Applying Optimization Technology to Drive Design of a 100-Meter Composite Wind Turbine Blade

Warren Dias
Altair Engineering, Inc.

Abstract

This presentation demonstrates how numerical optimization can be applied using OptiStruct to aid in the design development of a 100-meter composite wind turbine blade. For this proof of concept, blade geometry, composite material properties, wind speed and rotational velocity of the turbine were provided by Sandia National Laboratories. Other quantities were assumed. The scope of this study was to develop a process to identify the internal reinforcement structure of the blade and perform design studies on the composite skin of the blade (pressure and suction sides). Early topology optimization studies were performed to determine the optimal number and placement of spars. This was followed by composite free size optimization studies to identify the optimal ply shapes and coverage regions for the different unidirectional, biaxial and tri-axial ply materials. Subsequent to this, ply bundle sizing and ply stacking sequence optimization studies were carried out to determine the number of plies per material and shape, and how best they should be stacked in the laminate, all in order to meet certain structural requirements and satisfy ply book rules.

Learning Objectives

- Use of advanced numerical optimization algorithms to drive the design process
  - Topology optimization to determine the internal reinforcement structure of the blade
  - Blade skin design through the application of composite free size optimization to determine ply shapes and ply coverage zones, composite ply bundle sizing optimization to determine number of plies, and ply shuffling optimization to determine an optimal ply layup schedule
- Design efficient blade structures considering performance criteria and manufacturability
- Generate and evaluate multiple, innovative design concepts with advanced, lightweight composite materials

Overview

A quick review of the recent past will show that wind turbine sizes have steadily increased. This necessity is to keep up with the ever increasing energy demands, and is expected to continue in the future as well. As a result, blade sizes are getting much larger, bringing with it a new set of challenges, particularly design related. Blade mass scales significantly with blade length, so larger blades mean more weight and higher costs, but, these need to be lowered. Larger blades also mean greater structural problems – higher stresses, buckling issues, and strength and stiffness requirements, to name a few. To support such an evolution of wind turbine blade design, alternative materials, and innovative designs and design techniques need to be sought.

Moving to Composite Materials

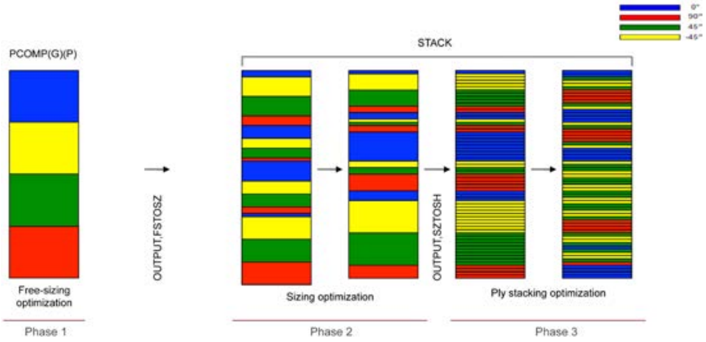
Similar to the aerospace industry, composite materials have proven very attractive for wind turbine blade design, and threaten to be the norm. Their customizable properties are highly desirable in tuning performance characteristics while keeping weight down. Of course, such flexibility brings with it complexity, and herein lies the design challenges. But here's also where the use of advanced optimization technology and software such as Altair OptiStruct come in, and can play a crucial role, taking advantage of the flexibility and simplifying the complexities involved with designing structures made from composite materials. Using optimization technology can also help eliminate the "trial and error" process, and particularly when there is no existing design reference. And such was the case of the 100-meter blade design discussed here – it is the first of its kind.

Optimization in the Design Process

- Optimization can be applied in multiple ways throughout the design process. But in order to extract maximum benefit from this technology, it should be deployed in the early stages of design to generate design concepts, and thereafter, appropriately deployed throughout the design cycle. In other words, optimization should drive design!
- Applying optimization early in the design cycle can help identify material layout such as spar and rib locations. It can also help identify the optimal ply shapes and fibre orientation for each ply in the laminate build up for structures made of composites. Additionally, early optimization studies allow the consideration of different design concepts such as adding a 3rd shear web versus ribs, constant width spar caps, etc.

