

Siemens PLM Software

# Optimizing composite aerostructure designs to increase production rate

## White Paper

The increased use of composite materials in aircraft introduces production rate constraints that were not an issue when aerostructures were made mostly out of metal. In order for aircraft with a high content of composites to continue to lead the industry, the design of these high tech materials must evolve to support higher production rates. The right engineering tools are essential to optimizing design for increased production rate.

**Answers for industry.**

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# Executive summary

The use of composite materials in the commercial aerospace industry has increased dramatically in the last decade, and carbon fiber reinforced plastic (CFRP) is the primary material of choice. This trend is seen for all types and sizes of commercial airplanes, including wide body, regional, business as well as general aviation aircraft.

As part of achieving excellence in aircraft development, especially when a high percentage of the airframe is made of composite materials, affordability must be a key consideration early in the conceptualization of the aircraft. This must be addressed in plans for configuring the aircraft, achieving schedule and rate within target cost, reducing defects and incorporating a robust development process that enables error-free changes.

Because of the unique nature of composite materials, modern aerostructures are more complex to design and manufacture. This is due in large part to the interdependence of the composite structure with the entire airframe assembly. Creating the initial designs and making subsequent changes to these complex aerostructures is more time-consuming and potentially more error-prone than a traditional metallic aircraft.

Composite manufacturing also presents unique challenges, including limitations on speed relative to metallic part fabrication. These comparatively slower manufacturing processes decrease the rate of production that is required to achieve maximum profitability.

# Providing a framework for decreasing cost and increasing production rate

All of the stakeholders in composite structure development must work concurrently and collaboratively to develop a composite design that is optimized for a high production rate. There are many factors that affect the production rate of a composite structure.

For example, if the design is not optimized for weight, then it is quite likely that too much material is in the part. Since composite manufacturing is predominately an additive manufacturing process, the laying down of extra material adds time and uses more resources than necessary to meet design requirements. Both of these factors drive cost and decrease rate.

Another concern is the integration of the composite part into the overall aerostructure. You must consider how to consolidate parts versus using traditional assembly methods, the cost considerations of both approaches, and the impact on the production rate.

The needs of analysis, design, manufacturing and quality organizations must all be incorporated into the decision of how best to improve the production rate for composite aerostructures. This means integrating the disciplines in a way that enables all the stakeholders to be able to collaboratively optimize their processes.

The central hurdle to integrating the development team to efficiently execute their responsibilities so they can increase their production rate begins with having an appropriate definition of the design.

If a consistent and complete definition can be created that captures the full “DNA” of the design, it becomes much more straightforward for the development team to make intelligent design decisions that increase rate and allow the overall production process to move more rapidly.

The key is to develop an overall framework for affordability that includes all the disciplines required to optimize the

aerostructure design for cost and production rate. A collaborative framework for affordability allows the development organization to focus on a few key metrics, including:

- Achieving rate at target cost
- Meeting deadlines
- Meeting specifications, particularly with regard to weight
- Implementing robust aircraft development processes that produce high-quality products

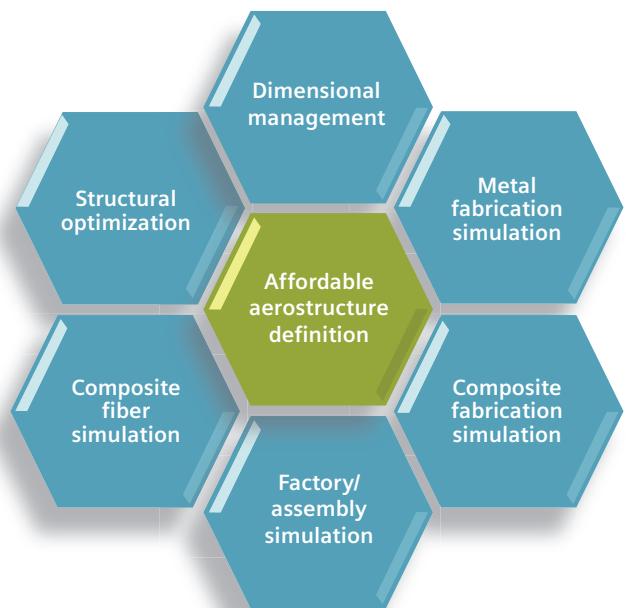


Figure 1. Framework for increasing production rate based on consistent and complete aerostructure definition.

