Digital Fabric Mechanics Analyzer

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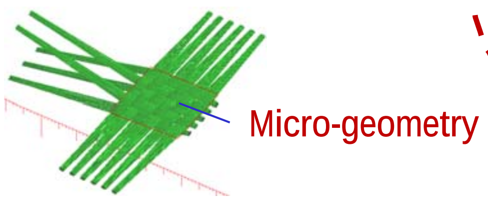
Composites Laboratory

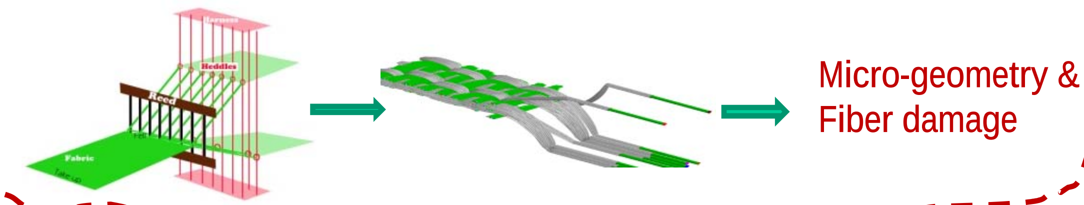
Applications

- Textile process simulation

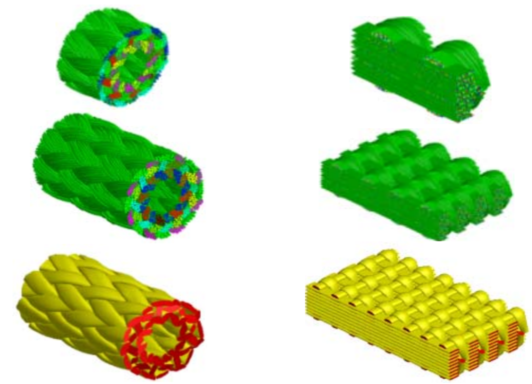
Static Simulation (Weaving)



Dynamic Simulation (Weaving+ Beat-up)



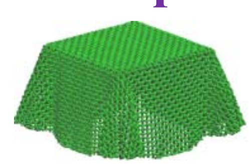
- Dynamic relaxation with periodic boundary conditions (DFMA: Fabricmechanics.com)
  - Unit cell fiber-level micro-geometry
  - Assembly of unit cells ⟹ Fabrics
  - Yarn Geometry



- Fabric stress analysis
  - Static Analysis: fiber stress, fabric deformation, fabric strength, fabric damage
  - Dynamic Analysis

Impact

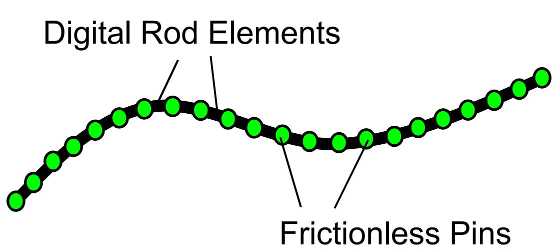
Drape



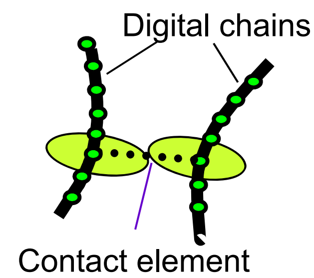
Molding

Fiber-level fabric Mechanics Analysis

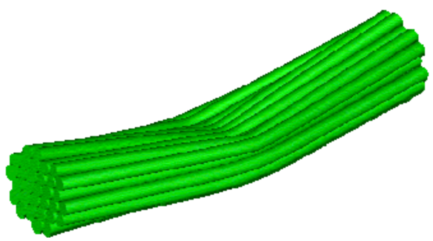
Basic Concepts:



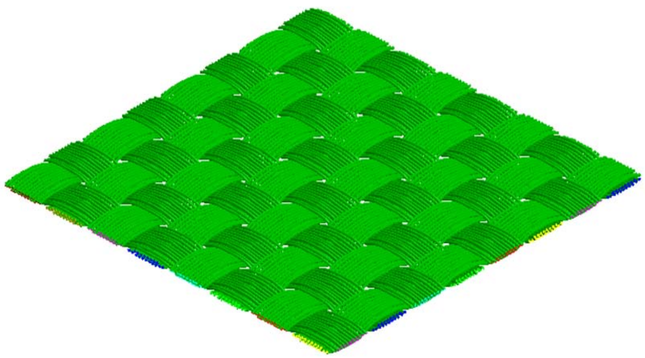
1. Digital fibers: 1-D flexible component



2. Contact of digital fibers



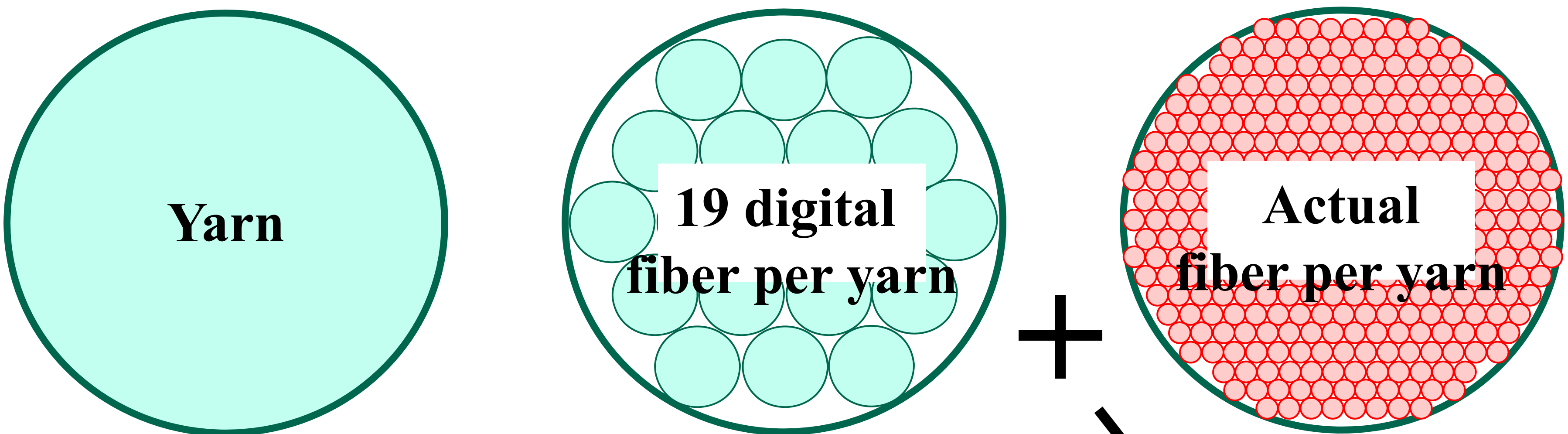
3. Digital Yarn: Assembly of digital fibers

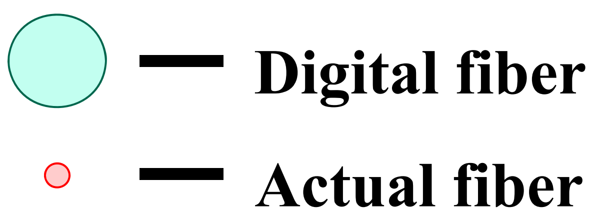


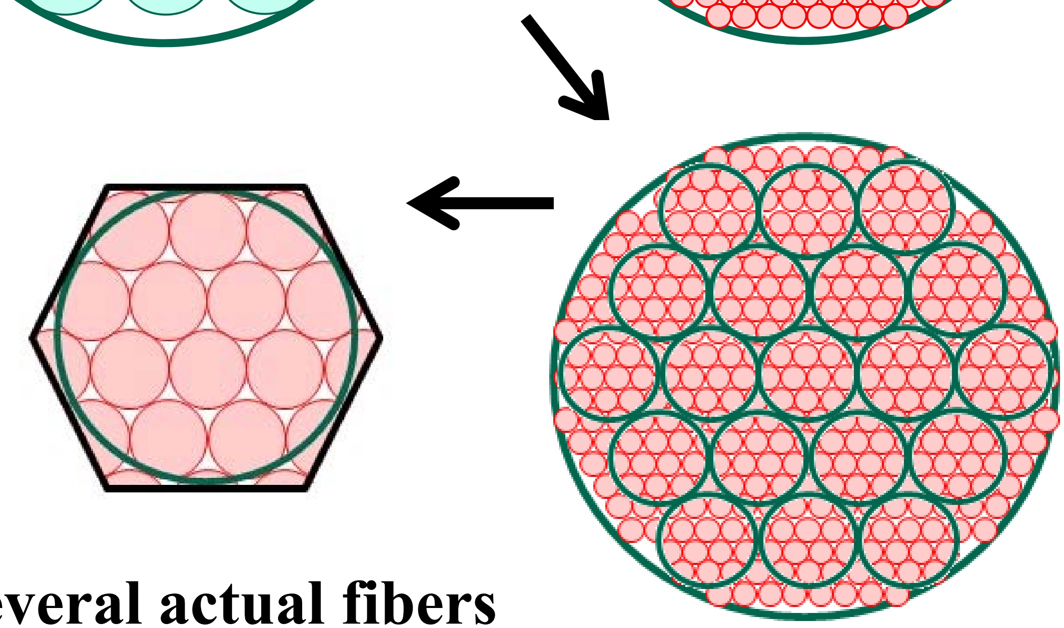
4. Fabric: Assembly of digital yarns

Assumption on Digital Yarns: Length of all digital fibers inside a digital yarn are the same. (Iso-length assumption)

Digital fibers and Actual fibers







1 yarn = 19 digital fiber
1 digital fiber represent several actual fibers

Software Structure

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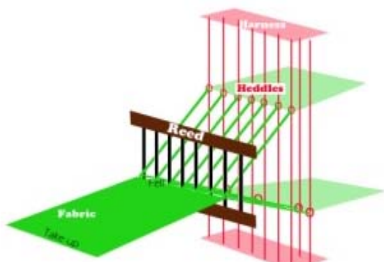
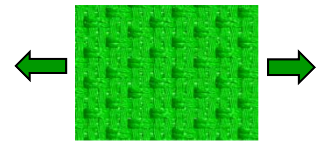
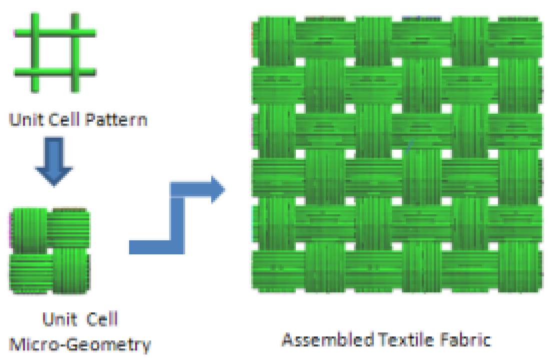


