Bridging the gap between design and analysis advances aerospace composites

SIEMENS

White Paper

How part-type methodologies in the Fibersim™ portfolio of software for composites engineering from Siemens PLM Software enables you to capture the essential details of a composite design – its DNA – and make simulation and verification via analysis more accurate and straightforward.

Answers for industry.

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Executive summary

The mechanics of composite materials are well described by classical laminate theory, which combines the properties of individual composite layers to predict the behavior of a laminated structure. Yet in many instances, despite the well known nature of these materials, analyzing practical composite structures remains a challenge. These challenges derive from two areas.

First, the complexity of the design definition is often difficult to communicate during the engineering process and makes it hard to achieve a truly accurate analysis of a composite structure. This leads to approximations and ambiguity in the design.

Second, the fiber orientations assumed in the as-designed composite structure are frequently different from the fiber orientations in the as-built composite structure. This means the fundamental material properties of the composite structure are often misunderstood, because the orientation of the fibers is central to their definition.

Both of these issues push design engineers to use increased margin in an aerostructure design to account for the uncertainty in the analysis. This ultimately leads to designs that weigh and cost more, decreasing the competitiveness of composites as a material choice and making their implementation less straightforward.

The key to addressing these two problems is an appropriate definition that takes into account the impact of the material, design approach and manufacturing method. This definition encapsulates the "DNA" of the composite design and helps to define a complete and fully robust set of analysis parameters to increase confidence in the analytical result, reduce margin and more fully optimize the design. Once the design is captured in this way, it may be accurately communicated to the analysis tools that will be used to predict its performance.

This white paper will explain how part-type methodologies in the Fibersim™ portfolio of software for composites engineering from Siemens PLM Software enables you to capture the essential details of a composite design – its DNA – and make simulation and verification via analysis more accurate and straightforward. It will also discuss how this approach leads to a more efficient and profitable composite development process overall.

Several specific cases will be explored in which the DNA of a composite structure is defined in a way that is complete and easily repurposed for use, not just in analysis, but also in manufacturing, maintenance and other disciplines.

Using analysis to mitigate risk and improve performance

Analysts and designers in aerospace usually work somewhat separately, focusing on their own domains rather than seeing the project from a more comprehensive viewpoint. This approach makes it slow, difficult and expensive to make changes after the first iteration. Product development in this case is largely a serial process, which is not compatible with tight budgets or management's desire for shorter product cycles and less rework.

Structural composites that require detailed analyses have been used in aerospace for well over three decades, but high volume production of large and complex assemblies is a recent development. This has led to the desire for increased optimization to reduce weight and cost, as composite components have begun to make up a larger percentage of the aerostructure.

The design of composite parts involves more unknowns and interdependencies than does that of a metallic part design. The typical serial product development processes associated with composite part development eliminate many chances to make the complex adjustments necessary to improve a design. This negatively affects design advantages that are specific to composites, such as tailoring material orientations. Serial processes also routinely inflate design allowances and safety factors, effectively treating composites as "black aluminum," and forgoing the benefits to be gained by the design of the material itself. The ideal scenario would be to exchange data quickly and easily between a composites design tool and the structural analysis tool in a way that captures the definition of the design accurately and completely, as shown in Figure 1.

For example, in preliminary design there is usually very little detail of the geometry that will go into the design. It is at this point that the logical definition of the composite design is first created. If this cannot be transferred directly to the systems used by the design engineer, the potential for errors to occur in the ensuing manual translation is very high. This is only the first place inefficiencies can occur.

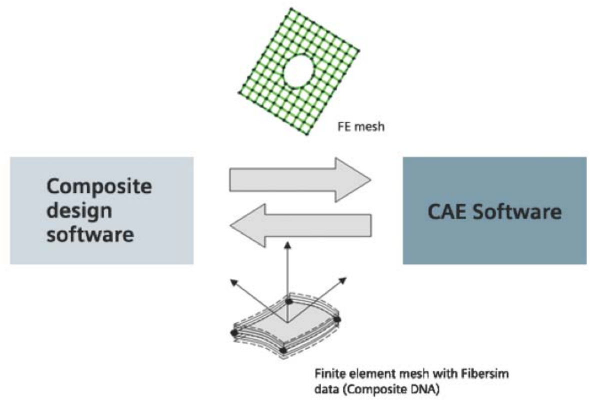

Figure 1. Shown is the exchange of composites information between the design software and the analysis software.

