

Advanced Composite Engineering using MSC.Patran and FiberSIM

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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 are typically produced in low volumes of a few tens or hundreds per year, with few requiring very complex surface shaping. The automotive industry, by contrast, produces a very wide variety of products, ranging over an order of magnitude in size and weight, and comprising dozens (if not hundreds) of basic structural forms.

Hence, in engineering an automotive composite part, tight interaction between design and analysis plays a very significant role. Typically, the analyst performs several finite element analyses based on expected loads with MSC.Patran and MSC.Nastran to determine the requirements for the design, including laminate thickness and materials. And the designer uses FiberSIM, a suite of CAD-integrated software products for composites, to determine the exact final shape and lay-up of the part to meet the analyst's specifications.

In most cases, the final design contains details and modifications that create significant differences between the actual part and the MSC.Patran analysis model. 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 detailed analysis of the final part.

This paper describes how the tight integration of MSC.Patran and FiberSIM addresses these issues. For the first time, it is possible for analysts to access the CAD master model of a composite part in its to-be-manufactured state, at any time during the design process, and verify that the part meets the design performance specifications. This new link provides two-way interaction between design and analysis that accounts for draping distortions, ply wrinkling and darting.

Practical case studies highlight how composite engineering can be improved and risk can be reduced through the use of this new integrated simulation-driven tool.

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INTRODUCTION

The automotive industry produces a wide variety of parts with very different basic structural forms (see figure 1). Composite materials can help reduce this large number of parts by allowing design and manufacturing of more complex components. However, tight interaction between composite design and analysis must be achieved in order to engineer components of increasing complexity.

By linking the capabilities of the CAD system to analysis, advanced composite modeling with FiberSIM and MSC.Patran allows designers, analysts and manufacturing engineers to share the same master model part definition, complete with all details of the actual laminate.

By making the entire exchange process quick and easy, engineers are free to undertake several iterations in order to optimize a part and verify its structural integrity using its to-be-manufactured configuration.

By using a feature-based approach, advanced composite design automates the most tedious and difficult steps of composite part design. Efficient data management, integrated manufacturing process simulation, and the automatic treatment of details specific to composite design allow the designer to prevent otherwise unpredictable conceptual errors (sec. 2). Simultaneously, analysis can take advantage of a more accurate representation of the part (sec. 3).

Current automotive applications of the composite engineering environment include floor panels, door panels, ducts, structural components, seat buckets. Based on a few key examples, evidence of the need for a complete composite engineering environment with access to embedded design and analysis tools is shown in sec. 4.

2. COMPOSITE DESIGN

Composites offer tremendous potential weight savings, increased performance, and design flexibility to engineers. However, designing parts with these materials can be very complicated and costly. By creating a composite engineering environment with embedded design and analysis capabilities, it becomes possible to increase engineering productivity and drastically reduce development time. In the following, some of the key improvements resulting from the use of a state-of-the-art composite engineering environment are detailed.

2.1 Data Management

A typical composite part is made of tens or hundreds of individual plies of various materials, each having a unique shape, orientation and location. Each individual ply is likely to have more information than an entire sheet metal part. This complexity is compounded by the fact that in most cases the final design of a part is never analyzed in its to-be-manufactured state. This greatly increases both the perceived and real risk of

using composite materials. Therefore, it becomes imperative to use a composite engineering environment to maintain a complete and detailed description of the final part design and allow concurrent changes to propagate throughout the model.

2.2 Draping and Flat Pattern

The manufacturing of curved composite parts is aided by the use of draping simulations that can predict the fabric deformations in the early stages of design. Various material and process simulation models have been developed in recent years [1,2]. For example, FiberSIM software supports several simulation processes for orthogonal and cross-ply woven fabric, unidirectional tape, dry and prepreg materials (see figure 2). Consequently, composite analysis benefits from draping simulations and flat pattern producibility by getting an accurate evaluation of fiber orientations and local thickness variations. Both are principal factors in the determination of such mechanical properties as porosity/permeability, stiffness, or thermal expansion coefficients of the part.

2.3 Design/Analysis Interface

Analysis and design must rely on the same master CAD model. This enables producibility simulations to be performed using native CAD geometry with no translation or approximation. This also ensures that accurate analysis properties are extracted because they are generated from the same CAD model that is used for design. For example, FiberSIM uses the CAD part surfaces, 3D ply boundaries and ply stack-up to compute ply orientations for structural analysis with MSC.Patran and MSC.Nastran.

2.4 Concurrent Engineering Architecture

The composite engineering environment operates entirely from within the CAD system and MSC.Patran. Users then work within a familiar environment so there is no new interface to learn. This encourages use of the composite software early and often in the design process, supporting a concurrent engineering methodology.

3. COMPOSITE ANALYSIS

From micro-mechanics to macro-mechanics, the analysis of composite structures involves many different aspects of continuum mechanics and structural analysis. The following sections discuss two of the essential types of composite analyses in the context of the advanced composite engineering environment.

