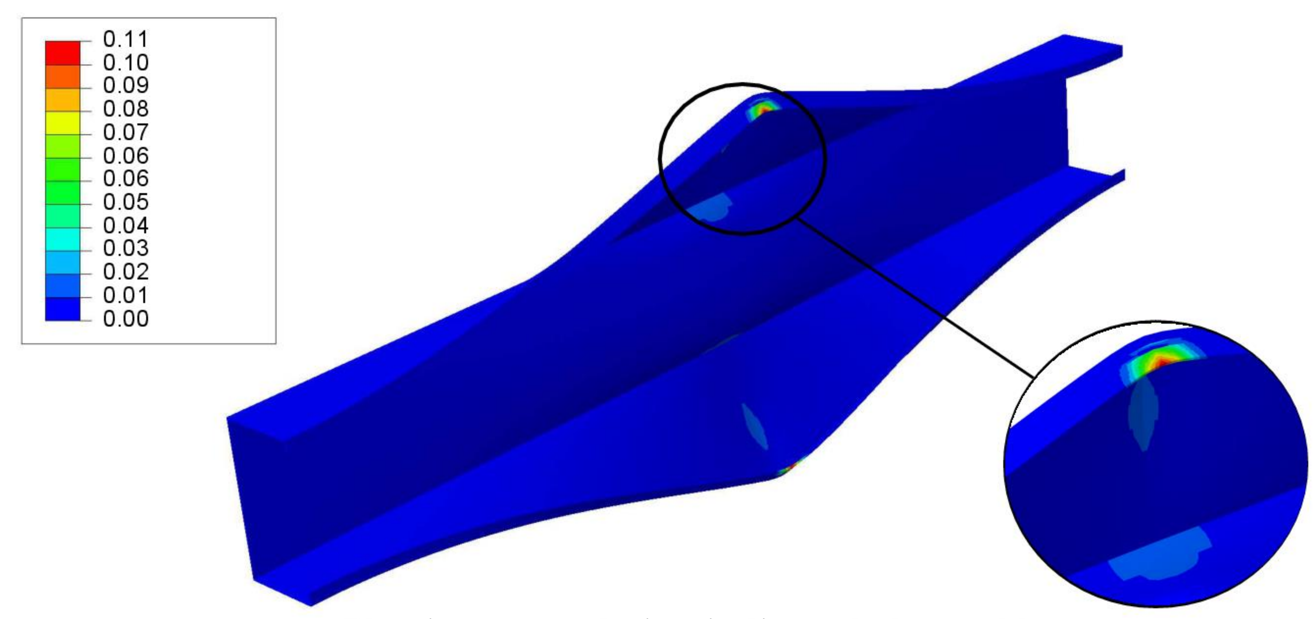


Multiscale modeling using CUF 1D models (CUF²)

Elastoplastic analysis of metallic structure

- Plastically deformable beam is under line loading conditions at mid-span
- Perfect plasticity is modeled via Isotropic von-Mises plasticity with strain-hardening
- Local effects are perfectly detected by efficient CUF 1D models

