MSC.Patran and FiberSIM: An Integrated Solution for the Engineering of Composite Parts

Olivier Guillermín

VISTAGY, Inc.
486 Totten Pond Road
Waltham, MA 02451
(781) 290 0506
olivier@vistagy.com

ABSTRACT

Designing with composites is inherently peculiar and becomes very complicated when a part is made of hundreds of individual plies of various materials, each having a different shape, fiber orientation, and location. In most cases, the final design of a part contains details and modifications that create significant differences between the CAD model for design and the CAE model for analysis of the part. In addition, both models may be quite different from the actual manufactured prototype. Noticeable changes in fiber orientation can occur during manual lay-up, inducing wrinkling and large thickness changes. Ply drop-offs and staggers may change the laminate symmetry and balance. Darting and splicing of the plies may have to be performed on the shop floor to accommodate draping problems.

This paper describes how the combination of FiberSIM and MSC.Patran Laminate Modeler software provides an integrated solution for composite engineering. With these tools, complete and detailed information of the part in its to-be-manufactured state can be stored in the CAD and CAE models at any time during the design and analysis process. Therefore it becomes quick and easy to verify that the actual part will meet the design performance specifications. And for the first time, appropriate CAD-to-CAE and CAD-to-CAM links make it possible to access the exact same information contained in the master model of the composite part.

Practical case studies from the aerospace industry highlight how composite engineering is improved, and risks, costs, and development cycle times are reduced through the use of these new simulation-driven tools.
INTRODUCTION

Today’s advanced continuous fiber composite materials offer dramatic opportunities for producing lightweight laminates with tremendous performance capabilities. However, the high cost and complexity of designing and manufacturing composites have largely offset the benefits of using these materials (figure 1).

To unlock the full potential of lightweight laminates, the FiberSIM and MSC.Patran Laminate Modeler software have been developed and integrated to provide a high-performance composite engineering environment for designing and manufacturing composite parts.

By shortening the entire product development cycle time, these applications allow designers and engineers to undertake many more iterations in order to optimize a part and verify its structural integrity (figure 2).

PRELIMINARY DESIGN AND ANALYSIS

Structural Requirements

Preliminary structural analysis (or sizing) provides the percentages or proportions of the various fibers and reinforcements that make the composite part sustain its design loads. In general, especially in aerospace engineering, the sizing process results in a description of the part surface in terms of a connected quilt of “zones” (figure 3), each zone being associated a target laminate such as 10% of 0 degree fibers, 30% of +45 degree fibers, etc. MSC.Patran Laminate Modeler and FiberSIM have integrated this step by allowing analysts to transfer the structural requirements directly from Laminate Modeler to FiberSIM in the form of zones with associated target laminates. From this data, a FiberSIM functionality exists that can automatically define and create the plies corresponding to the zones and target laminate requirements. Such a design automation tool dramatically speeds up the preliminary design and analysis process.

Draping Models

Since the early work of mathematician Chebyshev on the draping of woven fabric, the mapping of flat pieces of fabric to three-dimensional surfaces has been the subject of many research experiments and simulations [1,2]. Over the last twenty years, the draping of fiber-reinforced composite sheets has generated numerous research works, including Robertson et al. [3,4], Van der Weeen [5], Smiley and Pipes [6], Van West et al. [7], Heisey and Haller [8], Gutowski et al. [9], Tam [10], and Gefin et al. [11].

State-of-the-art draping models assume a geometric mechanism to transform an initial unit square of fabric into the corresponding draped shape (figure 4). The algorithms rely on the CAD system for the necessary geometry data. They are not computationally intensive and can provide a quick answer. Assumptions commonly made in current draping models include:

- The yarns are inextensible in the fiber direction,
• Tool-ply and ply-ply friction is neglected,
• Crossover points of warp and weft yarns act as pivoting joints for woven fabric, or the transverse spacing between fibers is constant for unidirectional materials,
• The composite ply maps perfectly onto the tool surface without discontinuities,
• The manufacturing process (hand lay-up, fiber placement, tape laying) defines how the composite sheet is laid up onto the tool surface.