In turn, success in each one of these areas requires an emphasis on key engineering disciplines that affect design, such as:

#### **Dimensional management**

Dimensional management is a discipline that simulates manufacturing and assembly processes, and predicts the amount and causes of variation. A digital prototype is used to create a comprehensive representation of geometry, product variation (tolerances), assembly process variation (sequence, assembly attachment definition, tooling) and measurements. This model is used to predict if there will be any assembly build problems before physical parts are made or tooling is cut. This is particularly important in the design of composite aerostructures since the thickness of a composite part can be variable and require sufficient foresight to avoid assembly issues.

#### **Structural optimization**

Structural optimization is done to help specify the materials to use and the thickness, size and cross-section shape of the structural members on the aircraft. This work is done in collaboration between the design and analysis groups to evolve the design so that it is as light as possible while still meeting safety requirements. At this point, key design decisions affecting cost and rate of production are made.

#### **Composite design and fiber simulation**

This is a key part of the aerostructure design challenge and requires design engineers to create increasingly detailed definitions of the design that can be used to communicate with the analysis and manufacturing groups. One major challenge is that the complexity of the design definition is often difficult to communicate during the engineering process, and makes a truly accurate analysis of a composite structure hard to achieve. This leads to approximations and ambiguity in the design. Another key challenge is that 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 that the fundamental material properties of the composite structure are often misunderstood since the orientation of the fibers are central to the definition. The design engineers must take these factors into account and create a definition that is easily repurposed by the analysis and manufacturing groups to assure successful execution of the program.

#### **Factory simulation**

Factory simulations are used by manufacturing engineers to create virtual definitions of the production operation at various levels. These virtual definitions allow for individual processes, the flow of operations and the management of suppliers to be optimized for the fastest possible production rate.

#### **Part fabrication simulation**

It is essential to ensure that the part can be manufactured and is appropriately designed for the manufacturing processes that will be used to produce it. Whether the part is metallic or composite, this is an important step in the handoff between design and manufacturing.

Each of these areas offers potential for reducing cost and improving rate. However, due to the increased use of carbon fiber composite material in aircraft, several areas standout, including:

- Increasing rate by reducing the weight of the part through optimization
- Increasing rate by reducing the weight of the part by better communicating data between design and analysis
- Consolidating parts to minimize assembly procedures
- More quickly bringing the part into optimized, high-volume production

In the next sections, we will discuss how these four areas affect cost and production rate.

# Increasing rate by optimizing for reduced weight

Just a single unneeded ply distributed over the total size of any of the modern composite aircraft can result in a significant loss of time in manufacturing. There is great incentive to find and eliminate such overdesign, 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 amount of material in a composite part is driven by the number of layers. 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 preliminary sizing of a composite structure.

Because composite parts that weigh more have more material in them, optimizing a design to reduce weight and thereby reduce the amount of material used in manufacturing, increases rate. Because the designer and the analyst typically use different engineering software for optimization, collaboration between them is greatly enhanced when both are working with shared geometry through native computer-aided design (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 to refine zones to improve the definition of the analysis model, and speeds the operation, thereby making the process of weight optimization more tractable. This ultimately leads to a higher rate of producing parts.

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 2.

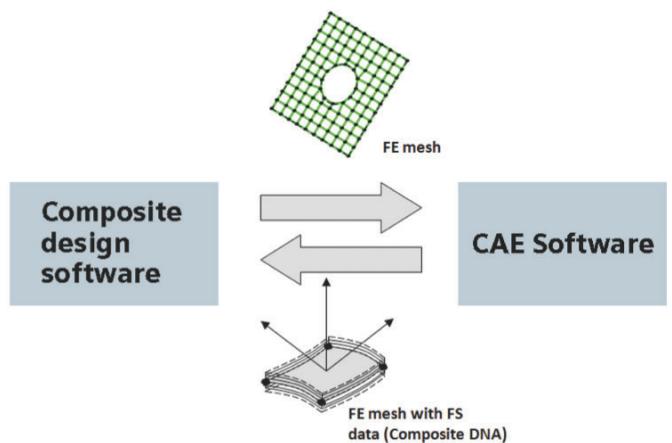


Figure 2. Exchange of composites information from the design tool to the analysis tool enhances collaboration.

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 that are 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.

By 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 non-geometric 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 design rules that automate the creation of the complete ply definition. Figure 3 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.

