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Composite A220 wing: MAXIMIZING AIRCRAFT WING FABRICATION, ASSEMBLY

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COLUMNS

FEATURES

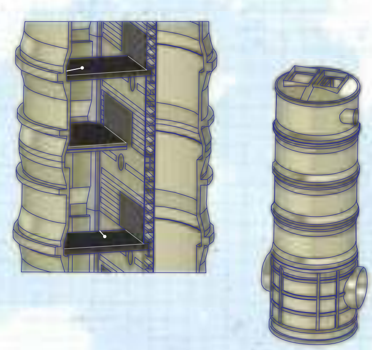
» DEPARTMENTS

» ON THE COVER

At its dedicated wing manufacturing facility in Belfast, Northern Ireland, Spirit AeroSystems has perfected its patented resin transfer infusion (RTI) process and assembly activities for the delivery of Airbus A220 wings. Beginning at raw material receipt and ending at final assembly, the 10-year-old facility has effectively prepared the Tier 1 for future programs and production ramp-up. See p. 30.

Source | Spirit AeroSystems

FOCUS ON DESIGN



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The past few weeks have been a whirlwind as I've been transitioning into the role of editor-in-chief of *CompositesWorld*, succeeding Jeff Sloan as he assumes the role of publisher and brand VP for *CW*. It's been an incredibly busy and exciting time as I've been getting up to speed with the latest in the industry, while also picking back up a few familiar threads. It's been fascinating seeing progress made with ongoing R&D projects such as the Clean Sky 2/Clean Aviation Multifunctional Fuselage Demonstrator (MFFD), the subject of Ginger Gardiner's feature story from the July issue of *CW*. I've also been amazed to see so many advanced air mobility (AAM) vehicles that were early prototypes during my previous stint seemingly nearing entry into service as air taxis. Suffice it to say, I've kept a curious eye on news from the composites industry during my time reporting on other areas of manufacturing, yet there's still been plenty to catch up on.

> This year marks the fifth annual National Composites Week.

As I reenter the composites community, I've begun to reconnect with these ongoing stories and projects. One of the initiatives I was involved with back in 2019 was the launch of National Composites Week (NCW), a week devoted to celebrating the ways in which composites enable innovations in a wide range of industries. Annually taking place the last full week of August, NCW was launched through a collaboration between braided textile provider A&P Technology, advanced materials supplier Hexcel and *CompositesWorld*.

Since its inception, NCW has grown in scope and support with participants such as the ACMA, SAMPE and Composites One. Each year, the celebration puts a focus on an aspect of the role composites play in our world. NCW has put a spotlight on how essential composites are for a whole host of applications ranging from aerospace to infrastructure. It has highlighted the ways composites help move environmental and sustainability efforts forward, from enabling wind energy to lowering carbon emissions through lightweighting in automotive and transportation markets.

This year will mark the fifth annual National Composites Week, which will take place August 21-25, 2023. The theme of this year's event is "Composites Are Now!" recognizing the ways composites are shaping the world today. So many applications that once seemed far-fetched are now a reality because of composites. From advances in aerospace to the advent of AAM, composites are changing the way we travel. As NASA's Artemis program works toward returning people to the moon and commercial space companies make increasingly impressive milestones, these materials are playing a large role in what is proving to be a new golden age of space exploration.

The composites community has much to celebrate and spread the word about. NCW encourages those involved in the composites industry — raw material suppliers, designers, toolmakers, fabricators, educators, students — to bring attention to the role composite materials and fabrication processes play in the manufacturing world at large. Social media, traditional media and in-person events are a great way to bring attention to your operations, capabilities and products. Give shout-outs to your team via social media, share a video demonstration of your product or process, open your doors to the public for an educational event or conduct a virtual tour. Shine a light on the contributions your company makes to our world. Tag *CW* in your social media posts and we'll happily reshare and help spread the word. Make sure to use the hashtags #NationalCompositesWeek and #CompositesAreNow.

For more information visit **nationalcompositesweek.com**. You'll find a helpful guide and downloadable tools and templates designed to help you develop and execute NCW events and outreach for your facility. We encourage you to get involved and share your story about the important work you do.

SCOTT FRANCIS — Editor-In-Chief

What OceanGate teaches us

Deep diving

Cyclops-class submersible, *Titan*, undergoing dive operations, as reported by OceanGate in October 2019. Source | OceanGate

When I first heard, on June 18, the news that OceanGate had lost contact with its *Titan* submersible during a dive to the Titanic wreck, I was immediately taken back to early 2017 and my interview with OceanGate CEO Stockton Rush. I had spoken to Rush for about an hour about the unprecedented application of carbon fiber composites in the fabrication of the hull of *Cyclops 2*, *Titan*'s predecessor. The reason for the interview was to gather information for a story I subsequently wrote for *CW*, published in May 2017 (which you can find on the *CW* site).

The story was part of our Focus on Design series, which, as the name implies, focuses on design and materials use decisions in the engineering of a composite part or structure. My interview with Rush revolved around four main topics: The unusual pressure and cyclic loading of the deep-sea environment, Rush's stated need for weight reduction in deep-sea submersibles, the design parameters and performance requirements of a carbon fiber composite hull and the safety considerations to be taken into account when operating a deep-sea submersible.

My impression during the interview was that Rush was passionate about deep-sea exploration and had invested much of his personal fortune and energy in development of what he hoped would be a lightweight, durable submersible capable of multiple missions — mostly for scientific purposes. I also got the impression that Rush, although obviously familiar with the basics of composite materials and composites manufacturing, lacked the kind of in-depth knowledge that one might need to develop a high-performance carbon fiber hull of the type he had in mind. Still, Rush had engaged several reputable composite material and technology suppliers to develop the hull, and all of them had significant knowledge and experience. I hoped/assumed Rush would apply whatever expertise they might have shared with him.

A few days after OceanGate reported loss of contact with *Titan*, the U.S. Navy reported that on the day of contact loss and near the area of contact loss, its sensors had detected "an acoustic anomaly consistent with an implosion." The subsequent discovery on the ocean floor of *Titan*'s remains confirmed our fears that Rush and his four passengers had been lost.

The U.S. Coast Guard and other specialists will assess the wreckage and other data and, I hope, eventually report the cause of *Titan*'s demise. In the meantime, we are left to assess the information available to us, which is voluminous. This has given birth to robust, passionate and widespread speculation (some of it informed, some of it not) about the cause of *Titan*'s implosion, along with even more speculation about who was to blame. This occurred in mass media outlets like *The New York Times*, *The Washington Post* and *The New Yorker*, plus a litany of social media channels. *CompositesWorld* got into the act on LinkedIn.

Fruit of the poisonous tree

A byproduct of this speculation is a "fruit of the poisonous tree" phenomenon that sometimes occurs — that is, a tendency to heap blame on everything and everyone associated with the accident. In this case, everyone and everything associated with OceanGate and *Titan*. Interviews (including mine with Rush), videos and documents of and about Rush and the development of *Titan* were unearthed and pointed to as proof of Rush's arrogance, hubris and carelessness. Rush was criticized for not subjecting *Titan* to classification, which might have detected the flaws apparently built into the submersible. Rush was vilified as a wealthy, entitled, risk-taker who callously sacrificed his life and the lives of his passengers in pursuit of more wealth and notoriety.

On the materials front, other fruit from this poisonous tree included carbon fiber composites, titanium, acrylic polymer (used in *Titan*'s viewport) and even the Sony PlayStation controller used to operate *Titan*. Carbon fiber composites received particular vitriol. There was discussion about carbon fiber's performance in tension (good) and compression (not as good). There was discussion about whether the safety factor (2.25) of the hull's design was sufficient for the application. There was discussion about the hull's fabrication and whether OceanGate had tested appropriately for porosity. There was discussion about cyclic loading on the hull during dives and the lack of testing between dives. Even James Cameron chimed in, declaring that carbon fiber had no business being applied in the manufacture of a hull for a deep-sea submersible.

Again, some of this criticism about how carbon fiber was applied in the *Titan* hull was made by people with extensive composites experience, and they referenced reliable sources and data to support their arguments. Others, lacking such knowledge, made simply wrong-headed statements about carbon fiber composites — their design, fabrication, capabilities and failure mode. Eventually, particularly in the popular press, carbon fiber itself bore the blame: *Titan*'s implosion was the result of a hull failure, caused by Rush's inappropriate application of carbon fiber composites.

The New Yorker finished its report on the *Titan* accident with this: "But, in 2021, Stockton Rush told an interviewer that he would "like to be remembered as an innovator. I think it was General MacArthur who said, 'You're remembered for the rules you break.' And I've broken some rules to make this." He was sitting in the *Titan*'s hull, docked in the Port of St. John's, the nearest port to the site where he eventually died. "The carbon fiber and titanium? There's a rule you don't do that. Well, I did."

The opportunity exists to learn lessons about how composites should and should not be developed.

The four-legged stool

Of course, anyone who knows composite materials knows it's not that simple, and it's not fair to place blame for *Titan*'s failure at the feet of carbon fiber composites. In fact, this accident, the tragic loss of life notwithstanding, can and should provide an excellent lesson on the important and complex interdependence of materials, design, tooling and fabrication in composites manufacturing.

There's an old saying in the composites industry that says you can make a bad part from a good tool, but you can't make a good part from a bad tool. You can extend this to materials, design and fabrication as well. Fabrication of a composite part that meets the performance requirements of the application depends on intelligent materials selection, robust design engineering, strong tooling development and a well-controlled fabrication regime that includes reliable testing. And, of course, the "requirements of the application" matter. For example, the requirements for the performance of a composite aircraft fuselage are significantly greater than the requirements for the performance of a composite golf club shaft. Regardless of the application, however, failure in any of these core functions imperils the entire structure and can lead to service failure and, in the worst case, loss of life.

This isn't a trivial enterprise. Composites, as the name implies, encompass a vast universe of fiber types, fiber formats, resin types, tooling types and fabrication methods, all of which can be mixed and matched to produce structural parts for a variety of uses — aircraft wings, wind turbine blades, sailboat hulls, electric vehicle battery enclosures.

Linking up these variables in a sensible way requires a level of knowledge and experience that many of you have spent entire careers developing. Lacking this knowledge and experience is not a crime, but if you want to apply composites in a new and interesting way, it's incumbent on you to find the experts who can save you from your ignorance.

What was at risk

Does this mean that carbon fiber composites should not have been applied to the hull of the *Titan*? It does not. The proper combination of materials, design engineering, tooling and fabrication could produce a carbon fiber composite submersible hull capable of doing everything Stockton Rush wanted *Titan* to do — provide repeated and safe deployment in deep-sea exploration.

Accomplishing this would have required that Rush recognize the profound risk represented by his ignorance and submit to the expertise and knowledge that this industry has to offer. That, apparently, was not Rush's modus operandi.

We are, undeniably, attracted to innovators and risk-takers like Rush who "push the envelope" and dare to break rules in an effort to advance human capability and performance. This was the ethos driving creation of the internet, early space exploration and the advent of the airplane, among other human endeavors. But risk-taking depends entirely on the *nature* of the risk. *Titan* was at a depth of 3,500 meters and under 4,993 psi (344 bar) of pressure when it imploded. Such an environment is violent and unforgiving and offers no margin for risk-induced error.

If it were Rush and Rush only in the *Titan* on June 18, we might have said that he pushed the boundaries and paid the price for his aggressiveness. We might have been thankful that no one else was aboard *Titan*. And we might have, more quickly, moved into discussion on how Rush's work could lead to better composite hull designs and safer submersibles.

As it stands, we are angry at Rush for having taken four lives with his and eager — appropriately so — to condemn his arrogance. But the opportunity still exists to learn lessons about how composite structures should and should not be developed.

What, exactly, those lessons are, will be explored by *CW* in the coming weeks. We will assess the technical feasibility of composites use in a submersible and shed much-needed light on how the proper marriage of design, materials, tooling and fabrication can produce a composite hull that meets the performance requirements of a deep-sea environment. CW

ABOUT THE AUTHOR

Jeff Sloan is brand vice president of *CompositesWorld*, and has been engaged in plastics- and composites-industry journalism for 27 years. **jsloan@gardnerweb.com**

The basics of composite drawing interpretation

»Fiber orientation is critical to the performance of any fiber-reinforced polymer (FRP) laminate, especially those used in aerospace structures. Designers carefully choose the fiber type, fiber form (unidirectional, bidirectional, multiaxial, braided, etc.), and primary fiber axial orientation of each ply that goes into the design. The ply orientation requirements are designated on the part drawing using a common system of drawing views, ply tables and orientation symbols. Flag notes are used in the ply table to call out the materials, splice overlaps, fiber orientation tolerances and more. In this article, we clarify how this information is commonly disseminated and understood, to assist those who are tasked with interpreting composite drawings.

First, let's look at the orientation symbol on the drawing, what it represents and how it is applicable to the laminate structure (Fig. 1). Typically, the 0° axis of the symbol designates the primary load direction of the laminate or the global structure. The ISO standard counterclockwise orientation symbol (or some version of it) is found on the plan view of the part — looking at the backside of the laminate, from the layup operator's perspective, the symbol is located exactly where the fiber orientation is controlled and should be inspected on the laminate. It is of great importance to control the fiber axes at this single location, as the fiber directions can change significantly over a contoured shape. This is taken into consideration at the design level to ensure that fiber axial loads are realized throughout the structure. When the panel is a honeycomb sandwich structure, the core will be shown in a cutout section, adjacent to a local callout for the core ribbon direction.

The laminate construction is further depicted using a ply definition diagram (PDD) that is shown in a detail view related to the cross-section(s) taken from the plan view. The designer provides as many section views and PDDs as required to clearly identify and locate each ply, adhesive layer and component in the laminate stack (Fig. 2). This method enables instant communication of the plies/layers that exist at each section.

A master ply table is usually found on the same drawing sheet as the plan view and includes every ply, adhesive layer, component, etc. that is included in the part laminate. The ply table will always have the ply numbers, orientation and material information (Fig. 3) but may also include columns that designate part (dash) numbers, engineering sequence information, ply splice requirements and more — whatever is necessary to define the

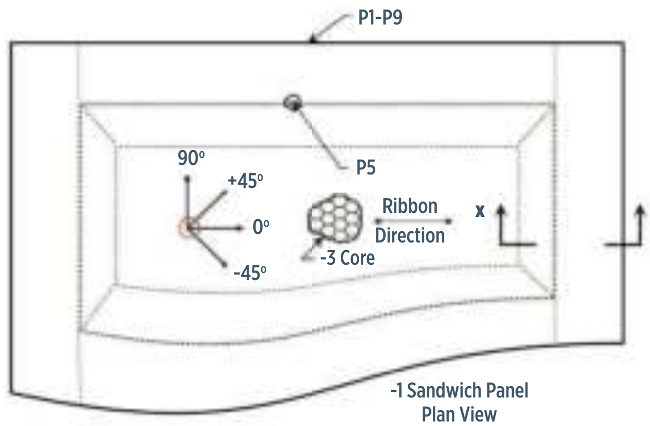


FIG. 1 Plan view

The fiber orientation is controlled and can be inspected at the exact point where it is shown in the plan view of the part laminate drawing. A red circle on this illustration denotes the intersection where this is applicable. Also note the core callout on the plan view. Source (all images) | Abaris Training Resources Inc.

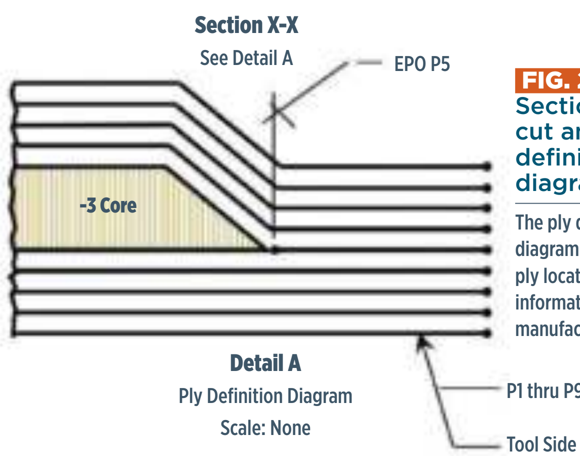


FIG. 2 Section cut and ply definition diagram

The ply definition diagram provides ply location information to manufacturing.

PLY TABLE		
Ply No.	Orientation	Material
P1	+45	1
P2	-45	1
P3	0	1
P4	90	1
-3 Core	--	--
P5	0 or 90	2
P6	90	1
P7	0	1
P8	-45	1
P9	+45	1

FIG. 3 Master ply table

The ply table is used to communicate laminate construction information.

