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Reducing weight in composite aerostructures

White Paper

Unifying design, analysis and manufacturing to reduce the weight of aerospace composites.

Answers for industry.

A white paper issued by: Siemens PLM Software.

Contents

Executive summary

In the wake of the first commercial, composite-intensive airframe programs, most notably the Boeing 787 Dreamliner, many aircraft manufacturers are selecting carbon fiber reinforced plastic (CFRP) as the structural material of choice for the fuselage and/or wings for its next project. This is true for all types and sizes of commercial airplanes, including wide body, regional, business as well as general aviation aircraft.

As a consequence of this trend, aerostructures are getting more complex to design and manufacture. This is due in large part to the nature of the composite structure and its interdependency with the total airframe. Creating the initial designs and making subsequent changes to these complex aerostructures is becoming more time-consuming and potentially more error-prone. This complexity makes efforts to decrease weight – one of the primary reasons for adopting composites – more challenging because it slows the rate of optimization that is required to achieve the maximum potential of these high tech materials.

During this transitional period into a new age for aerospace materials, lessons on composite engineering and manufacturing must be assimilated quickly to effectively adapt the overall development process to this new reality. The complexity of the multiple interactions between material choices, tooling selection, design methodology and manufacturing processes must be fully appreciated in order to devise the most robust and efficient approach to optimizing composite aerostructures to achieve lower costs, higher quality and reduced weight.

The key to efficiently optimizing composite structures for weight is to develop an appropriate definition that captures the impact of material, design approach and manufacturing methodology.This definition encapsulates the “DNA” of the composite design, and helps to define a complete set of analysis parameters to increase confidence in the analytical result, reduce margin and more fully optimize the design. Once captured in this way, the design may be communicated with high fidelity to analysis tools that help the team develop a design that facilitates the highest performance at the lowest weight.

Defining the weight reduction 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 computer-aided design (CAD) geometric modeling systems as single, solid parts, the logical structure of the composite part definition, which is mostly nongeometric, is poorly expressed.

The inability of CAD systems to adequately represent the uniqueness of composite parts limits its usefulness for all stakeholders in the concurrent engineering process, especially analysts. This difficulty leads to errors and additional margin in the design to account for the unknowns. This additional margin inevitably increases the weight of the composite structure, decreasing the value of using composites.

There are many obstacles to effective collaboration between designers and analysts due to different domain knowledge, special techniques and specialized language. The working definitions necessary to support these workflows vary significantly between members of the development team.

However, there is a common set of data that the design engineer and the analyst share that 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 definition of a design so that it can be fully optimized across disciplines.

Providing a framework for weight optimization

Just a single unneeded ply distributed over the total size of any of the modern composite aircraft could result in hundreds of pounds of excess weight. There is great incentive to find and eliminate such over-design, but it is very difficult to do so after the initial sizing has occurred. This is partly due to the challenge of exchanging data between design disciplines and associated engineering software applications.

The weight of a composite part is driven by the number of layers of composite material in the part. In order to minimize the number of layers, the orientation of each layer needs to be tailored to provide maximum strength and stiffness under all load cases. This is the primary task in the preliminary sizing of a composite structure.

Completing this preliminary sizing, the analyst generates a set of specifications for the designer, which are used to develop the initial design. Typically, these specifications are written documents and spreadsheets that the designer uses to develop the boundaries of plies and schematics of cross sections. Converting these specifications into the combination of geometric and nongeometric data necessary for the initial design is difficult and time consuming.

However, with the Fibersim™ portfolio of software for composites engineering from Siemens PLM Software, this specification can be imported directly into the design model in the form of a simple neutral file. Fibersim, which helps manufacturers unravel the complexities of these materials by supporting the entire composites engineering process, enables this data to be easily integrated so the designer can specify rules that automate the creation of the complete ply definition. Figure 1 shows a thickness plot of an analysis model from which the zone input was created, and the resulting designed part with the plies fully developed with automated substructure avoidance and drop-off rules imposed. Identifying key information to share, as in this example, helps define the framework for data exchange.

