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Review of Structural Analysis Work at SNL

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

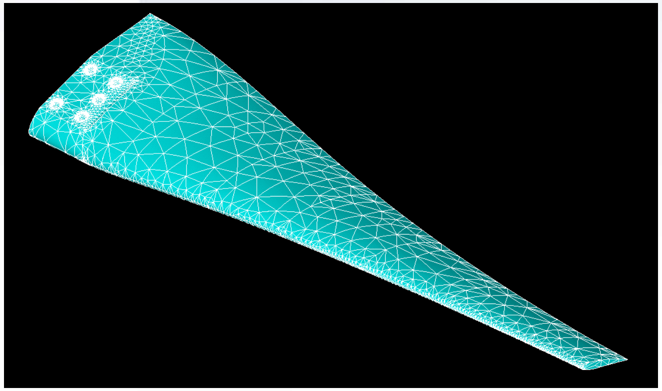
Verdant Blade FEA Analysis

- Geometry defined from IGES file created from Verdant model
- Material properties
  - E = 10,300 ksi
  - ν = 0.33
  - ρ = 0.0947 lb/in^3
- Model fixed at bolt locations
- Static analysis performed with and verified against measured loads from NREL test
- Modal analysis of first 10 modes

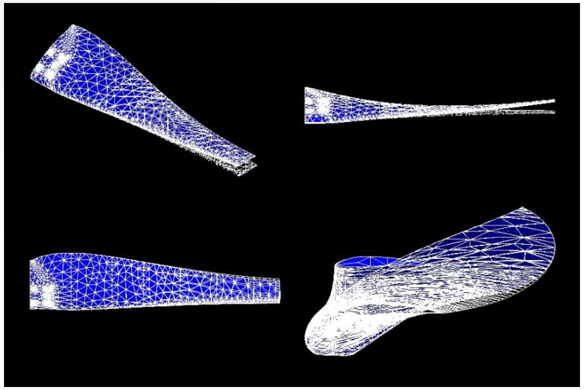
Property	Measured	FEA
Weight (lb)	374	378
CG_X, CG_Y, CG_Z (in)	-	3.407, 1.301, 32.548
I_{XX}, I_{YY}, I_{ZZ}, ($lb\text{-}in^2$) (about rotor center)	-	5.766×10^5, 5.866×10^5, 1.542×10^4
I_{XX}, I_{YY}, I_{ZZ}, ($lb\text{-}in^2$) (about mass center)	-	1.757×10^5, 1.819×10^5, 1.039×10^4

Span (in)	Strain ($\mu\varepsilon$)	
	Measured	FEA
19.6	26	26
35.1	41	39
47.1	55	57
60.9	81	87
74.7	110	120
88.5	76	100

Tip Displacement (in)		
Measured	FEA	FEA (corrected)
0.135	0.093	0.135



Verdant ANSYS FEA Model



First Flap Mode at 32 Hz

Hydrodynamic and Structural Design

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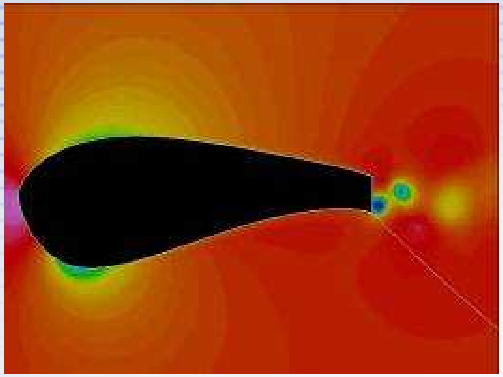
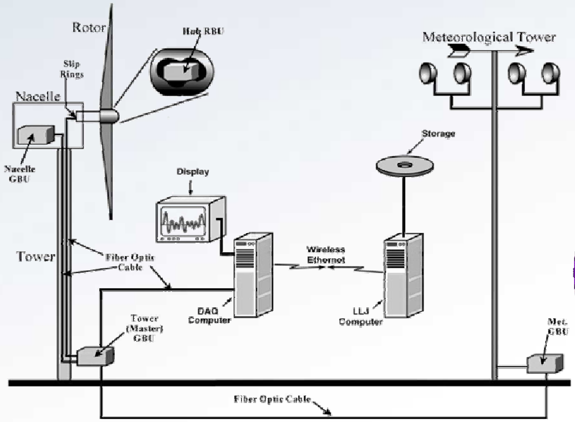
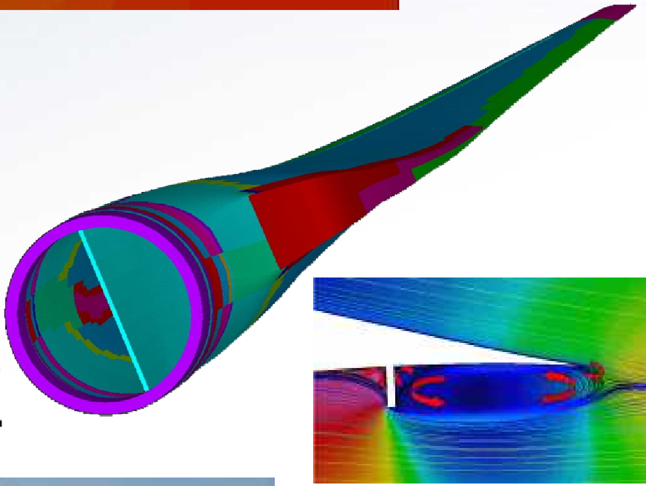
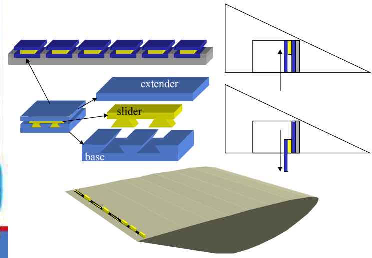
Department Activities