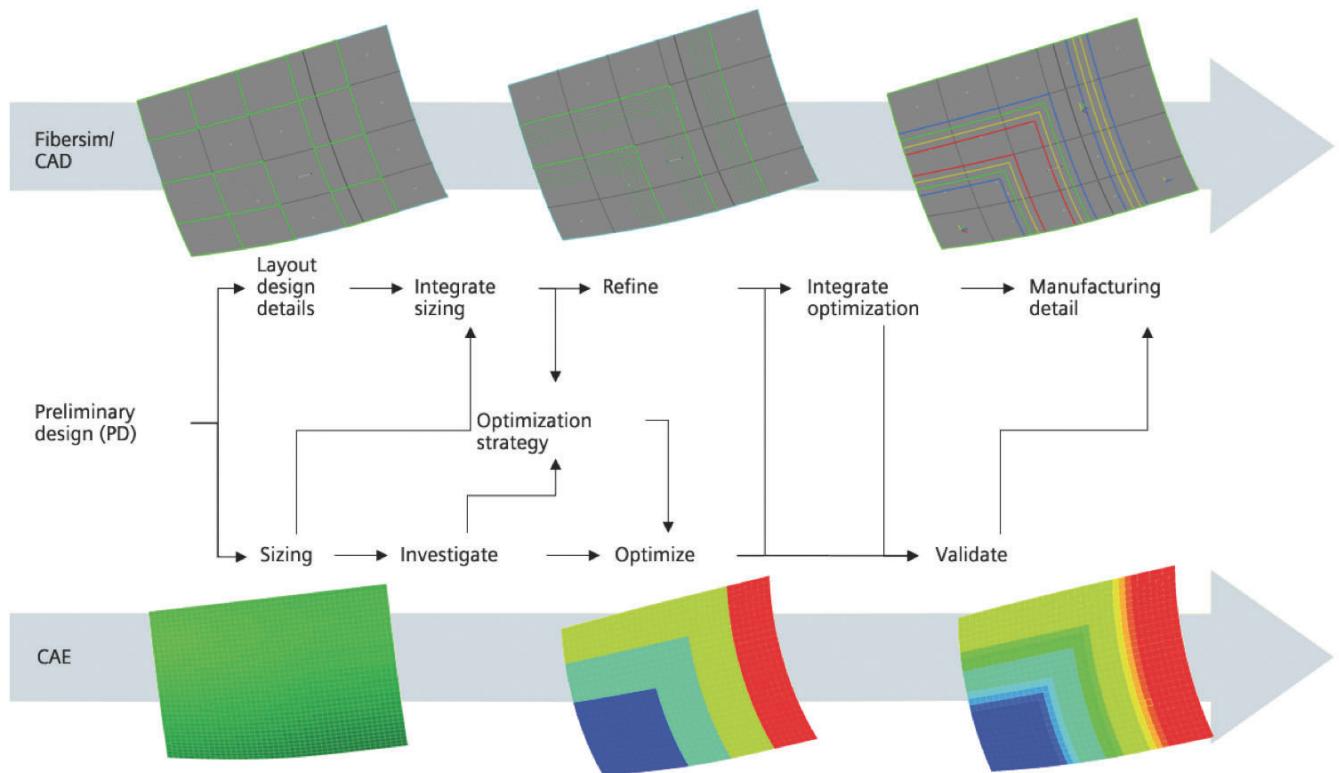


Figure 3. Pictured are the parallel and integrated design and analysis workflows using Fibersim in conjunction with CAE tools.

# Increasing rate by facilitating more design-analysis cycles

The state of the art in composite 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 composite engineering process than composite material technology per se.

For example, an efficient, composite 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 non-structural 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. As a result, iterations that take place involve concurrent data exchange between the design tool and computer-aided engineering (CAE) systems. Figure 4 shows the example workflow.