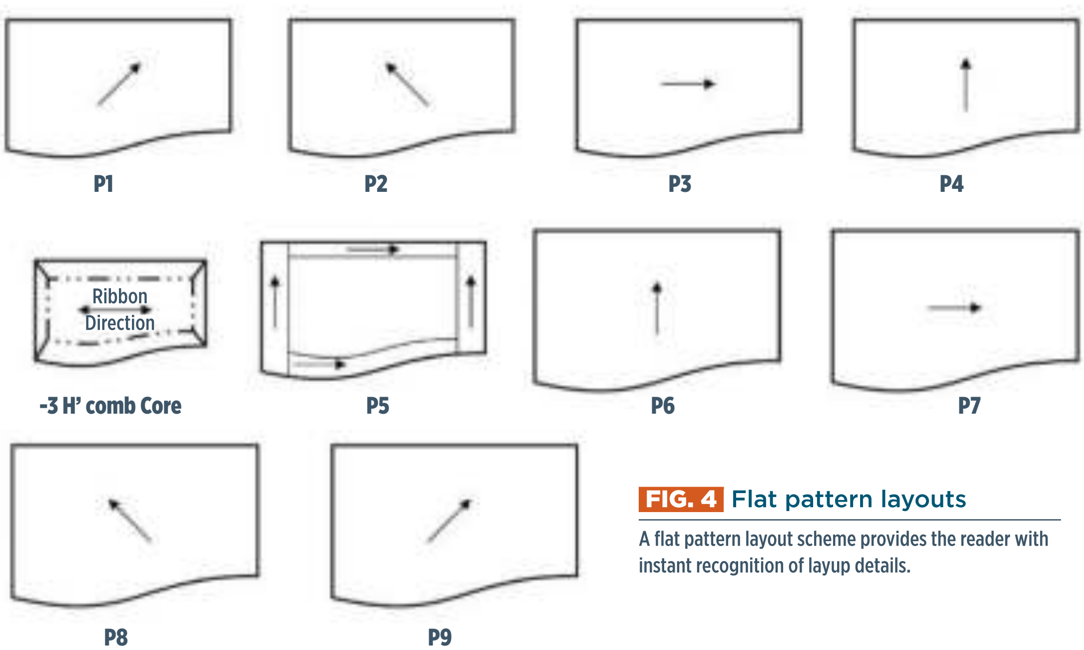


FIG. 4 Flat pattern layouts

A flat pattern layout scheme provides the reader with instant recognition of layup details.

layup. Some designers may also use mini localized ply tables adjacent to each ply definition diagram for further clarification of complex layups. The information in the mini tables will always match up with that of the master ply table.

Design engineers create a full-size, unwrapped, flat pattern layout of each ply/layer so that this information can be used to cut the materials needed for layup. Full-size digital files can be sent to an automated ply cutter system or used to make ply templates. A smaller scaled version of the flat pattern layout is often found on its own sheet of the drawing. This can be useful in determining the ply/layer configuration and layup sequence (Fig. 4).

Each drawing has a parts list and notes list. These are either found on the first sheet of the drawing or in a separate document that is part of the overall drawing package. The parts list will include all parts (dash numbers) that are applicable, and the notes will provide all other relevant information.

There are two types of notes to be aware of — the general notes that apply to all elements of the drawing, and the flag notes that are specific to wherever the flags are shown on the field of the drawing or in the ply table(s). The ply orientation tolerances are called out in the general notes (not in the drawing tolerance block) and apply where the orientation symbol is located on the plan view. (Yes, I said it again — it is that important!) All other materials used in layup are called out in flag notes. Flag notes are designated as such, either inside a flag-shaped symbol as seen in the ply table (3), or by other means described in the notes list.

The following is a list of steps for "reading" a composite part drawing:

- Read the title block for the part description (title), drawing number, revision level and other identifying information.
- Survey the plan view, side view and section/PDD views to get a sense of the laminate construction, overall dimensions and where the flag notes appear on the field of the drawing.
- Note the location of the orientation symbol and core ribbon direction callout (if applicable) as shown in the plan view.
- Review the master ply table and the flat pattern layout.
- Read the entire parts list and all of the notes, paying special attention to the material callouts, specifications and special instructions found in the flag notes.
- Continue to repeat these steps as needed until the layup is well understood.

While this column covers many of the fundamentals, it should be noted that specific drawing practices can vary from one manufacturer to another. You might find different flag note symbols, ply numbering designations or other minor variations in how the plies are drawn in the PDDs. If you work for a Tier supplier to multiple companies, or a small company doing build-to-print business, you may have several different drawing methods to deal with. It is suggested that you look for the commonalities between the drawings — after all, they are all communicating the same type of information. CW

ABOUT THE AUTHOR

Louis Dorworth is the direct services manager at Abaris Training Resources Inc. (Reno, Nev., U.S.). Lou has been involved in the composites industry since 1978 and has experience in material and process (M&P) engineering, research and development (R&D), tooling, manufacturing engineering, teaching and troubleshooting. Lou is a coauthor of the textbook titled "Essentials of Advanced Composite Fabrication and Damage Repair," second edition.

Optimized approach to predict delamination failure in CFRTP structures

»The use of carbon fiber-reinforced thermoplastic (CFRTP) composites is growing as mobility companies seek high-performance parts with reduced weight to reduce energy consumption. One such material is TAFNEX carbon fiber-reinforced polypropylene (CF/PP) unidirectional (UD) tape, developed by Mitsui Chemicals (Tokyo, Japan). TAFNEX features a new PP formulation plus special fiber interface technology, enabling fully impregnated tapes that can reduce weight versus metals and plastics, and also offer excellent processability, low moisture absorption and short cycle times. TAFNEX also improves sustainability via low process temperatures, good recycling properties and a high potential for structural components with a lower carbon footprint.

ARRK Engineering (Munich, Germany) worked with Mitsui Chemicals to investigate simulation methods using an automotive bumper beam made with TAFNEX. A key issue for such safety-relevant components is the accurate prediction of delamination in the composite materials. This analysis is necessary because delamination may significantly reduce strength and provide an early failure mode. However, predicting delamination isn't possible with standard finite element modeling (FEM) because it is based on modeling the structures as shells, or surfaces, without thickness.

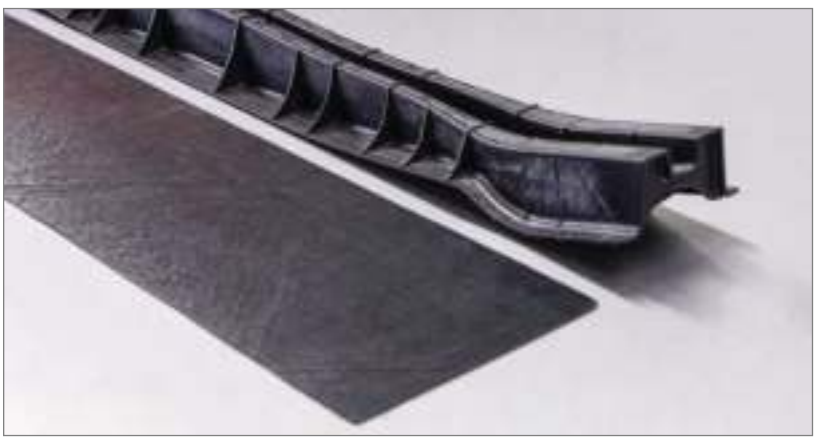
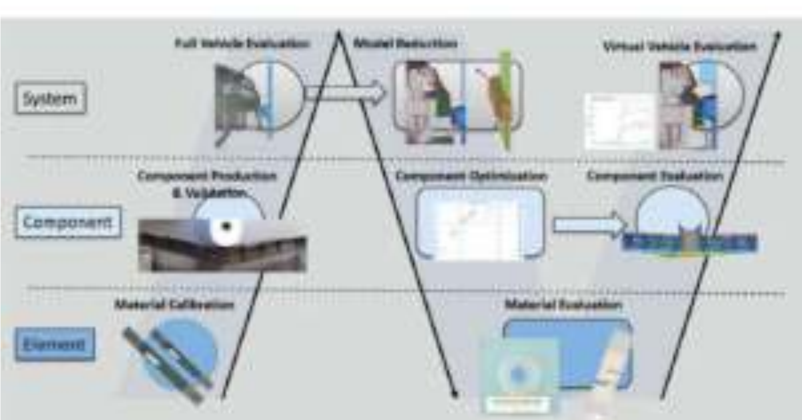


FIG. 1 Front bumper beam and TAFNEX CF-PP UD tape

ARRK Engineering optimized a CFRTP front bumper beam made using KraussMaffei's FiberForm process and composite sheet made of TAFNEX carbon fiber/polypropylene (CF/PP) unidirectional (UD) sheet overmolded with long glass fiber-reinforced PP (EDX4030), both materials from Mitsui Chemicals.

Source (all images) | ARRK Engineering, Mitsui Chemicals



■ Simulation and physical validation tests

ARRK Engineering used a combination of simulation and physical validation tests to optimize a CFRTP bumper beam, enabling accurate prediction of delamination while minimizing runtime, development time and cost.

Stacked shell modeling is an approach used to predict delamination very precisely. Typically, every ply in a composite laminate is modeled as a shell in the stack. However, the resulting large number of stacked surfaces requires excessive runtime and high calculation costs. Thus, its application has been limited and it isn't affordable to use for full vehicle simulations.

In order to correctly evaluate delamination of composites while retaining a good runtime performance of the simulation, ARRK Engineering developed reduced stacked shell modeling using LS-DYNA software from Ansys (Canonsburg, Pa., U.S.). This approach was used to predict delamination in the TAFNEX bumper beam and perform a full vehicle crash simulation. The front bumper beam was made using the FiberForm process from KraussMaffei (Munich, Germany), where a TAFNEX CF/PP UD sheet, produced by Van Wees UD and Crossply Technology B.V. (Tillburg, Netherlands) was thermoformed and then overmolded with Mitsui Chemicals' 30% long glass fiber-reinforced PP (EDX4030).

Reduced stacked shell modeling

ARRK Engineering set up a conventional single shell simulation model and a stacked shell model. The number of stacked shell layers was optimized to limit the amount of elements and contact surfaces yet have the possibility for delamination on both sides of the laminate mid-plane. Optimal results were found when using three layers, as results largely converged at this point; additional layers produced similar results but with a higher calculation cost.

Thus, for this reduced stacked shell approach, plies were distributed onto three layers in a symmetric fashion (Fig. 2). Additionally, the connection between layers was realized using cohesive elements (e.g., used to model adhesive joints) in one model and beam elements as an alternative. The motivation for this alternative modeling was to further reduce runtime while enabling the use of more sophisticated material models.

Material card creation and validation

Virtual material models were created in LS-DYNA based on extensive testing performed at ARRK Engineering, including tension, compression, shear, bending, interlaminar shear, double-cantilever beam and end-notched flexure. Two separate material models were prepared for in-plane and out-of-plane properties of the TAFNEX sheet, while a micromechanics approach was used for the EDX4030 long glass fiber overmolding compound using MAT_215 in LS-DYNA.

To validate these material models, physical tests and simulations were completed in the form of quasi-static and dynamic bending of the front bumper beam with a cylindrical impactor, comparable to a center pole crash load case.

A comparison of force-displacement curves and failure modes can be found in Fig. 3. The results showed that the single shell model overpredicted the failure load at a maximum 8.5 kilonewtons, while the reduced stacked shell model failed closer to 7 kilonewtons and displayed delamination in the bumper beam sidewalls. With a mesh size of 4 millimeters and using 20 CPU, the reduced stacked shell modeling runtime increased by 40% versus single shell modeling. However, this is lower than typical stacked shell modeling and it accurately predicted both failure mechanism and load.

Structural laminate optimization, full vehicle evaluation

After completing validation, the front bumper beam was evaluated virtually in a full vehicle setup according to the FMVSS-US Part 581 regulation. This simulation showed that the beam had insufficient energy absorption, resulting in »

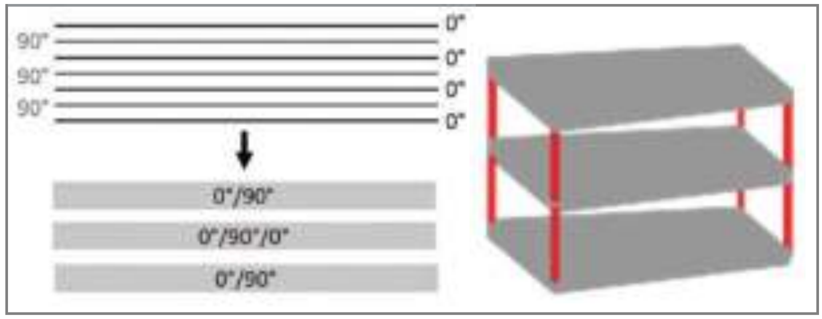


FIG. 2 Reduced stacked shell modeling

This approach distributed the CFRTP composite laminate plies onto three layers in a symmetric fashion. The connection between layers was realized using cohesive elements in one model and beam elements as an alternative model with in-plane and out-of-plane elements sharing nodes.

■ Bumper beam testing

Material cards were validated using quasi-static and dynamic bending tests of the bumper beam with a cylindrical impactor.

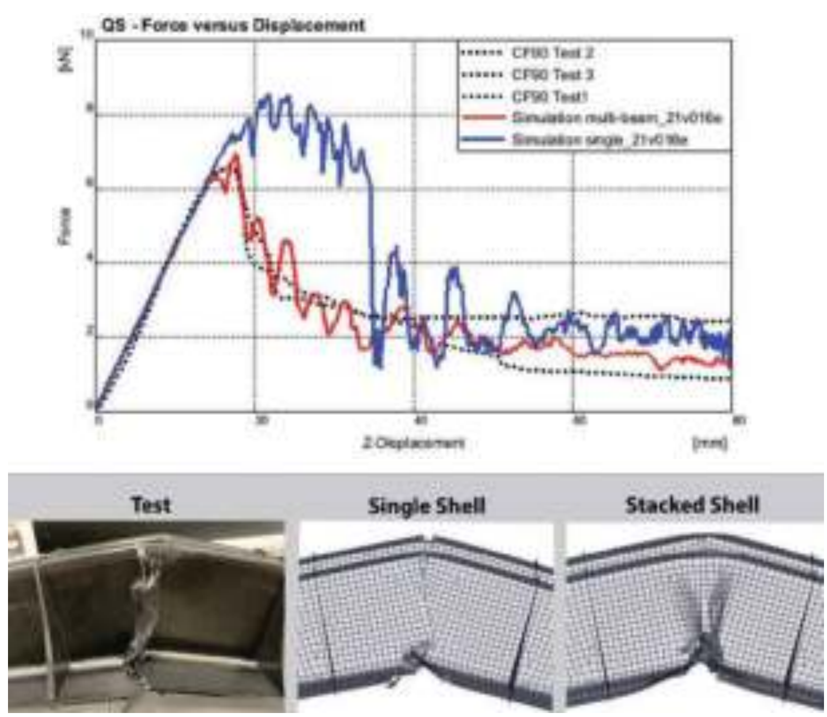
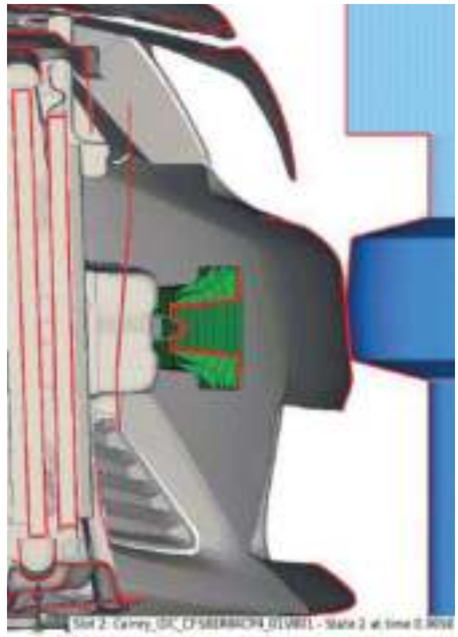


FIG. 3 Comparison of force-displacement curves and failure behavior between test and simulation

Force-displacement curves for quasi-static bending of the CF90 bumper beam shows that single shell modeling (blue) overpredicts the failure load compared to reduced stacked shell modeling (red). Physical tests show failure of the beam sidewalls is dominated by delamination (left). While the reduced stacked shell model with beams (right) shows a comparable level of delamination as in the test, single shell models (center) cannot physically separate in the out-of-plane direction.



Full vehicle crash simulation

A full vehicle simulation of the overmolded CFRTP bumper beam with optimized TAFNEX laminate showed a doubling in absorbed energy, reduced number of failed elements and significantly decreased beam intrusion into the vehicle during crash.

significant intrusion and damage to the vehicle's radiator. Based on the energy target from the full vehicle simulation, ARRK performed a parametric study to clarify the correlation between laminate stiffness and absorbed energy. The results were used to develop an optimized stiffness target and a composite layup to achieve this. New front bumper beams were tested with this improved layup. Test results showed the bumper beam's load level and stiffness were improved according to predictions.

The optimized layup beam was then re-evaluated in a full vehicle simulation (above). Contact force and absorbed energy were doubled with a reduced number of failed elements and significantly decreased beam intrusion into the vehicle.