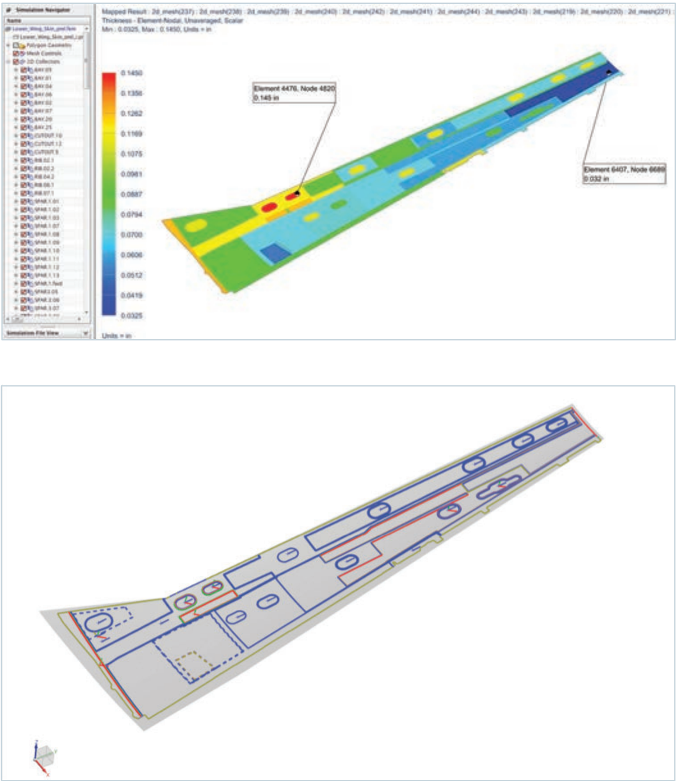
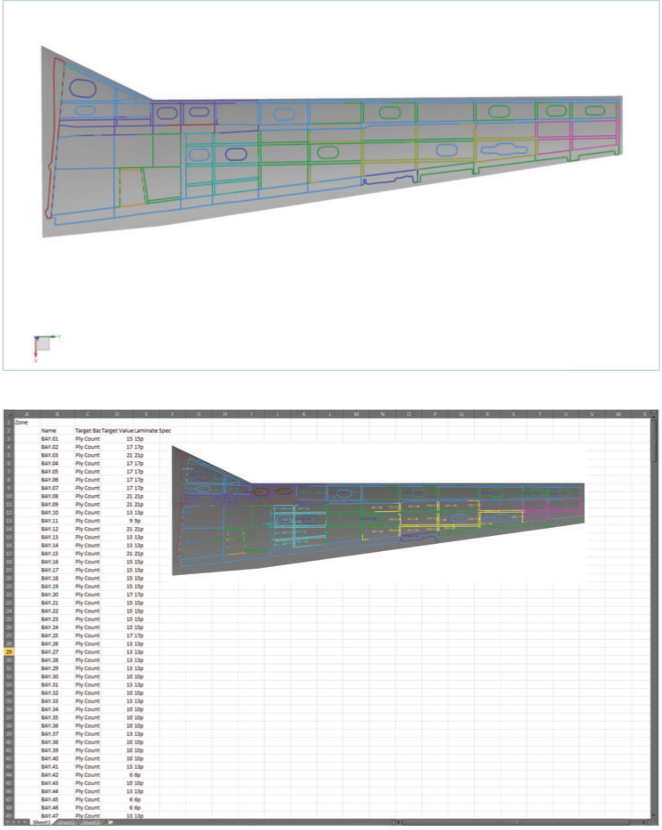


Figure 1: FEA thickness plot (top) and CAD detailed ply design (bottom).

Developing an initial definition

In composites, the first touch points are regions or zones built from the loft surface and system lines, typically provided by the systems group, and from the material specifications and sizing data provided by the analysis group. These key elements are unlikely to change too frequently or drastically and represent information that can be usefully shared. However, if this information changes, it must be rapidly updated without error. Figure 2 shows an example of this kind of information.

The granularity of zone definitions is of great importance when designing for reduced weight. Sometimes there is a resistance to defining too many zones since the management of the related information is complex. Allowing the easy updating and communication of this information makes increasing the granularity of zones more straightforward. Increasing the granularity of zones by intelligently decreasing the size can help to improve the accuracy of the design and reduce weight by as much as 15 percent.