Once detailed design begins, analysts need to provide updated laminate definitions for design engineers. This may be because of a change in specification to account for new load cases, or simply because the analysis has been updated to a more accurate level. It is critical to be able to easily and accurately communicate this information to the design engineer, who now has begun to define the final design. Failure to communicate this information efficiently will result in lost work because the design will have to be totally rebuilt to incorporate the changes. This can make the difference between world-class products and those that fail to meet specification or advance the state-of-the-art.

Finally, before official release of the design, there is a verification step to ensure that the design meets the specification as defined in the customer requirements. The work involved in this step can be varied. It may require simply documenting that the design as prepared for release to manufacturing by the supply chain contains the essential elements of the design as the analyst indicated. It also may require a full analysis of the design to ensure it will function as required.

To help eliminate these problems in aerospace companies, Fibersim helps you define composite structures with enough fidelity that the specialized details of a design are captured. It communicates this definition without loss to and from a variety of structural and thermal analysis software packages. This workflow is illustrated in Figure 2.

This integration ties together the disciplines of composite part design (CAD) and analysis (CAE), facilitating concurrent engineering from preliminary sizing through the validation of final models with detailed ply-based part definitions.

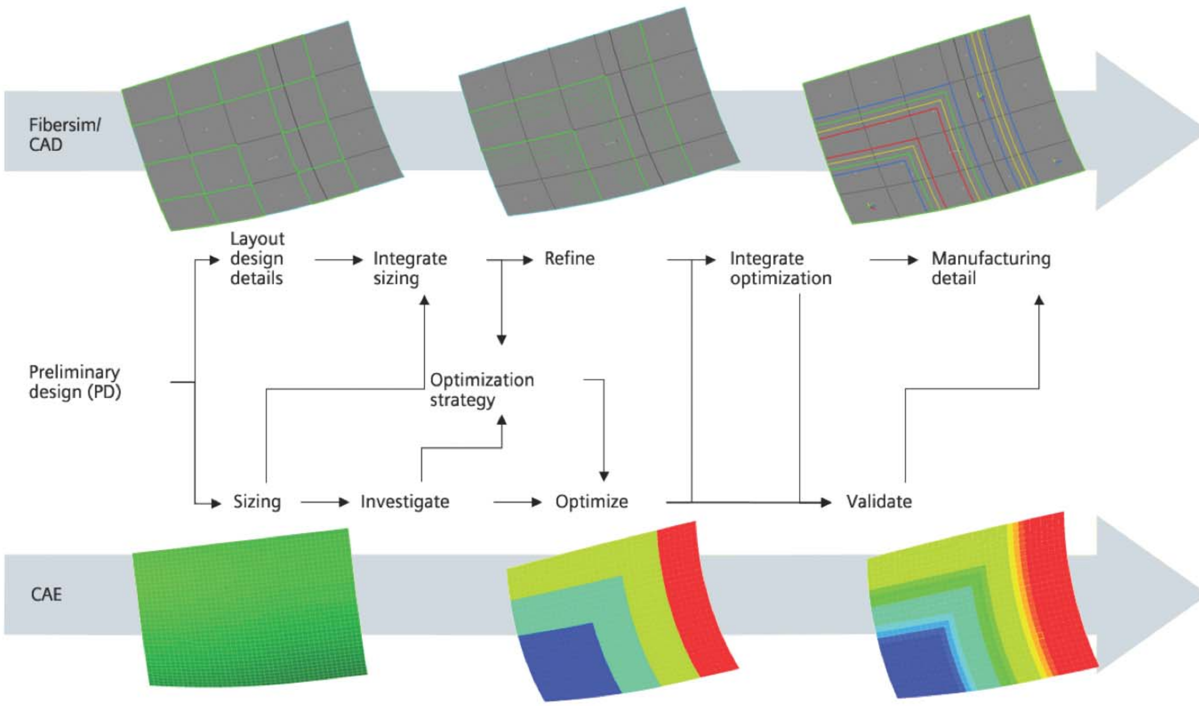

Figure 2. Parallel and integrated design and analysis workflows using Fibersim in conjunction with CAE tools.