Application and outlook

ARRK Engineering showed that reduced stacked shell modeling can be used to accurately predict delamination in a CFRTP component. This approach provides a robust prediction capability while retaining efficient runtime performance and enables full vehicle simulations that reduce development time and cost. While other studies by [1] and [2] also showed application of stacked shells to evaluate delamination in composites, this new approach by ARRK Engineering was focused on maintaining computational performance in order to be able to integrate this modeling in full vehicle simulations. This was achieved by calibrating the material to a mesh size of 4 millimeters and reduced integrated element formulation, while reducing the stack to three layers with multiple plies in each layer. CW

References:
[1] Shi D., (2016) "A Robust Crash Simulation Model for Composite Structures." (Doctoral dissertation) Michigan State University.
[2] Labeas, G., Fotopoulos, K., (2015, October) "Interlaminar Stresses Calculation Using a Stacked-Shell Finite Element Modeling Approach." *International Journal of Applied Mechanics*.

ABOUT THE AUTHOR

Olaf Hartmann is group leader for Material Simulation and Consulting at ARRK Engineering (Munich, Germany). He is focused on bringing efficient and predictive modeling into series development in automotive and aerospace applications. During the last 10 years, he has conceived and led numerous projects connecting Japanese and German industry. Hartmann holds a M.Sc. in material science from Friedrich-Alexander-University Erlangen-Nürnberg.

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PHOTO CREDITS *Top left to right:* Eve Air Mobility / Joby Aviation
Above: NASA

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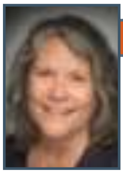
Composites GBI lost a little ground in June

June — 48.0

» The June Gardner Business Index (GBI): Composites Fabricating could be worse and it could be better. A reading of 48 is down one point from May, just barely staying within a two-point range around flat, or a reading of 50.

The three closely linked manufacturing GBI components, new orders, production and backlog, contracted *faster* in June for the second month in a row. Employment and supplier deliveries tracked hand-in-hand, both in expansion territory, but even this activity has slowed the past couple of months.

Future business, a sentiment/outlook measure included in the survey that is not part of the index calculation, but related to it, sometimes paints a more positive picture than GBI components because of its "look ahead" nature. However, that is not the case for the composites industry at this time, given the future business metric joined supplier deliveries and employment in expanding more slowly in June. CW



ABOUT THE AUTHOR

Jan Schafer, MBA, is the director of market research for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, Ohio, U.S.). She has been an essential part of Gardner Intelligence for over five years, and has led research and analysis in various industries for over 30 years.

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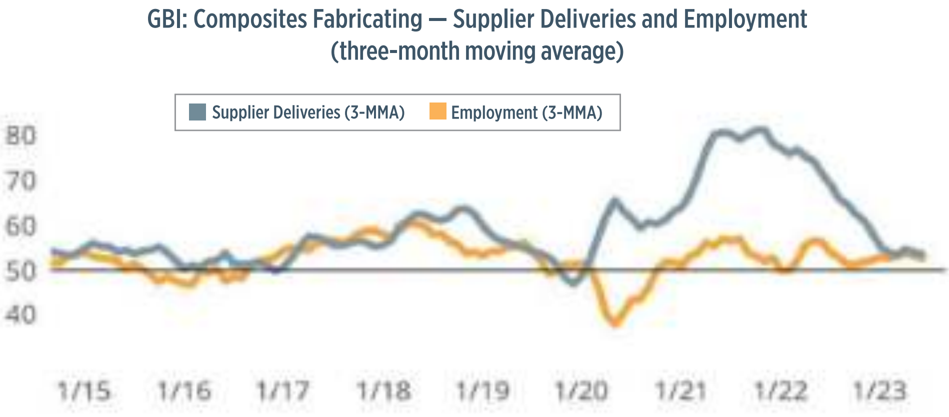
Downturned activity

GBI: Composites Fabricating in June is slightly down versus May.

Source (all images) | Gardner Intelligence



Slowing down

Supplier deliveries and employment remain in expansion, but growth rates have slowed.

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GARDNER BUSINESS INDEX

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Cryosphere pioneer Infinite Composites is scaling for growth in commercial space and sustainable transportation; Beyond Gravity wins a contract for carbon fiber payload fairings; *CW* gives a run-down of some of the highlights at this year's Paris Air Show; and more.

Infinite Composites: Type V tanks for space, hydrogen, automotive and more

Source | Infinite Composites

Infinite Composites (Tulsa, Okla., U.S.) was founded in 2010 and delivered its first Type V composite pressure vessels in 2013. Compared to Type I, II and III tanks using metal, and Type IV tanks using a plastic liner, Type V pressure vessels offer the lightest weight, featuring a fully composite construction reinforced primarily with carbon fiber but *without* a liner. However, because the liner serves as a barrier to prevent gases and cryogenic liquids from permeating into the composite laminate at high pressures — e.g., up to 14,000 psi/993 bar — building linerless tanks that can perform reliably for potentially thousands of pressurization cycles is no easy feat.

Infinite Composites has succeeded, supplying Type V tanks sized 5 to 325 liters for use in spacecraft, aviation, ground transportation and industrial gas applications. The company has tanks certified to AIAA S-081B-2018 for space systems and is working with multiple customers to develop Type V tanks for hydrogen storage, including for cryogenic liquid hydrogen (LH_2).

NGV to space

Infinite Composites got its start when the founders built a Formula One-style race car powered by compressed natural gas (CNG) and experienced first-hand how the weight of the all-metal CNG fuel tank reduced the car's efficiency, demanding multiple refuelings during the competition.

As they researched lighter weight alternatives, explains Matt Villarreal, CEO of Infinite Composites, "we became convinced that Type V tanks could revolutionize space exploration and sustainable transportation."

Most of the company's early tanks were in CNG applications, says Villarreal, "but in 2016, we decided that space was the best fit for us because the natural gas vehicle [NGV] market was very commoditized and demanded scale. Around that same time, SpaceX reached out to us, and the NASA Marshall Space Flight Center also wanted some tanks. So, we changed the company name to Infinite Composites to reflect a broader scope of applications. Our mission is to make Type V composite pressure vessels as ubiquitous as metal tanks."

Why Type V tanks?

Linerless composite pressure vessels eliminate the weight of a metal or plastic liner as well as the logistics and manufacturing cost/time. "This also eliminates issues with entrapped air between the liner and composite overwrap and other quality issues, which have led to tank failures in the past," says Villarreal. "We also eliminate the issue of liner fatigue failure, so we get a longer cycle life out of the tanks."

Villarreal claims Infinite Composites Type V tanks have up to 90% less mass than typical all-metal tanks used to store and transport industrial gases, and up to 40% less mass compared to composite-overwrapped metal pressure vessels (COPVs) traditionally used in space vehicles. However, he concedes that Type V tanks will have higher permeation than pressure vessels with metal liners. There is also less flight heritage with Type V tanks, but that is beginning to change.

Manufacturing and materials for Type V tanks

Typical for most composite pressure vessels, Infinite Composites uses filament winding to make its tanks. Carbon fiber, including Toray (Tokyo, Japan) T800 and T1100 fibers, are the primary reinforcements but Infinite Composites has also used basalt, glass and other fibers in different tank applications. Graphene additives from Applied Graphene Materials (Cleveland, U.K.) are used in its resins.

"We have an automated process that can go overnight," says Villarreal. "We use a removable mandrel and a variety of proprietary resin systems that give us the combination of permeation barrier and load-bearing structure for the carbon fiber composite laminate. We can tailor those resins to be compatible with different applications, for example with different high-pressure and cryogenic fluids such as helium, hydrogen, methane, high-test peroxide or nitrous oxide."

For the metallic boss interface, attached to the composite structure for connecting to external valves and fueling systems, Infinite Composites uses a proprietary process that mitigates the mismatch in thermal expansion between the dissimilar materials. This enables intimate bonding on a nanoscale level which can remain intact even after 20 years of daily use.

These pressure vessels have passed numerous tests, including burst pressure up to 993 bar, 816°C bonfire testing, cryogenic testing to -207°C, pneumatic testing to simulate 200 launches and landings of an orbital class rocket and pressure/temperature cycling simulating 20 years of service. "We've also done filling tests with cryogens like liquid oxygen and liquid helium," says Villarreal.

Growth in New Space

Infinite Composites is supplying tanks for multiple LEO and GEO satellites as well as a lunar lander, all of which should be in space by 2024. "But we're increasingly getting more customers wanting larger and larger tanks," says Villarreal. "We've had interest from groups that want all-composite tanks with more than a 36-foot-diameter for their launch vehicles. We can't make tanks that large yet, but the interest is out there. I think that's where the market is going. And space continues to be the biggest growth sector for us, although hydrogen applications are picking up as well."

"We're at the intersection of all these markets — hydrogen for more sustainable aviation and global transportation, industrial applications for gas storage and transport and New Space — and we see the technology for these applications converging," he adds. "We're even selling some of the same tanks to hydrogen aircraft programs that we would to space vehicle groups. I don't think there will be a big difference in the technologies that are being used in these markets within five years or so."

Read the full article online at short.compositesworld.com/InfiniteComposites

Source | ESA, CNE and ArianeGroup

CARBON FIBER

Beyond Gravity wins contract for *Ariane 6* payload fairings

Beyond Gravity (formerly RUAG Space, Zürich, Switzerland) has won an order to produce the carbon fiber payload fairings for ArianeGroup's (Les Mureaux, France) new *Ariane 6* rocket. The new European launcher replaces *Ariane 5*, which was successfully launched more than 100 times and has been in service since 1996.

Beyond Gravity offers two different-sized payload fairing variants that consist of two half-shells that separate once they reach orbit. Accounting for one-third of a launch vehicle's total length and rising to the height of a six-story building, the 20-meter-high variant (A64) is said to safeguard valuable cargo on its voyage to space. The smaller version is 14 meters high. Both variants have a 5.4-meter diameter, ensuring ample room for a variety of payloads.

The *Ariane 6* payload fairings, which are the A64 variant, are manufactured by Beyond Gravity at its Emmen site. In a semi-automated process, the company manufactures each half-shell in one piece from carbon fiber-reinforced composites that are "cured" in an industrial oven. This reduces costs compared with autoclave-produced half-shells and enables production to move twice as quickly. The resulting payload fairings weigh only 1.8 to 2.6 tons.

Paul Horstink, executive vice president, Beyond Gravity, notes that with the commercial market in mind, the company is also "driving future innovations, such as further shortening lead times or exploring possibilities in reusability to redefine the boundaries of space exploration."

"Over the years, Beyond Gravity has manufactured more than 250 payload fairings for the Ariane launcher rockets," André Wall, CEO of Beyond Gravity, adds, noting their decades of close partnership with ArianeGroup producing payload fairings since Ariane's first flight in 1979.

Beyond Gravity's expertise in composite payload fairings has also won it a contract for the United Launch Alliance's (ULA) *Vulcan* rockets and the European *Vega-C* rockets. Another contract, this time from Amazon, was awarded to the company in June 2022 for scalable carbon fiber-reinforced polymer (CFRP) dispenser systems.

Ariane 6, a program of the European Space Agency (ESA), is a family of launchers designed to offer maximum flexibility to customers in the institutional and commercial markets.

Solvay, Spirit collaborate to accelerate composites adoption


Source | Spirit AeroSystems

Solvay (Alpharetta, Ga., U.S.) has strengthened its relationship with Spirit AeroSystems (Europe) Ltd. (Prestwick, Scotland) as it becomes a strategic partner of Spirit's Aerospace Innovation Centre (AIC) in Prestwick, Scotland. The AIC facilitates collaborative research into sustainable aircraft technologies and processes with Spirit's industrial, academic and supply chain partners. Both companies intend to further engage on composite development opportunities to meet the performance, cost and production-rate requirements of future aircraft.

The collaborators aim to develop advanced manufacturing concepts and secure a step change in composite fabrication, automation and assembly technologies to de-risk and shorten the development cycle. Further strategic alignment on future innovation will also be explored.

"Solvay's expertise in product development, combined with our own capabilities in advanced manufacturing and aerospace design, will allow us to create new technologies and processes that will push the industry forward," Jahan Ali, director of research and technology, Europe at Spirit AeroSystems, believes. "Spirit looks forward to continued collaboration with Solvay as we work toward achieving shared goals of enhanced performance, sustainability and competitiveness on future aircraft."

ARTICLE UPDATE

In the article, "Manufacturing the MFFD thermoplastic composite fuselage," featured in our July 2023 issue, we mistakenly included The Welding Institute (TWI, Cambridge, U.K.) as a partner in the consortium for the TORNADO subproject instead of the TCTool subproject listed in Fig. 1. We apologize for the mistake and encourage our readers to look up the TCTool results paper, "Development of innovative automated solutions for the assembly of multifunctional thermoplastic composite fuselage" published in 2021. If you'd like to see *CW* publish an article on this topic, please email senior technical editor Ginger Gardiner: ggardiner@compositesworld.com.

Paris Air Show 2023 highlights


Source | *CW*

It has been four years and one pandemic since the aerospace industry convened in France for the Paris Air Show. The 2023 return of one of the largest aircraft manufacturing events in the world at Aéroport Paris Le Bourget was a busy, bustling, frantic expression of pent-up energy featuring the entire aerospace supply chain, from raw materials producers to Tier fabricators to OEMs and customers. *CW* spent a couple days navigating this massive biennial event and captured these highlights.

Advanced air mobility

Noticeable by its presence this year was a heavy dose of advanced air mobility (AAM) exhibits, including an AAM pavilion featuring the who's who in this dynamic emerging market. Exhibitors representing this space included Lilium, Volocopter, Archer, EHang, Ascendance, Joby Aviation, Airbus, Overair and Wisk.

Wisk. Wisk (Mountain View, Calif., U.S.) hosted a media event to introduce its Generation 6 aircraft — the version it intends to certify with the U.S. Federal Aviation Administration (FAA). Brian Yutko, CEO of Wisk, noted first that Boeing, which previously had partial ownership of Wisk, had recently fully acquired the company and made it a wholly owned subsidiary. Wisk, as a result, appears to have the deep pockets it needs to certify and bring to market its four-seat, 12-tiltrotor eVTOL.

The deep pockets will be necessary; Yutko reported that Wisk will enter the market with a fully autonomous aircraft, thereby skipping the intermediate step of coming to market with a piloted aircraft first. This means that certification for Wisk will come around 2030, and not in the 2025-2026 timeframe that other AAM firms are targeting with piloted systems.

Certification strategy aside, Yutko emphasized the features of the Generation 6, composites-intensive aircraft. It will offer a maximum range of 100 miles, remote human oversight from a central control location, a status display screen for each of the four passengers, bag storage in a "frunk" in the plane's nose, and the usual array of redundant power and propulsion to enable safe landing in all situations.

Also, like most other AAM manufacturers, Wisk is relying on qualified composite materials and processes for its Generation 6 aircraft. And, unlike most of its competitors, Yutko said Wisk will be the direct operator of its air taxi service — at least at the start.

Overair. Overair, a relatively new AAM entrant, is based in Santa Ana, Calif., U.S. It exhibited a sub-scale model of its four-tiltrotor *Butterfly* eVTOL at the Paris Air Show with South Korean aerospace company Hanwha, which recently invested $170 million in Overair. Valerie Manning, ex-Airbus and currently CCO of Overair, said the company is finalizing design of its first-generation aircraft, which will have a range of 100 miles and will be piloted. The company is targeting certification sometime after 2026. Manning said Overair is still developing its manufacturing strategy and determining where the cutoff will be from low-rate to high-rate manufacturing, but what is certain is that high-rate manufacturing will not be done in Santa Ana and will be done with a partner.

Like other eVTOLs, *Butterfly* will be composites-intensive. And the use of just four tiltrotors — most competitors use six or more — means that Overair's design will rely on large (20-foot) propellers that Manning says will be enablers for the aircraft. The propellers are derivative of Kaman Aerospace's composite K-MAX helicopter blade and provide low noise, strong mechanical performance and helicopter-like cyclic pitch control to help minimize vibration.

Archer Aviation. Attracting a lot of attention at the show was Archer Aviation's (San Jose, Calif., U.S.) *Midnight* eVTOL. It features six tiltrotors on the wing leading edge and six lifter propellers on the wing trailing edge. It will have a range of 100 miles, seating for five (pilot and four passengers), a takeoff weight of 6,500 pounds and payload capacity of 5,500 pounds.

Archer CEO Adam Goldstein was at the show and spent a few minutes with *CW* talking about the company's manufacturing strategy. Goldstein noted first that Archer will be holding close what it considers the company's core IP: Powertrain and flight controls. All other technologies, he said, would be developed through partnerships.

The most notable partnership Archer has established is with automaker Stellantis (Auburn Hills, Mich., U.S.), which announced in January that it would work with Archer to construct a composites manufacturing and aircraft assembly facility in Covington, Ga., U.S. At the Paris Air Show, Goldstein said Stellantis will also produce the plane's motors, battery packs, and wiring and harnesses.

