Research Advances for Wind Blade Manufacturing

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Some Wind Energy Efforts at Iowa State University

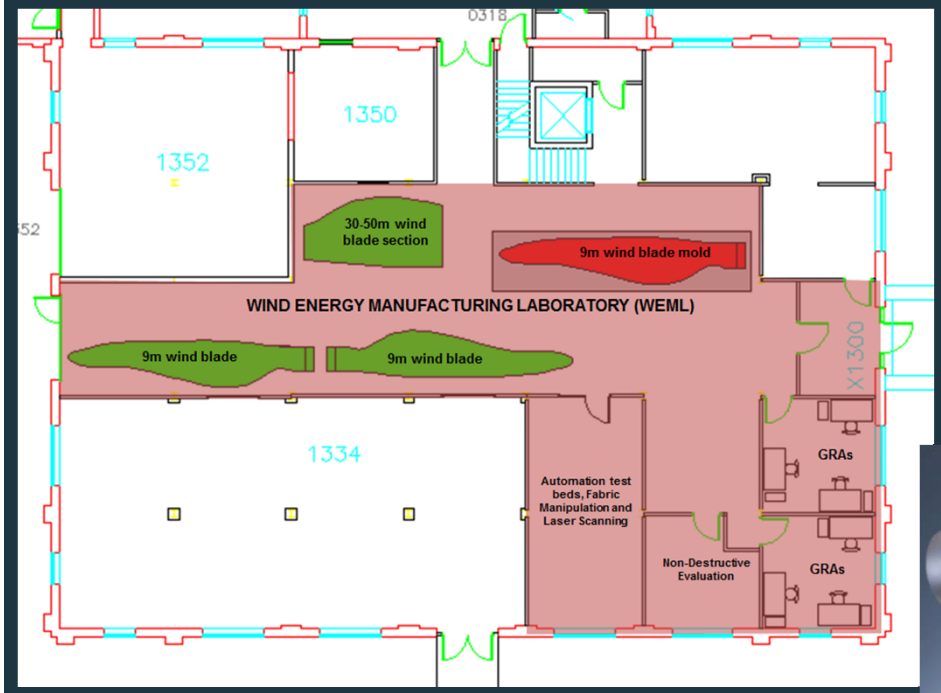
- Wind Energy Initiative
  - $500,000 to pursue funding
  - Over 40 investigators collaborating
  - External partners
- NSF IGERT
  - 30 PhD students over 5 year period
  - PhD in *Wind Energy, Science Engineering and Policy*
- NSF REU
  - 3 years; 10 students each year for 10-week program
  - Individual & group projects, short course, lectures, tours
- Wind Energy Minor

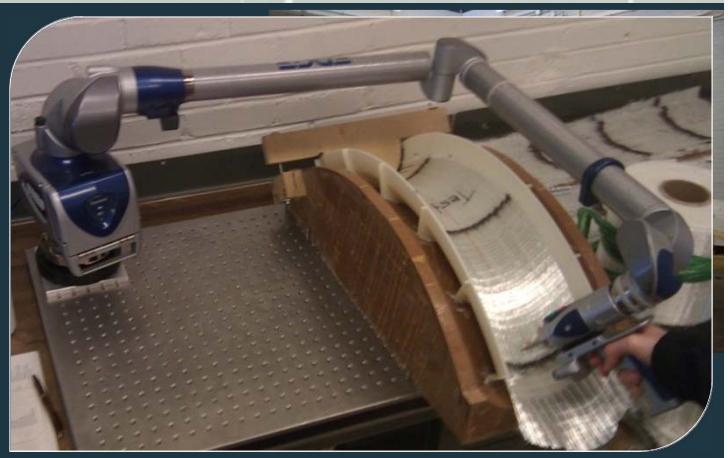
Overview

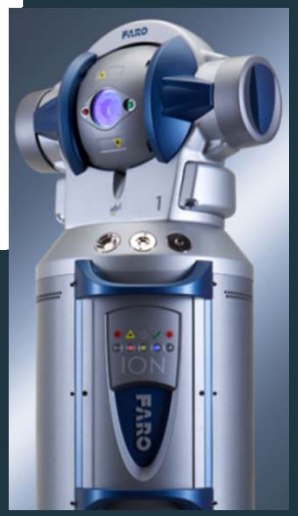
- The Wind Energy Manufacturing Laboratory (WEML)
- The Advanced Manufacturing Innovation Initiative (AMII)
- Wind Blade Manufacturing Research
- Design for Manufacturability

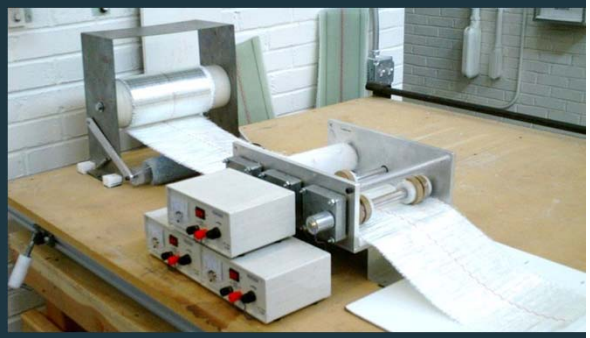
WEML
Wind Energy Manufacturing Laboratory

The Wind Energy Manufacturing Laboratory









Automation Testbed in WEML– 10m x 3m x 2m automated gantry

Advanced Manufacturing Innovation Initiative (AMII)

Research

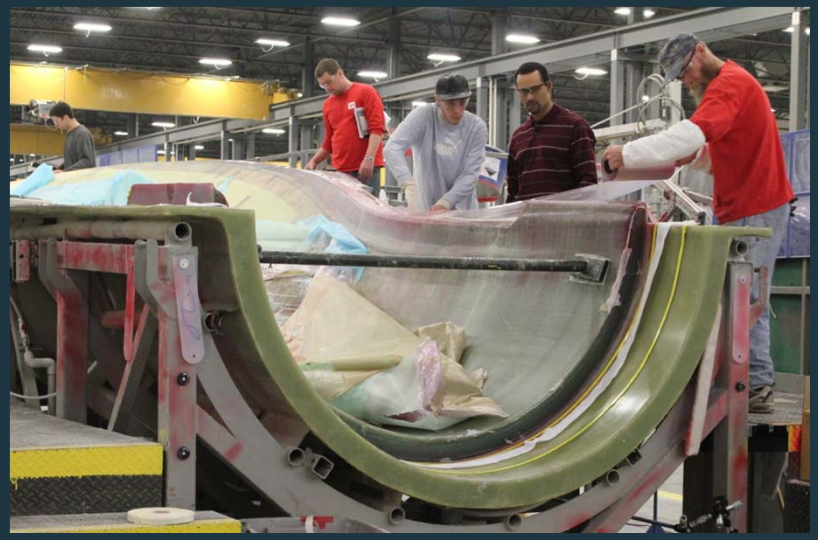
- Iowa State University
- TPI Composites
- Sandia National Laboratories

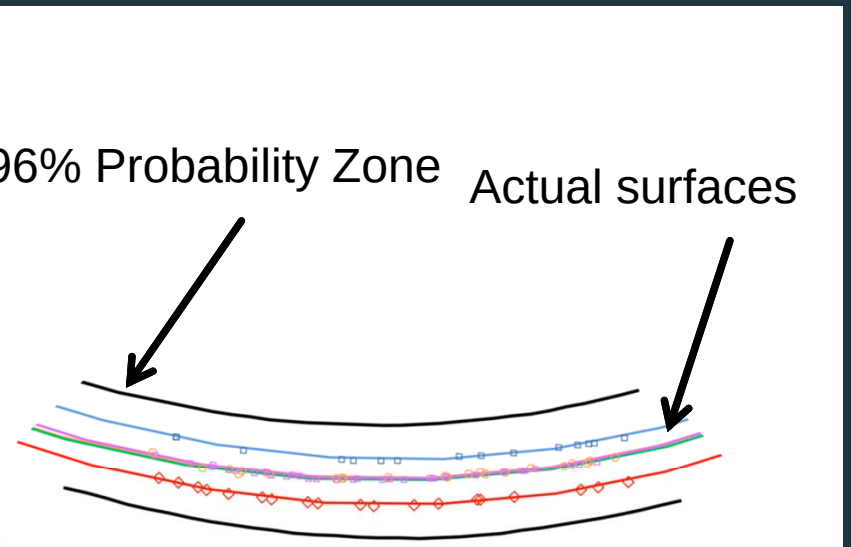
Funding

- U.S. Department of Energy
- TPI Composites
- Iowa Power Fund

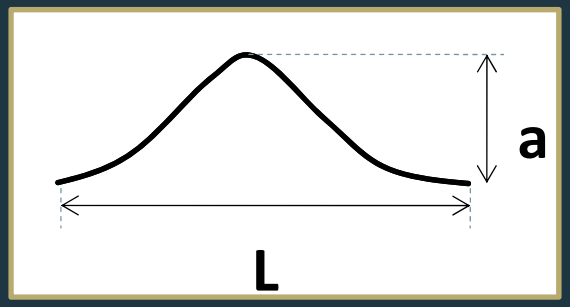
Selected AMII Research Efforts

Assembly Variation Analysis





Air Coupled Ultrasonics



Aspect ratio is defined as :

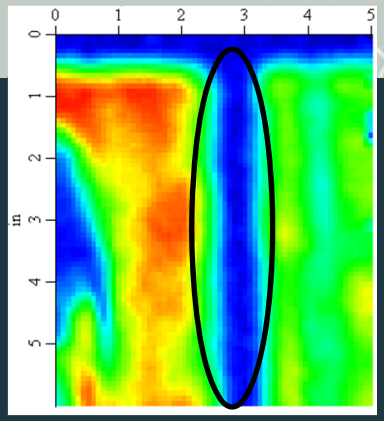
AR = L / a

AR = 6

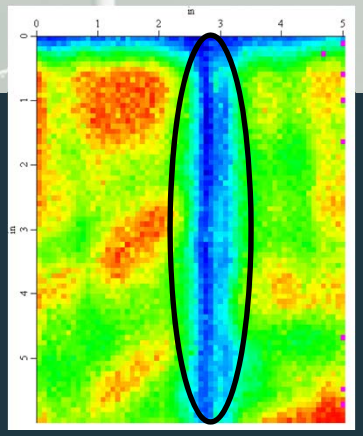
AR = 10

Air Coupled Ultrasonics

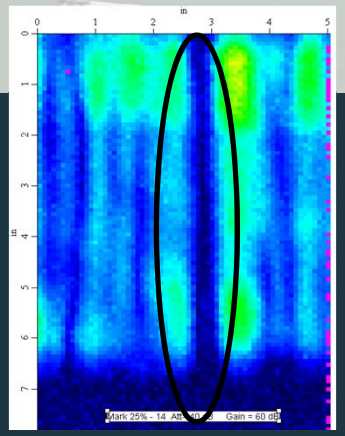
Aspect ratios: 6, 10, 14
Depth information: 6mm



WS-01: AR 6

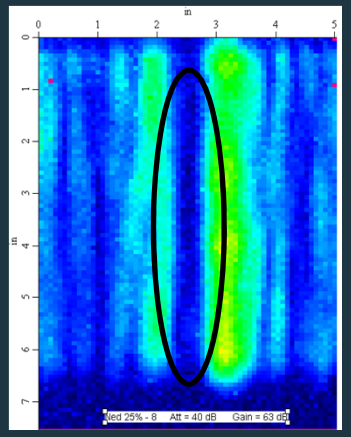


WS-01: AR 10

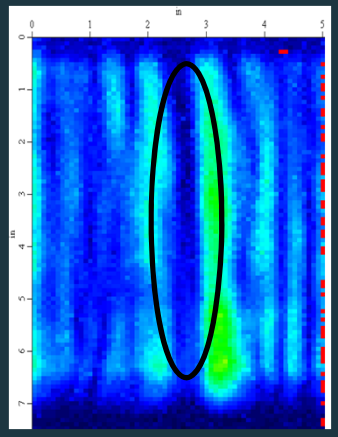


WS-01: AR 14

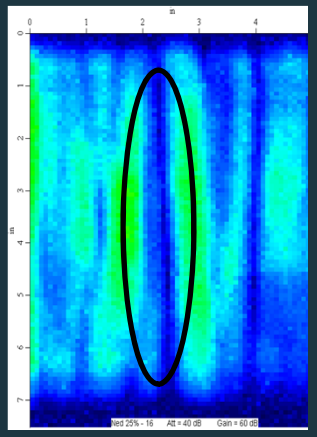
Aspect ratios: 8, 12, 16
Depth information: 6mm