3.1 Core sampling

Laminates can be classified based on symmetry and balance of their stacking sequence. 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.

Within FiberSIM, it is possible to perform “a core sample” and obtain the true ply orientations at any location on the part. One can locally analyze the laminate stack-up and compare the targeted and actual laminate ply sequences. Using computational tools embedded in the composite engineering environment, a quick “on-the-fly” characterization of symmetry, balance and warping is provided. Hence, the need for further detailed finite element analysis is assessed early on. Figure 3 shows core sample locations used for “on-the-fly” laminate characterization of a duct skin. The corresponding results are given in table I.

3.2 Finite Element Analysis

The use of detailed linear and nonlinear finite element analysis is fundamental in the development of composite parts [3]. Here, automatic and accurate mapping of laminate information between the CAD model and the FE model is necessary. FiberSIM and MSC.Patran are seamlessly integrated in order to exchange the data required for a detailed design and analysis of the composite part. In MSC.Patran, the composite finite element model includes the actual ply boundaries and fiber orientations generated in the CAD model by draping simulation. Furthermore, analysts and designers working with FiberSIM and MSC.Patran can readily exchange design modifications during the development process.

5. APPLICATIONS

The advantage of using a common detailed virtual prototype for design and analysis in the early stages of the composite part engineering process is clearly shown in the following examples.

5.1 Thermal Warpage of a Fairing

In this example, it is shown how residual thermal deformations appear during curing and induce unpredicted warping in a fairing made of a sandwich laminate. Here, the use of FiberSIM and MSC.Patran enables engineers to visualize and quantify the source of residual deformations before the part is built, avoiding scrapped parts. Corrective action can be taken directly at the preliminary design stage [4,5].

As shown in figure 4, the original lay-up of the sandwich bottom skin is not quasi-isotropic in the back of the fairing. Due to compounded curvature, the 0/90 ply over the side of the fairing turns out to be oriented at +/-45 in the back, thus aligning itself with the smaller +/-45 ply which covers only the back of the side.

At the same time, the top skin (not shown in the figure) uses a different lay-up pattern that provides quasi-isotropy everywhere.

Hence, during cooling, differential thermal expansion between resin and fiber generates warp strains in the region where the top and bottom skins do not make a symmetric laminate. And the part undergoes significant thermal spring-back (1.5 inch) when removed from the mold, making it unusable.

The dimensions of the fairing are 1.23m x 0.52m x 1.23m. The structure is manufactured using a sandwich with laminated skins of unidirectional fiber compound applied on a 25mm thick honeycomb core. The material properties of the fiber compound are given in table II.

Thermo-mechanical finite element analysis is used to simulate the cooling phase of the curing process [6,7]. A curing temperature of 200°C is assumed. The structure is simply supported in order to allow unconstrained thermal deformations. The analysis of the original configuration yields a 35.5mm spring-back displacement, in very good agreement with the measured displacement (see figure 5).

The solution to the problem consists in rotating the +/-45 partial ply in the back of the fairing to make it a 0/90 ply (see figure 6). After modification, quasi-isotropy of both sandwich skins is ensured. Finite element analysis of the revised lay-up yields a 2.3mm maximum displacement, well within the customer's assigned tolerance (see figure 7).

5.2 Cone Vibrations

In this example, a turbine cone is shown to undergo excessive vibrations leading to failure under standard in-service conditions. The vibrations are the result of an uneven hoop laminate stiffness related to material scissoring at the edge of the part. Such a problem can be avoided by using concurrent analysis and design to quickly simulate and analyze various draping procedures in order to select one that ensures appropriate and constant fiber orientation along the part equatorial edge.

In the following, comparison is made between the initial and the revised versions of the composite part. The initial design uses hand lay-up (see figure 8) with a lay-up start point at the top. This lay-up clearly shows regions of highly sheared material with most of the fibers in the longitudinal instead of the hoop direction. A revised lay-up was produced by FiberSIM, using the same ply shape but with a lay-up start point on the equatorial edge of the part (see figure 9).

The cone height is 0.42m, and the radius 0.45m. The structure is made of a repeated 8-ply laminate, using cyclic symmetry. A plain weave graphite/resin compound is used (see table III).

The in-service loading condition of the cone is simulated using finite element analysis with MSC.Nastran. Static centrifugal loading is assumed, with a rotational velocity of 3000 rpm. Clamped boundary conditions are used on the planar surface at the top of the cone in order to represent the part attachment.

Graphical plots of the deformations under loading are displayed in figures 10 and 11. The original configuration, which leads to failure of the part under in-service conditions, presents a deformed shape with a maximum displacement about 2.8 times that of the revised configuration, which ensures that the part keeps its integrity in service.