Goldstein also said initial low-rate production (tens of units per year) of *Midnight* will be performed at the company's headquarters in San Jose. Beyond that, production will enter Phase 1 at the Georgia facility, with capacity up to 650 units per year. Phase 2 production, up to 2,300 units per year, also in Georgia, will follow that, although Goldstein said a timeline for this transition has not been established — growth will depend, he said, on consumer demand and infrastructure development.

GKN Aerospace

At the show, GKN Aerospace (Hoogeveen, Netherlands) announced that it had signed a multi-year agreement with eVTOL manufacturer Joby Aviation for the fabrication of thermoplastic flight control surfaces for Joby aircraft. The flight control surfaces comprise a lightweight thermoplastic structural assembly manufactured using an advanced out-of-autoclave (OOA) production method.

This contract is significant for the eVTOL/AAM market. It's well understood that low-rate, first-generation aircraft in this space will depend primarily on already-qualified, thermoset-based, autoclave-cured composite materials. As aircraft enter high-rate production, it's likely that increased industrialization with OOA materials and processes will be needed, with thermoplastics at or near the top of the list. This step by Joby and GKN Aerospace signal a preliminary shift in this direction.

Boom Supersonic

Boom Supersonic (Denver, Colo., U.S.), which is developing a new supersonic jet aircraft — called *Overture* — for commercial transport, made several significant announcements at the Paris Air Show. The biggest, for the composites industry, was news that Boom has chosen its manufacturing partners for composite structures in the wings, fuselage and tail.

Boom CEO Blake Scholl announced that the wing will be fabricated by composites specialist Aeronnova (Toledo, Spain); the fuselage structures will be fabricated by Leonardo (Rome, Italy); and the tail structures, including rudder and elevators, will be fabricated by Aciturri (Miranda de Ebro, Burgos, Spain). Representatives from each company were on hand to be recognized for their selection. The supply chain for *Overture* is expected to be launched in 2024.

Scholl was asked about composite materials selection for *Overture*. He said Boom is focused on the use of "proven material systems" that have "certification pedigree." This means primarily prepregged thermoset materials with autoclave cure. Scholl did leave open the possibility of using newer materials in subsequent aircraft iterations/platforms.

Scholl also provided an update on construction of Boom's Superfactory final assembly line in Greensboro, N.C., U.S. It's expected to be completed by mid-2024 and provide capacity for production of 33 aircraft per year. In the meantime, the first flight test aircraft is being assembled right now and, said Scholl, is expected to make its maiden flight later in 2023. *Overture* is in the midst of a 10-year certification plan that, Scholl said, is expected to culminate in final certification and entry into service in 2029.

Matrix Composites

Resin transfer molding (RTM) and aircraft engine composites specialist Matrix Composites (Rockledge, Fla., U.S.), now an ITT company, reported at the Paris Air Show that it is strategically expanding its materials expertise to include high-temperature (750-800°F) resin systems, including polyamide and bismaleimide (BMI).

William Zmyndak, VP/GM aerospace at Matrix, said Matrix is looking to expand its manufacturing capabilities, particularly in closed military aircraft engines that have little or no bypass air and thus very high operating temperatures. Zmyndak noted that Matrix is keeping a close eye on the Next-Gen Fighter program and what the temperature requirements of the engine in that aircraft might be.

As part of this capability upgrade, Zmyndak said Matrix is adding new CNC capacity and improving dimensional tolerancing on its existing CNC system. Similarly, the company is adding a used RTM press to its capital equipment lineup; Matrix will have a total of six presses when this addition is complete.

Read the full report online
short.compositesworld.com/PAShighlights

Composites manufacturing for general aviation aircraft

General aviation, certified and experimental, has increasingly embraced composites over the decades, a path further driven by leveraged innovation in materials and processes and the evolving AAM market.

By Gary Bond / Contributing Writer

»General aviation is a broad term that encompasses all civil aviation that is not large-scale, regularly scheduled freight and passenger operations. This means anything from ultralights to multi-engine turboprops and turbofan jet planes. For the purposes of this article, we'll primarily focus on piston-powered, fixed-wing aircraft typically used for business or pleasure travel. In the U.S., that's about 175,000 planes flying into roughly 5,000 public airports, of which only ~10% have regularly scheduled commercial flights.

General aviation, both certified and experimental, has embraced fiber-reinforced composites for more than 60 years. During the late 1950s, Piper Aircraft (Vero Beach, Fla., U.S.) built an all-fiberglass prototype, the PA-29 *Papoose*. In the 1960s, sailplane (glider) manufacturers, always looking to reduce weight and improve lift-over-drag ratios, began to extensively use fiberglass. After an eight-year certification process, in 1969 the *Windecker Eagle I* became the first U.S. Federal Aviation Administration (FAA) certified, all-composite-powered airplane with its nonwoven fiberglass "Fibaloy" and foam construction.

Composite experimental (homebuilt or kit) general aviation aircraft really took off in the early 1970s with Burt Rutan's very popular *VariEze* (and derivations like the *Long-EZ*) canard pusher aircraft. One of Rutan's innovations was to use sandwich foam as the "tool" which allowed for "moldless" fabrication of composites.

In the 1990s, general aviation began to use carbon fiber composites and slowly worked out of a major slump from the

Experimental, fixed-wing aircraft

DarkAero 1 is a long-range, high-speed, two-person, experimental all-composite airplane. The entire airframe, made mostly from carbon fiber/epoxy, weighs about 200 pounds. Source | DarkAero

1980s. Major general aviation manufacturers such as Cirrus Aircraft and Diamond Aircraft Industries introduced still-popular lines of single-engine certified planes. Experimental planes soon moved to ever-increasing carbon fiber content, and the new Light Sport Aircraft (LSA) category brought in more opportunities for composites.

Categories of general aviation aircraft

The three main categories of general aviation fixed-wing planes (Certified, Experimental and LSA) all bring with them various levels of challenges for composites.

Certified planes are government-approved (by the FAA in the U.S.) and require years of development and testing to prove out the design and manufacturing processes. Experimental planes are majority-built by individuals from plans or kits, and while there is some governmental oversight, it is more relaxed and thus open to more innovation.

LSA is something of a bridge between the other two categories. These planes are not as rigorously certified (using industry-consensus standards instead of government mandates) and are therefore open to more innovation but generally are manufacturer-built with more process control than Experimental aircraft. LSA designs are also limited in aircraft weight, number of occupants and speed, though new rules are being considered to expand those limits and possibly add a new category, Light Personal Aircraft.

Experimental aircraft M&P

Composite materials and processing vary across general aviation categories. But broadly speaking, the emphasis is on low cost and moderate performance with standard, untoughened epoxies and E-glass fiber reinforcement being very common (though standard modulus carbon fiber is becoming more widespread).

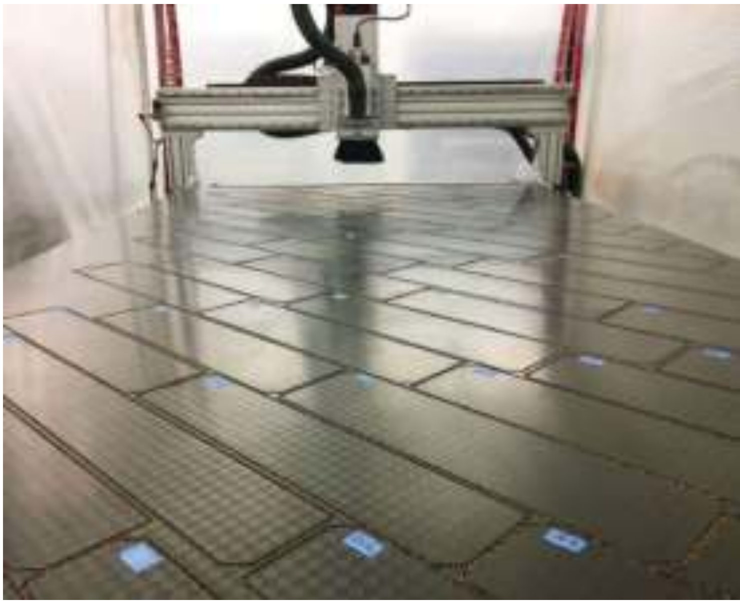
For the Experimental category, basic wet layup processing has historically dominated, either for fiberglass or carbon fiber. Low-viscosity, two-part room temperature curing epoxy is hand-mixed in precise ratios by weight and manually spread onto dry cloth, then cut to shape and laid on simple tooling or shaped foam, which acts as a flyaway tool for sandwich structures.

In recent years, infusion processing such as vacuum-assisted resin transfer molding (VARTM) has become more popular. Dry fabrics include 7781 fiberglass and/or 2x2 carbon twill (hybrid layups with mostly fiberglass and limited amounts of carbon fiber are common) which are then laid up in a mold with tackifier and bagged; the low-viscosity, two-part epoxy is pulled into the layup with vacuum. Planes like the Arion *Lightning* or DarkAero's *DarkAero 1* are taking advantage of the less messy, better quality, higher fiber volume parts that infusion can provide.

DarkAero (Madison, Wis., U.S.), formed by a team of three engineer brothers, saw carbon fiber as being the key to achieving their aggressive performance goals (275 mile per hour cruise for more than six hours) through improved aerodynamic shapes with optimal structural efficiency. The DarkAero design uses mostly »

Implementing infusion tactics

Lantor Soric infusible core is used on the fiberglass fairing just aft of the canopy on the *DarkAero 1*. Source | DarkAero



Achieving optimal aerodynamics, structural efficiency

Carbon fiber/epoxy over aramid honeycomb panels are fabricated in 4 × 8-foot sheets and then CNC cut to shape to make very structurally efficient ribs, shear webs and bulkheads for the *DarkAero 1*. Source | DarkAero

Complex structure fabrication

Center spar layup of carbon fiber/epoxy prepreg for the Icon A5 LSA.

Source | Icon Aircraft

spread tow plain weave, locally reinforced with unidirectional (UD) fabrics in areas that have most or all of their load in one direction. Localized stiffness is provided with a mix of aramid honeycomb, foam or Lantor (Veenendaal, The Netherlands) Soric infusible core. For smaller and more complicated geometries like the carbon fiber spinner — the cone-like part in front of the propeller — DarkAero uses 2x2 twill for its superior drape and conformability. Parts are room-temperature cured on tools after infusion and later post-cured at the same time as the bonded subassemblies.

DarkAero's substructure is kept simple and low cost with carbon fiber fabric faced sandwich panels made in large 4 × 8-foot sheets. The final substructure shapes are CNC machined and the subassembly is bonded together at elevated temperatures with paste adhesive. Curing is performed in ovens; autoclaves are too expensive, and out-of-autoclave materials are improving to the point where oven cures are sufficient.

DarkAero goes beyond the normal skins and substructure for application of composites — even the aircraft's brackets, hardpoints and bell cranks are made by machining solid billets of infused, multiaxial noncrimp carbon fiber fabrics, which enable the company to build up quasi-isotropic laminates quickly.

DarkAero recognizes that there are a number of challenges in designing and building a high-performance single-engine aircraft, but as Keegan Karl, one of the three Karl brothers who founded DarkAero, put it, "Understanding the nuances of composite design and manufacturing is a key piece of the puzzle."

Light Sport Aircraft M&P

Much like Experimental aircraft, wet layup or infusion have often been used for LSA composites, but prepregs have been increasingly employed to improve quality and performance. Flight Design GmbH (Hoerselberg-Hainich, Germany), one of the more popular builders of LSAs, has moved away from wet layup to Hexcel (Stamford, Conn., U.S.) M79 prepreg for its new F2-LSA (which the company is also working to certify as the F2-C23).

And it's not just land and air where LSAs

■ **CNC-cut plys, hand layup**

Carbon fiber-reinforced epoxy is being hand laid to the uniquely shaped main aft bulkhead for the Icon A5. Numerous Virtek (Waterloo, Ont., Canada) laser projectors speed location of ply details.

Source | Icon Aircraft

can be found — Icon Aircraft's (Vacaville, Calif., U.S.) very sporty A5 is an amphibian, meaning it can land either on runways or bodies of water like lakes or ocean bays. Icon decided from initial design to use prepregs to derive maximum performance benefit for its unique land-sea application. Additionally, it sees manufacturing advantages in prepreg: less labor, quicker processing and more consistent results than wet layup.

Icon chose composites because they allow the company to fabricate very complicated shapes easily and are corrosion resistant, the latter being a very important consideration for a plane that might spend a considerable amount of its life on or around water. More than 95% of the Icon LSA structure is made using 2x2 carbon fiber twill/epoxy prepreg with some local areas of UD standard modulus carbon fiber prepreg to reinforce highly loaded (and highly directional loaded) zones.

To reduce production costs and improve repeatability, Icon CNC cuts all ply details and uses laser projectors and templates to locate the plies in the tools during hand layup. Instead of adding additional plies for structural stiffness in certain areas, closed-cell foam core is used as needed to increase the stiffness of the structure, for very little weight penalty and high cost savings. The foam core is CNC machined and a beveled ramp is added to ease ply transitions. It can then be heat-formed to shape. Composite parts are generally oven-cured, but for certain highly loaded structures such as the wing spar, an autoclave is used to reduce porosity and yield the very best quality and performance possible.

Assembly is mostly paste bond (epoxy) using grit blasting and solvent wiping for surface preparation. Bond gaps are designed into the assembly and controlled using bonding fixtures. Mixing and application of paste adhesive is all done by hand. Initial cure is at room temperature followed by an elevated post-cure.

Despite flying in potentially harsh conditions, the performance of the composites seems to justify the original design selection rationale. Icon's director of engineering, Rodolfo Correa, says that after eight years of service history and several of the airframes with more than 1,000 flight hours, there have been no failures in bonded joints or laminated parts. So satisfied is the company with the results that Icon is moving to certify the A5 in addition to continuing to offer the LSA model of the A5. »

■ **Hands-on component bonding, assembly**

Bonded assembly of the fuselage, center wing box and sponsons (for stability on the water) of the Icon A5 amphibious airplane. Source | Icon Aircraft

■ **On-demand, in-house "wet preg"**

Diamond Aircraft designed and built its own in-house, on-demand equipment for controlling resin application to dry fabrics to create "wet preg."

Source | Diamond Aircraft

Semi-automated layup

Layup of carbon fiber/epoxy "wet preg" for the right-hand fuselage of a Diamond DA50 RG.

Source | Diamond Aircraft

Certified aircraft M&P

First-generation general aviation certified planes (with significant production runs) with a high composites content such as the Diamond *Katana*/DA-20 or the Cirrus SR20 were generally E-glass, because of its low cost and ease of inspection (being semi-translucent, a strong backlight can reveal most defects with a simple visual inspection).

However, second-generation planes such as the Diamond DA-42 or the Cirrus SR22 increasingly applied carbon fiber and/or S2 glass, while third-generation craft like the DA-62, SF50 *Vision Jet* and Epic's E1000 are moving to mostly or all-carbon fiber construction for its structural efficiency.

Similarly, the trend in resin systems is to choose higher performing (tougher and higher glass transition temperature (T_g)) epoxies that enable darker paint as well as improve damage resistance. Processing is generally hand layup of prepregs with either oven or autoclave cures.

The Cirrus Aircraft (Duluth, Minn., U.S.) series of SR aircraft are said to be the best-selling single-engine piston general aviation planes in recent years and have been all-composite since their inception in the late 1990s. While the company's latest composite advancements remain undisclosed, Cirrus has had a long-standing relationship with Toray Advanced Composites (TAC, Tacoma, Wash., U.S.) using its BT250 epoxy systems and TC275-1. The latter is a 275°F cure vacuum bag only (VBO) epoxy prepreg used on the SF50 *Vision Jet*. Processing is conventional hand layup with paste-bonded assembly.

One of Cirrus' major competitors in the all-composite certified general aviation market is Diamond Aircraft (Wiener Neustadt, Austria). Leveraging its fiberglass powered-sailplane experience, Diamond still uses "wet preg" as a semi-automated way to help control wet layup resin application (see Learn More).

Much like Cirrus, over time Diamond has upped the share of carbon fiber in its designs from 10% (versus 90% fiberglass) in the early DA20 C1 models, to 50% in the DA42, and with the latest designs — DA50 RG and DA62 — the percentages have completely flipped to 90% carbon fiber and only about 10% fiberglass. Diamond has used high strength and standard modulus carbon fiber, which increases availability of the material (and associated data) and improves airframe performance, propelling its increased use.

Diamond's "wet preg" process generates on-demand, in-house prepreg (or wet layups, depending on your perspective). Rolls of dry fiber are run through custom-designed equipment that meters a certain amount of low-viscosity epoxy resin to produce a wet prepreg that is immediately cut to shape and laid up in molds. The original resin used in the DA20, DA40 and DA42 was L160 or L285 epoxy from Momentive (Esslingen am Neckar, Germany). Newer designs (DA42-VI, DA50 RG and DA62) moved to RIM935 infusion epoxy by Westlake Epoxy (formerly Hexion, Columbus, Ohio, U.S.) for its high T_g. Early models of Diamond were limited to most or all-white paint schemes due to the low T_g of the L285; moving to the RIM935 has allowed the company to add new and dramatic color schemes which are generally preferred by customers.

