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Hydroelectric turbine blades: COMPOSITES ENABLE ENERGY FROM WATER

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COLUMNS

DEPARTMENTS

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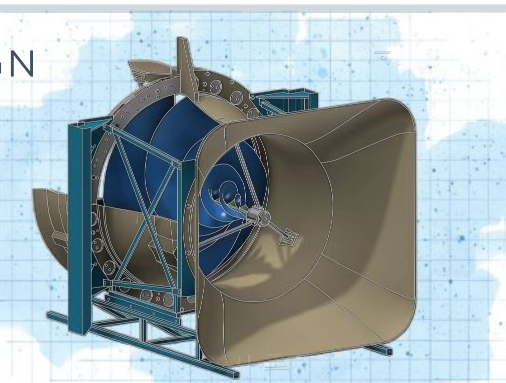
ON THE COVER

Renewable energy company Kinetic NRG set out to design a modular hydroelectric turbine able to capture more energy from water sources such as rivers and irrigation canals. The result is the Hydro-kinetic Energy Generator (HEG) system, a spiral-shaped, glass fiber/epoxy turbine blade prototype. The spiral shape, combined with the nacelle, increases water pressure available for capture. See p. 44.

Source | ACS-A

FOCUS ON DESIGN



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It's been about a year since the coronavirus became a pandemic, and with vaccines in distribution, many of us are now trying to imagine what life might be like in a world where the virus is, if not eradicated, at least under control and manageable.

I know that many of us would like to think that we can simply revert to all of our pre-pandemic behaviors, both socially and professionally — traveling for work or for pleasure, gathering at will with friends and family, attending sporting events, trade shows and conferences, or visiting customers and/or suppliers.

> Moving forward will require some recalibration.

Reverting to this pre-pandemic behavior, however, assumes that the environment in which we live our lives has remained unchanged. In fact, it is rather difficult to think about an aspect of our lives that has not been touched and changed by the pandemic. Therefore, moving forward in this post-pandemic world — successfully — will require some recalibration of ourselves and the composites industry as a whole, recognizing what has changed and how that might affect our options and actions.

This begs the question: What has changed in the composites industry that should be recognized and accounted for? Or, perhaps more importantly, what have we learned in the last 12 months?

The first and most obvious thing we have learned is just how valuable commercial air travel is, and how much we took it for granted. The implications of severely limited air travel are many, but for the composites industry, there are two big ones. The first, is the large and negative impact on aircraft production. Aerospace is the most valuable end market served by the composites industry, thus the reduction of build rates by Boeing and Airbus that have trickled down throughout the supply chain, putting substantial economic pressure on fabricators, moldmakers and raw material suppliers. The second implication is the restriction on in-person interaction among composites industry professionals. Composites manufacturing, as you know, is highly tactile and demands a certain level of physical interaction to understand how resins and fibers are combined to make a finished part. Virtual interactions, videos and photos can be helpful, but at some point that in-person connection becomes essential to advance ideas and technologies.

The second thing we have learned is that in an asymmetrical economic downturn, such as that wrought by the pandemic, there are winners as well as losers. As I noted in my January editorial, the social interaction limits imposed by the pandemic have driven consumers to outdoor activities, made apparent by the substantial increase in demand for boats, recreational vehicles and sporting goods within the last 12 months. And the global wind energy industry enjoyed one of its strongest years ever in 2020, even with a pandemic-induced slowdown last spring.

The third thing we have learned — are learning — is that the global supply chain that delivers raw materials to manufacturers has some vulnerabilities that we are still struggling to come to terms with. For example, as the recreational marine and recreational vehicle markets surged in 2020, the supply of glass fiber gun rovings tightened. The result is long lead times for rovings deliveries and higher prices. The causes of this tight supply are numerous. First, the vast majority of the world's glass fiber rovings comes out of China, and as the Chinese economy recovered in late 2020, demand within China for rovings increased. On top of that, Chinese rovings suppliers, which until recently had been paying — in an effort to maintain market share — the 25% tariff on product exported to the U.S., decided to stop paying the tariff and implemented a 20% price hike on their U.S. customers. Overlaying all of this is a global supply imbalance of shipping containers. The pandemic has limited the supply of manual labor at major sea ports, thus many containers are spending more time than usual either on a ship awaiting unloading, or on the dock awaiting processing. This has, in turn, slowed the circulation of shipping containers between and among trading countries.

The bottom line is that even if the global economy was brought to a hard and sudden stop by the pandemic, emergence from it has been and will continue to be uneven, with incremental and sporadic return to some of the norms we knew before. Ultimately, however, I believe strongly that we will be interacting in-person again, wherever that may be. And I hope to see you there.

JEFF SLOAN — Editor-In-Chief

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Aerospace: R&D investment now is critical to post-pandemic growth

»My February 2020 column, "The coming decade: Clarity with a strong dose of uncertainty," was written at the beginning of 2020, a time when very few people had any inkling that a new virus emanating from Wuhan, China, might turn into the pandemic that it did, with such consequential effects on the world's population and economy. Even as March arrived, and the seriousness started to become evident, few thought we'd still be under the thumb of this pandemic a year later. With multiple vaccines approved and in distribution, one can see a possible end and a path back to something like "normal." Still, that timeline varies by region and country.

> Companies that continue to invest in innovation during a downturn are better positioned.

In that February 2020 column, I postulated that the direction of the aerospace industry as it relates to composites was coming into focus — significant R&D investments were being made into higher rate manufacturing, adapting technologies from other markets, like automotive, to meet aerospace qualification processes. The targets were clearly next-generation single-aisle aircraft, built in much larger volumes than typical composites-intensive airplanes.

In contrast, I opined that the direction of the automotive market was more *un*certain. Electrification was gaining momentum, but it seemed internal combustion engines (ICEs) were not going away soon, so the supply community had to work in both spaces. It was not clear how composites fit into that landscape.

What a difference a year makes. The direction of the automotive industry today has made it clear that electric vehicles (EVs) are the future. As I outlined in my January 2021 column, governments and automakers are moving swiftly, with OEMs developing electric-powered platforms, driven by mandates and falling battery costs. Although Tesla finished 2020 as the leading EV manufacturer, that lead may not last long, with General Motors (GM) and Volkswagen announcing investments of $27 billion and $41 billion, respectively, to develop and manufacture up to 100 electric models, combined, by 2025. A number of companies are already supplying composite battery enclosures, with new materials being developed for these and other applications on battery electric vehicles. Although the automotive industry suffered a drop in production in 2020, and the initial response of the supply community was to reduce spending, investments in R&D are climbing again.

Compared to the automotive industry, the pandemic had a swift and large impact on commercial aviation, with passenger volume falling by 90% in the first months. Entities along the entire aerospace supply chain moved quickly to contain costs as aircraft orders were delayed or canceled, furloughing or laying off both young and experienced personnel. While many layoffs were in manufacturing roles, OEMs and suppliers have also reduced R&D investments and exited R&D consortia. I have heard of some smaller suppliers shutting down their research departments entirely.

I fear this will have a significant impact on the launch timing of future aircraft. Having seen so many cool innovations being developed in 2019 to reduce layup time, automate inspection and move away from the autoclave, I worry about the maturation of these technologies.

We know it will take time for the aerospace industry to recover financially. Masses of people have to start flying again, domestically as well as internationally. I went almost 10 months, the longest stretch in over 40 years, without setting foot on an airplane. I've now made three trips, albeit none for business purposes, and we know the return of business travel is essential before profitability occurs, and for robust delivery of aircraft to resume. The planes I have been on haven't been full, for safety reasons, but they have been far from empty. It seems the airlines are doing a good job with sanitation, so I hope this, combined with vaccines, portends a stronger-than-expected return to the skies for many people.

History has shown that companies that continue to invest in innovation during a downturn are better positioned than rivals to capitalize when the recovery gains steam. There are sectors within aerospace, like urban air mobility (UAM), space and defense that are still investing, and some government funding continues. However, commercial aviation is the lifeblood of the aerospace industry. Composites have established a significant position in twin-aisle designs, yet are still trying to gain traction for the large structures in single-aisle aircraft. The efforts underway pre-pandemic seemed to be on a course to deliver major breakthroughs, and still have a chance to do just that. Resuming R&D in these projects doesn't have to happen all at once, but a strong commitment to progressively ramping up investment in composites innovation is imperative for the industry to take advantage as soon as the time is right. CW

ABOUT THE AUTHOR

Dale Brosius is the chief commercialization officer for the Institute for Advanced Composites Manufacturing Innovation (IACMI), a DOE-sponsored public-private partnership targeting high-volume applications of composites in energy-related industries including vehicles and wind. He is also head of his own consulting company, which serves clients in the global composites industry. His career has included positions at U.S.-based firms Dow Chemical Co. (Midland, MI), Fiberite (Tempe, AZ) and successor Cytec Industries Inc. (Woodland Park, NJ), and Bankstown Airport, NSW, Australia-based Quickstep Holdings. He served as chair of the Society of Plastics Engineers Composites and Thermoset Divisions. Brosius has a BS in chemical engineering from Texas A&M University and an MBA.

Supply chain challenges persist into the new year

January—52.3

»The Composites Index extended its Q4 2020 rally with a January reading of 52.3. For the month, supplier deliveries, new orders and production activity supported the Index's latest reading while employment, backlog and, in particular, export orders hindered further gains; more specifically, quickening expansion in new orders and production activity was counter-balanced by the worsening contraction in export activity. The supplier deliveries reading was little changed and remains near record levels.

Having moved past the seasonal surge in shipping demand, January's stubbornly high supplier delivery reading may suggest that network freight capacity was only a minor factor during the fourth quarter's run-up. Never before in the Index's history have supplier delivery and production readings been this far apart and for so long. The implications associated with this divergence are considerable, and could extend well beyond undermining production activity's full potential. In particular, if the trend in expanding new orders persists, the current situation could at best cause backlogs to quickly rise, and at worst result in missed sales opportunities and strained customer relationships. CW

ABOUT THE AUTHOR

Michael Guckes is the Chief Economist/Director of Analytics for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, Ohio, U.S.). He has performed economic analysis, modeling and forecasting work for nearly 20 years in a wide range of industries. Guckes received his BA in political science and economics from Kenyon College and his MBA from Ohio State University.
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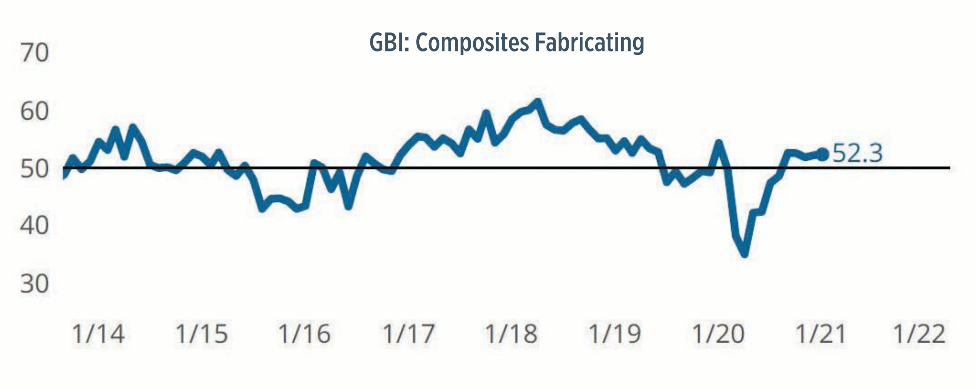
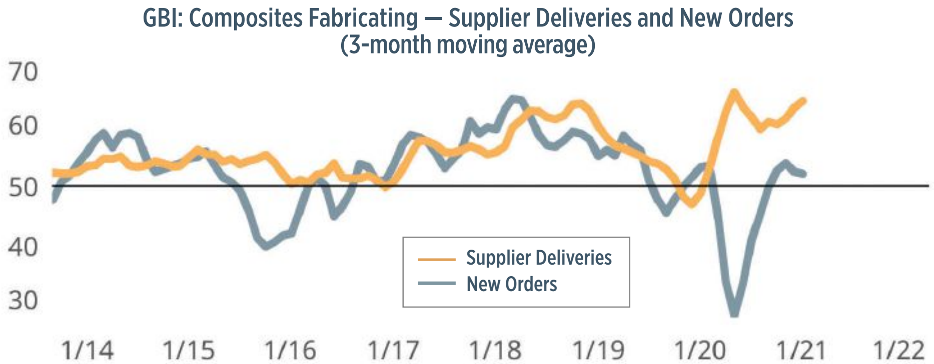


Composites Fabricating Business Index

Improved readings for production and new orders activity were almost entirely offset by a sharp contraction in export activity.