5.3 Resin Transfer Molding (RTM)

With the recent advance of liquid molding as a promising industrial process for laminated part manufacturing, accurate numerical simulation is becoming a key ingredient in the design and analysis validation schema [8,9].

More details must be included in the models to obtain realistic RTM simulations. One such detail is material scissoring, which modifies local porosity and permeability and may induce significant changes in resin flow during injection of the part. Material scissoring can be due to the general curvature of the part, or to edge or corner wrapping. When material scissoring is not taken into account, the RTM simulation cannot reproduce the actual flow front variations or the “race tracking” effects occurring along high porosity/permeability channels.

In the following, a simple hemisphere model is used to demonstrate how material scissoring modifies the resin flow front during injection. In this example, the resin is injected at the top of the hemisphere and a “vent” boundary condition is assumed along the bottom equatorial circle.

A full-body layer of woven fabric [0/90] is draped over the hemisphere from the top, generating material scissoring in the equatorial regions along the $\pm 45^\circ$ axes of the draping rosette. The actual warp and weft fiber orientations are computed with FiberSIM and transferred to the RTM simulation software, using property mapping. The true local porosity and permeability are then computed from this data. The simulation nominal fiber and resin properties are given in table IV. In this example, local porosity and permeability changes induced by material scissoring reach about 50%.

Figures 12 and 13 show the flow front at a late stage of the RTM injection process, both with and without material scissoring.

Hence, in reality, the flow front advances on the hemisphere much faster in the regions of higher permeability. Clearly, significant differences exist between the actual injection process and a RTM simulation that would not account for material scissoring.

6. CONCLUSION

At a time when emphasis is placed on reducing risks, lowering costs and increasing production rates, much benefit can be drawn from the synergetic use of FiberSIM and MSC.Patran for composite structures.

Closing the loop between the designer and the analyst 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.

The FiberSIM and MSC.Patran composite engineering environment provides a seamless link between the industry's most popular finite element analysis software package and the CAD master model, to achieve improved composite design, manufacturing and performance simulation.

While some of the current state-of-the-art composite applications using a composite engineering environment have been demonstrated in this presentation, additional automotive engineering applications will be demonstrated in the future.

7. REFERENCES

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- (2) B.P. Van West and S.C. Luby, "Fabric Draping Simulation in Composites Manufacturing Part II: Analytical Methods", *Journal of Advanced Materials*, Vol. 4, 1997, pp. 36-41.
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- (5) *FiberSIM Catia[®] User Manual*, Composite Design Technologies Corporation, Waltham, MA, October 1999.
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- (7) *MSC/PATRAN User's Guide, Vers. 2*, MSC.Software Corporation, Los Angeles, CA, November 1999.
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- (9) R. Gauvin, F. Trochu, "Key Issues in Numerical Simulation for Liquid Composite Molding Processes", *Polymer Composites*, Vol. 19, 1998, pp. 233-240.



Figure 1 Examples of automobile body panels and parts.

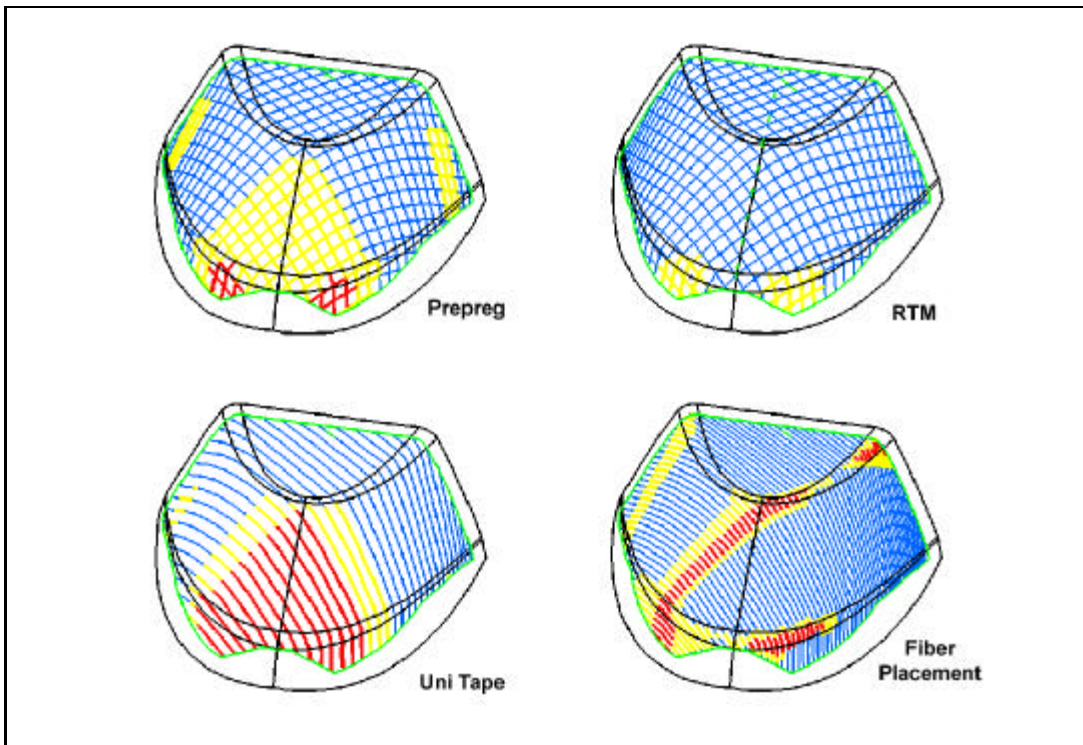


Figure 2 FiberSIM draping simulation for different materials. Color changes indicate material scissoring and fabric deformations.

