FIBERSIM: ADVANCED CAD SOFTWARE FOR COMPOSITE ENGINEERING, FROM RACING TO PRODUCTION

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Abstract

The principal challenge in applying composite materials to automotive vehicles is to provide structural performance that allows for significant weight reductions over conventional materials such as steel. However, the automotive market is quite different from the proven aerospace composite arena. Aircraft parts are typically produced in low volumes with few requiring very complex surface shaping. The automotive industry, by contrast, produces a variety of products comprising hundreds of basic structural forms. Dramatic changes in fiber orientation can occur, inducing large thickness changes, loss of laminate stack-up symmetry and balance. All of these issues can have a considerable effect on the behavior of the final part.

This paper describes how the FiberSIM suite of software tools supports the entire composite engineering process by using a unique material simulation technology that predicts how composite material conform to complex surfaces. Engineers can quickly visualize ply shapes and fiber orientations, and identify manufacturing problems during the design phase. Designers can also create and automatically update drawings and related manufacturing data directly from the master CAD model, thus reducing opportunities for errors and delays on the manufacturing floor.

Practical case studies from automotive highlight how composite engineering can be improved and risk can be reduced by the use of these new integrated 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.

To unlock the full potential of lightweight laminates, new software applications have been developed that transform general CAD systems into a high-performance composite engineering environment for designing and manufacturing composite parts.

By shortening the entire design and analysis cycle time, these applications allow designers and engineers to undertake many more iterations in order to optimize a part and verify its structural integrity. In particular, state-of-the-art composite engineering software provides a link between the CAD system and analysis software. Hence, designers and analysts can share the same master model part definition that resides in the CAD system, complete with all details of the part in its to-be-manufactured state.

Based on existing engineering applications, evidence of the benefits that can be drawn from the use of these new applications is demonstrated.

Design Applications

Producibility and Flattening

Two different approaches are currently used in the simulation of the behavior of laminated composites. The first approach, generally referred to as mapping, relies on the kinematics of fabric deformation and has been the subject of constant research for over a century, especially in the textile industry [1,2]. The second approach is based on the use of laminated plate theories and the application of the finite element method to multilayered shell and membrane structures [3]. Designers and design engineers preferably rely on the first one to incorporate simulation driven decisions in the design process. Analysts will typically use the second approach to produce complex mechanical simulations of the composite part (see section below on finite element analysis).

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 research experiments and simulations. Over the last twenty years, the draping of fiber-reinforced composite sheets has generated numerous research works, including Robertson et al. [4,5], Van der Weeen [6], Smiley and Pipes [7], Van West et al. [8], Heisey and Haller [9], Gutowski et al. [10], Tam [11], and Gelin et al. [12].

State-of-the art draping models assume a geometric mechanism to transform an initial unit square of fabric into the corresponding draped shape. 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 [13,14,15,16] (figure 1).

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 (figure 2). The simulation guides the lay-up process, ensures repeatability and minimizes material waste. 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 (figure 3). The ability to predict fiber paths using the appropriate mapping model has important practical applications (figure 4). 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. Exact fabric flat patterns can be developed from the simulation. 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.

Finite Element Analysis

Throughout the engineering of a part (figure 5), 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. 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 [17]. 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.

Feature-based Model

A typical part is made of tens or hundreds of individual plies of various materials, each having a unique shape, orientation and location (figure 6). Each individual ply is likely to have more information than an entire sheet metal part. Therefore, it becomes imperative to use a hierarchical CAD model to maintain a complete and detailed description of the final part design and allow changes to propagate throughout the model.

State-of-the-art composite engineering software provides high level composite features in the CAD system, allowing the engineer to efficiently manage the large amount of data generated during laminate design [18]. The engineer works with familiar composite features including zones, laminates, plies, cores, and rosettes. The engineer can also manage the non-geometric attributes for these composite features, such as part number, material specification, and ply or fiber orientation. Composite engineering software also maintains associativity between features. The part boundary, material, ply boundary, or the lay-up skin related items such as flat patterns are easily updated when changes are made to the part. As the design progresses, the actual laminate can be analyzed and the number of plies, thickness, materials, and true fiber orientations can be verified.