Index activity divergence

The spread between supplier deliveries and production activity will be made worse if fabricators cannot capitalize on the current and (potentially) future improvements in new orders.

_CW_ Editor-in-Chief Jeff Sloan discusses IACMI's evolution with Dale Brosius and Uday Vaidya, and strategic partners Continuous Composites and Arkema/Sartomer are developing a library of photocurable resins for use in a variety of composite applications.

Q&A: Dale Brosius and Uday Vaidya, IACMI

CW *checks in with Dale Brosius, chief commercialization officer and executive director of IACMI (Institute for Advanced Composites Manufacturing Innovation, Knoxville, Tenn., U.S.), a public-private composites consortium, and Uday Vaidya, chief technology officer of IACMI. Brosius and Vaidya were part of the team that launched IACMI in 2015. They talk here with* CW *Editor-in-Chief Jeff Sloan about the first five years of the organization, how it has evolved and what the future might hold as IACMI continues its quest to help drive composite materials and process growth. This Q&A is excerpted from the* CW Talks *podcast and is edited for clarity. To hear the entire interview, please visit www.compositesworld.com/podcast.*

JS: What were your expectations for IACMI when it was launched? How does IACMI today align with what you hoped it would become?

UV: Organizations like ACMA, SME and SAMPE are great partners in composites, but an organization like IACMI, which provides the industry opportunity to launch projects of their choosing, and led by industry, was very interesting and game-changing in my view. As the institute has evolved, that model has stayed very firm.

DB: I was pleasantly surprised by the strong industry support for IACMI and the willingness to collaborate on projects where members have to share intellectual property. I've also been pleasantly surprised, like Uday, by our great workforce development program.

JS: What do you consider the most notable projects from the last five years?

UV: It's difficult to pick one versus others. For example, we had a signature project with Volkswagen that had partnerships across the entire IACMI enterprise, starting with the concept to finish an SMC [sheet molding compound] tailgate that included Oak Ridge National Lab (ORNL), University of Tennessee, Purdue University, Michigan State University, IACMI and industry partners. There's also been a lot of interest in low-cost carbon fiber, the textile-grade carbon fiber pioneered at ORNL. In 2015, the fiber was being produced with the precursor, but there were very few outlets in terms of downstream processing. So IACMI led the way for all the database creation, and created a range of intermediate options for compounding, injection molding, pultrusion and packaging into NCFs [noncrimp fabrics] and things like that. [See p. 14.]

DB: I think the building of a 150-plus member consortium consisting of small and medium enterprises through OEMs which represent the entire value chain, is a good one. We have provided engaging and impactful internships to over 100 university students, with many of those hired into the composites industry moving on to pursue advanced degrees. We've initiated, and we are closing in on completing, over 50 projects. That's quite a few projects over a five-year period. So far, we've helped validate and commercialize more than 15 new products, with more to come.

JS: The original funding model of IACMI anticipated a five-year lifespan for the organization. As the organization evolves, what is the new IACMI structure? How is it different from what was established originally?

DB: From the beginning, IACMI was designed to continue beyond that five-year period, but we had to work hard to develop a sustainability plan to do that. So our strategy included diversification into other markets outside our original mandate — aerospace, plus infrastructure and construction, for example. And we're also working with our members to pursue funding from other federal agencies, in addition to DOE. We've been awarded contracts in conjunction with our industrial and educational partners to get contracts from the DOD and from NASA, as well as other DOE projects. And we're evolving our governance model to emphasize greater participation from industry.

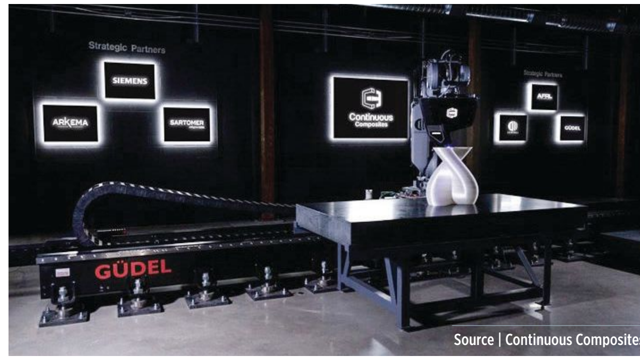
JS: IACMI has created working groups that were introduced at the fall 2020 meeting. What are those?

UV: We introduced six working groups, which were very well received. Each of the working groups had over 100 participants on average. They focus on recycling technologies, high-rate aerospace manufacturing, wind energy, design simulation, future mobility and infrastructure/construction. And these working groups are guided by industry input, so they have a lot of energy. I believe it will shape the institute in a very significant way.

BIZ BRIEF

Joby Aviation, Bye Aerospace and **Solvay** have accelerated their involvement in development of all-electric aircraft. More specifically, the U.S. Air Force's (USAF) Agility Prime team has issued a completed airworthiness evaluation for Joby's eVTOL aircraft. Bye Aerospace production has commenced on Serial #001, the first production-conforming prototype for its two-seat *eFlyer 2*, with assembly of an all-carbon fiber fuselage. Solvay announced that it is supplying materials for **Vertical Aerospace**'s eVTOL flagship aircraft.

Commercializing UV-curable thermosets for continuous fiber 3D printing



Source | Continuous Composites

In September 2020, continuous fiber 3D printing specialist Continuous Composites (Coeur d'Alene, Idaho, U.S.) announced a strategic partnership with specialty materials company Arkema (Colombes, France) through its Sartomer business line, to combine Continuous Composites' patented Continuous Fiber 3D (CF3D) printing technology with Arkema's photocurable N3xtDimension resin solutions. The combination is expected to result in development, certification and commercialization of a library of advanced material solutions to suit the needs of a wide variety of applications and industries.

To complement its CF3D printing system, which is an out-of-autoclave (OOA), scalable 3D printing technology based on the use of snap-cure resins and continuous fibers, Continuous Composites required a catalog of resins that met the high-performance mechanical requirements of customers in industries ranging from aerospace to energy to defense.

This need for high mechanical properties such as glass transition temperatures (T_g) and fire, smoke and toxicity (FST) led to a focus on thermoset resins, though Tyler Alvarado, CEO of Continuous Composites, notes that CF3D technology can use thermoplastics as well. "Our core competency is that we are taking a dry, continuous fiber, and then we're impregnating that with a snap-curing — in this case, UV-curable — resin," he says. "We're really focused on this snap-curing thermoset approach that allows the composite structure to take shape right there in freeform, enabling us to leverage the anisotropic properties of the continuous fiber, and create these complex organic geometries that are extremely lightweight and very strong. We can produce a very high-quality composite laminate with very high fiber content and low porosity."

Sartomer's N3xtDimension liquid resins, part of Arkema's newly launched 3D Printing Solutions by Arkema platform, in combination with structural fibers ranging from carbon and glass fiber to Dyneema and aramids, proved an ideal match, and the companies are now working to develop a library of UV-curable resins meeting a range of mechanical property requirements.

In addition to the resins' mechanical properties, eliminating the need for heat cure on the final parts enables two of CF3D's most innovative features: fast print speeds, and the ability to print unsupported in open air. With the ability to harden and shape a composite material without need for layup support, cost and lead time involved in acquiring molds and tooling is eliminated, and design constraints are removed.

Further, CF3D "is a very stable machine … and prints significantly faster than traditional thermoplastic machines," Alvarado says. These speeds are made possible by the elimination of problems such as managing temperature gradients within the laminate and warpage. Further, the system isn't limited by a heating process (due to its use of UV light cure).

There are two variables to print speed, he adds: material cure and print accuracy. Alvarado says Continuous Composites' team has developed its own integration of a CNC controller as the underlying motion platform control for the 3D printing system, so that they can move through points accurately and repeatedly, allowing them to drastically increase the speed at which they're printing. Using the CNC controller, over the next year, Continuous Composites plans to increase the system's print speed up to three times.

As with any innovation, though, there have been challenges associated with transferring Sartomer's UV-curable resin technology to higher-performance and structural applications, according to Sartomer's Klang. For example, one area of focus has been increasing temperature resistance. "We're at close to 230°C," he notes, "which really gets us in some very interesting new types of applications."

Dr. Sumeet Jain, senior director of 3D printing at Arkema Worldwide adds: "With this partnership, we are working from the bottom up, to change the way that composites are manufactured. This is not trivial. We've been working together for four years already, and we're just getting started."

Read the full article online at **short.compositesworld.com/CF3D**

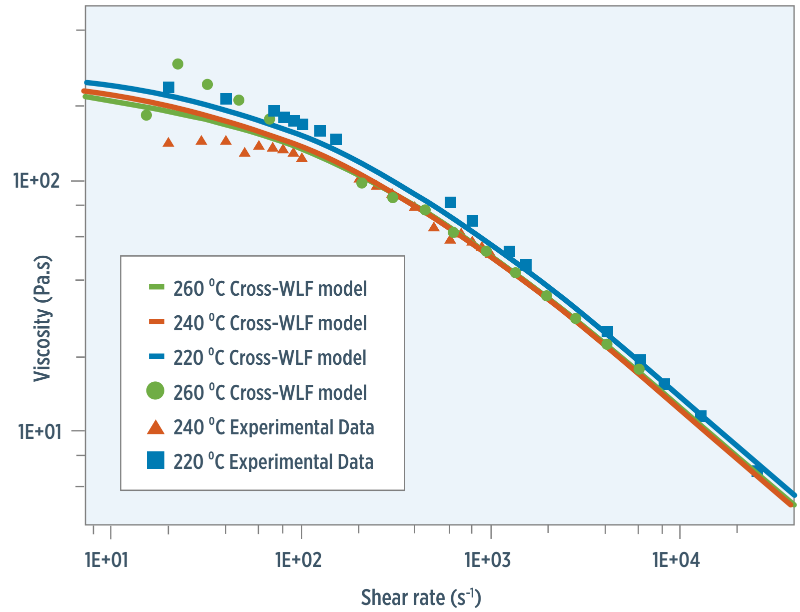
BIZ BRIEF

Advanced composite structure specialist **Carbon ThreeSixty** is now leading its new NATEP project to design, develop and manufacture 12 fully tested, ultra-low mass, proof-of-concept carbon fiber-reinforced plastic (CFRP) wheels for rotary wing aircraft. The project, which began on Jan. 1, 2021, will run for the next 18 months. Consortium partners **Leonardo** (Rome, Italy) and the **National Composites Centre** (NCC, Bristol, U.K.) will leverage their expertise, with an aim to improve performance, safety and full ownership cost.

Thermoplastic tapes reinforced with textile-based PAN carbon fiber

IACMI project trials inline production of thermoplastic tapes reinforced with textile-based PAN carbon fiber.

By Peggy Malnati / Contributing Writer



Predicted vs. measured rheology and shear rates

This graph shows predicted versus measured rheology and shear rates for generic homopolymer polypropylene at different temperatures.

Source, all images | University of Tennessee-Knoxville

» A longstanding challenge in the advanced composites industry is to find ways to produce lower-cost carbon fiber so that all industries that want to use this valuable and effective composites reinforcement can. Carbon fiber costs have come down considerably thanks to decades of work to enhance productivity via precursor chemistry, machinery innovation, process enhancements and more.

One area that has shown great promise is the use of alternative precursors to conventional aerospace-grade polyacrylonitrile (PAN). For example, the U.S. Dept. of Energy (DOE, Washington, D.C., U.S.) and Oak Ridge National Laboratory (ORNL, Oak Ridge, Tenn., U.S.) have developed methods for producing carbon fiber from alternative precursors ranging from polymers to lignin to coal.

Alternative precursors

One of the most promising of these precursors, and the one closest to commercialization, is textile-based PAN, which is similar to the fiber used to produce acrylic sweaters. Like other alternative precursors ORNL has investigated, textile-based PAN carbon fiber (TCF) is different from specialty aerospace PAN carbon fiber in several ways.

One of the differences is that textile-based PAN precursor, because it is intended for use in the textile industry (think drapes, clothes, furniture fabrics), is supplied in a wide-tow format that is inherently less costly than specialized aerospace-grade PAN precursor. During carbon fiber production, this has the effect of increasing throughput and lowering conversion costs compared with conventional PAN fiber. It also tends to produce much larger tow fiber — on the order of 300K to 450K on the line at ORNL's Carbon Fiber Technology Facility versus 3K to 50K typical of conventional PAN carbon fiber. Moreover, while it takes longer to process TCF precursor, since it doesn't contain reaction accelerators like conventional PAN and is typically run at lower temperatures (a function of the need to balance residence time and temperature), the fact that so much more fiber can be processed at a given time and that energy usage is lower on a weight or volume basis helps reduce costs. In fact, ORNL estimates that ~60% total energy savings for fiber conversion and ~50% cost savings are possible.