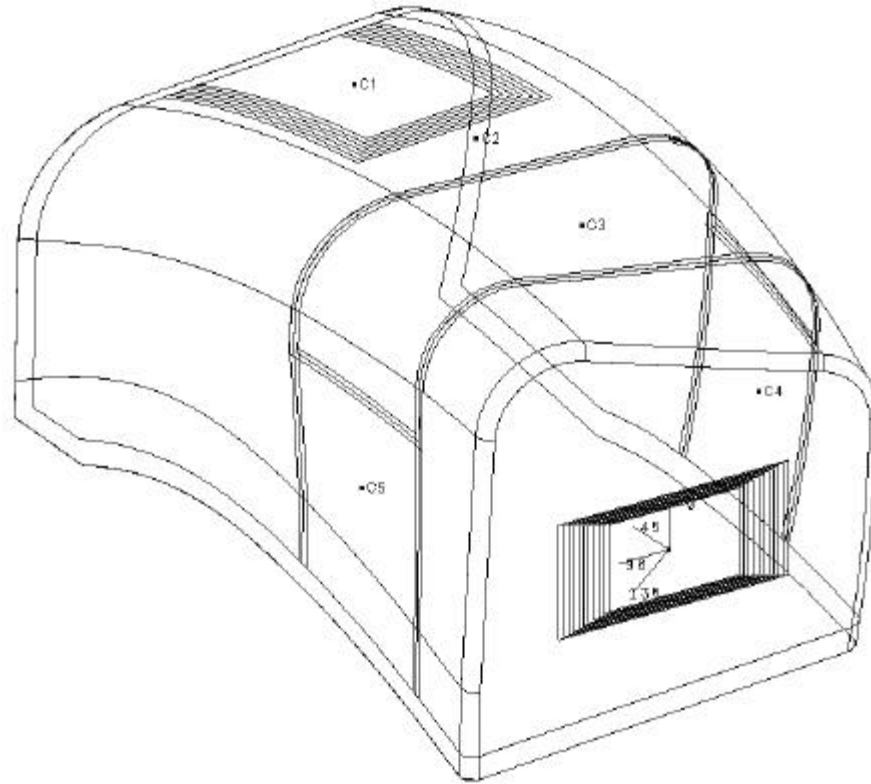


Figure 3 FiberSIM model with core sample point locations for “on-the-fly” laminate characterization.

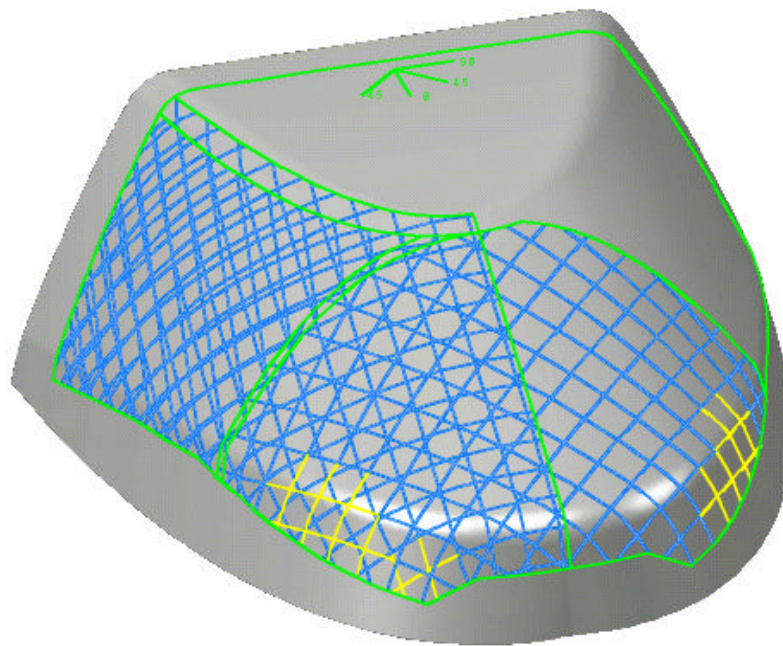


Figure 4 Original draping of the inside (bottom) skin of the fairing showing non quasi-isotropic fiber orientations in the back.

