# Simulating Composite Structures

Composites provide new solutions for manufacturers looking for stronger, lighter and more cost-effective materials. At the same time, they pose new modeling and manufacturing challenges because of the nature of the materials. With the right simulation tools, designers can account for residual stresses, predict performance, analyze reliability and potential failures, optimize construction, and export accurate information to manufacturing, all before a physical prototype is built.

Increasingly, manufacturers are using composites to reliably solve real-world industry problems. 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. 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. According to the market research company MarketsandMarkets, the market for composites is expected to grow from $70 billion to $105 billion by 2021.

However, composites also pose unique modeling and manufacturing challenges because of their different constituent materials and orientations. When composites are used as an alternative to long-standing materials, such as metals, it is particularly challenging to determine their long-term reliability. The good news is that you can overcome these challenges using the correct tools.

**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 key method for achieving this is to reduce the overall weight of the aircraft. But reducing the weight while still maintaining the structure's integrity is a major challenge. The problem is that — unlike 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 that 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 approach, the pre-design stage uses only a simple shape rather than an accurate depiction of the final complex multilayered 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.

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 are using the ANSYS Composite PrepPost module of ANSYS Mechanical Enterprise for the pre- and post-processing of composites in their early design stages. Many aircraft manufacturers are continually expanding their analysis capabilities and are successfully 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.

In addition to structural analyses, simulating the curing processes can predict process-induced distortion. During cool-down and removal from the tool, curved composite laminates distort as a result of mismatch between the through-thickness and the in-plane thermal expansion coefficients as well as complex cure shrinkage mechanisms. Distorted components may cause problems during the assembly, significantly increasing overall product cost as well as its in-service performance. The platform of the ANSYS Composite Cure Simulation (ACCS) module has been used in many applications to compensate process-induced distortion to meet geometrical tolerances and increase the final product performance.

**Composites in Action: Wind Turbines**
Fiber-reinforced composites are used in the manufacture of rotor blades for wind turbines. 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 several hundreds of layers and selectable fiber orientation. To accurately simulate a rotor blade for a wind turbine, it is necessary to define material characteristics,

Courtesy of LMAT Ltd., UK
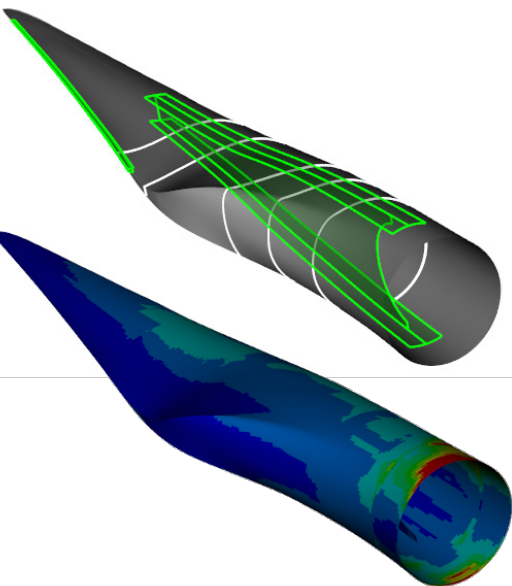
fiber orientations and layer construction, and then analyze the results. By using the draping tools in Composite PrepPost, it is also possible to assess the constructability of a design, enabling the designer to incorporate production process parameters into the simulation. In post-processing, the same software can be used to perform a layer-by-layer analysis with stability calculations, taking into account all conventional failure criteria for fiber-reinforced materials and sandwich structures.

Specifically, during development, rotor blade designers can easily define the laminate structure of the blades by using tabular modeling ply files, which consist of the lay-up definition of individual fabrics, stacks or sub-laminates. The material database enables 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. Designers can specify the orientation of each ply, including the overlap amount and fiber direction. Parametric and network-independent modeling enables designers to efficiently optimize design materials; they can model plies with variable thickness and complex shaped boundaries by using the CAD interfaces of Composite PrepPost. This enables designers to model the laminate more precisely and independently of the finite element mesh.

