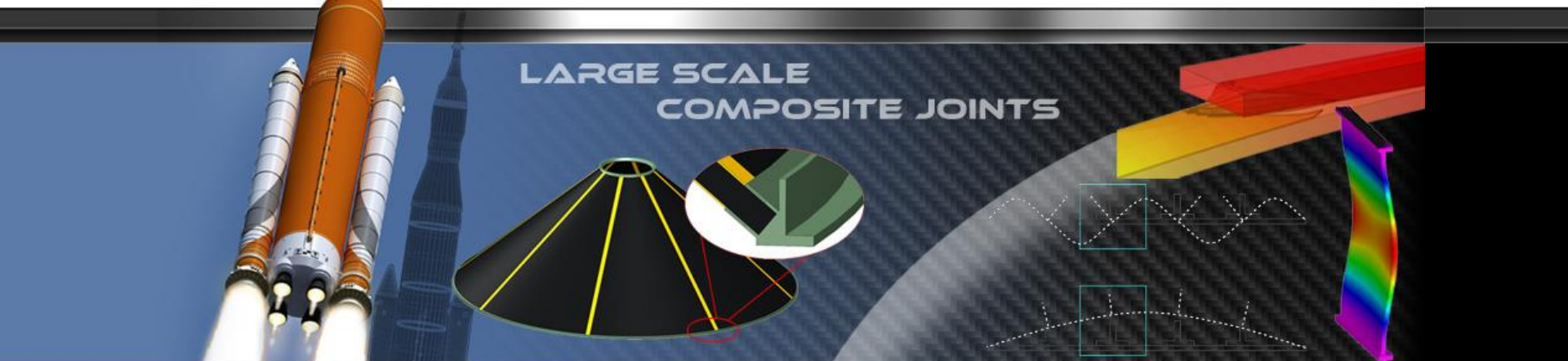




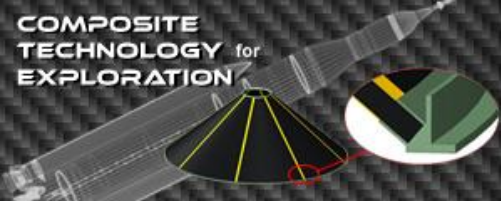
COMPOSITE TECHNOLOGY for EXPLORATION



An Automated Meshing Framework for Progressive Damage Analysis of Fabrics Using CompDam

Andrew Bergan
NASA Langley Research Center

35th American Society for Composites Technical Conference
14–17 September 2020

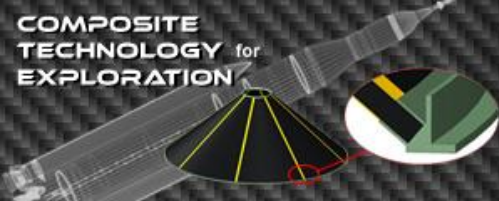


Outline

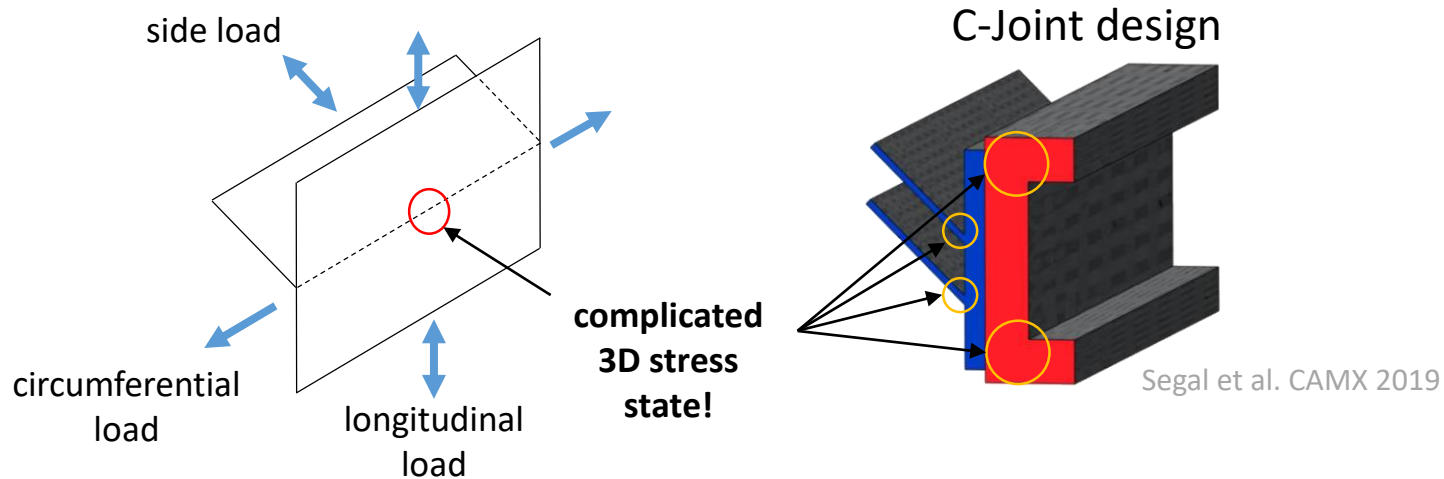


- Background and motivation
 - Geometry model – *using Virtual Textile Morphology Suite software*
 - Fabric modeling algorithm
 - Tows
 - Matrix
 - Assembly
 - Warp-tension demonstration
 - Summary
- New development*

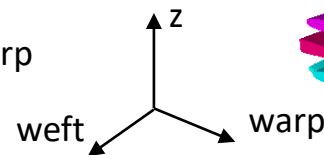
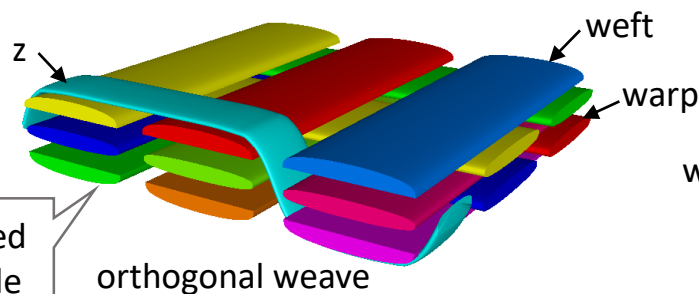
-
- Advance the state-of-the-art in the analyses of composite bonded joints
- SLS
- Universal stage adapter
- Co-Manifested Payload
- PAF
- Payload attach fitting (PAF)
- Composite honeycomb panels
- Circumferential (C) joint
- Composite?



3D Woven Materials for C-Joints



- Hard to design C-Joint using traditional laminated unidirectional plies and 2D fabrics since they cannot sustain high out-of-plane stresses
- 3D woven materials offer fiber reinforcement in the out-of-plane direction → provides options for all composite C-Joint designs [Segal 2019]
- Notional 3D woven material architectures:

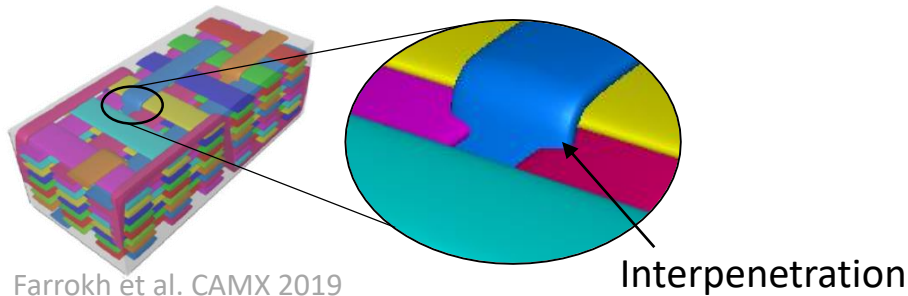


angle interlock

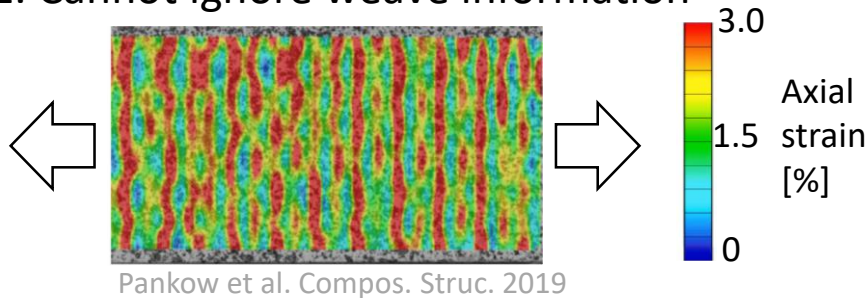
How to analyze a 3D woven structural detail?

Analysis Challenges: Modeling the fabric at the Mesoscale

1. Correct fiber volume content and orientations requires *non-uniform* cross sections



2. Cannot ignore weave information

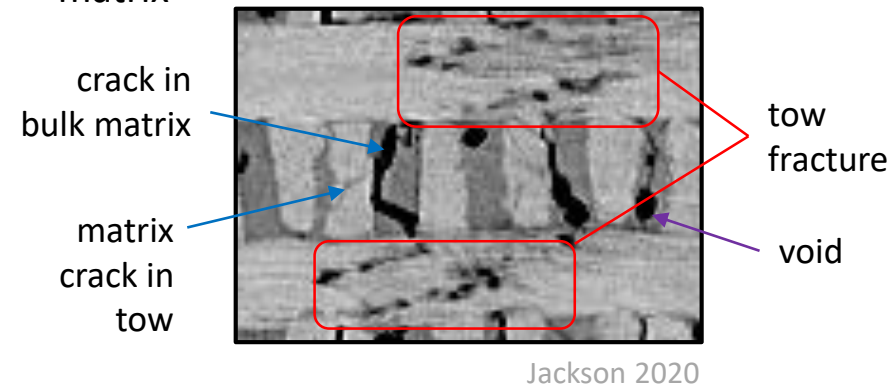


3. Meshing difficulties:

- Tow interpenetrations
- Matrix slivers where tows cross over each other
- Mesh suitable for damage modeling?

