IMPROVING WIND BLADE MANUFACTURABILITY

Collier Research Corporation's HyperSizer software optimizes both composite design and manufacturability.

By Chris Hardee

For more information on Collier Research Corporation's HyperSizer software, call 757-825-0000 or visit www.hypersizer.com.

COMPOSITES CAN BE A DESIGNER'S DREAM — or a manufacturer's nightmare. If you're designing a one-of-a-kind Formula One race car, where performance is paramount and cost and manufacturability are of less concern, you can cut weight, modify, and adapt in creative ways. But if you're designing a wind blade for competitive energy markets, over-customizing can result in a product that is extremely complex and difficult to produce. For a cost-sensitive product like a wind blade, you need to strike a design balance that accounts for both the subtleties of the physics and the realities of the factory floor.

As a 35-to 40-meter 1.5MW wind blade spins, it is subjected to a complicated collection of static and dynamic forces that vary along the blade from supporting root to tip. To account for these diverse loads, the several-hundred-ply-thick composite stack beneath the surface also varies — in material selection, number of plies, and overall thickness. The actual construction for each blade part depends on the specific structural characteristics required to ensure adequate strength and deliver optimal performance.

The root of a 1.5MW blade requires a thick, heavy construction to support the gravitational loads of the six- to seven-ton blade weight. The energy-capturing part of the blade must be rigid enough to prevent

Figure 1: The aerodynamic similarities between long, thin aircraft wings (such as those on Steve Fosett's Global Flyer, top) and modern wind turbine blades can be used to guide design blade decisions. Composites manufacturing lessons learned in aerospace can also be applied to wind blades (left).

buckling from aerodynamic forces but light enough to maximize rotor speed. The box-shaped spar or I-beam with accompanying shear webs (which runs the length of the blade) requires a material and construction approach that provides increased bending stiffness. To create a successful design, the wind blade engineer must consider each of these structures and their functions.

BALANCING COMPETING DESIGN DEMANDS

Given the variety of composites and the flexibility of stack design and layup, wind blade design solutions can be as complex as the loading scenarios. The dominant material for blades manufactured today is glass fiber reinforced polymer (GFRP). The more expensive carbon fiber reinforced polymer (CFRP), with its better strength-to-weight characteristics, is being used more frequently as blade length increases.

Within these two broad composite categories are a wide variety of fabrics and tapes with varying fiber orientations and resulting properties: zero-degree materials (with fibers running along the axis of the blade, from root to tip in the direction of the load) are used in the blade skins to control tip deflection; 45-degree materials (both positive and negative) are used to prevent twisting; and 90-degree materials (with fibers oriented around the circumference of the blade) are used sparingly to counter buckling effects. An expanding library of composites — Sandia National Laboratories' Wind Energy Technology Department has a database of approximately 150 — gives the designer a wide variety of choices.

The composite engineer also has the almost limitless ability to add or delete laminate layers to either increase strength or shave off weight. But unlimited design flexibility has downsides as well. At every ply drop or add there is a potential structural weakness, and every transition introduces another layer of manufacturing complexity. At one extreme, a designer could create a uniformly thick blade, strong enough to weather any potential gust — but too heavy to generate maximum wattage. At the other, the design could be a jigsaw puzzle of laminate zones, customized to meet every subtlety of real-world loading — but a problematic and costly challenge to fabricate.

An ideal wind-blade design provides high performance at competitive cost while meeting the industry standard 20-year lifespan. To achieve this, designers must consider blade strength, stability (buckling), and stiffness (wing-tip deflection), as

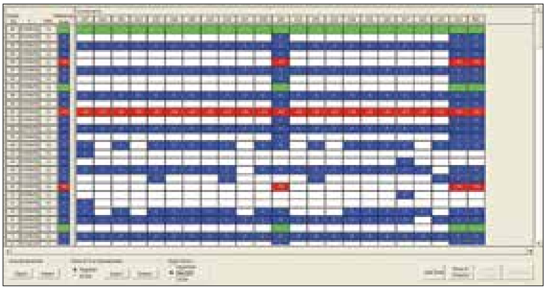

Figure 2: The data in HyperSizer can be formatted in Excel spreadsheets and color codes matched to either FiberSIM or CATIA for direct export. In this HyperSizer screen shot, with the FiberSIM box checked (lower left), the color code represents the following: blue signifies 0-degree fiber orientation; green denotes +45 degree; and red is -45 degree. The software can also be set to match CATIA's standard color codes. (Note that this static screen shot displays only a portion of the laminate thickness that can be seen when actually using the software.)