This, in turn, provides the opportunity to produce less costly fiber in unusually large quantities, and to use it to make products with a smaller carbon footprint. In industries like automotive/ground transportation, consumer electronics, sporting goods, building and construction and wind energy, TCF is an attractive reinforcement as applications tend to be stiffness driven, compared to strength-driven applications in aerospace. Notably, non-aerospace industries could potentially consume a lot of fiber.

However, TCF is still a different product than conventional PAN carbon fiber, so work is needed not only to better characterize this fiber, but also to find ways to convert and use it. Because it can be processed in an ultrawide tow band, this precursor requires modification of process equipment all the way through the fiber production process. It also changes post-production surface and packaging, and it will, of course, affect conversion processes ranging from making tapes and fabrics to prepregs and preforms.

Recognizing all the ways that TCF can solve the carbon fiber cost/availability problem on the one hand, but also creates new problems in how to handle, convert and package this material on the other hand, the Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, Tenn., U.S.) has been working on a number of member-supported research projects over the past three years to address these issues. One interesting project has looked at ways to convert the ultrawide tow band TCF into thermoplastic composite tapes.

Reducing costs

Interest in thermoplastic composite tapes has been growing in many industries, but these products tend to be expensive, as specialized equipment and know-how are required to successfully impregnate any fiber with pre-polymerized, high-molecular weight and high-viscosity thermoplastic resins versus their unreacted, low-viscosity thermoset counterparts. It is all too easy to produce tapes with lots of voids and poor fiber wetout, ending with final parts that not only look awful, but run the risk of premature failure.

Dr. Uday Vaidya, professor and governor's chair for Advanced Composites Manufacturing, University of Tennessee-Knoxville (UTK, Knoxville, Tenn., U.S.) and IACMI chief technology officer (CTO), has collaborated on thermoplastic composites programs since the early 2000s with George Husman, president of Husman Consulting Inc. (Cape Coral, Fla., U.S.) and retired director and CTO of Zoltek Co. Inc. (St. Louis, Mo., U.S.). Their many interactions led to the idea of inline impregnation of conventional heavy-tow carbon fibers (24K to 50K) to produce thermoplastic composite tapes at the back end of the fiber production line. Producing tapes immediately after fiber production would eliminate a separate intermediate process step and all the shipping and handling that entails. It is hoped this would help reduce costs of both tapes and parts made from those tapes.

Making this concept come true required development in process and equipment to make carbon fiber-reinforced thermoplastic tapes in different tow sizes. Vaidya and Husman filed a provisional patent in conjunction with the University of Tennessee Research Foundation (UTRF, Knoxville, Tenn., U.S.) in 2018, covering a process for inline production of thermoplastic tapes reinforced with up to 50K tow carbon fiber. The following year, Vaidya and his UTK team extended this work to include thermoplastic impregnation of ultra-wideband TCF (300K to 450K tow) with a second filing.

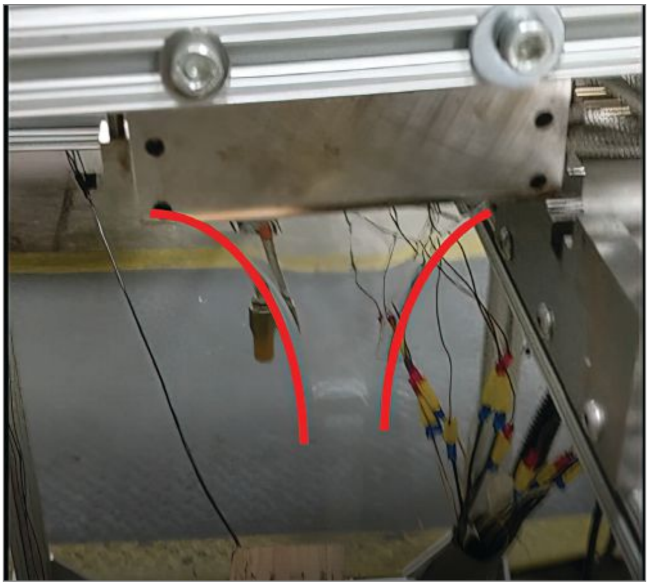
TCF TP Tapes

As would be expected, there has been no shortage of technical challenges to address along the way. Fiber feed and handling required significant equipment modification as TCF tends to be wider and involve more filaments than conventional carbon fiber. It's also prone to catenary behavior during the fiber impregnation step of tape production. That means that a sinusoidal wave forms as tows feed into the impregnation die, causing tows to split unevenly and enter the die under different tensions, leading to tapes that twist, deform and achieve poor fiber wetout.

"Finding a way to maintain a balance between fiber tension and flexibility proved really challenging and required a lot of work," explains Vaidya. "Our team came to understand just how important it was to maintain tow integrity in order to spread the filaments and achieve a high degree of wetout, which, of course, is critical to producing quality tapes."

Then there was the sizing issue. TCF tow bands are heavily sized to help fiber move smoothly from creel to impregnation die where it is wet out with resin to produce tape. However, once at the die, previous research had shown that to achieve good wetout with higher-viscosity thermoplastics, the presence of sizing actually impeded impregnation, making it highly desirable to remove the sizing. Trial and error eventually led the team to develop a technique to burn off sizing just before tows entered the impregnation die.

To accurately predict resin rheology and polymer feed through the impregnation die and make good tape, new simulation and validation work was needed. The team focused on producing TCF tapes with polypropylene (PP) as well as polyamide 6 (PA6) — two thermoplastics widely used in automotive for their toughness and affordability. The team used PolyXtrue extrusion die design software from Plastic Flow LLC (Hancock, Mich., U.S.), which is based on the Williams-Landel-Ferry (WLF) model and provided excellent correlation with measured rheology and shear-rate results. »



Polymer exits flooding die

Polymer exiting the flooding die during TCF thermoplastic tape production. Red lines highlight flow of the polymer (which is not otherwise visible owing to resin transparency).

Thermoplastic composite tapes before and after

The UTK team has had to solve numerous challenges to develop both process and equipment capable of inline impregnation of carbon fiber — conventional or TCF — to produce thermoplastic composite tapes. The top photo shows ultra-wideband TCF tows entering the impregnation die; the lower image shows completed thermoplastic composite tapes rolled onto creels of different sizes that are ready for testing.

Die design itself was another important research area, especially when the team moved from standard 12K to 50K tows, and then to ultra-wideband TCF tows. At that stage, the die had to be completely redesigned and a two-stage process adapted. During the first stage, fiber is impregnated; during the second stage, optimized break angles for the tensioning/impregnation pins — which control the tension at which the carbon fiber is pulled, the fiber weight fraction (FWF), as well as quality control — are set in order to achieve desired properties in the completed tapes. Presently, the team has produced 30-50% FWF tapes in both PP and PA6, even with the heavier tows.

To rapidly cool tapes after they exit the die, a post-impregnation air-cooling system was developed. The team even had to work out a method to take up completed tapes onto creels/spools, owing to the width of the products and the challenges of downstream use of those tapes.

Vaidya says the team is currently focused on electronic integration, which includes building a formal graphical user interface and developing a programmable-logic controller (PLC)-based system. Ultimately, the team's goal is to develop a thermoplastic tape production module that can be added to the back end of a TCF or conventional carbon fiber production line to facilitate production of secondary/intermediate thermoplastic tapes.

"Our team has faced many technical challenges, but we've also had some accomplishments," Vaidya explains. "Handling such a wide tow band and successfully — and quickly — impregnating the fibers to achieve quality thermoplastic tapes without voids has been difficult. However, our team has explored a number of process parameters, including multiple iterations of die design; polymer flow simulations through the die; and various aspects of fiber feed, tensioning and preheating. Not only have we proven out some of the claims in our patent, but we've also achieved impregnation line speeds of 12 feet/minute [3.7 meters/minute] while producing 30% FWF polypropylene and PA6 tapes."

Next steps

Vaidya says intellectual property protections surrounding this tape technology have been filed with the UT Research Foundation — one with traditional 24K and 50K fibers and one with the wide-tow fibers. Commercialization, he says, will focus on inline impregnation within a carbon fiber line. "This will greatly reduce post-processing and adapt readily, bringing the overall cost of the intermediate down further," he says.

How might these tapes be applied? Vaidya says the options are many: "For example, the material can be chopped into long-fiber form, used in pultrusion feedstock, large-tank filament winding, overmolding (similar to organosheet) in compression molding, sheet stock in hybrid processes — e.g., with LFT [long-fiber thermoplastic], SMC [sheet molding compound] and other synergistic materials." This opens a range of product types that would benefit from stiffness improvements, high-impact toughness and improved processability such as shapes, draws and bends, recycling and reversible chemistries.

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Applications, he says, include automotive, trucks, wind blades, infrastructure (bridges), construction, sporting goods, marine and offshore products. "The wide-tow carbon fiber thermoplastic intermediate may now offer avenues to consider carbon fiber where it was too expensive previously," Vaidya concludes. CW

ABOUT THE AUTHOR

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■ Outboard torque box

In the Clean Sky 2 IIAMS project, MTorres produced a 4-meter-long outer torque box without fasteners using vacuum bag-only resin infusion for both left and right wings of a C-295 turboprop demonstrator.

Source | IIAMS project, Airbus Defence and Space, MTorres.

Advancing the OOA infused wing box

MTorres integrates lower cover, front and rear spars into unitized flying demonstrator using one-shot, low-cost, portable production.

By Ginger Gardiner / Senior Editor

»As the aerospace industry anticipates its recovery from the COVID-19 pandemic, the previous push for high-rate production has pivoted to an urgent drive to reduce environmental threats to the planet and to people. This effort includes limits on greenhouse gas (GHG) emissions, energy and water usage and creating waste that cannot be recycled. Though these initiatives were ongoing pre-COVID, their emphasis is now heightened, as is the need for much lower cost to produce composite structures. The Clean Sky 2 pan-European aviation program has funded research and development in all of these areas and has significantly advanced a variety of fiber-reinforced composite technologies.

Included in Clean Sky 2's seventh call for proposals (CFP07, October 2017) is the Airbus Defence and Space (Airbus DS, Cadiz, Spain) request for an innovative and flexible pilot plant to produce a highly-integrated wing box flying demonstrator using automated fiber placement (AFP) and liquid resin infusion.

There have been other resin-infused and/or out-of-autoclave (OOA) wing box demonstrators, including an OOA "blended" wing box unveiled by GKN Aerospace (Redditch, U.K.) in 2013; the Airbus A220 wing produced by Spirit AeroSystems Belfast in Northern Ireland using resin transfer infusion in an autoclave; and the OOA wing produced by AeroComposit (Moscow, Russia) for the *MS-21* jetliner. However, all of those have assembled discrete composite stringer-stiffened skins and spars with mechanical fasteners (see Learn More).

The wing box requested by Airbus DS in Clean Sky 2 was to take a step forward by integrating the stiffened lower skin with stiffened forward and rear spars, enabling a more complete module *without* fasteners to be forwarded for assembly with the remaining wing components.