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 is not physically able to drape over the entire surface and 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. 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.

MANUFACTURING APPLICATIONS

Surface Offset and Solid Generation

Because of the complex laminated structure of a composite part, the thickness of the final solid resulting from the lay-up varies throughout the part. Thus, even a part created on a very simple and smooth tool-surface can produce a final volume with complex geometry when all the details of laminate thickness changes, cores and inserts, ply boundaries, holes, drop-offs and staggers are taken into account (figure 7). It is very difficult to adequately model this solid in a CAD system because it requires accurate knowledge of the distribution of thickness, as well as sophisticated surfacing capabilities. However, a model of the as-manufactured solid is very desirable because it enables design of matched-mold tooling, machining of mating surfaces and allows virtual assembly of parts to check for fit and serviceability. Laminate offset surface capabilities address these issues through automatic optimization of the computed offset surface. Such a capability is built upon proven thickness calculation capabilities and advanced surfacing techniques to capture the thickness variations in the laminate without resorting to explicit surfaces for all ply transitions in the laminate.

Manufacturing 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, material tables, sequence charts, ply lay-up diagrams, arrow text, laminate thickness and ply counts, draped and schematic cross-sections (figure 8).

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. 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. 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.

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 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.

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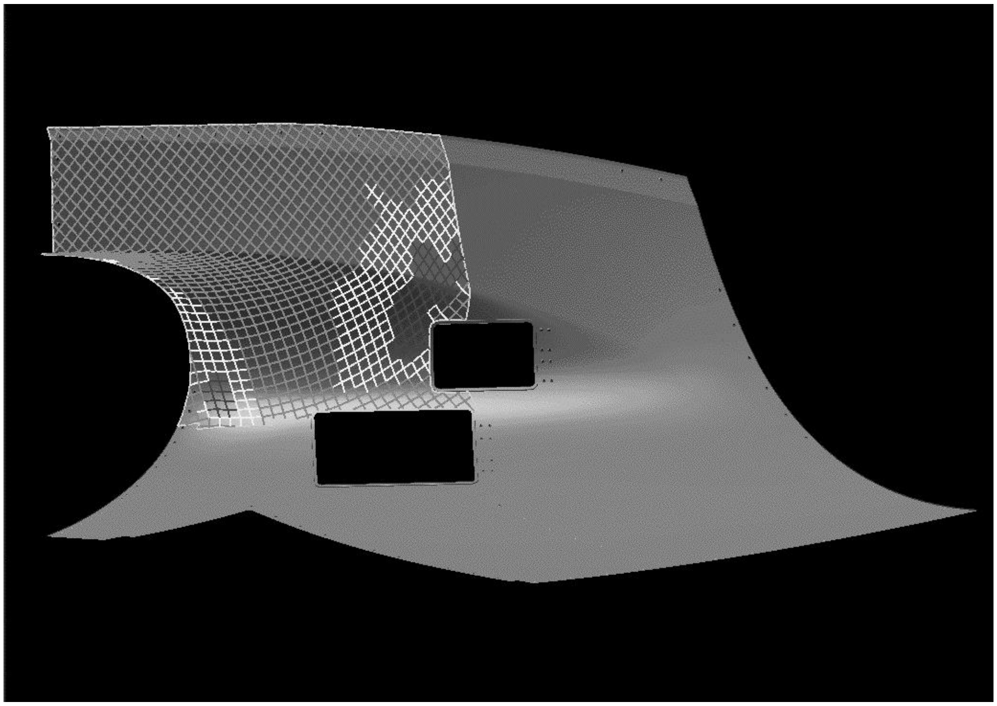

Figure 1 Ply producibility on a part with compound curvature.