Defining the challenge for composite designers and analysts

Composite parts are not really parts. They are complex, inseparable assemblies of individual pieces of composite material. Because they are defined within the CAD geometric modeling systems as single, detail parts, the logical structure of the composite part definition, which is mostly non-geometric, is poorly expressed.

There are many obstacles to effective collaboration between designers and analysts, including different domain knowledge, special techniques and the use of different vocabularies. Analysts think in terms of material properties, load cases, stress and strains. Designers work with ply coverage, nonstructural details and design rules.

However, the design engineer and the analyst share a common set of data which describes the intrinsic definition of the composite part: The structure of this data set and its contents form the DNA of a composite part. This DNA, or logical structure of a composite part, is developed through successive iterations between analysis, manufacturing and design. To enable the highest levels of efficiency between design and analysis, part-type specific approaches are necessary to capture the essential DNA of a design.

The inability of CAD systems to adequately represent the unique DNA of a composite part limits their use for all the stakeholders, especially analysts, in the concurrent engineering process. This difficulty leads to errors and adds margin to the design to account for the unknowns.

For example, the definitions of fuselage panels, frames, stringers or other complex composite aerostructure components are fundamentally different in that their basic structure is matched to the requirements of these parts, which are all different. The layup of the composite layers, their orientation, expected manufacturing methods and material all contribute to the unique properties of the part.

Fibersim has been developed in conjunction with industry leaders in composite development to capture this kind of design data. The advantage of capturing the part-type specific DNA of composite designs is that it can be re-used without significant reinterpretation in the concurrent engineering processes. The efficiencies gained from the straightforward re-use of data provide benefits for manufacturing, redesign, maintenance and support.

An additional concern when creating composite part definitions is that there are two locations in which the data can be changed. Because the parameters that drive a composite part definition are often defined programmatically, any practical reuse of the data needs to refer to the original data that was used in the part definition. For basic definitions, a simple schema may be enough, but in the real world of composite structure development, maintaining an intelligent source of data – its specific DNA – is preferable. Fibersim's tight integration into the CAD system provides this capability.

Closing the chasm between composites design and analysis

The state-of-the-art has advanced sufficiently so that today's focus in composite development is on overall structural and design optimization rather than traditional manufacturing concerns, such as drap ability or void formation. And so the challenges of moving the state-of-the-art forward have more to do with inefficiencies in collaboration that development teams face, rather than composite material technology per se.

Fibersim's creation of a well described data set that completely captures the DNA of a composite structure helps to connect the analyst and design engineer, resulting in the more efficient creation of a better product.

For example, the common DNA between analysis and design definitions for composites includes certain "touch points." Often, these touch points comprise "zones," which are built from lofted surfaces provided by the systems group and from material specifications and sizing data from the analysis group. Figure 3 illustrates a workflow that uses these touch points as a mechanism for communication.

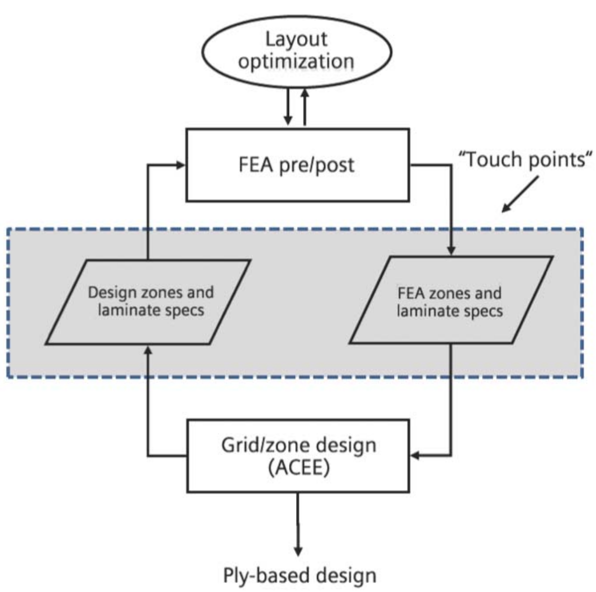

Figure 3. Workflow between design and analysis that captures "touch points."