- Blade Technology
  - Materials and Manufacturing
  - Structural, Aerodynamic, and Full System Modeling
  - Sensors and Structural Health Monitoring
  - Advanced Blade Concepts
  - Lab - Field Testing and Data Acquisition
- System Reliability
  - Industry Data Collection
  - Improve reliability of the existing technology and future designs
- System Integration & Outreach
  - Integration Studies & TEAM
  - Wind/Radar





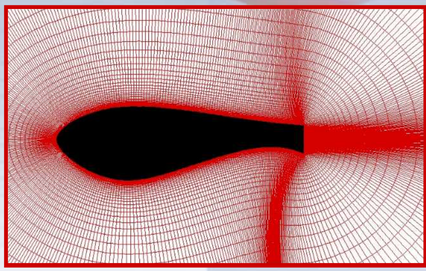


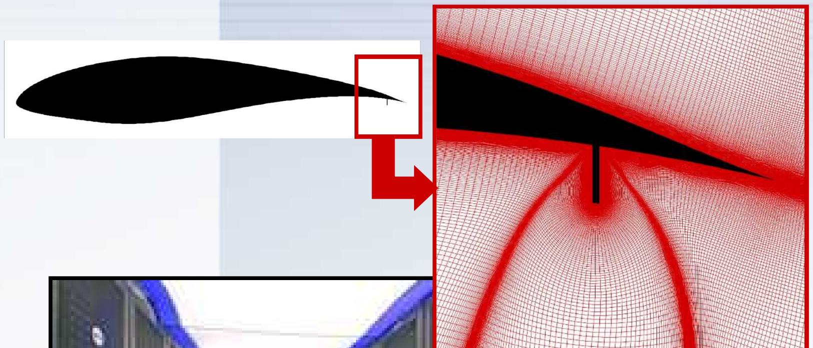


SNL CRADA Tasks

- **Task 1: Design Requirements (NREL/SNL/Verdant)**
  - Role: Participate in the development of design requirements document for Verdant Power rotor.
  - Allocation: 15k
  - Team: Paquette, Veers
- **Task 2: Baseline Fatigue Testing (NREL/SNL/Verdant)**
  - Role: Provide testing and analysis assistance.
  - Allocation: 10k
  - Team: Paquette, Johnson
- **Task 3: Blade/Rotor Performance Modeling (NREL/Verdant)**
- **Task 4: Hydrofoil Survey and Selection (NREL/SNL)**
  - Role: Provide consultation for hydrofoil selection and produce hydrofoil performance data.
  - Allocation: 20k
  - Team: Paquette, Barone, van Dam
- **Task 5: Load Estimation (NREL/Verdant)**
- **Task 6: FEA Structural Design (NREL/SNL/Verdant)**
  - Role: Develop laminate specification to meet strength and stiffness requirements.
  - Allocation: 80k
  - Team: Paquette, Resor
- **Task 7: Develop Candidate Designs (NREL/SNL/Verdant)**
  - Role: Contribute to development plan for one or two design concepts.
  - Allocation: 25k
  - Team: Paquette, Veers, Barone, Resor