This wing box also would use narrow (0.25- or 0.5-inch-wide) dry carbon fiber tapes and high-temperature (180°C T_g) curing resins, but with energy-saving, low-cost heating systems and sensor-based digital control and simulation to predict and manage processing, shorten trial-and-error loops during development and enable fast training of manufacturing personnel. This digitization

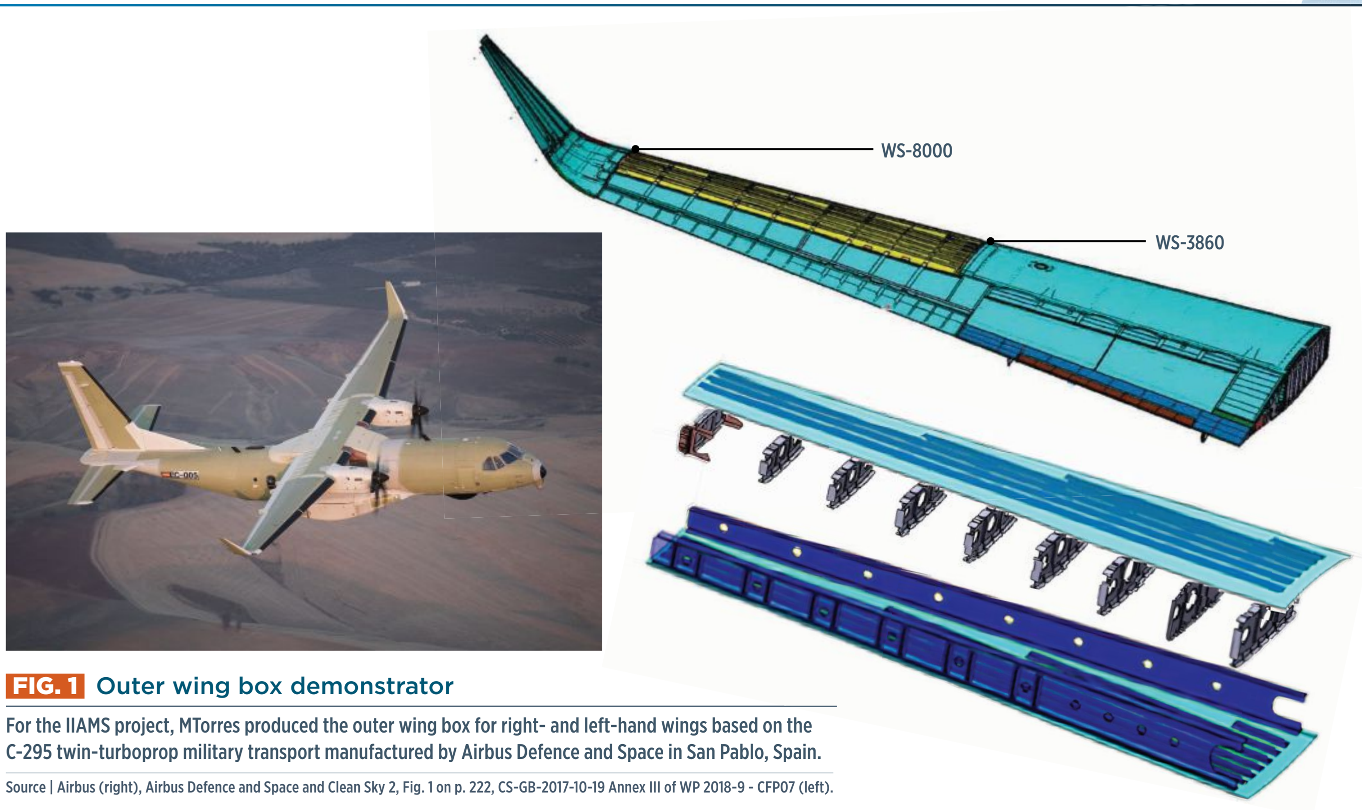


FIG. 1 Outer wing box demonstrator

For the IIAMS project, MTorres produced the outer wing box for right- and left-hand wings based on the C-295 twin-turboprop military transport manufactured by Airbus Defence and Space in San Pablo, Spain.

Source | Airbus (right), Airbus Defence and Space and Clean Sky 2, Fig. 1 on p. 222, CS-GB-2017-10-19 Annex III of WP 2018-9 - CFP07 (left).

would evolve to include an augmented reality mobile application (app) that also provides user and maintenance manuals, process sequence definition, paperless process and parts tracking and projection of CATIA models onto the part to aid in precise placement of stiffener preforms, tooling inserts and carbon fiber-reinforced polymer (CFRP) caul plates.

Perhaps most demanding, this project required that all tooling and manufacturing equipment be portable and flexible, easy to deploy at any manufacturing site, and adaptable for other part designs and upgrades as more advanced tooling, heating and composites 4.0 process control technologies become available.

As explained by the topic manager Luis Rubio, head of composite development engineering – technology and process at Airbus DS, "The final purpose of the project is to demonstrate that an alternative technology [to prepreg and autoclave] with lower costs, reduced lead times and environmental footprint can achieve similar design tolerances and quality levels."

MTorres (Torres de Elorz, Spain) responded, applying without partners. "We had all of the capabilities in-house: AFP, infusion, dry tape materials and automation," explains Sebastian Diaz, senior manager of composite applied technologies at MTorres. The company was awarded the Innovative Infusion Airframe Manufacturing System (IIAMS) project, funded via the European Union's Horizon 2020 program under grant agreement No 820845, and began work in October 2018.

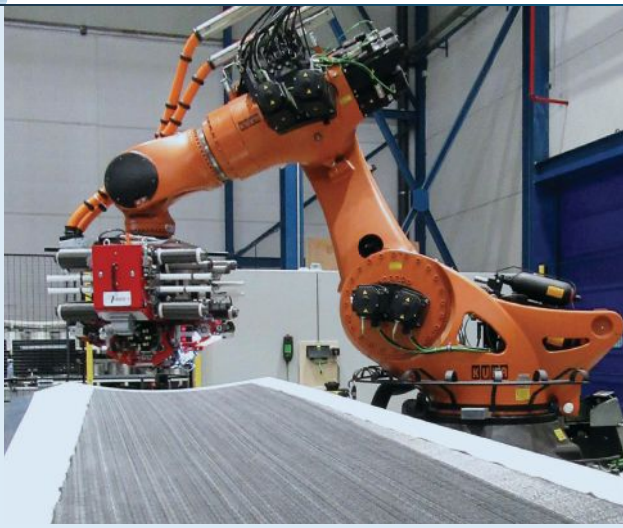
Outer wing box demonstrator

The demonstrator Airbus DS chose was an outer wing box based on its C-295 twin turboprop military transport (Fig. 1), produced »

FIG. 2 HDF spar preform

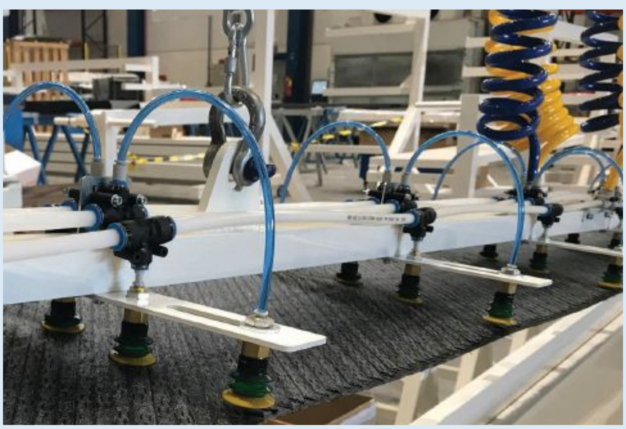
This C-shaped preform for the J-spars began with a flat blank of MTorres novel dry fiber UD tape (up to 10 plies) which was then hot drape formed on a male CFRP tool.

Source | IIAMS project, Airbus Defense and Space, MTorres.

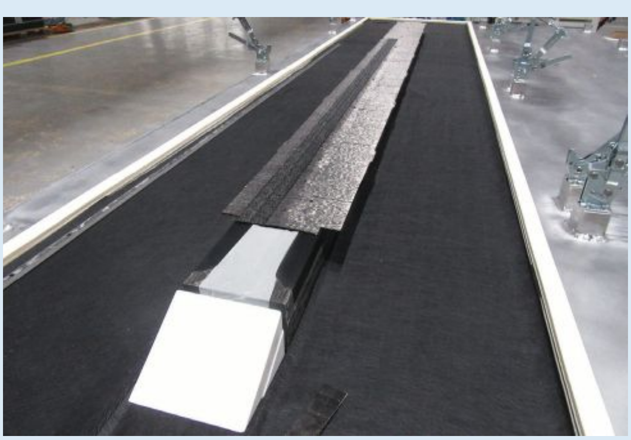


1 AFP was used to lay up wing box skin (shown here) as well as 2D blanks for stringers, spars and spar stiffeners.

Source (all steps) | IIAMS project, Airbus Defense and Space, MTorres.



2 Flat tape blanks were transported from the layup table to hot drape forming tools.



3 Stringer blank is placed on top of male HDF tool.

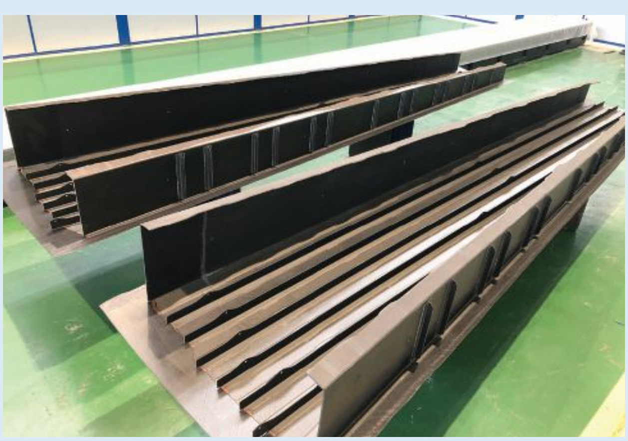
4 Silicone sheet and clamping frame are lowered onto stringer preform for heated debulk/preforming in the ACTI.

5 Stringer and spar preforms were placed onto the lower skin, aided by cylindrical (circled) and white positioning elements. Black CFRP cauls (arrows) were also used to help position stringers and placed on top of stringers and J-spars.

6 Preform assembly is vacuum bagged and prepared for infusion in the ACTI.

7 Initial demonstrator completed at MTorres shows the J-spar with two rib stiffeners (circled) and its sinusoidal feet (arrow).

8 ACTI forming/curing equipment and wing box tooling were lifted onto a standard moving truck and relocated to Airbus DS in Cadiz, Spain.



9 The final wing box was manufactured at Airbus Cadiz. IIAMS project left and right wing boxes for flight test are shown here.

in San Pablo, Seville, Spain. This 4.14-meter-long composite outboard torque box mates to an inboard *metal* torsion box. The composite wing box also attaches to a winglet, leading edge and trailing edge.

"We were to manufacture two 4-meter-long demonstrators, the right- and left-hand wings, which will be installed for in-flight trials," says Diaz. "Manufacturing was to be a one-shot process, no secondary bonding. We made only the "U," comprising the lower skin with six integrated stringers and the spars on each side. The skin, stringers and spars all vary in thickness. The J-shape of the spars and integration of their stiffeners was quite challenging to manufacture. We also faced the challenge of how to maintain tight tolerances and accurate geometry with this manufacturing process. This accuracy is critical, especially at the root for assembly to the inner wing box and then also at the winglet."

Design of the innovative, industrial manufacturing was developed at MTorres, while Airbus DS provided the part design specifications. "We worked easily together to design the best manufacturing process, verifying that this design could be produced by our process and vice versa," says Diaz.

Automated center for thermo infusion (ACTI)

Per Airbus DS specification, all tooling and manufacturing equipment used to produce the wing box must be portable, able to be transported to other facilities with standard vehicles and set up quickly without special measures. This led to the development of the automated center for thermo infusion (ACTI), which performs hot drape forming of the stringers and spars; infusion of the stringers, spars and skin; and cure cycles. Hot drape forming (HDF) — developed as heated debulking in aerostructures and as heated preforming outside of aerospace — removes voids in layups and converts 2D blanks for the stringers and spars into shaped preforms (Learn More).

The ACTI has a useful inner area of roughly 5.5 x 2.2 meters and looks similar to a traditional HDF system, with steel frame and an upper half that is electronically raised and lowered, complete with locking and other safety devices. The cure tool and multiple hot drape forming tools are positioned inside the ACTI. "No pressure is applied, only vacuum," notes Diaz. "ACTI uses heated air with air flow that has been defined to provide fast heat transfer both in the hot drape forming and infusion processes."

He also notes the system is self-leveling. "The stiffness of the ACTI structure (and the curing tool) has been designed to comply with tolerances under operational loads in a simply supported condition on only two support sections," Diaz explains. "This means that dimensional accuracy is kept when resting on the floor, with no further leveling or other geometrical tuning required. ACTI also features low energy and low manufacturing costs."

The latter is due, in large part, to the replacement of assembly of multiple cured parts with assembly of multiple »

FIG. 3 Precise preform placement

Preforms for J-spars and stringers were positioned using twin metallic cylinders (seen at far left and right), white positioners and a CFRP caul with cutouts for the stringers/positioners.

Source | IIAMS project, Airbus Defense and Space, MTorres.

preforms, which are then infused and cured into a single integrated structure. "The curing tool is also the assembly tool," says Diaz. "All elements are dry preforms assembled into the curing tool and then co-infused together in a single-shot process." No assembly jig is needed, and strict tolerances are achieved via innovative elements in the tooling.