4. Damage modeling

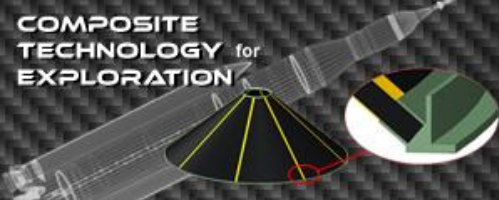
- Complicated network of matrix cracks: along tow interface, through tows, through bulk matrix



5. Boundary conditions:

- Representative volume elements (RVE) are very large (10 mm) → may not be useful for structural details
- Need to capture both geometric and material nonlinearities

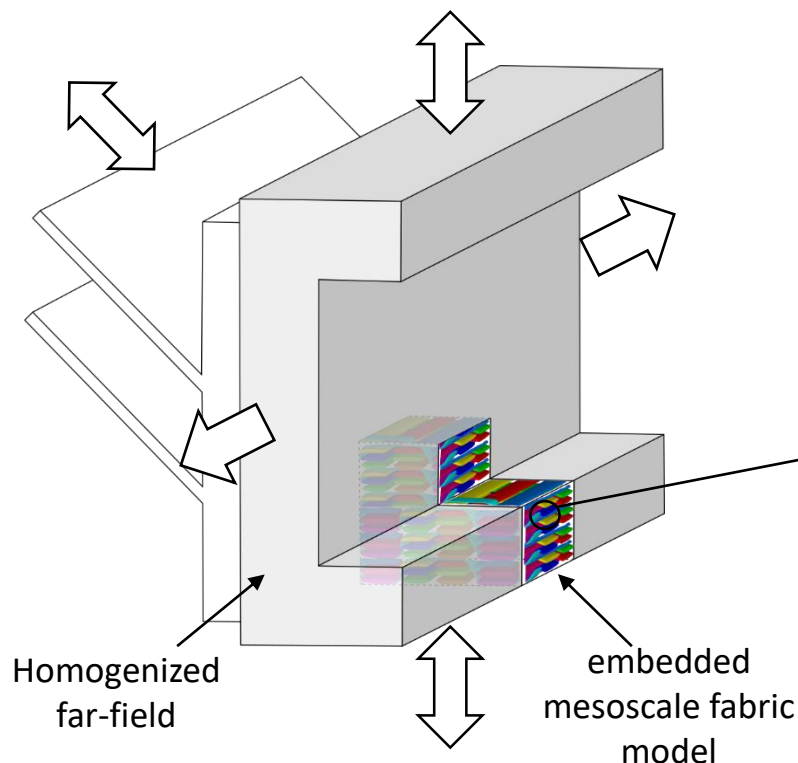
Existing practice relies nearly exclusively on structural testing due to analysis challenges



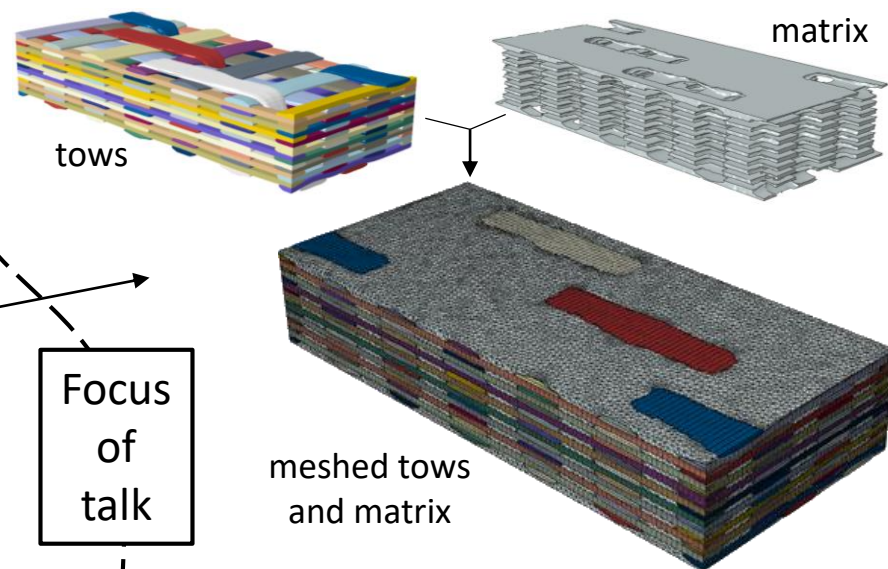
Vision for 3D Composite Structural Detail Analysis



Structural model



Conformal fabric model for local hot spots

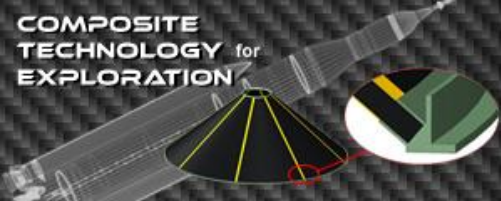


Focus of talk

Enables prediction of strength and damage tolerance of (3D) fabric structures

- *Structure/material interaction*
- *Damage considered in matrix, tows, tow/matrix interfaces*

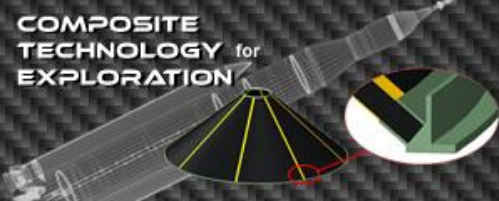
- Tows modeled as orthotropic continua; can “touch” each other
- Automatically generated from geometry for most fabric architectures
- CompDam model used for damage



Outline



- ~~Background and motivation~~
- Geometry model
- Fabric modeling algorithm
 - Tows
 - Matrix
 - Assembly
- Warp-tension demonstration
- Summary



Geometry Model

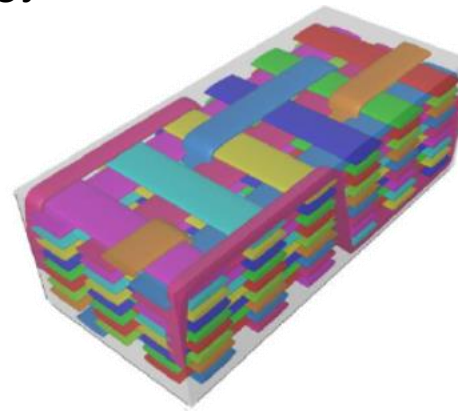


Starting point:

Geometry model created using Air Force Research Lab's Virtual Textile Morphology Suite (VTMS) using:

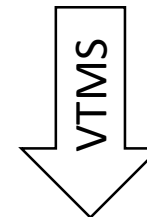
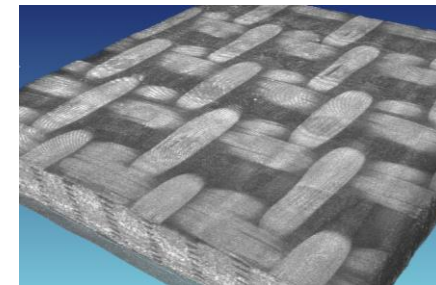
- Basic weave information
 - 8 layers of warp tows
 - All tows are 6k
 - Idealized texgen model
- X-Ray measurements
 - Warp tow spacing: 2.56 mm
 - Weft tow spacing: 2.88 mm
 - Typical tow: 2 mm x 0.22 mm (W x T)
 - Binder traversing thickness: 0.5 mm x 0.7 mm (warp x weft)

