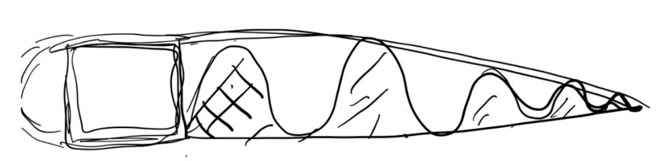
Department of Mechanical Engineering
UNIVERSITY OF WISCONSIN–MADISON

Blades of Glory: Morphing Blades

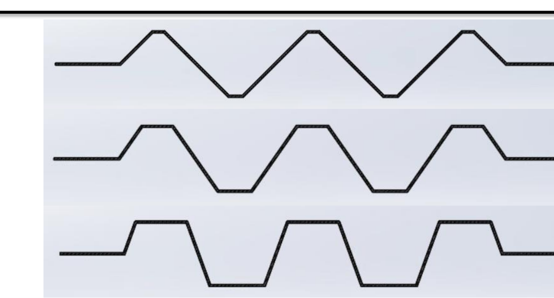
Project Motivations

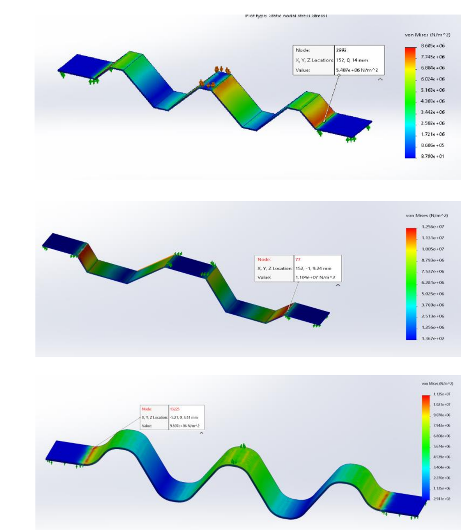
- This project revolves around the design, fabrication, and testing of morphing blades for aerostructures such as wind turbines and aircraft
- The client, Dr. Pavana Prabhakar of the UW-Madison Manufacturing and Mechanics Lab, is interested in developing these structures in order to make them more maneuverable and energy efficient.
  - The personal motivation for this project team has been the development of a morphing trailing edge section for use in wind turbine blades.
  - The ability for these blades to change shape along this section of themselves has the potential to increase the efficiency of wind energy harvesting as well as increase the lifetime of the turbine blade by reducing stress.
- These structures were required to be built out of a sandwich composite material incorporating a lightweight corrugated core structure made from woven fiber composites and an additively manufactured polymer body.

