Advanced Fiber Placement Techniques for Optimum Composite Structure Strength

Challenges:

- Simulation software to display natural fiber path on a complex or bi-cubic surface
- Use of advanced steer techniques to drape surface at 0^0 , 45^0 and 90^0 pattern
- Achieve optimal structural strength by advanced fiber steering techniques to:
    1. Ensure steer is within specifications
    2. Ensure no gaps or overlaps between adjacent fibers
- 3D problem = 3D mathematical modeling and analysis

Objectives:

- In real life, illustrating fiber natural path is straightforward. The software in question can be used against these real examples for proof of concept
- Commonly used 2D projection of 3D objects to predict fiber paths is not possible for complex curvatures as path continuity cannot be guaranteed
- More importantly, 2D projection technique cannot provide steer information
- Over-steered fibers, gaps and overlaps contribute to and must be eliminated:

1. Ineffective adhesion and prolonged cure times during manufacture
2. Damage to fiber during fiber placement
3. More fiber layers and ensuing added weight to fulfil strength testing and approval
4. Introduction of internal stress to the structure in equilibrium state
5. Crack initiation and propagation sites under load
6. Reduced quality and in service life time

Advanced Techniques:

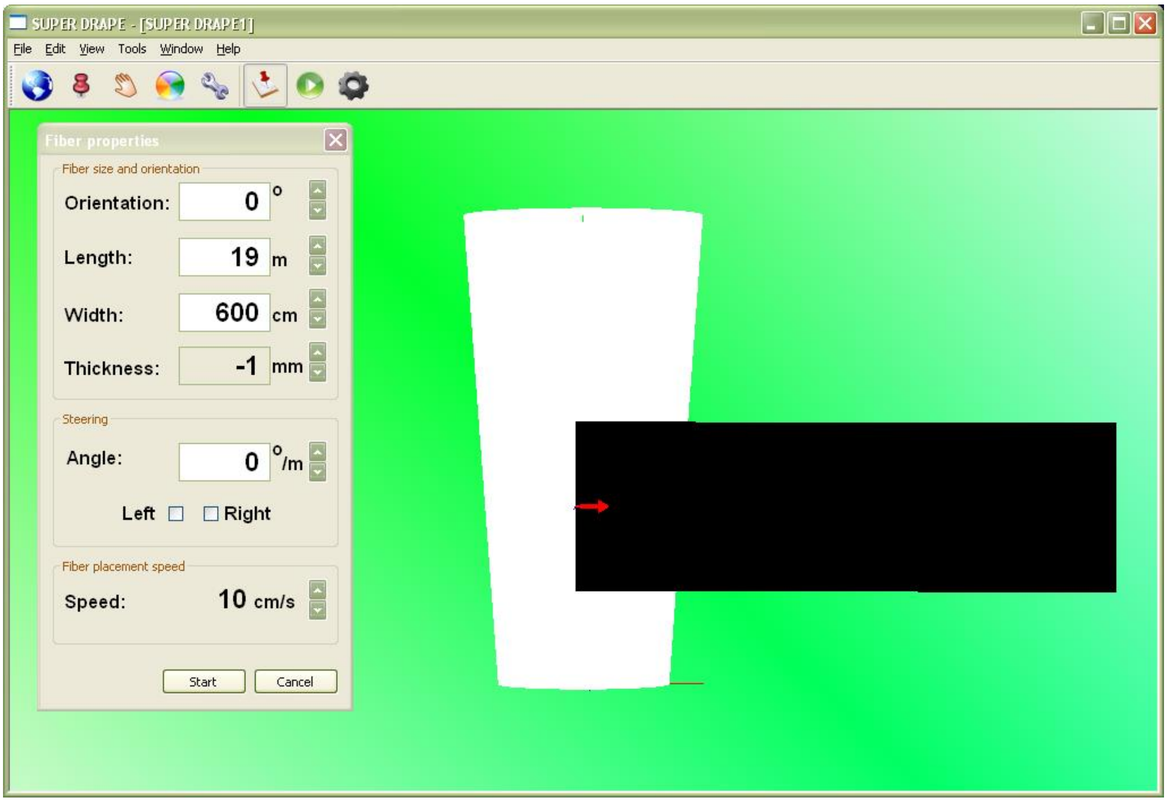
- We aim to illustrate the capabilities of the software in question with a simple everyday object
- A Starbucks paper cup and its insulation sleeve represent a special case of the carbon fiber placement process
- The conical geometry of Starbucks paper cup measures: rim diameter 85mm, base diameter 60mm and height 165mm
- Insulation sleeve length is 250mm and width 60mm
- The insulation sleeve sits comfortably when placed on the cup, however, unfold the sleeve and it becomes apparent it is the steer on the sleeve makes this possible
- Main difference between insulation sleeves and carbon fibers used for fiber placement is that sleeve stencil dimensions can be deduced from 2D projection (i.e. crudely flattening) of the cup