WS-02 AR 8



WS-02 AR 12



WS-02 AR 16

Air Coupled Ultrasonics

Measurements, Analysis, and Process Planning for Fabric Layup

Challenges in Blade Fabrication

- Much of the composite manufacturing state-of-the-art is too expensive for blades (aerospace solutions are not always feasible/cost-effective)
- Glass composites for blades use broad fabric panels which do not “want” to go into a 3D mold (this is not Automated Tape Layup, therefore… touch labor required)
- Manual layup methods prevalent when the mold geometry is complex (Hancock & Potter 2006)

Challenges in Blade Fabrication

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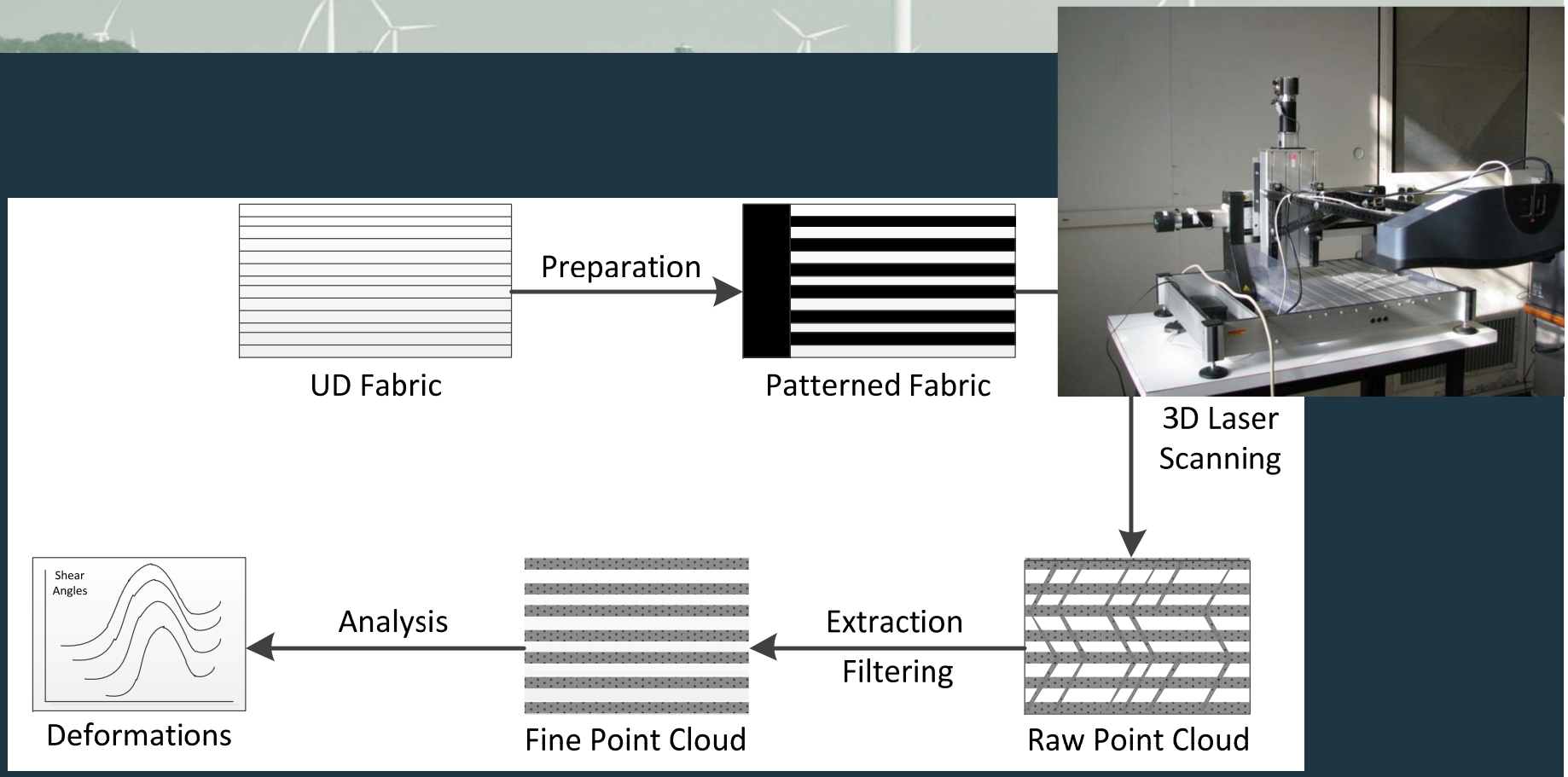
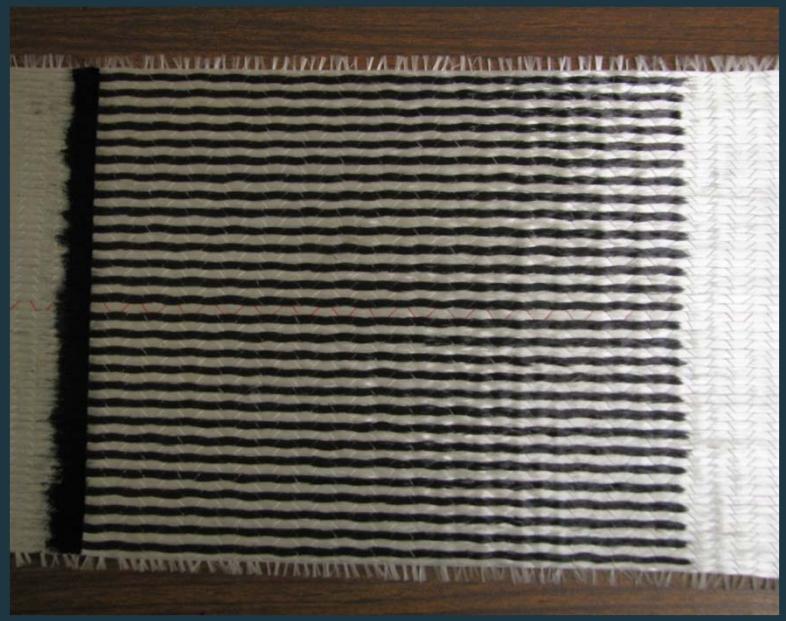
- Glass com d fabric panels whi 3D mold (this is not Auton equired)
- Manual lay the mold geometry i

Measurement Overview



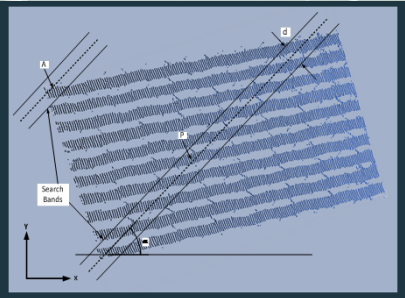
Fabric Preparation

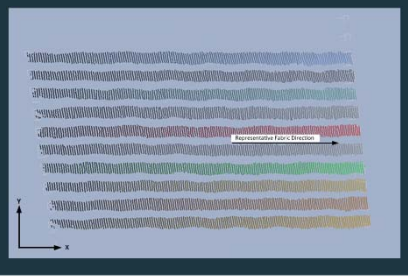
- Alternate tows painted in black
- Black tows are laser non-reflective
- Could be woven into fabric



Fiber Tow Direction and Shear Angle Determination

- Find surface normal
- Solve for tow direction within search band
- In-plane shear angle computed

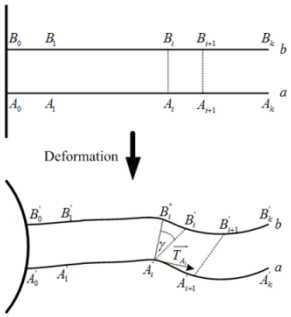




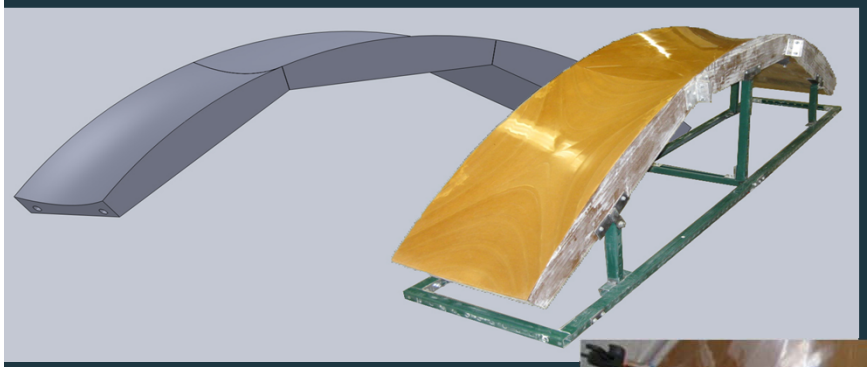
- $A_1, A_2, \ldots, A_k$ and $B_1, B_2, \ldots, B_k$ are points of neighboring tows such that the length of $A_0 A_i$ is equal to the length of $(B_0 B_i \; i \in \{1, 2, \ldots, k\})$
- In-plane shear angle is computed as

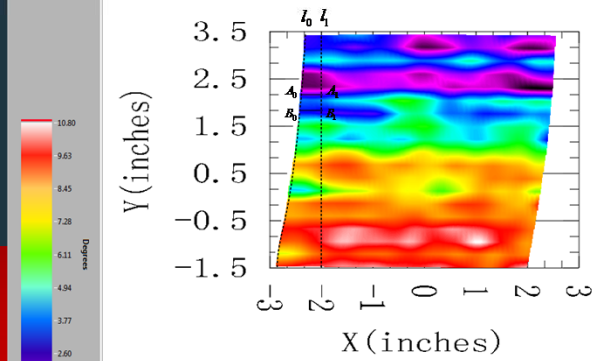
$$\gamma = \pi / 2 - \angle (\overrightarrow{T_{A_i}}, \overrightarrow{A_i B_i'})$$