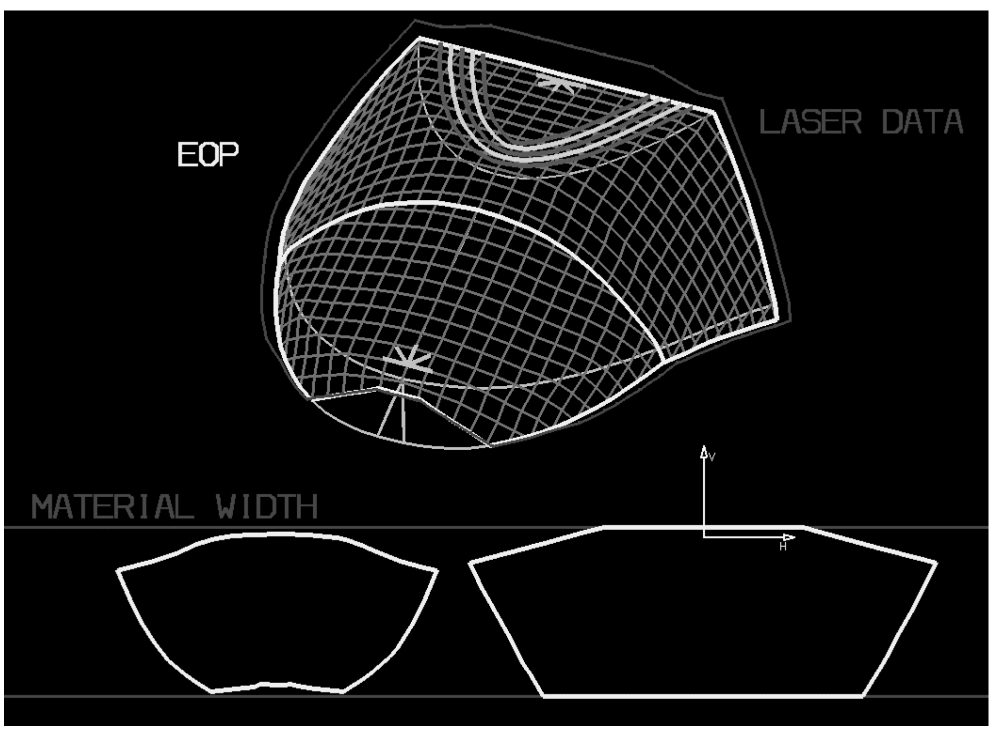

Figure 2 Ply splicing for generation of flat patterns within roll width.