- Therefore, Starbuck is not at any point interested in steer values. This example will, however, illustrate important properties of fiber placement process

Starbucks paper cup and insulation sleeve:

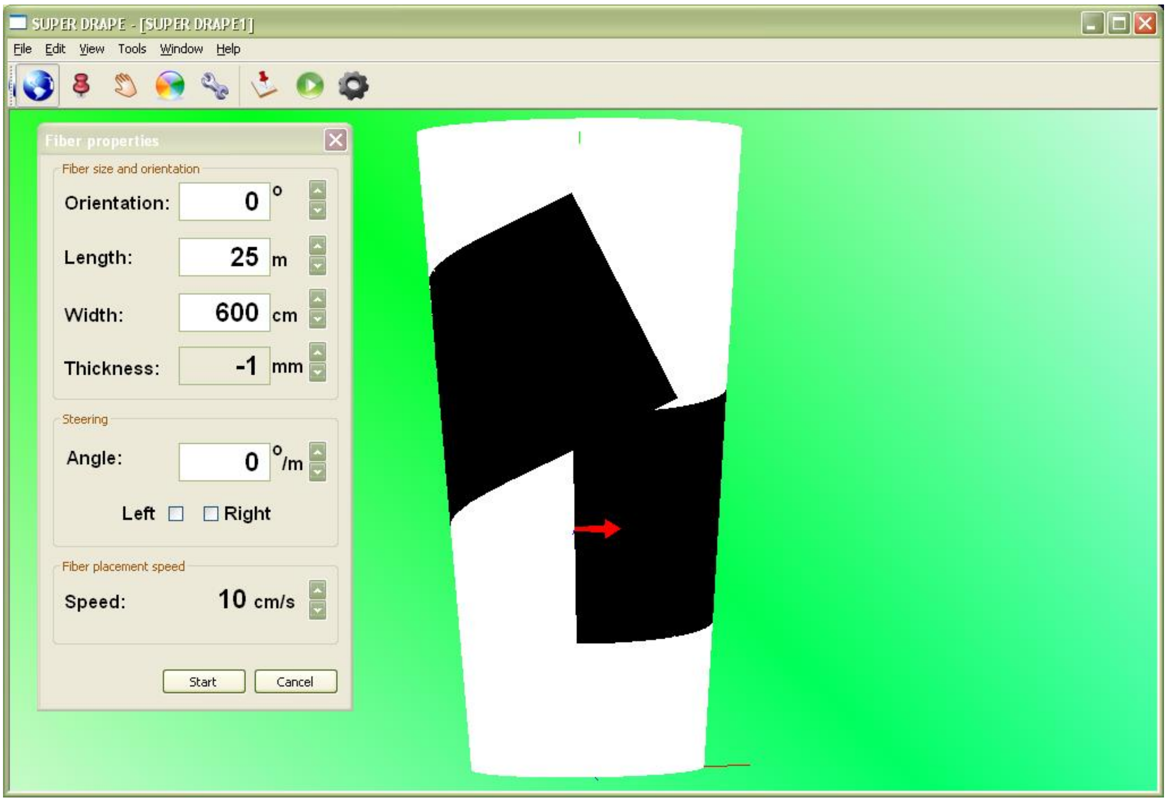
Modeling Starbucks cup:

- Using the measured dimensions, the paper cup is modeled in the ADS software (units of meters used in the software)
- The sleeve is given start position and size (corresponding to actual cup). However, in the initial run the sleeve is rigid without steering