Another key aspect of this approach is to remove destructive and non-destructive tests (NDT), instead relying on process data collected during the various manufacturing steps to verify process quality and flag out-of-spec parameters. Sensors used with the ACTI collect temperature, vacuum, resin flow and state of cure. "Both air temperature and part temperatures are monitored," says Diaz. "The tooling has integrated thermocouples that track temperature for the molds and the part surfaces." All data is recorded, analyzed and used to print graphs and help guide manufacturing decisions.

"Both in IIAMS and in future projects, the data help to improve process setup in the early stages," Diaz explains. Resin flow and state of cure are monitored using Netzsch (Selb, Germany) dielectric sensors, installed directly into the CFRP cure tools. "We needed non-contact sensors for the skin because there is no direct contact between resin and mold," says Diaz. "The sensors monitor the change of the dielectric field as the resin arrives and then becomes solid during cure. We used this data to shorten the cure cycle."

Later in the project, the sensors and ACTI were combined with a human machine interface (HMI) developed by MTorres, which allows true process control from a computer, including vacuum and temperature, as well as resin flow via feed valve. The goal, according to Airbus DS, is to advance mass production of integrated composite primary structures by making the process more streamlined and intelligent.

Lightweight tooling and portability

MTorres produced two sets of molds — one for the right wing and one for the left wing. "Parts with identical geometry, like stiffeners, had only one set," notes Diaz. "Other tools were shared, when possible."

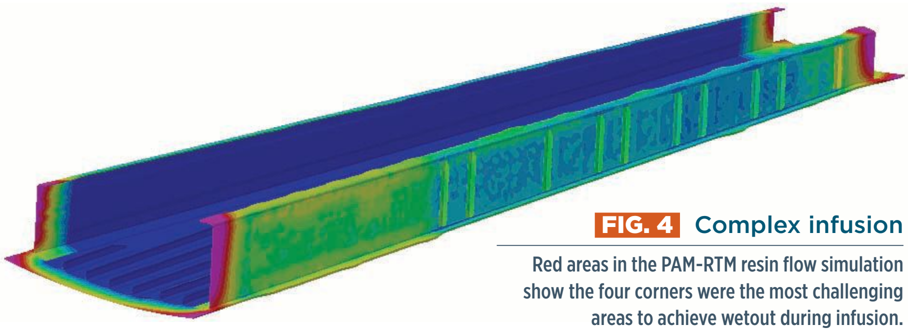


FIG. 4 Complex infusion

Red areas in the PAM-RTM resin flow simulation show the four corners were the most challenging areas to achieve wetout during infusion.

Source | IIAMS project, Airbus Defense and Space, MTorres.

A single, one-piece curing tool was used to form the 3D shape of the skin, onto which all of the other preforms were located. Measuring roughly 4.5 meters long, the right and left versions of this tool were made using CFRP, says Diaz. "This makes it easier to maintain tolerances because we designed the tooling with the same layup and processing as the parts, so the CTE is very close to that of the final part. These CFRP cure tools are also lightweight, roughly 200 kilograms, and thus movable with a small electric forklift. This would be impossible if we used metal for a 4.5-meter-long tool." The rest of the tooling — cauls, positioners and HDF tools — were easily managed by hand.

HDF of the stringers, spars and spar stiffener preforms used male (IML) tools, also made from CFRP. During use, these were mounted on an aluminum table and set within the ACTI.

AFP using novel dry fiber tape

All of the wing box structural elements — skin, stringers, spars, spar stiffeners — were produced using MTorres AFP technology for dry fiber tapes. "The proposal call said to use fast and cheap materials," says Diaz. "But commercially available dry fiber tapes, especially from the larger suppliers, were not so easy to purchase and we had the expertise to make our own material (Learn More). So, we used our 0.5-inch-wide, 300 grams per square meter (gsm) dry carbon fiber tape made from Mitsubishi Rayon (Tokyo, Japan) 50K high-strength (HS) fiber. Our tape was engineered to facilitate and perform well during infusion, but also during layup using our AFP heads. We know all of the parameters for AFP layup, hot drape forming and resin infusion, and if we needed to make any small changes, we could because we had the tape-making line available."

MTorres also tested its wing box manufacturing process with 200-gsm tape from Hexcel (Les Avenières, France) made from its intermediate modulus (IM) fiber. "Although our process can work well with both types of tapes," says Diaz, "during the development phase, it was easier » and cheaper to lay with our material versus the commercially available material — the width and stiffness was engineered so that its behavior from spools to table was smooth and fast. It was also readily available."

He notes that two strategies were followed for AFP: one for the lower skin and another for the stringers, spars and spar stiffeners. The skin (3-6 millimeters thick) was laid to the final 3D shape on top of the curing tool (Step 1, p. 20), using a semipermeable membrane — patented by Airbus in its Vacuum Assisted Process (VAP) infusion. The stringers, spars and spar stiffeners were laid as flat blanks (2D) onto a vacuum table and then moved onto the HDF tools to achieve their final 3D shape (Step 2, p. 20).

Heated preforming

"We moved the flat blanks for the stringers, spars and spar stiffeners from the layup table to the hot forming station using a gantry with vacuum grippers," explains Diaz. "The automated system can move the blanks in a flat state and place them onto the male forming tools [Step 3, p. 20] without creating wrinkles." The forming tools were installed on an aluminum forming table, which was placed into the ACTI. A reusable silicone vacuum bag (Mosites Rubber Co., Fort Worth, Texas, U.S.) was placed on top of the blanks, which were then heated in the ACTI to 130°C and shaped using vacuum pressure (Step 4, p. 20). "Vacuum was smoothly applied following a predefined ramp by means of a control valve when the temperature setpoint was reached," says Diaz.

He notes that dry tapes are easier to preform/hot drape form, "because the bond between layers is softer than in prepregs. Despite being dry material, it *is* an HDF/heated debulking in which the resulting preform keeps the shape thanks to the binders included in the tapes."

For the stringers and spar stiffeners, blanks were formed into two Ls, which were then placed back-to-back on the curing tool to form T-stringers/stiffeners. Each of the six skin stringers is different and requires different shaped blanks to create the preforms. Each of the 24 spar stiffeners is also a different length.

The front and rear J-spars comprise one blank formed into a C, which faces toward the inside of the wing box, and another blank formed into a Z facing toward the outside — the two are placed back to back. The spars also have sinusoidal-shaped feet on the outside of the wing box (arrow in Step 7, p. 21). "We cut the shape for the spar feet on the flat layup table before we moved the blank to the forming station," says Diaz. "Nothing could be trimmed or milled afterward in this area. The blanks were placed straight onto the male forming tool with the spar feet at the left side of the tool and the top flange at its right side."

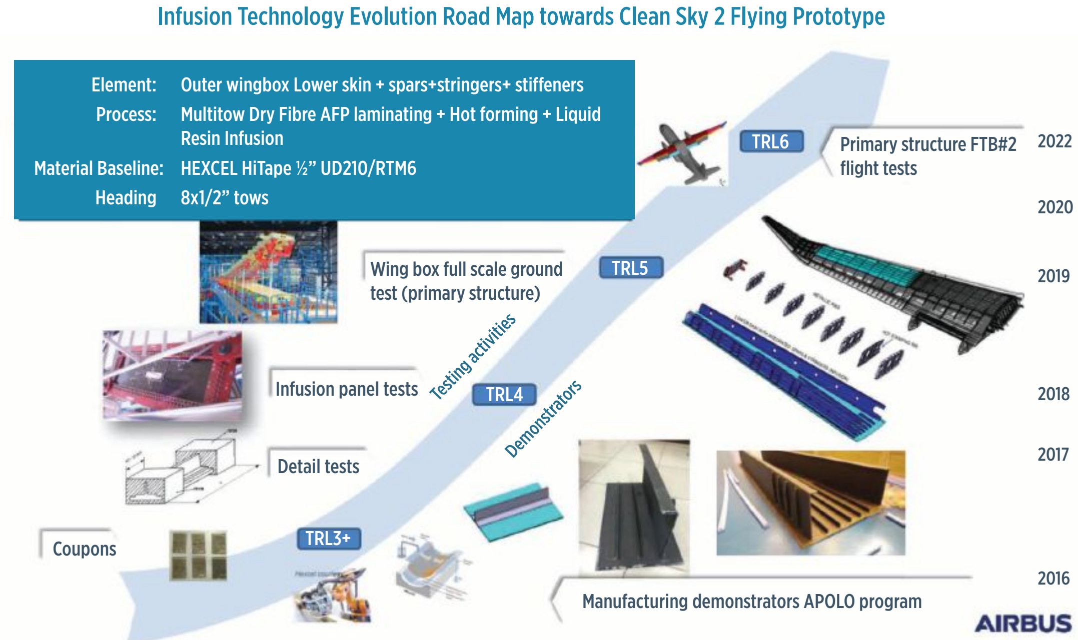


FIG. 5 Liquid resin infusion roadmap — path to certification

The IIAMS wing box demonstrator is the latest step in a multi-year strategy to mature a dry fiber AFP/resin-infused wing box to TRL 6 by 2022 and lay the groundwork for its certification in a future regional turboprop aircraft. Full-scale component structural testing of the IIAMS wing box will complete design qualification requirements for the Clean Sky 2 Flight Test Bed 2 (FTB#2).

Photo Credit: Fig. 1, "Structural Radar Research of Airbus Defense and Space as Clean Sky Partnership" by Manuel Iglesias Vallejo, Rubén Tejerina Hernanz, Antonio Jiménez, et al., Airbus Defence and Space, 8th European Conference for Aeronautics and Space Sciences (EUCASS), July 1-4, 2019.

One-shot infusion

The next step was to place the stringer, spar and spar stiffener preforms onto the already laid lower wing skin (Step 5, p. 20). "We were indexing each preform as we placed it onto the skin and cure tool," says Diaz. Cylinders that act as location elements can be seen at the end of the spar on the left of Step 5 and at the end of both spars in Fig. 3 (p. 22). These images also show white positioning devices for the stringers and J-spars. There were 13 positioners in the final preform assembly, and each one was different.

Caul plates were also a key part of the preform location and placement system. They served the traditional purpose of maintaining uniform pressure and temperature across regions of complex layups and/or geometry, but would also be key for infusion, as discussed below. A black CFRP caul plate with cutouts for the stringer preforms can be seen at the end of the stringers and spars in Step 5 and Fig. 3.

"The location of the stringer preforms depends on the location of that caul," Diaz explains. "The digital technology that we developed to monitor and control the manufacturing process included an augmented reality app that projected the CATIA models onto the layup. This was used to help guide placement of the caul plates, positioning elements and then preforms. It also showed the next steps to be performed. The app allows self-support on tablet computers so that all workers have easy access to all information."

A final set of black CFRP caul plates were then placed on top of the L preforms for the T-stringers and also along the inside and outside of each J-spar, extending up onto the flange and down onto the foot on the outside of the wing box, as shown in Step 5 and Fig. 3. "Spars also make use of a sort of caul plate on the inner side at the ends, in order to get increased accuracy in the joint areas," says Diaz. "All of these caul plates were used during the HDF process and remained attached to the preforms through layup."

The completed dry preform assembly, with caul plates, was then covered with peel ply and a vacuum bag film. The entire assembly of skin, stringers and spars was then placed into the ACTI and the tooling was heated to 120°C. Hexcel RTM6 epoxy resin was heated to 70°C and degassed before infusion through a single resin feed location. "The ACTI was prepared to feed resin from four locations," notes Diaz, "but after extensive simulation and tests, we decided it was easier and cheaper to have a single resin inlet."

Even with a single inlet, the infusion process was very complex, comprising three different modes. "We first performed flow simulation, using PAM-RTM software [ESI Group, Paris, France]," says Diaz. "There was such a complex mix of flow fronts and parameters needed for complete wetout. For example, resin flow was faster in the center of the wing box, but it was a challenge to wet out all of the stiffeners."

VAP, with a semi-permeable membrane, worked well for the lower skin, but this was exchanged for high-temperature flow mesh along the stringers and on the inside of the spars. "The corners were the most challenging areas to wet out," notes Diaz, "but they were also the most critical for holding tolerances for assembly, as well as along the edges." This can be seen in the red areas of the flow simulation in Fig. 4 (p. 23). "In these areas, a customized approach was developed to achieve the precise dimensions required," he explains." At the joint areas, tight tolerances in both sides of the spars were required. We also used vacuum ports along the perimeter and on top of the spars." »

The infusion was relatively quick, as predicted by simulations, followed by a two-hour cure at 180°C, using only hot air, and not heated tooling. After being demolded, each wing box demonstrator was then inspected using ultrasonic testing (UT). This was done as part of the IIAMS project deliverables, to analyze the quality of the demonstrators. Industrial application of this process, however, will reduce traditional NDT in favor of digital sensors and faster inline inspection tools such as vision systems.