Out-of-plane stresses become important in thick laminates and assemblies with out-of-plane load effects (such as a T-joint). The software also allows designers to create and modify volume models to fully capture 3-D stress states. These 3-D models can be created rapidly using the extrusion function of Composite PrepPost and advanced CAD features such as extrusion guides, snap-tos and cut-offs. The composite workflows in ANSYS Workbench supports the assembly of shell and solid element composite structures. This even works with isotropic parts and you can seamlessly switch between shell and solid models.

After the calculation, the modeling plies 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 on a layer by layer basis. In 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 a 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 Compound Annual Growth Rate (CAGR) for 2009 to 2019, according to Counterpoint Market Intelligence Ltd. — compared to the use of traditional materials such as titanium and other metal structures. For many designers, the potential
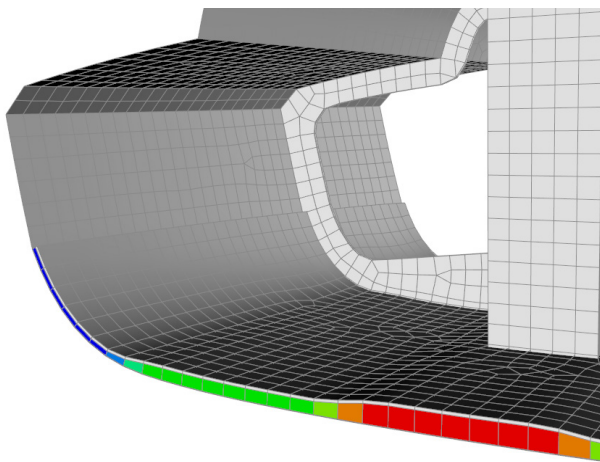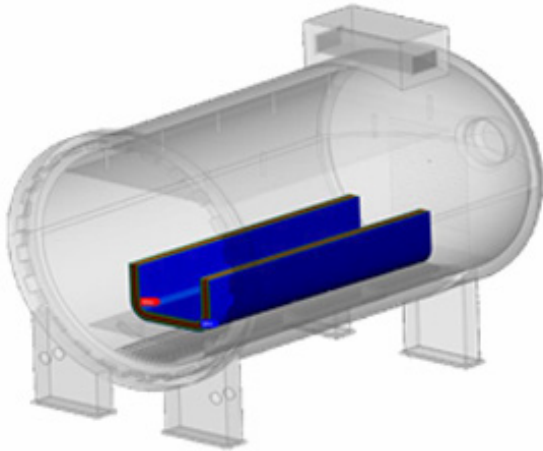
for using composites is great for any structure that is not impact-bearing (such as landing gear or the lower frame). All of the other structures in the aircraft, including beams, shelves and skin, can be made of composite panels. As an example, the recent Boeing 787 design is constructed of more than 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 that will serve more than one function on the aircraft and streamline the design process.

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 the heat. 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, between landing in a desert region and flying at high altitude, an airplane experiences significant environmental temperature changes. 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 an optimal solution. 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?
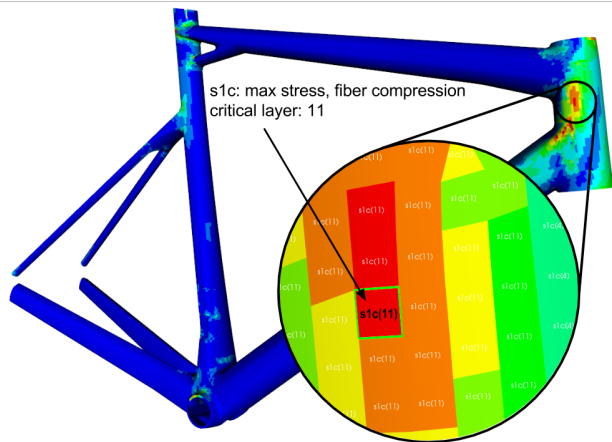
One likely cause of failure in aerospace applications is an impact to the outer skin of the aircraft, such as hail or bird strike. These occur at different angles. The simulation software must be robust enough to determine how the composite responds to each type of impact. Finally, designers must determine crashworthiness, 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. ANSYS Workbench supports both implicit and explicit solvers for composites. An explicit solver can render high-impact, rapid crash simulations. For instance, the software includes

s1c: max stress, fiber compression
critical layer: 11

Courtesy of BMC Switzerland

a model of a bird that can be used to impact the wing or fuselage to determine the effect on different types of composites. In contrast, designers typically use an implicit solver when looking at impacts, which renders only a slow impact.