In the last five years, draping simulation has been integrated in major CAD systems used in production worldwide [12,13,14,15].

Producibility and Flattening

In composites design, a draping simulation is used to generate fiber paths, identify areas of wrinkling and bridging, develop flat patterns, and allow the prediction of accurate local laminate mechanical properties such as stiffness, permeability, volume fraction, and thickness. The simulation guides the lay-up process, ensure repeatability and minimize material waste (figures 5 and 6). In woven fabrics, drapability is facilitated by the fabric ability to undergo large in-plane shear deformations due to a trellising action of warp and weft yarns. In unidirectional fabrics, fibers slide relative to one another for in-plane shear to occur, and it is generally assumed that the distance between the fibers remains constant whereas the fibers of the woven fabric come closer to each other under shearing. On compound curved surfaces, fiber paths depend on the fabric deformations and on the lay-up process. The ability to predict fiber paths using the appropriate mapping model has important practical applications:

• Knowledge of fiber paths and shear deformations allows prediction of wrinkling and bridging in the fabric and indicates locations for the cutting of relief darts (figure 7),
• Exact fabric flat patterns can be developed from the simulation (figure 8),
• The simulation can help define the best lay-up start point and keep track of this information to assure repeatability of draping,
• A number of secondary physical properties can be determined for the simulation: ply thickness, fiber volume fraction, outside mold definition, mass properties,
• The simulation can be used as a design tool for optimizing a draping in terms of minimized total fabric shear deformation or specified fiber orientations at points on the surface, or for positioning unavoidable darts and splices at uncritical areas of the part.

Laminate and Ply Analysis

Composite design involves the bringing together of a large number of individual components (plies, cores) to satisfy various requirements (fiber orientations, thickness, stack-up, etc.) that change over the surface of the part. It is therefore necessary to be able to check the arrangement of critical areas of the part, to ensure that all design requirements are being met. A core sample is the term used to denote the design evaluation at given points of the laminate. A core sample "pierces" the laminate at the given points and provides information about the laminate design at those points. Core sample results may include information such as target and actual thickness and fiber orientations, orientation percentages, and ply counts. It is well known that laminates can be classified, based on their stacking sequence, into categories including symmetric and/or
balanced laminates. Symmetry and balance have become key criteria in evaluating complex composite parts where coupling effects between in-plane and out-of-plane deformations may induce undesired warping or in-plane shearing of the part. By using the core sample, one can locally analyze the laminate stack-up and compare the targeted and the actual behavior of the laminate.

DETAILED DESIGN AND ANALYSIS

Finite Element Analysis

Throughout the engineering of a part, analysis and design must rely on the same master CAD model. This ensures that accurate analysis properties are extracted because they are generated from the same CAD model that is used for design. Hence, the CAD part surfaces, 3D ply boundaries, and ply stack-up must be used to compute true fiber orientations for structural analysis (figure 9). It is also important that property mapping from the CAD model to the FEA model be elaborate enough so that laminate definitions are independent from the finite element mesh (figure 10). This enables the analysis model to be modified and optimized without re-specifying plies. This encourages use of composite design and analysis products early and often in the design process, supporting an efficient engineering methodology [16,17,18,19] (figures 11 and 12).

Detailed Design

Two basic types of wrinkling that can occur during the lay-up process. The first type is called out-of-plane wrinkling, or puckering. This type of wrinkling is common in apparel. Out-of-plane wrinkling is caused by an excess of material in a given region of the surface. The second type of wrinkling is called in-plane wrinkling, or bridging. In-plane bridging is caused by a lack of material in a given region. The material, not physically able to drape over the entire surface, spans or bridges regions of the surface. Splicing the ply into two or more pieces helps alleviate wrinkling. Splicing eliminates wrinkling by reducing the overall surface a single ply has to drape. Splicing must take into consideration the dimensions of the flat pattern and the bolt width of the material to minimize the number of splices (figure 13). Darting techniques attempt to eliminate wrinkling without dividing the ply into smaller pieces. Darting usually cut the fibers that initiate the wrinkling and prevent them from propagating the wrinkling outward in the ply. Darting techniques cannot be used in case of bridging because they would generate an invalid flat pattern that overlaps onto itself.