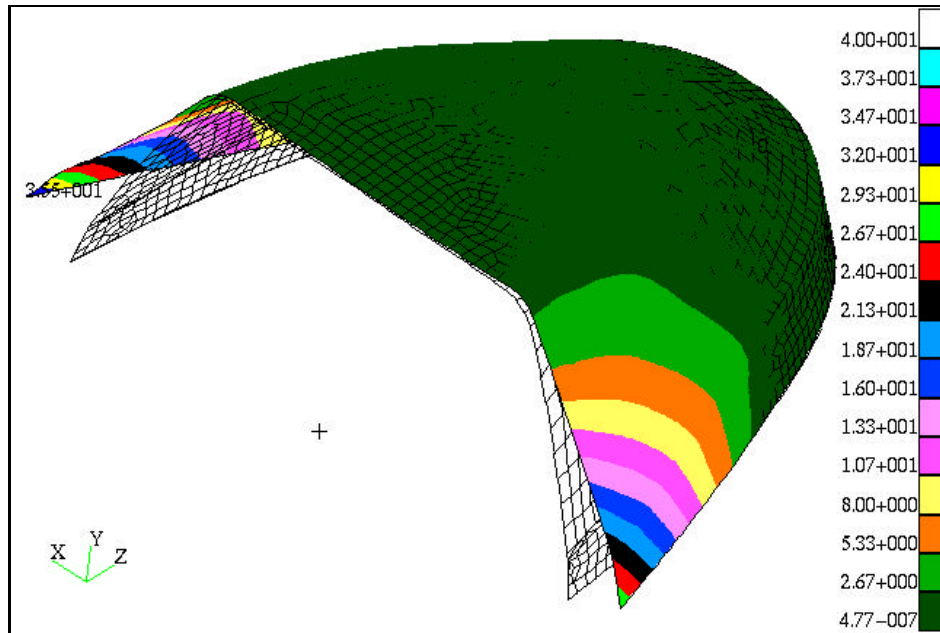


Figure 5 MSC.Nastran thermo-mechanical displacements of original part.

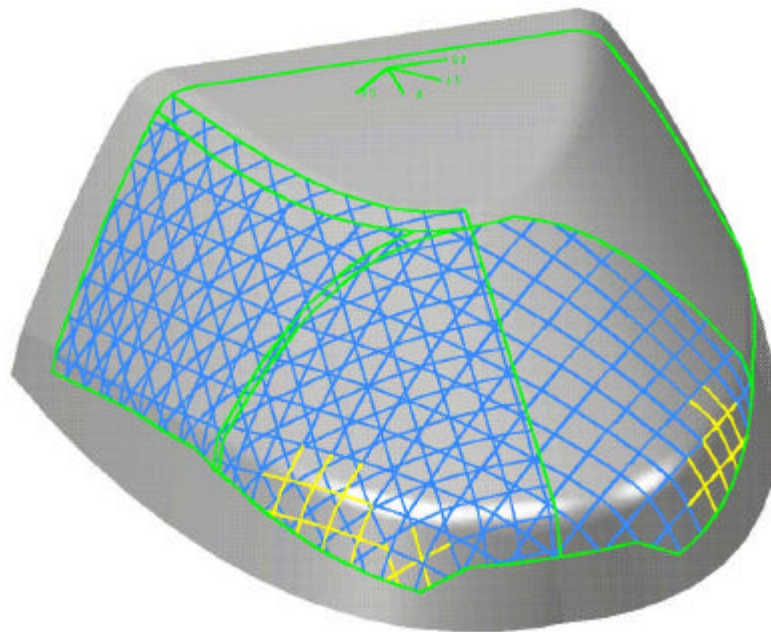


Figure 6 Revised draping of the inside (bottom) skin of the fairing showing quasi-isotropic fiber orientations in the back.