where $\overrightarrow{T_{A_i}}$ is the tangent direction at A_i



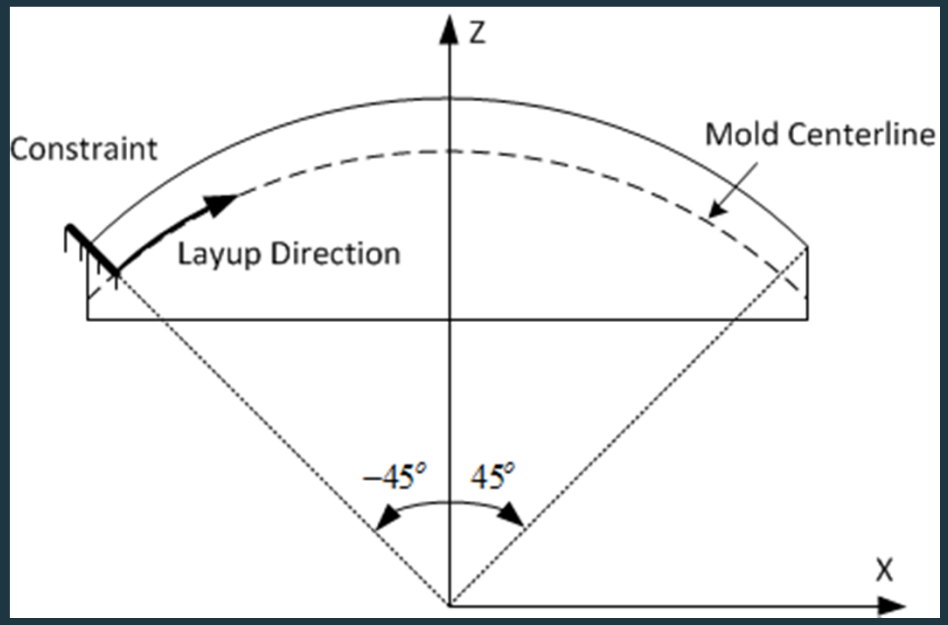
3D Measurements





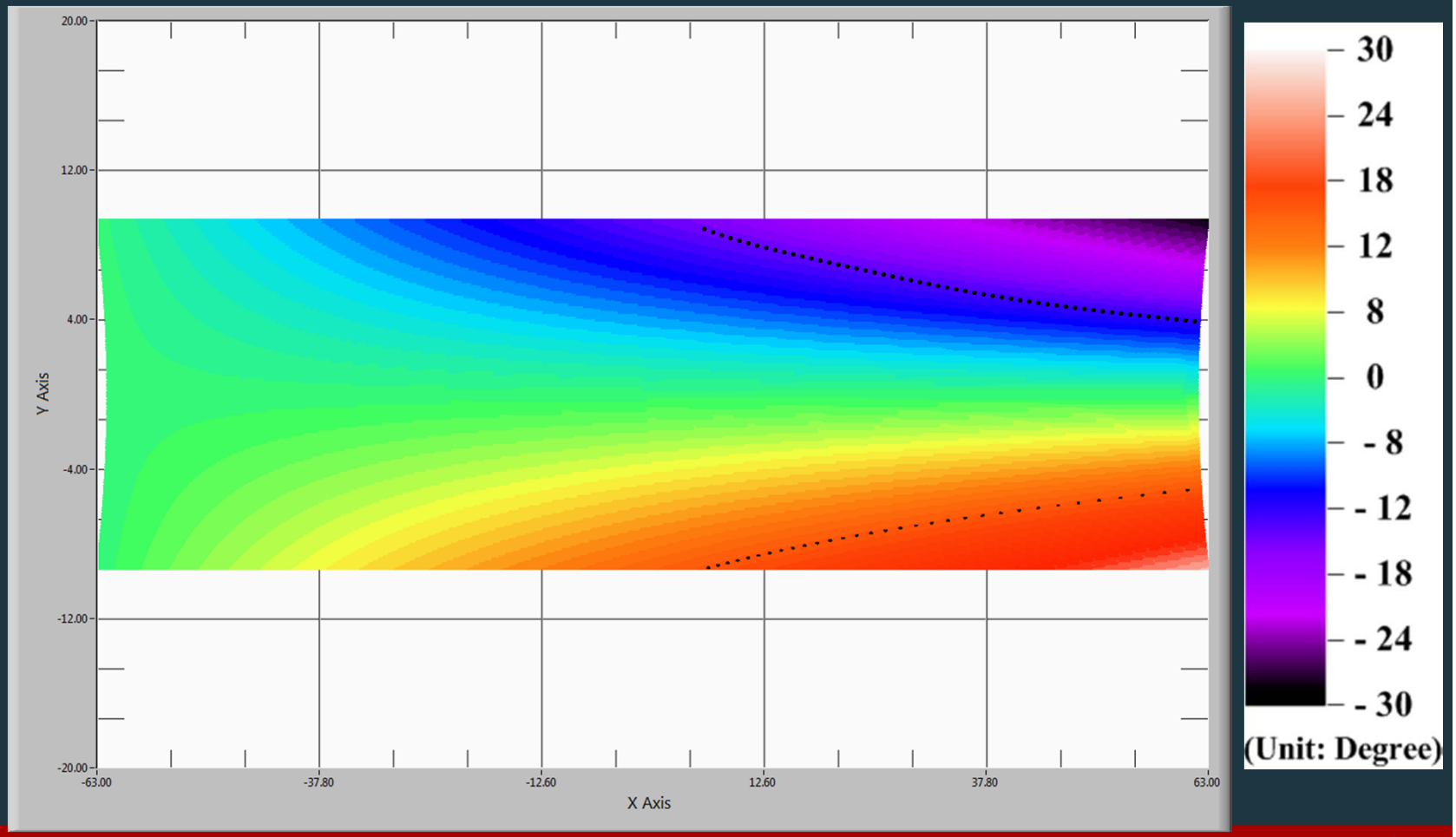
Layup Plan

- Constraint at -45 degree
- Smoothing along mold centerline

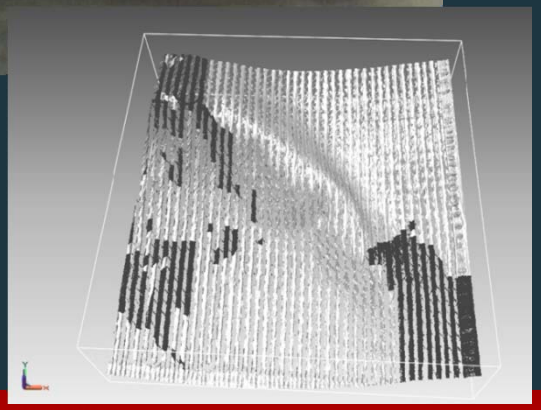


- Since layup of UD has one free end, deformations OOM can occur
- Existing software assumes that fabric conforms to the mold surface

Simulated Shear Angle Distribution



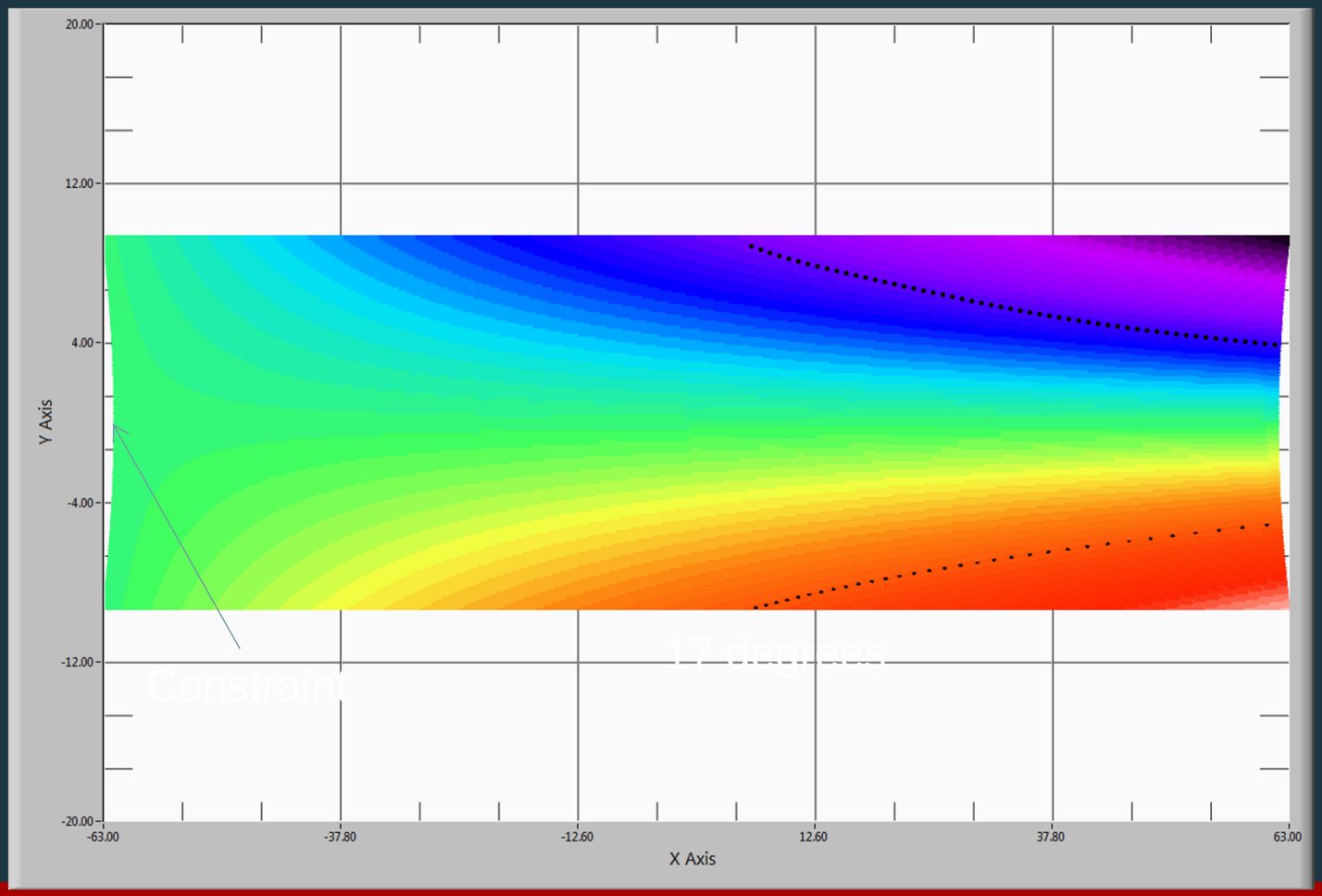
OOM Wave Develops

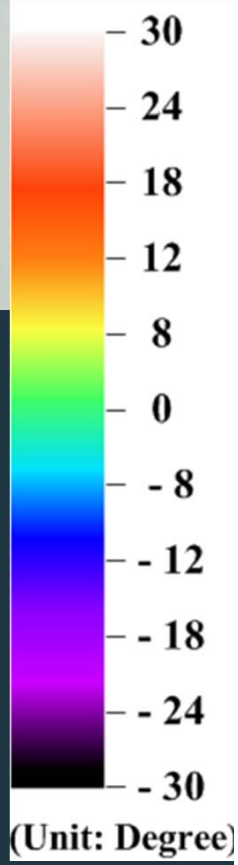


Objective for Process Planning

- Development method for
  - pre-shear planning
  - in-process manipulation planning
- To achieve
  - For feasible layups: optimize the shear distribution pattern and more robust to handling errors
  - For non-feasible layups: make them feasible?