Textile Process Simulator

Main Solver

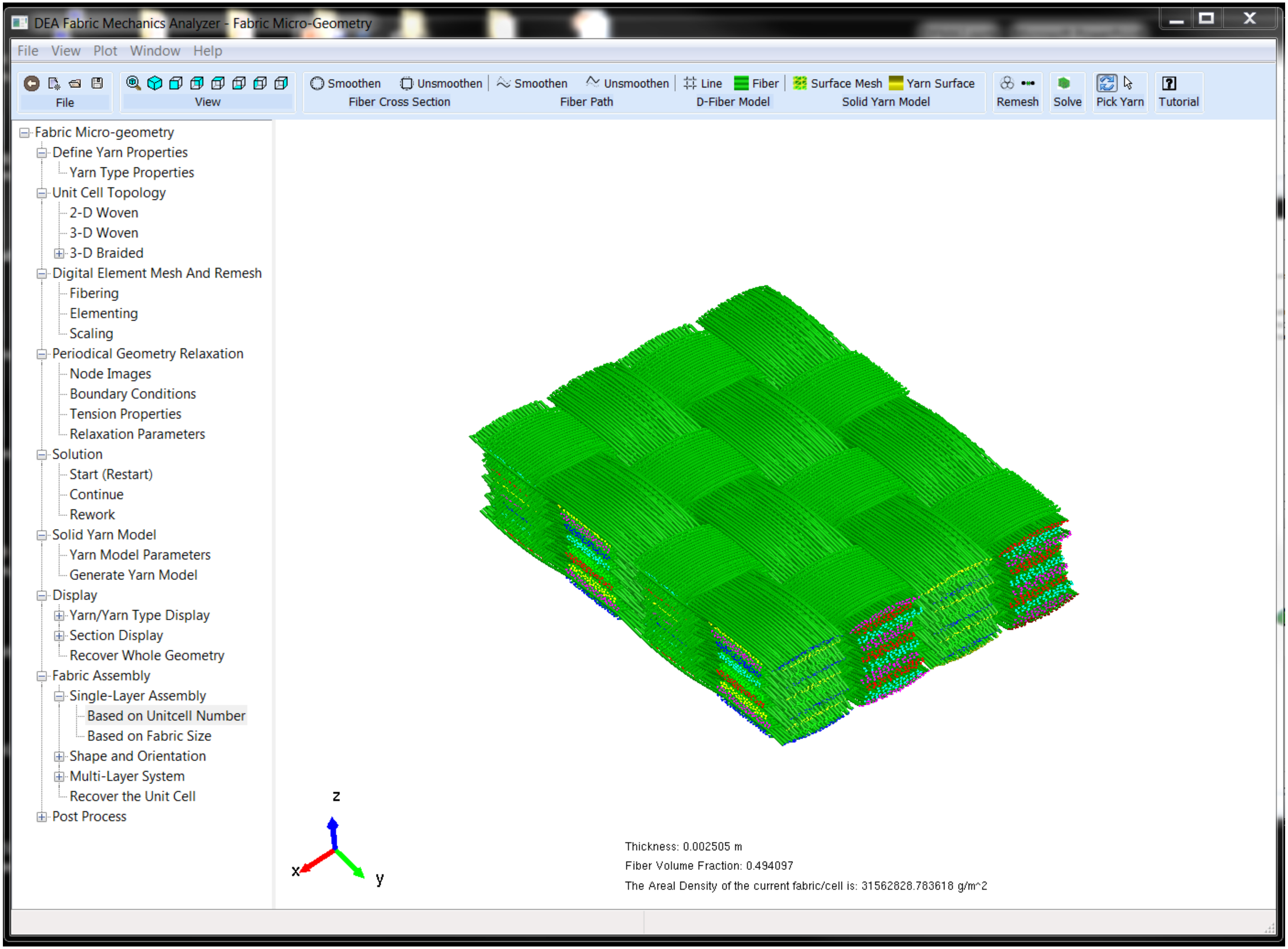


Stress, strength deformation, impact, molding, draping analysis



Determine Fabric Micro-Geometry

Part 1: Interface for Fabric Micro-Geometry



Unit Cell Micro-Geometry

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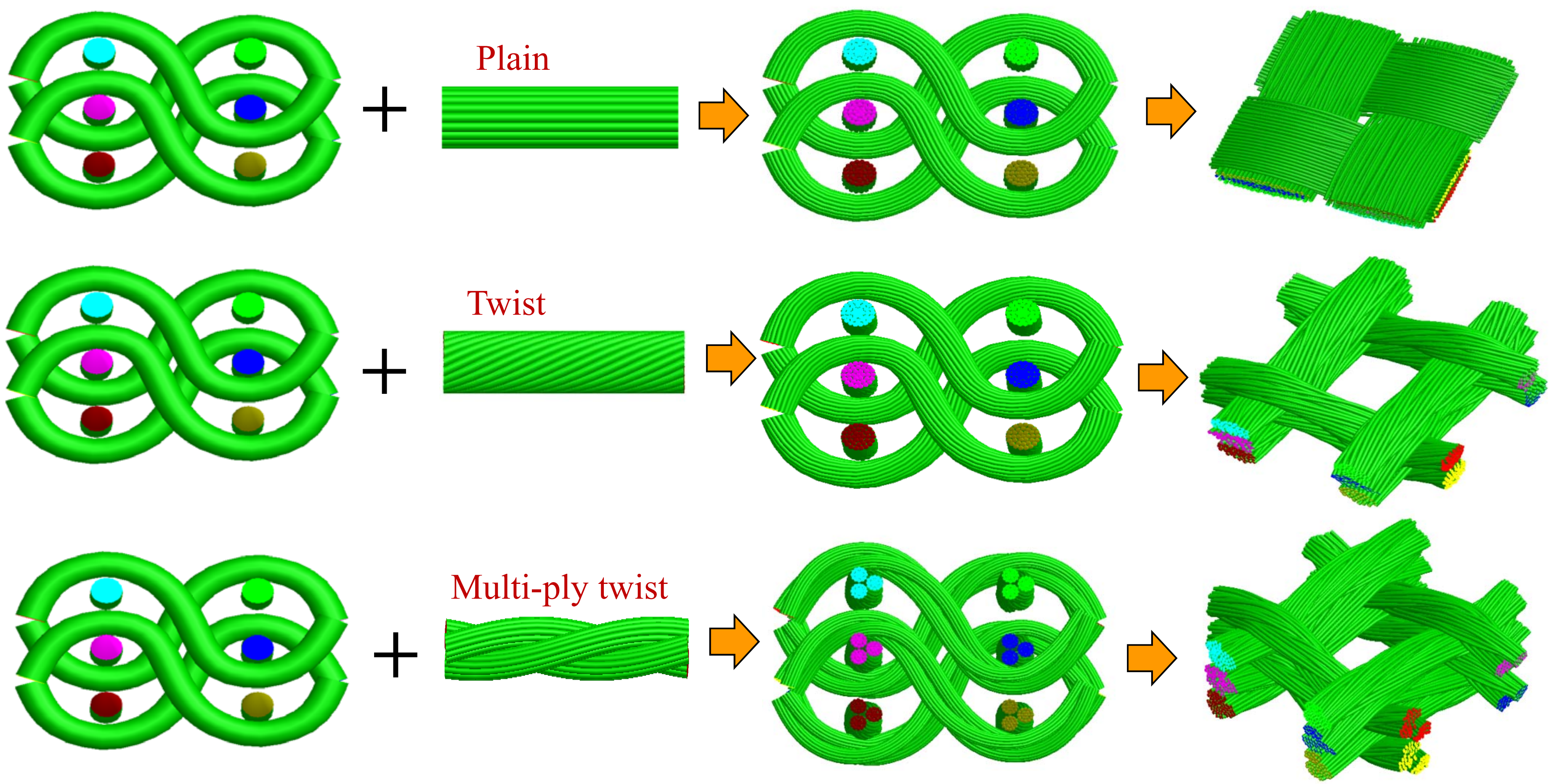
Cell Topology | Tow Structure | Cell Topology with assigned yarn structure | Unit cell micro-geometry



Micro-geometry is determined by dynamic relaxation approach with periodic boundary conditions.