Touch points are unlikely to change frequently or drastically and they represent information that can be used as the basis for shared concepts. In the current development process, the designer provides the analyst with a definition based on the initial laminate specifications. The analyst maps this data onto the initial finite element (FE) mesh of the part. The designer moves on to designing nonstructural wing elements, laying out transitions, detailing the design of drop-off areas and preparing fasteners and inserts. The analyst applies physical properties to the meshed geometry, a critical consideration with composites, as well as loads and boundary conditions. Iterations that take place now involve concurrent data exchange between Fibersim and CAE systems.

Sharing this intelligent composite DNA between Fibersim and CAE systems lets analysts directly apply composite design features, such as system lines and zone partitioning, to create and control a mesh for a composite skin. The interface also enables analysts to use lines of beams for stiffening elements, such as stringers or frames, in a fuselage section. In addition, common access to native geometry exposes named attributes from CAD, which supports automated responses to design changes.

Another element of DNA for collaboration that Fibersim addresses is the assignment of physical properties. The capability to seamlessly share detailed layup and material specifications improves the analyst's efficiency and productivity and has a significant impact on a design's accuracy. Figure 4 shows the materials database in Fibersim.

Bridging the gap between analysis and design in this way supports everything from simple linear static to nonlinear buckling and progressive failure analyses. Using multidisciplinary approaches also makes it more straightforward to optimize the composite structure's performance requirements. There is more to designing a layup than simply cutting weight. The design must also meet multiple manufacturing constraints, design rules and other requirements that require coupled structural and thermal analyses.

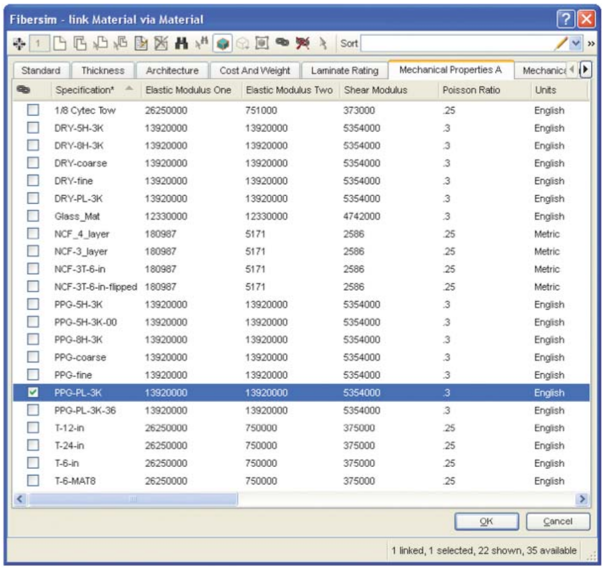

Figure 4. The Fibersim materials database enables you to assign physical properties to plies.

Here, sharing composite DNA across disciplines allows you to seamlessly exchange and optimize designs. For example, using a common geometry slashes the number of complicated dependency failures because the logical relationships implicit in its DNA persist between Fibersim and CAE systems, thus removing the need for frequent, complicated refreshes. Using Fibersim, all changes flow from a constrained set of sources and allow for easy, automated remeshing in analysis as well as automated translation and design updates.

For example, when designing a fuselage panel, this approach assigns new specifications to zones. Figure 5 shows the underlying datum definitions from the assembly. These datum definitions are shown in magenta and represent the footprints of the underlying substructure which will drive the composite part definition. The ability to link the underlying definition of the assembly to the composite definition is therefore important.