All structures of an aircraft have to be manufactured in tight geometrical and structural tolerances to meet the strict aerospace assembly rules. Hence, the prediction of process-induced deformations and residual stresses is important. The ANSYS Composite Cure Simulation (ACCS) module allows to simulate curing processes between a few minutes and 48 hours and, as a final step, the predicted distortion can be used to compensate the tooling surfaces upfront. Thus, designers can let the parts distort into the desired shape. This saves costly re-machining of the toolings and increases the product consistency. The platform of ACCS is successfully used to design rib, spar and wing-skin tools across the European aerospace industry.

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

**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 that use fabrics, stack-ups, and sub-laminates.

• 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 as part of a suite of solver and simulation solutions, including import and export capabilities as well as physics and thermal analysis.

• Interface with third party applications to exchange laminate definitions and further processing.
• Consider variable material data and be able to define material fields to consider degradation, shear dependency, etc.

• Model composite assembly and submodeling. Combine isotropic and composite parts and switch seamless between shell and solid models.

• Predict the development of residual stresses and process-induced distortion that occur in curing processes.

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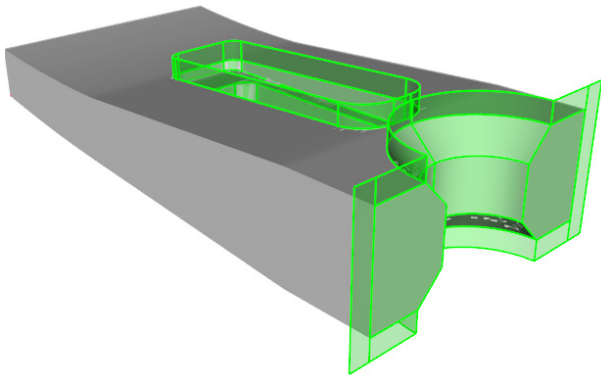
With Composite PrepPost, composite layers can be defined using multiple oriented element sets that can overlap or have different orientations, allowing for asymmetric laminate definition. Sometimes, asymmetric laminate definitions are required, for example in the case of a T-shaped structure. In this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

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).
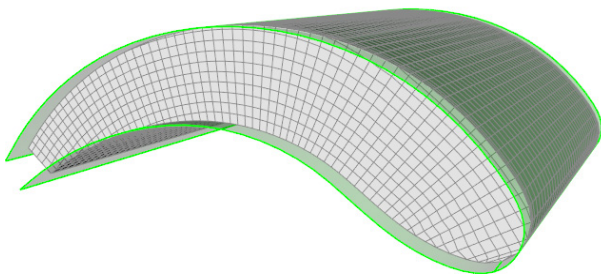
Composite PrepPost supports all common failure criteria for ply and core in any combination (from simple stress analysis to advanced failure criteria such as Hashin or Puck). Results can be expressed as global results, allowing designers to identify critical areas quickly. Or, detailed ply- and layer-wise results can reveal the exact failure model as well as the exact location in the model.

Composite PrepPost supports the most common formats for exchanging laminate definitions, such as Excel and Composite CAE H5. It 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. Additionally, interfaces to CAD (STP and IGS) and BECAS open a wide range to further analyze composites in terms of pre- and post-processing as well as manufacturing. And, most of the interfaces are bidirectional so users can readily update models to reflect changes made in CAD!

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.

The composite workflows in ANSYS Workbench supports seamless modeling. Configuring assemblies of isotropic and mixed composites is supported as well as submodeling for detailed analysis. Variable material data can be easily defined and are consumed by downstream analyses.

ACCS is fully integrated into ANSYS Workbench and supports the current composite workflows. As an add-on module to ANSYS Mechanical Enterprise, ACCS is dedicated to simulating curing processes of composite structures. The simulation of curing and the development of stresses allows you to design toolings without trial-and-error methods and to build in tighter tolerances. Finally, designers can avoid costly modifications of the toolings and can increase their product's performance.

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