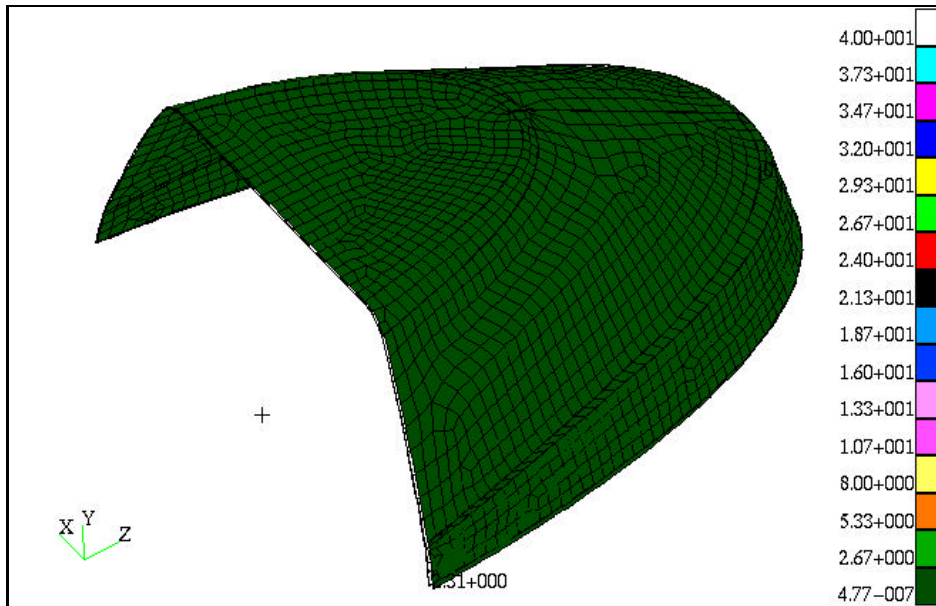


Figure 7 MSC.Nastran thermo-mechanical displacement results of revised design.

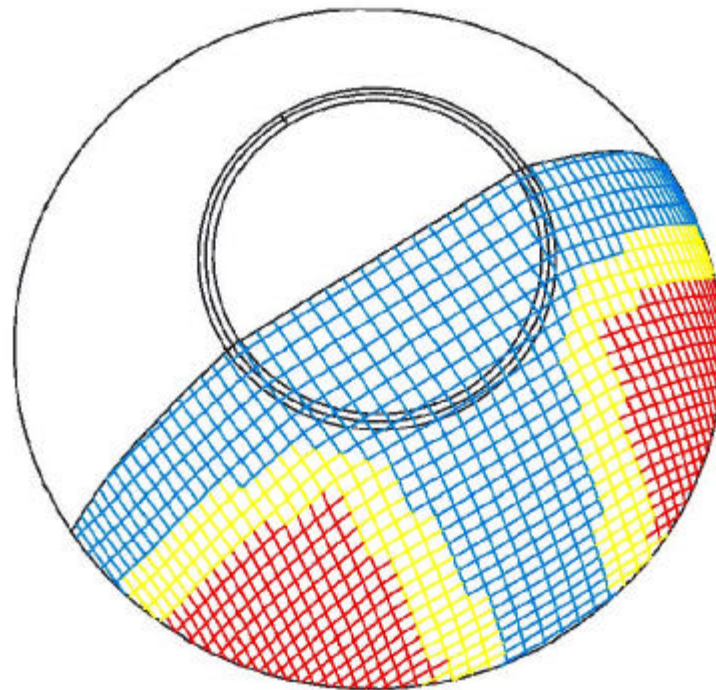


Figure 8 FiberSIM fiber paths on original half-body plies. The lay-up shows material scissoring (in red) in the +/- 45 degree regions.

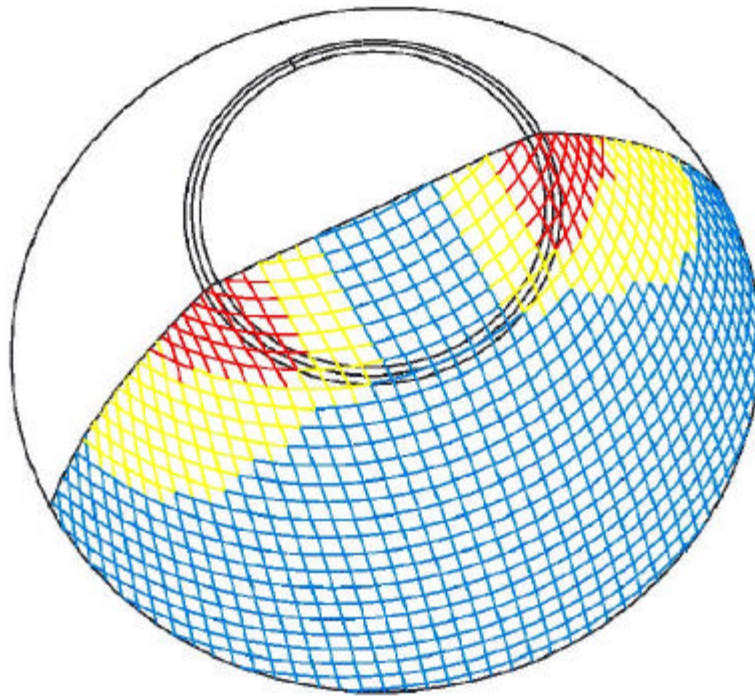


Figure 9 FiberSIM fiber paths on revised half-body plies. The lay-up shows fibers aligned with the equatorial edge of the part.