Zone

Name	Target Bas	Target Value	Laminate Spec
BAY.01	Ply Count	15	15p
BAY.02	Ply Count	17	17p
BAY.03	Ply Count	21	21p
BAY.04	Ply Count	17	17p
BAY.05	Ply Count	17	17p
BAY.06	Ply Count	17	17p
BAY.07	Ply Count	17	17p
BAY.08	Ply Count	21	21p
BAY.09	Ply Count	21	21p
BAY.10	Ply Count	13	13p
BAY.11	Ply Count	9	9p
BAY.12	Ply Count	21	21p
BAY.13	Ply Count	13	13p
BAY.14	Ply Count	13	13p
BAY.15	Ply Count	21	21p
BAY.16	Ply Count	15	15p
BAY.17	Ply Count	15	15p
BAY.18	Ply Count	15	15p
BAY.19	Ply Count	15	15p
BAY.20	Ply Count	17	17p
BAY.21	Ply Count	15	15p
BAY.22	Ply Count	15	15p
BAY.23	Ply Count	15	15p
BAY.24	Ply Count	15	15p
BAY.25	Ply Count	17	17p
BAY.26	Ply Count	13	13p
BAY.27	Ply Count	13	13p
BAY.28	Ply Count	13	13p
BAY.29	Ply Count	13	13p
BAY.30	Ply Count	10	10p
BAY.31	Ply Count	13	13p
BAY.32	Ply Count	10	10p
BAY.33	Ply Count	13	13p
BAY.34	Ply Count	10	10p
BAY.35	Ply Count	10	10p
BAY.36	Ply Count	10	10p
BAY.37	Ply Count	13	13p
BAY.38	Ply Count	10	10p
BAY.39	Ply Count	10	10p
BAY.40	Ply Count	10	10p
BAY.41	Ply Count	13	13p
BAY.42	Ply Count	6	6p
BAY.43	Ply Count	10	10p
BAY.44	Ply Count	13	13p
BAY.45	Ply Count	6	6p
BAY.46	Ply Count	6	6p
BAY.47	Ply Count	13	13p

Figure 2: Zone-based definition exchanged between CAD (top) and CAE (bottom).

Improving quality by facilitating more design-analysis cycles

Although the designer and analyst typically use different engineering software, collaboration between them is greatly enhanced when both are working with shared geometry through native CAD interfaces that allow an automated response to design changes. The analyst can directly use system lines and zone partitioning to create and control a mesh of shell or membrane elements for a composite skin, or lines of beams or bars for stiffening elements. And the analyst can easily communicate zone and laminate requirements back to the designer. This makes it easier and faster to refine zones to improve the definition of the analysis model, thereby making the process of weight optimization more tractable.

Since designing composite parts involves more unknowns and interdependencies than a metallic part, a serial product development process eliminates opportunities to make the complex adjustments necessary to improve a design. This reduces the design advantages that are specific to composites, such as tailoring material orientation. Serial processes also routinely inflate design allowances and safety factors, effectively treating composites as "black aluminum" and forgoing the benefits to be gained by designing for the unique properties of the material. 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 3.

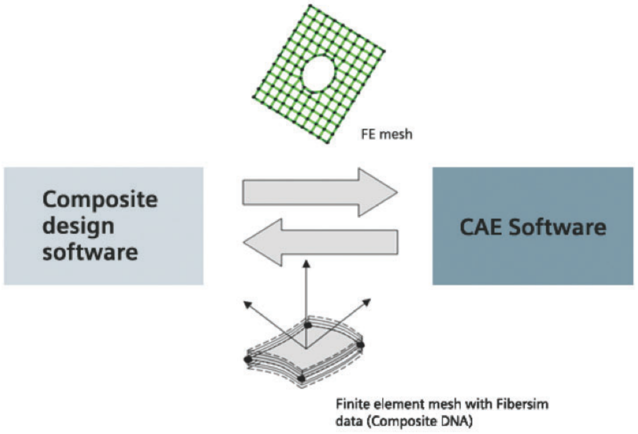


Figure 3: Exchange of composites information from design tool to analysis tool enhances collaboration.

For example, in preliminary design there is usually very little detail about 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.

Once detailed design begins, analysts need to provide updated definitions of the laminates for the design engineers. This may be to account for new load cases or simply because the analysis has been updated to a more accurate level. Being able to easily and accurately communicate this information to the design engineer, who has begun to define the final design, is critical. 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 producing world-class products and products that fail to meet specification.