Idealized model

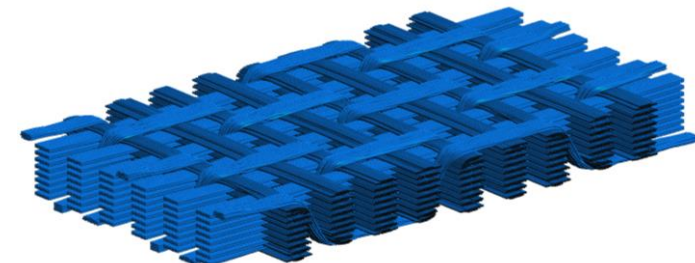


Farrokh et al. 2019

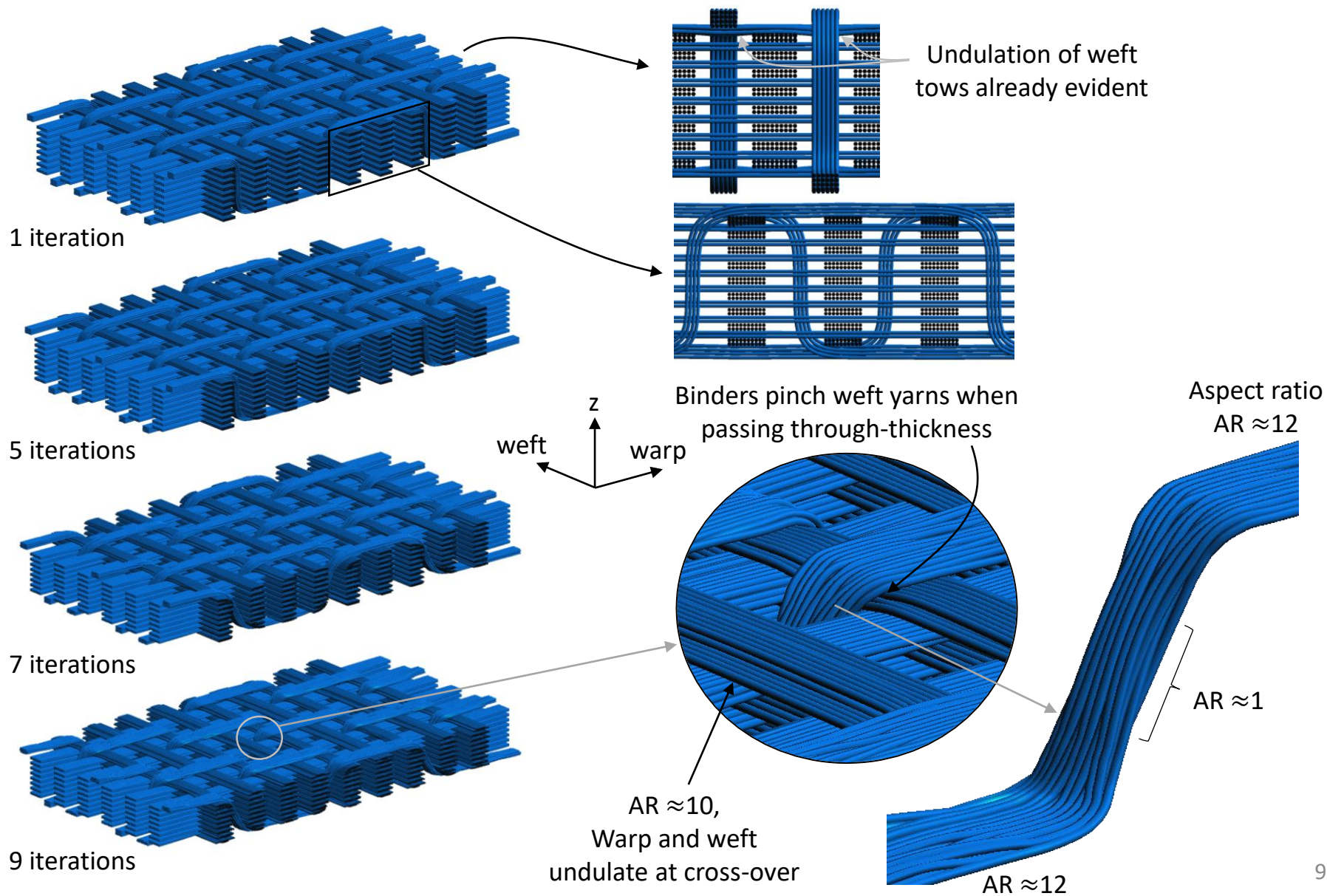
X-Ray CT scan



Result:

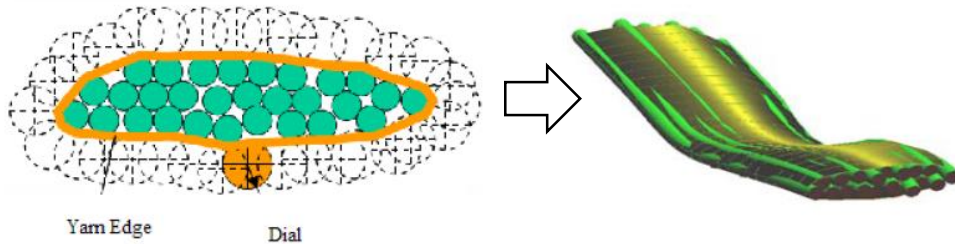


Geometry Model



Geometry Model

Create a surface mesh from filament bundles:

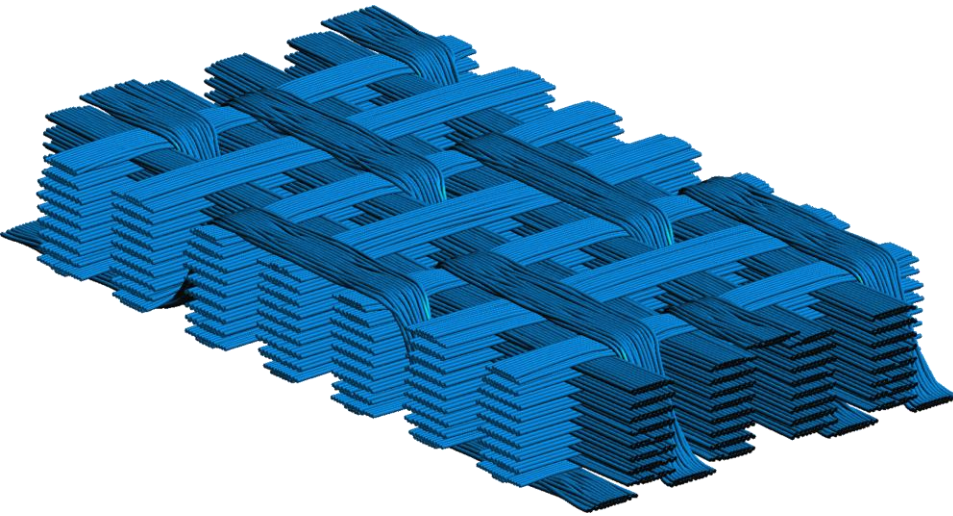


Yarn Edge

Dial

Zhou et al. AIAA 2008

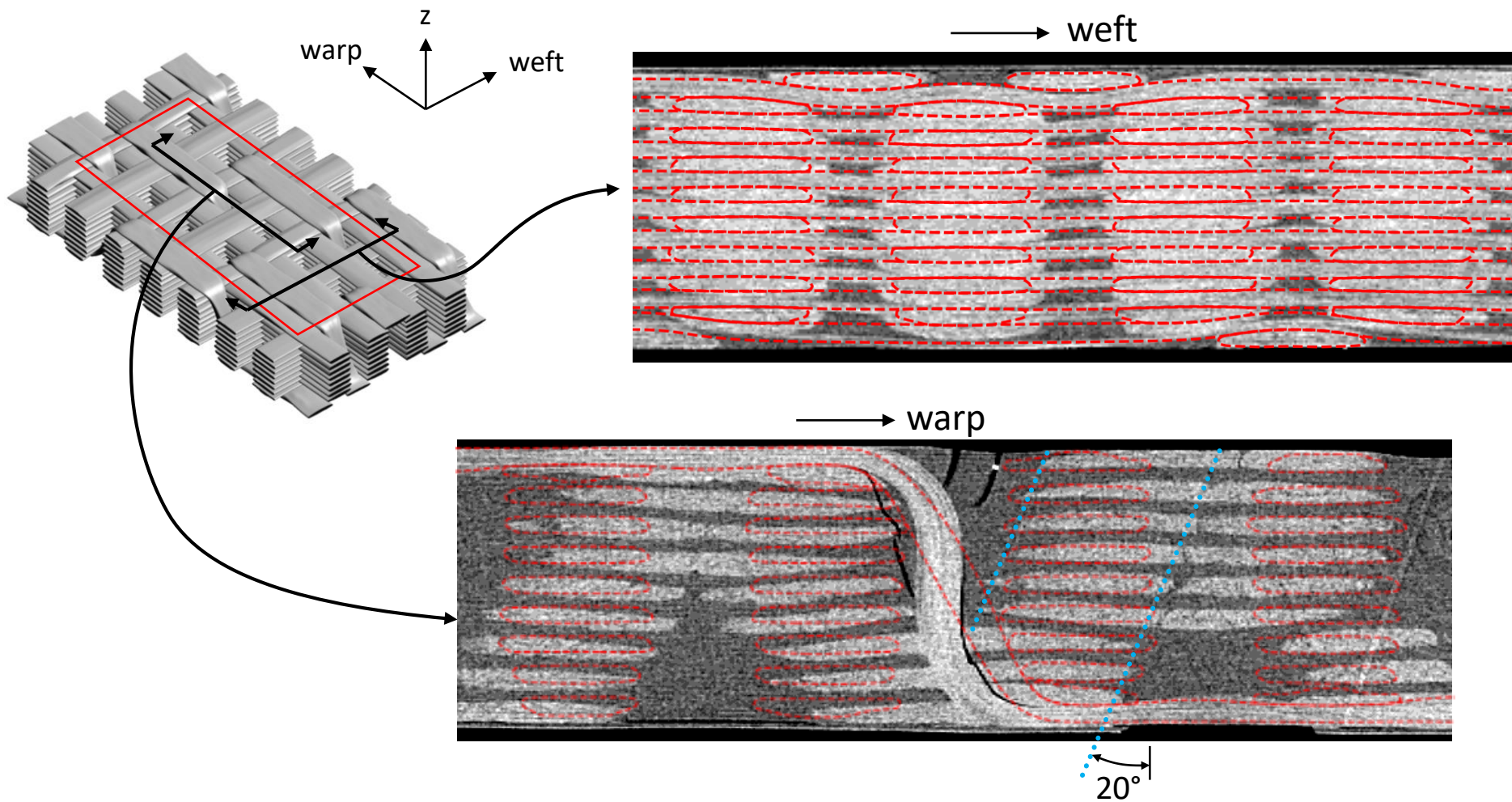
final filament model, trimmed



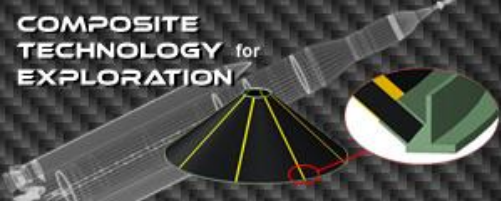
tows wrapped with surface mesh



Geometry Model vs. X-Ray CT



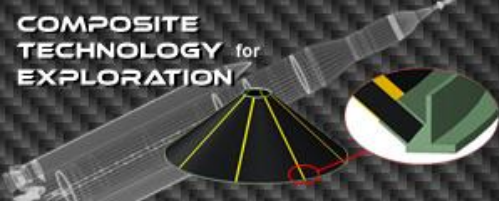
Generally good agreement found between model and X-Ray CT