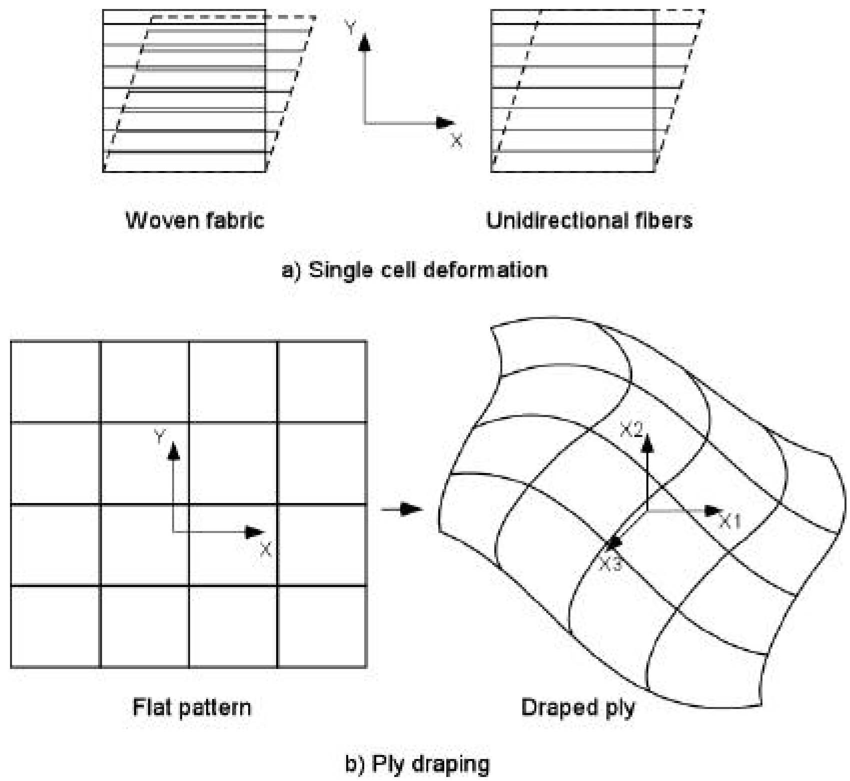

Figure 3   Draping simulation models using the kinematics approach.

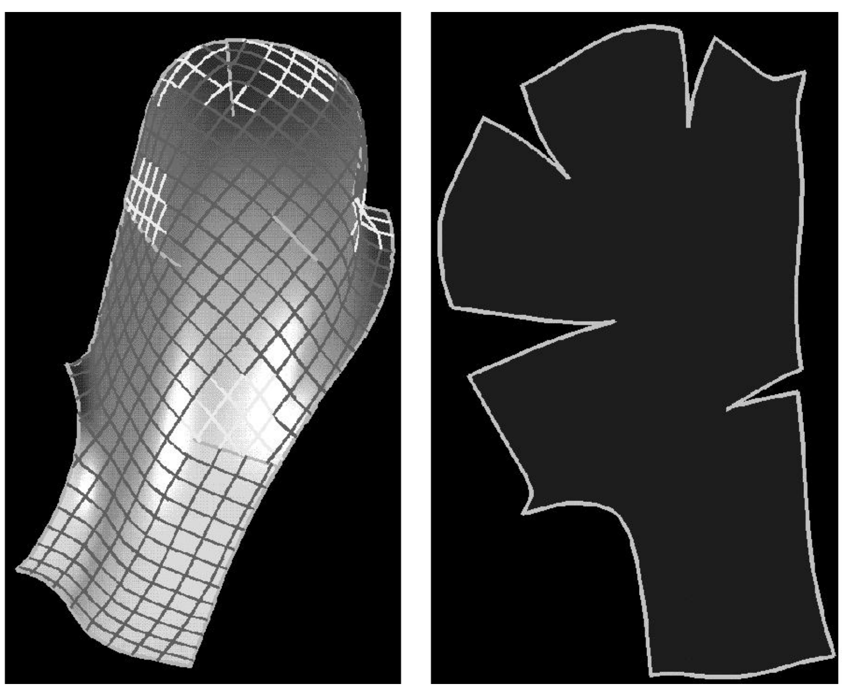

Figure 4   Composite ply with darts, and corresponding flat pattern.