According to Diaz, although the infusion cure cycle was similar to that for an autoclave-cured prepreg wing box, the overall cycle time should be lower. "We have eliminated most of the assembly afterward and we also don't have to shim anything like with prepreg, yet our quality is the same. For example, the bonding between the last layer of the skin and the first layer of a stringer needs no adhesive film in the middle to improve mechanical properties and account for tolerances." This is obviously more efficient, but he notes that part production rate was not initially the driving factor. "This method is not competing with manufacturing of individual parts but with a completed wing box assembly."

> Only final outer wing full-scale static and functional tests remain for FTB#2 qualification.

Complete demonstrators, path to certification

"We had only 18 months to complete this project, which included designing the process and tooling and manufacturing the tooling and demonstrators," says Diaz. "By month 14, we had the first demonstrator ready for display at JEC in late February 2020 [Step 3], but then JEC was canceled due to the pandemic. Although the project finished in late September 2020, if you subtract the months we could not work due to COVID-19, we actually finished in month 16. We were able to keep this very tight schedule due to our in-house design capability and ability to manufacture the tooling prototypes using our AFP and CNC milling machines."

A simplified, 1-meter-long demonstrator was made at MTorres to check all of the process parameters. Then, the first full-size demonstrator was produced. Tooling and manufacturing equipment were then relocated to Airbus DS in Cadiz (Step 8, p. 21), where the final demonstrator was produced. This was also part of the project's deliverables, proving that the equipment could be easily transported and installed at multiple locations.

As explained in "IIAMS wing box road map to certification" (Learn More), Airbus DS has played a key role in the Clean Sky program, progressing from co-leader of the Green Regional Aircraft (GRA) integrated technology demonstrator (ITD) in Clean Sky, to co-leader of the AIRFRAME ITD, as well as leader for the flight testbed 2 (FTB#2) in the REGIONAL integrated aircraft demonstrator platform (IADP) within Clean Sky 2. The FTB#2 will include other composites and airframe developments, including in the cockpit and other wing components.

All of the projects to prepare the FTB#2 are, in fact, part of a broader, long-range strategy at Airbus. The goal is to develop a future turboprop airframe that is lighter and more efficient than legacy airframes, and production processes that are cheaper and use less energy, manufacturing liquids and ancillary materials, yet also generate less scrap and offer increased recyclability.

"Step by step we [Airbus DS] are going through the entire airframe structures test pyramid from coupons to the full-scale structural tests of the outer wing," explains A.E. Jiménez Gahete in a September 2020 *Materiales Compuestos* article titled, "Airbus Defence and Space highly integrated wing box section manufactured by dry fiber placement and liquid resin infusion." Materials characterization testing, a design details test matrix and subcomponent tests for design allowables have all been completed with positive results. MTorres aided in this testing, including manufacturing test coupons and parts, as well as demonstrators to validate the wing box manufacturing process and design details. Only the final outer wing full-scale static and functional tests remain, says Gahete, to obtain the FTB#2 qualification for flight.

"One-shot infusion reduces joints, decreases weight and increases robustness," says Diaz. "The novel dry tape MTorres has developed produced excellent results, both in the processing — AFP, hot drape forming and infusion — and in the part's structural properties." He notes that, historically, there has been doubt that resin-infused composites could match the same structural performance and tolerances as autoclave-cured prepreg.

"To get the same tolerances in a single-shot process with soft [non-metallic] tooling was our greatest challenge," he concedes. "But we have proven this technology works and that it can produce the large primary structures needed for future aircraft. Our next step is to keep advancing the digital technologies and portability of the production system." CW

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ABOUT THE AUTHOR

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Tow steering, Part 3: The birth of tow shearing

In-plane shearing of tows, versus in-plane bending of tows, hopes to take automated fiber placement directionality to new levels.

In-plane shearing

iCOMAT's Rapid Tow Shearing (RTS) technology relies on in-plane shearing, not in-plane bending, to steer tows. The company says it can shear dry or prepregged tapes 6.35-500 mm wide to a radius as small as 50 mm.

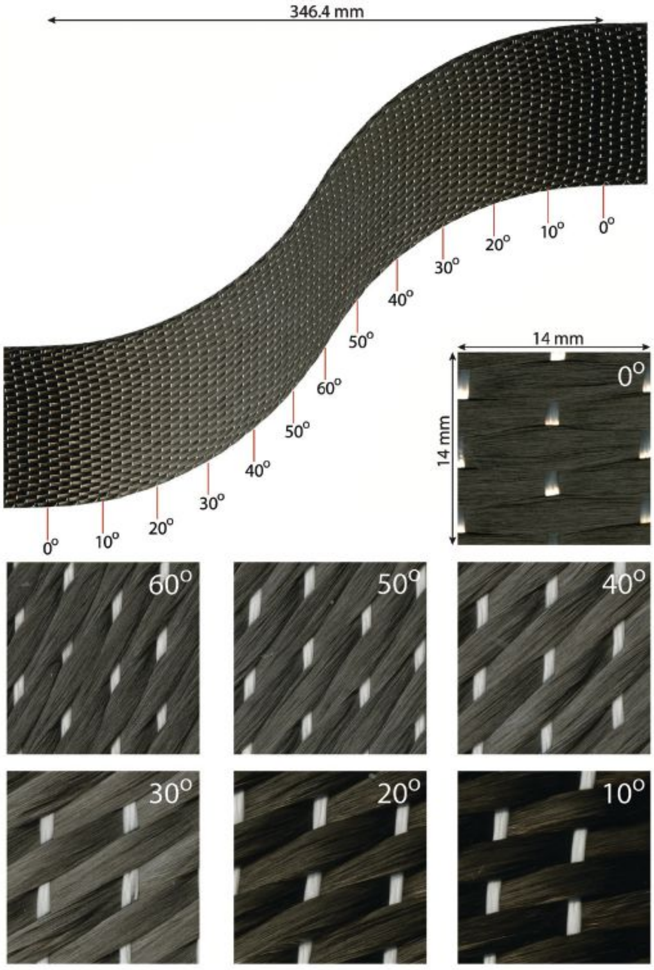
Source | iCOMAT

By Jeff Sloan / Editor-in-Chief

»In early 2020, NASA issued its final report on the Passive Aeroelastic Tailoring (PAT) project, which evaluated the design, optimization and fabrication of a tow-steered wing skin. The report suggested that the material and hardware surrounding automated fiber placement (AFP) systems would need further maturation to help increase the quality and consistency of tow-steered aerostructures. The report also suggested that ancillary technologies be evaluated more closely, and made specific reference to tow *shearing*.

Continuous tow shearing (CTS) was invented at the Advanced Composites Collaboration for Innovation & Science at the University of Bristol (Bristol, U.K., currently Bristol Composites Institute) in 2010 under an EPSRC grant by Byung Chul (Eric) Kim (primary inventor), Paul Weaver and Kevin Potter. Evangelos Zympeloudis further developed the technology from 2014 onwards at the university and has been leading the commercialization of the technology. iCOMAT (Bristol) was established to commercialize tow shearing in 2019 by Zympeloudis, Kim and the University of Bristol as a spin-off company, with Evangelos as the CEO of the company and Kim as the chief technology advisor. iCOMAT has worked to mature the overall process and recently rebranded it to RTS (rapid tow shearing) to highlight productivity gains that have resulted from this work.

Zympeloudis says tow shearing was developed as an alternative to tow steering, which uses in-plane bending of tows and is prone to defect generation, including tow buckling, overlaps



Increasing laminate thickness

Tow shearing avoids the buckling, laps and gaps endemic to traditional tow steering. In addition, as the angle of shear increases using iCOMAT's RTS technology, tape width narrows while the thickness increases. Note, for example, in the top image, the tape width difference between 0° and 60°. This is a feature that designers have exploited to locally increase the thickness of a laminate, without increasing the number of plies. Source | iCOMAT

and gaps. He notes that such defects, even if well managed by the AFP machine, must be accounted for in the design to guard against knockdown, which complicates design, fabrication and testing efforts.

iCOMAT instead uses in-plane shearing to move tows *laterally* as they are placed and re-orient the fibers along a radius. This is accomplished, says Zympeloudis, through the use of intellectual property (IP) in two places: the material and the placement head. "I can't go into great detail," he says, "but we do many things to the material before we place it, and the placement head itself is critical to iCOMAT's shearing technology.

Zympeloudis says iCOMAT's technology, delivered through a placement head attached to the end of a 6-axis robot, can shear off-the-shelf dry or prepregged materials to a radius as small as 50 millimeters (2 inches) in tape widths ranging from 6.35-500 millimeters (0.25 inch to 19.7 inches). He says dry fibers are most amenable to shearing, but with proprietary modification, prepregged tapes can be sheared as well. "We can shear any UD prepreg we have tried, and we have tried a lot," Zympeloudis says. "But we have not tested *all* UD prepregs on the market."

One notable feature of tapes placed using iCOMAT's shearing technology is that as the angle of shear increases, lateral movement of the fibers relative to one another causes the tow/tape width to decrease and thickness to increase. This is a feature, says Zympeloudis, that designers have exploited to locally increase the thickness of a laminate, without increasing the number of plies in the laminate.

iCOMAT points to several benefits of RTS, including more efficient composites fabrication, reduced waste, better load path management, no gaps or overlaps and no fiber buckling. "It's a radical way to manufacture with composites that drastically improves structural and production performance," Zympeloudis contends.

The company is currently involved in seven R&D trials with leading OEMs to evaluate RTS and its application. And later in 2021, iCOMAT will place its first system, called RTS 2D, with a customer in a manufacturing environment.

Although RTS appears to be ideally suited for commercial aerospace use — particularly in wing skins — Zympeloudis acknowledges that there are several years worth of design, manufacturing, testing and certification work to be done before shearing technology appears on a commercial aircraft. So, not surprisingly, iCOMAT is targeting defense applications first and hopes to have tow-sheared parts flying by 2023. Zympeloudis also points to automotive as another target. He says RTS could be used to make curved beams for cars and trucks to near-net shape, with minimal waste.

Regarding testing and certification, Zympeloudis notes that there is no established ASTM standard designed specifically for testing steered or sheared fibers. "As soon as you start steering, many of the ASTM standards go out the window, but we think it might be possible to use existing standards, such as ASTM D3039 [standard test method for tensile properties] with RTS. You can go a long way using existing standards, but we are also working to develop dedicated test methods for RTS." CW

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Invar, wire additive manufacturing expand aerocomposite tooling options

Invar facesheets and backing structures are candidates for large-format 3D printing to more quickly and efficiently produce aerostructures tooling.

By Peggy Malnati / Contributing Writer

Aerospace Invar tool

Lincoln Electric Additive Solutions has recently delivered its first aerospace tool with the facesheet 3D printed in Invar. Although the design of the tool has been described as "traditional," by additively manufacturing the cure surface from Invar instead of machining a block or plate of the alloy, the manufacturing process was simplified and cycle time was reduced.

Source, all images | Lincoln Electric Additive Solutions

»As the use of composites has soared in commercial aircraft in the last decade, so too has the size of parts being converted from metals to composites — mostly to carbon fiber-reinforced epoxy prepreg. That has made it more challenging to find tooling options that can be produced in large sizes relatively affordably and quickly.

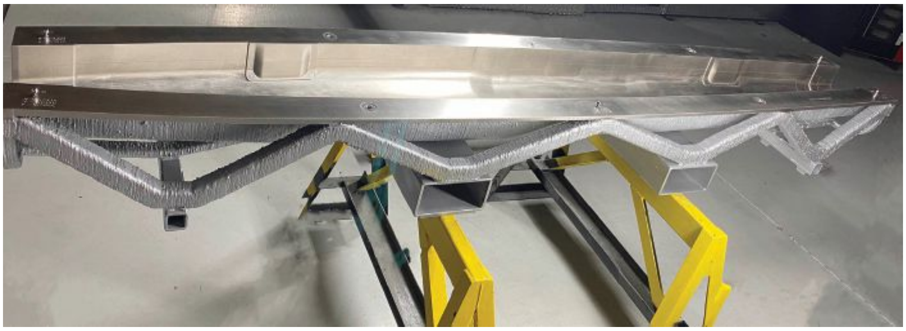
One challenge is that typical carbon fiber composite prepreg has a very low coefficient of (linear) thermal expansion (CLTE or CTE). As composite aerostructure parts get larger, so too must the tools in which they're formed. However, if a tool material has a higher CLTE than the material being molded in it, then final part dimensions can deviate unacceptably from specifications. In tools with trapped/undercut features, the cured part could actually break during cooling and/or demolding, or could become die-locked in the tool.