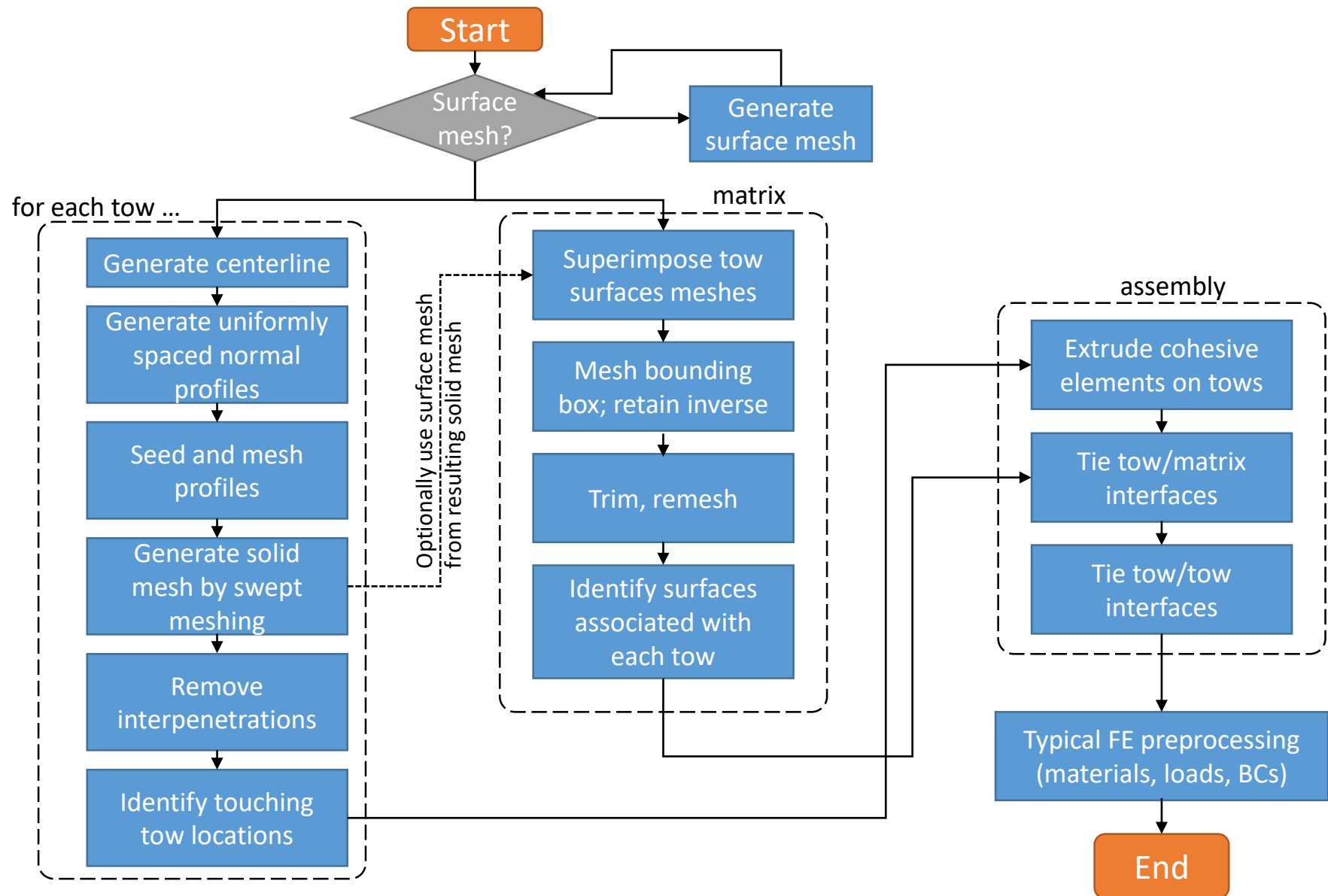
Outline



- ~~Background and Motivation~~
- ~~Geometry model~~
- Fabric modeling algorithm
 - Tows
 - Matrix
 - Assembly
- Warp-tension demonstration
- Summary and next steps



Fabric PDFA Model Construction Algorithm



Fabric Modeling: Tows

Generate centerline

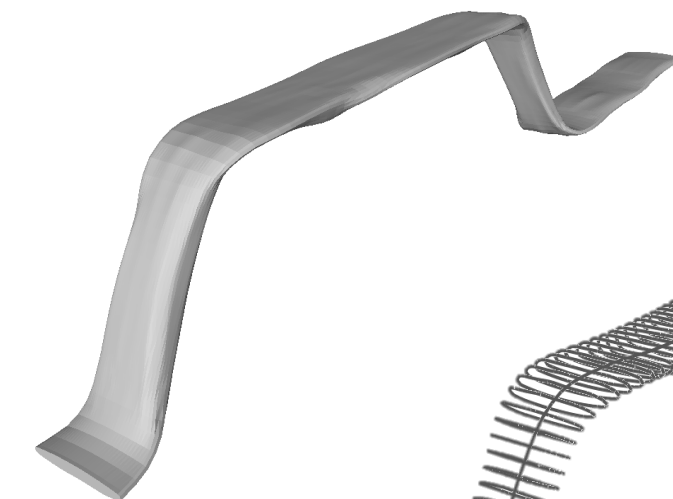
Generate uniformly
spaced normal
profiles

Seed and mesh
profiles

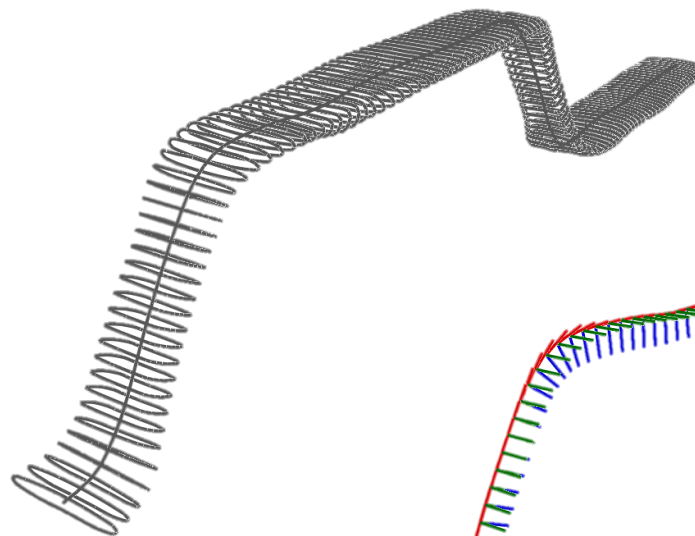
Generate solid
mesh by swept
meshing

Remove
interpenetrations

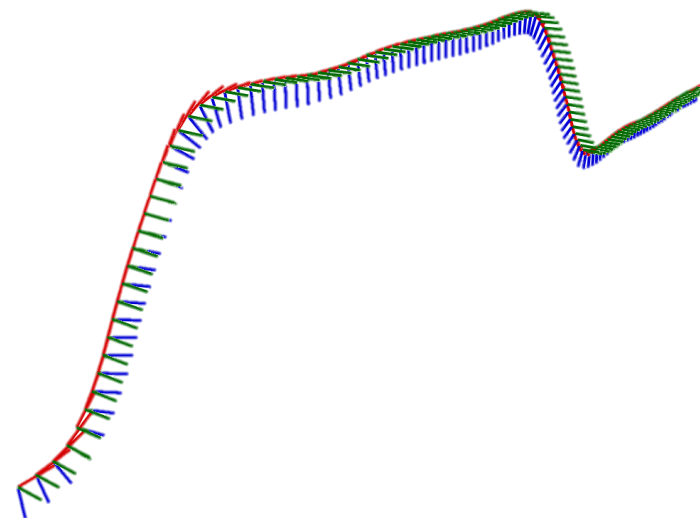
Identify touching
tow locations



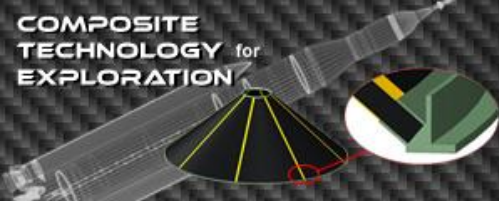
Surface mesh
(input)