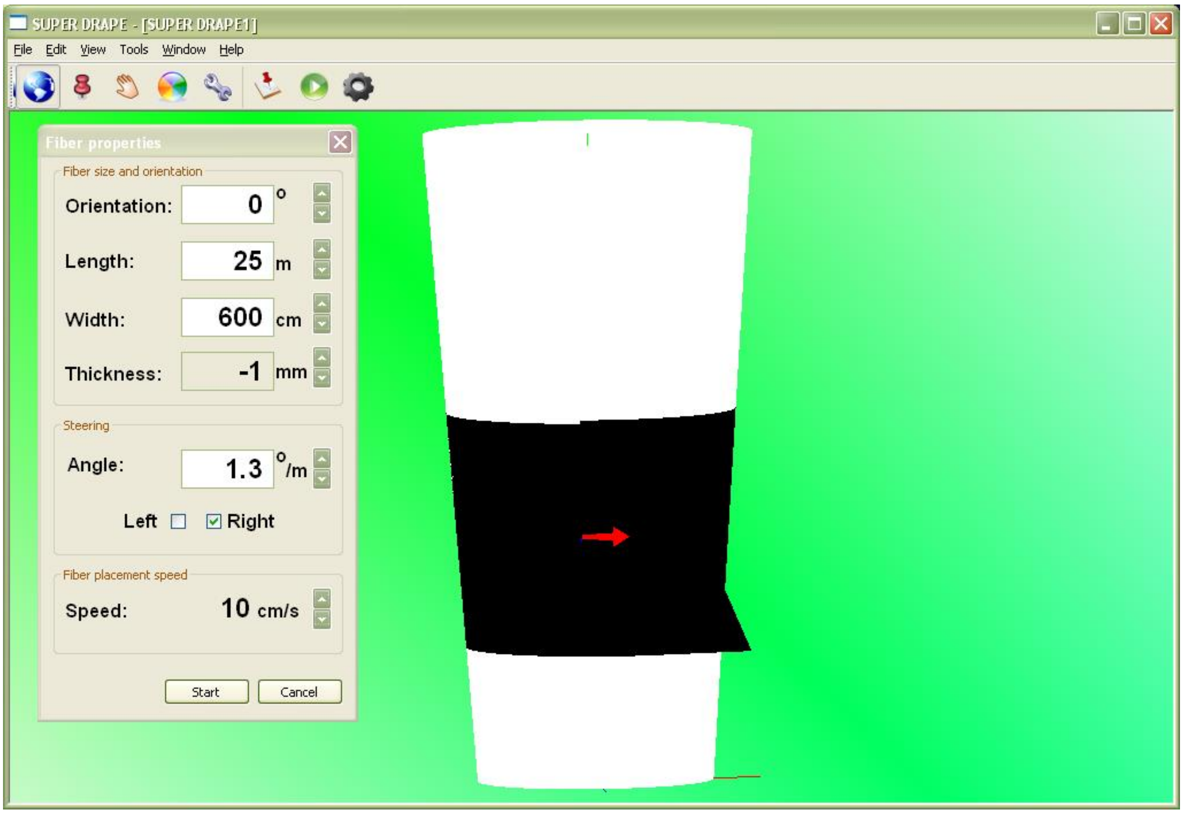
Draping Starbucks cup sleeve:

- As draping finalises, it becomes apparent that rigid draped sleeve results in the offset between sleeve begin and end points