Naïve Layup

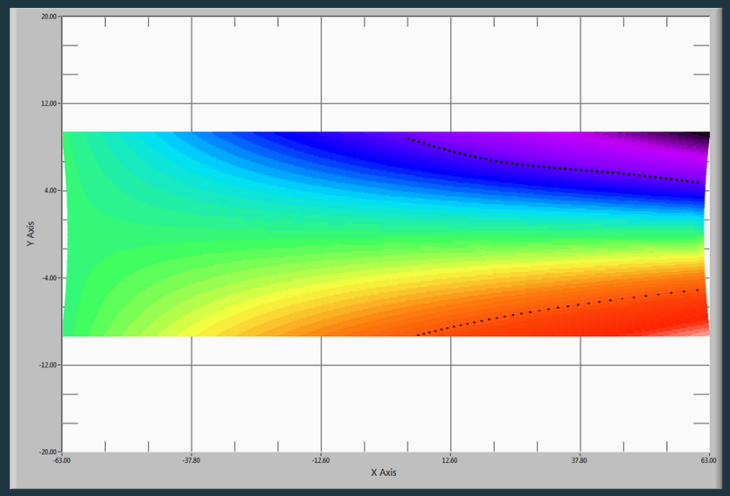


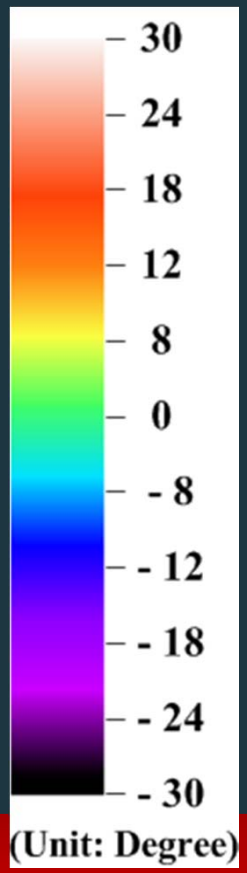


Shear Locking Limit: 17 degrees

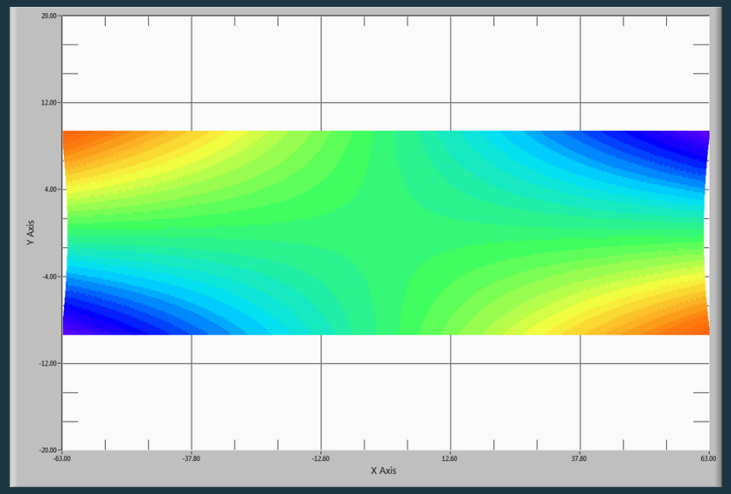
Solution via Process Planning

Start from Left Side





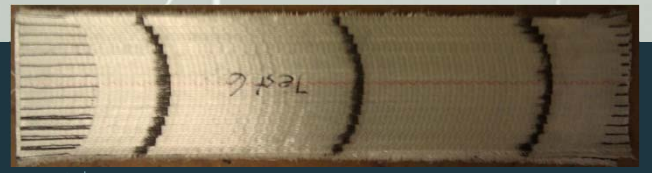
Start from Center

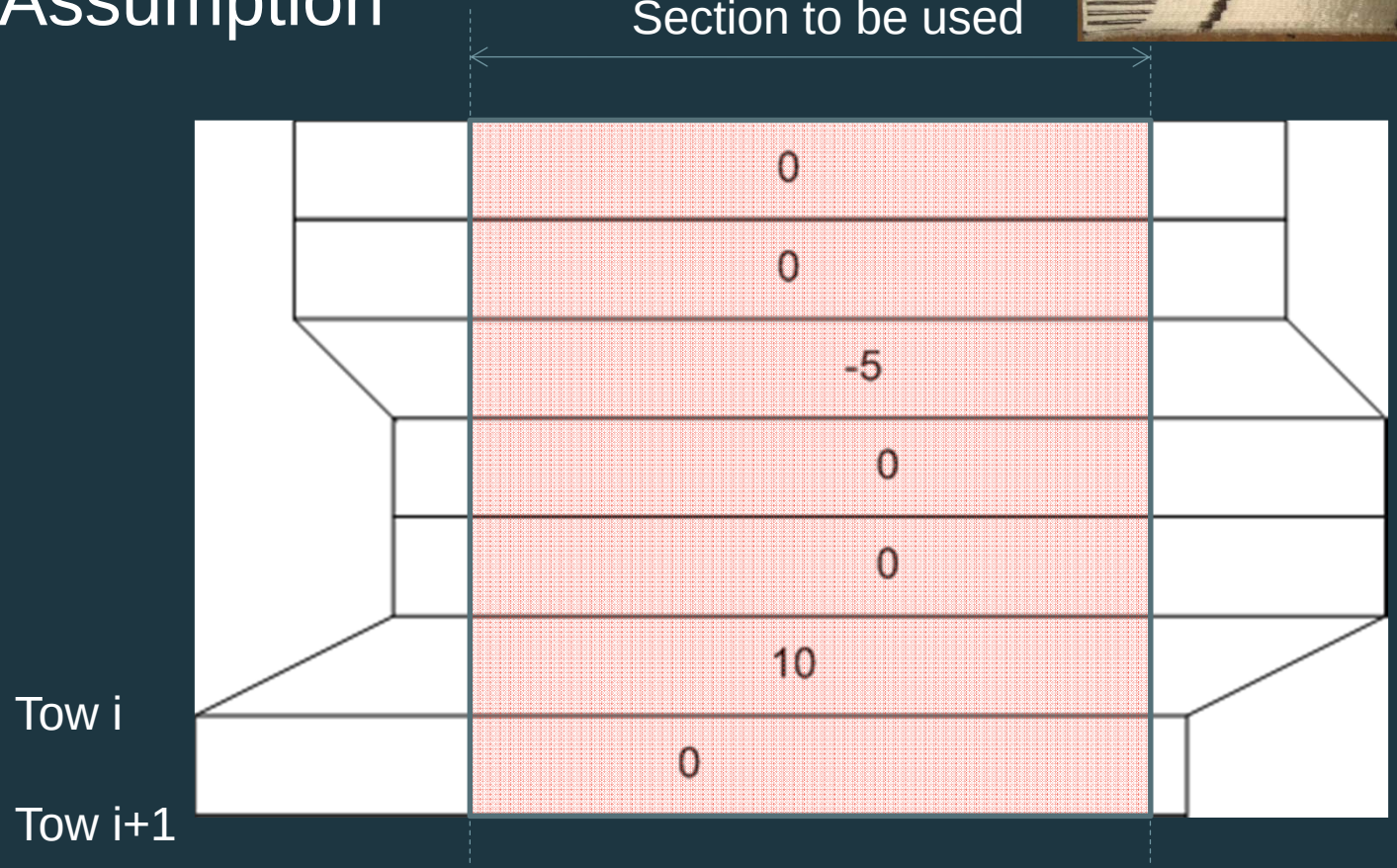


Shear Locking Limit: 17 degrees

Pre-shearing

- Assumption

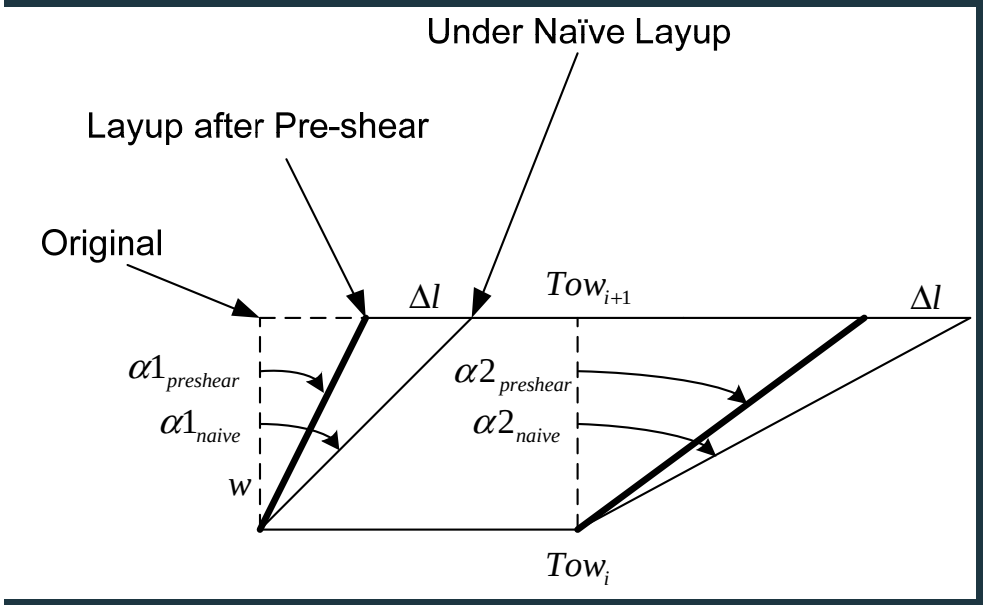




Range of Modification is [-SLL, SLL]

Pre-shearing Planning

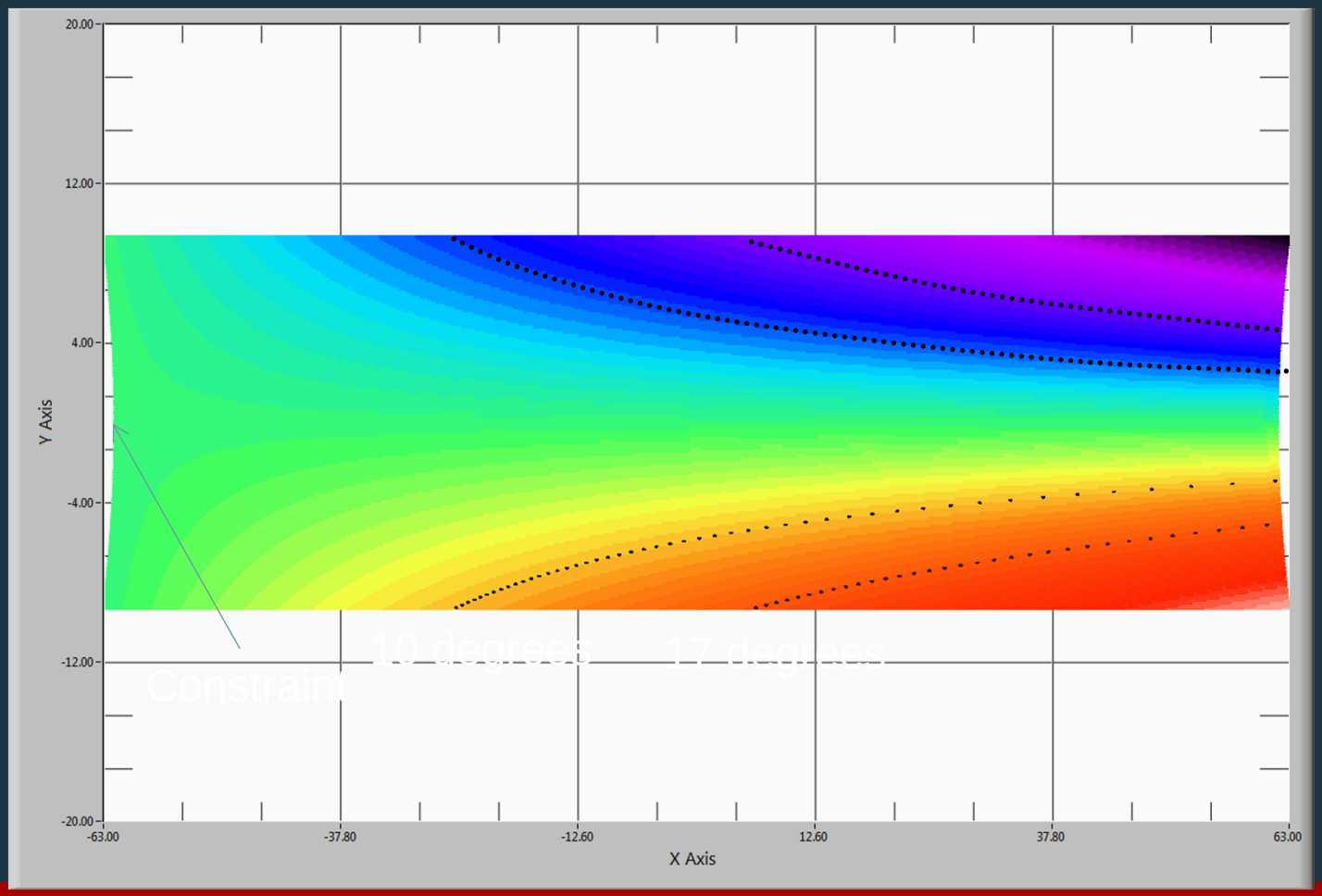
- Unit cell deformation

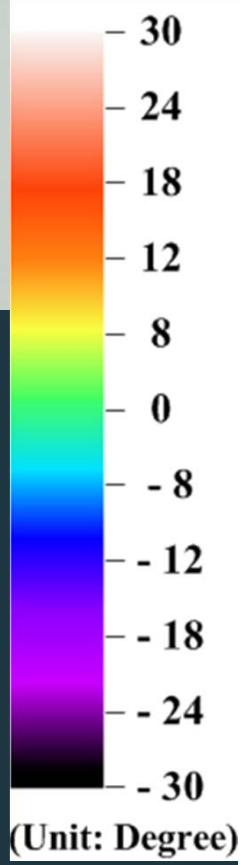


$$\Delta l \approx w \times \left(\tan \alpha_{naive} - \tan \alpha_{preshear} \right)$$

- Δl provides uniform change of the **tangent values** of shear angle distribution between neighboring tow pairs
- Δl is the quantity to be "embedded" in the fabric prior to the layup process