Profiles



Material
coordinates



Fabric Modeling: Tows

Generate centerline

Generate uniformly spaced normal profiles

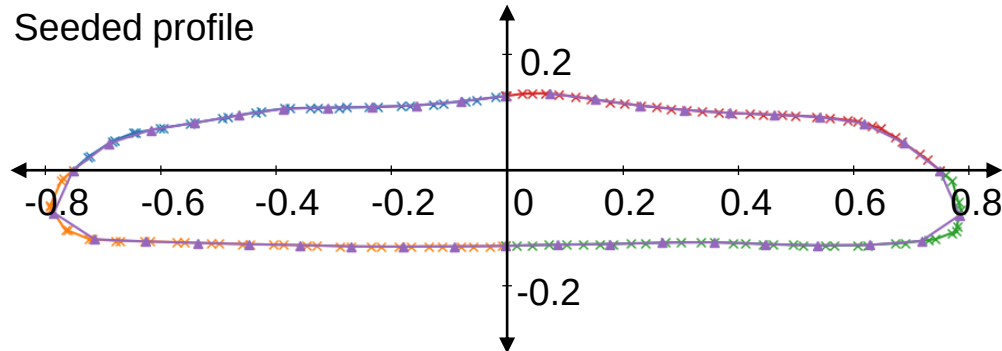
Seed and mesh profiles

Generate solid mesh by swept meshing

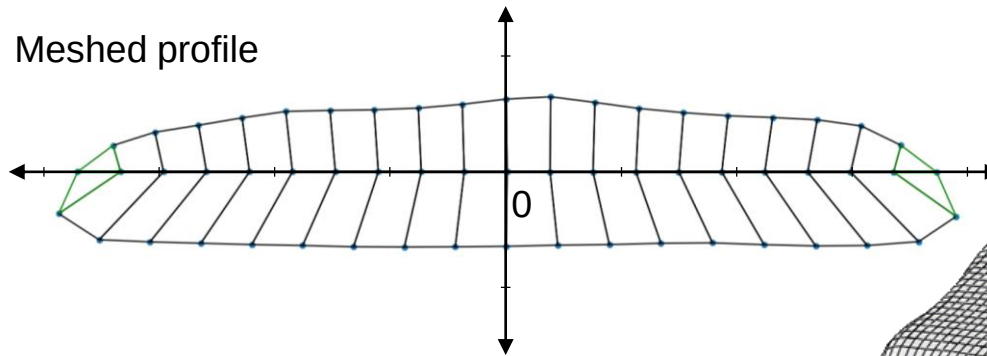
Remove interpenetrations

Identify touching tow locations

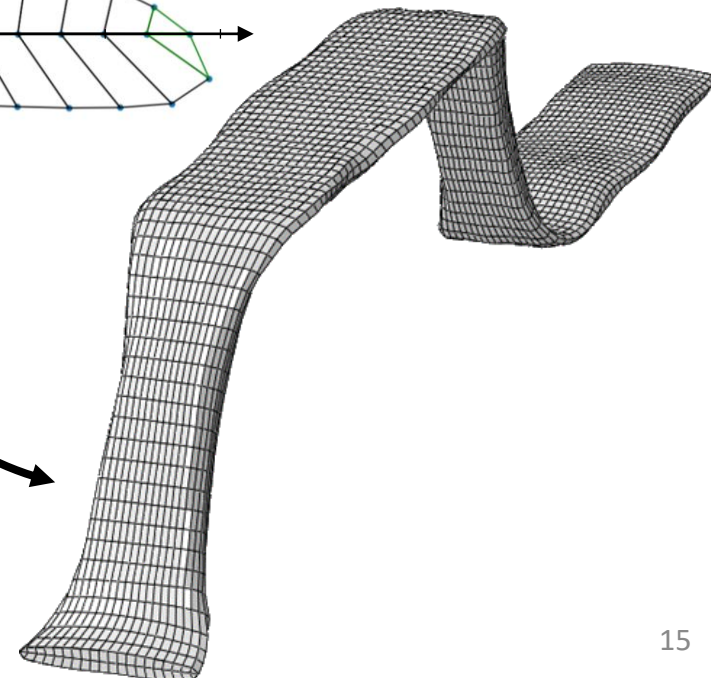
Seeded profile



Meshed profile

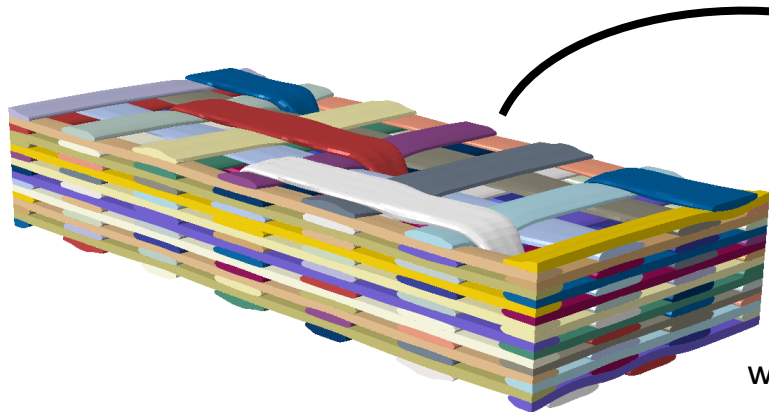


3D swept mesh

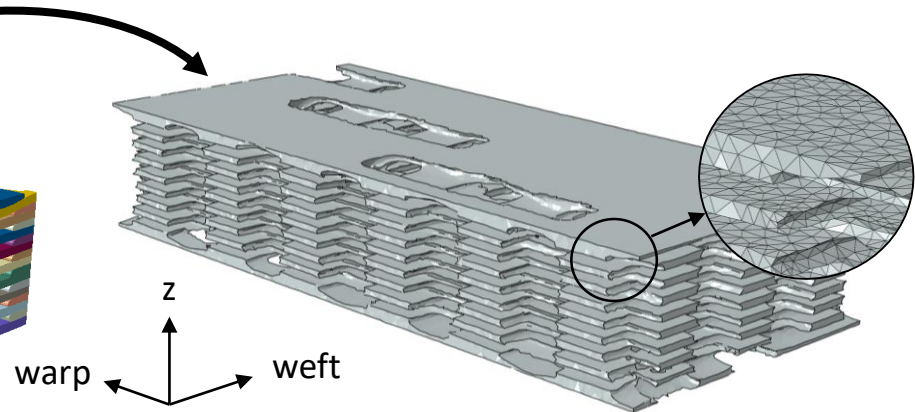


Fabric Modeling: Matrix

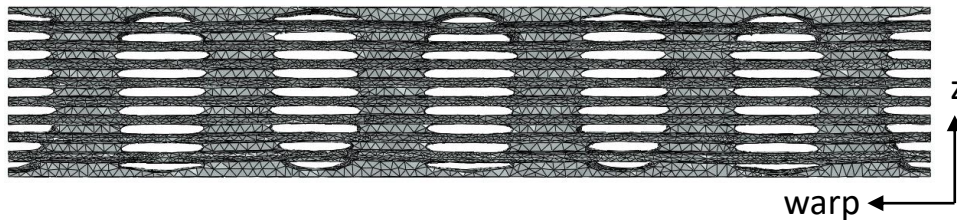
TetWild [Hu et al. 2018]