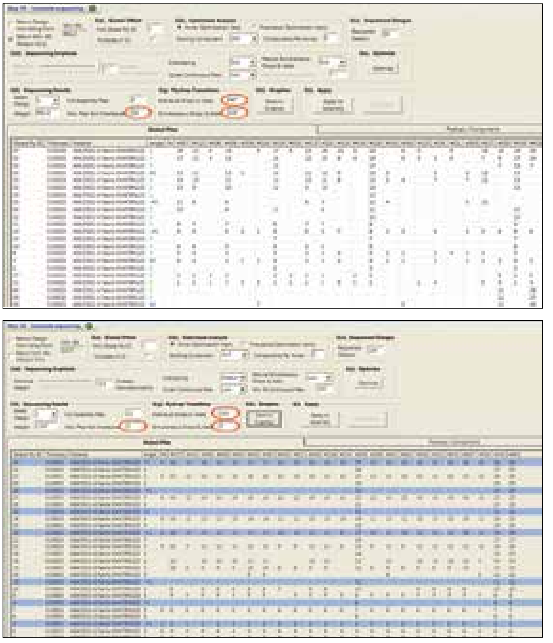

Figure 3: These screen shots illustrate laminate sequencing in a sample wind blade before (top) and after (bottom) HyperSizer optimizes for key manufacturability measures: the number of individual drops or adds in the design, which significantly contributes to engineering cost, was reduced from 467 to 145 (circled in red); the number of simultaneous drops and adds was cut from 105 to zero; and the maximum number of plies not interleaved was cut from 16 to two. (Note that this static screen shot displays only a portion of the laminate thickness that can be seen when actually using the software.)

they have always done. But as blade length increases, they must also take weight into account to maximize performance. And to compete more effectively with other turbine manufacturers as well as established energy technologies, they must keep manufacturing process efficiency and cost in mind. To balance these competing criteria during design development, engineers working with high-performance composites are faced with numerous decisions.

AEROSPACE-PROVEN OPTIMIZATION SOFTWARE

The aircraft and space industries have wrestled with the challenges of composite design for years. Out of those efforts at NASA came a structural sizing and optimization software package, which has been renamed HyperSizer and commercialized by Collier Research Corporation as part of the space-agency's technology transfer initiative.

HyperSizer evaluates complex composite and metallic designs and automatically searches for solutions that minimize weight while maximizing strength. Over the years, the software has been integral in the design and validation of high-profile, zero-failure space projects such as the NASA Ares I and V Launch Vehicles and the new Composite Crew Module. HyperSizer has also played a design role in commercial aircraft — such as Goodrich engine structures and Bombardier's LearJet — and with experimental test craft, like Steve Fossett's Virgin Atlantic GlobalFlyer (see Figure 1).

With mission-tested success in aerospace applications, HyperSizer's crossover to the wind industry is a natural, since the design challenges of working with composites are similar in both industries. Collier has recently begun collaborating with Sandia National Laboratories' Wind Energy Technology Department on the optimization of a new 13.2MW 100-meter blade to demonstrate the software's capabilities. This project, like other Sandia turbine prototype efforts, is conceived to develop innovative technology that seeds commercial R&D and stimulates manufacturing advances.

OPTIMIZING DESIGNS FOR MANUFACTURABILITY

On a wind blade design project of any scale, HyperSizer can be easily integrated with other widely used composite software design tools, including CAD programs (such as CATIA), composite design software (FiberSIM, for example), and a host of commercial finite element analysis codes (including Abaqus and Nastran).

A HyperSizer optimization starts with a baseline finite element model (FEM) and an FEA run to determine internal loads and deflections. The simulation results are imported into HyperSizer where the code conducts a trade study for a blade characteristic (such as laminate strength and stability), automatically surveying up to millions of design candidate constructions in a ply-by-ply, even finite-element-by-element process, to a multitude of failure criteria. From the many possible solutions, a design is then chosen and exported — along with its accompanying material properties — back into the FEA software where the model is rerun. This iterative loop, enabled by HyperFEA, is repeated as needed for additional characteristics, such as stiffness, until a final blade design is reached that meets a predetermined design target for strength, weight, performance, and cost. Because the optimization is automated, it eliminates costly, error-prone offline spreadsheets and manual calculations.

HyperSizer allows for an easy exchange of laminate specifications with FiberSIM and CATIA (see Figure 2). These software tools are good at modeling, displaying, and managing design data of complex composite parts, as well as automating manufacturing operations, such as cutting, fiber placement, and tape-laying.

But to address composite stack composition in a detailed enough way to truly influence weight savings and manufacturability, HyperSizer can be used to complement FiberSIM and CATIA's capabilities. It accomplishes this by providing detail on four diagnostic measures key to efficient composite manufacturing:

- The total number of plies dropped (the more ply drops you have, the more cutting, splicing, and lining up of plies are required on the shop floor)
- The simultaneous occurrence of ply drops and adds (which manufacturers try to avoid because it can introduce weakness in the stack)
- The alternation of ply drops with continuous plies, or interleaving (a feature that can also introduce weakness or a chance for defects)
- The number and pattern of laminate zones and transition boundaries (another factor contributing to manufacturing efficiency and cost)

As an illustration of the improvements that HyperSizer can make on these key manufacturability measures, consider the optimization of a sample wind blade design (see Figure 3). The total individual ply drops and adds