The handling of wet preg plies can be challenging and sometimes a bit messy; Diamond has considered introducing automated layup technology to help reduce cycle times and ease technician workload. Diamond has also added resin infusion to its processing repertoire — using it for parts which are more porosity-critical such as carbon fiber spars (for structural reasons) and fiberglass radomes (lower porosity for better electromagnetic transmission translating to better radar performance).

Diamond's bonded assemblies use peel ply and sandpaper for surface preparation. The bondline resin is the same as the native wet preg but thickened to a paste with cotton flakes or microballoons. Mixing and application is all done by hand. The adhesive cures at room temperature followed by the entire structure (laminate and bondline) receiving an elevated temperature post-cure.

In Diamond's 40 years of experience, the company says it has never had a plane retired due to composite issues. The airframes are inspected every 6,000 flight hours and generally have no findings or repair work needed. "Composites are in our DNA," says Diamond Aircraft's head of design organization, Robert Kremnitzer, reflecting back on the extensive service life for Diamond's products. "We wouldn't think any different. We wouldn't design any different. We think it's a great material."

Epic Aircraft (Bend, Ore., U.S.) turned a popular kit (Experimental) plane into one of the highest performing certified turboprops around. Powered by a single Pratt & Whitney Canada (Longueuil, QC, Canada) PT6A-67A turboprop (whose family of venerable PT6 engines has recently just topped 1 *billion* flight hours), the E1000, and now E1000 GX, can cruise at 380 miles per hour with 2,000 miles of range at up to 34,000 feet in pressurized comfort.

It was that performance and durability (e.g., fatigue resistance, especially critical for a pressurized fuselage) that first drew Epic to carbon fiber composites. Along the seven-year process to gain FAA type and production certification, it learned and refined the design through testing and retesting, finally achieving a very robust composite airframe tested to about twice the highest load expected during service.

In 2021, Epic certified the E1000 GX, which is now the company's standard production plane. The GX upgrades the avionics and puts a five-bladed composite prop on the front of the »

Surface preparation for bonding

Diamond DA50 RG fuselage halves and frames are being prepped for final assembly bonding. Note that the vertical stabilizer is an integral part of the large fuselage assembly. Source | Diamond Aircraft

Qualified composite material use

This Epic E1000 GX fuselage half is laid up with Toray 2510 carbon fiber/epoxy prepreg. Note the honeycomb core bays with violet-colored Henkel EA 9696 epoxy film adhesive. Source | Epic Aircraft

■ Advanced design, optimized assembly operations

Epic E1000 GX fuselage halves, bulkhead and firewall are prepped for bonding. In the foreground is a carbon fiber/epoxy one-piece (virtually from wingtip-to-wingtip) wing spar — one of two for flight load redundancy. Source | Epic Aircraft

PT6A-67A turboprop. The new composite prop improves takeoff performance and at the same time reduces noise and increases passenger comfort.

Brock Strunk, chief engineer for Epic, cut his composite certification teeth with Lancair and has extensive experience in industry-wide efforts to support shared composite material databases to help general aviation. These efforts include Advanced General Aviation Technology Experiments (AGATE), National Center for Advanced Materials Performance (NCAMP) and CMH-17. Strunk is a major proponent of public databases, which allow for smaller aircraft companies to more easily incorporate advanced composite materials into their designs.

> The future looks bright for composites across sectors of general aviation.

Epic hand lays carbon and fiberglass 2510 epoxy prepreg from TAC to fabricate the approximate 550 composite parts in each shipset. Close technical relationships with its composite and adhesive material suppliers have been critical and Epic uses its technical expertise to help optimize fabrication processes. In addition, by choosing composite materials that were already qualified and had public databases, Epic was able to use the money saved to develop a deeper understanding of how process variability affects final properties to implement a robust composite production system.

The majority of Epic's parts are made from fabric prepreg with highly loaded structure such as wing and horizontal spars using UD prepreg. Localized stiffness is typically provided with Hexcel aramid/phenolic honeycomb over-expanded (OX) core and Henkel (Madison Heights, Mich., U.S.) Loctite EA 9696 Aero epoxy film adhesive with some limited use of foam core, mainly in complex geometries where it can be heat-shaped. Assembly is bonded paste adhesive joints; the epoxy paste adhesive, also from Henkel, has extra thickeners mixed in to help resist slump during the bonding of the fuselage halves and close-out of the wings.

Potential future advances

Technological growth for composites in general aviation will likely be driven by one single factor: cost. General aviation OEMs are willing to explore new, lightweight options and processing techniques to make airframes more fuel efficient (or even electrified or hydrogen-powered), but moving from tried-and-true materials and processes can be cost-prohibitive. And not just from the price of raw materials, but also the time and cost to qualify and certify new composite structure.

Published databases like NCAMP and CMH-17 are a major help to small manufacturers in adopting new materials; material suppliers should consider including a basic set of allowables with any new structural composite material system they bring to market.

Driven by market projections of composites on general aviation aircraft as well as advanced air mobility (AAM), the composites industry is moving to develop higher performing composites that simultaneously reduce material, processing and in-service costs.

Advances in toughened epoxy resins achieve cure more rapidly at lower temperatures and pressures while still providing autoclave-like properties, enabling use of stiffer intermediate modulus carbon fibers in UD formats. UD fibers are roughly 25-50% more efficient than their woven cloth counterparts. Together, significant weight reductions are possible and less internal wing space is taken up, leaving more room for fuel.

Robust composite airframe

The final structural assembly of the Epic E1000 GX. The forward fuselage carbon fiber structure is a pressure bulkhead that also forms part of the firewall. Blue areas are surfacing film containing copper lightning protection. Note the leading edges of the wing are left bare for later bonding of inflatable de-icing boot systems.

Source | Epic Aircraft

High-performance semi-crystalline thermoplastic resins such as polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) will continue to come down in price and offer much better out-of-plane and damage tolerance properties when compared to epoxy — even toughened epoxies. High-temperature processing requirements bring their own set of challenges, but new processing and modeling can help address those.

Carbon fiber, especially intermediate modulus, will find general aviation primary structure applications for its unbeatable structural performance, particularly in stiffness. New advances in large-tow carbon fibers and new production plants with additional carbon fiber capacity add up to a reduction in cost of the carbon fiber, further driving its utilization across general aviation.

Research and development (R&D) of new composite processes, including advanced fiber placement (AFP) and automated tape laying (ATL), not only yield very high quality and consistent composite structures, they take advantage of UD carbon fiber for the ultimate structural efficiency and can also fabricate large, integrated, complex structures, reducing assembly costs. Another processing technique, press forming, which uses heated tools and mechanical force to cure, offers the possibility of reducing part processing cycle time from hours or days to minutes.

A modest proposal to accelerate implementation of innovation

The current revolution in local and regional air transportation (as captured by the term AAM) that includes vertical takeoff and landing (VTOL), short takeoff and vertical landing (STOVL) and short takeoff and landing (STOL), as well as conventional fixed-wing transports, offers a unique opportunity for general aviation companies to leverage materials and technologies to drive their industry forward.

Imagine a partnership where an established general aviation company teams with an up-and-coming AAM group (or the teaming could involve multiple partners from both general aviation and AAM). Jointly working with material suppliers, they cooperatively define cost, processing and performance goals for a suite of materials (prepregs, adhesives, etc.). The materials are qualified through an FAA-approved data system such as NCAMP or CMH-17 while the high-rate, low-cost processing is developed and validated through a government/academia composite fabrication R&D facility such as the National Institute for Aviation Research's (NIAR) Advanced Technologies Lab for Aerospace Systems (ATLAS) center in Wichita, Kan., U.S. The partnership could jointly invest in a single, multi-purpose production facility or each leverage the knowledge and data to create their own factory.

By working together, AAM organizations gain invaluable knowledge from the years of composites design, analysis and fabrication expertise the general aviation companies have developed over the years. At the same time, general aviation companies secure new resources to help reduce non-recurring costs to implement new structurally efficient materials and cost-reducing processes.

Overall, the future looks bright for composites across all sectors of general aviation. Leveraging materials and processes being developed for other markets will enable significant performance gains (taking more farther and faster for less fuel burned) while simultaneously improving durability and reducing acquisition costs. CW

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Plant tour: Spirit AeroSystems, Belfast, Northern Ireland, U.K.

Purpose-built facility employs resin transfer infusion (RTI) and assembly technology to manufacture today's composite A220 wings, and prepares for future new programs and production ramp-ups.

By Hannah Mason / Technical Editor

»The Airbus (Toulouse, France) A220 single-aisle aircraft family, today consisting of an A220-100 variant seating 100-130 passengers and a -300 variant seating 130-160 and produced under the Airbus Canada Limited Partnership, was originally developed and launched by Bombardier (Montreal, Canada) as the CS100 and CS300, respectively, in 2008. The first C-Series aircraft entered into commercial service in 2016, and Airbus acquired a majority stake in Bombardier's C-Series in 2018 (see Learn More), after which it reintroduced the aircraft as the A220 family.

Most recently, Airbus has announced its intention to scale up production of the aircraft from an average of six per month in 2022 to 14 per month by the end of the decade, and has teased the eventual launch of a larger A220 variant that industry analysts have called the A220-500.

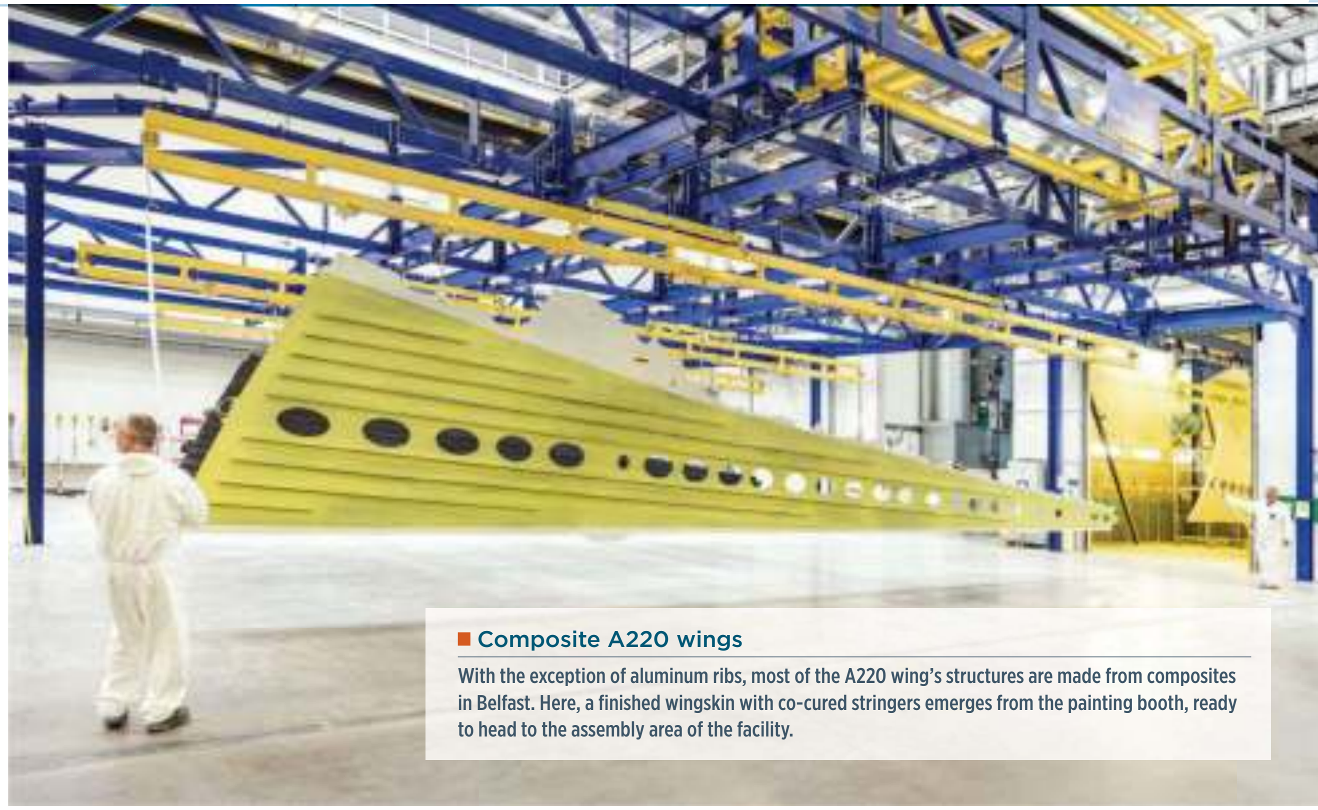
Importantly for the composites industry, Airbus reports that more than 40% of the A220's primary structure is made from composites, including the wings, empennage and rear fuselage/pressure bulkhead, decisions that were made to enable corrosion resistance and weight savings, leading to a reported 20% increase in fuel efficiency and 50% decrease in NOX emissions. The wings specifically are made in Belfast, Northern Ireland, U.K., in a dedicated A220 wing manufacturing facility run by global Tier 1 aerostructures manufacturer Spirit AeroSystems (headquartered in Wichita, Kan., U.S.).

CW recently had the chance to tour this facility and learn more

Purpose-built wing manufacturing facility

In 2020, Tier 1 aerostructures manufacturer Spirit AeroSystems acquired the Airbus A220 composite wing manufacturing facility from Bombardier in Belfast, Northern Ireland. The 600,000-square-foot facility fabricates and assembles the entire wing torque box for the A220-100 and -300.

Source (all images) | Spirit AeroSystems



■ Composite A220 wings

With the exception of aluminum ribs, most of the A220 wing's structures are made from composites in Belfast. Here, a finished wingskin with co-cured stringers emerges from the painting booth, ready to head to the assembly area of the facility.

from Spirit about the development of the C-Series/A220 wing manufacturing process, current production and how Spirit is preparing for future ramp-ups and new programs.

History of Spirit AeroSystems in Belfast

Spirit claims its Belfast operations make it the largest manufacturer in Northern Ireland. Across six facilities, Spirit Belfast employs around 3,500 people and manufactures composite and aluminum structures including wings, fuselages, nacelles and horizontal stabilizers for commercial, aftermarket and, increasingly, defense and space customers, including Airbus, Bombardier and Rolls-Royce (London, U.K.). The company is also involved in composites maintenance, repair and overhaul (MRO); research and development (R&D); and the collaborative research hub Northern Ireland Advanced Composites and Engineering Centre (NIACE), as well as local education and internship initiatives.

Spirit's main factory in Belfast has been in operation since 1936, originally founded by Short Brothers PLC, obtained by Bombardier in 1989 and then ultimately acquired by Spirit in 2020. Less than a mile down the road is a purpose-built, 600,000-square-foot facility opened in 2013 by Bombardier for manufacture and assembly of the composite wings for the then-C-Series aircraft.

Ten years later, at the time of *CW*'s tour, the wing manufacturing facility continues to deliver the A220's composite wings, using the patented and award-winning resin transfer infusion (RTI) process developed specifically for them.

Developing the RTI process

"The technology was developed over a 20-year period," explains Mark Braniff, head of research and technology at Spirit »

■ Cuts and offcuts

Pictured is Spirit AeroSystems Belfast's 20-meter cutting bed. Not pictured is the 20-meter offcut bed. Spirit also collects manufacturing scrap which the R&D team uses for prototype tools and other efforts.

■ Kitting

All fabrics are meticulously kitted, barcoded and stored on "surfboard carousels" (seen in red, far back right) that are wheeled from station to station.

■ Laser-guided layup

A team of technicians lays up wingskins by hand, aided by a series of Virtek laser projection systems mounted to the ceiling throughout the facility.

AeroSystems, Belfast. The RTI process, which won the Royal Academy MacRobert Award in 2019, was developed by the Belfast site (Bombardier, at the time) as the result of an R&D strategy in the 1990s aimed at increasing automation to stay cost-competitive in aerospace manufacturing.

At this time, the few composite wings that were manufactured — mostly for small defense or regional aircraft — were made from costly and hand labor-intensive prepreg layup. Braniff, who was on the original team that developed RTI, adds that multiple technologies were innovated by the company at that time, focused on faster ways to manufacture wing structures by replacing prepreg with resin infusion of dry preforms.

He says, "Over that period, we increased our expertise in resin infusion and worked on several research programs. We developed a bespoke resin infusion technology based on current practices and our in-house derived improvements." Patented in 1998, the process essentially combines industry-standard vacuum-assisted resin transfer molding (VARTM) with autoclave cure. "We realized right away it was going to be very hard to certify a vacuum-only resin-infused component [for commercial aircraft]. We incorporated a robust autoclave pressure cycle after the vacuum infusion phase, and that's what really makes our system stand out from the rest of the world," Braniff explains.

As designed, the process is largely manual with hand layup of biaxial noncrimp fabric (NCF). "Today, with advances in technology, we're looking at more automation, and we're actively working on that for the future," Braniff adds.