3-D Woven Fabric Unit Cell Micro-geometry

—Multi-level mesh and simulation

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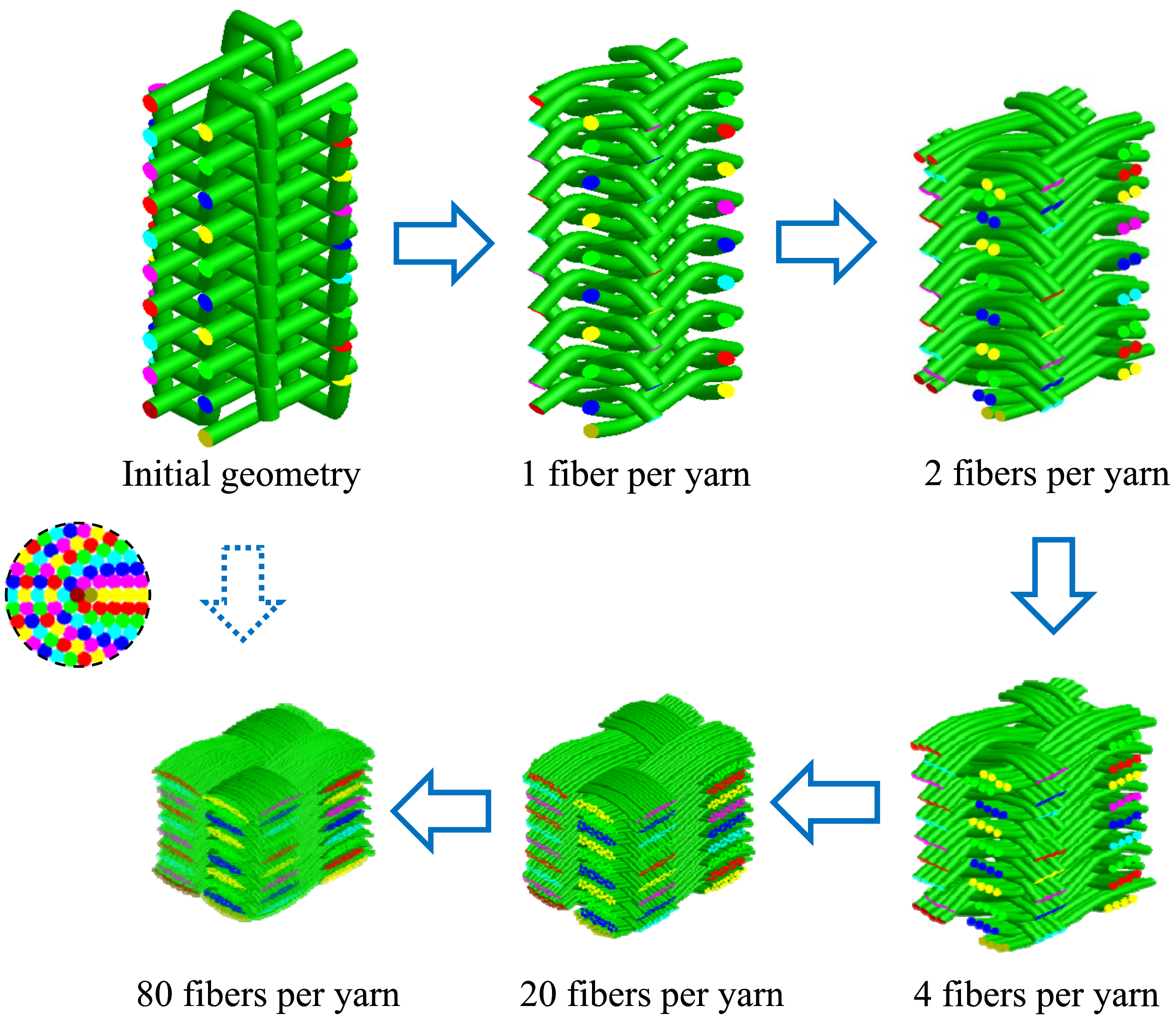
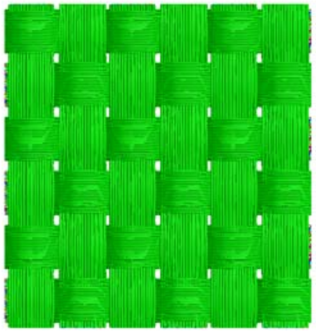
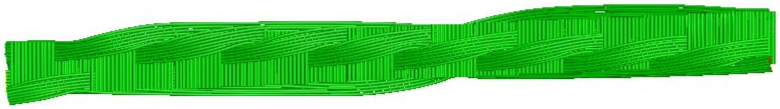


Uniform Fabric Assembly

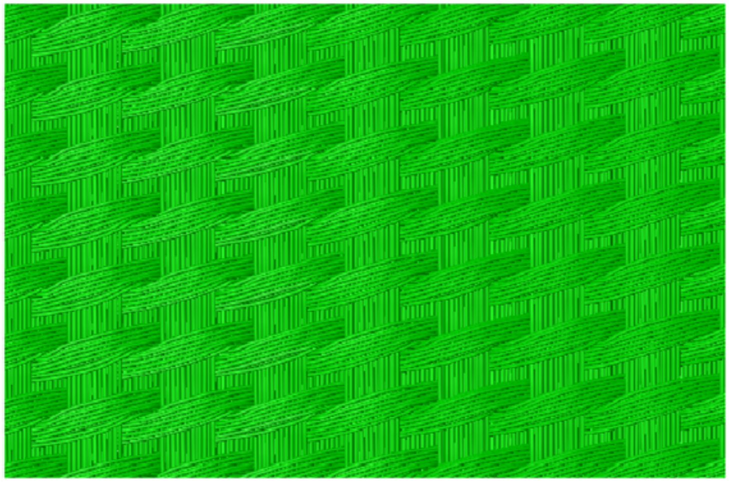
Rectangular unit cell

Assembly





Non - rectangular unit cell
(Angle-interlock)



Hybrid Unit Cell Assembly (Coming Soon)

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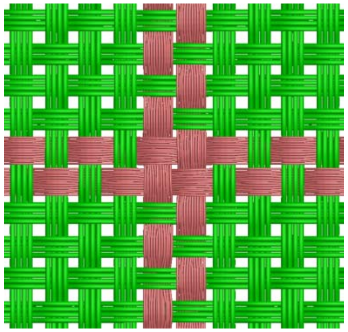
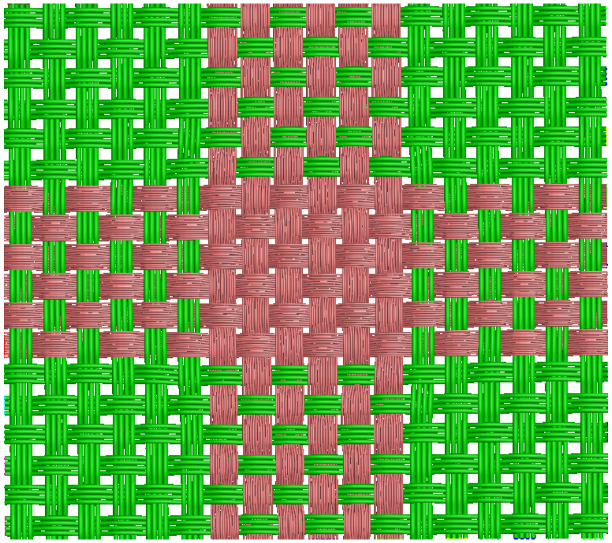


Representative Structures

Assembly



Expanded Fabrics

The representative structure of a fabric is not the unit cell of the fabric. It contains all cells required to assemble a hybrid fabric.

Preprocessor 1: Basic cells in hybrid meshes

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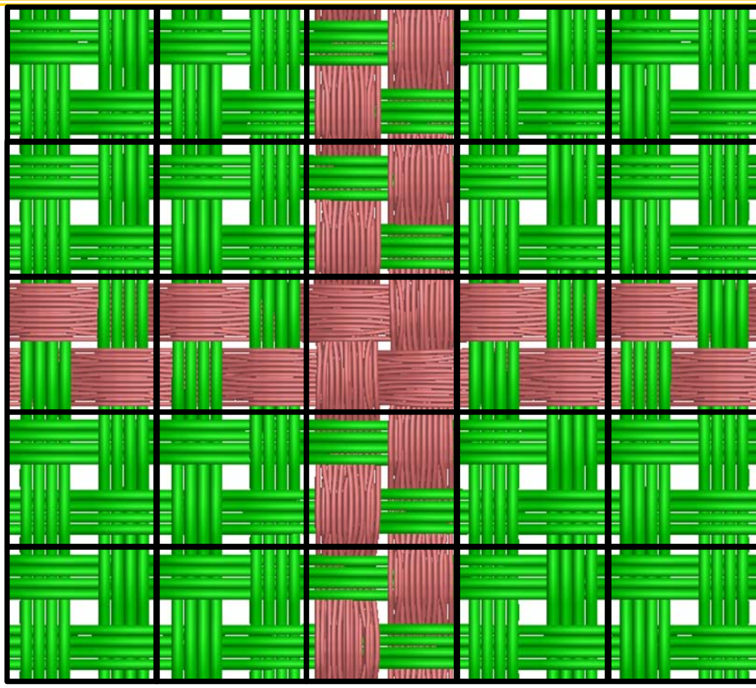


5, 1	5, 2	5, 3	5, 4	5, 5
4, 1	4, 2	4, 3	4, 4	4, 5
3, 1	3, 2	3, 3	3, 4	3, 5
2, 1	2,2	2, 3	2, 4	2, 5
1, 1	1, 2	1, 3	1, 4	1, 5

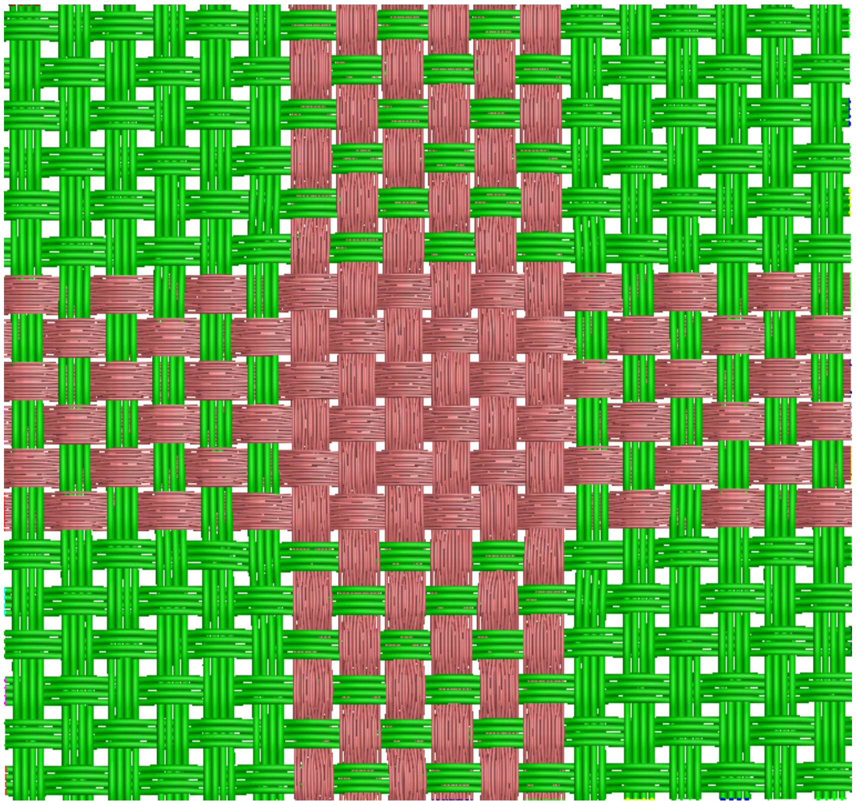
A two-level hybrid mesh include 25 basic cells:

1. Yellow cells: with periodic boundary in x- and y-directions
2. Light blue cells:
   - with periodic boundary conditions in y-direction
   - left and right boundary displacements: defined by the neighboring cells
3. Deep blue cells:
   - with periodic boundary conditions in x-direction
   - top and bottom boundary displacements: defined by neighboring cells
4. White cells:
   - all boundaries: defined by neighboring cells