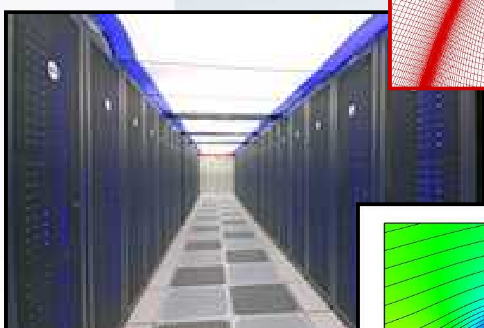
Computational Airfoil Analysis

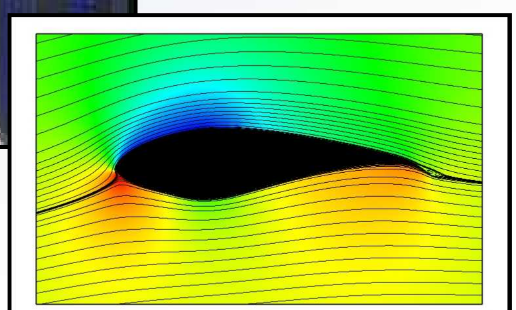




Automated Airfoil Analysis Tools

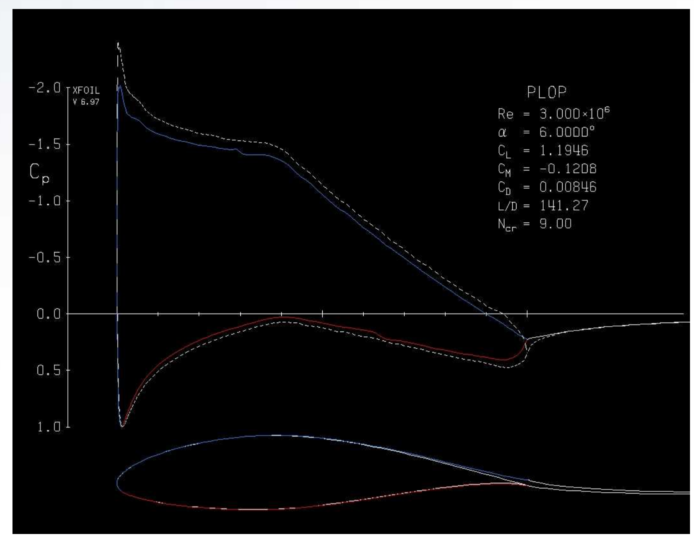
- Automatic mesh generator with geometry modifications
- Automated batch script generator for parametric studies
- NASA ARC2D code generates CFD solutions





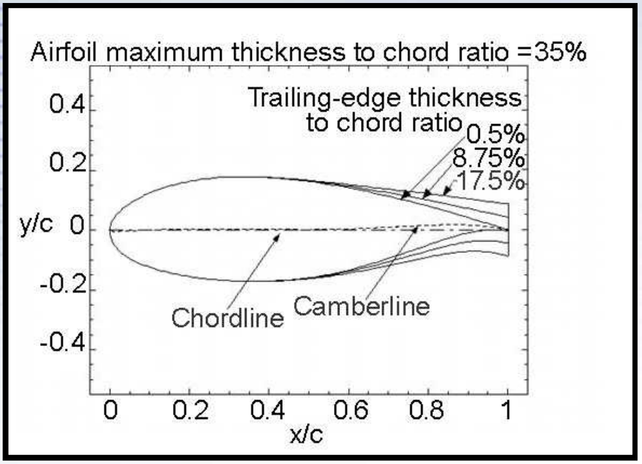
XFOIL Panel Code

- Quick turnaround airfoil analysis
- Simple shape changes
- Shape design mode



Flatback Airfoils
Possible Use in Kinetic Hydropower

- **Advantages**
  - **Structural benefit of larger sectional area for given chord and thickness.**
  - **Hydrodynamic benefit of decreased sensitivity to blade soiling.**
  - **Possible suction surface cavitation benefits**
- **Disadvantages**
  - **Increased drag**
  - **Possible risk of cavitation in turbulent wake**
  - **Noise?**