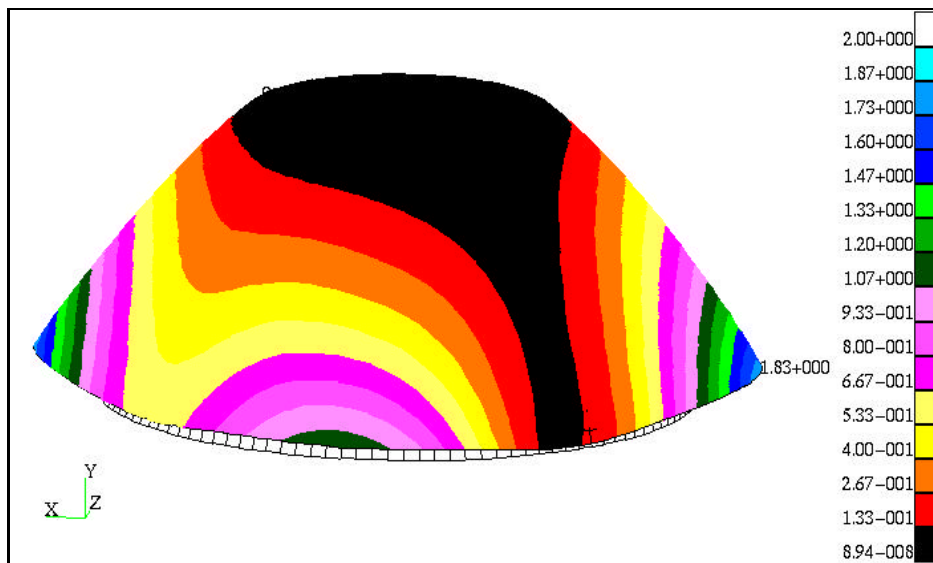


Figure 10 MSC.Nastran centrifugal loading displacements of original spinner.

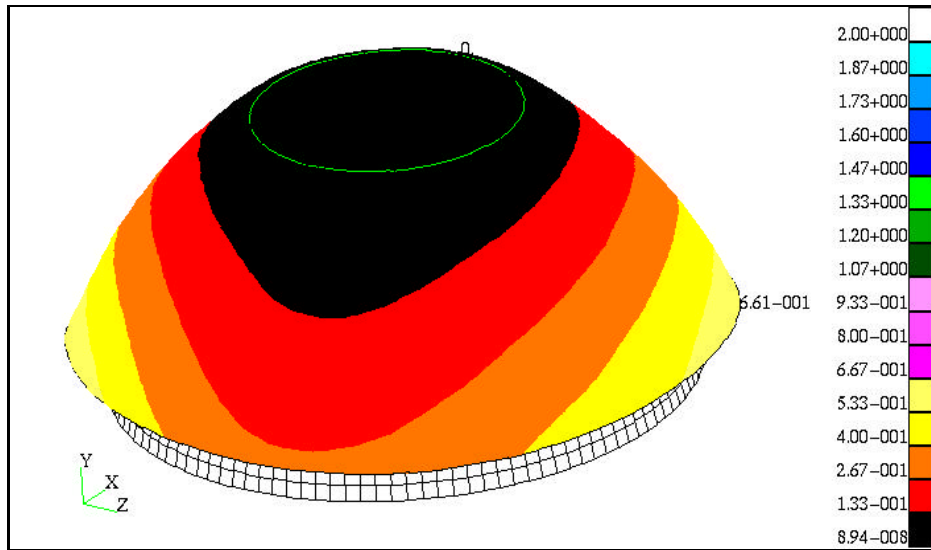


Figure 11 MSC.Nastran centrifugal loading displacements of revised spinner.

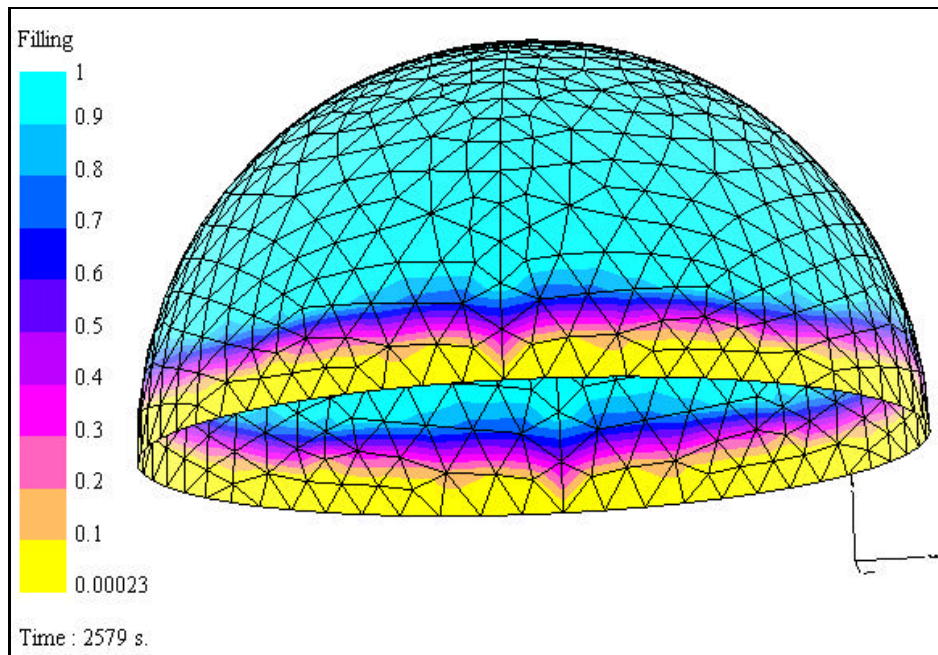


Figure 12 Resin injection without material scissoring effects. Flow front and resin filling ratios are displayed.