Relaxation sequence: 1. yellow cells, 2. blue cells, 3. white cells

Preprocessor 2: Fabric Assembly

Hybrid Mesh Assembly Map:



Fabric with 81 cells

5, 1	**5, 1**	**5, 2**	**5, 3**	**5, 3**	**5, 3**	**5, 4**	**5, 5**	**5, 5**
5, 1	5, 1	5, 2	5, 3	5, 3	5, 3	5, 4	5, 5	5, 5
4, 1	4, 1	4, 2	4, 3	4, 3	4, 3	4, 4	4, 5	4, 5
3, 1	3, 1	3, 2	3, 3	3, 3	3, 3	3, 4	3, 5	3, 5
3, 1	3, 1	3, 2	3, 3	3, 3	3, 3	3, 4	3, 5	3, 5
3, 1	3, 1	3, 2	3, 3	3, 3	3, 3	3, 4	3, 5	3, 5
2, 1	2, 1	2,2	2, 3	2, 3	2, 3	2, 4	2, 5	2, 5
1, 1	1, 1	1, 2	1, 3	1, 3	1, 3	1, 4	1, 5	1, 5
1, 1	1, 1	1, 2	1, 3	1, 3	1, 3	1, 4	1, 5	1, 5

Assembly Map

Hybrid Assembly of π Joint (Coming soon)

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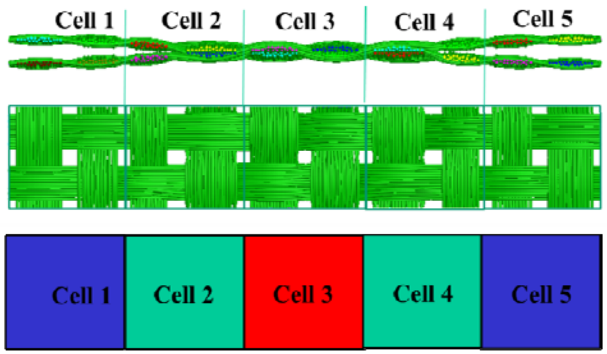
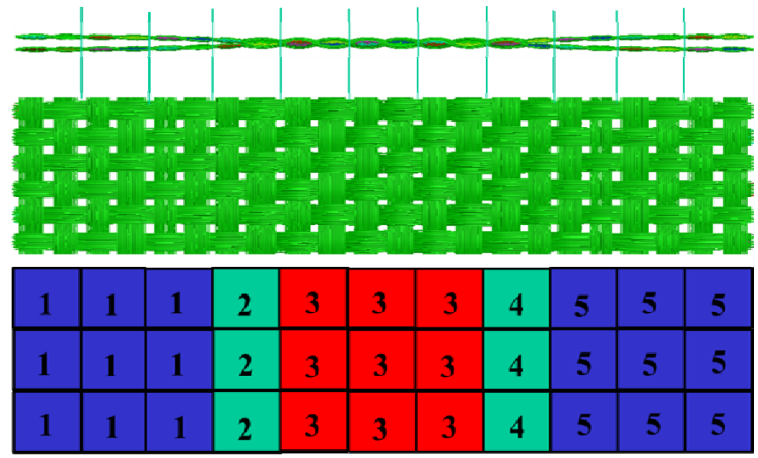
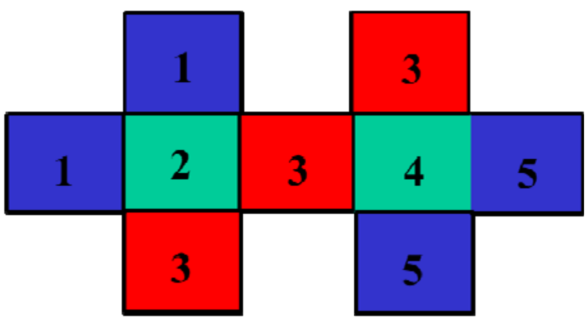


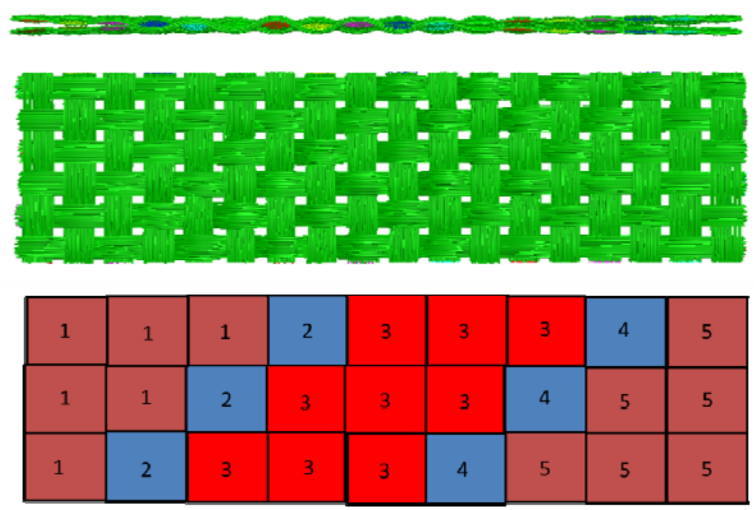
Representative structure for a 90° π joint



Expanded 90° π joint as woven



Representative structure for a 45° π joint



Expanded 45° π joint as woven

Goal of Hybrid Assembly

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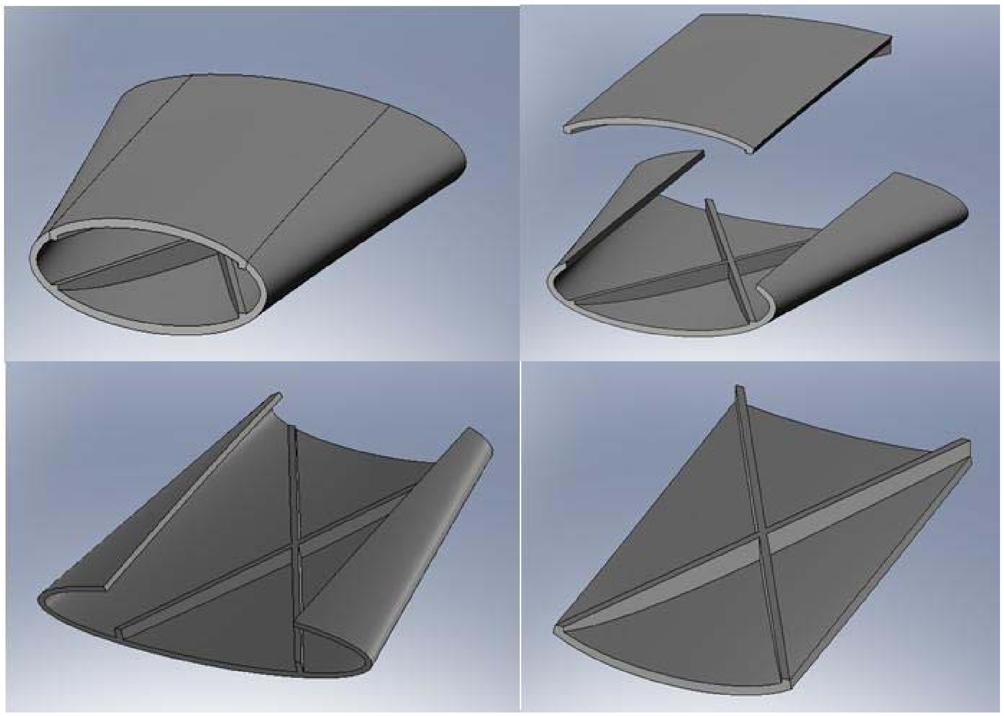
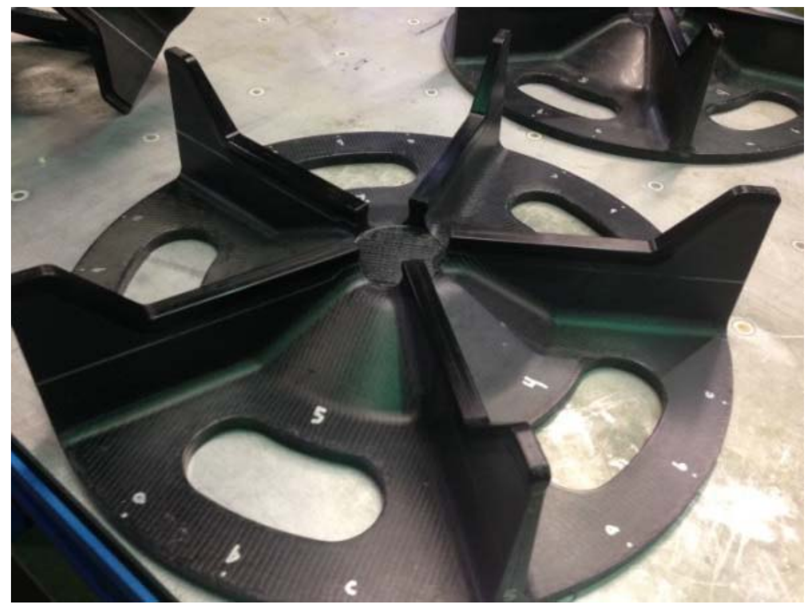
- Generate complex structure such as:





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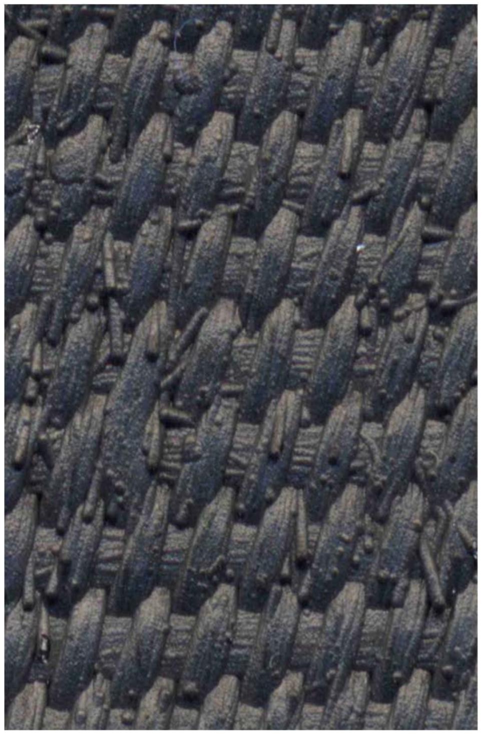
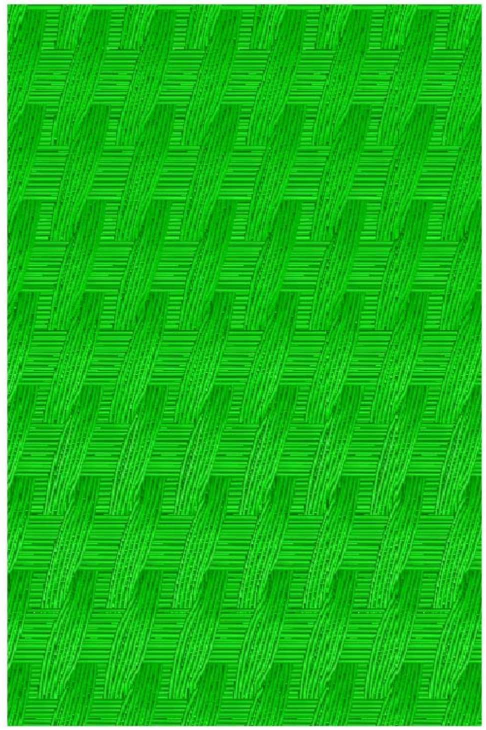
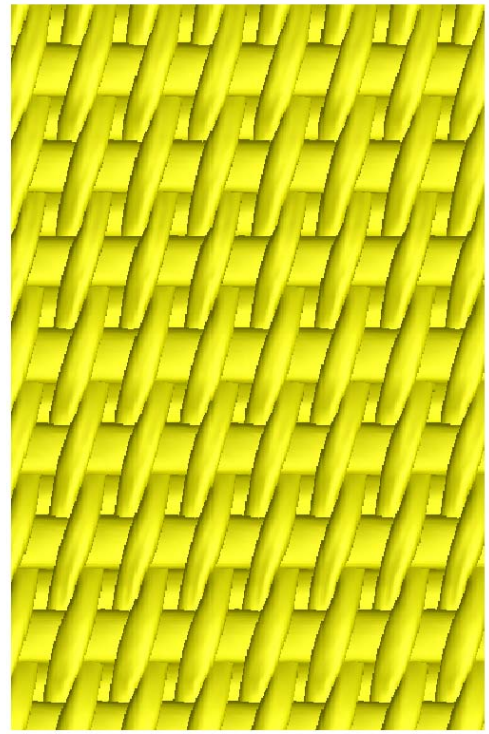
Fabric Surface comparison



Microscopic picture



Assembly with fiber mode



Assembly with solid yarn mode

Various Fabric Micro-Geometries

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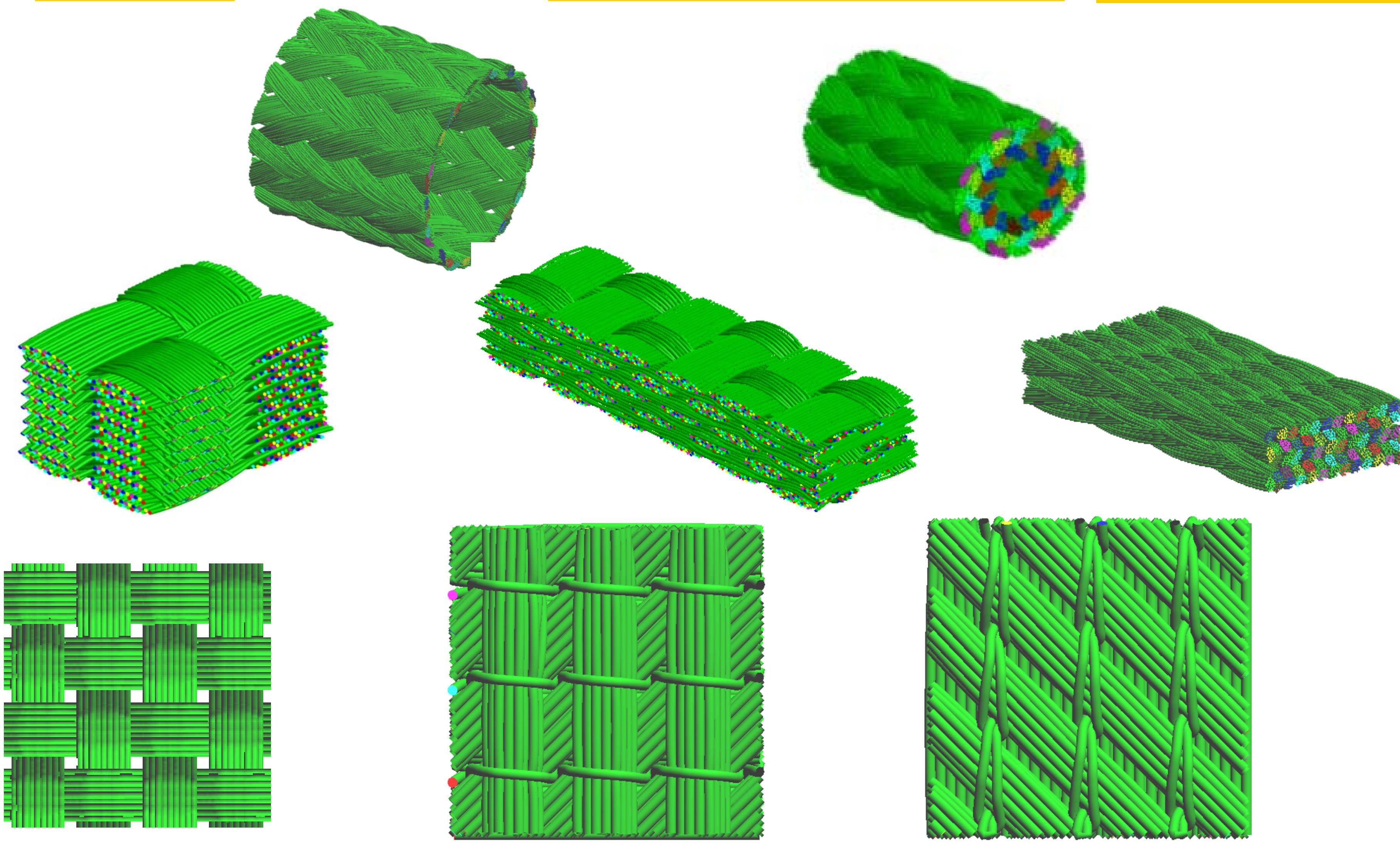

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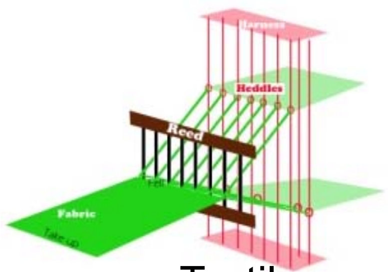
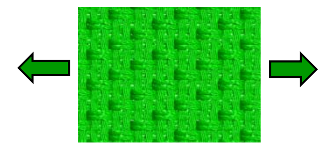
Software Structure



Textile Process Simulator

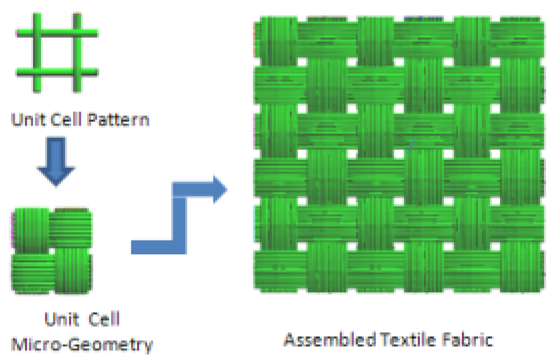
Part 3

Main Solver



Stress, strength deformation, impact, molding, draping analysis

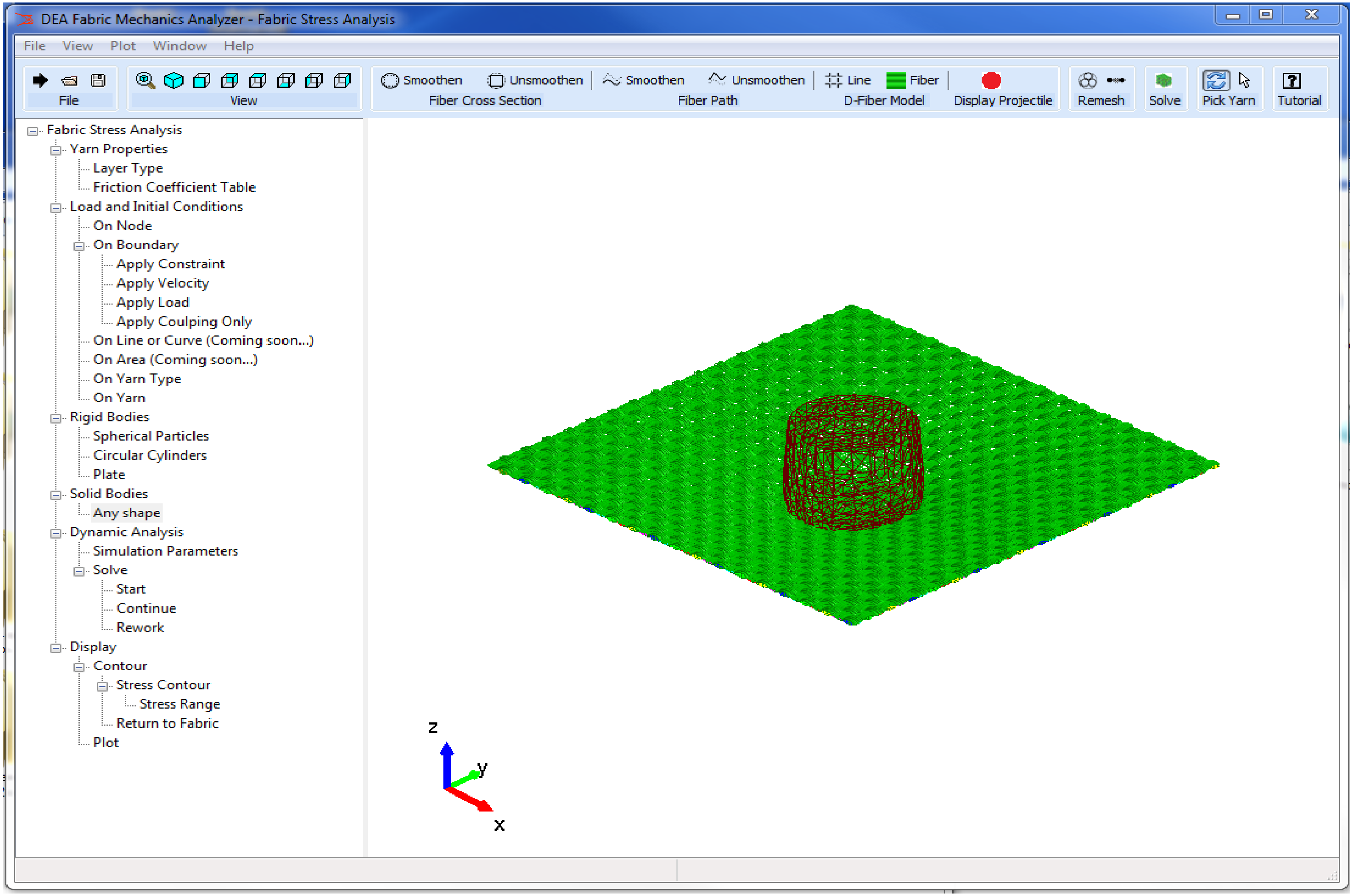
Part 2



Determine Fabric Micro-Geometry

Part 1

Part 2: Stress, Deformation, Impact Analysis



Fabric Stress, Deformation and Strength Analysis

The software has been used for the following area:

1. Stress and strength analysis of fabrics
2. Draping process
3. Molding process:
   - Helmet manufacturing process

     External mold and internal plug
   - Airplane Engine Blade

     Double moulding and net-shape forming
4. Ballistic penetration process
   - PC based simulation
   - Cluster based simulation (Parallel code)
   - Projectiles: Particles, rigid body, and elastic body
5. Fiber properties:

   Elastic or elasto-plastic in both longitudinal and transverse direction

6. Post process and Virtualization Capability:

   Displacement and stress

Example 1:
Fabric Stress and Strength Analysis

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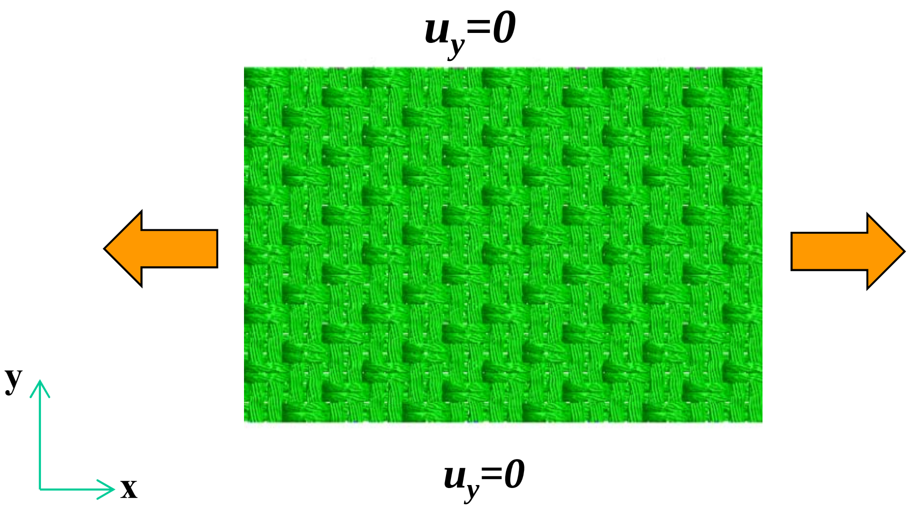
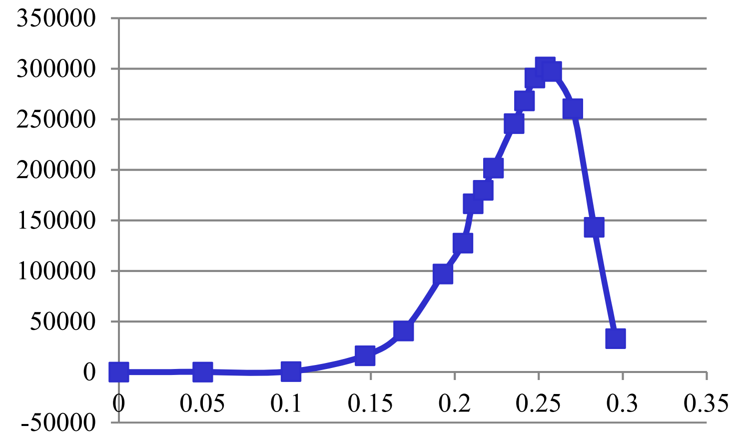
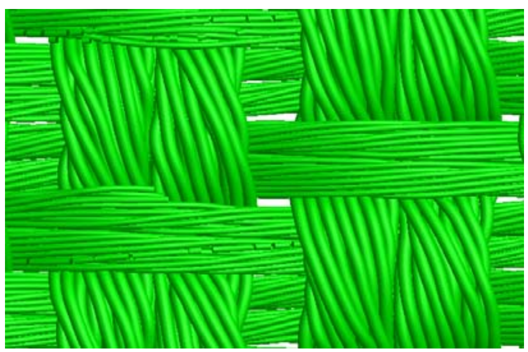


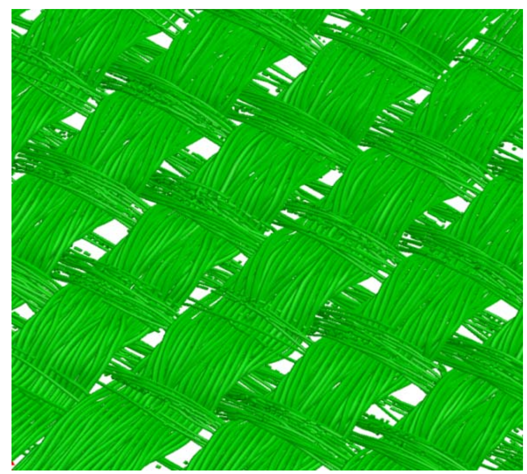
Boundary Load

N_l - ε_l relations





Failure begins



Massive Fiber failure

Example 2: Draping Process

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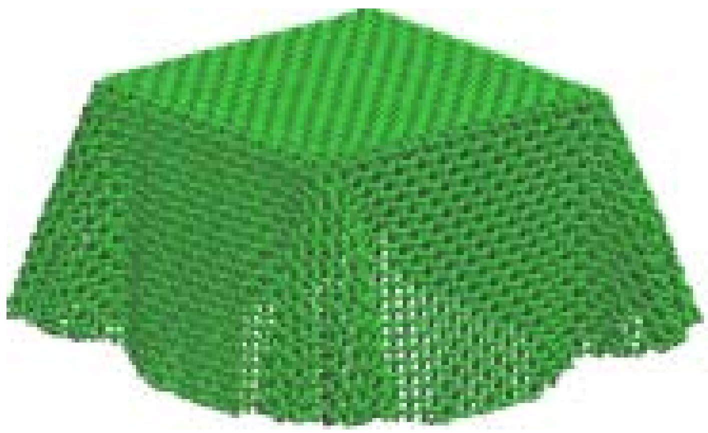

Net Shape Composite and the Molding Process

—Dynamic molding process

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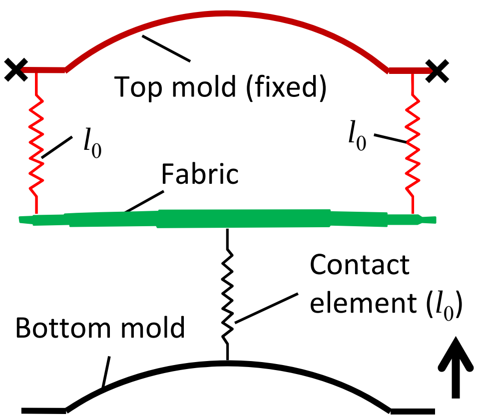
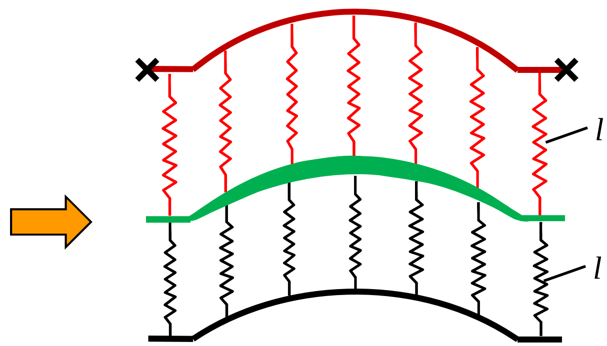


Initial settings



Final positions

Finished product

- Top mold fixed, bottom mold free to move
- Shortest distance between fabric and both molds is l_0
- l_0 is defined contact element length