Flatback Creation

Sandia BSDS Blade

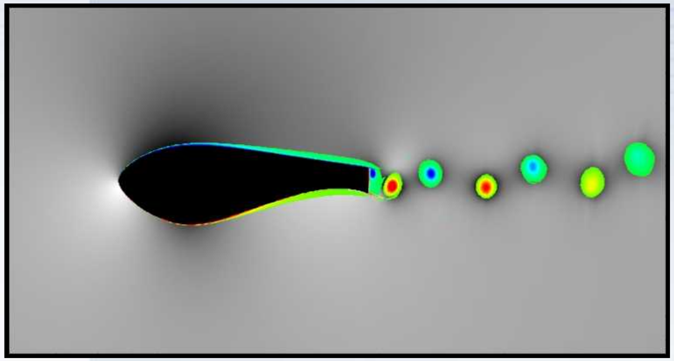
Wind Tunnel Flatback Model

Sandia National Laboratories

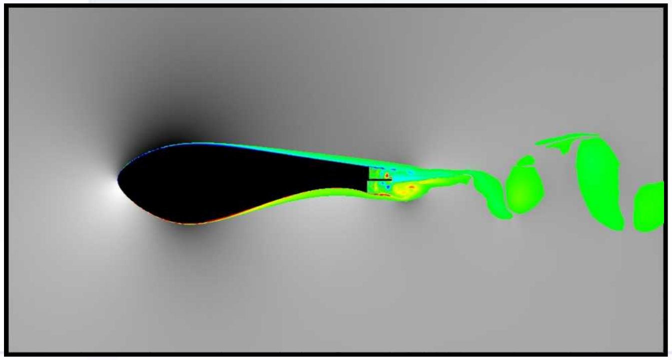
Flatback Airfoil CFD Modeling

Unsteady 2D CFD Simulation of Flatback Airfoil Wake

Flatback Airfoil

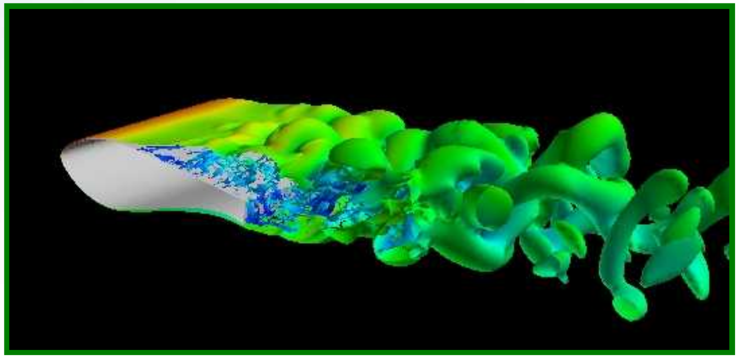


Flatback Airfoil with Splitter Plate Attachment



Unsteady CFD Simulation of 3D Flatback Airfoil Wake

- More accurate drag prediction than 2D computation.
- Provides prediction of unsteady forces due to turbulent wake.
- Provides a means to assess cavitation risks.



Rotor CFD

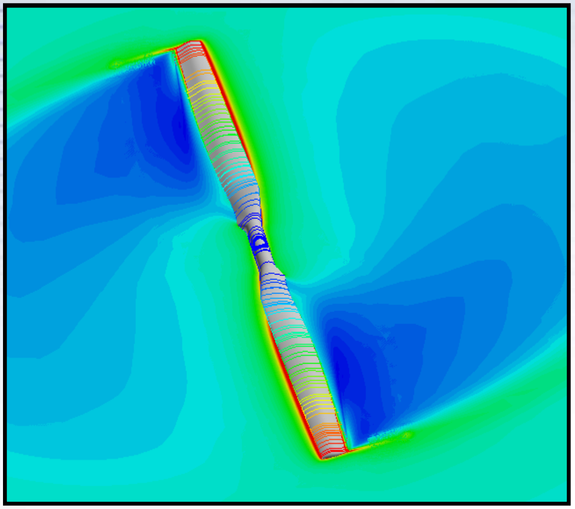
Full Rotor CFD Capability (with Case Van Dam, UC Davis)

- OVERFLOW 2 Code developed at NASA Langley
- Uses sliding overset meshes to compute the flow about rotating geometries
- Validated against existing wind turbine aerodynamic data
- Computationally intensive

Application to Water Turbines

- No code modifications required
- Can be used to:
  - Verify hydrodynamic performance of a design
  - Compare hydrodynamic performance of several designs
  - Explore tower-rotor interactions

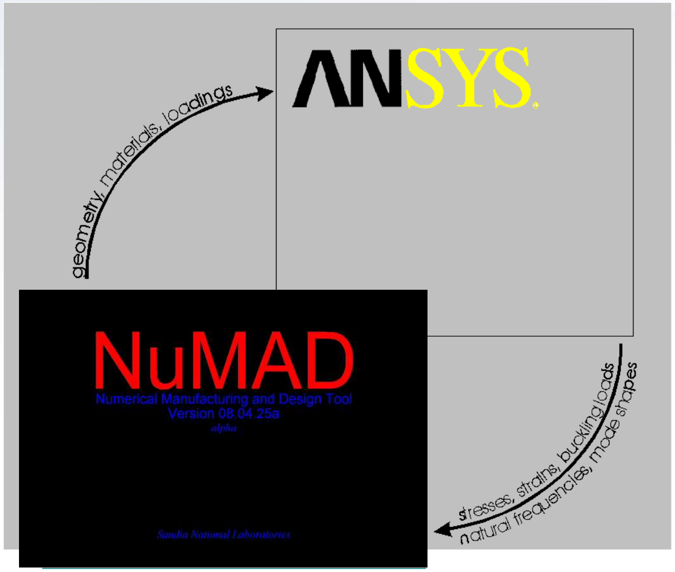
Simulated Flow about the NREL Phase VI Rotor