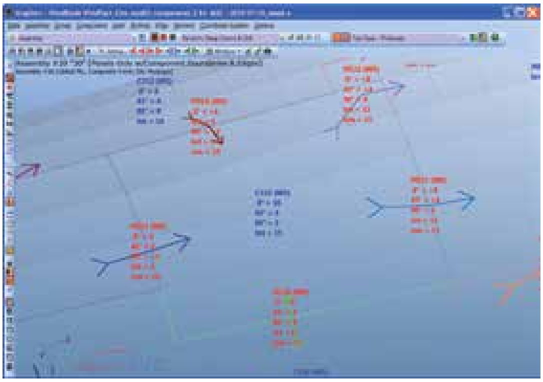

Figure 4: This screen shot illustrates the detailed composite characteristics that are optimized in HyperSizer. The blue numbers indicate the number of plies of varying fiber orientation (0, 45, and 90 degrees) within the stack. The red numbers indicate the ply drops across the zone transitions

for the design were reduced from 467 to 145 (69 percent). Simultaneous ply drops and adds were also dramatically reduced, from 105 to zero. In addition, the maximum number of ply drops not interleaved with continuous plies was reduced from 16 before the optimization (a construction described by engineers as equivalent to "falling off a cliff") to two after using HyperSizer. And finally, laminate zones, shapes, and transitions were improved, making fabrication operations such as cutting, layup, assembly, and finishing more efficient for both touch-labor and automated manufacturing processes (see Figure 4).

The HyperSizer-optimized blade design was also significantly lighter, while meeting all loading scenarios and industry lifetime standards. In various test case optimizations, blade weight has been reduced as much as 20 to 25 percent, a savings equivalent to averages seen over many years in aerospace industry projects.

IMPACTING THE FACTORY FLOOR, CHANGING THE ENERGY LANDSCAPE

Simplifying manufacturing processes for wind blades — or any composite structure, for that matter — provides huge competitive benefits. In the wind industry, the standard is 24-hour turnaround in the mold. If designs are optimized for manufacturability, operators are ensured of getting the part out of the mold on schedule (or even developing ways to shorten the process) and getting the next one in (see Figure 5). Improved manufacturability means fewer processing steps, less machine time, and reduced blade cost.

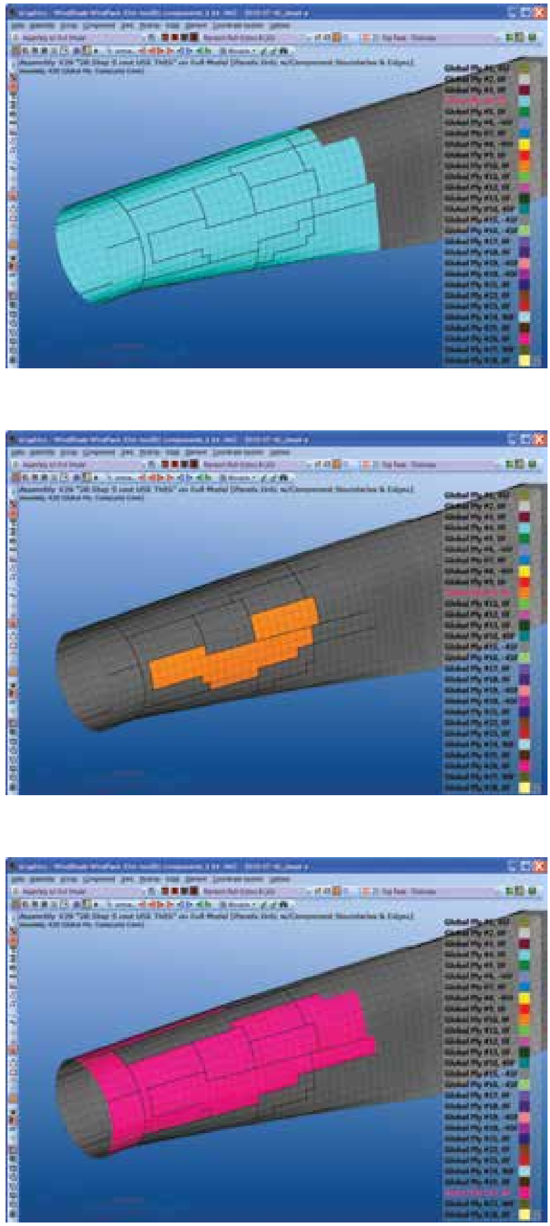

Figure 5: This series of three screen shots illustrate how HyperSizer guides a layup operator on the shop floor through ply sequencing during the manufacturing process.

The wind industry has made great strides over the last decade. Technology is improving at a rapid pace. Installed capacity is up. Prices are coming down. Optimizing composite designs has the potential to make additional significant contributions to wind's growth. The results can be seen in blades that are lighter and deliver higher performance. More efficient manufacturing will contribute less expensive blades that can be produced more quickly. Taken together, these factors could help trigger the tipping point for wind and alter our view of the energy future.