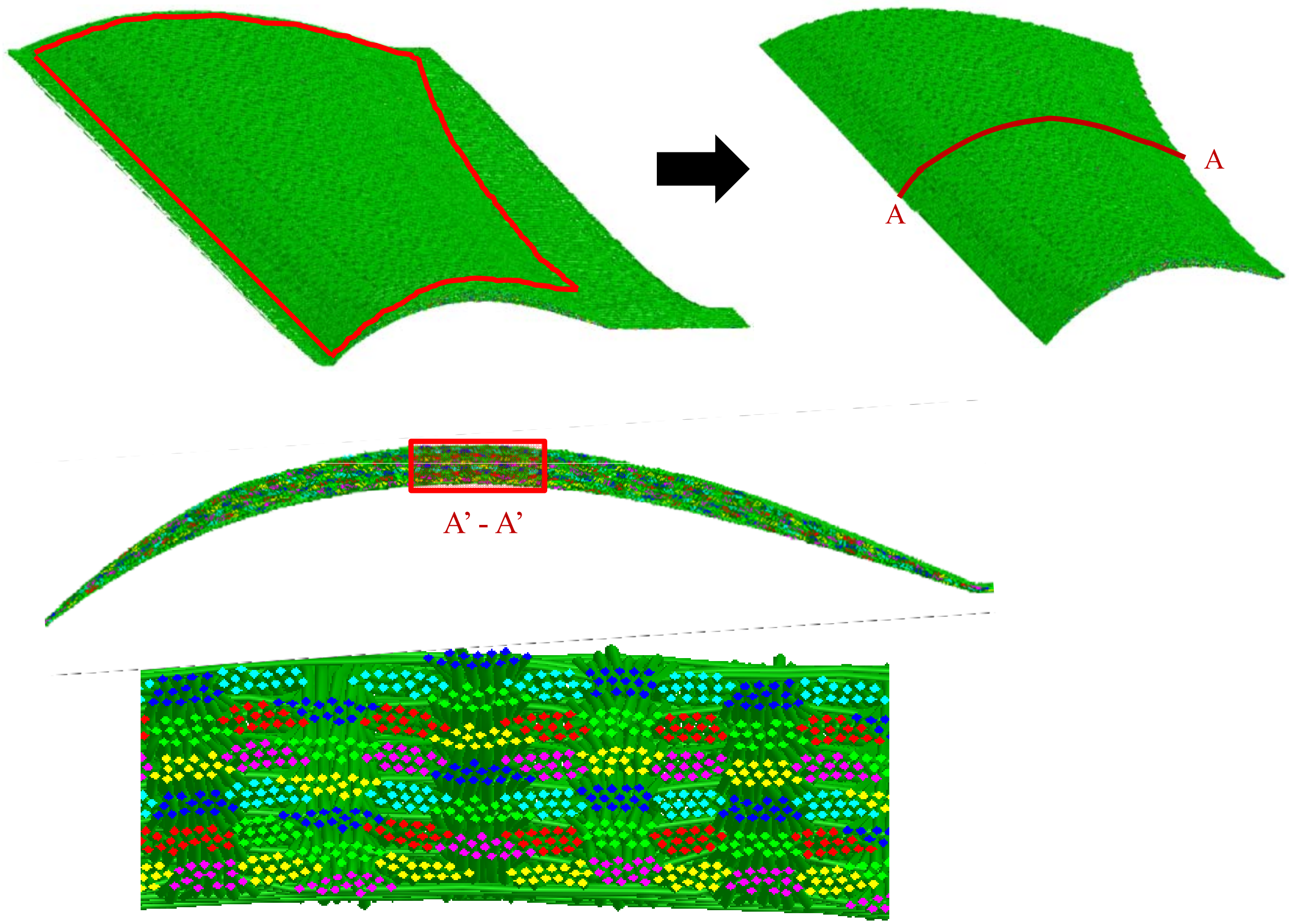
- All contact elements are equal

- Remove both molds and relative contact elements

4. Net Shape Composite and the Molding Process

—Micro- and macro- geometry of fabric reinforced composite

Airplane engine blade



Example 3: Molding Process (Helmet)

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Upper mold: Made of metal materials

Lower mold: Plug (Rubber like material)

Simulation process:

- Drape the fabric on the lower mold(plug)
- The lower mold move upward until the pressure between upper mold and the lower mold reach a certain value.

Helmet

Ballistic Penetration Simulation

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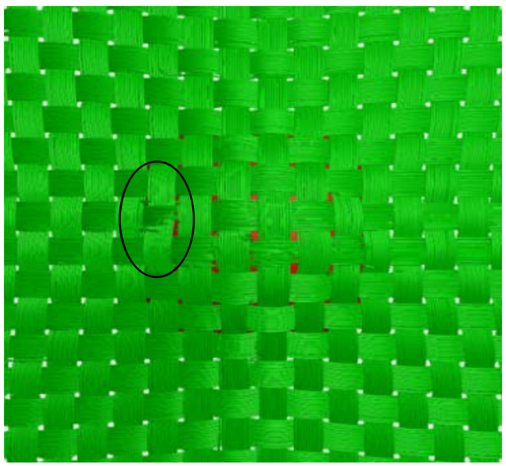
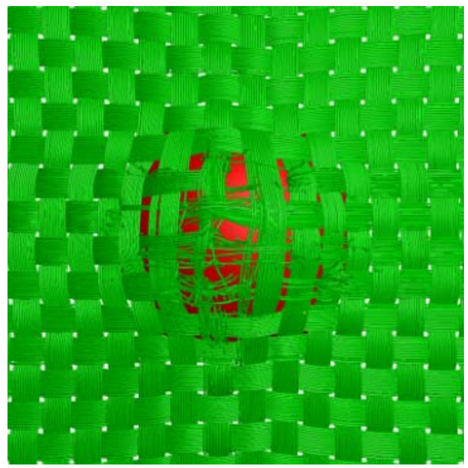
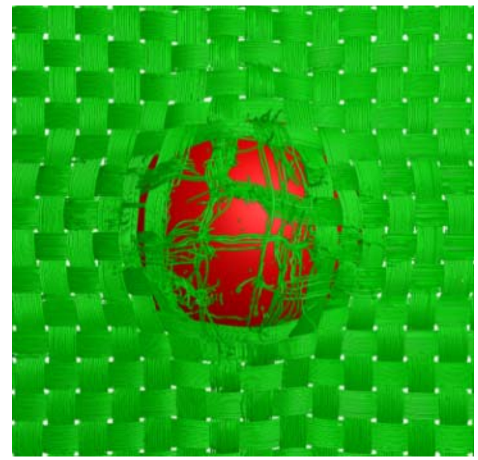