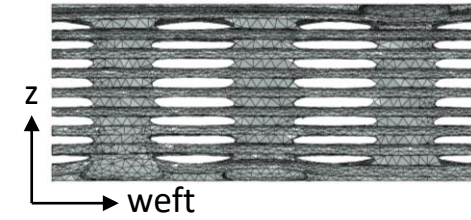
Superimposed tow surface meshes



Matrix tetrahedral mesh

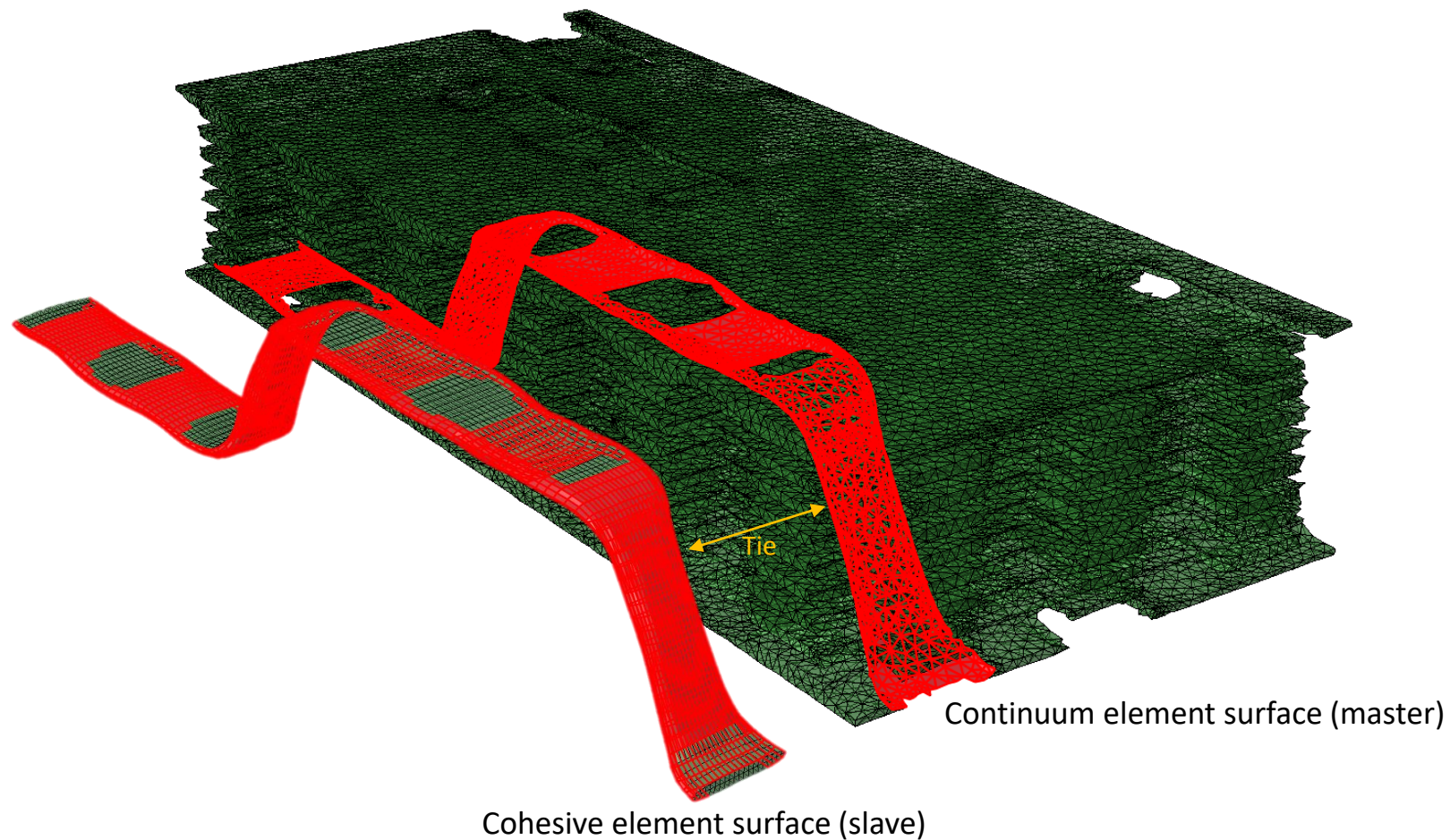


Matrix mesh, looking along weft

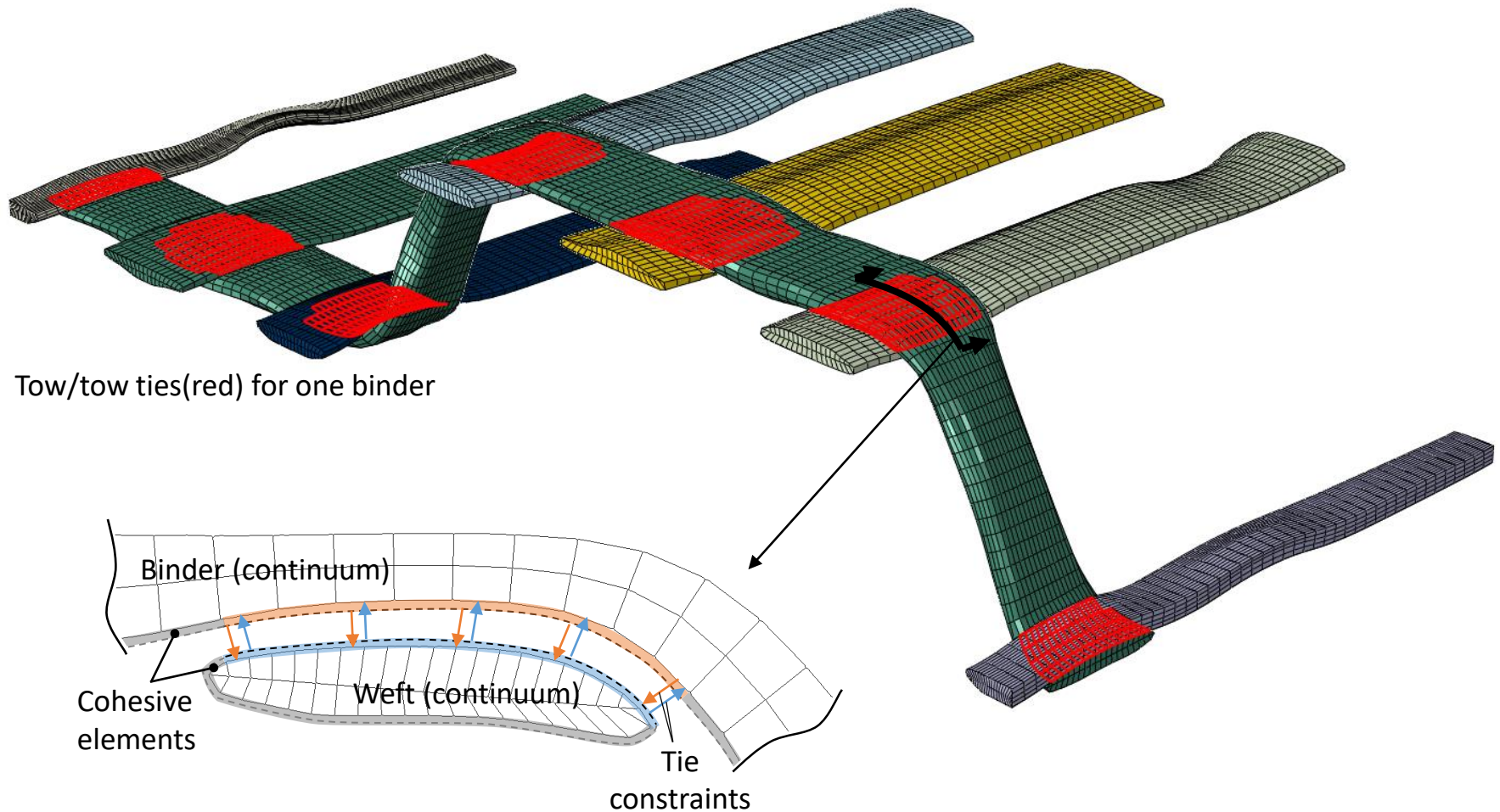


Matrix mesh, looking along warp

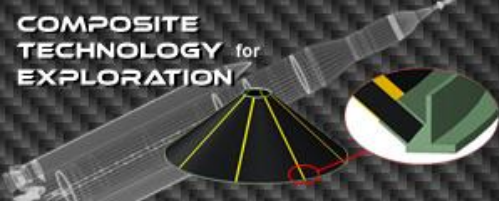
Fabric Modeling: Assembly



Fabric Modeling: Assembly



Schematic of redundant cohesive elements at tow/tow interface



Warp-Tension Analysis

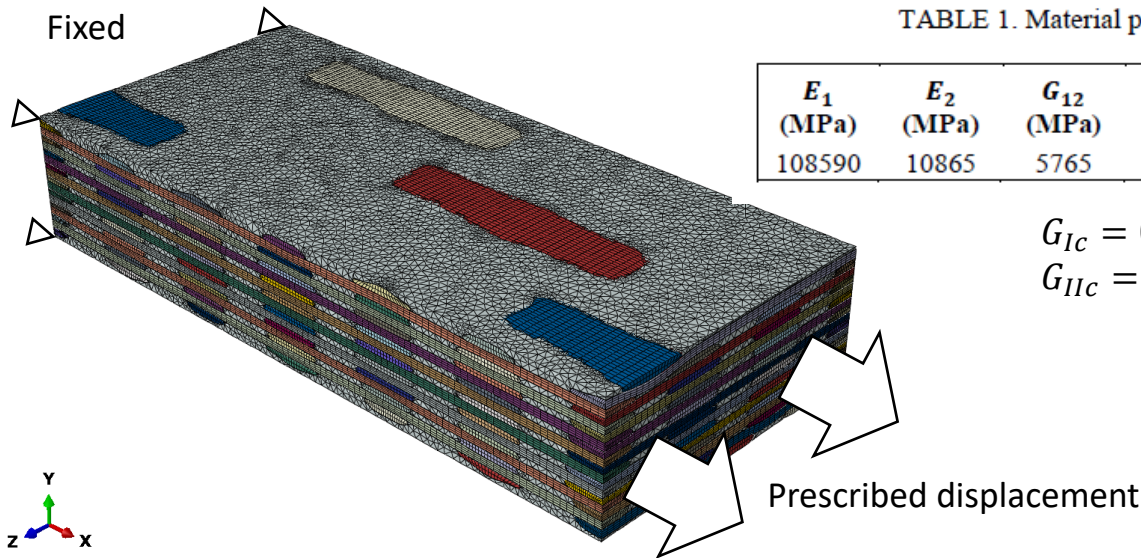


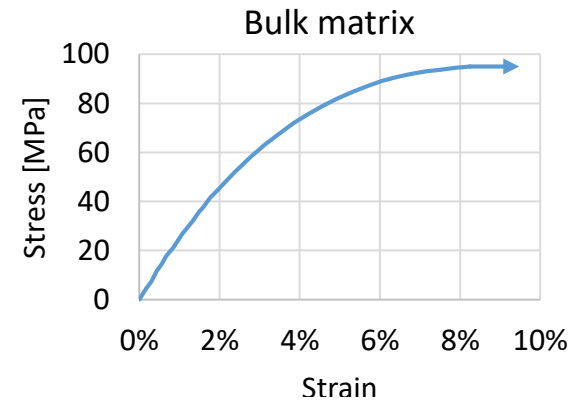
TABLE 1. Material properties for the AS4/RTM-6 tows Ricks et al. CAASE 2020

E_1 (MPa)	E_2 (MPa)	G_{12} (MPa)	ν_{12}	ν_{23}	X_T (MPa)	Y_T (MPa)	S_L (MPa)
108590	10865	5765	0.23	0.25	2709	72	70

$$G_{Ic} = 0.216 \text{ kJ/m}^2$$

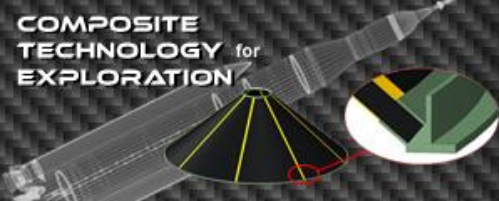
$$G_{IIc} = 0.857 \text{ kJ/m}^2$$

Wu et al. COMPB 2017 (RTM6-2)