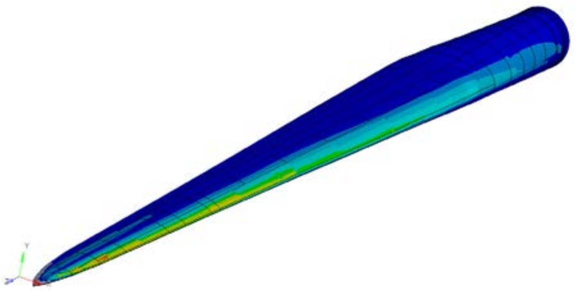
- Further downstream, applying optimization can help determine the number of plies required and the optimal ply layup sequence – all while preserving manufacturing and ply book rules – as driven by various design and structural requirements such as mass, rotational inertia, buckling, tip deflection, strength, composite failure, etc.

Optimizing Laminate Composite Structures

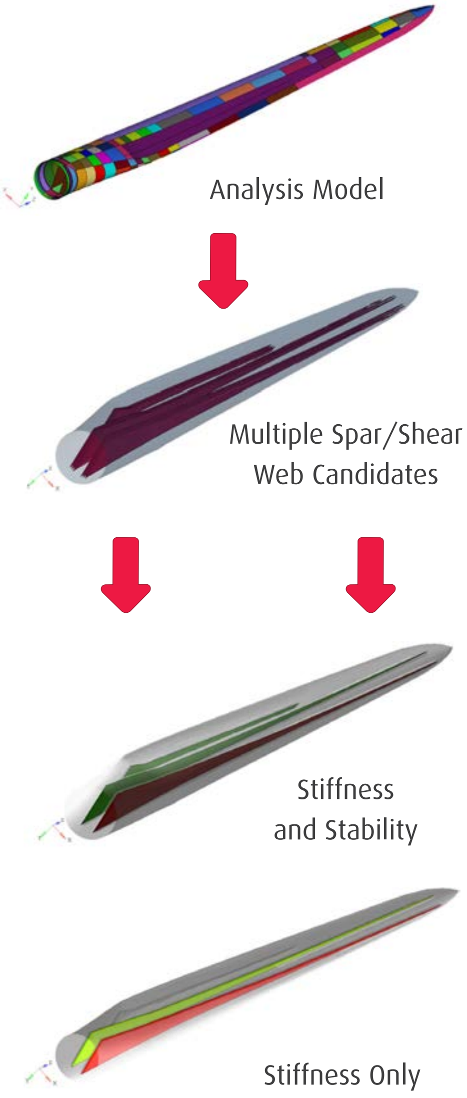


Model Setup and Results

The analysis model was setup with multiple load cases, viz. natural frequency, centrifugal force, gravity, buckling and fluid load (wind flow) as determined from a fluid-structure interaction analysis. Different ply materials (Unidirectional, biaxial and tri-axial), along with foam, resin and a gel coat were also considered in the model setup.

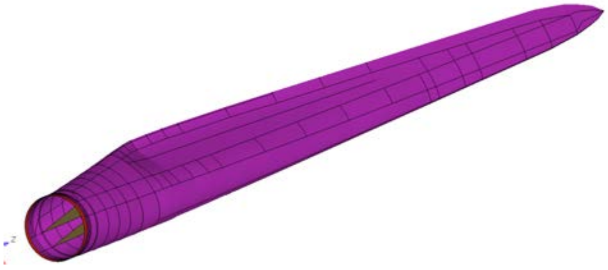


Generating Design Concepts – Topology Optimization



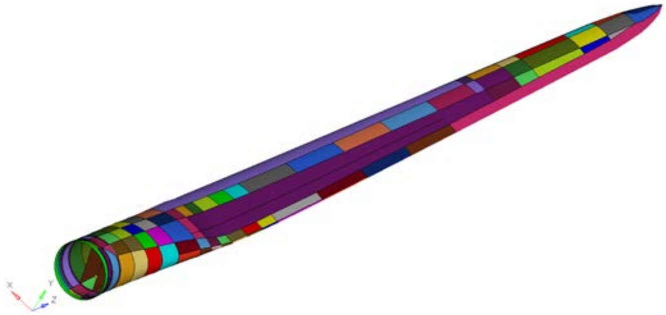
1. Internal Reinforcement Design

Topology optimization was run to determine the optimal number and placement of spars and shear webs. This was done through an approach using multiple potential candidates for the reinforcement structure.



