

Simulating Composite Structures



Composites pose different modeling challenges because of the nature of the material. With the right simulation tools, designers can predict performance, analyze reliability and potential failures, optimize construction, and export accurate information to manufacturing, all before a physical prototype is built.

The very nature of composite materials — multiple layers with significantly different physical or chemical qualities — makes them attractive for manufacturing because they are lightweight and high in strength. However, they also pose unique modeling challenges because of their different constituent materials and orientations. The good news is that you can overcome these challenges using the correct tools. Furthermore, composites are being used reliably to solve real-world industry problems, such as in aerospace and energy applications.

According to Lucintel, a leading global management and market research firm, the market for composites is expected to reach \$19 billion in 2011. The expanding availability of composite materials is leading to many innovative designs across multiple markets that require lightweight, high-performance materials, such as aerospace, defense, energy, sports, construction, marine, and automotive applications. However, when composites are used as an alternative to long-standing materials, such as metals, it is particularly challenging to determine their long-term reliability.

Design Challenges

The major advantages of composite materials include their ability to provide high performance, flexible shapes and low weight. This is particularly important for aircraft manufacturers, who are trying to provide new designs that are cost effective and use less fuel. A major way to achieve this is by reducing the overall weight of the aircraft. But the question is, how do you reduce weight and still maintain the structure's integrity? The problem is that, unlike with metals, there are no real-life, long-term data on how composites perform in aircraft. One way to determine integrity is to put composite parts through rigorous physical testing. Typically, designers use analytical tools to perform some minor pre-design analysis, which reveals how a simple composite shape (such as a cylinder or flat plate) performs. Then, they move directly to prototyping and physical testing. Using this method, the pre-design stage uses only a simple shape, rather than an accurate depiction of the final complex multi-layered shape, so any data is a rough estimate. You can improve the time, cost and accuracy of this type of design process by using a robust composite simulation system before prototyping.

You can improve the time, cost and accuracy of a design process that relies on rigorous physical testing by using a robust composite simulation system before prototyping.

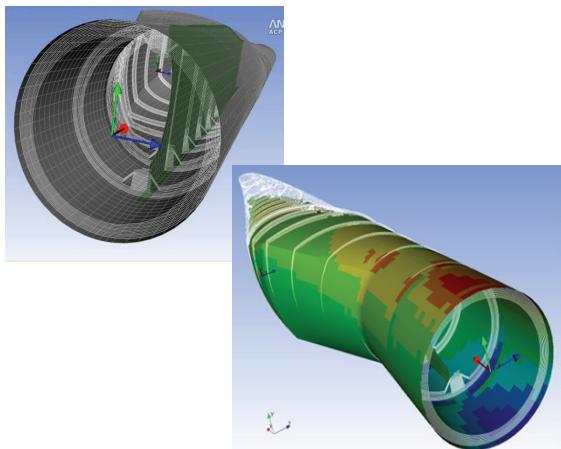


The most effective way forward, then, is to combine physical testing with significantly more pre-design simulation. This process is already well under way at numerous manufacturers that use ANSYS® Composite PrepPost software in their early design stages. Currently, many aircraft manufacturers are in the process of validating their composite models. This provides them with a simulation methodology that allows them to work on future designs and use even less physical testing. By taking advantage of robust simulation models, manufacturers can significantly reduce the costs of prototyping with expensive composite materials.



The challenge of simulating a composite material is to achieve an accurate depiction of its formulation. Unlike a conventional material, such as steel, a composite is a mix of fibrous materials of different thicknesses that are layered to make a single material. The fiber orientation in each layer (the direction of the main fiber) differs in terms of angles, thickness, and material from the layer above and below it. When performing a composite material simulation, it is necessary to accurately capture and define all of these components. A single model, then, could require dozens, hundreds, or even thousands of layers or plies.

Investigating failures is also different for composites compared to conventional materials. In a composite, designers analyze local failures to define which ply, out of dozens of plies, is failing and specifically where it is failing. Analysis also considers that although one ply may fail, the structure may still be robust enough to continue in service. The goal of failure investigation is to discover the point at which the structure can no longer maintain its integrity. A good simulation tool reveals which ply will fail under specific circumstances.