A laminate is ready for manufacture only after all staggers and drop-offs have been defined. Series of plies with similar boundaries usually have to be applied a curve offset or ply drop-off transformation in order to differentiate the ply. The most common cases are when a pad-up or a zone-to-zone transition creates an abrupt change of thickness or laminate profile that needs to be smoothed. Automatic generation of staggers and drop-offs is used to efficiently reduce the time spent in detailed ply definition [20] (figure 14).
MANUFACTURING APPLICATIONS

Documentation

For composite parts, a difficult task facing the engineer is creating accurate design documentation. With composite engineering software, once the information has been entered into a model, the engineer can use electronic documentation products to automatically generate engineering drawings (figures 15 and 16), material tables, sequence charts, ply lay-up diagrams, arrow text, laminate thickness and ply counts, draped and schematic cross-sections.

Hand Lay-up

Flat pattern export applications automatically generate a flat pattern data file for export from the CAD workstation to the nesting software and cutting system. Working directly from the CAD system, flat pattern export maintains file integrity and eliminates the need for manual manipulation of drawings and attributes in the transfer. Engineering changes are communicated quickly and correctly to the manufacturing floor through this automated process.

Laser projection systems can reduce errors and shorten the lay-up time for composite parts by displaying ply outlines directly on the lay-up tool. These outlines aid in the location and orientation of plies during the lay-up process. With a laser projection interface application, users can generate laser data files from within their CAD system directly from the 3D model of the composite part. Laser projection interfaces use the CAD model of the composite part to generate the laser projection data and calibration files, including ply names and sequences. As the lay-up of a composite part progresses, the accumulation of plies offsets the surface on which the laser is projected. This results in considerable parallax error in the projected profile, especially in thick or highly contoured parts. A laser projection interface will automatically account for material thickness and offset due to ply build-up when generating the laser projection data. In addition, using the CAD model of the tool surface, the laser projection interface may provide additional data that will aid the programming of multi-head systems for very large or highly contoured parts, where a single projection head may not meet the requirements.

Fiber and Tow Placement

Fiber and tow placement machines combine the advantages of filament winding, contour tape laying, and computer control to automate the production of complex composite parts that conventionally require extensive hand lay-up. Using fiber and tow placement machines can reduce costs, cycle times, structural weight, and handwork/ rework when manufacturing composite parts, but creating data files to simulate the process and then drive the machines is time consuming and error-prone. With a fiber/tow placement interface application, engineers generate fiber placement data files directly from the CAD model, and can also visualize back in the CAD system the results of the process simulation.
CONCLUSION

At a time when emphasis is placed on reducing risks, lowering costs and increasing production rates, much benefit can be drawn from the use of software tools for conceptual design of composite structures.

Using an advanced feature-based composite engineering CAD environment allows companies to proceed to the manufacturing stage with greater confidence that parts have been properly designed. It also eliminates the practice of part over-design that so often defeats the original purpose of using composites in the first place and sometimes leads to failure.

New software applications provide critical aids for composite engineering by capturing the part specifications and detailed design, automating the creation and modification of the part models, managing the complex set of composite data associated to the part, sharing this information across the appropriate company entities for design, analysis, and manufacturing.

REFERENCES

Figure 1  Typical ply lay-up of an aircraft composite wing skin.

Figure 2  The composite engineering process.
Figure 3  Design zones derived from structural requirements.

Figure 4  Draping simulation models using the kinematics approach.
Figure 5 Draping simulation for a belly fairing.

Figure 6 Draping simulation for a bulkhead.
Figure 7  Wheelcover ply before and after darting.

Figure 8  Flat pattern with darts.
Figure 9  FiberSIM ply on helicopter canopy.

Figure 10  Laminate Modeler ply with true fiber orientations.
Figure 11  Curing analysis with true fiber orientations.

Figure 12  Draping simulation and analysis of a spinner.
Figure 13  Ply splicing according to material width.

Figure 14  Generation of drop-offs (top). Typical drop-off section profiles (bottom).
Figure 15  Mold tooling for actual composite canopy.

Figure 16  Engineering drawing for canopy.