Consequently, prototype and low-volume production tools for traditional composite aerostructure parts have typically been fabricated from hand layup/autoclave-cured carbon fiber/epoxy prepreg itself, with higher volume production tools typically machined from blocks or plates of Invar, a nickel-iron alloy renowned for its low CLTE. Both tool materials are expensive and can have long lead times, which has caused many in the industry to seek alternatives in large-format additive manufacturing (LFAM).

As reported in the *CW* December 2020 issue (see Learn More), one option that's been tried is to 3D print a thermoplastic composite core and then apply conventional carbon fiber/epoxy tooling prepreg facesheets to the core. This entire assembly is then autoclave cured together (without need for adhesives) to produce a tool. While this approach may prove viable to mold prototype and low-volume production parts, high-production volumes still require a more durable option. That option is now available in the form of mold facesheets and backing structures fabricated with 3D-printed Invar.

Gas-metal arc welding

Presently, there are several printing technologies for both small- and large-format metal additive manufacturing. Some systems use laser-fused metal powders, with or without a binder (which must be flashed off in a post-print bake cycle). Another technology option is wire-arc additive manufacturing (WAAM). Generally, WAAM systems combine metal (in wire form), a gas-metal arc welding (GMAW) power source mounted on an industrial robot, and a numerically controlled (NC) multi-axis positioner on which the build takes place.



Wisk cure tool fabrication process

One of the few design constraints on WAAM prints is the reach of the robot and its associated wire-arc welding arm. That can be overcome by printing smaller sections and then welding them together post-printing, prior to machining to clean up the molding surface. In this image, the Wisk cure tool with integral backing structure was printed in Invar in two sections, which were then welded together prior to machining the facesheet to achieve an acceptable surface (left). After machining, the tool was checked for surface finish (bottom). By printing smaller sections and welding them together, total printing and production time for the tool are reduced.

Unlike powder-metal AM technologies, WAAM permits a much larger build area, offers much faster deposition rates (5-10 pounds/2.3-4.5 kilograms per hour) and, overall, uses less expensive material. Versus machining plates/blocks of metal or castings, WAAM can reduce lead times from months to weeks, helping manufacturers bring parts to market faster. It also significantly increases design freedom and part-consolidation opportunities. For example, rather than machining a facesheet and then building a separate backing structure for an aerostructure tool, the entire tool with integral backing structure can be printed in a single build with less waste/scrap. Additionally, the ability to print lattice structures can lead to lighter printed tools, which makes them easier to ship and store, and improves thermal properties, reducing autoclave heat-up/cool-down cycles.

Currently, WAAM's biggest limitations are the physical reach of the robots used and the size of the room that encloses the printing cell in which the build takes place. On the other hand, this cell does not need to be in a cleanroom, as with many metal AM processes. The only room requirements are an air handling system to collect fumes and localized shielding of the gas source.

As with 3D-printed plastic parts or tools, WAAM produces a near-net shape part or tool whose surface is striated and bumpy (in this case, from the weld beads). Thus, post-print machining of the molding surface is needed to bring WAAM-fabricated tools into dimensional compliance.

Supply integration

Several companies sell large-format WAAM systems, although very few offer printing services. One of the latter is the Additive Solutions unit of Lincoln Electric Co. (Cleveland, Ohio, U.S.), which offers custom WAAM printing services using the company's own GMAW-based WAAM technology on 20 machines at its 75,000-square-foot/6,968-square-meter facility in Cleveland. Post-process machining of 3D-printed components is conducted at its Baker Industries (Macomb, Mich., U.S.) subsidiary, which provides tool engineering and fabrication services for automotive and aerospace markets, plus custom-machining services.

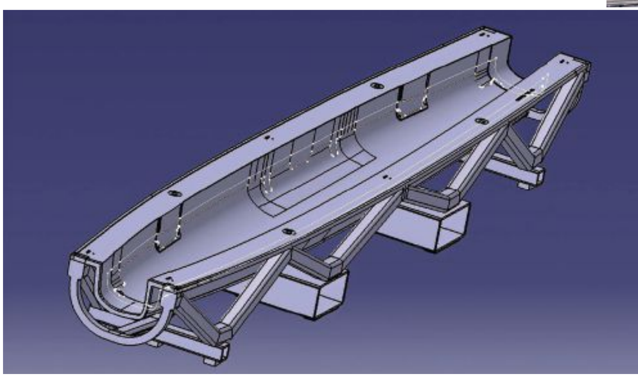
Lincoln Electric is a long-time supplier of welding and cutting equipment, automation and consumables such as welding wire in various tool steel, stainless, nickel, bronze and aluminum alloys. Reportedly, the company has been exploring metal AM for more than a decade. Lincoln Additive Solutions launched in 2019 and began printing with Invar wire in 2020. Metal additive manufacturing has long been used to prototype parts and to repair or replace legacy parts, but now — with the addition of Invar wire — it also can be used to produce aerospace tooling.

"What's different about Lincoln Electric is that we're in control of the entire process, from start to finish, since we manufacture power sources, welding equipment, flexible automation [robots and positioners], post-print subtractive processes [machining] and our own wire feedstock," explains Mike Wangelin, business development/sales manager for Lincoln's Additive Solutions. "Not only do we have decades of experience in welding and advanced automation, but we also own and develop our own additive software, which not only sections a 3D model into layers to generate the deposition path, but also programs the robot and positioner. Our SculptPrint operating system was originally developed to drive complex 5-axis NC machining and has since been adapted to AM. Since we own the software, as more is learned about the WAAM process and efficiencies are gained, immediate updates are made. Backed by the power of our large parent corporation, we're able to invest in each advanced technology segment along the way to drive the whole WAAM process forward."

Lincoln's current WAAM systems have a build space of 4 x 6 x 6 feet (1.2 x 1.8 x 1.8 meters), although Wangelin says that is expandable as needed. "Basically, right now the system can print in a 5-foot cube (0.14 cubic meters), but that's part-dependent," he explains. "If it's a narrower part, print volume is increased up to »

Advancing WAAM technology

Boeing and Lincoln collaborated to design and 3D print an aerospace composite cure tool (below) that integrated the entire backing structure as well as the facesheet into the printing process, expanding the technology's capability. After printing, the tool was finish machined at Baker Aerospace (right) prior to functional testing at Boeing's St. Louis, Mo., U.S., facility to document dimensional stability, surface roughness and vacuum integrity.



9 feet [2.7 meters] long. We're only limited by the robot's reach, so we could easily use a larger robot or pedestal to raise the robot up, if needed, to extend our current build envelope. We've been working on a couple of projects that are 10 feet [3.1 meters] long and vertically printing 4- to 5-foot [1.2- to 1.5-meter] segments and welding them together after printing. Printing shorter segments and then joining them not only extends the effective reach, but it also shortens tool build times."

Proof is in the printing

Lincoln reports that it has already produced and delivered its first WAAM Invar tool to an aerospace customer. While the production tool is described as "traditional in design," by 3D printing its facesheet in Invar, Wangelin says the fabrication process was simplified significantly and overall cycle time was reduced. Lincoln also delivered several carbon-steel production tools to aerospace customers in 2020.

Currently, Lincoln is collaborating with The Boeing Co. (Seattle, Wash., U.S.) on a project focused on incorporating an Invar backing structure into the 3D print to produce a fully integral 3D-printed tool for a composite part on an aerospace program under development at Wisk Aero LLC (Mountain View, Calif., U.S.). Wisk, which is backed by Boeing and Kitty Hawk Corp. (Mountain View, Calif., U.S.), is developing commercial aircraft for the urban air mobility (UAM) market.

"Boeing continues to be an industry leader in additive manufacturing technology development and integration, but we also acknowledge the need for tool engineering's philosophy to evolve because traditional tool design hasn't capitalized on newer technical capabilities," explains Melissa Orme, Boeing Additive Manufacturing vice president. "We recognized the technical expertise of Lincoln Electric and their commitment to rapidly advancing wire-feed additive manufacturing technology by collaborating with them on the Wisk project."

Teams from Boeing Research & Technology and Boeing Additive Manufacturing proposed the development of a composite cure tool that pushed the envelope of WAAM technology to the next level and provided design optimization support to help Lincoln develop the fully 3D-printed Invar composite cure tool.

"Tooling is the last item needed before a production run, so there's always schedule pressure to produce tools as quickly and affordably as possible," adds Wangelin. "As aerostructure parts become more complex, and tooling lead times and costs start to come down because of AM, Lincoln Additive Solutions can offer a real advantage by cutting production and delivery times — especially for complex tools. Add to that our focus on design for additive collaboration and our work in topology optimization, and we have something that will be of great interest to aerospace customers."

"The Boeing and Lincoln Electric collaboration to advance state-of-the-art WAAM technology is a revolutionary achievement and a testament to both companies' commitment to innovative technology development," adds Michael Matlack, Boeing associate technical fellow. After finish machining at Baker Aerospace, the WAAM cure tool will undergo functional testing at Boeing's St. Louis, Mo., U.S., facility to document dimensional stability, surface roughness and vacuum integrity. CW

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More on LFAM tooling | short.compositesworld.com/LFAM

Watch the WAAM process | short.compositesworld.com/WAAMprocss

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Tech Table: Curing Ovens

By **Grace Nehls** / Assistant Editor

› While autoclave cure is the established standard for effective consolidation and cure of composite parts and structures, especially for aerospace manufacturing, out-of-autoclave (OOA) processes have been steadily evolving and becoming more prevalent as fabricators seek ways to reduce composites manufacturing cycle time. In fact, it is possible now to achieve autoclave properties — e.g., <1% porosity — out of the autoclave. And as fabrication migrates out of the autoclave, several benefits follow: Elimination of autoclave capex investment, elimination of freezers for prepreg storage, reduced energy consumption and shorter cycle times. Ultimately, the OOA process validates the use of composites for an expanded spectrum of applications.

Within this sphere, composites curing ovens have followed OOA's evolutionary path, with more flexible systems and more accurate, higher-end controls to further improve part quality. Composites curing ovens now possess a range of footprint dimensions, temperature ranges, heat sources, specialization, and, depending on the supplier, are completely

TECH TABLE: COMPOSITE CURING OVENS *G=gas; E=electric

Company	Oven Model	Oven Dimensions (mm)	Heating Source*	Maximum Temperature (°F/°C)	Material and Process Capability	Additional Features
Benko Products	SW6-350-66	1,800 H x 1,800 W x 1,800 D	E	350/177	Wet layup, prepregs	Digital vacuum port manifold; batch report; dual-loop non-contact IR and air temperature
	SW6-500-66	1,800 H x 1,800 W x 1,800 D	G,E	500/260		
	SW6-650-68	1,800 H x 1,800 W x 2,400 D	G,E	700/371		
	SW8-500-78	2,400 H x 2,100 W x 2,400 D	G,E	700/371		
	SW8-650-79	2,400 H x 2,100 W x 2,700 D	G,E	700/371		
Despatch - ITW EAE	RAD1-42	1,170 W x 930 D x 950 H	E	104-649/ 40-343	Vacuum bag	119-liter chamber; aluminized steel interior; 5-year heater warranty; protocol 3 controller with data logging
	RAD2-19	1,510 W x 1,120 D x 1,960 H	E	104-649/ 40-343		552-liter chamber; adjustable louvers; 5-year heater warranty; protocol 3 controller with data logging; optional vacuum ports, jacks and advanced controls
	RAD2-35	1,780 W x 1,240 D x 2,085 H	E	104-649/ 40-343		552-liter chamber; adjustable louvers; 5-year heater warranty; protocol 3 controller with data logging; optional vacuum ports, jacks and advanced controls
	TAD2-52	2,120 W x 1,230 D x 2,410 H	E	104-649/ 40-343		1,490-liter chamber; aluminized steel interior; protocol 3 controller with data logging; optional vacuum ports, jacks and advanced control
	TAD3-10	2,550 W x 1,590 D x 2,590 H	G,E	104-649/ 40-343		1,490-liter chamber; aluminized steel interior; protocol 3 controller with data logging; optional vacuum ports, jacks and advanced control
	TAD3-21	3,210 W x 2,170 D x 2,590 H	G,E	104-649/ 40-343		1,490-liter chamber; aluminized steel interior; protocol 3 controller with data logging; optional vacuum ports, jacks and advanced control
	TAD3-48	4,340 W x 2,380 D x 3,300 H	G,E	104-649/ 40-343		13,450-liter chamber; adjustable louvers; unitized construction; F4T controller; optional vacuum ports, jacks and advanced control
	TAD3-96	4,340 W x 4,570 D x 3,300 H	G,E	104-649/ 40-343		13,450-liter chamber; adjustable louvers; unitized construction; F4T controller; optional vacuum ports, jacks and advanced control

customizable in an attempt to fit the needs of specific process requirements. This is the fourth in a series of Tech Tables that *CW* has published, each designed to provide as comprehensive a list as possible of suppliers, their products and selected product specifications.