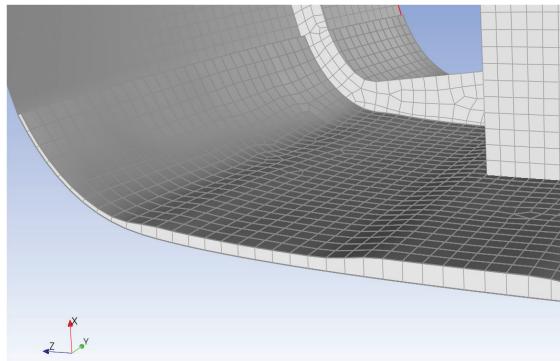


Laminate definition for a wind turbine blade and associated failure estimates

Composites in Action: Wind Turbines

Fiber-reinforced composites are regularly used in the manufacture of rotor blades for wind turbines, and the development of new, increasingly larger rotor blades with more complex structures requires the use of clear and easy-to-handle simulation programs. Rotor blades are particularly challenging to design because they require an aerodynamic free-form geometry that is manufactured using a complex laminate structure with a large number of layers and selectable fiber orientation. To accurately simulate a rotor for a wind turbine, it is necessary to define material characteristics, fiber orientations, and layer construction and then analyze the results. By using the draping tools in ANSYS Composite PrepPost, it is also possible to assess the constructability of a design, enabling the designer to incorporate production process parameters into the simulation. In post-processing, the same software can be used to perform a layer-by-layer analysis with stability calculations, taking into account all conventional failure criteria.

"The intuitive implementation of composite design development in ANSYS Composite PrepPost brought on a revolution in composite simulations. By means of the simple and quick operation, real-time results to complex problems can be generated. Consequently, we are able to achieve a continuous design process from the calculation model to the drawing on the shop floor, in which the changes in the design can be implemented without errors," said Hendrik Mester, Rotor Blade Development, REpower Systems AG (wind turbines). In addition to time savings and faster modeling, REpower Systems noted that the use of Composite PrepPost led to optimized material consumption and cost savings.



Thick cores can be defined by importing a CAD geometry model.

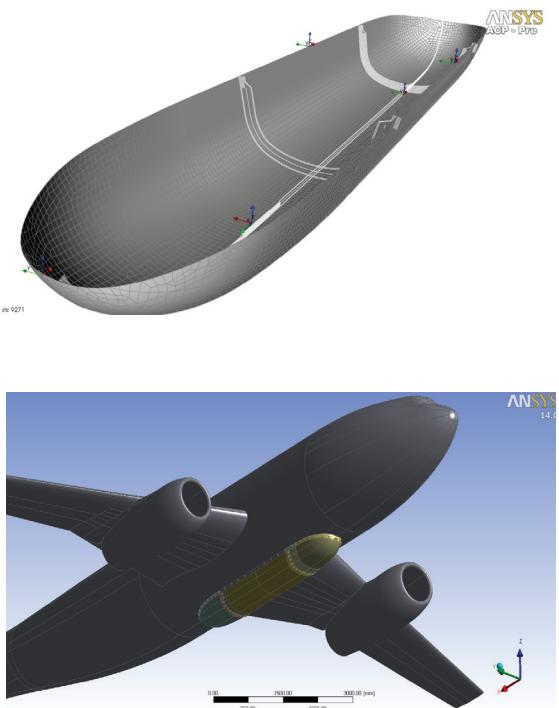
Specifically, during development, rotor blade designers can define the laminate structure of the blades by using modeling ply files, which consist of individual fabrics, stacks, or sublaminates. PrepPost's material database allows designers to save and make changes to the data outside of the calculation model, enabling the material's data to be imported and exported from the database for use in future designs. A user can specify the orientation of each ply, including the overlap amount and fiber direction. Parametric and network-independent modeling enables efficient optimization of design materials. The software also allows designers to create and modify volume models. These 3-D models can be created rapidly using the extrusion function and guide geometry. Core thicknesses can be specified by importing CAD geometries into the software.