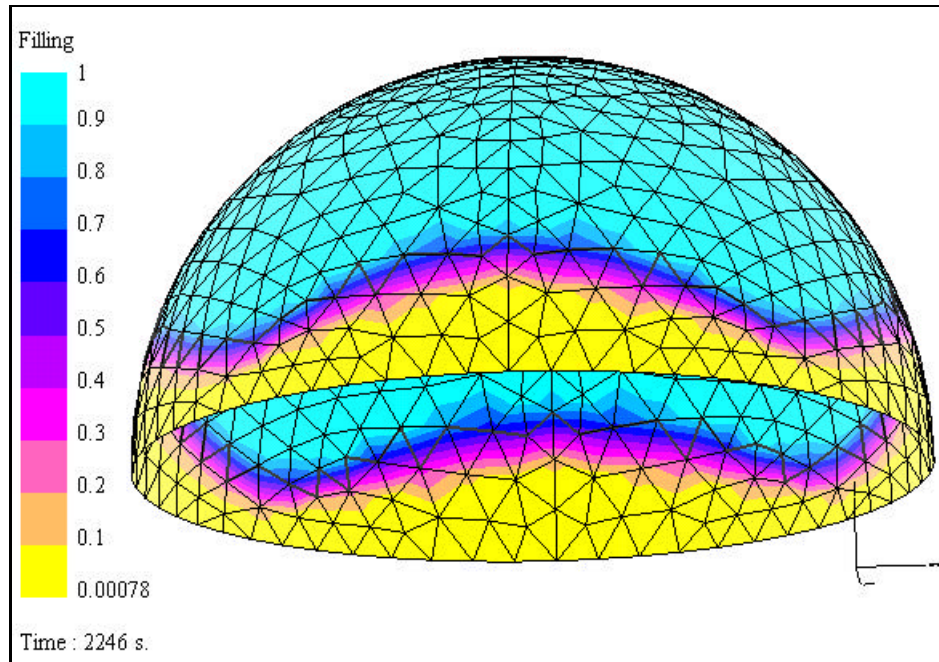


Figure 13 Resin injection with material scissoring effects. Flow front and resin filling ratios are displayed.

TABLE I Laminate results for symmetry, balance and warping.

LAMINATE RATING ANALYSIS					

SYMMETRY, BALANCE, AND WARPAGE INFORMATION					

Name:	A				
Parent:	PART001				
Rosette:	ROS001				
Identifier:	*C1				
Location:	(-693.988, -511.814, -130.228)				
	Target	Specified	Actual		
Thickness:	1.140	1.143	1.143		
Ply Count:	6	6			
	Percentages		Ply Counts		
Orientation	Target	Specified	Target	Specified	
0	50.0	66.7	3	4	
45	50.0	33.3	3	2	
90	0.0	0.0	0	0	
135	0.0	0.0	0	0	
% Symmetry:	100.00				
% Weighted Symmetry:	100.00				
% Mechanical Symmetry:	100.00				
% Laminate Balance:	66.67				
% Laminate Warpage:	0.00 (FOR TEMP. CHANGE OF 250.0)				
NAME	ORIENT	MATERIAL NAME	THICKNESS	SYMMETRY	BALANCE
-----	-----	-----	-----	-----	-----
PLY01	0/90	PPG-PL-3K	0.1905	Yes	Yes
PLY02	+/-45	PPG-PL-3K	0.1905	Yes	No
PLY03	0/90	PPG-PL-3K	0.1905	Yes	Yes
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PLY17	0/90	PPG-PL-3K	0.1905	Yes	Yes
PLY18	+/-45	PPG-PL-3K	0.1905	Yes	No
PLY19	0/90	PPG-PL-3K	0.1905	Yes	Yes
. . .					

TABLE II Mechanical properties of canopy compound (SI units).

E11	E22	NU12	G12	ALPHA1	ALPHA2
50000.	1000.	0.3	500.	-5.0e-6	90.0e-6

TABLE III Material properties of the cone composite compound (SI units).

E11	E22	NU12	G12	Specific gravity
1.7e11	3.4e9	0.3	1.7e9	1.5

TABLE IV Material properties of fabric and resin (SI units).

Nominal fiber content	Nominal permeability warp	Nominal permeability weft	Resin viscosity
0.5	1.2e-11	1.2e-11	0.01