Sandia's 53 TeraFlop Thunderbird Computing Cluster

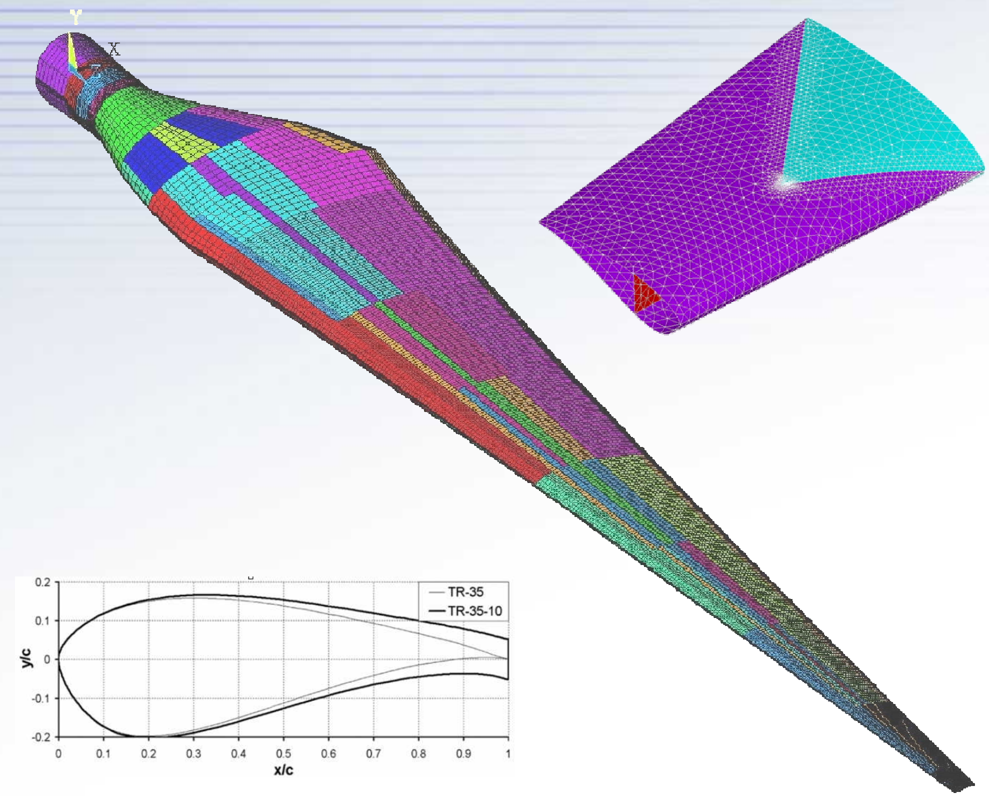
NuMAD
Blade Structural Design Tool

- **NuMAD Objective**
  - **Promote utilization of FEA in addition to spreadsheet-based beam models**
  - **Significantly decrease model generation time for 3-D, FE models of wind turbine blades**
- **Approach**
  - **GUI pre-processor for ANSYS®**
  - **Tailored to analyze wind blades**
  - **Quickly generate 3-D structural models**
  - **Flexibility/Expandability**
    - **materials database**
    - **airfoils database**
  - **Standard MS Windows® application**
  - **Analysis used to find weak spots in blades**
  - **Development guided by industry input**
  - **Beam Property Extraction (BPE) capability**