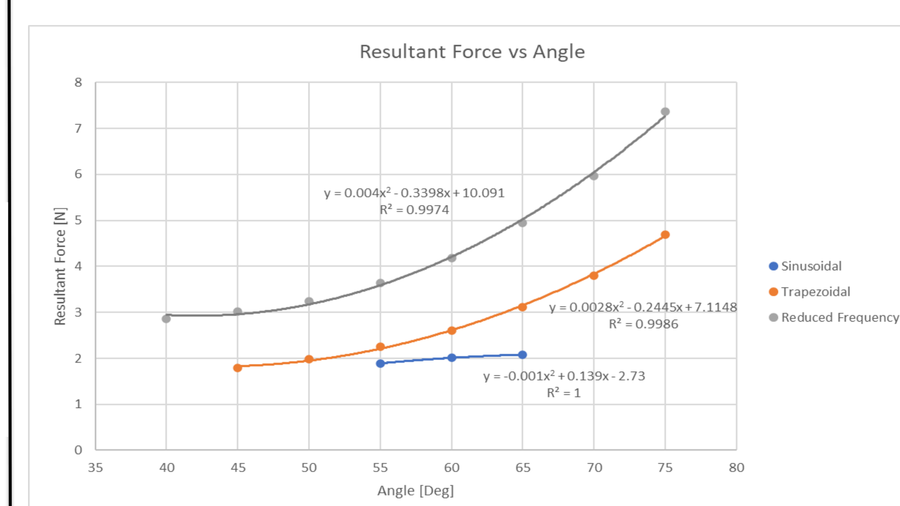


3D Modeling

- Three separate core models with different corrugation patterns were designed.
- Each model was designed parametrically to test multiple variations of each corrugation pattern.
  - Multiple configurations were created by varying the internal angle of the unit cell while maintaining the total length and total number of cells.
  - Trapezoidal models had angles varying between 40 and 75 degrees while Sinusoidal models were varied from 55-65 degrees.
- Each configuration was subjected to a FEA simulation in SolidWorks.
- A 1 mm displacement was applied to the center of the core with the end portions of each model fixed in space.
- Each study was compared in terms of:
  - Resultant force for displacement
  - Maximum Effective Stress
  - Stress at the 'neck' points, where the pattern ends



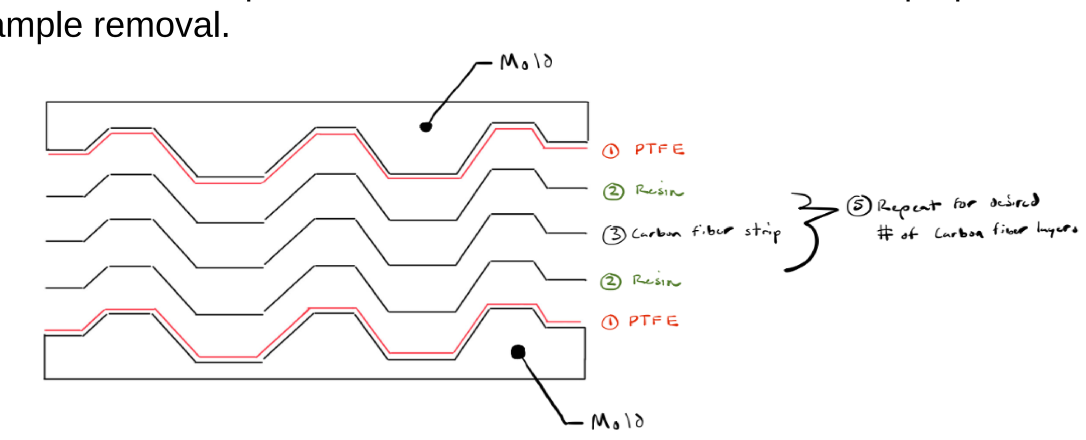




- For each pattern, a single parametric version was chosen based on:
  - Resultant Force (Bending Stiffness)
  - Ease of Construction
- The configurations chosen for fabrication and further testing were:
  - Trapezoidal/RF Trapezoidal - 50 degrees
  - Sinusoidal - 55 degrees

Carbon Fiber Core Fabrication

- Compared 3 different materials for the molds
  - Concerns of compatibility of the resin with the mold material.
  - All 3 materials were compatible, so PLA was selected due to its lower cost.
- Required a method to ensure the release of the core samples from the mold after curing.
  - Tested 2 commercial release coatings (Fibrelease, PVA)
  - Lining the molds with PTFE plastic sheets affixed with double sided tape proved to be the easiest method of sample removal.



- Post-processing - Trim samples in accordance with ASTM standards.
  - Carbon fiber particles can be skin/eye/respiratory irritants, as well as electrically conductive

Materials
- PLA Molds
- 4 layers of Carbon Fiber
- Resin/Hardener
- Two sufficiently large sheets of PTFE
- 2 in wide double-sided tape
- 3 - C-clamps
- 2 workers

Final Process
- Lay in tape smoothly into molds
- Affix PTFE sheets
- Epoxy -> carbon fiber -> epoxy
  - Repeat 4 times
- Close mold
- Clamp at 3 equidistant locations
- Cut and sand samples to size in the Composites Lab