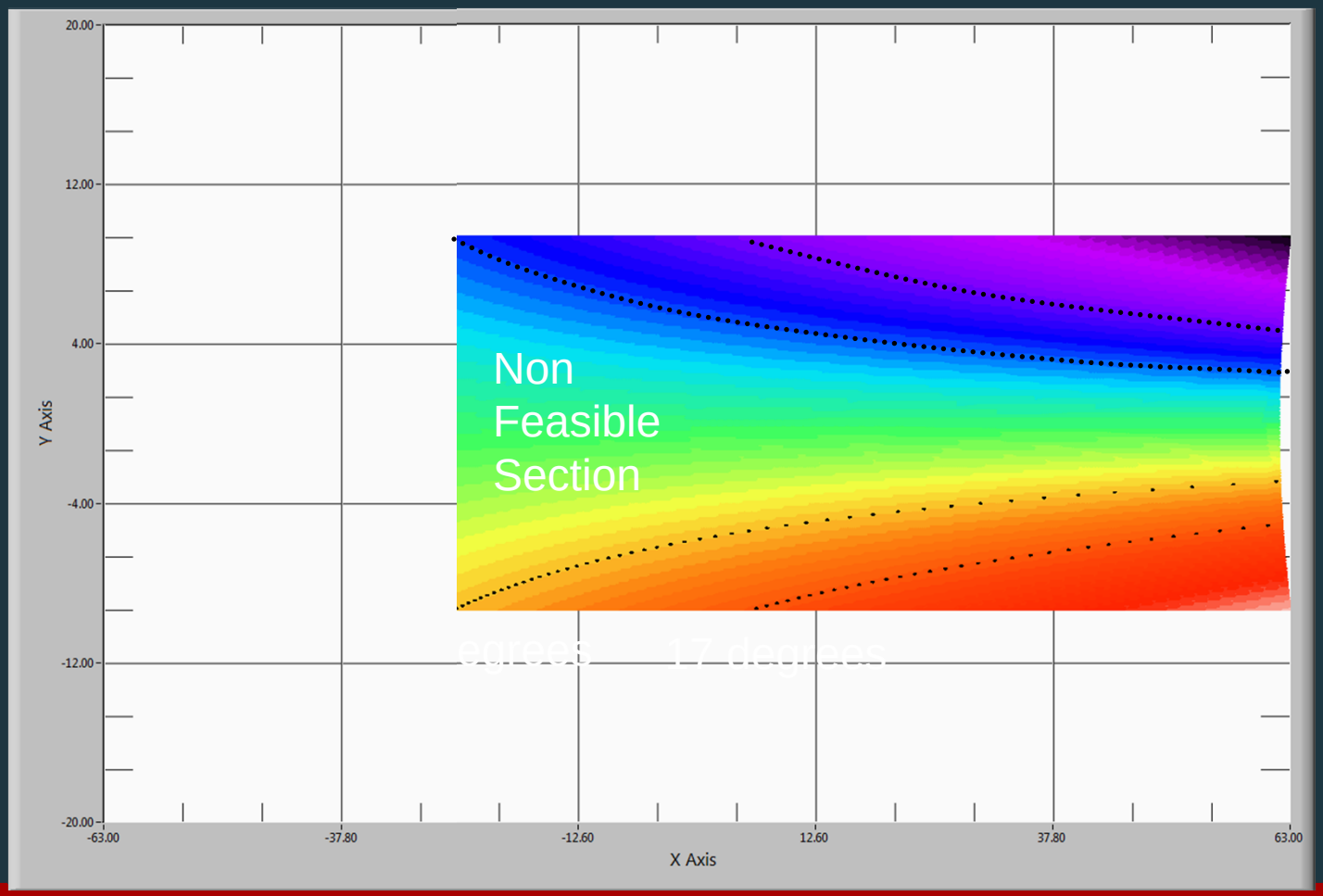
Naïve Layup – 10 degree SLL

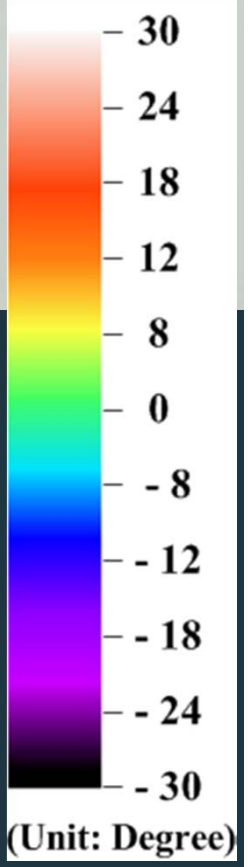




Shear Locking Limit: 10 degrees

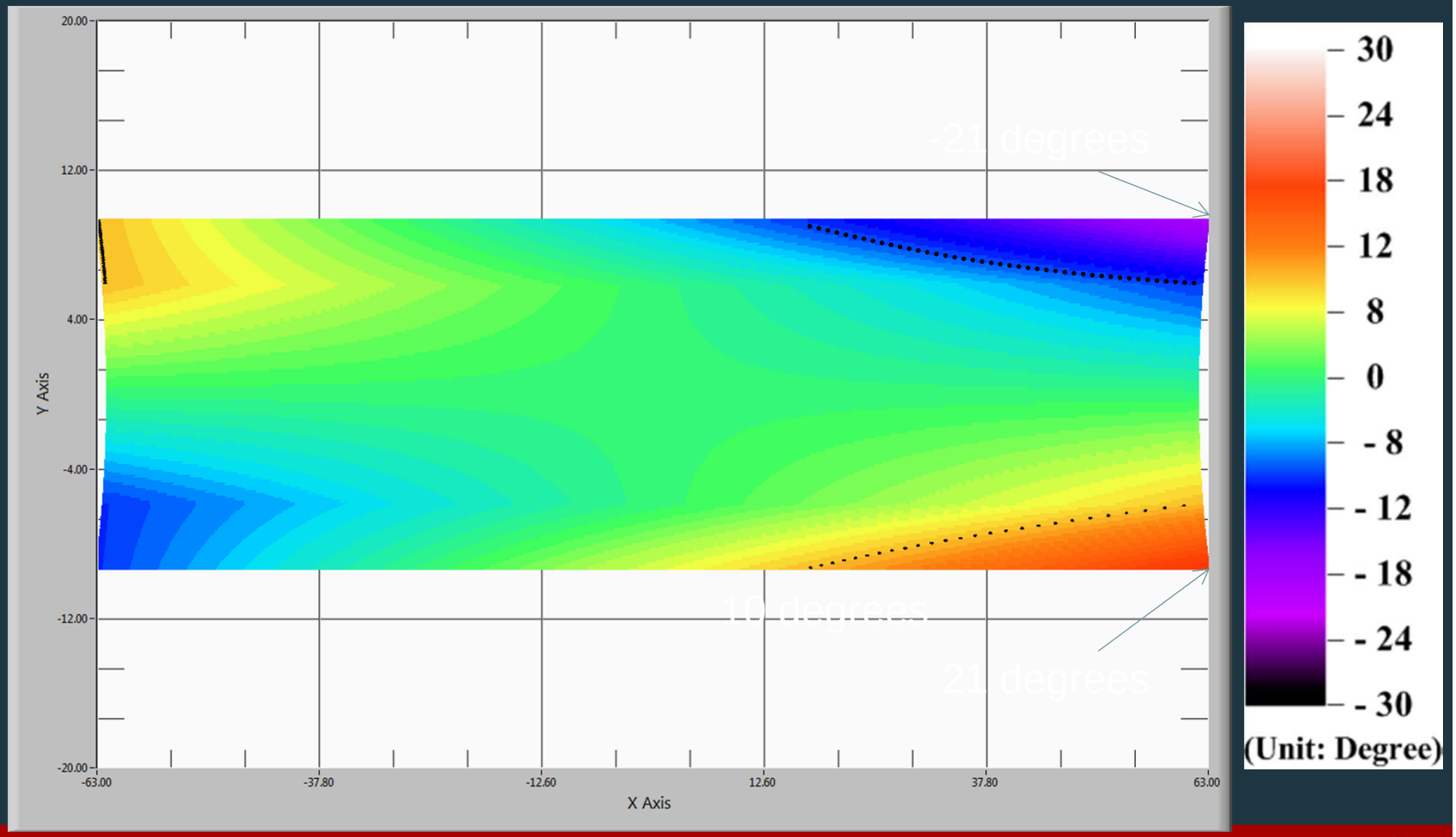
Naïve Layup – 10 degree SLL





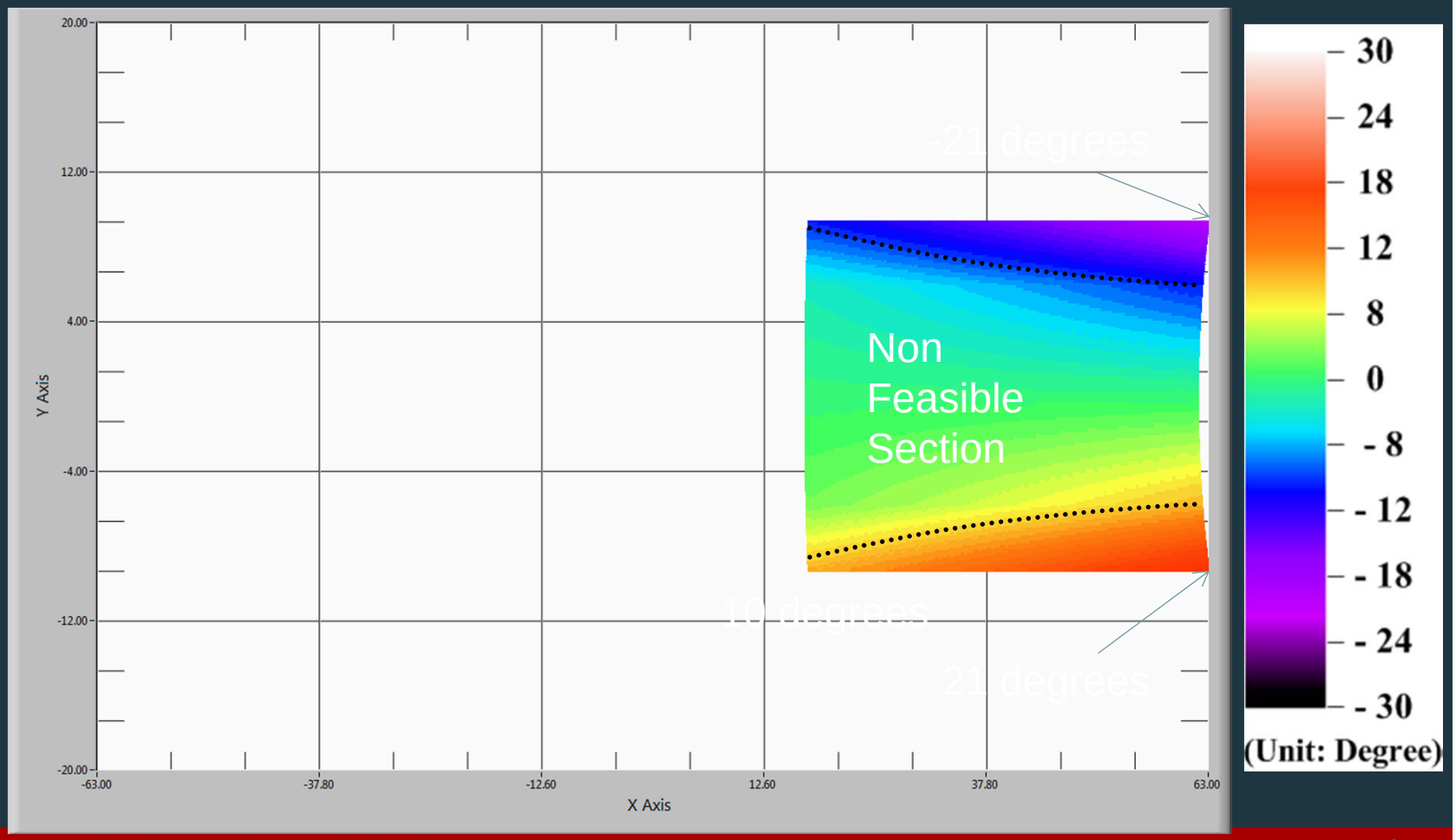
Shear Locking Limit: 10 degrees

Layup with Pre-shearing



Shear Locking Limit: 10 degrees

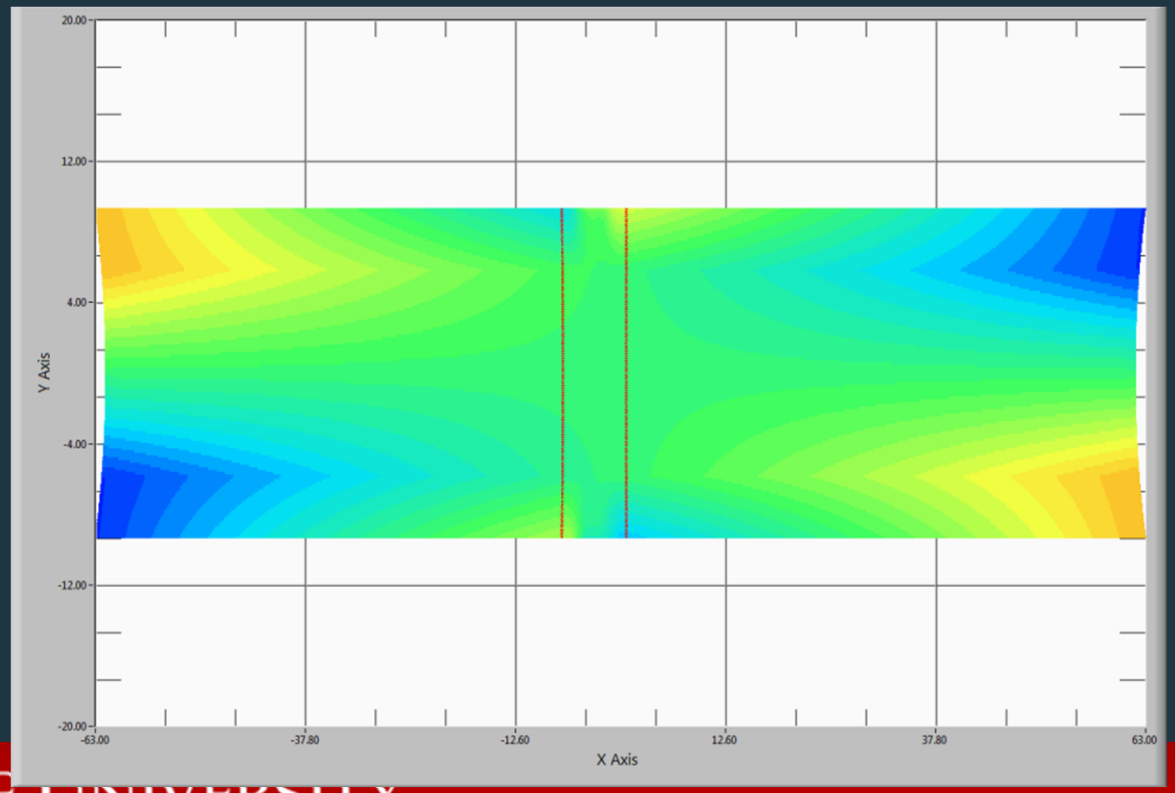
Layup with Pre-shearing