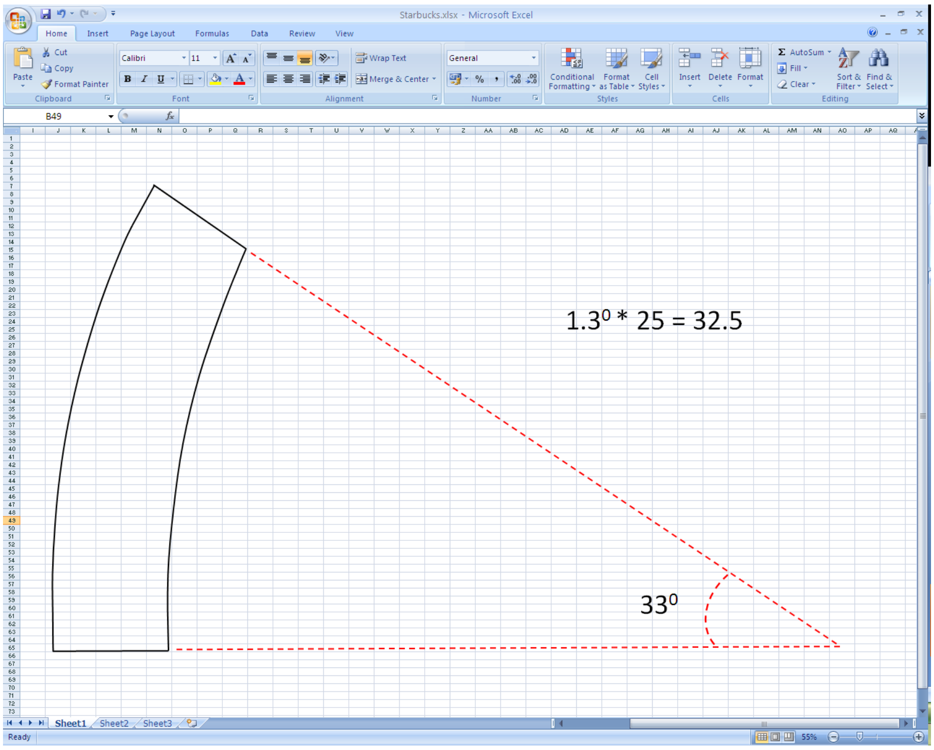
Draping Starbucks cup sleeve with steering:

- When a uniform 1.3 degree/ meter steering (to the right) is given to draping then the offset is removed and sleeve begin and end points align:



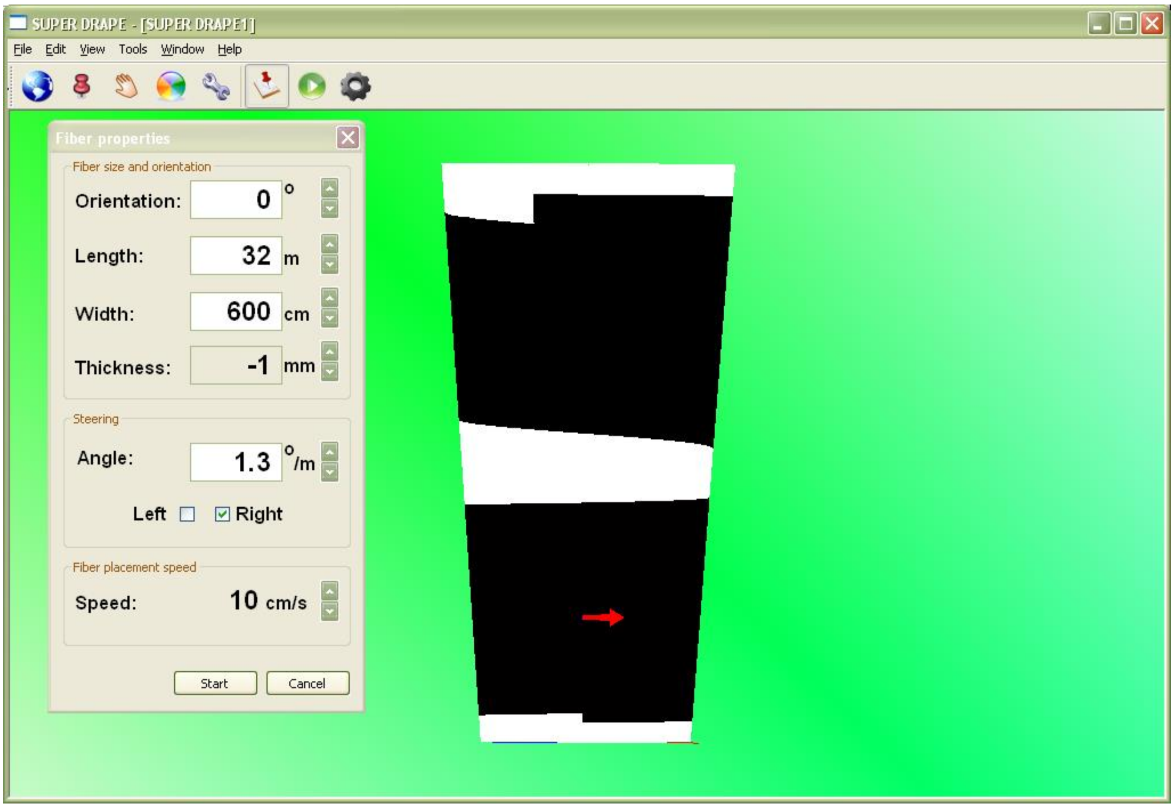
Is the Software correct?