After the calculation, the modeling ply files or the individual layers can be dissolved into single analysis layers. When the design is complete, the software enables post-processing analysis, where the integrity of the material can be tested both globally and layer by layer. In ANSYS Composite PrepPost, the specified failure mode, the failing individual layer and the associated load case can all be presented simultaneously in a single contour plot for complete analysis.

Composites in Action: Aerospace

Today's aerospace designers are looking to decrease weight and cost while retaining high reliability performance. One segment of that industry is aerostructures, which includes structures, doors, fuselage, nacelles/pylons, stabilizers, windows and wings. In the aerostructures market, the use of composites is the fastest-growing sector — 12.7 percent CAGR for 2009 to 2019 per Counterpoint Market Intelligence Ltd — compared to the use of traditional materials such as titanium and other metal structures. For many designers, the potential for using composites is great for any structure that is not impact-bearing (such as landing gear or the lower frame). All of the other structures in the aircraft, including beams, shelves and skin, can be made of composite panels. As an example, the recent Boeing 787 design is constructed of more than 50 percent composite materials.

Designing an aircraft using composite materials solves several problems. For instance, it helps reduce the overall weight and enables unique shapes that would be much harder to create with metals. As a result, designers can improve the aerodynamics of the aircraft as well. For example, in the design of the new 787, Boeing created a new type of wing shape using composites. Looking to the future, aerospace designers are working on multi-functional composites, which will serve more than one function on the aircraft and streamline the design process.



ANSYS Workbench™ empowers multiphysics solutions with aeroloads calculated from CFD analysis mapped onto a composite radome structure, shown beneath the aircraft body.

One of the challenges in using composites in aircraft is thermal management. Since composites do not conduct away heat as metals do, designers need to find different ways to dissipate it. As a result of the rise of the use of composites, thermal management is now as important a problem for new airplanes as aerodynamics. For example, if a plane lands in the Middle East or flies in sub-zero temperatures over the North Pole, there are significant thermal impacts. In addition, designers need to consider electrical dissipation in the event an aircraft is struck by lightning, or how to ground the aircraft during fueling. The composites used must deal with a surge in voltage. One way to address this is embedding a wire mesh, but this is not optimal. With a robust simulation package that has multiphysics capabilities, such as the ANSYS coupled-field analysis capabilities combined with Composite PrepPost, designers can perform electrical and thermal modeling on the complex composite shapes used in the aircraft design and pursue creative solutions to thermal challenges.

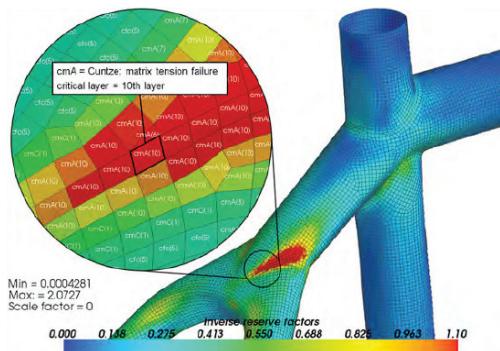
As with the wind turbine application, aerospace designs need to have a thorough understanding of what is occurring with an individual ply. They need to know where the composite is going to fail, answering questions such as: Which ply will fail first and why? Once one ply starts to fail, will the others follow? At what point will the product be nonfunctional?

One likely cause of failure in aerospace applications is an impact to the outer skin of the aircraft, such as hail and bird strike. These occur at different angles. The simulation software must be robust enough to determine how the composite responds to each type of impact. Finally, designers must determine crash-worthiness, projecting what type of impact an aircraft could survive. One of the major challenges with a composite is that the failure may not be evident to the human eye; it may be internal to the ply. Designers need a software with good fatigue and failure models as well as explicit tools for impact analysis.

With Composite PrepPost, designers use an explicit solver, a tool that is specifically designed for this kind of application. In contrast, designers typically use an implicit solver when looking at impacts, which renders only a slow impact. An explicit solver can render high-impact, rapid crash simulations. For instance, the software includes a model of a bird that can be used to impact the wing or fuselage to determine the effect on different types of composites.