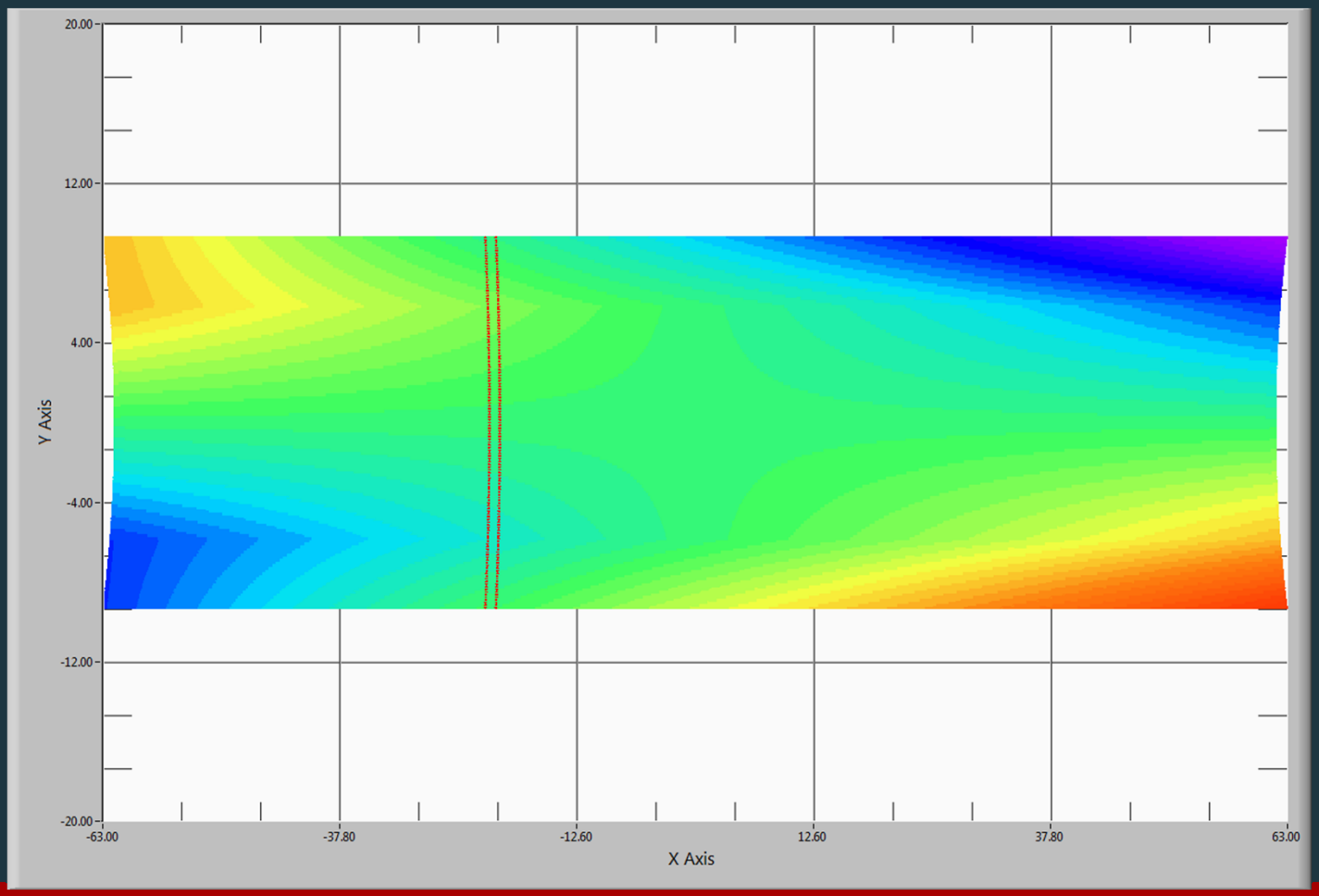
Cut by the plane tangent to layup direction

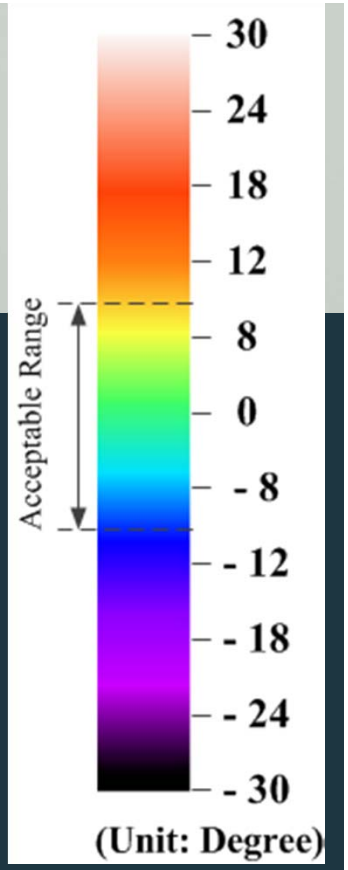
In-Process Manipulation Planning

- Where to accommodate these Δl values?
- Arbitrarily select a section from the feasible region
- 'Designer waves' over this region used to increase tow lengths

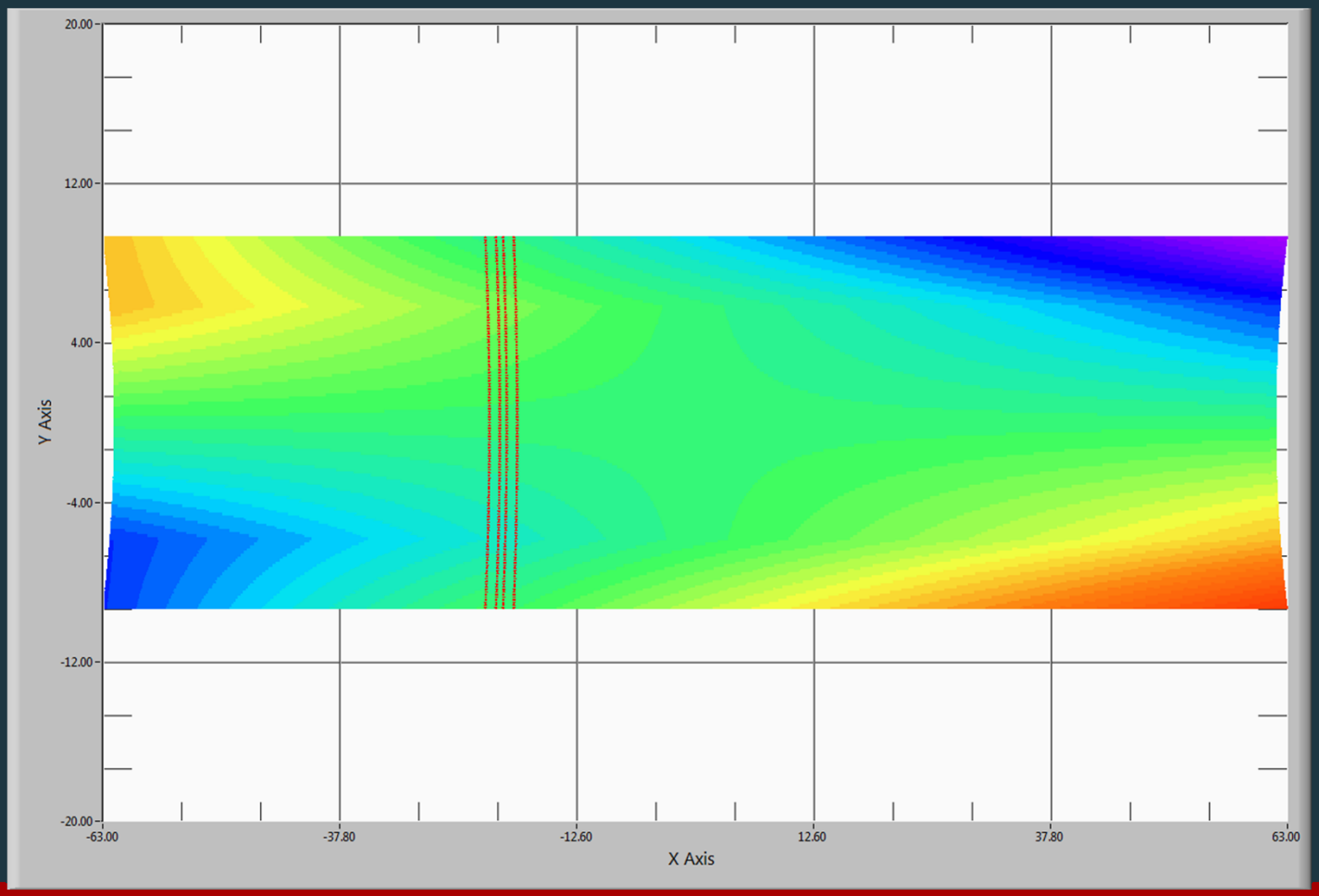


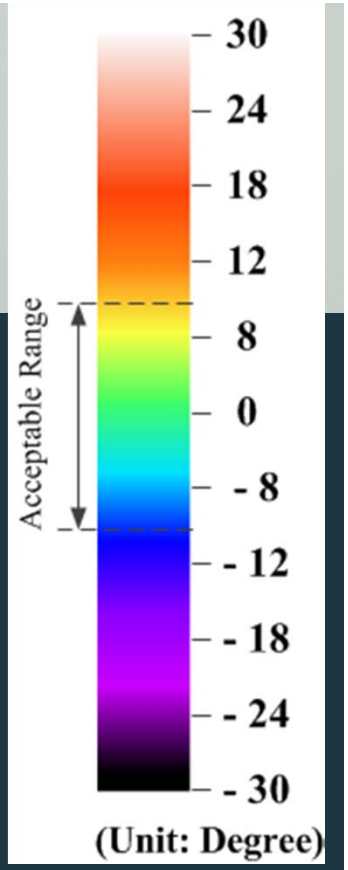
Pre-shear + 1 "Designer Wave"