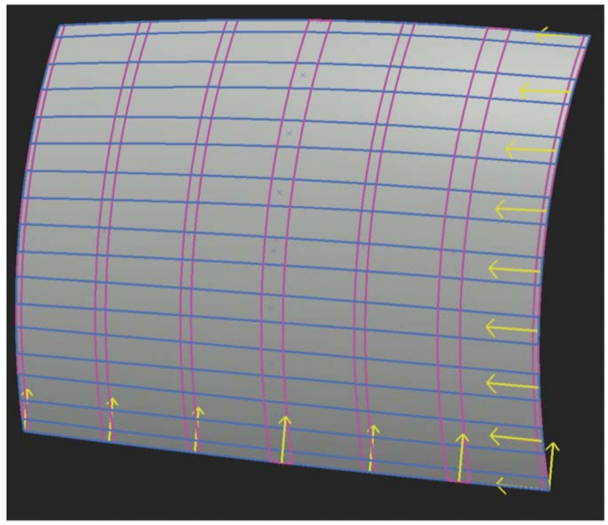

Figure 5. Fibersim captures datum definitions from substructure geometry.

Increasing ply count or altering zone thickness triggers an automatic update that adds new ply drop-offs, while maintaining transition definitions, material choices and detailed geometry. Figure 6 shows analysis zone definitions derived from the substructure definitions and laminate requirements.

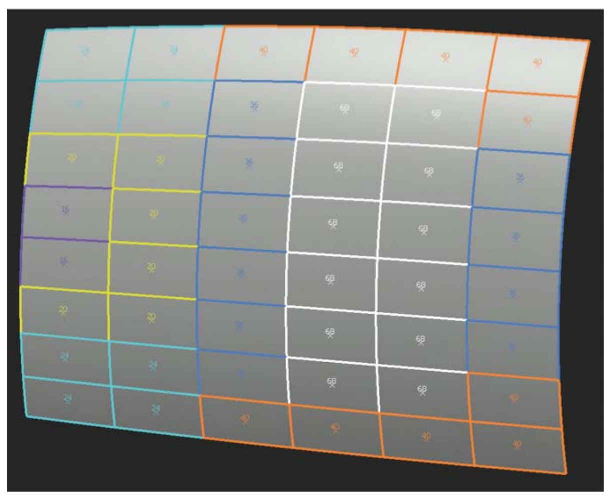

Figure 6. Fibersim automatically derives analysis zone definitions from substructure and laminate requirements.

In parallel with the analysis, the design engineer creates design zones from the analysis zones to create the detailed ply definitions. The ability to connect this detailed analysis data to the ply definitions makes the iterative and evolutionary process of design more tractable, and in the case of complex designs, even possible. Figure 7 shows design zones derived from the analysis zones.

The ability to automate the consolidation of analysis zones to design zones dramatically speeds the development process and ensures accuracy as data is exchanged within the design team.

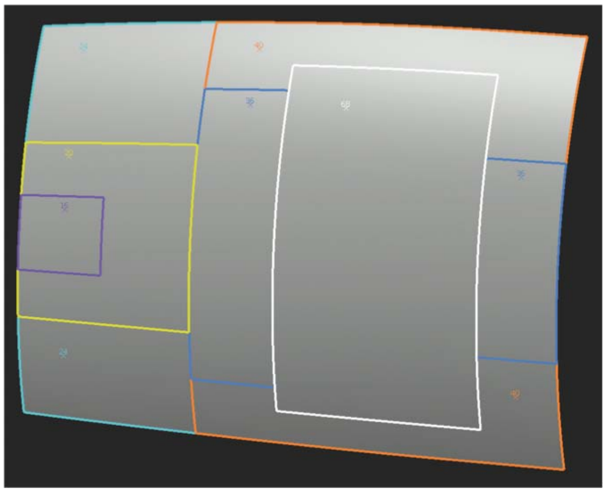

Figure 7. Fibersim automatically derives design zone definitions from analysis zone definitions.

Even with the detailed design almost finalized, the shared geometry can further support collaboration for design validation. For example, the analyst can access mesh control curves in the design definition which let him or her include the effects of ply drop-offs for precision meshing in the CAE system. This is an impossible task without this kind of powerful, composite DNA-based approach.