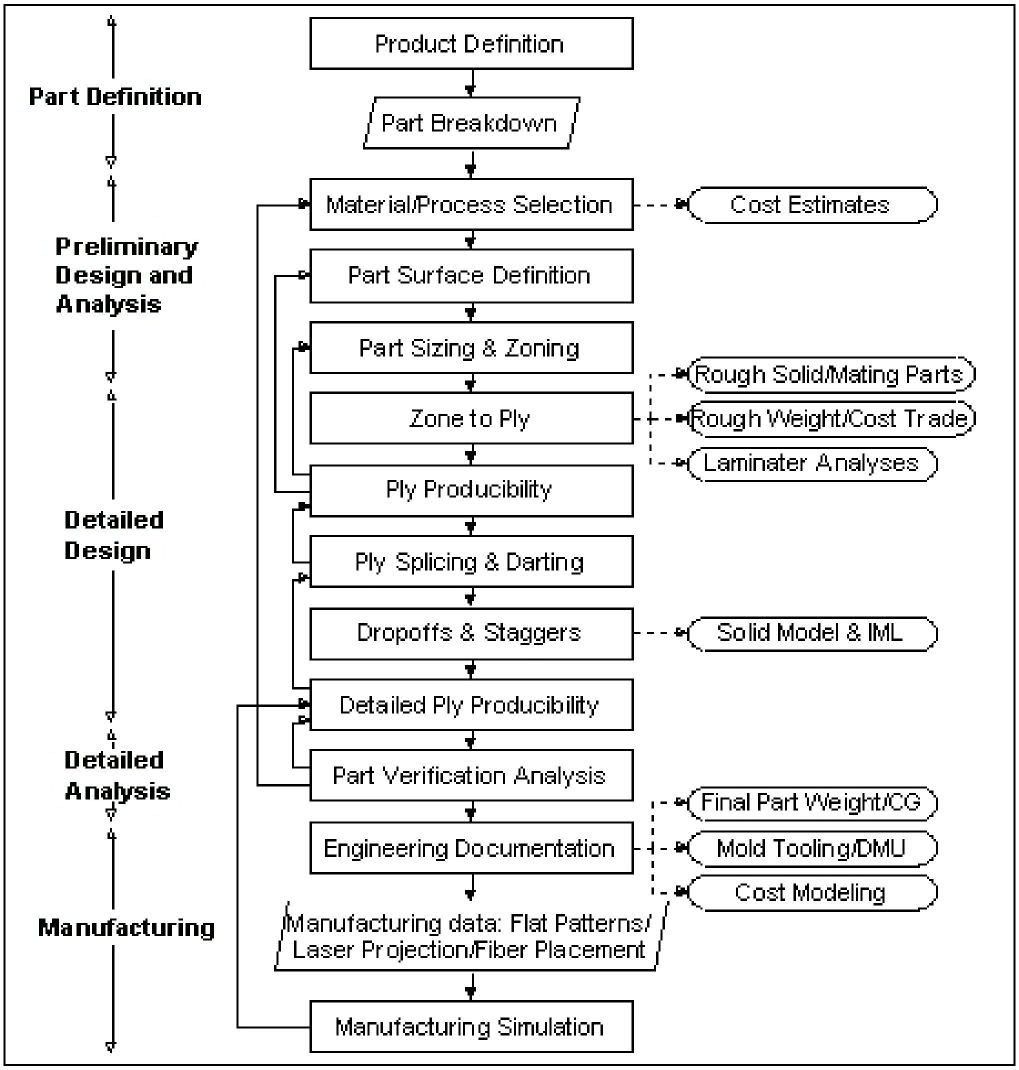

Figure 5 The design and analysis steps of the composite engineering process.

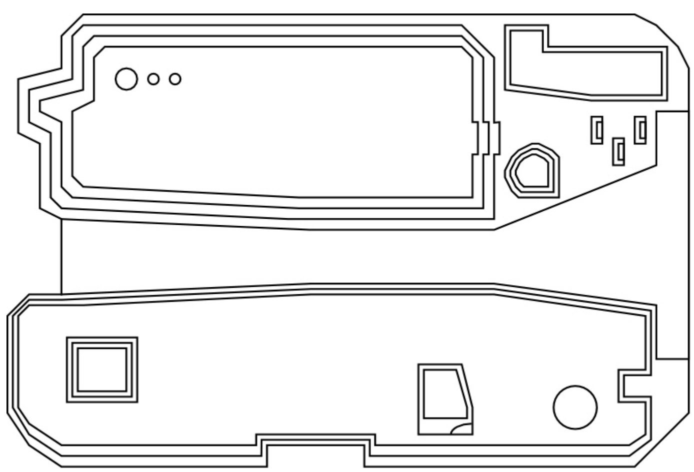

Figure 6 Example lay-up of an automotive composite part.