Finally, before official release of the design, it needs to be verified to ensure that the design meets the specification as defined in the customer requirements. It may require simply documenting that the design, as prepared for release to in-house manufacturing or the supply chain, contains the essential elements of the design as the analyst indicated, or it may require a full analysis of the design to ensure it will function as required.

Bridging the gap between composites design and analysis

The state of the art in composites development has advanced sufficiently so that the focus is on overall structural and design optimization rather than traditional manufacturing concerns, such as drapability or void formation. So the challenge of moving the state of the art forward has more to do with inefficiencies in the composites engineering process rather than composite material technology per se.

For example, an efficient, Fibersim-based composites engineering process may proceed as follows: 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 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 as well as loads and boundary conditions. Iterations that take place now involve concurrent data exchange between Fibersim and computer-aided engineering (CAE) systems. Figure 4 shows an example of this workflow.

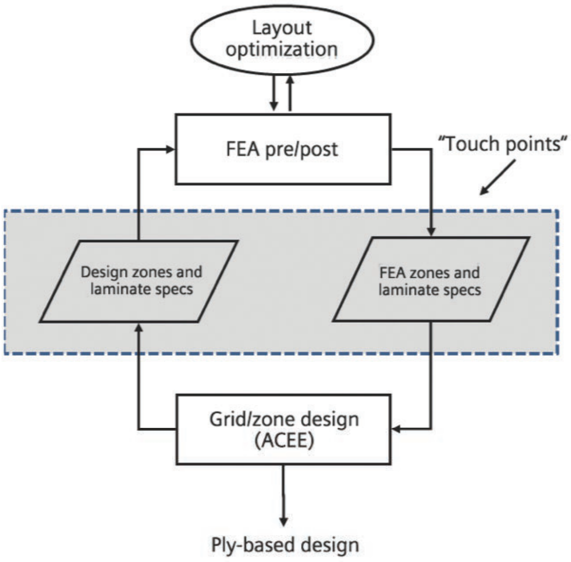
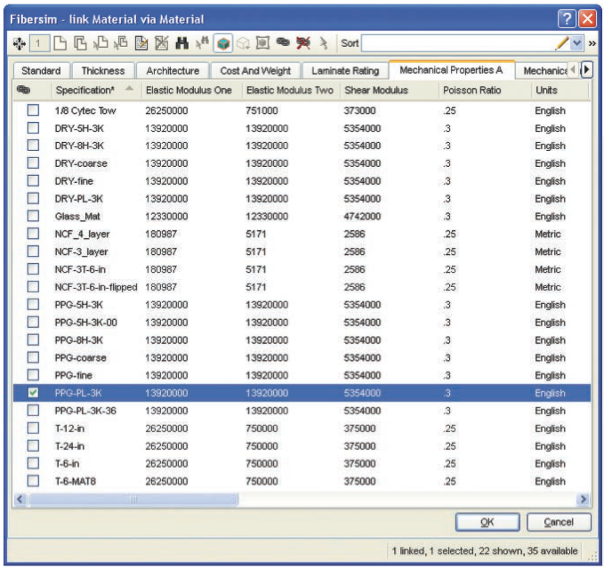


Figure 4: Pictured is the workflow between design and analysis that captures touch points.

Sharing this rich composite data between Fibersim and computer-aided engineering (CAE) systems lets analysts directly apply 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, the common access to native geometry exposes named attributes from the CAD system, which supports automated responses to design changes.

Another important area that Fibersim can be used to address is the assignment of physical properties. The capability to seamlessly share detailed layup and material specifications helps the analyst's efficiency and productivity, and has a significant impact on the accuracy of a design. Figure 5 shows the materials database in Fibersim.