Another example is related to creating complex geometries such as frames, stringers and shear ties. These parts often have C-, L- or hat-shaped cross-sections that sweep through a complex path. The parts are produced using a variety of manufacturing processes, such as resin infusion, hot drape, forming or automated layup techniques, but they must all have their specific DNA captured as part of the development process to achieve the desired result. In this example, controlling the fiber orientation is central to ensuring the design intent is met so that the product will meet functional requirements.

For example, capturing and preserving design intent for the part shown in Figure 8 requires that the appropriate strategy be used for defining the 0° direction.

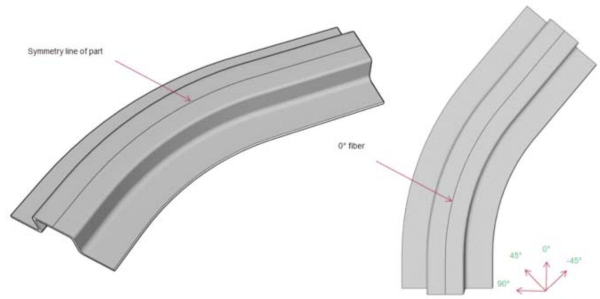

Figure 8. An example of a spine-based part design.

This is a function both of the desired orientation and manufacturing process. A traditional rosette will yield an idealized 0° direction over an entire part. But a spine-based rosette and simulation help preserve the design intent of the 0° fiber running along the symmetry line of the part. Fibersim can be used to design this kind of part by aligning the 0° fiber with the line of symmetry, thus ensuring that the part will be analyzed as desired. Figure 9 shows an example of this kind of simulation result. Note that the fibers in the simulation do not deviate along the line of symmetry of the part.

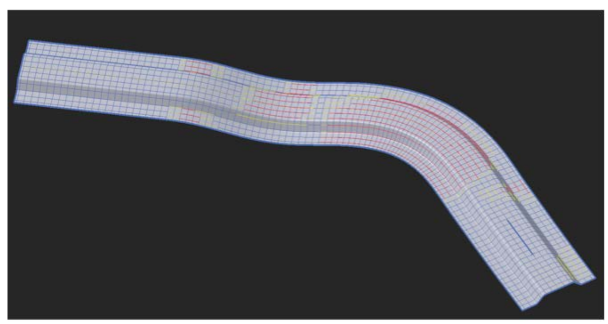

Figure 9. The result of a Fibersim simulation of a spine-based part.

This approach, which is enabled by Fibersim, solves key problems when designing complex shapes, such as uneven properties from curing caused by wrinkles or the spread of fibers leading to resin-poor areas in the curing process. This is sometimes called “tiger striping” in hat stringers. It can also reduce the likelihood of flexing or springback of the part from the tool after curing.

Conclusion

It is obvious that bridging the gap between design and analysis for composite structures has many benefits. First, the team can make modifications earlier in the development process, and it can accommodate changes late in the process to enhance optimization. Second, analysts can perform more accurate analyses on the as-designed part definition using the true material properties.

Such an approach to concurrent engineering yields shorter lead times and a parallel workflow that supports more and faster iterations. Both designers and analysts can continue working while synchronizing significant changes. What's more, the technique cuts the risks, program costs and potential liabilities associated with using new materials and novel technologies.

Fibersim makes all of these capabilities possible by developing a design definition that captures the part-type specific DNA of a composite structure and provides high fidelity between the CAD and CAE representations of the design.

This approach saves money and time and delivers more competitive products that enable aerospace organizations to extract the most value from using composites as the material of choice.

About Siemens PLM Software

Siemens PLM Software, a business unit of the Siemens Industry Automation Division, is a leading global provider of product lifecycle management (PLM) software and services with 7 million licensed seats and more than 71,000 customers worldwide. Headquartered in Plano, Texas, Siemens PLM Software works collaboratively with companies to deliver open solutions that help them turn more ideas into successful products. For more information on Siemens PLM Software products and services, visit www.siemens.com/plm.

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