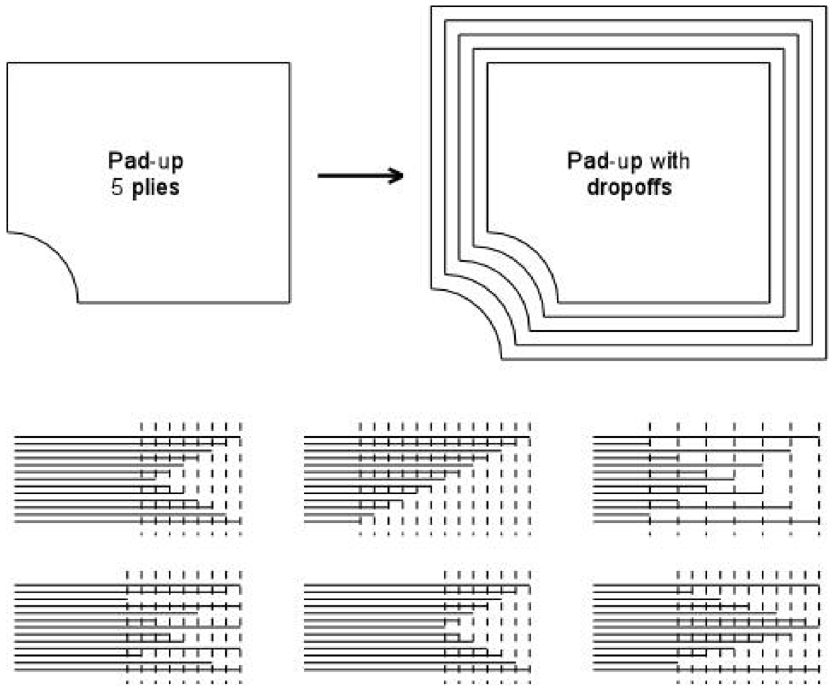

Figure 7 Pad-up shown without and with drop-offs (top). Typical drop-off profiles (bottom).

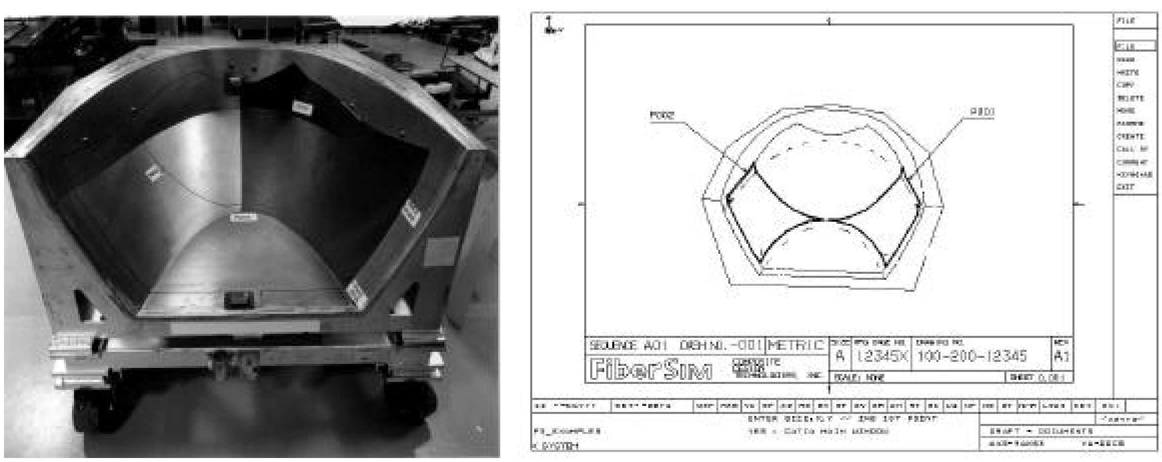

Figure 8 Actual composite part mold and plies, and corresponding CAD drawing.