- The sleeve template is drawn in Microsoft Excel
- Starbucks sleeve measures roughly 250mm in length
- Two lines are drawn and rotated (from Excel object properties) to deduce overall steering of the sleeve. Overall steer amounts to approximately 33^0
- Software steer value of 1.3^0 / meter is therefore correct



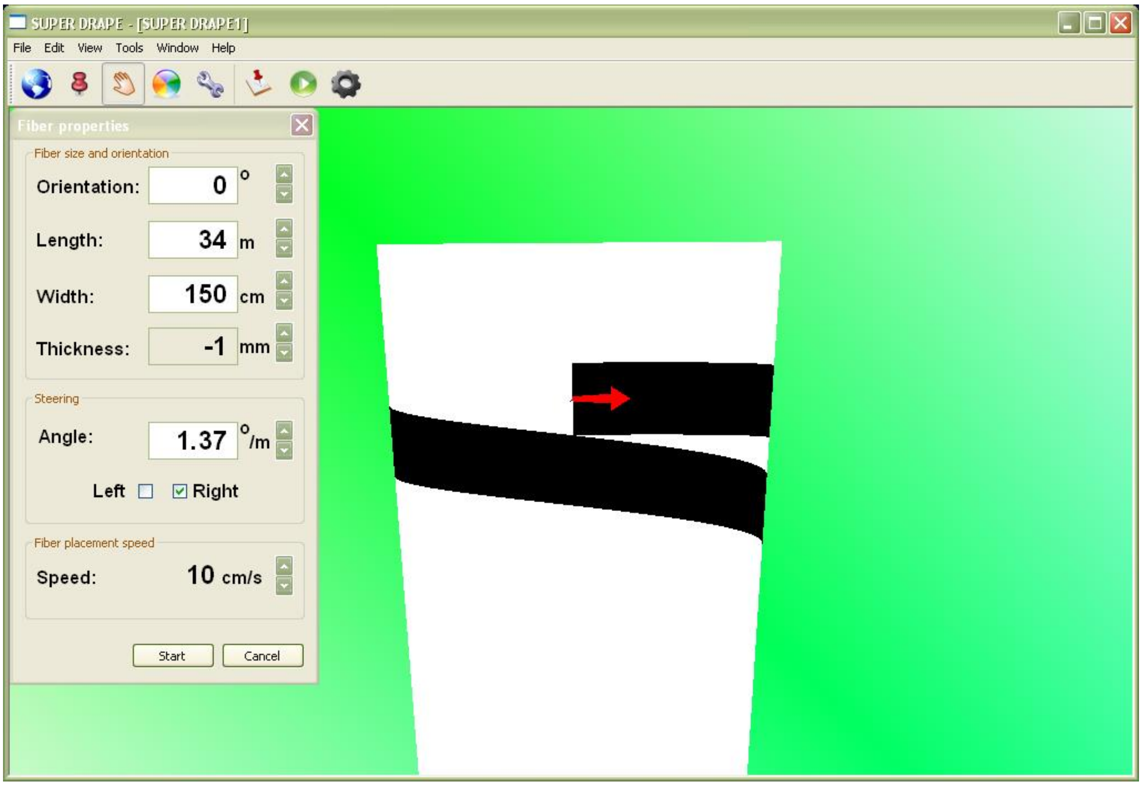
Useful physical properties (1)