The R&D team perfected the RTI process through manufacture of small test panels first, working up over the years to parts of increasing size and complexity, including a 12-meter wing spar for TANGO and wingskins for ALCAS, both EU-funded R&D programs. The RTI process is "highly versatile. It can be used for very large wingskins right down to quite thin-gauge composite structures such as fan cowl doors," Braniff says. In fact, before the wing manufacturing facility was built, the first dedicated RTI facility was established in Belfast in 2007, initially focused on manufacturing STC

V2500 fan cowl doors for the Airbus A320 aircraft family and the MRO market. "This was a fantastic learning opportunity and helped us de-risk the composite wing facility," he says.

In 2008, Bombardier launched its C-series single-aisle aircraft program, and decided to target a lightweight, aerodynamic composite design for the wings to meet environmental performance, fuel efficiency and operating cost goals (Learn More). Given its initial demonstrated successes with RTI, the Belfast facility was chosen to build the wings — provided it could achieve technology readiness level (TRL) 9.

Over the next two years, Bombardier put significant investment into making this happen at the Belfast site, including building a two-third size torque box with upper and lower skins, spars and stringers produced via RTI. "It was a massive transition from R&D to production, the sort of thing that doesn't come along too often," Braniff says. "But it was the right thing to do because it filled in all the little gaps — we developed the process all the way back to the material specs. We learned a lot from testing R&D parts, and many test results transitioned into the certification program."

He adds, "We were on a very tight timescale to get to first flight. We had to complete the traditional pyramid of testing from coupons to subelements, culminating in full-scale wing testing. We achieved a large percentage of the testing in Belfast — not a lot of companies can do that anymore." The Belfast site worked with Bombardier in Montreal and achieved certification through Transport Canada and the FAA. "It was a massive team effort," he notes.

In 2010, commercial production began on the wings at one of Bombardier's Belfast facilities, and Braniff and several other colleagues who had worked on the original R&D were transitioned onto the product development team for the first several years. He notes, "We were able to embed the RTI knowledge into production engineering solutions. It was a good decision, because the learning had been immense and the transfer of knowledge was very beneficial."

The dedicated wing manufacturing facility broke ground in 2010, and officially opened in 2013. "It's an unusual factory," Braniff adds, "in that it contains all the production elements from raw material receipt right through to final assembly. The basic torque box [for the A220] is all built in Belfast."

Fabricating A220 wingskins, spars and stringers

CW's tour begins in the 150,000-square-foot fabrication section of the facility, led by Braniff, Joanne Millar, director of Airbus operations at Spirit AeroSystems and Mark McQuillan, operations engineering manager for Airbus programs at Spirit. Here, all upper and lower wingskins, spars and stringers for A220 wings are fabricated, from layup to tool loading for infusion.

This section of the building is designated as a temperature- and humidity-controlled cleanroom, where cutting, kitting and layup occurs. Braniff notes, "Many might think a cleanroom is only needed for prepreg-based operations. However, with all of the quality controls required for aerospace manufacturing, especially co-cured stringer to skin joints, you end up almost at a cleanroom standard anyway." Humidity control was also added to minimize moisture retention in the preforms.

Everything in the factory is integrated digitally using the company's in-house iFactory software, McQuillan explains, which tracks all aspects of material and process conformity until the wing is »

Preforming

Wingskins, stringers and spars each go through one or multiple infrared preforming phases before infusion. Here, a wingskin is loaded into the machine.

Into the autoclave

The RTI process combines resin transfer molding with an autoclave cure cycle as the most efficient, most easily certifiable way to get the needed porosity and fiber volume fraction levels. Not pictured here is the company's most recent double-decker autoclave system, which enables the company to cure more parts at a time.

ready for assembly. Employees start by scanning their identification cards at their workstations to make sure they're approved for the project they're working on, and the system logs who has completed which part of the process. Bar codes on tools and plies are scanned at each step of the process.

Wingskin, spar and stringer layup

Each wing component comprises several different uni- and multidirectional carbon fiber NCFs supplied by Saertex (Saerbeck, Germany) using Teijin (Tokyo, Japan) carbon fibers. All fabrics are binder coated to facilitate preforming, and are cut using an ultrasonic cutting machine from GFM International (Retford, U.K.), which features a 20-meter cutting bed and a 20-meter offcut bed. Braniff notes that the offcut table and nearby offcut storage bins were added a few years ago, when Spirit decided to start collecting manufacturing waste and look for potential recycling opportunities. The R&D team has begun using some of the stored offcuts to infuse and machine demonstrator tooling, with hopes of expanding into more uses in the future.

Technicians cut and kit all fabrics for multiple wings at a time. These are labeled with barcode stickers — the only paper involved in the process, McQuillan notes — and delivered to a series of wheeled storage carousels. Large plies are stored on individual "surfboards" (named for the shape of the original foam boards used for this), which consist of tube-shaped frames for wrapping the large plies. Small plies are stored in multi-drawer units.

The surfboard carousels are then wheeled to the appropriate layup area depending on whether it is an A220-100 or A220-300 wing. Braniff explains that the outer mold line (OML) tools are manufactured from Invar for thermal compatibility with the curing wingskin. The matched inner mold line (IML) tool, known internally as a "bag," is manufactured on site and capable of multiple cure cycles. These semi-flexible IML bags are thermally matched to the part and produced on Invar master molds for an exact fit with the wingskin preforms and stringer mandrels.

A team of four technicians lays up plies by hand for each wingskin, spar and stringer, guided by a series of Virtek (Waterloo, Canada) laser projection systems installed on the factory ceiling. The layup begins with a ply of copper mesh for lightning strike protection (LSP).

Braniff says layup of the wingskins is relatively straightforward, while the stringers — each a different shape and level of curvature along the length of each wing — were more challenging, and took several years of R&D work to perfect. Saertex and resin supplier Solvay (Brussels, Belgium) provide a tailored version of the same NCFs used for the rest of the wing components, narrower rolls that can then be rolled out onto a flat stacking table and cut to length by the technician, guided by the Virtek system. Each ply layer is then heat tacked to the ply beneath it, forming a "flat pack" that will then be shaped into two L-shaped preforms for the following infrared preforming process, and then connected to form the final T-shaped stringer.

Ready for assembly

A cured, trimmed wingskin with co-cured stringers awaits painting and assembly.

Into the paint booth

Paint is applied to protect the composite surfaces from stored fuel while the wing is in service.

Infrared preforming

Each part requires at least one infrared preforming step during the layup process, sometimes more than one depending on part complexity. Preforming is done by one of several infrared preforming systems supplied by Belfast partner PAC Group, the largest of which is the 21-meter-long × 4.5-meter-wide wingskin preformer. Each preformer includes multiple individually controlled infrared heating zones and a purpose-built cooling system. Cooling the parts down to the required temperature is the key to the process, Braniff says, to ensure that the binder holds the preform's shape. A specially designed cooling and duct system was built for this purpose.

The stringer "flat packs" are laid up onto a series of custom carbon fiber composite holding fixtures located on a powered table. The horizontal fixtures and support mandrels are held in

■ Attaching the final components

Once lifted from the vertical jigs, final components can be assembled to the wings.

place by a central line of removable spacer blocks. A tailored diaphragm is lowered over the assembly and vacuum applied. In the preformer, automated infrared heat cycles form the L-shaped preforms. After cooldown, the spacers are removed and the horizontal fixtures push together to form the T-shaped stringer. A cavity void in the base of the T shape is filled with a bespoke, tackified carbon fiber noodle, which is debulked in place with a final, room temperature vacuum cycle.

The complex curvature of the spars makes them "just as challenging as the stringers," Braniff says. The wing design and main landing gear configuration of the aircraft result in a kink in the rear spar, making it too difficult to manufacture in one piece without fiber distortion at the kink point. Therefore, the rear spars are designed in two pieces, inner and outer, that are then mechanically fastened later during final torque box assembly.

Spar layup is challenging, with a complex flange geometry to match the associated IML surface. The spars therefore require multiple preforming cycles with specific ply layups in between to ensure the proper shape is maintained and held with no wrinkles or other distortion.

> Braniff emphasizes that faster cycle times and increasing automation are the way forward.

The preforming systems are set up so that as one tool or stringer layup table is in the preformer, another layup is being worked on outside of it. Thus, multiple stringers, spars and wing skins are seen in various stages of layup and preforming during our tour.

Automated stringer loading

Next in the process, before heading to the autoclave, the T-shaped stringer preforms are loaded onto the wingskin preform to form one integrated part, via a semi-automated stringer loading cell. "The cell locates the stringer preforms onto the wingskin very accurately, and is critical to achieving a successful co-cured structure," Braniff says.

The automated system picks up the entire stringer preform tool, inverts it and lowers the preform down onto the wingskin already located on the OML cure tool. "Manually moving everything around by hand or by crane would be too difficult. The automated system ensures the preform is positioned exactly at the right place within the cure tool," Braniff says. Then the matched IML "bag" cure tool is placed on top of the stringer and skin assembly. The integrated preform — wingskin with stringers — is ready for the autoclave.

Spar preforms are similarly lifted, rotated and placed onto female OML cure tools in a dedicated loading cell, ready for infusion.

Autoclave infusion and finishing

The tour leaves the cleanroom to enter the second half of the fabrication area, which includes the autoclaves, tool storage and maintenance, machining, nondestructive testing (NDT) and painting.

Two 70 × 18-foot Scholz (Coesfeld, Germany) autoclaves are being loaded as the tour walks by. Braniff explains that the time in the autoclave is one of the longest parts of the fabrication process, so as Spirit looks to the future and ways to meet higher manufacturing rates, this is one area of focus. In summer 2022, the company installed double-deck racks and rails within each of the autoclaves, large enough to be able to cure two full wingskins — co-cured with the stringers — at one time, or one wingskin and several spars.

This double-deck system took 18 months to design and develop. Overall, Braniff says that autoclaving more parts at one time has substantially increased output — "more than if we were to try to shorten individual cycles." He notes that additional R&D work continues to determine if the cycle times can be shortened in other areas.

A resin injection cell next to the autoclave features Solvay Cytec 890 1K epoxy resin in 200-kilogram drums. Using a system of » water-heated pots, the high-viscosity resin is heated and degassed before injection into the autoclaves via a pipe and valve system. Resin is infused into the preheated OML wingskin tools under vacuum using minimal pot pressure to maintain flow rate, Braniff explains. The autoclave is heated and pressurized to achieve the final cure parameters and to deliver parts that he claims have zero porosity and high fiber volume fractions (FVF).

Braniff emphasizes that vacuum integrity is the “secret sauce” of the entire operation, and that multiple, stringent vacuum leak tests are done before the resin is ever injected into the tool. “In this way, we can resolve any vacuum integrity issues early in the process and ultimately abort a cycle prior to injection, removing the part from the autoclave if required. It gives some flexibility for reworking the tool assemblies and avoids the loss of high-cost components.”

An M&P staff member is always on site to control the infusion process, and there are several “critical process gates” or checks that have to be achieved before the infusion can proceed. “The RTI process controls the FVF very accurately. We achieve a uniform distribution of the resin and we are targeting FVFs typical of traditional unidirectional tape laid structures. Porosity is also very low,” Braniff says. Thanks to Spirit’s stringent vacuum integrity standards and control measures, he says that the attrition rate for parts is “extremely low.”

■ Semi-automated drilling

Drilling is one of the assembly operations done on Spirit’s line of wingskin assembly jigs (top image). Most of the 6,000 holes per wingskin are drilled by drill stations or robotic arms.

Trimming, inspection and painting

Next, the tour passes by a series of five-axis machining stations to trim the cured composite parts and to machine access cover holes into the wingskins. Holes are also drilled into the finished wingskins to aid the assembly team.

Down the line are two nondestructive testing (NDT) systems. The first is a gantry-style NDT system from General Electric (Boston, Mass., U.S.); the second is a Tecnatom (São Paulo, Brazil) phased-array inspection gantry robot cell. Both C-scan-based systems are calibrated to measure part thickness and scan for typical defects like porosity and delamination.

Finally, a paint booth rounds out the fabrication section of the building. A green-colored paint is used to help protect the cured composite surfaces from direct contact with fuel, inhibit moisture uptake and aid in visual inspection within the fuel tank.

Concluding the fabrication area of the tour, Braniff notes, “Having worked on the R&D program, we were able to help specify a lot of the production equipment. There’s a lot of infrared preforming technology that required a significant increase in scale. The injection system was totally bespoke to the A220 wing. The stringer manufacturing process is very special, and produces repeatable, defect-free components daily. A lot of the equipment specifications came from the original R&D projects.”

Wing assembly

The overall facility is split into two parts — fabrication and assembly — with an area in between for support activities and dispatch of parts in and out of the factory. Here, various other components are also brought in from other Tier 1 partners.

The assembly area of the factory is packed with 10 assembly jigs — five for port/left-hand wings and five for starboard/right-hand wings. The jigs are positioned on edge instead of the more typical laid flat arrangement to save floor space and increase access to both sides of each wingskin at once. In this area of the facility, the entire torque box is assembled, from the wingskins, spars and stringers that are seen elsewhere in the factory to ribs, leading and trailing edges. “Ultimately, 90% of the components are composite, not including the aluminum ribs,” Millar says. Assembled torque boxes are then removed from the vertical jigs and relocated horizontally in the pulse line, where wings move sequentially down the line as systems and control surfaces are added.

As one walks past each of the jigs, the different phases of assembly can be seen one by one. “It’s a very sequential process, much more so than a fuselage assembly,” says Millar. She explains that the assembly portion of the facility is also paperless, though running on a different software platform than the fabrication area. All specs are stored and sent to Airbus ahead of final assembly.

First, more than 6,000 holes need to be drilled into each wingskin

■ **Ready for flight**

The manufacturing and assembly system is designed so that Airbus can "plug and play" the wings straight onto the rest of the aircraft once they arrive at the final assembly facility.

for fasteners. "Drilling is the most critical part of the build," Millar explains. Drilling is done via four bespoke Electroimpact (Mukilteo, Wash., U.S.) drilling stations, which drill the larger holes, and two smaller ancillary robot arms for the smaller holes. "The robotic arms work in tandem with the drilling stations, meeting up about three-fourths of the way through the wing," she says.

Next, spars and ribs are fastened together, and the upper wingskin is attached. The lower wingskin is fastened in place last. "We worked with Airbus to create a plug-and-play situation," Millar explains. "We finish the wing as much as possible, so that Airbus can attach the wing tips and close out the wing to the center-box joint at the final assembly line."

A pneumatic, vacuum-assisted lifter removes each semi-assembled wing from the vertical jig and places it onto a horizontal table, where final components like leading edges and ailerons, flaps and spoilers are attached, hydraulic systems are installed and fuel leak tests are performed. Finally, the lower wingskin is sealed, and the A220 wing is ready to go.

The assembly stations form a U-turn around the assembly section of the building, leading us back to the end of the dispatch area in the middle of the factory. Here, an on-site Airbus inspector does a final series of tests before the wing is moved to a shipping container via a vacuum-assisted lifter. The flaps are removed for ease of shipping to be reassembled later. Each set of wings is shipped first to Liverpool, U.K., and then New York, N.Y., U.S., before heading to its final assembly destination at Airbus A220 assembly facilities in Mirabel, Canada or Mobile, Ala., U.S.

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More on *CW*'s 2016 Spirit tour in Prestwick, Scotland | short.compositesworld.com/SpiritPrestwick

Increasing automation to meet higher rates

What's next for Spirit's Belfast wing manufacturing facility? Braniff emphasizes that faster cycle times and increased automation are the way forward, and that Spirit is working on various paths toward these ends.

For example, the company has trialed out-of-autoclave processes to replace the time-consuming autoclave process. However, "when we looked at the intricacies of heating and cooling the tools, the autoclave was the obvious choice based on demonstrated efficiencies. The autoclave is incredibly efficient at handling large thermal masses, with heating and cooling rates enhanced through pressurization," Braniff says, as well as achieving the FVFs needed to achieve the wings' weight goals.

Spirit's R&D team also designed and built a pick-and-place system to automate the NCF ply layup process, but it was expensive, "and when benchmarked against the manual process it wasn't any faster. Once we had the teams trained up on laying down the fabric, it was the most efficient method," Braniff adds.

Still, Spirit is working toward developing automation capabilities where they make sense. For example, Spirit's Prestwick, Scotland, facility is working on capabilities for automated stringer preforming, which could eventually be installed in Belfast (Learn More). Also in the future, Braniff notes that a gantry-style dry fiber placement (DFP) system could be on the table. However, to switch to DFP would mean that changes to the currently certified materials would be needed. "It's challenging to retrofit automation into existing contracts. It's something we're actively pursuing though, and it may be that we develop it and use it for other platforms," he explains.

In the future, as Airbus evolves its needs and rates, there may be more opportunities, and Spirit is exploring new manufacturing and material developments. CW

ABOUT THE AUTHOR

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Recycling hydrogen tanks to produce automotive structural components

Voith Composites and partners develop recycling solutions for hydrogen storage tanks and manufacturing methods to produce automotive parts from the recycled materials.