	Specification*	Elastic Modulus One	Elastic Modulus Two	Shear Modulus	Poisson Ratio	Units
☐	1/8 Cytec Tow	26250000	751000	373000	.25	English
☐	DRY-5H-3K	13920000	13920000	5354000	.3	English
☐	DRY-8H-3K	13920000	13920000	5354000	.3	English
☐	DRY-coarse	13920000	13920000	5354000	.3	English
☐	DRY-fine	13920000	13920000	5354000	.3	English
☐	DRY-PL-3K	13920000	13920000	5354000	.3	English
☐	Glass_Mat	12330000	12330000	4742000	.3	English
☐	NCF_4_layer	180987	5171	2586	.25	Metric
☐	NCF-3_layer	180987	5171	2586	.25	Metric
☐	NCF-3T-6-in	180987	5171	2586	.25	Metric
☐	NCF-3T-6-in-flipped	180987	5171	2586	.25	Metric
☐	PPG-5H-3K	13920000	13920000	5354000	.3	English
☐	PPG-5H-3K-00	13920000	13920000	5354000	.3	English
☐	PPG-8H-3K	13920000	13920000	5354000	.3	English
☐	PPG-coarse	13920000	13920000	5354000	.3	English
☐	PPG-fine	13920000	13920000	5354000	.3	English
☑	PPG-PL-3K	13920000	13920000	5354000	.3	English
☐	PPG-PL-3K-36	13920000	13920000	5354000	.3	English
☐	T-12-in	26250000	750000	375000	.25	English
☐	T-24-in	26250000	750000	375000	.25	English
☐	T-6-in	26250000	750000	375000	.25	English
☐	T-6-MAT8	26250000	750000	375000	.25	English

1 linked, 1 selected, 22 shown, 35 available

Figure 5: The materials database allows the user to assign for physical properties plies within Fibersim.

Bridging the gap between analysis and design by defining common material parameters supports everything from simple linear static to nonlinear buckling and progressive failure analyses.

The sharing of the Fibersim-based composite definition across disciplines allows the seamless exchange and optimization of designs. For example, using a common geometry slashes the number of complicated dependency failures because the logical relationships implicit in the logical structure of the composite design persist between Fibersim and CAE systems, thus removing the need for frequent, complicated refreshes. By using Fibersim, all changes flow from a constrained set of sources and allow for easy, automated remeshing in analysis as well as the automated translation and updating of designs.

For example, when designing a fuselage panel, this approach assigns new specifications to zones. Figure 6 shows the underlying datum definitions from the assembly. These datum definitions are shown in magenta and represent the footprints of the underlying substructure. These will drive the composite part definition so being able to link the underlying definition of the assembly to the composite definition is important.

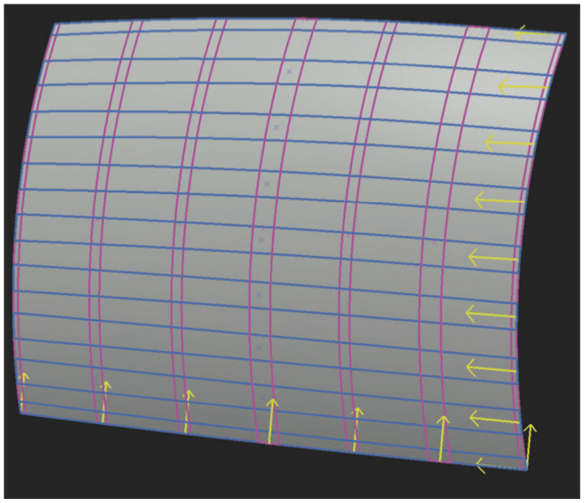


Figure 6: Datum definitions shown as substructure requirements geometry captured within Fibersim.

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 7 shows analysis zone definitions automatically derived from the substructure definitions and laminate requirements.

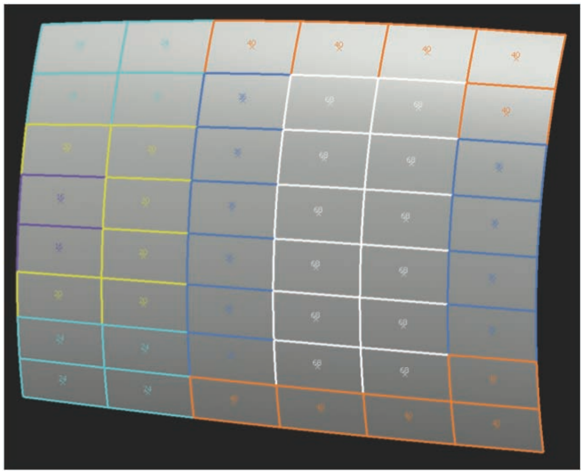


Figure 7: Analysis zone definitions automatically derived from substructure and laminate requirements by Fibersim.