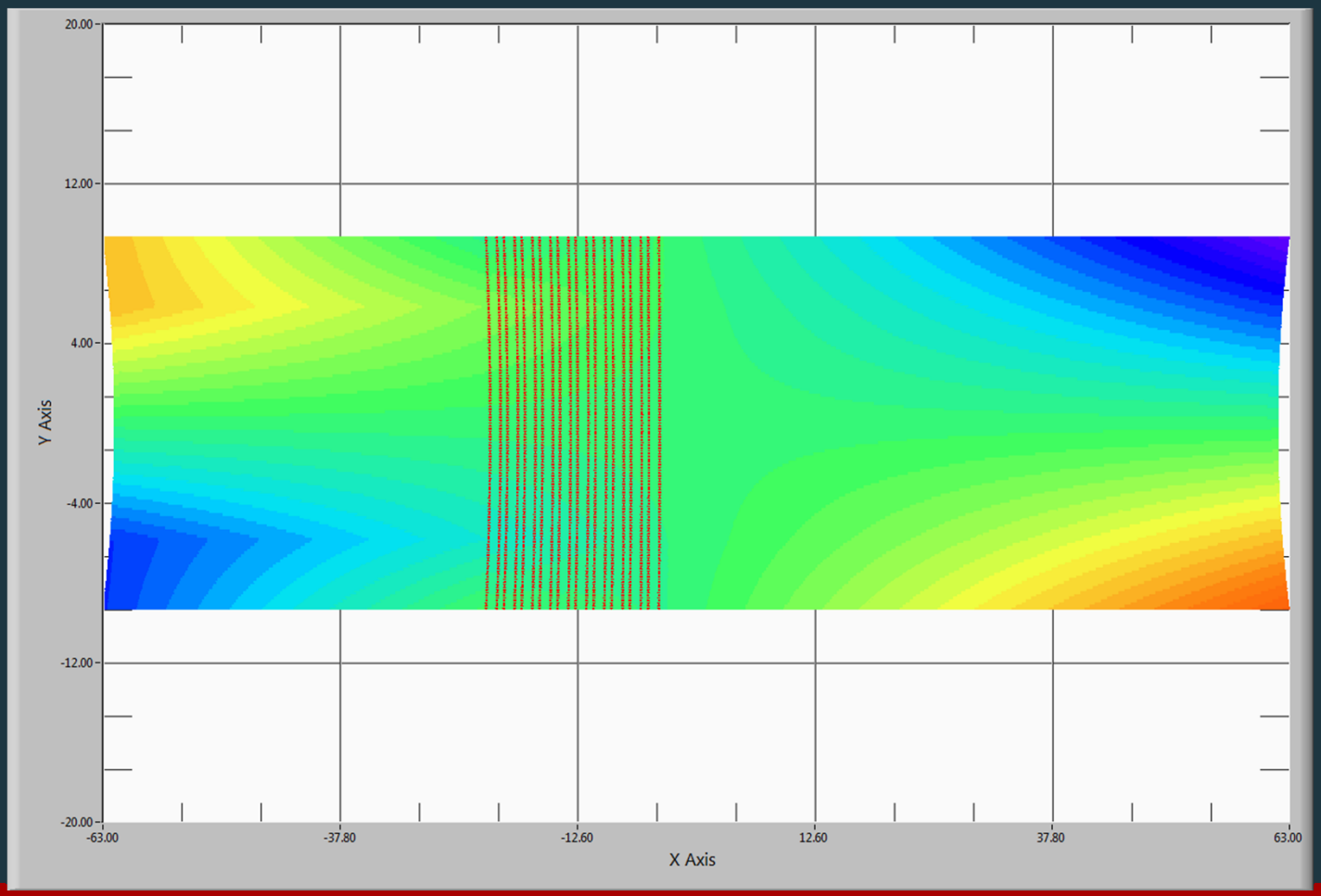


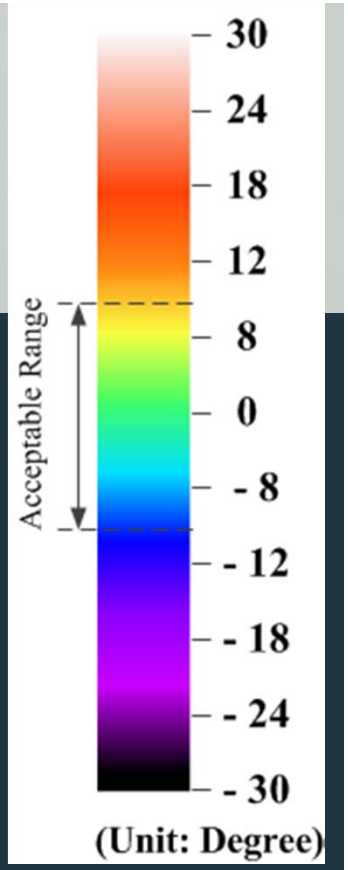
Pre-shear + 2 Designer Waves



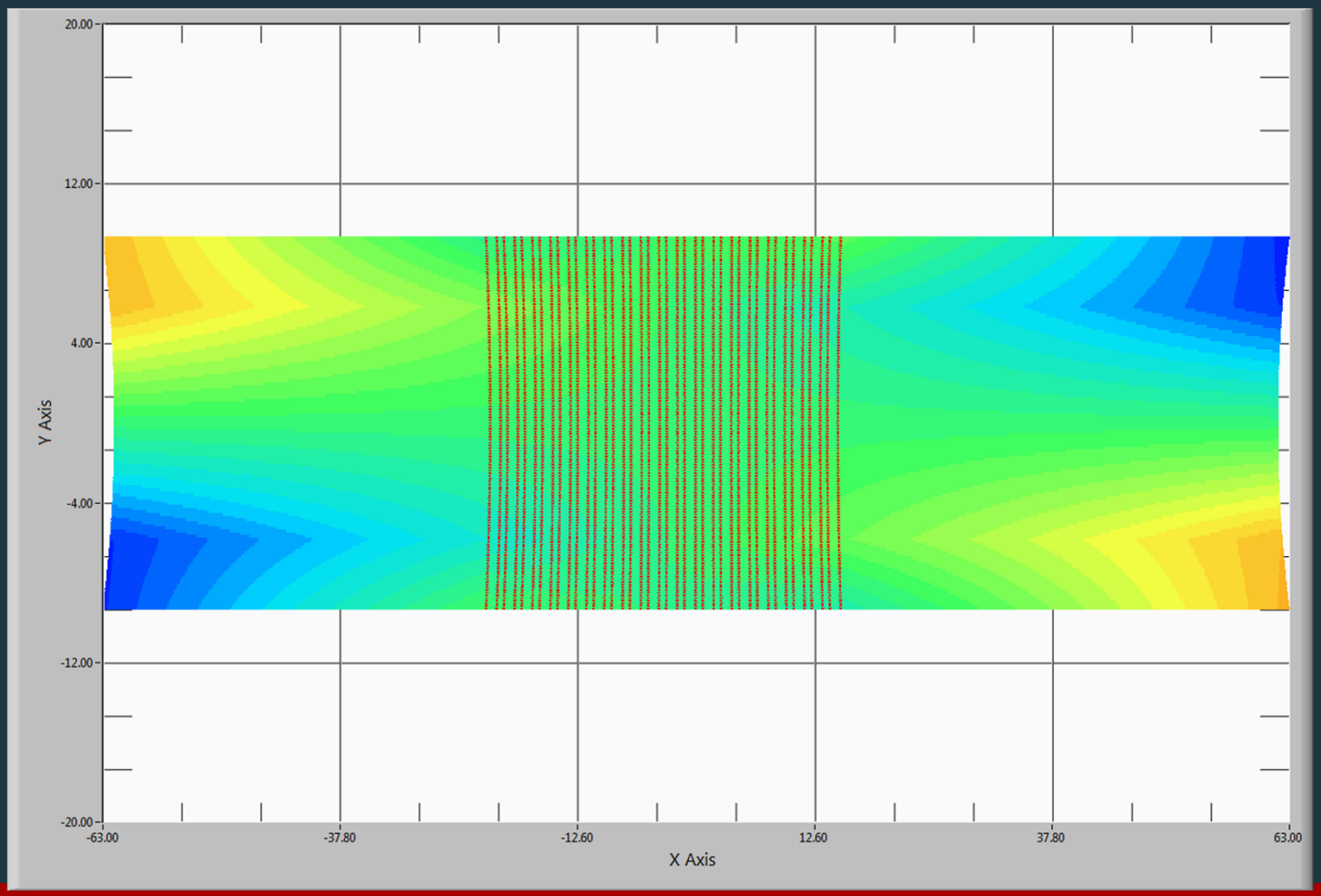


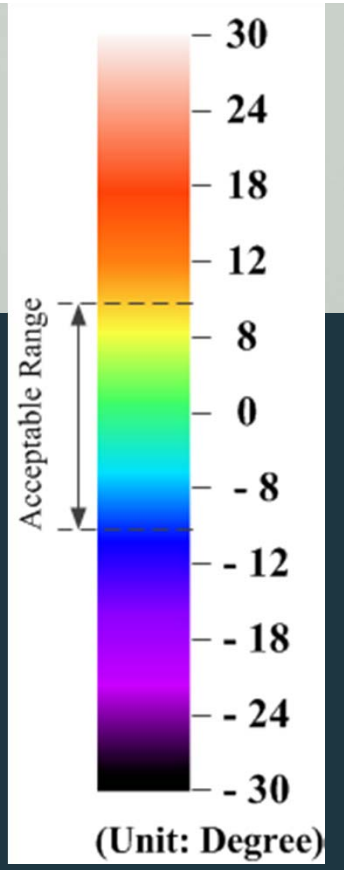
Pre-shear +10 designer waves



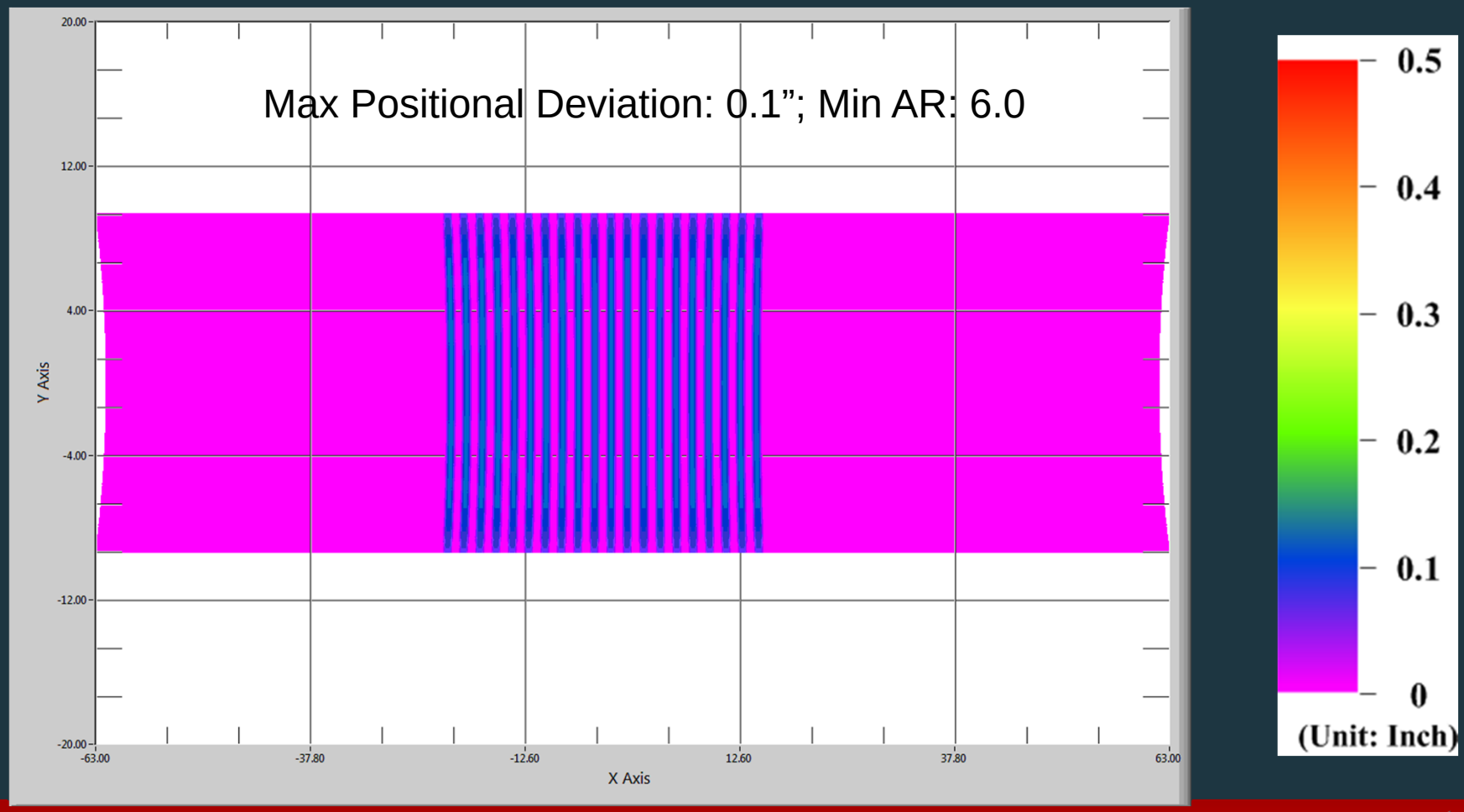


Pre-shear
+ 20 waves

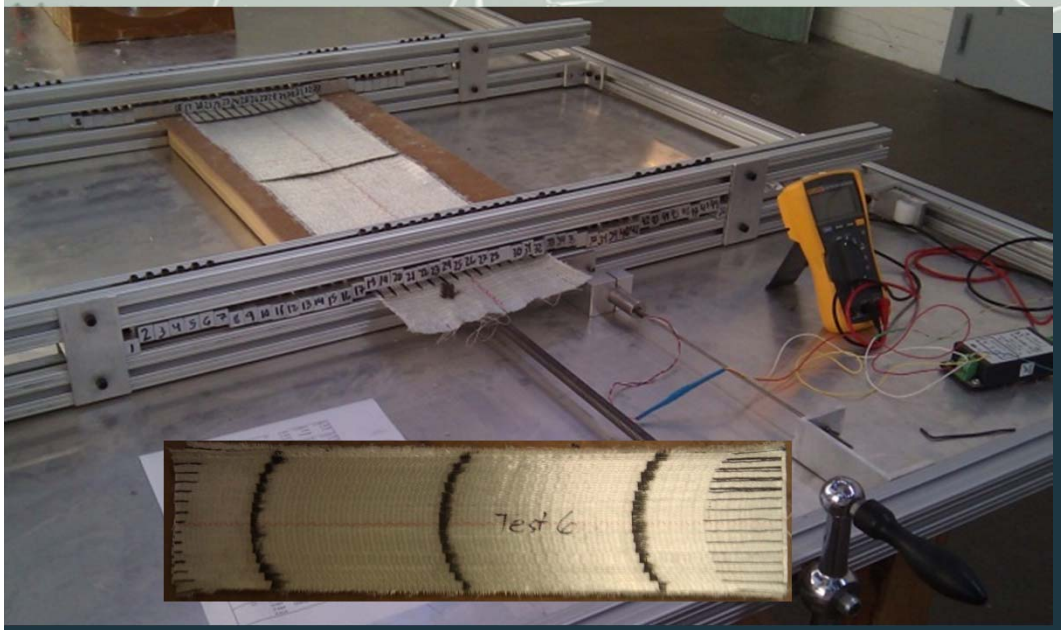


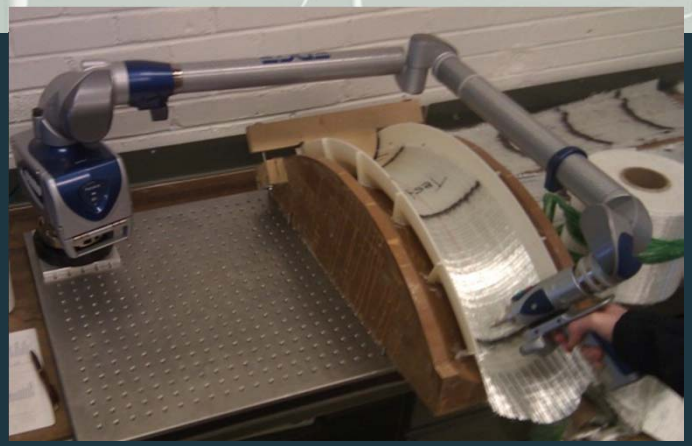


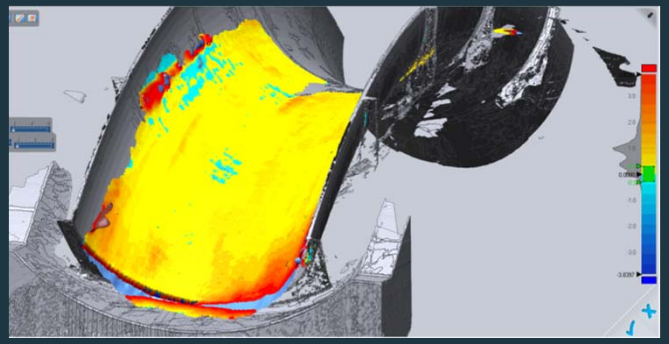
Positional Deviation

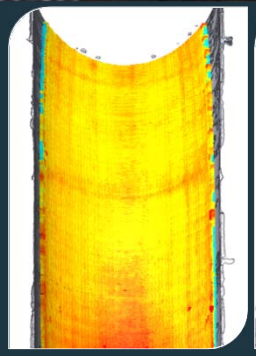


Fabric Manipulations Techniques