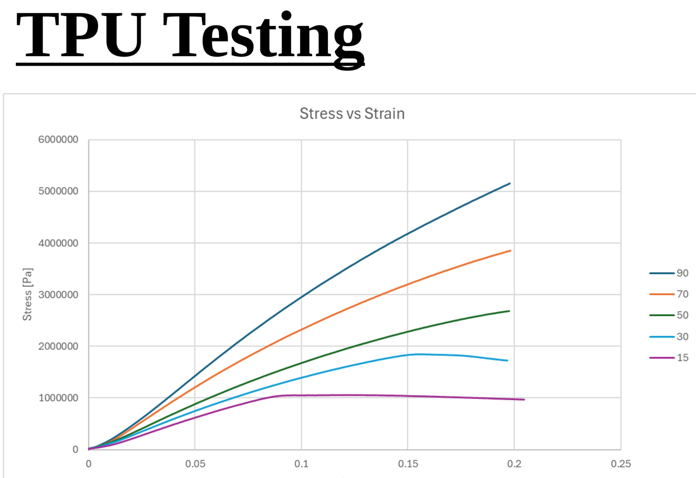
Carbon Fiber Testing

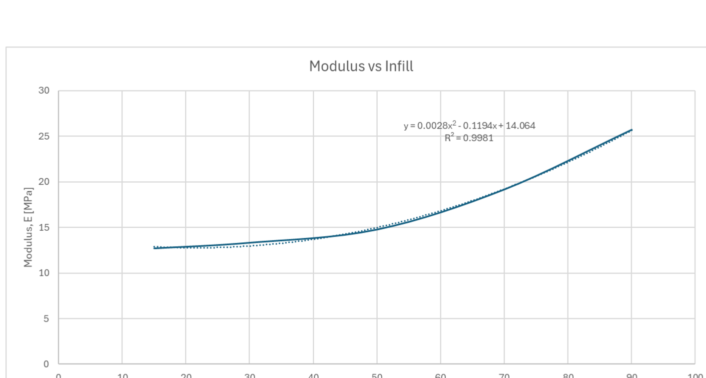
- Three-point bending tests are performed using a Sintech tensile testing machine in accordance with ASTM C393 - Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure
- 3 core samples of each configuration were tested using a 5 kN load cell.

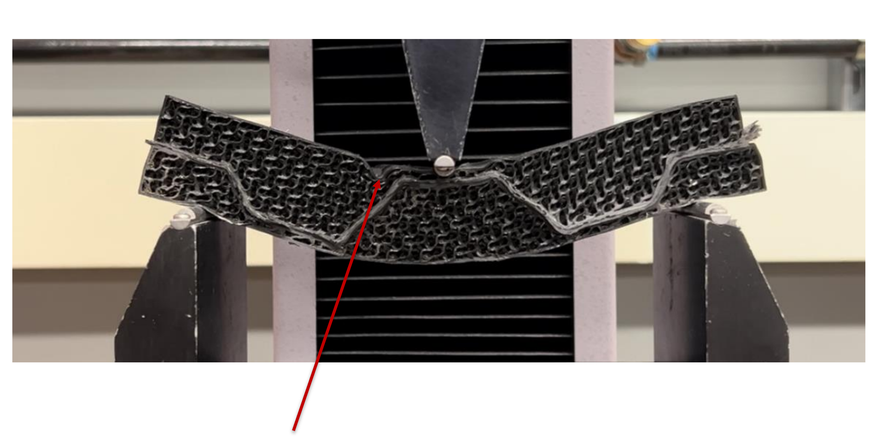
Shape	Avg Stiffness Value (lb/in)
Trapezoidal	2.0714
RF Trapezoidal	2.7048
Sinusoidal	2.381

- Values were slightly lower than the predictions from FEA simulations
  - Imperfect Model (epoxy, layers, material properties)
  - Imperfect Simulation (Boundaries and loading)
- Samples showed no physical damage or delamination after testing.
- To focus efforts, it was decided to narrow down our ongoing research to only 2 patterns.
  - Sinusoidal and RF Trapezoidal were selected for their slightly higher bending stiffness values.