Source | Voith Composites

Source | *CW*

Source | Voith Composites

Voith Composites (Garching, Germany) manufactures automotive components with a focus on automated and Composites 4.0-enabled processes. It has recently leveraged its expertise for the emerging hydrogen economy with 700-bar hydrogen tanks for the heavy goods sector. Fabricated with an automated towpreg winding process, the tanks are said to be lighter weight with a higher hydrogen capacity than conventional filament-wound carbon fiber-reinforced polymer (CFRP) tanks.

At the same time, Voith is also focused on sustainability, especially as automakers face increasing pressure to adopt recycling and sustainability solutions for their components. Over the past year, Voith has focused on technologies and partnerships to enable its high-pressure CFRP tanks to be recycled at the end of their 15-year lifespans — as well as solutions for manufacturing new automotive components using the resulting recycled carbon fiber (rCF).

Voith and its partners, including Toray (Tokyo, Japan, for materials), Tenowo (Hof, Germany, for nonwoven manufacturing) and Delta-Preg (Sant'Egidio alla Vibrata, Italy, for resin impregnation), are working on two different recycling processes, one for recycling of manufacturing scraps and one for end-of-life (EOL) parts such as hydrogen tanks.

In the first process, dry carbon fiber cuttings from Voith's hydrogen tank winding process are collected and cut to about 60 millimeters in length. These fibers are oriented and manufactured into a dry nonwoven fabric, impregnated with resin and laid up into a prepreg stack to be pressed in a closed-mold process into a final end-use part.

This process has already been used to manufacture demonstrator automotive components. At JEC World 2023 in Paris, France, Voith showcased a structural component for stiffening the underbody of a sports car, made in collaboration with a European automaker.

In a second recycling method, an acid-based solvolysis process is used to extract carbon fibers and resins from a composite part that has reached its EOL. In this process, 60-80 millimeters of carbon fibers are extracted and, in a separate process, re-oriented and remanufactured into 50-millimeter-wide unidirectional tapes that are then impregnated with epoxy. The prepreg tapes can then be tailored into a preform for a new automotive component, using the Voith Roving Applicator (VRA) technology, an automated process that cuts tapes to predetermined lengths and places at specified angles.

Currently, shredded EOL parts are fed into a pilot-scale system, resulting in extracted fibers of relatively short length (up to 80 millimeters). In future, the goal is to extend the process to continuous rovings such as those used in Voith's towpreg-wound high-pressure hydrogen tanks. Another goal is to remanufacture the extracted resin components into new resins.

Over the past year, Voith reports that work on this process has been ongoing, with a primary goal of determining whether a fully functional component could be made from recycled carbon fibers. This work has included determining how well the stacks can be pressed, how the resin will flow and how the carbon fiber will behave, all of which was important to determine how the variables can be fine-tuned and how the manufacturing process can be adapted to the company's recycling concept.

Today, Voith continues to test prototype parts and coupons, but reports that the results so far are positive. For example, tensile strength of the rCF tapes is in the range of 80-90% compared to virgin carbon fiber.

As both of these processes continue to move forward, Mario Krupka, international sales manager at Voith Composites, explains that moving toward bio-based or recycled resin with its rCF will be the next step. "The first step is to impregnate the rCF with our standard epoxy resin system, matching the resin used in typical virgin CF tapes," he says. "The second step is to combine the rCF with a vitrimer epoxy resin from another supplier. The final step would be to use a 100% bio-based epoxy resin system, or the epoxy resin extracted from the solvolysis recycling process."

For both processes, recycling itself is done by Voith's partners. Voith then uses the recycled materials to produce CFRP components at its production facilities. The company says it is continuing to work with its automaker partners, with the ultimate goal of incorporating rCF components into production sports and luxury vehicles. CW

MANUFACTURING SUPPLIERS

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New Products

» AEROSPACE PREPREGS

Aerospace-focused RTM resin, rapid-cure prepreg

In response to OEM requirements to increase production efficiency, **Hexcel** (Stamford, Conn., U.S.) has launched two new aerospace material products that each deliver faster cure cycles, enabling higher production build rates.

HexPly M51 is a rapid-curing prepreg designed for hot-in/hot-out press curing. Fully compatible with automated tape laying (ATL), automated fiber placement (AFP) and pick-and-place processes, HexPly M51 is REACH-compliant and has a 40-minute cure cycle at 180°C. The prepreg was used to manufacture a rib component in partnership with GKN Aerospace (Redditch, U.K.) as part of the ASCEND project.

Hexcel HiFlow HF610F-2 resin is a new resin transfer molding (RTM) resin suitable for high-rate manufacturing of small- to medium-sized parts enabling robust, high-rate injection processes. A part developed by Airbus Stade (Germany) for the Wing of Tomorrow (WOT) project uses HiMax noncrimp fabrics and HiTape unidirectional reinforcements in combination with the new liquid resin to deliver a total molding time of just 30 minutes.


Source | Hexcel

Other examples in which these technologies were incorporated include a shark fin panel, also manufactured for WOT by Airbus UK (Bristol) with HiMax and HexFlow materials, and a carbon fiber-reinforced polymer (CFRP) passenger door beam made by Airbus with HiFlow and HexForce materials. hexcel.com

Source | PRF Composite Materials

» RECYCLED MATERIALS

Recycled carbon fiber prepreg composite

As part of a portfolio of products designed to deliver improved sustainability, **PRF Composite Materials** (Poole, Dorset, U.K.) is introducing Reepreg, the company's new carbon fiber prepreg material made with recycled chopped carbon mat.

PRF's processing enables almost full impregnation, which makes Reepreg drapeable and easily handled by the constructor, without falling apart when used — a feature that the PRF team believes sets it apart from other recycled mat products. The mat is made using recycled carbon fiber prepreg waste. In the near future, PRF says the finished component — including scrap from trimming components — will also be recyclable, thus improving circularity and extending the life cycle of this product.

Reepreg will be available in combination with PRF's component prepreg resin systems and in standard weights of 100, 200 and 300 gsm. The material can be processed in autoclave and press, and can be used as a core material in conjunction with PRF's woven and unidirectional prepreg materials. **prfcomposites.com**

Source | Park Aerospace

» BONDING ADHESIVE

Epoxy-based structural film adhesive intended for aerospace, MRO

Park Aerospace Corp. (Newton, Kan., U.S.) launches the company's new Aeroadhere FAE-350-1 structural film adhesive product for use in bonding of aerospace primary and secondary structures.

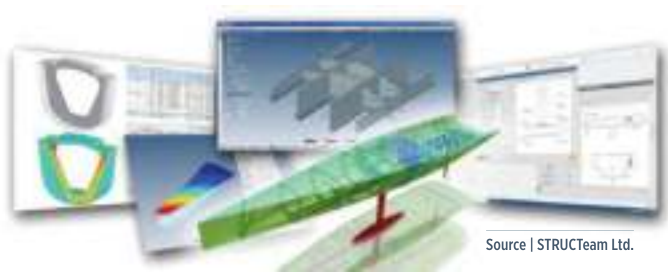
Aeroadhere FAE-350-1 film adhesive is a 350°F curing epoxy formulation film adhesive designed for composite-to-composite, composite-to-honeycomb, composite-to-metal, metal-to-metal and metal-to-honeycomb bonding applications. Aeroadhere FAE-350-1 has demonstrated strong toughness and high temperature capabilities. It is intended to be used in aerospace original equipment and maintenance, repair and overhaul (MRO) applications.

Park Aerospace Corp. develops and manufactures solutions and hot melt advanced composite materials used to produce composite structures for the global aerospace markets. As a complement to these offerings, Park designs and fabricates composite parts, structures and assemblies and low-volume tooling for the aerospace industry. **parkaerospace.com**

» ONLINE DESIGN ENGINEERING SUBSCRIPTION

Web-based design modules include Yacht Designer license

STRUCTeam Ltd. (Cowes, U.K.) has released a performance-orientated upgrade to CompoSIDE, the company's integrated suite of web-based design engineering modules for composite marine applications. The new updates to the software have been developed to support naval architects, marine engineers and design teams that are defining hull construction and scantlings for vessels under 24 m.



Source | STRUCTeam Ltd.

The Yacht Designer subscription is fully inclusive of the revised ISO 12215-5:2019 standard and is said to provide seamless interaction between modules, including YACHTScant and FESpace. This enables users to combine design optimization and ISO compliance with monohull small craft — hull construction and scantlings.

"CompoSIDE has become an essential tool for many of our customers in the design and production of composite parts, products and the specification of structural elements," says Julien Sellier, managing director of CompoSIDE and STRUCTeam. "This new offering is the perfect addition to a comprehensive suite of engineering modules."

Additional key features include a default materials library, ply-by-ply laminate modeling and analysis (CLT), FEA for panels and beams, composite beams and section modeling and a bill of materials. **structeam-ltd.com**

Composites enable massive wastewater infrastructure project

To build complex drop shafts for New Zealand's Central Interceptor project, RPC Technologies pushed the limits with glass and carbon fiber, vertical filament winding and UV-cure resins.

By Hannah Mason / Technical Editor

Multi-material composite vertical shafts

Auckland's Central Interceptor wastewater and stormwater tunnel is connected to wastewater management, odor treatment and other facilities by a series of vertical shafts. Traditionally made from concrete, eight shafts — up to 7.5 meters in diameter — for this project were designed from fiberglass and carbon fiber composites by RPC Technologies to meet challenging requirements.

Source (all images) RPC Technologies

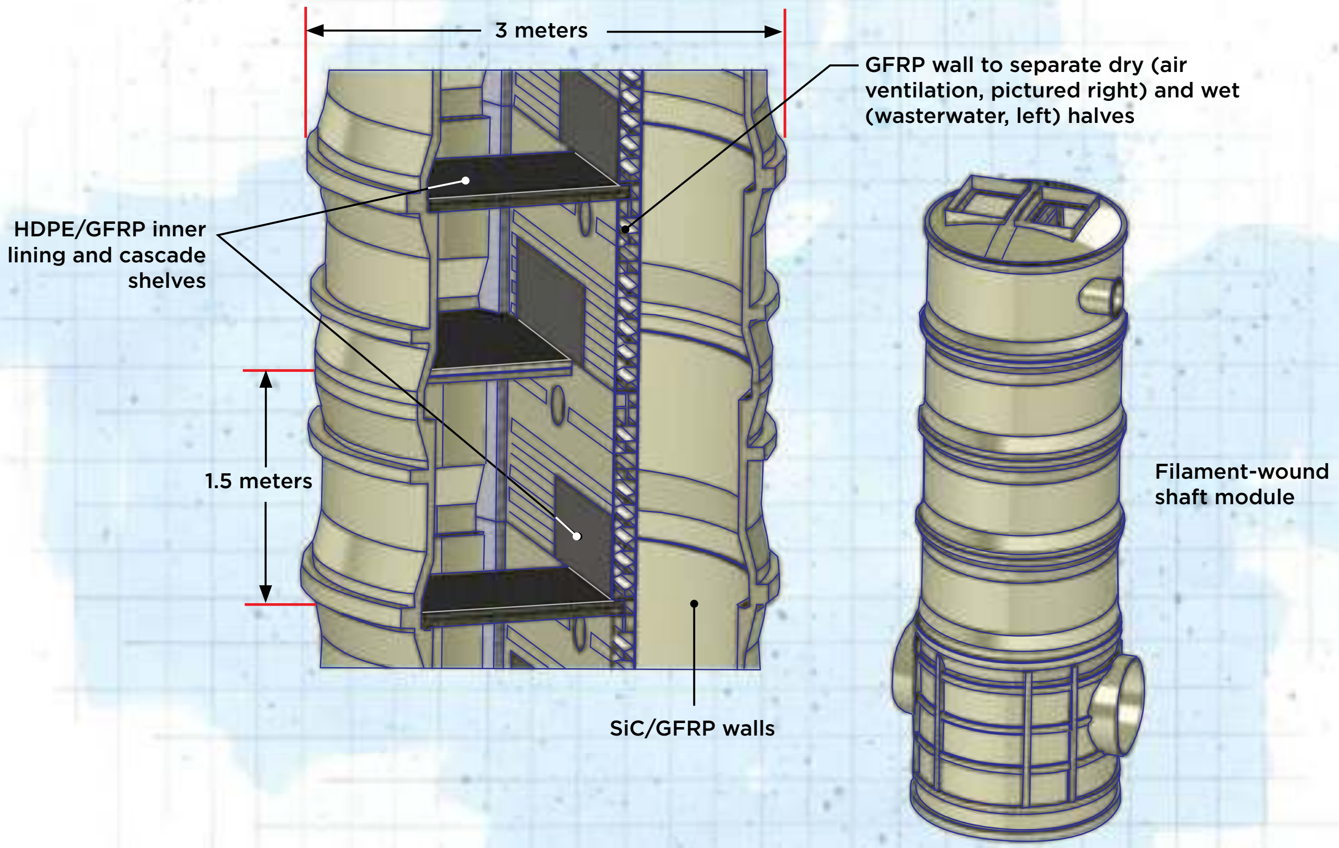
»The Central Interceptor (CI) is a massive, 14.7-kilometer, 4.5-meter-diameter tunnel with a 226,000-cubic-meter capacity that, when completed, will run underneath the New Zealand capital of Auckland, collecting waste- and stormwater from smaller connecting pipes around the city and channeling them to the Māngere Wastewater Treatment Plant.

Led by delivery team Ghella Abergeldie JV (GAJV, Auckland, New Zealand) for its customer Watercare (Auckland), this project aims to replace existing aging infrastructure with one central tunnel that is able to handle the growing population of Auckland and alleviate current overflow issues. Begun in 2019, the project is scheduled for completion in 2026. As large as it will be, the CI itself — made from segments of high-density polyethylene (HDPE)-lined concrete — is only one component of the larger system. Servicing the main tunnel are more than 5 kilometers of sewers, a pump station and facilities for odor control, air treatment and wastewater management, all connected by a series of 18 vertical shafts reaching depths of up to 70 meters.

Traditionally, these shafts would be made from concrete, and, in this project, half of the 18 total shafts are. However, several requirements led Watercare to consider alternate materials for at least some of the shafts. For example, the entire project must be designed to last 100 years, including survival of major earthquake events. Moreover, concrete shafts, while generally durable and long-lasting, are subject to corrosion from the sewer chemicals and gases traveling through them, and would need to be repaired and/or replaced multiple times within the needed timeframe.

Corrosion resistance and durability led Watercare to seek composite solutions for some of the vertical shafts that run from the street level down to the CI. For this, Watercare turned to RPC Technologies Pty Ltd. (Seven Hills, New South Wales, Australia), which specializes in design, engineering and manufacturing of glass fiber-reinforced polymer (GFRP) composites, including more than 40 years of experience in developing GFRP water and wastewater management solutions.

Tony Caristo, managing director at RPC, explains that the company was approached to manufacture two of the smaller, 3-meter-diameter shafts in GFRP — the remainder of the shafts



Source (original image) RPC Technologies

DESIGN RESULTS **Filament-wound GFRP/CFRP cascade shafts**

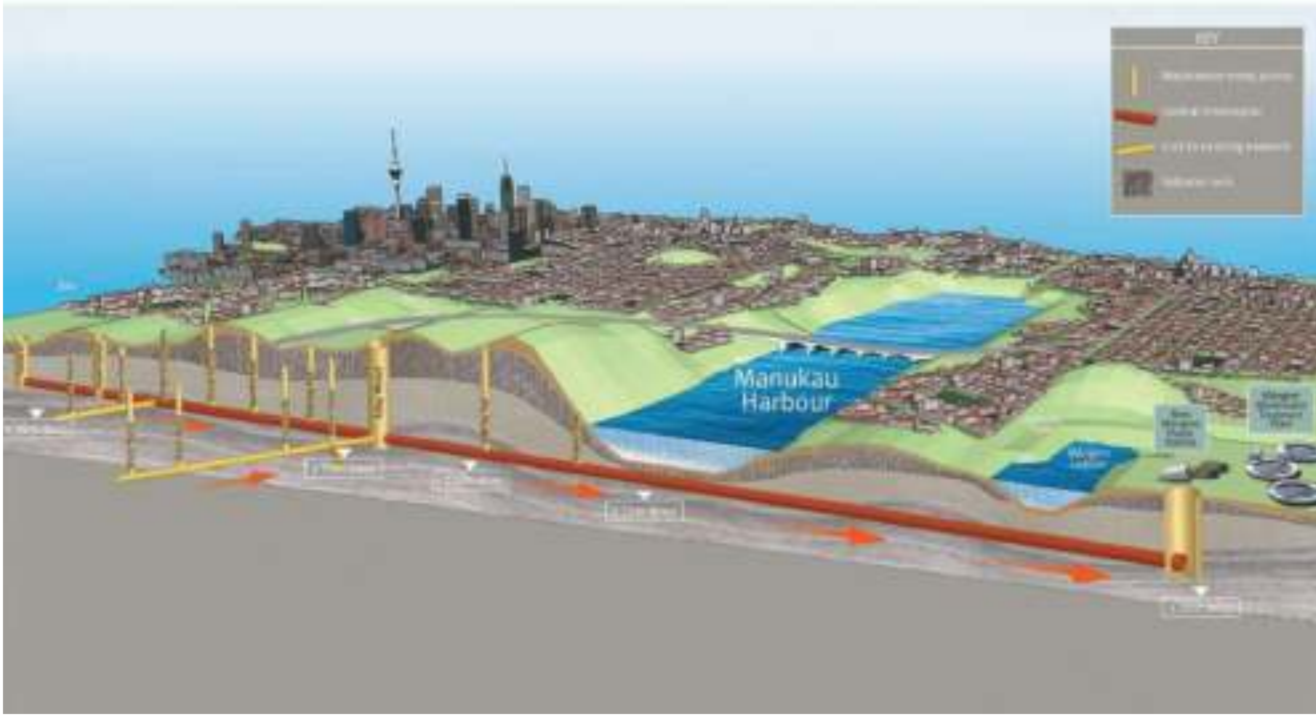
- Corrosion resistance, impact, depth and 100-year durability requirements lead to mix of HDPE and SiC-lined glass and carbon fiber.
- Sandwich cascade panels dissipate energy from wastewater.
- Automated vertical filament winding and UV-cure resins enable large-scale 7.5-meter-diameter shafts.