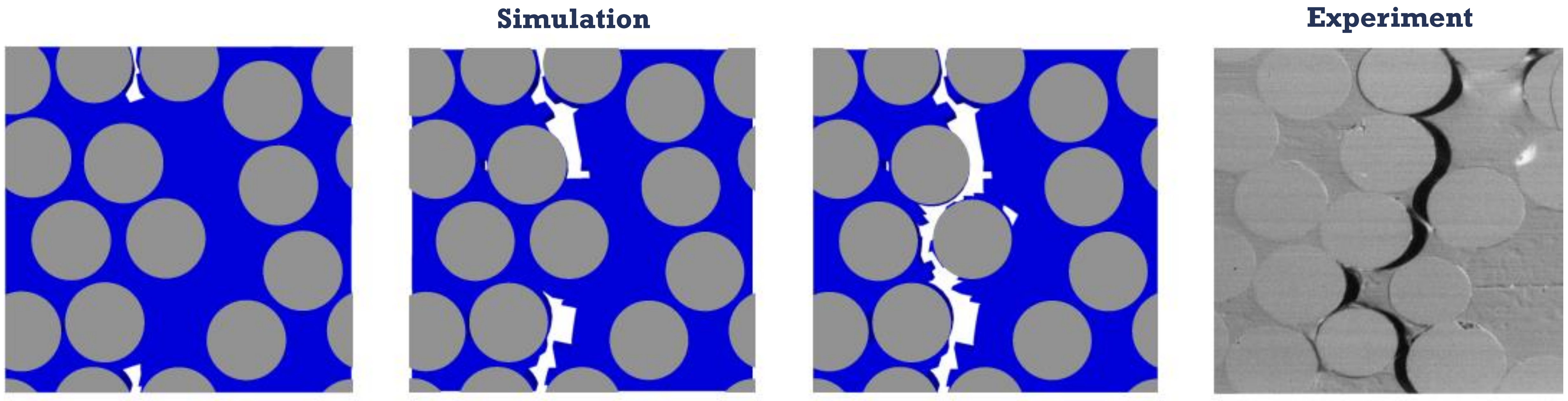
Problem size (DOF): CUF-LE model : 69,948 ABAQUS 3D : 1,342,656



Plastic accumulation in lipped channel beam

Micromechanical damage propagation in composite materials

Simulation **Experiment**



- Match well with crack paths observed in experiments
- Scalable to other computationally intensive progressive failure analysis such as impact

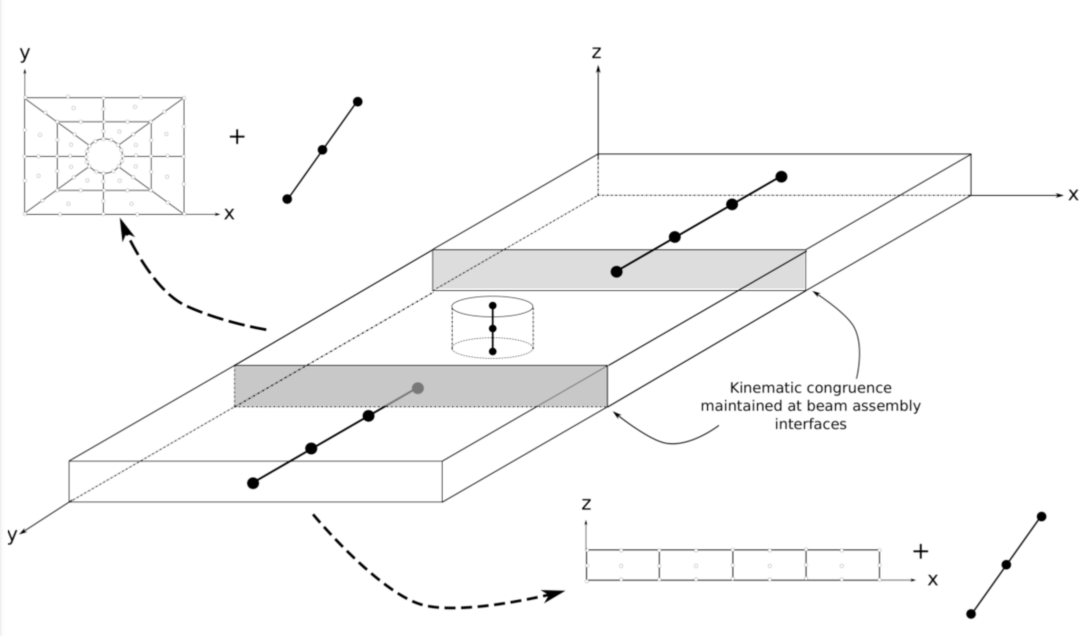
Efficiency:

4x reduction in DOF

3x reduction in total wall time

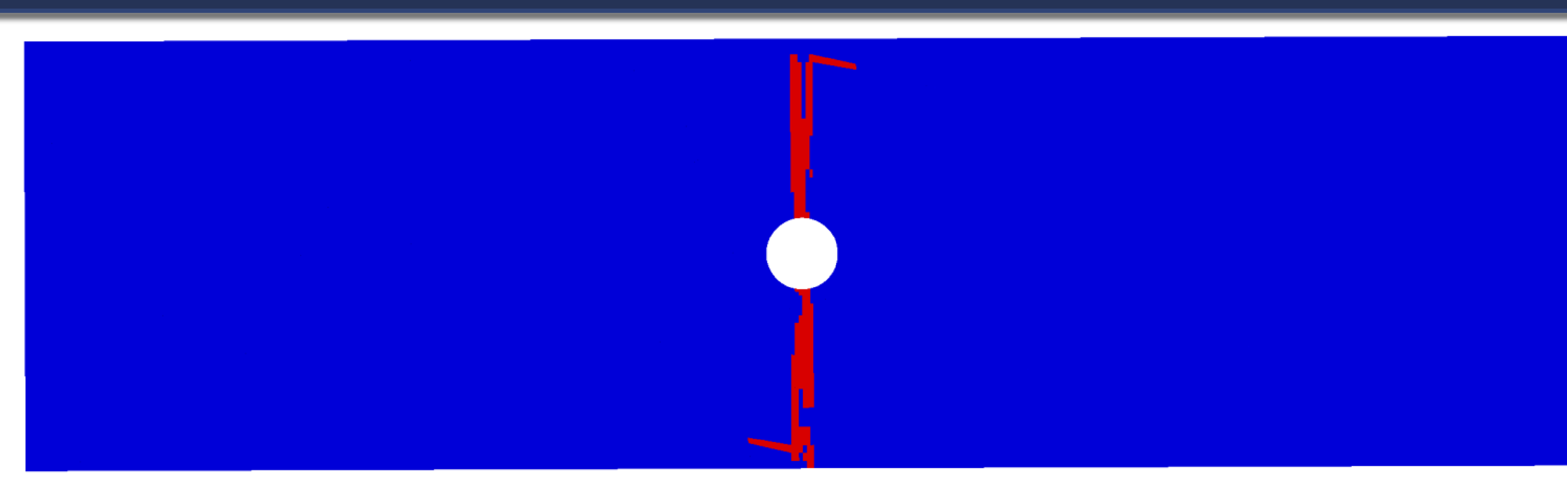
Work done in collaboration with Prof. Anthony Waas' group at William E. Boeing Department of Aeronautics and Astronautics University of Washington, USA

Multiscale progressive damage analysis in composite structures (CUF²)



Component-wise modeling of composite laminates

- **CUF²** : Multiscale framework based on CUF models (both at macro and subscale)
- Analogous to traditional multiscale approach
- Efficiency is derived at both scales
- Each layer of composite is modeled as a component
- Local kinematic enrichment is easily achieved



Damage propagation in notched $[90]_8$ specimen

	Predictions (MPa)	Total CPU Time
Experimental	26.4	-
*CUF*²	28.9	~ 27 min
3D FEM	27.8	~ 4 hours

Efficiency:

5.4x reduction in DOF

9x reduction in total wall time

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Publications

1. **I. Kaleel**, M. Petrolo, A. M. Waas, E. Carrera. Computationally efficient, high-fidelity micromechanics framework using refined 1D models. *Composite Structures* (2017) 181:358-367.
2. E. Carrera, **I. Kaleel**, M. Petrolo. Elastoplastic analysis of compact and thin walled structures using classical and refined beam finite element models. *Mechanics of Advanced Materials and Structures* (2017) In-press.
3. **I. Kaleel**, M. Petrolo, A. M. Waas, E. Carrera. Micromechanical Progressive Failure Analysis of Fiber-Reinforced Composite using Refined Beam Models. (Submitted), 2017
4. M. Petrolo, **I. Kaleel**, G. De Pietro, E. Carrera. Wave propagation in compact, thin-walled, and layered beams using refined finite element models. (Submitted), 2016

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