2. Blade Skin Design

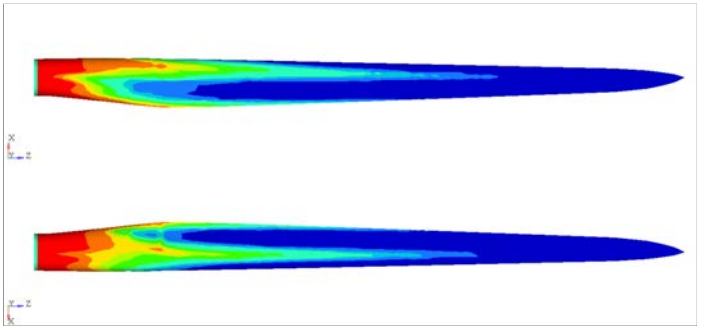
Designable Ply Material	**Non Design Ply Material**
Saertex	Foam
Triax	Resin
UD	Gel Coat



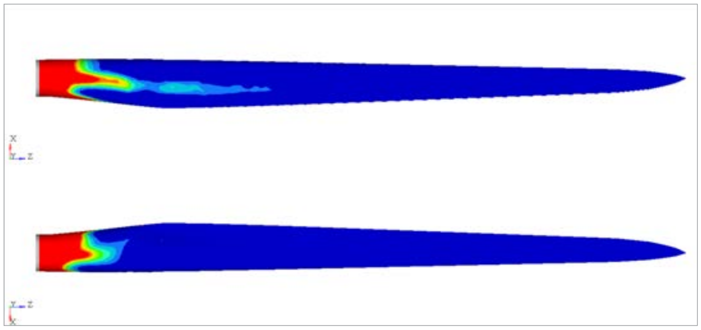
Composite Free Sizing Optimization

The goal of free sizing is to come up with optimized material thickness distribution, i.e. ply shapes for laminate composite structures, for each of the designable ply materials. In other words, through free sizing optimization, we can establish the different ply shapes and coverage areas that are required for the UD (unidirectional), biaxial and tri-axial plies. Through this, we can also identify drop off zones and laminate boundaries. The setup can be enhanced further through the definition of composite-specific manufacturing constraints such as ply or laminate drop-off constraints, ply percentage constraints, balance constraints, designable or non-designable core, etc.