TPU Testing





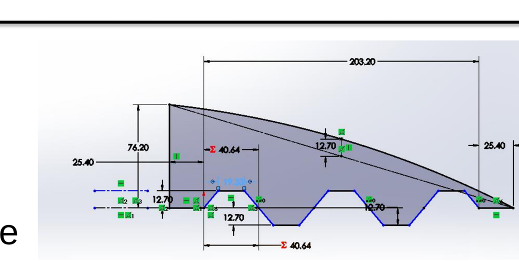


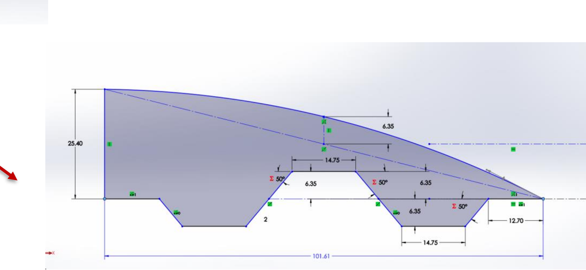
Sample	Experimental Stiffness Value (lb/in)	FEA Stiffness Value (lb/in)
Sample 1	63.027	121.46
Sample 2	40.115	

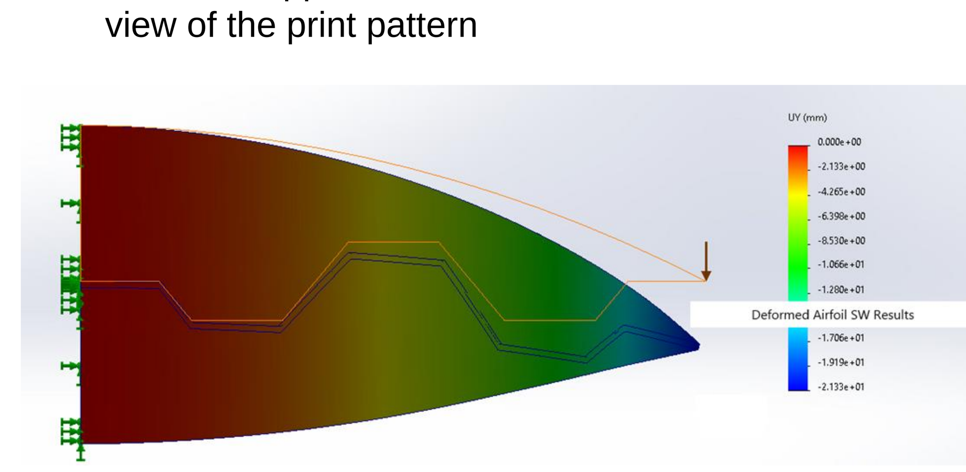
- To determine what in-fill to use, 0.5 in x 0.5 in x 0.5 in cubes at 15%, 30%, 50%, 70%, and 90% infill underwent compression testing.
- Goal was to identify differences between modulus of elasticity and yield stress.
- Buckling happened at highlighted point around 1 inch of deformation for both samples.
- Fabricated with infill visible for a view of the flexure when testing.

Airfoil and Next Steps

- Client Feedback
  - Scale down the Carbon Fiber Core length and height.
  - In SW, adjust the extruded width of top airfoil to 1.5 in so that the print can be stopped at 1 in for a clear view of the print pattern







- Force of 250 N resulted in a y-displacement of 21.33 mm at the tip of the airfoil.
- Used the y-displacement and the airfoil length (4 in) to calculate the angle of declination (11.86 deg).
- Meets engineering specification of 10 degrees of inclination/declination.
- FEA simulations tend to overestimate material stiffness.

Proposed Next Steps:
- Complete TPU and Carbon Fiber Flat Samples
  - Fabrication
  - Testing
- Airfoil development
- Airfoil Testing
  - Proposed testing Rig (pictured on right)