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 detailed analysis data to the end ply definitions makes the iterative and evolutionary process of design more manageable, even in the case of complex designs. Figure 8 shows design zones derived from the analysis zones.

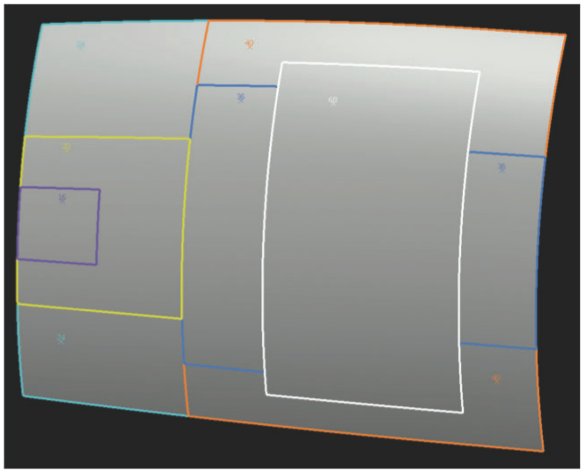


Figure 8: Design zone definitions can be automatically derived from analysis zone definitions with Fibersim.

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

Even with the detailed design almost finalized, the shared geometry can further support collaboration for design validation. As an example, the analyst can access mesh control curves in the design definition, enabling that person to include the effects of ply drop-offs for precision meshing in the CAE system. This would be an impossible task without taking this kind of powerful approach.

Fibersim provides the capability to define composite structures with enough fidelity that the specialized details of a design are captured and communicated throughout the process. It communicates this definition without loss of data provided by a variety of structural and thermal analysis software packages. This workflow is illustrated in Figure 9.