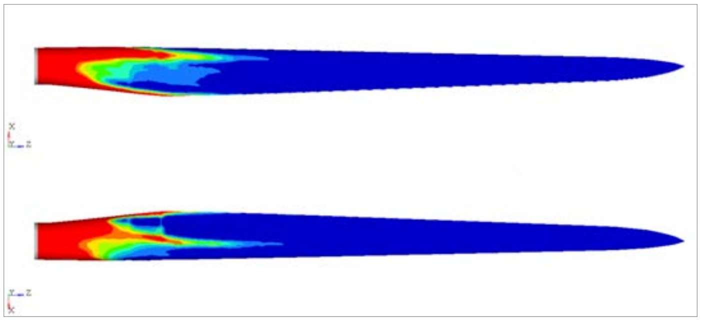
Ply Material Thickness



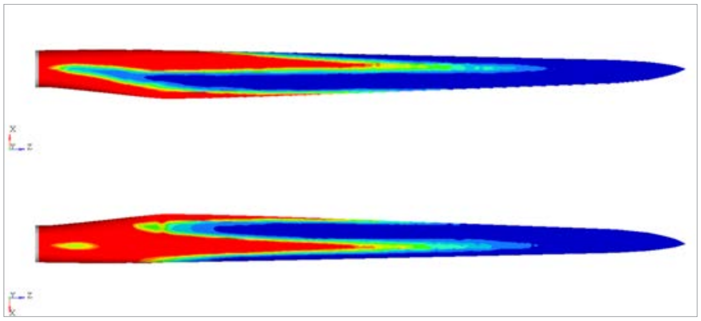
Total Laminate Thickness Distribution



Saertex Material Distribution



Triax Material Distribution

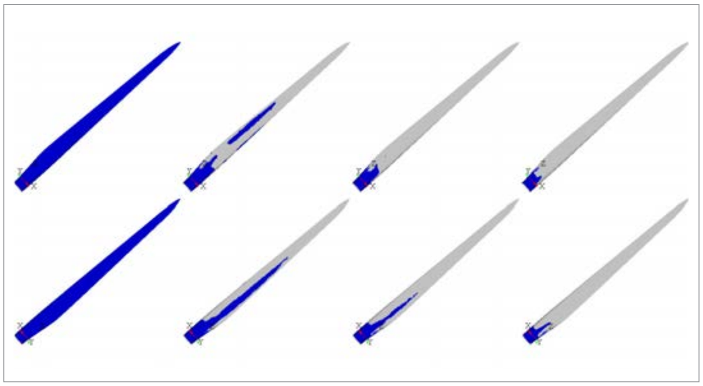


Unidirectional Material Distribution

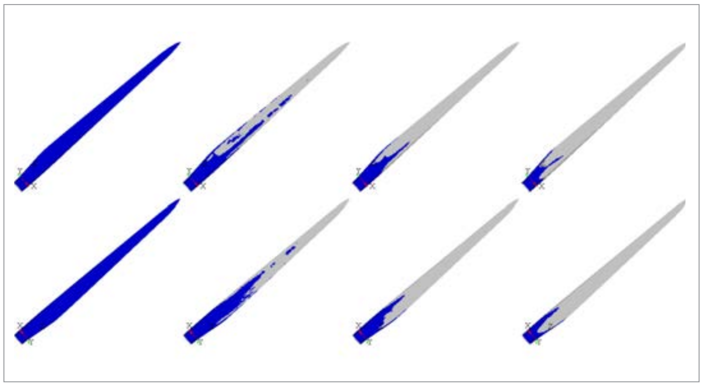
Detailed Laminate Composite Design

- With ply shape concepts generated, the design is then fine tuned to meet key performance criteria, and enable consideration for manufacturability through ply-book rules.
- From the results of free sizing, it is possible to determine the optimal shape of plies. This is done through various algorithms built in to OptiStruct. The following step is to then determine the optimal number of plies required for each designable material, done using a traditional size optimization approach. Manufacturing ply data such as thickness can also be specified as input.
- Once the number of plies has been determined, the next step is to identify an optimal stacking sequence in which the various plies need to be laid up. It is imperative that during this phase, all behavioral constraints are preserved, and any additional ply book stacking rules be met as well.
- To streamline the design process and improve usability, a pure ply based modeling approach is used, consistent with how such structures are built in the physical world.