- The steering value of 1.3⁰ / meter calculated can align sleeve start and end points only at a specific fiber start point. Different fiber start positions on object would require different steer values
- By the same argument, if when a sleeve is draped onto already draped sleeve, using exact same drape start position, a new set of steer value is required to align sleeve start and end points. In another words, resultant increase of surface thickness from continuous draping matter, it changes fiber steer characteristics



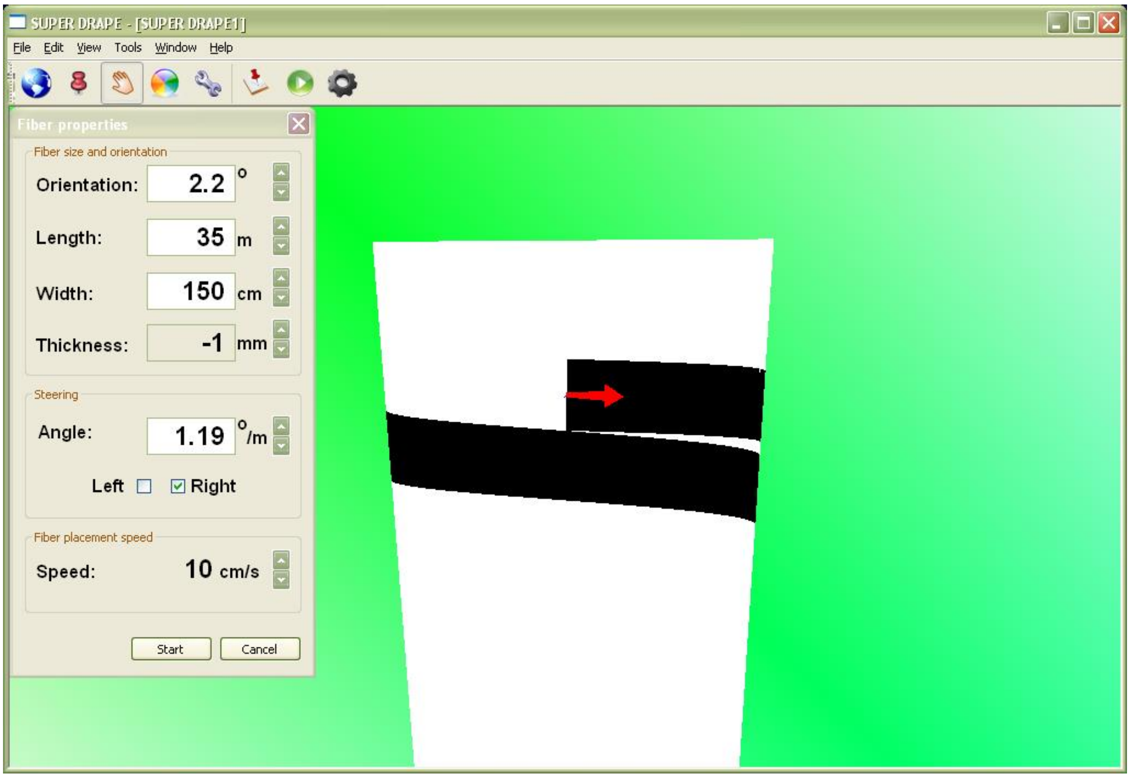
Useful physical properties (2)

- Steering and orientation can be used in conjunction to lessen fiber internal stress and damage
- Using Starbucks cup again an arbitrary fiber strip is positioned at 0^0 direction
- A steer value of 1.37^0 / meter is required so that the next time strip visits start position the strip does not overlap strip start point (juxtapose technique is not used to remove gaps thereafter)



Useful physical properties (3)

- Same fiber is re-draped however on this second iteration the 0^0 orientation is changed to 2.2^0
- As a consequence steer value of 1.19^0 / meter is now required to ensure next time strip visits start position there is no overlap (juxtapose technique is not used to remove gaps thereafter but as evident in the figures a less steer is needed to remove gaps)
- Note, as draping progresses towards the bottom and narrower end of the cup, steeper steering is required to remove gaps



Drape matrix and reverse engineering (1)

- The matrix used to manufacture composite structures via fiber placement technique can be of complex bi-cubic nature
- It may not always feasible to use the CAD model of the surface to calculate the fiber drape coordinates on the actual matrix because of manufacturing allowances

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