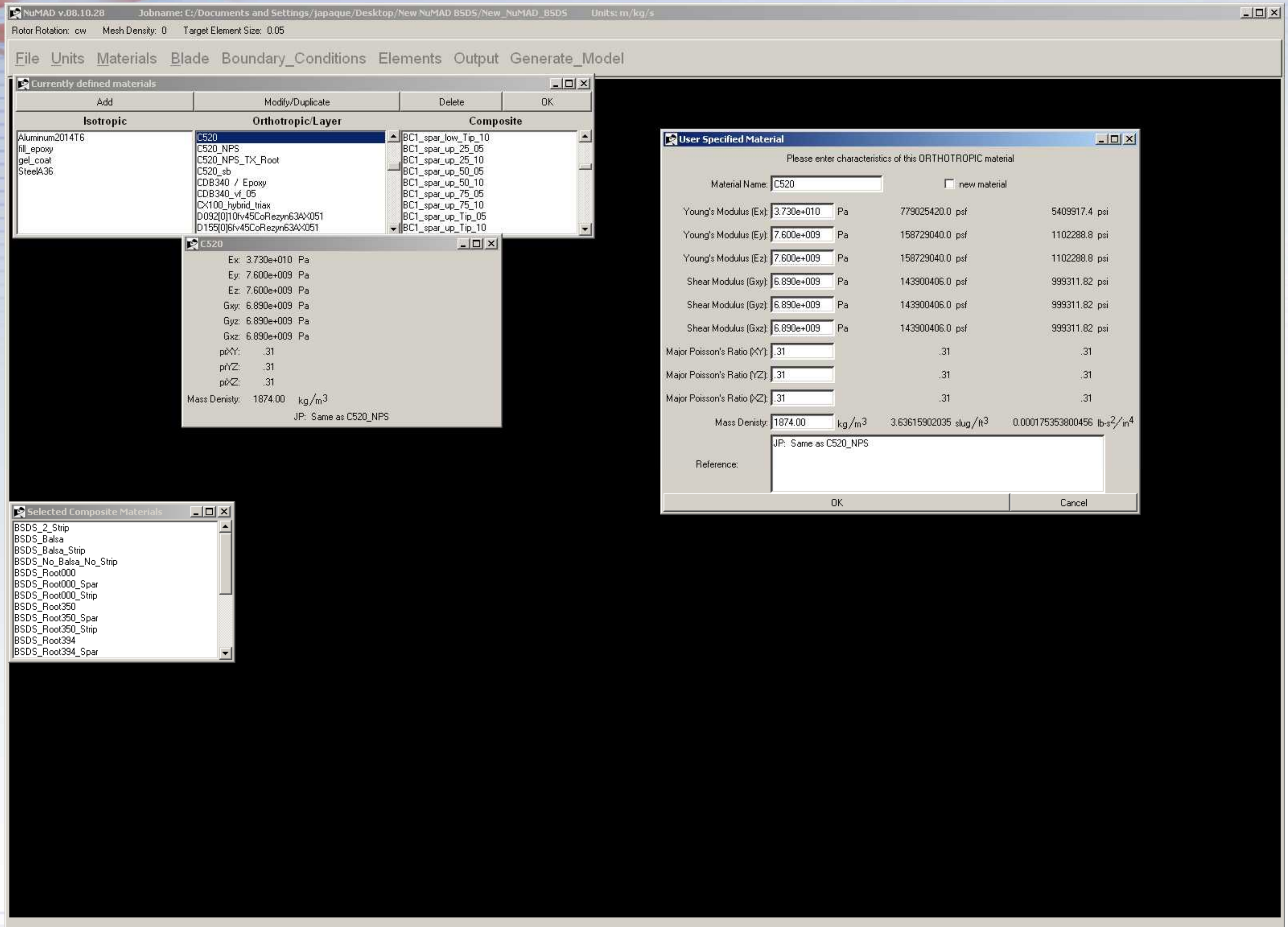
Recent NuMAD Upgrades

- Redesigned GUI
- Transitional meshing
- Multiple element options
    - Layered shells
    - Layered bricks
- Precise skin material definition
- Inboard/outboard skin material tapering
- Triangular skin material areas
- Flatback airfoil capability
- Airfoil definition-independent