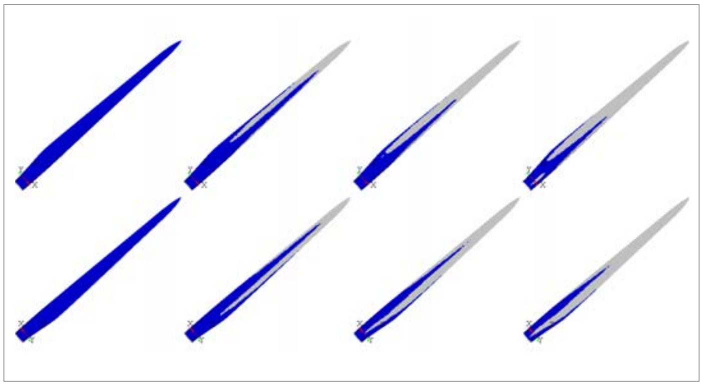
Extracted Ply Shapes



Saertex Ply Shapes



Triax Ply Shapes



Unidirectional Ply Shapes

Ply Layup Schedule – Pressure and Suction Sides

Stacking sequence for STACK 1

Iteration 0	Iteration 1	Iteration 2	Iteration 3	Iteration 4
109101	109101	112207	112101	112101
111101	111101	112202	112102	112102
112101	112101	112201	112203	112203
112102	112102	109101	111101	111101
108201	108201	112101	108401	108401
112201	112201	112102	108301	108301
112202	112202	112203	112204	112204
112203	112203	111101	112205	112205
112204	112204	112204	112206	112206
112205	112205	112205	108201	108201
112206	112206	112206	112201	112201
112207	112207	108201	112202	112202
112208	112208	112208	112207	112207
112209	112209	112209	109101	109101
107301	107301	108301	112208	112208
108301	108301	112301	112209	112209
110301	110301	112302	112301	112301
112301	112301	112303	112302	112302
112302	112302	107301	112303	112303
112303	112303	112304	107301	107301
112304	112304	112305	112304	112304
112305	112305	112306	112305	112305
112306	112306	110301	112306	112306
112307	112307	112307	110301	110301
112308	112308	112308	112307	112307
112309	112309	112309	112308	112308
112310	112310	112310	112309	112309
112311	112311	112311	112310	112310
112312	112312	112312	112311	112311
112313	112313	112313	112312	112312
108401	108401	108401	112313	112313
112401	112401	112401	112401	112401

Legend
.005 degrees
.004 degrees
.003 degrees
.002 degrees
.001 degrees
0.0 degrees

Stacking sequence for STACK 2

Iteration 0	Iteration 1	Iteration 2	Iteration 3	Iteration 4
203101	206101	206209	206209	206209
205101	206201	206210	206210	206210
206101	206202	206211	206211	206211
202201	206203	206401	206401	206401
206201	206204	203101	203101	203101
206202	206205	206202	206202	206202
206203	206206	206201	206201	206201
206204	206207	206101	206101	206101
206205	206208	205101	205101	205101
206206	206209	206205	206205	206205
206207	206210	206204	206204	206204
206208	206211	206203	206203	206203
206209	206301	202201	202201	202201
206210	206302	206311	206311	206311
206211	206303	206310	206310	206310
201301	206304	201301	201301	201301
204301	206305	206303	206303	206303
206301	206306	206302	206302	206302
206302	206307	206301	206301	206301
206303	206308	204301	204301	204301
206304	206309	206309	206309	206309
206305	206310	206308	206308	206308
206306	206311	206307	206307	206307
206307	206401	202401	202401	202401
206308	203101	206306	206306	206306
206309	205101	206305	206305	206305
206310	202201	206304	206304	206304
206311	201301	202402	202402	202402
202401	204301	206208	206208	206208
202402	202401	206207	206207	206207
206401	202402	206206	206206	206206

Legend
.005 degrees
.004 degrees
.003 degrees
0.0 degrees
.002 degrees
.001 degrees

Conclusions

- Topology optimization can be applied to identify internal reinforcement structure (spars, shear webs or ribs).
- Free sizing optimization can be run to determine optimal ply shapes. Sizing and ply stacking optimization techniques can be used to fine tune designs to meet key performance targets such as buckling stability, strain, stress, deflection, etc.
- Optimization is particularly useful for composite structures – it helps manage the complexity while taking advantage of the design flexibility.
- Typical benefits include lighter designs, better performing designs, innovative designs, and a shorter and more efficient design process.
- Numerical optimization methods are well established and need to be applied more strategically in the design process.
- OptiStruct can play a pivotal role in the design and optimization of composite wind turbine blades.

References

[1] Griffith, D.T. and Ashwill, T.D, "The Sandia 100-meter All-glass Baseline Wind Turbine Blade: SNL100-00," Sandia National Laboratories Technical Report, June 2011, SAND2011-3779.

[2] Zhou, M., Fleury R., and Dias W., "Composite Design Optimization-From Concept to Ply-Book Details," 8th World Congress on Structural and Multidisciplinary Optimization, Lisbon, Portugal, 1-5 June 2009.