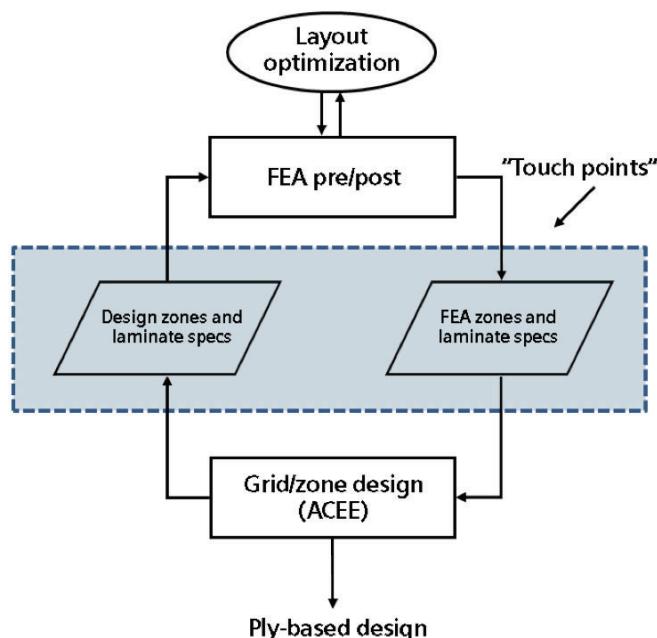


Figure 4. Pictured is the workflow between design and analysis that captures touch points.

Sharing this intelligent composite data between CAD 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, the common access to native geometry exposes named attributes from the CAD system, which supports automated responses to design changes.

Although the designer and the 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 to refine the zones to improve the definition of the analysis model, and speeds the process, thereby making the process of weight optimization more tractable.

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Another important area 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 a design's accuracy. Figure 5 shows the materials database in 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 re-meshing in analysis as well as the automated translation and updating of designs.

The screenshot shows a software interface titled "Fibersim - Link Material via Material". The window has a toolbar at the top with various icons. Below the toolbar is a menu bar with "File", "Edit", "View", "Insert", "Format", "Tools", "Help", and "Sort". The main area is a table with columns: Standard, Thickness, Architecture, Cost And Weight, Laminate Rating, Mechanical Properties A, and Mechanical B. The rows list various composite materials with their properties. One row, "PPG-PL-3K", is selected and highlighted with a blue border. At the bottom of the table, there are buttons for "OK" and "Cancel". A status bar at the bottom right indicates "1 linked, 1 selected, 22 shown, 35 available".

Standard	Thickness	Architecture	Cost And Weight	Laminate Rating	Mechanical Properties A	Mechanical B
Specification*						
<input type="checkbox"/> 1/8 Cytec Tow	26250000	751000	373000	.25	English	
<input type="checkbox"/> DRY-SH-3K	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> DRY-8H-3K	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> DRY-coarse	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> DRY-fine	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> DRY-PL-3K	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> Glass_Mat	12330000	12330000	4742000	.3	English	
<input type="checkbox"/> NCF_4_Layer	180987	5171	2586	.25	Metric	
<input type="checkbox"/> NCF-3_Layer	180987	5171	2586	.25	Metric	
<input type="checkbox"/> NCF-3T-6-in	180987	5171	2586	.25	Metric	
<input type="checkbox"/> NCF-3T-6-in-flipped	180987	5171	2586	.25	Metric	
<input type="checkbox"/> PPG-5H-3K	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> PPG-5H-3K-00	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> PPG-8H-3K	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> PPG-coarse	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> PPG-fine	13920000	13920000	5354000	.3	English	
<input checked="" type="checkbox"/> PPG-PL-3K	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> PPG-PL-3K-36	13920000	13920000	5354000	.3	English	
<input type="checkbox"/> T-12-in	26250000	750000	375000	.25	English	
<input type="checkbox"/> T-24-in	26250000	750000	375000	.25	English	
<input type="checkbox"/> T-6-in	26250000	750000	375000	.25	English	
<input type="checkbox"/> T-6-MAT8	26250000	750000	375000	.25	English	

Figure 5. Materials database that allows the user to assign for physical properties plies within Fibersim.

# Part consolidation and improving assembly efficiency

Increasing the production rate for composite structures comes not only from optimizing individual parts, but also by improving manufacturability of the overall assembly. This can be achieved by two methods; reducing the number of parts by consolidating the structure, and/or making the assemblies more efficiently.

Aircraft structures have thousands of parts and hundreds of thousands of fasteners. Drilling holes and installing fasteners is a major source of effort and rework in aircraft manufacturing.

If the number of fasteners is reduced, assembly costs and time can be drastically reduced. Consolidation of multiple part designs into a single part either through basic redesign or bonding can reduce the number of fasteners. This requires a multidisciplinary approach to reconfiguring the design of a traditional aircraft to make this kind of consolidation possible.