For confident analysis of composites in aerospace applications, designers need a broad-based simulation platform that includes thermal and electrical aspect modeling as well as explicit solver tools. The software platform also has to allow designers to use these tools in a practical manner.

Courtesy Technische Universität Chemnitz and GHOST Bikes GmbH.



Identification of failure modes and their exact ply locations on a bike frame

Selecting a Modeling Tool

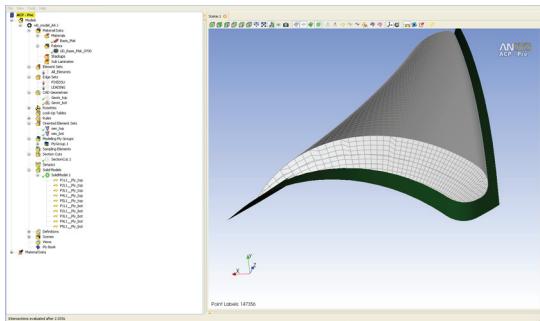
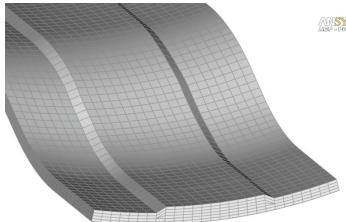
Selecting an appropriate simulation tool for composite design can dramatically increase success, reduce physical prototyping and improve product performance. Designers looking for a simulation tool should assess the tool's ability to do the following:

- Identify various failure modes, including failure within a layer (damage or complete failure in fibers and/or matrix material); failure between layers (delamination) induced by transverse shears and tension addressed by inter-laminar shear stress output; fiber debonding (separation of fiber and matrix); and crack characterization
- Define composite layers: using fabrics, stack-ups, and sublaminates
- Define material reference directions in curved structures: predicting draping, fiber angle, correction and generating flat wraps
- Identify critical parts: highlighting failure mode, failed layer and critical load step
- Perform accurate stress failure evaluation: offering three dimensional stress failure evaluation
- Work with existing simulation tools: part of a suite of solver and simulation solutions, including import and export capabilities as well as physics and thermal analysis

Answering the Challenges

An add-on module to existing ANSYS structural solver licenses (ANSYS Professional and above), ANSYS Composite PrepPost is dedicated to the modeling of layered composite structures. Part of ANSYS Workbench, Composite PrepPost offers direct import of ply specifications from ANSYS and Vistagy's FiberSIM®, enabling consistent part definitions that can be released to manufacturing and certification bodies.

With ANSYS Composite PrepPost, composite layers can be defined using multiple-oriented element sets that can overlap or have different orientations, allowing for asymmetric laminate definition. Sometimes, asymmetric laminate definitions are required, for example in the case of a T-shaped structure. In this case, multiple-oriented element sets can be overlapping and oriented differently to enable a unique asymmetric laminate definition.



3-D modeling of composites using extrusion techniques and fitting to CAD models

Using efficient selection rules, designers can reselect the group of elements for which physical plies are applied, and they can perform composite layup definitions using cut-off rules and CAD data. Designers can perform simple weight and cost estimations. In addition, they can identify various failure modes using simple to state-of-the-art failure criteria, including the use of cohesive zone models and conducting crack characterizations according to the virtual crack closure technique (VCCT). ANSYS Composite PrepPost supports all common failure criteria for ply and core in any combination (from simple stress analysis to advanced failure criteria such as Hashin or Puck). Results can be expressed as global results, allowing designers to identify critical areas. Or, detailed ply- and layer-wise results can identify the exact failure model as well as the exact location in the model.

Finally, designers can quickly generate a complex-shaped 3-D model of the composite design using the capability to extrude a mesh and fit it to an imported CAD model. The software can generate multiple CAD formats that are transferred to manufacturing facilities for use on fabric-cutting machines, for example. As designers take on composite simulation across a broad range of applications, those using Composite PrepPost can be confident that what is manufactured is what was designed and analyzed.

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