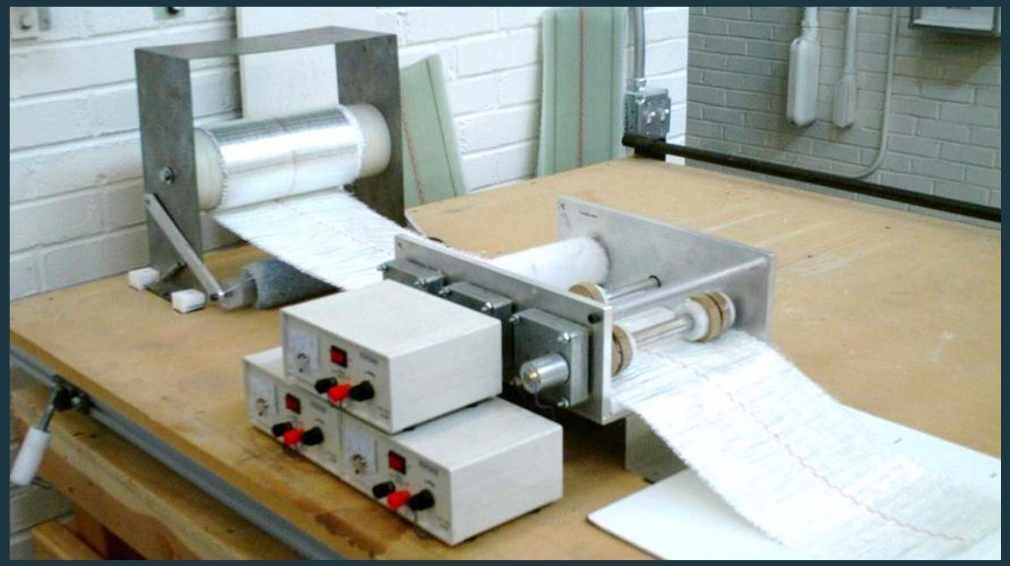


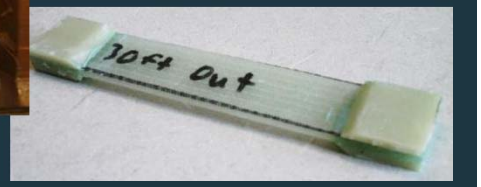






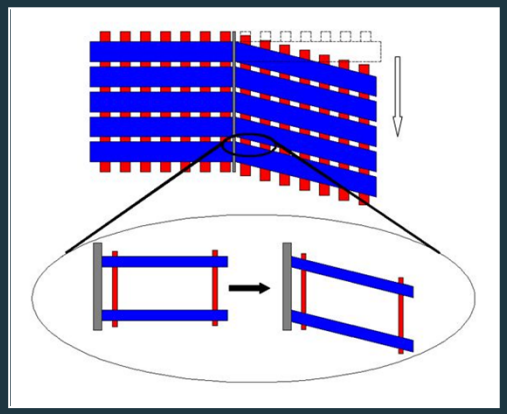
Automated Fabric Manipulator

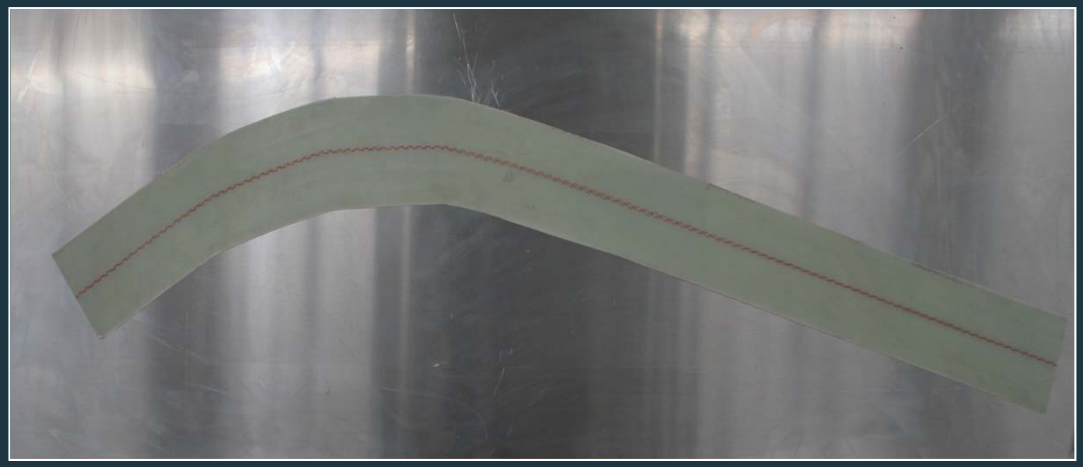


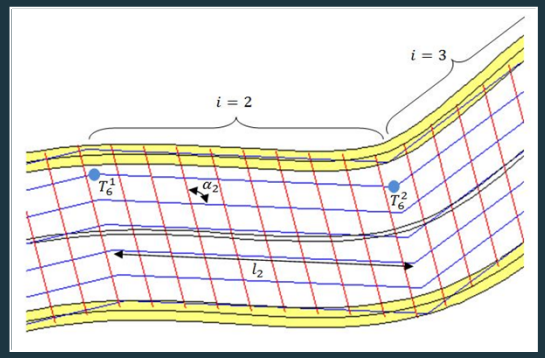


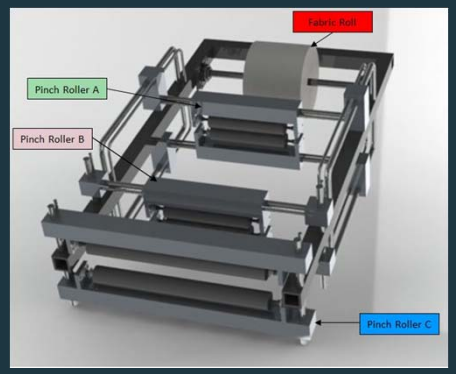
Automated Fabric Layup

Shifting Manipulation









Current and Future Direction

- Continue automation hardware to implement the fabric manipulation
- Methods for “Designer Waves”
- “Design for Manufacturability” analysis