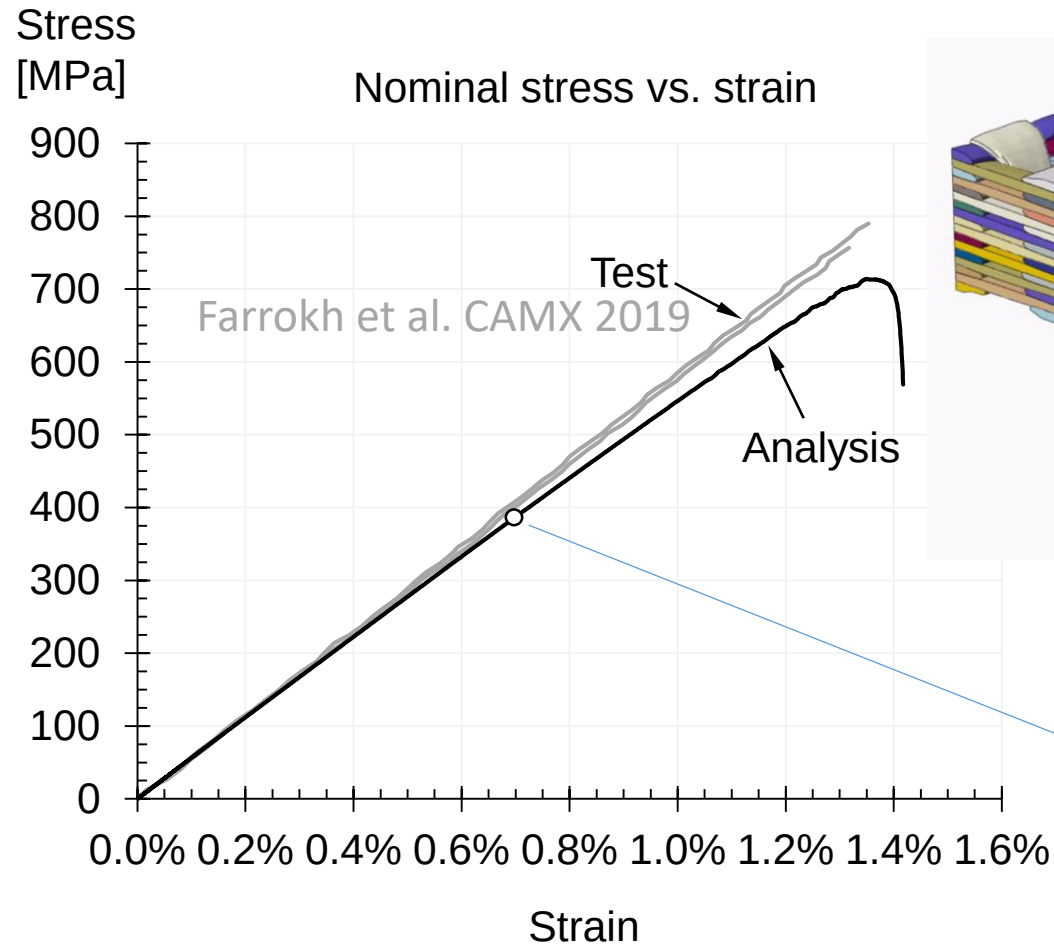


Gerlach et al. J. Polymer 2014

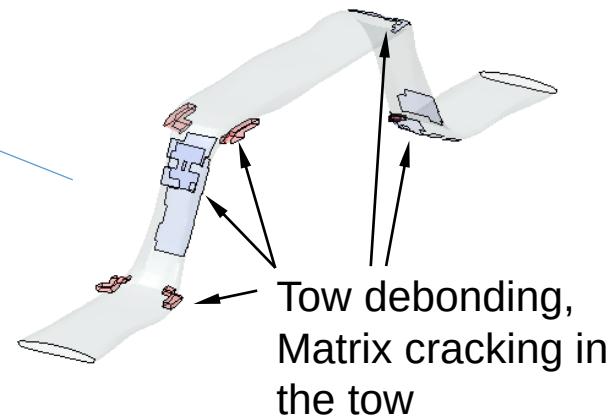
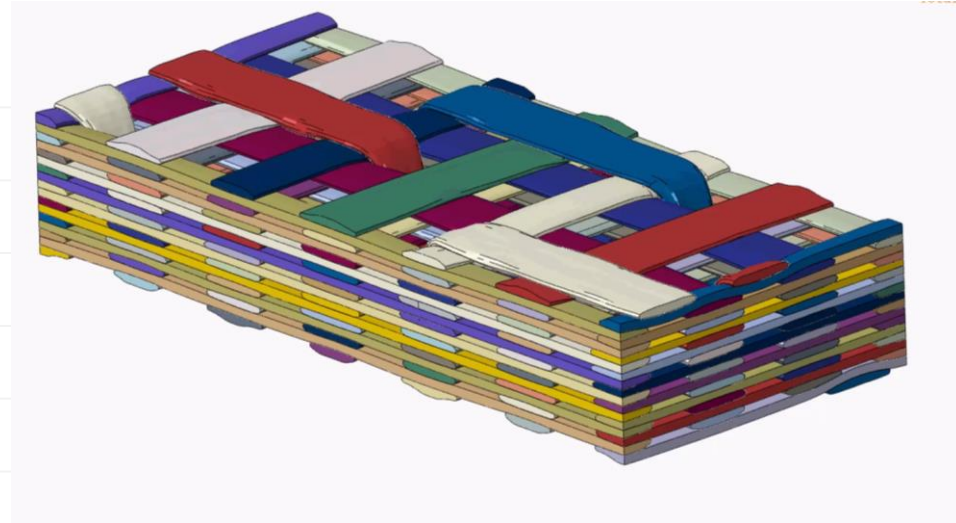
- Material nonlinearity:
 - Plasticity used for bulk matrix
 - Cohesive elements used for tow debonding
 - CompDam (matrix cracking and fiber tensile fracture) used for tow damage
- Analyzed in Abaqus/Explicit 2019, double precision
- Loading applied with smooth step
- Mass scaling with target number of increments > 300,000 (results found to be generally quasi-static)
- 3.9×10^6 DoF, ~4 hrs on 80 cores

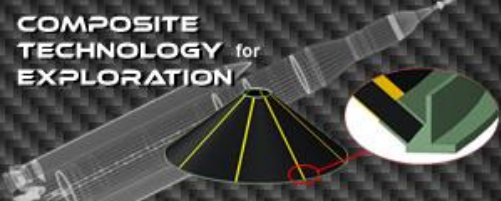


Warp-Tension Analysis Results



Deformations scaled 10x

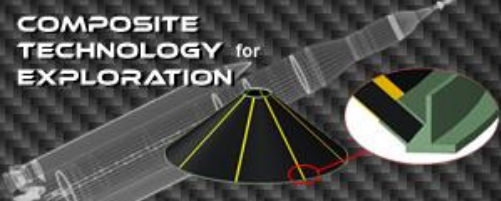




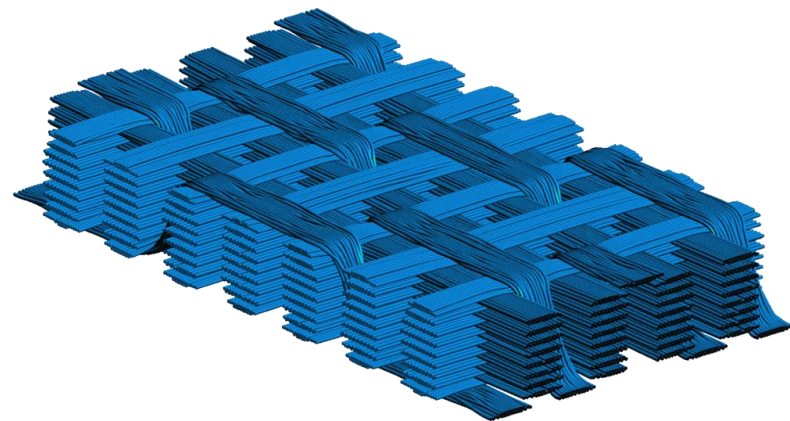
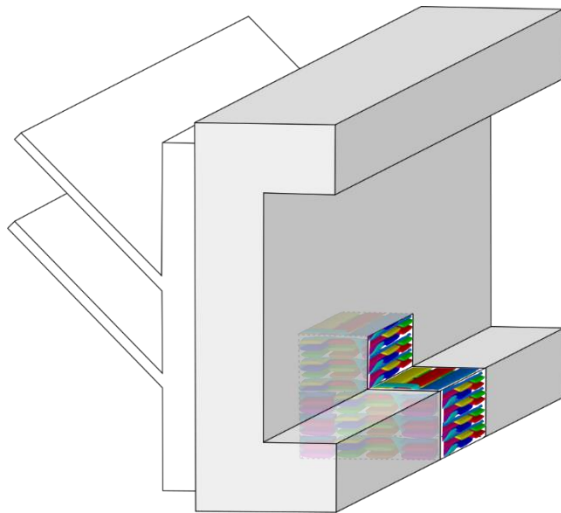
Summary



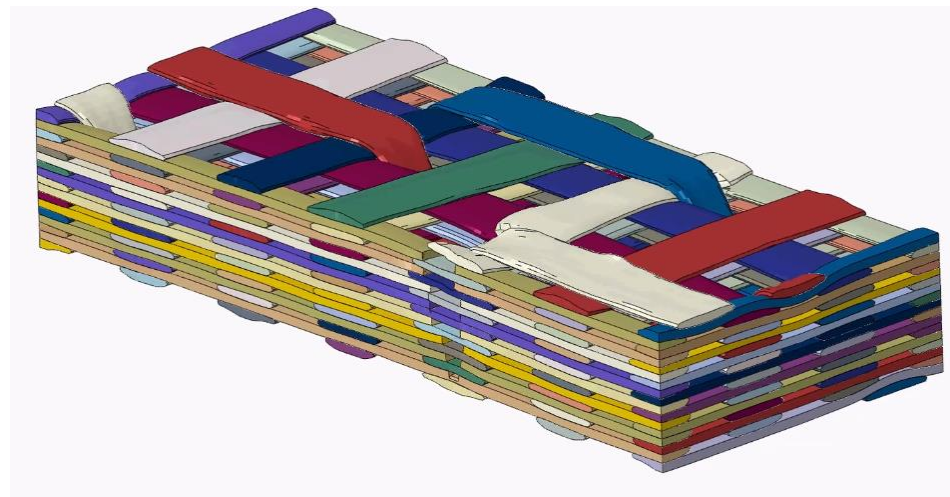
- New method developed for mesoscale PDFA model construction for fabrics:
 - Agnostic to fabric architecture
 - Accounts for touching tows
 - Capable of predicting material nonlinearity in matrix, tow, and tow/matrix interfaces
- Demonstrated the modeling capability for simple tension:
 - Good correlation in terms of initial stiffness and strength
 - Predicted stiffness degradation (between 350-700 MPa) does not agree with test results
- Critical technology gaps:
 - Validation test data for different architectures
 - New material property test development for tows and tow interfaces
 - Consideration for processing induced initial conditions (e.g. thermal residual stresses)



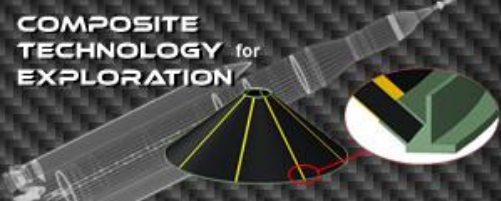
Questions?