Susan Kraus / Illustration

would all be constructed from traditional concrete by other companies. RPC pitched several of the larger 4.5- and 5-meter-diameter shafts in composites as well. "It'll last longer, protecting the tunnel shaft against acid or gases from the sewer. We knew composites were a better long-term solution," he says. The switch to composites, he adds, saves up to 6 months of construction time for the bigger shafts, removing the need for construction workers to install concrete on site in a confined space, improving worker safety. "We eventually convinced them [GAJV] that it was a good solution, and that it would save them considerable construction time." In fact, GAJV decided to extend the use of GFRP to even larger shafts.

RPC ended up being contracted to design and manufacture eight vertical shafts. Often identified by the Auckland roads they are installed closest to (see the table at right), the shafts range »

Shaft Location	Diameter	Depth	Number of Modules	Number of Shelves
Keith Hay Park	3 m	72 m	12	42
Walmsley Park	3 m	59 m	10	38
PS 23	4.5 m	24 m	5	6
Dundale	4.5 m	23 m	8	6
Miranda	4.5 m	14 m	5	4
Haycock	5.5 m	26 m	9	8
Rawalpindi	5.5 m	26 m	8	6
May Rd	7.5 m	69 m	21	3



The CI system

Vertical shafts (yellow) across the city feed wastewater and stormwater into the Central Interceptor (red), ultimately traveling to the Māngere Wastewater Treatment Plant (far right on map).

Wet and dry

A GFRP wall separates the two halves of each shaft, one filled with cascade shelves (pictured left in above image) to dissipate energy as waste- and stormwater falls through, the other to funnel air to an odor control facility.

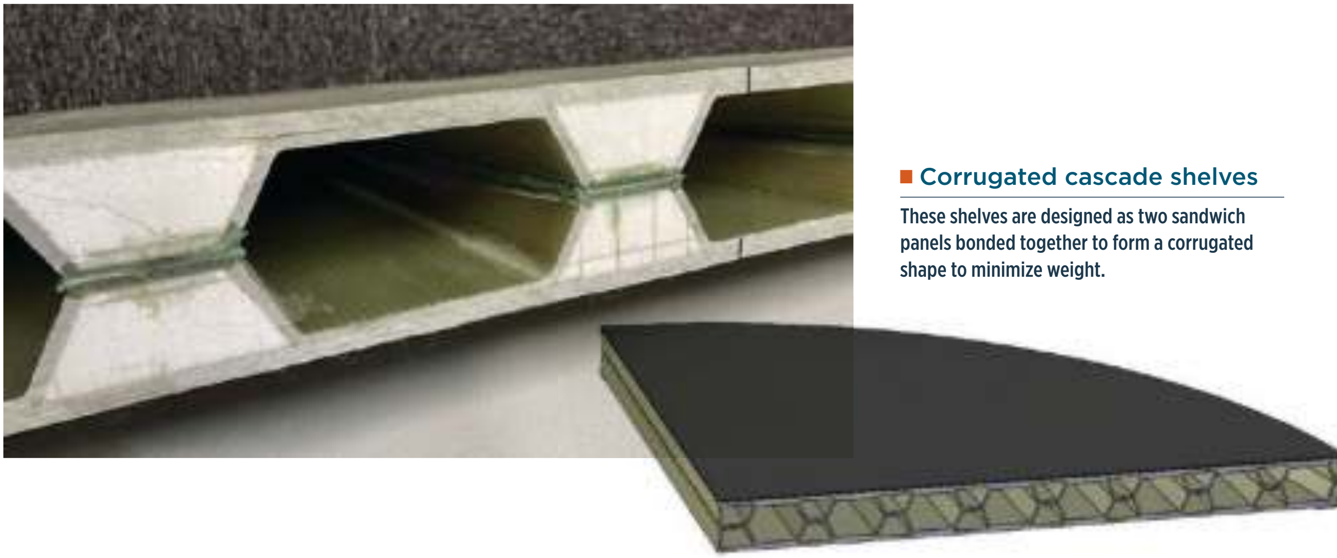
from 3 to 7.5 meters in diameter and depths from 14 to 72 meters. While all of the shafts have the same function and the same base design, differences in diameter, depth, construction methodology and more led to a number of design and manufacturing challenges throughout the project.

Designing and manufacturing GFRP shafts

At the most basic level, each cascade shaft is designed as a series of vertical tube segments — sometimes called "cans" — from 2.75 to 14.5 meters in length that are bolted together into the final shaft module. Within each segment, a dividing wall, made in two halves adhesively bonded in the middle, separate the "wet" and "dry" sides of the shaft.

Wastewater drops down the wet half of the cascade shaft, ultimately channeling into the CI, while air ventilates through the dry half, to be treated in an odor control facility. In the wet half of the shaft, a series of shelves, called cascade drop structures, are built into the shaft walls. "As the wastewater comes down, it cascades down the shelves, which dissipates the energy as it goes down," Caristo explains. This helps prevent buildup and overflow and reduces wear on the pipes.

For each shaft, Watercare provided the 3D model design, including dimensions, height and shelf placement, as well as mechanical property requirements. RPC then designed the individual structures and manufactured the components. The design



■ Corrugated cascade shelves

These shelves are designed as two sandwich panels bonded together to form a corrugated shape to minimize weight.

process was extensive and took about a year of back and forth, Caristo says, "because at each stage, the design had to be reviewed with the Watercare engineers."

To provide a 100-year service life, the shafts needed to meet specific long-term strength, fatigue, abrasion, erosion, external pressure and seismic deformation requirements. The raw materials and part designs were first analyzed via finite element analysis (FEA), followed by a 12-month testing process of test panels and prototypes at RPC's testing center in Newcastle, outside of Sydney, Australia. This testing process led to several iterations for each of the designs before reaching the final manufacturing steps. An adapted version of test method BS EN 13121-3:2016, developed for GFRP tanks and vessels by BSI Group (U.K.), was used to inform testing.

Shaft components are manufactured between two of RPC's six total facilities. The smaller shafts — the two 3-meter-diameter shafts and the three 4.5-meter-diameter shafts — are manufactured at RPC's facility in Batam, Indonesia. The larger, 5.5-meter-diameter and 7.5-meter-diameter shafts are manufactured in Batam and Corio, Victoria, Australia.

For the various segments and shelves, a variety of raw materials are used, Caristo says, including polyester and vinyl ester resins; methyl methacrylate (MMA) and epoxy adhesive; acid-resistant ECR glass fibers as triaxial and biaxial continuous rovings for the filament-wound tubes; and 0/90 biaxial, ±45 double bias or unidirectional fabrics for the shelves and dividing walls.

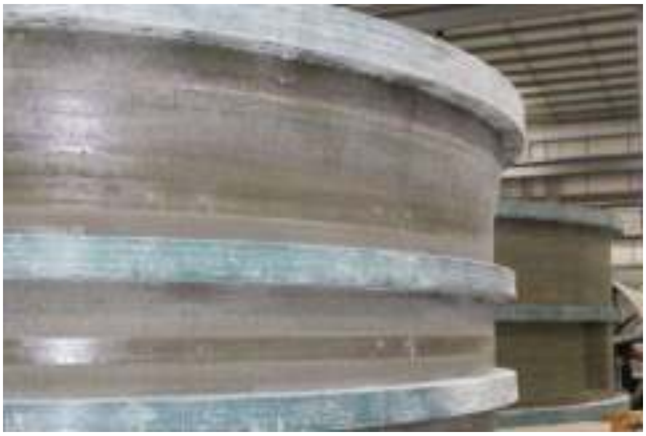
The diameter and numbers of segments differ per shaft, but each segment is built from individually designed, filament-wound GFRP (using biaxial or triaxial glass fiber rovings) manufactured on one of RPC's eight total filament winders supplied by CNC Technics (Hyderabad, India) and McClean Anderson (Schofield, Wis., U.S). Wall thickness varies along each shaft — thinner for segments that will be installed closest to ground level and that see the lightest loads, and thicker the deeper the shaft will be installed underground. For the 7.5-meter-diameter shaft, the deepest segment required a wall thickness of 300 millimeters.

Inside the shafts, the exposed surface of the cascade shelves are lined with HDPE, while the walls and splash zones include silicon carbide (SiC) within a corrosion barrier, to improve wear and abrasion resistance and to further protect the walls against chemicals from the wastewater. A series of GFRP lips are also manufactured directly into the inner walls, onto which the cascade shelves are bonded during assembly.

The cascade shelves, designed to support up to 70,000 kilograms each, are made from two GFRP and foam core sandwich panels made via vacuum-assisted infusion and then bonded together to form a corrugated, hexagonal shape. This shape, developed by RPC in previous wastewater treatment projects, adds torsional stiffness »

■ Carbon fiber and fiberglass beams

To support the cascade drop shelves over the width of the 7.5-meter-diameter shaft, fiberglass/carbon fiber composite sandwich structures were hand laid and vacuum-infused, then installed in a grid pattern.



Automated, vertical winding

RPC's 7.5-meter-diameter May Rd shaft is the largest it has built to date, and wider than the limitations of its typical horizontal filament winders. RPC worked with filament winder supplier CNC Technics to build an automated vertical winder, and used UV-cure resins to enable fast enough cure to prevent resin or fibers from slipping due to gravity.

Installing the shafts

The final challenge is installing each shaft module by module underground. RPC aims to have its final shafts installed by August 2024.

and strength at the lightest weight possible, Caristo says. He adds that to secure the hold, the MMA adhesive is heated in a curing oven to 90°C after application. Each shelf undergoes mechanical testing before assembly into the final shaft.

The tube-shaped segments and cascades are pre-assembled as much as possible at the manufacturing plant, then shipped to the construction site, where segments are bolted together to form the larger modules for installation.

Solving manufacturing challenges: Vertical winding and UV-cure resin

There were a number of design challenges encountered along the way that required analysis and redesign — such as difficult-to-access sewer entry points and very thick laminates for certain modules due to extreme depths — but the biggest challenge, Caristo says, was designing the 7.5-meter-diameter, 69-meter deep, 21-segment-long May Rd shaft. "We'd developed large cascade shafts before, up to 5 meters in diameter or so, but never one this large," he says. At first, Watercare "didn't quite believe we could go to such a large diameter with GFRP. But we knew that we had the technical ability to do it."

One challenge in designing the larger shaft was that the cascade shelves needed a stronger support structure to secure them across the wider diameter. RPC ultimately designed a grid of interlocking beams made from a combination of carbon and glass fiber fabrics infused into composite sandwich panels. RPC typically specializes in GFRP, but in this case, high rigidity and very light weight were needed, and the addition of carbon fiber made the most sense. "This material combination minimizes both weight and cost," Caristo says.

The main difficulty in the beams' design, Caristo adds, is that because of the requirement to accommodate potential earthquake activity, "the structure had to be rigid as well as flexible." The beam grid is designed in two pieces: An "S" shaped joint — which adds flexibility of movement — and "T" shaped beams. These slot together and are laminated to form an integrated structure to be bonded into the shaft module with the cascade shelves installed on top of them.

Another design challenge for the larger shafts was how to filament wind the segments themselves. The parts were too large to be wound on the company's traditional horizontally oriented filament winder, which has a limit of 6 meters. So, RPC's Corio, Australia, facility developed an automated, *vertical* filament winder able to cover the larger size capable of up to 8 meters in diameter. RPC developed the specifications for the system, which was built by partner CNC Technics. This system allowed for manufacture of the taller and wider structure, but also came with several of its own challenges. One was manufacturing ribs on the exterior of the 7.5-meter-diameter shaft. "With a normal horizontal filament winder, the laminate works quite well, it sticks," Caristo says, "but when you try to do the same thing in a vertical winder, gravity pulls everything down and keeping everything aligned is technically challenging."

RPC resolved the issue with the use of an ultraviolet (UV) light curing system and UV-cure polyester or vinyl ester resin (depending on the particular component) "which hardens the resin almost instantly," he says. This system worked to cure the part before gravity worked on the laminate, and also addressed heat distortion. Winding with traditional resin in such a large, thick laminate can cause heat buildup, Caristo explains, "which potentially could crack some of the laminate." With this UV-cure method, "you end up avoiding the heat buildup."

Ultimately, RPC built about half of the 21 total modules for the May Rd shaft in Corio using the vertical winder and UV-cure resins, and half in Batam, Indonesia, using a traditional horizontal winder. Caristo explains that rather than build a second vertical winder, the company decided to adapt the winder in Batam, building a new mandrel to accommodate the larger parts and adapting to UV-cure resin for the ribs to simplify the curing process.

+ LEARN MORE

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Final step: Installation

The CI project is slated for completion in 2026, but RPC's shafts are expected to be completely installed by August 2024. "Our structures have to be installed early in the process, because there are a lot of structures that need to be installed on top of these shafts," Caristo explains. Installation for shafts like these is complex, he adds, with the sheer size of the shafts, depth, visibility underground and site accessibility all playing roles in its success. The overall process is a team effort, requiring close cooperation between RPC, responsible for installation methodology and supervision, and GAJV.

Caristo notes that the Keith Hay Park shaft has been the most challenging so far — at 3 meters in diameter, it is one of the smaller shafts, but also the deepest at 72 meters. "Normally, we start at the bottom of the trench, and install one module at a time, working up," he says. "But this shaft was so deep, and full of construction site bentonite slurry, that we had to start from the top, and shift down each segment as we went down. It all worked very well, but was a challenge." CW

ABOUT THE AUTHOR

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Post Cure

Highlighting the behind-the-scenes of composites manufacturing

Opening new paradigms for hollow composite structures

Addyx Srl (Montesilvano, Italy) is a startup company that studies and designs innovative technological solutions dedicated to advanced composite materials. The company's carbon exoskeleton technology, for instance, made via additive manufacturing (AM), uses Addyx's patented WSM-170, a low environmental impact material, to produce a water-soluble expanding mandrel (top image) that enables topology-optimized composite structures with a high-quality surface finish — in particular, molded unidirectional (UD) pre-impregnated carbon fiber-reinforced ribs within hollow tubular components, as seen in the bottom image. WSM-170 is ideal for autoclave or out-of-autoclave processing methods.

The Addyx carbon exoskeleton technology improves a composite structure's mechanical performance (stiffness and strength) while integrating a means to improve impact resistance. Addyx also cites a reduction in laminating/manufacturing, time and scrap rate as well as weight savings of up to 30% compared to traditional production processes.

Source (all images) | Addyx Srl

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The *CompositesWorld* team wants to feature your composite part, manufacturing process or facility in next month's issue.

Send an image and caption to *CW* Technical Editor Hannah Mason at hmason@compositesworld.com, or connect with us on social media.

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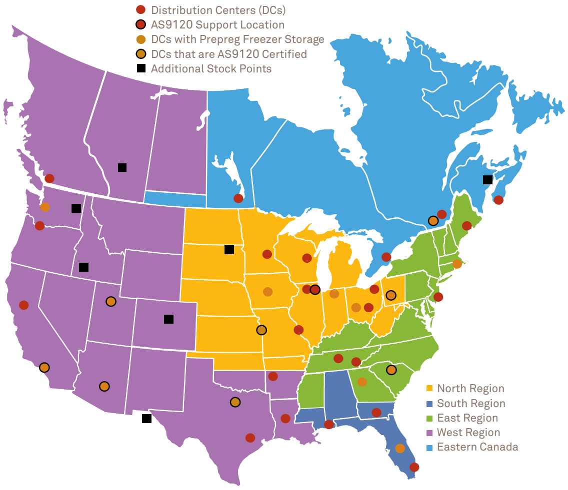

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