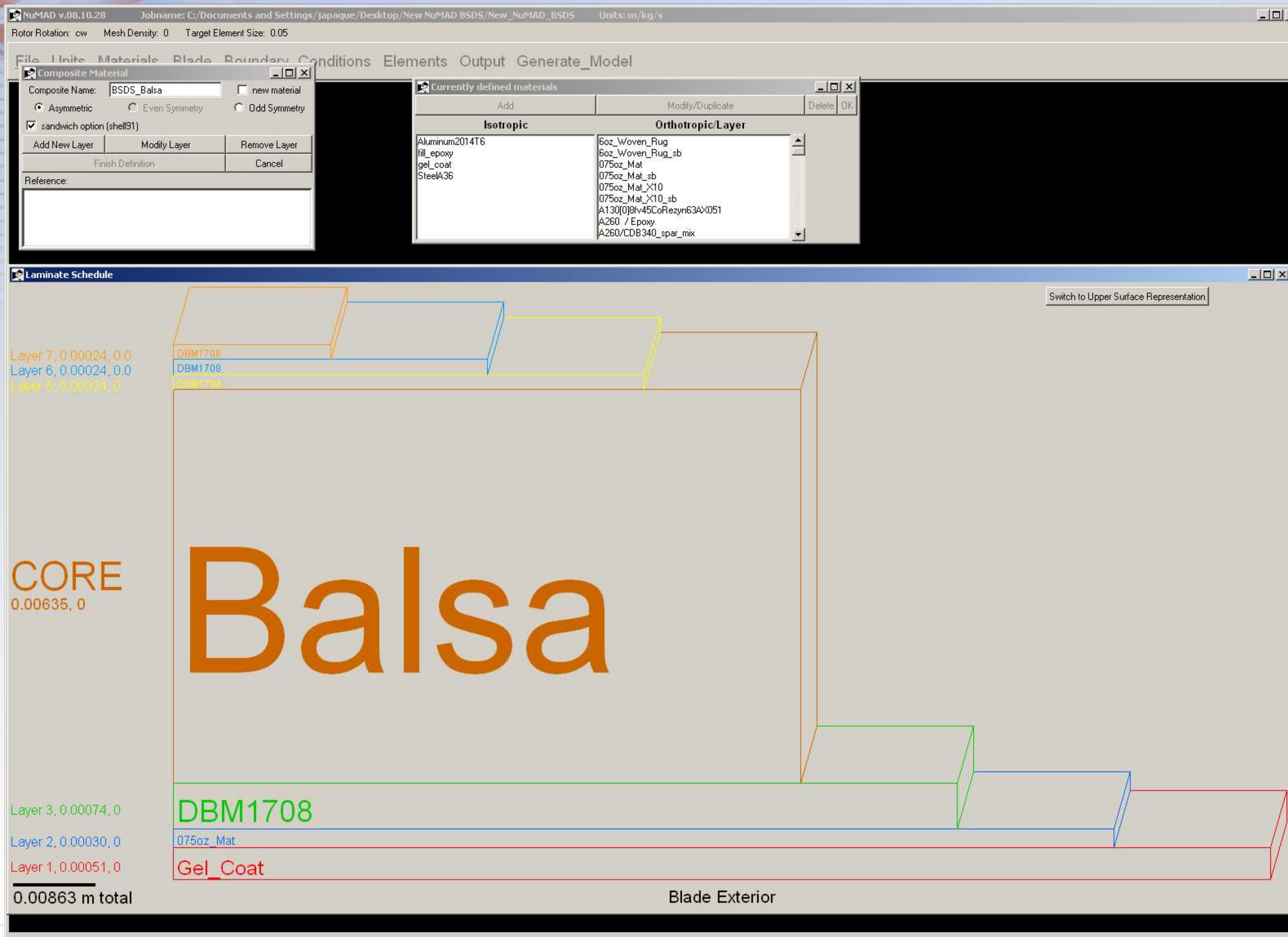
NuMAD Model Definition Process

Define Materials



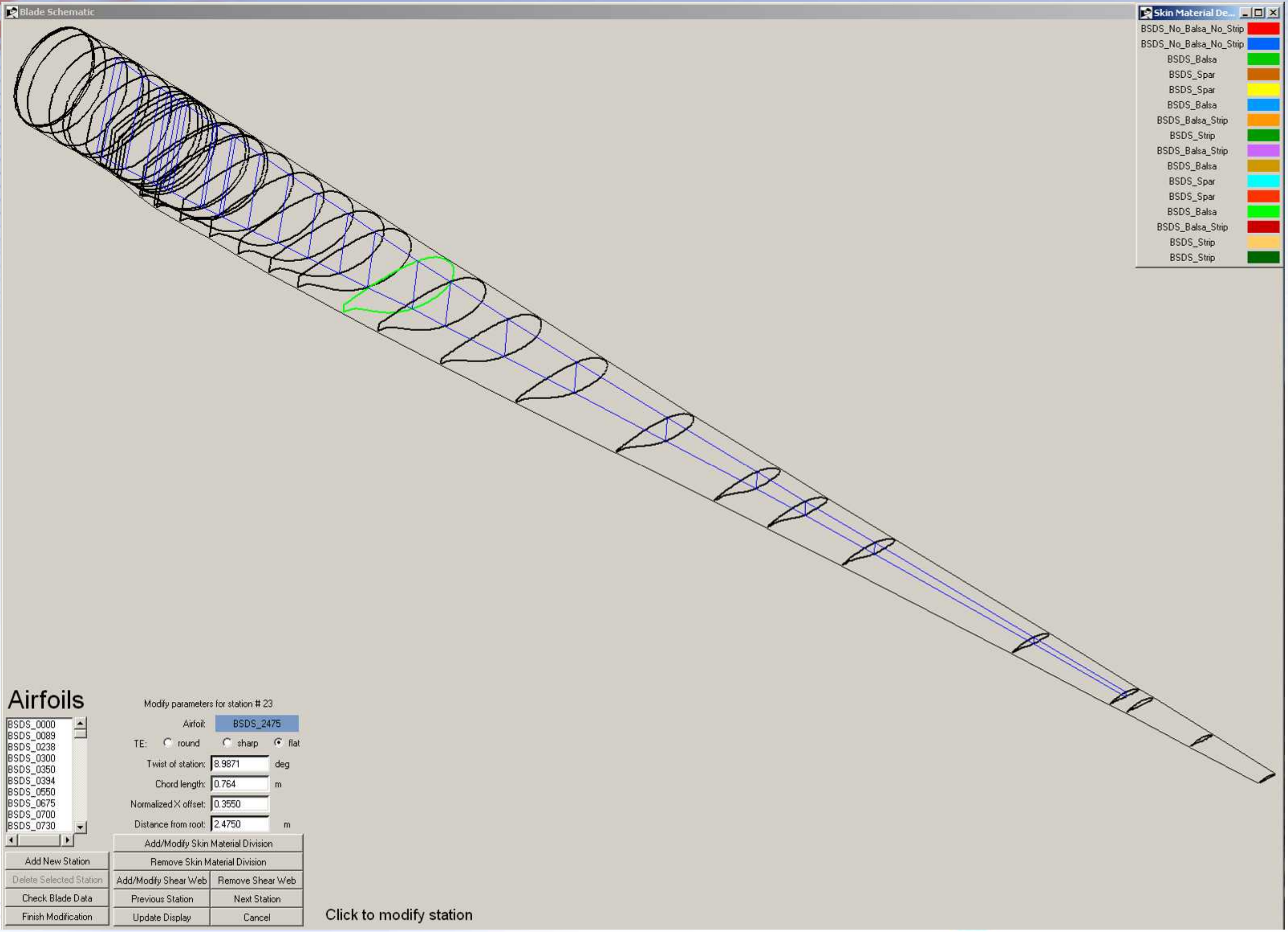
NuMAD Model Definition Process

Define Laminates



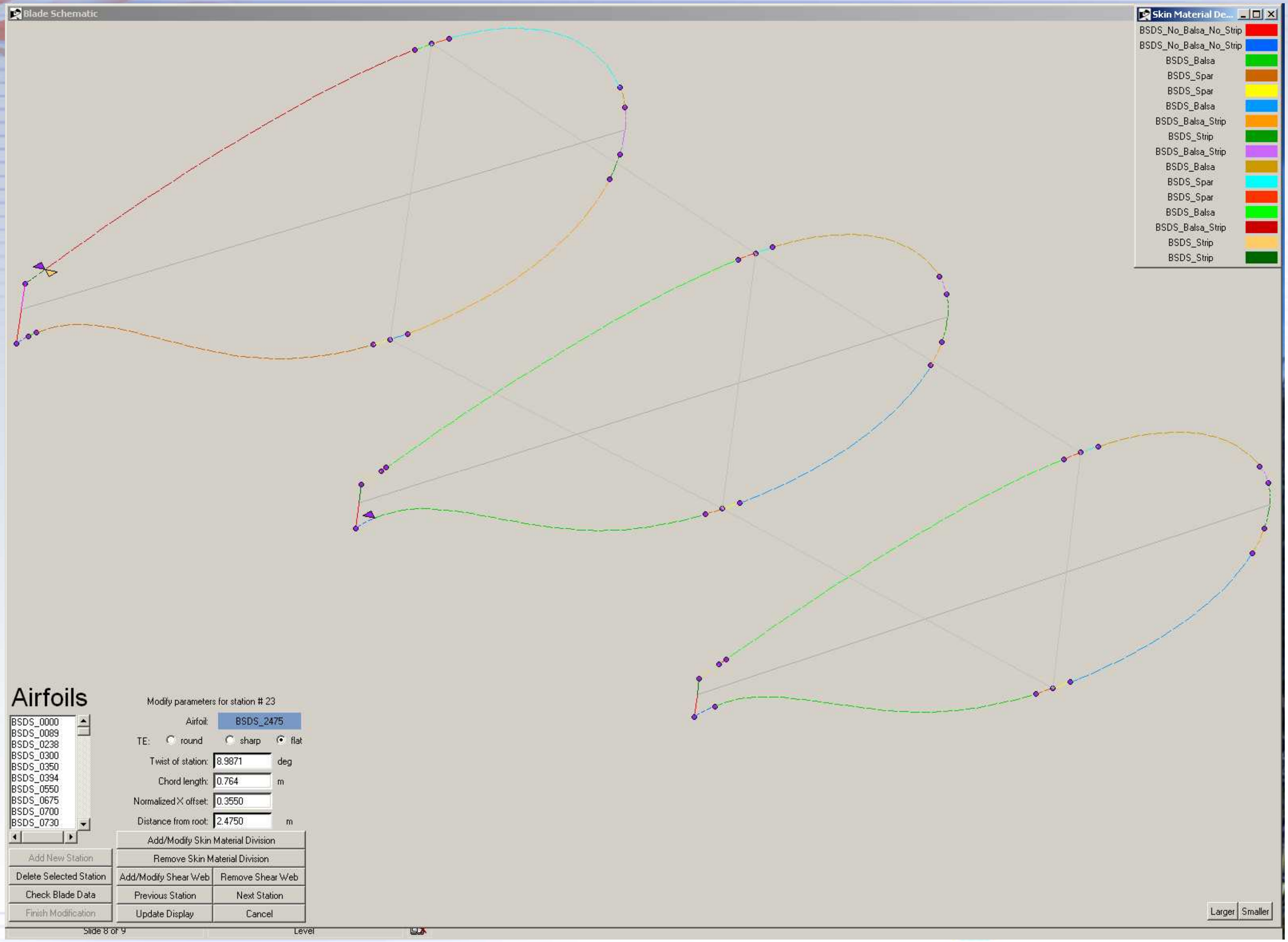
NuMAD Model Definition Process

Define Geometry

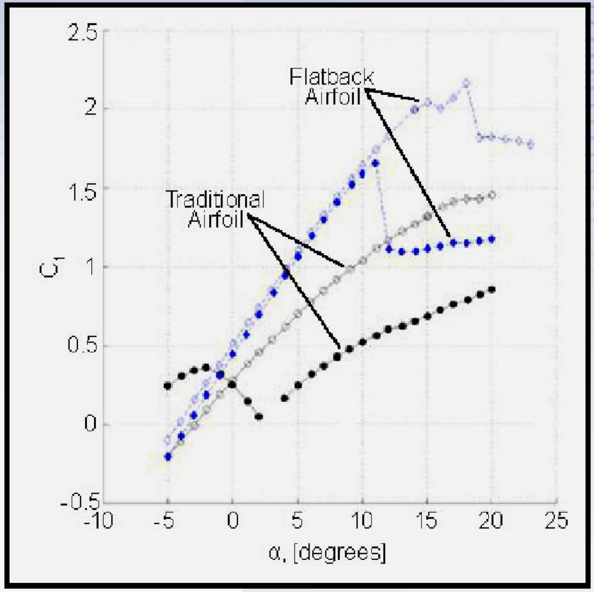


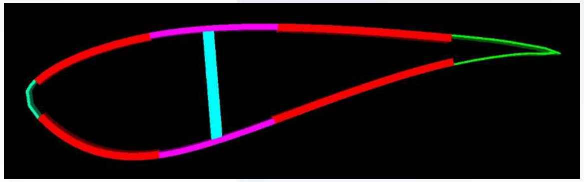
NuMAD Model Definition Process

Define Laminate Sections



Potential Challenges





- **Hydrofoil Selection and CFD Modeling**
  - **Tower-rotor interactions**
  - **Soiling effects**
  - **Modeling of cavitation and effect on structure over lifetime**
- **Structural Modeling**
  - **NuMAD and other codes were developed to analyze thin shell structures (i.e. wind turbine blades)**
  - **Kinetic hydropower blades will likely be thick structures**
  - **Severe event modeling impact from floating debris**
- **Manufacturing (AWPP)**
  - **Coatings (material protection, soiling reduction)**
  - **Molds**
  - **Materials**