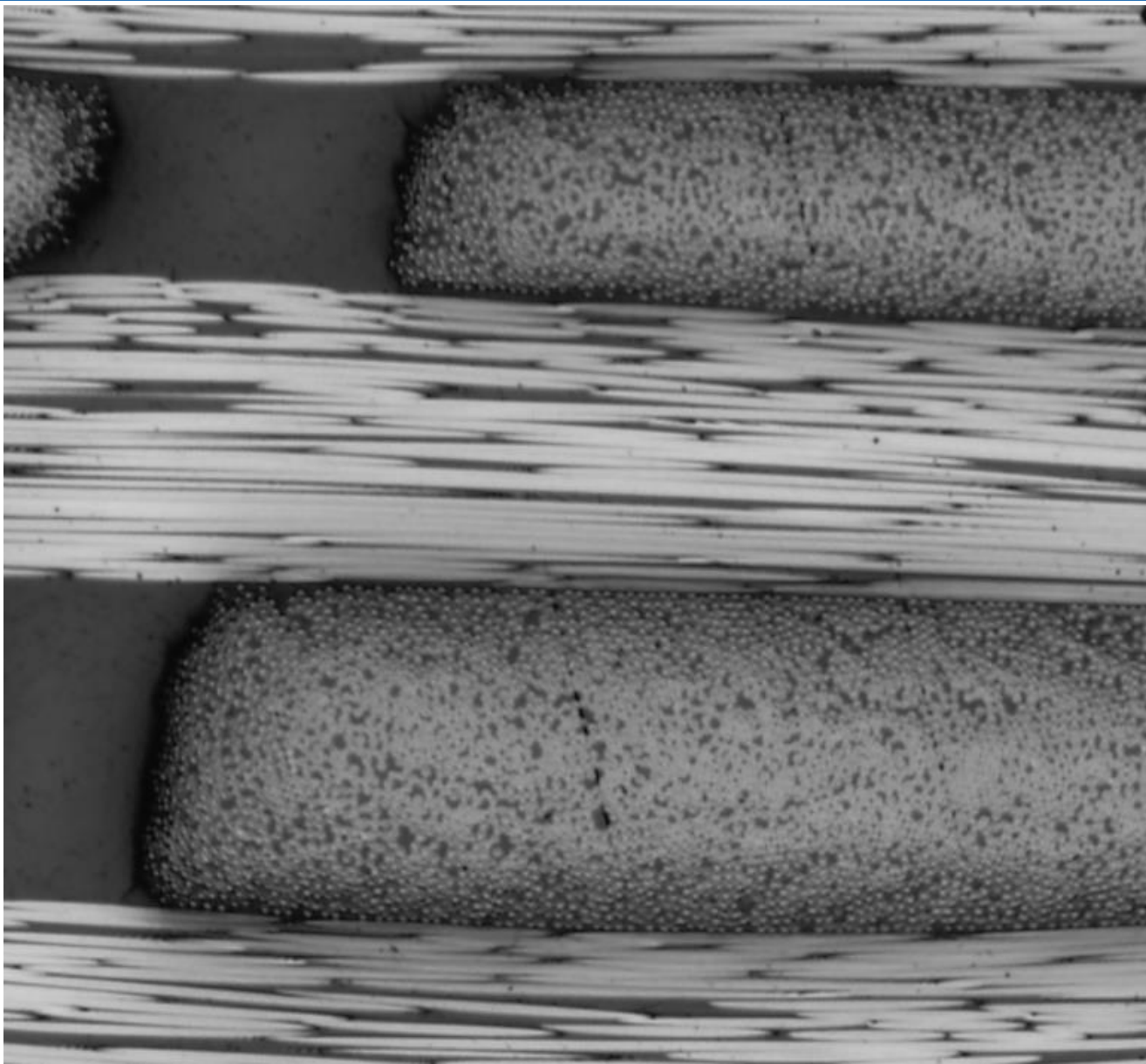
Andrew Bergan
andrew.c.bergan@nasa.gov
NASA Langley Research Center

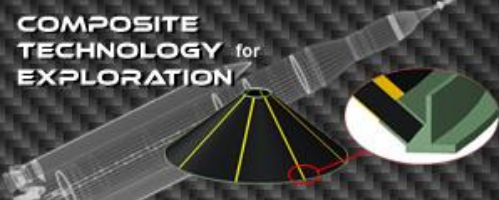


Backup



Do the Tows Touch?





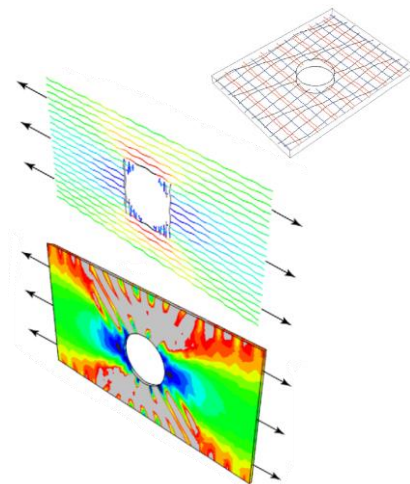
Selected Relevant Work

Fabric modeling at the mesoscale



Binary model

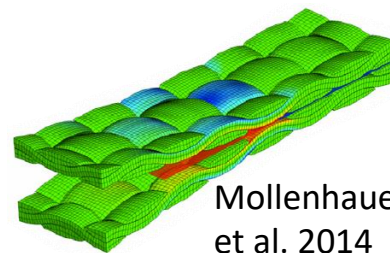
- Tows: trusses or beams
- Matrix: 3D continuum (whole model domain)
- Kinematic constraints
- Can consider:
 - Irregular geometry
 - Plasticity
 - Matrix cracking
 - Tow rupture
 - Debonding, slip, friction, and pull-out



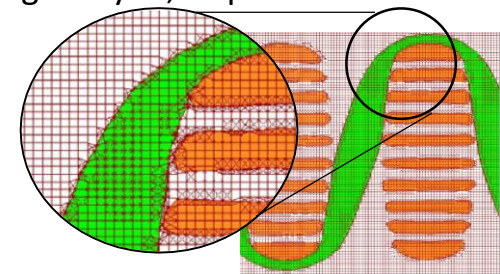
Cox et al. 1994 -> present

Subdivide/remesh mesh at tow boundary

- Initially regular structured mesh made to conform to tow boundaries by specialized algorithms
- Independent mesh method (IMM) – tow/matrix boundary resolved during analysis; requires matrix region between tows



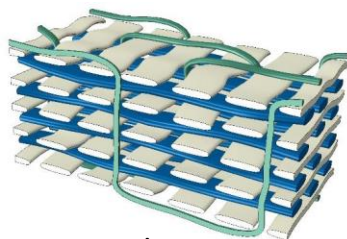
Mollenhauer et al. 2014



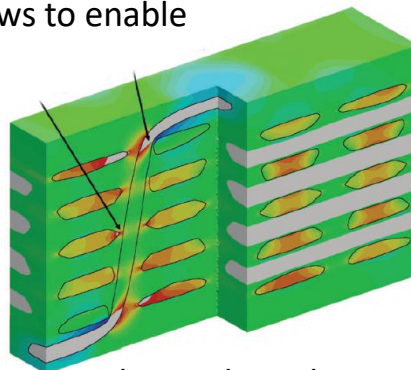
Mazumder et al. 2020

3D stress analysis models

- Tows and matrix 3D continua
- Tows orthotropic and homogeneous
- Main limitation is that artificial gaps must be enforced between tows to enable mesh generation



Enos et al. 2019



Whitcomb et al. 2020

Touching tow methods

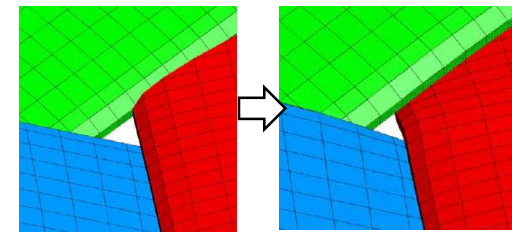
- Considers tows within a critical distance to be touching
- Touching tows connected with cohesive elements (nonlinear springs)
- Created by fictitious thermal contraction and subsequent expansion considering contact



Plain weave

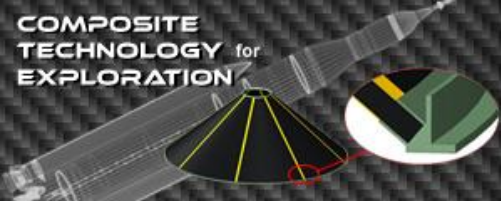
Hsu and Cheng 2013

LaRC

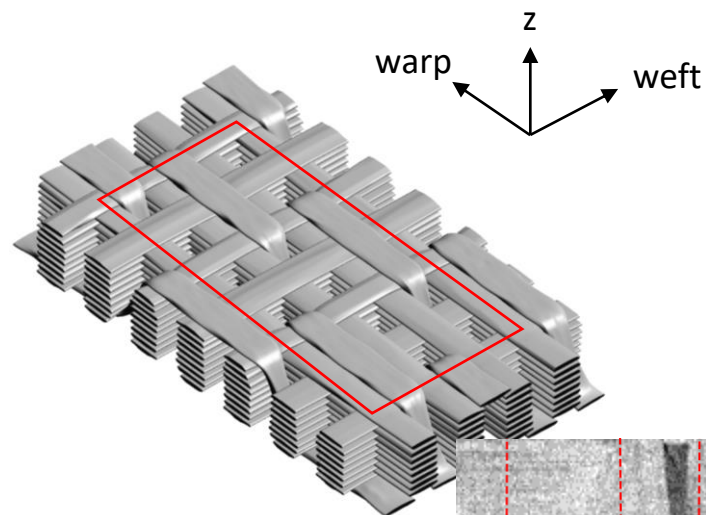


Triaxial braid

Wehrkamp, De Carvalho, and Pinho 2018



Geometry Model vs. X-Ray CT



→ warp

weft
↑