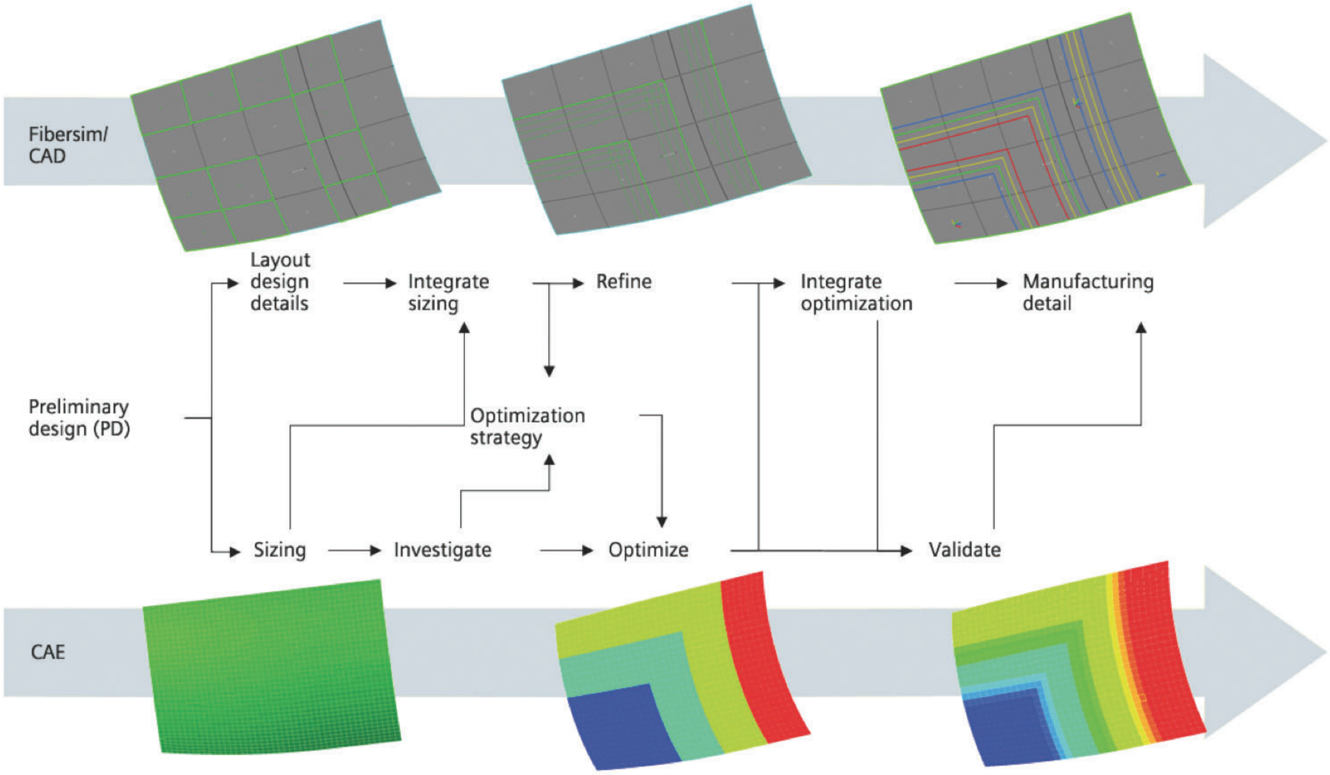


Figure 9: Pictured are the parallel and integrated design and analysis workflows using Fibersim in conjunction with CAE tools.

This integration ties together the disciplines of CAD and CAE, facilitating concurrent engineering from preliminary sizing through validation of final models with detailed ply-based part definitions. This dramatically improves the process and makes optimizing for reduced weight more efficient.

Considering the effect of the manufacturing process on weight

Often the choice of manufacturing process adds weight, sometimes unexpectedly, to a composite part. For example, a machine characteristic, such as minimum course deposition, induces a design constraint that affects ply contour and stagger layout, or interferes with a mating part footprint and modifies part weight. Therefore, such constraints must be an integral part of the design parameters, and cannot be left to manufacturing to deal with due to the risk of unforeseen and costly iterations or uncontrolled overdesign that will lead to heavier parts.

By working closely with the manufacturers of fiber placement machines, tape laying systems and computer-aided manufacturing (CAM) software for composites, an initial set of requirements has emerged that enhances the designer's environment so that he can use Fibersim to fully define and optimize the design of composite components or assemblies for automated manufacturing.

For example, most if not all fiber placement systems and some tape laying systems cannot layup less than a minimum length of fiber or tape material, usually a few inches. This minimum course length requirement influences the corner shape of +/-45 degree plies.

In a design, many ply corners must be modified to account for this minimum deposition rule as shown in Figure 10. Such corner treatments – called diamond shape, bird beaks, or dog or bat ears, depending on the manufacturing company – have an impact on the design. They can affect part weight, ply staggers and stress concentrations. As part of an efficient and robust development process, Fibersim enables you to ensure that the overall ply layout is consistent with minimum course length requirements. By using this approach, modifications that are necessary to achieve manufacturability are included in the design and don't add unforeseen weight to a composite part.

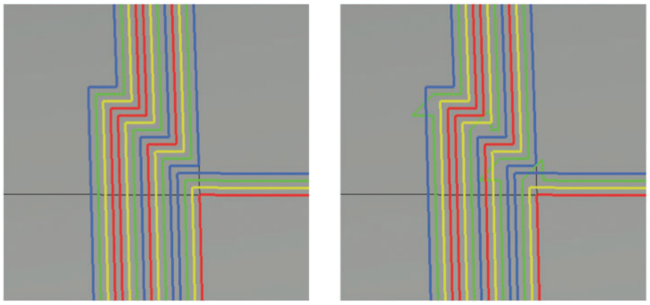


Figure 10: The left image shows a build up of ply corners without accommodation for minimum course length. The right image shows applied corner treatments, which increase manufacturability but also add weight to the part.

Conclusion

There are many benefits to having better tools and processes for composite structure development. First, they enable design teams to make modifications earlier in the development process and accommodate changes later in the process to enhance optimization. Second, they allow analysts to perform more accurate analyses on the as-designed part definition using the true material properties. And third, you can account for how material additions affect manufacturability in the design process and thereby avoid unforeseen weight variations in the finished part.

This approach to concurrent composite engineering uses a parallel workflow that supports more and faster design iterations. Both designers and analysts can continue working while synchronizing significant changes. Ultimately, this improvement in the process helps design teams fully optimize designs and reduce weight. What's more, the technique cuts the risks, program costs and potential liabilities associated with the use of new materials and novel technologies.

All of these capabilities are made possible by using Fibersim to develop a design definition that captures the part type-specific DNA of composite structures, and provides high fidelity between the CAD and CAE representations of the design.

This approach saves money and time and leads to more competitive products that enable aerospace organizations to extract the most value from using composites.

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