Failure Starts



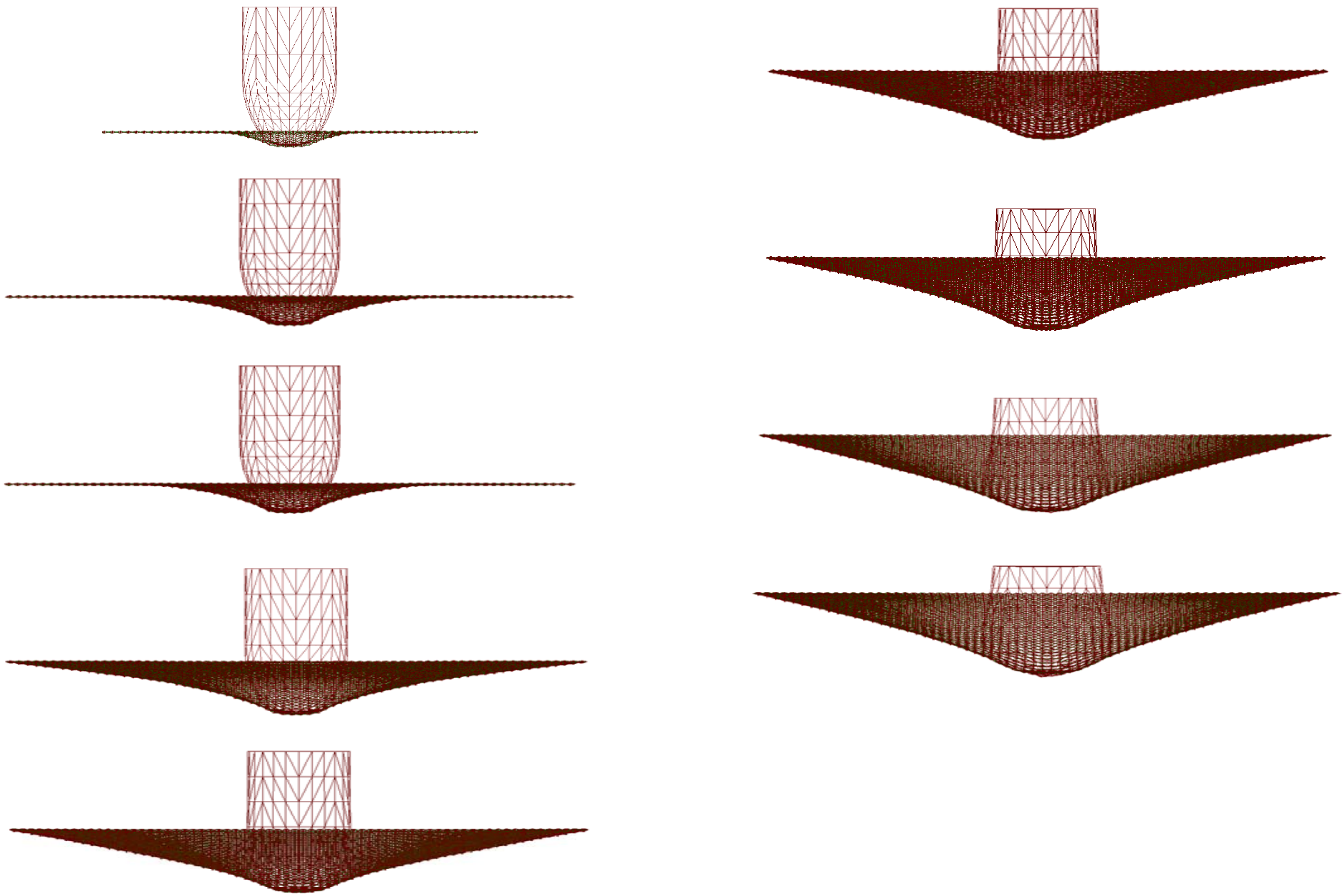
Progressive Failure



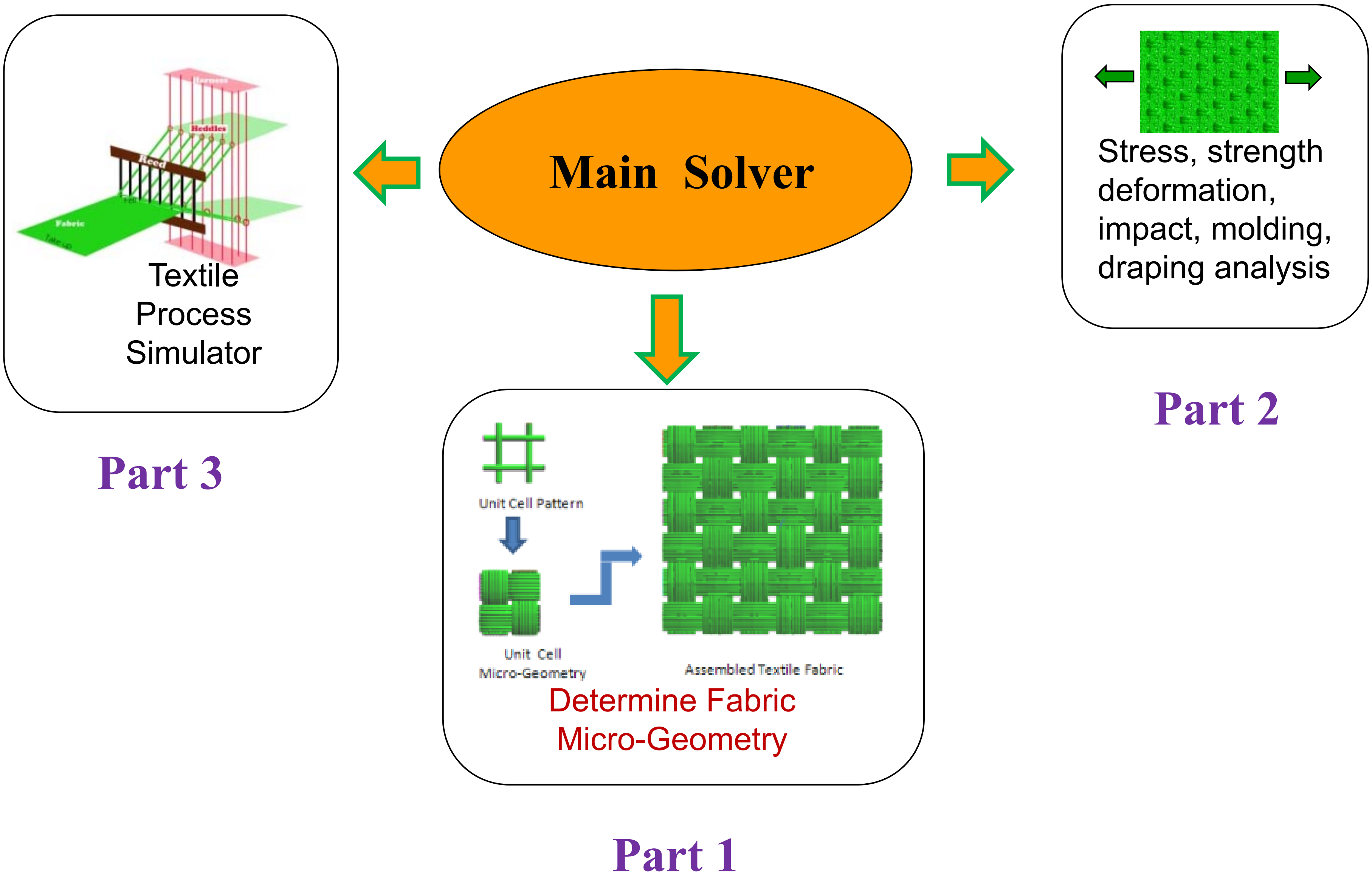
Prior to Perforation

(PC Based and Cluster Based)

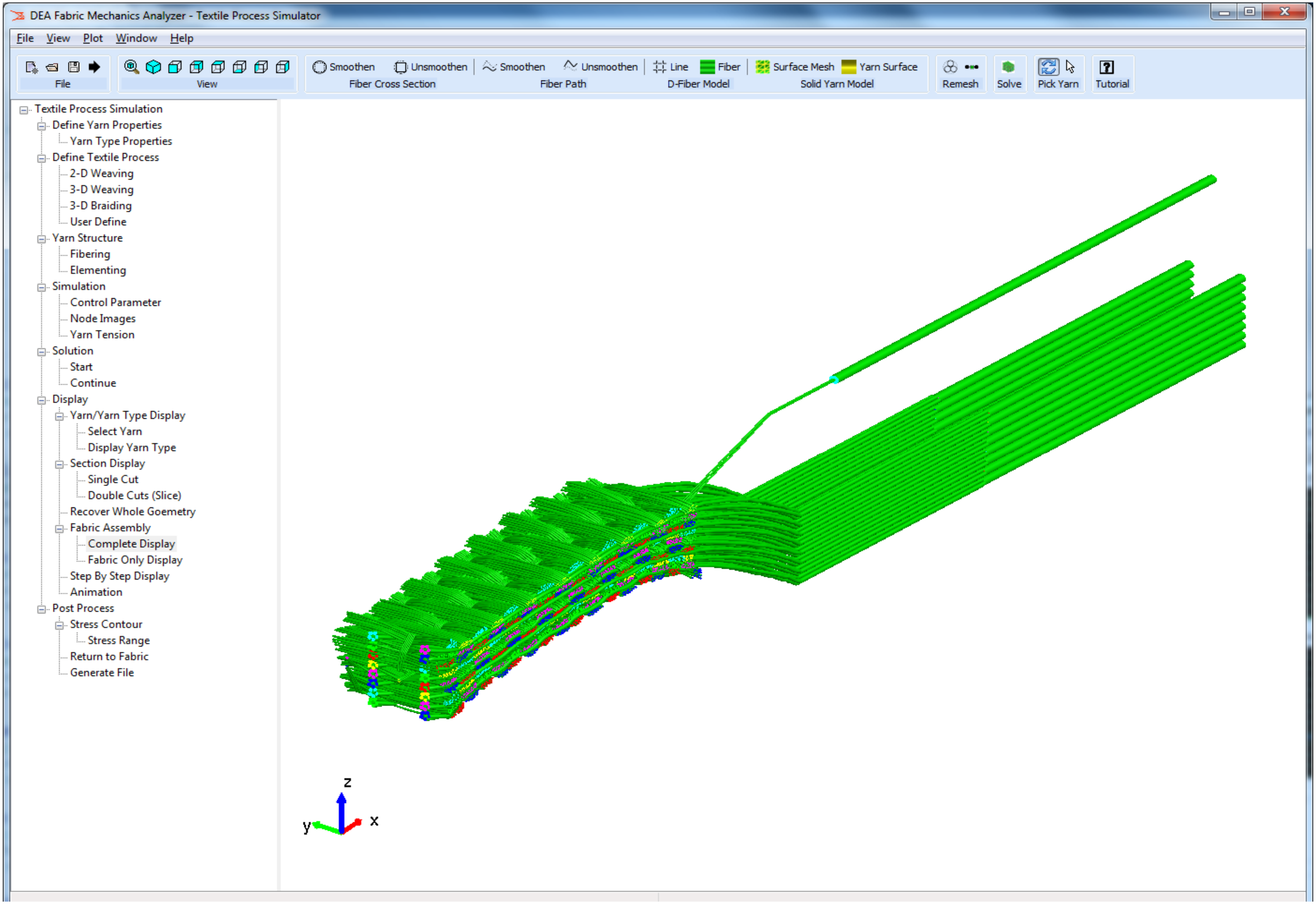
Impact with Deformable Body



Software Structure



Part 3: Weaving Process Simulator



3D WEAVING MACHINE STRUCTURE AND WEAVING PROCESS SIMULATION

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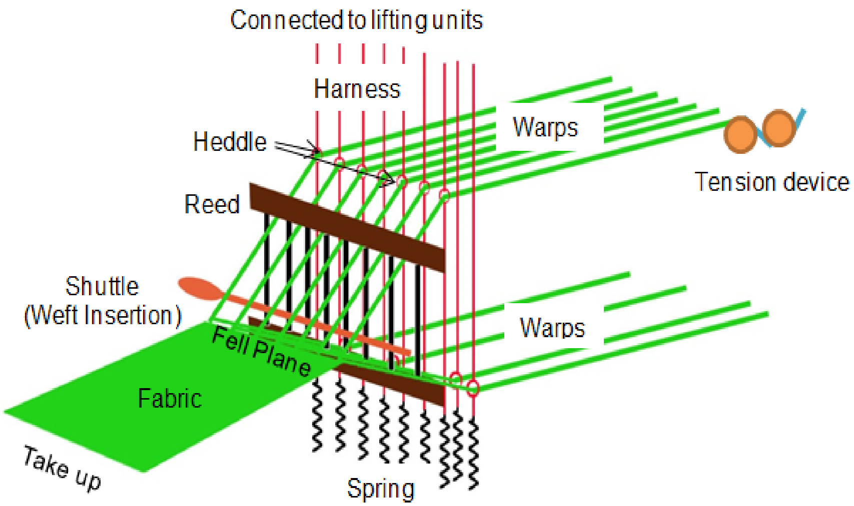

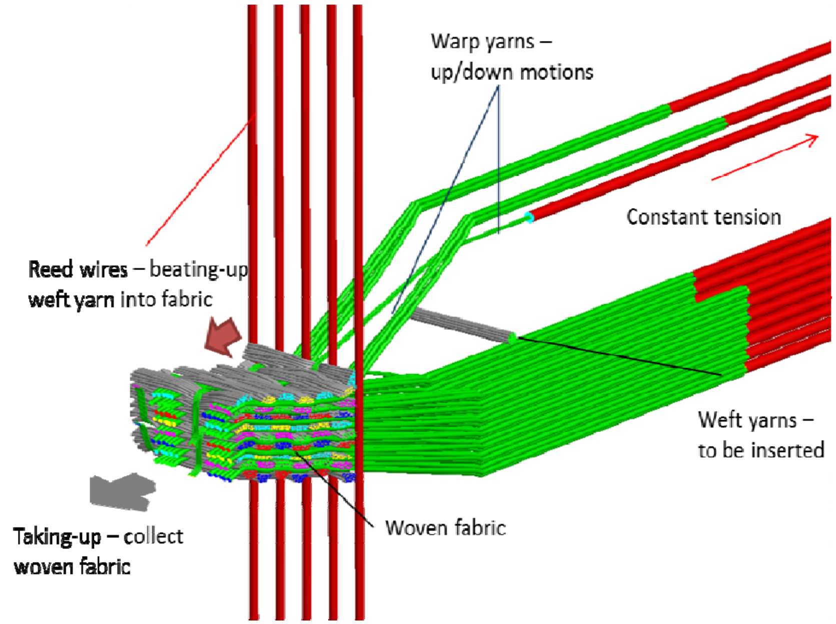

Machine structure → Process simulation

Applications of Process Simulation

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1. Simulate weaving process. Analyze weaving kinetics, such as yarn tension, beat-up velocity, beat-up force, take up frequency, inter-fiber friction, reed-fiber friction, on fabric thickness, unit cell length and unit-cell width.
2. Analyze fiber damage during the weaving process. The beat-up velocity and reed-fiber friction can play important role on the fiber damage. Fiber damage could affect the fabric strength and composite strength.
3. We have collaborated with 3-D weaving company to design 3-D weaving machine for 3-D armors. The simulator is used to calculate the beat-up load applied to the 3-D weaving machine. It will guide company for the design of new machine.
4. It can also be used to simulate braiding processes.

Software Version

- Window based version(Free download):
  - Have a user friendly graphic interface
  - Have pre-processor and post processor
  - Used open-mp (parallel code with shared memory) and C++ language.

- Cluster based version:
  - Use MPI and C++ language
  - Can be used for large scale simulation
  - Have to use the window-based version for pre- and post-processors

Future development of DFMA

Our research interests:

1. Textile composite analysis:

   Feasible digital fiber level micro-mechanics model for textile composites

2. Problem in manufacturing process:

   - Resin flow in textile composite preform
   - Gas infiltration in textile composite preform
   - Vapor deposition process

Acknowledgements

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Thank You!

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