Exploring design alternatives and easily creating the detailed designs for the newly configured structure is a much more straightforward with the appropriate design tools. Fibersim allows the investigation and rapid iteration necessary to determine the design that best consolidates parts, making it the most efficient and profitable design to manufacture.

Another approach is simply to make the use of fasteners more efficient by more tightly controlling the definition of the holes and fasteners in the bill of materials (BOM) that are part of the evolution of the composite structure. By employing a more rigorous approach to the management of fastener and hole definitions, the structure can be assembled more quickly at lower cost.

Developing intermediate assembly states directly derived from the released engineering dataset, which are easily and rapidly updatable based on changes in the engineering definition, is at the core of making assemblies with a large number of fasteners that can be manufactured more quickly and profitably. This is especially true now that there is a higher percentage of composites in an airframe. Rework or scrap of parts made from composite materials can cost an order of magnitude more than the legacy aluminum parts they are replacing.

The Syncrofit™ portfolio of software for designing and manufacturing complex airframe assembly from Siemens PLM Software is designed to address this concern. It makes the design and manufacture of complex aircraft assemblies much more straightforward. Importantly, it addresses the change process directly, enabling the swift and accurate update of manufacturing data based on the evolving engineering definition.

Using Syncrofit in combination with the Tecnomatix® software Manufacturing Process Planner and Process Simulate gives the development team heretofore unheard of control over fastener definitions. This makes the process faster, less error-prone and more profitable.

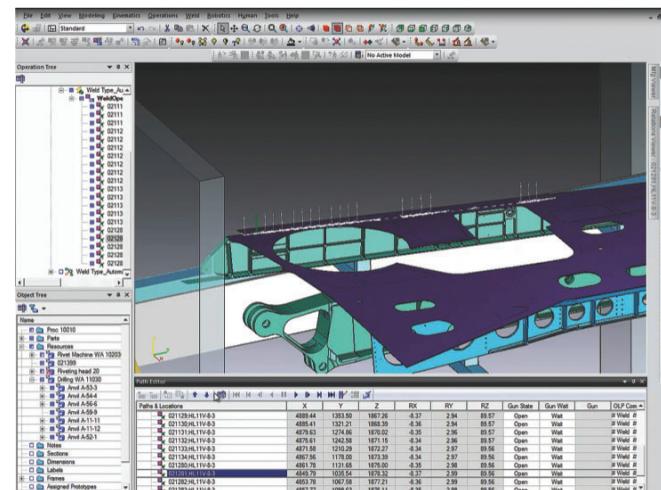


Figure 6. Syncrofit, Manufacturing Process Planner and Process Simulate can be used collaboratively to increase the production rate of airframe assemblies.

# Addressing the manufacturability of the design

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 or she 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 lay up less than a minimum length of fiber or tape material, usually a few inches. This minimum course length requirement affects 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 8. Such corner treatments – called diamond shape, bird beaks, dog ears or bat ears, depending on the manufacturing company – have an impact on the design. They can affect part weight, ply stagers and stress concentrations. As part of an efficient and robust development process, Fibersim ensures that the overall ply layout is consistent with minimum course extension (MCE) and 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.

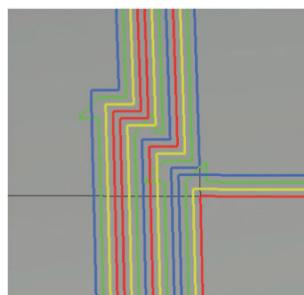


Figure 7: Shown are typical corner treatments, including MCE, which increases manufacturability but adds weight to a part.

# 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. Third, they allow for more control over the airframe assembly definition process. And fourth, they account for how material additions affect manufacturability in the design process, thereby avoiding 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 that will have a higher production rate. 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 and Syncrofit 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.

## Siemens Industry Software

### Headquarters

Granite Park One  
5800 Granite Parkway  
Suite 600  
Plano, TX 75024  
USA  
+1 972 987 3000

### Americas

Granite Park One  
5800 Granite Parkway  
Suite 600  
Plano, TX 75024  
USA  
+1 314 264 8499

### Europe

Stephenson House  
Sir William Siemens Square  
Frimley, Camberley  
Surrey, GU16 8QD  
+44 (0) 1276 413200

### Asia-Pacific

Suites 4301-4302, 43/F  
AIA Kowloon Tower, Landmark East  
100 How Ming Street  
Kwun Tong, Kowloon  
Hong Kong  
+852 2230 3308

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