This table of composites curing ovens has been built with data provided by suppliers, and is intended to provide a representation of the products they offer. While *CW* was unable to receive data from all composite curing oven suppliers, prominent companies unlisted — but which should be distinguished in this area — include Taricco Corp., JPW Industrial Ovens & Furnaces and ASC Process Systems. CW

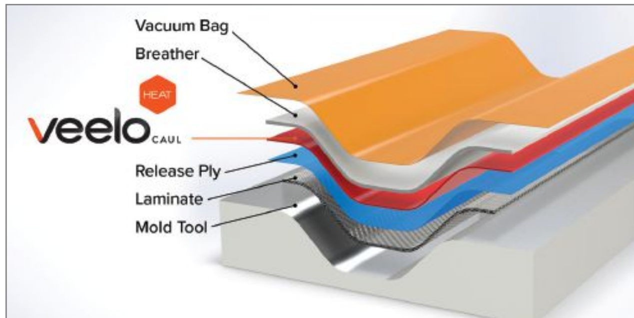
TECH TABLE: COMPOSITE CURING OVENS (continued) *G=gas; E=electric

Company	Oven Model	Oven Dimensions (mm)	Heating Source*	Maximum Temperature (°F/°C)	Material and Process Capability	Additional Features
Grieve Corp.	WRC446-500	2,083 L x 2,667 W x 2,210 H	G,E	500/260		Options include compliance with AMS 2750; vacuum ports; thermocouple jack panels; recorders and programmers.
	WRC566-500	2,388 L x 3,277 W x 2,210 H	G,E	500/260		
	WRC787-500	3,124 L x 4,115 W x 2,515 H	G,E	500/260		
	WRC8108-500	3,531 L x 4,902 W x 2,870 H	G,E	500/260		
	TAH-550	1,803 L x 1,956 W x 2,464 H	G,E	500/260		
	TBH-550	2,108 L x 2,261 W x 2,464 H	G,E	500/260		
	SA-550	2,413 L x 1,168 W x 2,616 H	G,E	500/260		
	SB-550	2,565 L x 1,168 W x 2,769 H	G,E	500/260		
LEWCO Inc.	EWT05ED-72-72-72	3,048 W x 2,134 D x 4,216 H	E	200-500/ 93-260	Any composite parts	AMS 2750 compliant; ±10°F uniformity; multi-recipe ramp/soak programming; cascade loop control with lead-lag; 1-10°F/min ramp rates; eight vacuum ports with high-temperature quick disconnect, manual shut-off valve and pressure gauge; eight type "J" thermocouple jacks inside oven and wired to controller; one vacuum transducer located on main header and wired to controller; redundant data logging
	EWT05ED-96-96-96	3,658 W x 2,743 D x 4,877 H	E	200-500/ 93-260		
	EWT05ED-96-144-96	5,636 W x 3,962 D x 4,623 H	E	200-500/ 93-260		
	EWT05ED-120-192-96	6,502 W x 5,182 D x 5,309 H	E	200-500/ 93-260		
Wisconsin Oven Corp.	SBH Series	Min: 610 W x 610 L x 610 H ; Max: 1,219 W x 1,219 L x 1,219 H	E	1,000/538	Any prepreg in molds under vacuum; post curing of composite materials; mandrel-wound composites, both wet cure and post cure	Vacuum systems, pumps, transducers and other accessories; WOC Premium advanced data acquisition and control system; rotators for mandrel-wound composites
	EWN Series	Min: 1,219 W x 1,219 L x 1,219 H; Max: 3,048 W x 4,877 L x 2,438 H	G,E	1,000/538		
	SWH Series	Min: 1,219 W x 1,829 L x 1,829 H; Max: 3,048 W x 7,620 L x 2,743 H	G,E	1,000/538		
	UWH Series	Min: 2,438 W x 7,315 L x 2,438 H; Max: 4,877 W x 13,716 L x 4,877 H	G,E	1,000/538		
	Custom Batch Ovens	Unlimited	G,E	1,000/538		

New Products

» COMPOSITES DEBULKING SYSTEM

Caul system enables in-situ hot debulking capabilities



Source | Veelo Technologies

Veelo Technologies (Cincinnati, Ohio, U.S.) leverages its heat technology capabilities to help manufacturers stay out of the autoclave and oven by offering a complete composites debulking system, the VeeloHEAT Caul. A lightweight heating solution that builds on existing debulk bagging procedures, the system enables effective and reliable in-situ hot debulk, eliminating the need to transport parts to an autoclave or oven. Debulking can take place at the tool during layup, substantially improving throughput and build rates, thus reducing overall manufacturing costs.

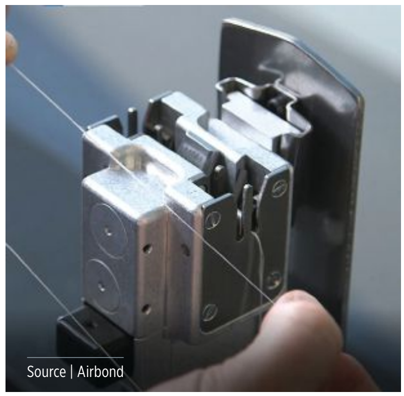
Due to its flexible and pliable design, the durable and damage-resistant caul is highly uniform across large surface areas and reportedly can easily accommodate custom shapes and large tools. It features an FKM-based heater system for high performance and material compatibility. In addition to fatigue resistance and a temperature range between 100°F-400°F, the system is also electrically efficient, with fast heating and cooling capabilities.

The caul is also controlled by the VeeloHEAT Controller, said to be a cost-effective solution capable of controlling 16 zones or more. The digital IoT controller is capable of storing data and receiving updates locally or via the cloud and is highly customizable. Applications of this system may include out-of-oven heated debulk, out-of-autoclave composites processing, accelerated cure in autoclave processing, net-shaped composite repair, secondarily bonded heating for metallic tooling and secondarily bonded heating for electrothermal de-icing. **veelotech.com**

» FIBER SPLICER

Composite fiber splicers handle challenging materials at higher concentrations

With the launch of 12 new composite fiber splicers, **Airbond** (Pontypool, U.K.) has doubled its product range — with models focused on waste recovery — and extended the limit of fiber splicing limits tenfold to enable splicing of more challenging materials at higher concentrations. Reportedly lighter, simpler and more tolerant of rough treatment, Airbond's patented yarn splicers now enable a wider range of applications with improved ergonomics and cover all fibers, including glass and carbon fiber, polypropylene (PP), nylon and other synthetic fibers.


Source | Airbond

Some models are now capable of splicing super-large yarns up to 16,000 Tex, compared to conventional 1,200-, 2,400- and 4,800-Tex yarns. These splicers have the option of a flow control system that supplies variable-pressure air to the blast chamber, while keeping the main factory line pressure unchanged. They can be used to deliver distinct, innovative techniques for joining brittle yarns such as glass and carbon fiber, and joining inherently strong aramid fibers.

A fixed-position splicer model has been added and enhanced for efficient waste yarn recovery. This can be used for "bit-winding" — a process where full-weight bobbins are created by repeatedly winding "shorts," and are then spliced together several times until a full weight is reached. This particular model can be bolted to a simple bit-winding machine and is designed for frequently repeated splicing over long time periods.

The wrapping splicer model for monofilaments and fibrillated fibers can be applied to monofilaments, braided yarn, heavily-sized or coated yarn and high-twist yarn, which Airbond says are traditionally problematic materials. Two yarn ends are overlapped, and a fine auxiliary yarn is tightly wrapped around them and bound to produce a joint of high strength. The jointing method has a patent pending.

All Airbond yarn splicers, which include a five-year guarantee in normal usage, have also been revised with a 3D-printed body for higher reliability.

Further, according to Graham Waters, managing director of Airbond, its splicer technology offers the composites industry a robust system suitable for composite companies that work in fiber manipulation, with reduced waste, time and cost. Airbond splicers can be manufactured to order.

airbondsplicer.com

» ANTIMICROBIAL PROTECTION

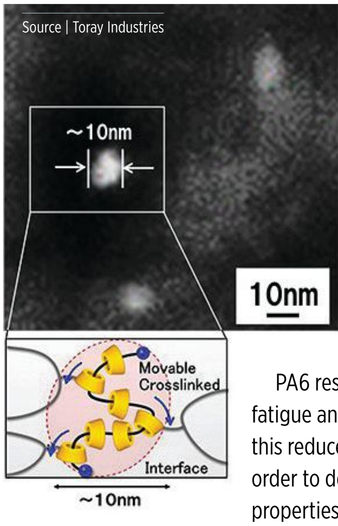
Antimicrobial agent protects UV-cured powder coatings

Keyland Polymer UV Powder (Cleveland, Ohio, U.S.) has announced its newest product offering, UVMax Defender, which provides added antimicrobial protection for Keyland Polymer's entire line of UV-cured powder coatings. The antimicrobial agent uses silver ion technology to help keep surfaces and products safe.

UVMax Defender can be used on plastic, composites, medium-density fiberboard (MDF), wood and metal substrates and is said to be ideal for healthcare, public transportation, education, food service, consumer goods or other coated products where harmful bacteria can be prevalent.

Keyland Polymer says that results from independent third-party testing using ISO 22196 standards confirmed that after 24 hours, surfaces coated with UVMax Defender showed reduced reproduction of E coli and staphylococcus microbes by more than 99.99%.

Keyland Polymer has also released its Cleaning Methods Evaluation Report. The company notes that report data demonstrate the robustness of a UV-cured powder coated surface when regularly cleaned using common household or commercial liquid cleaning products. This test is a modification of the NEMA LD 3-2000 method 3.4 Cleanability/Stain Resistance, 3.4.5. The test results confirmed that the use of the cited cleaning products causes no observable or measurable change in surface properties, color fastness, pencil hardness, film build or gloss loss. **kpuvpowder.com**



Source | Toray Industries

» THERMOPLASTIC POLYMERS

New flexible, toughened polymer retains high bending fatigue limit

Toray Industries Inc. (Tokoyo, Japan) has created a new polymer that retains the high thermal resistance, rigidity and strength of polyamide 6 (PA6) while delivering a bending fatigue limit that is 15-fold that of conventional polymers. Prospective applications include automotive, appliances and sporting goods.

PA6 resin typically incorporates a flexible elastomer to resist fatigue and optimize the lifespan. The tradeoff, however, is that this reduces PA6's thermal resistance, rigidity and strength. In order to develop a new material that offers all of these desirable properties, Toray says it focused on polyrotaxane, a polymer that has a sliding molecular bond, or whose structure moves in response to external forces.

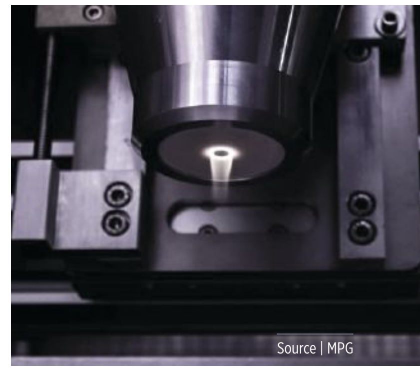
Drawing on proprietary nanoalloy microstructure control technology, Toray says it maximized the effectiveness of polyrotaxane by dispersing it amongst the 10-nanometer PA6 crystals. The resulting flexible stress-dispersion mechanism led to the creation of the new polymer. Tests at the SPring-8 synchrotron radiation facility in Japan confirmed that the new polymer suppresses changes in the crystal structure of PA6 when subjected to external forces.

Toray looks to initiate full-fledged sample work in fiscal year 2021 while cultivating applications in diverse industrial materials fields. **toray.com**

» SURFACE TREATMENT

Automated technology promotes better part surface adhesion

Molecular Plasma Group's (MPG, Foetz, Luxembourg) automated, solvent-free MolecularGRIP technology has been developed to promote better adhesion on inert and sensitive part surfaces. Said to be effective on a variety of material surfaces, including carbon fiber and


Source | MPG

natural fiber composites, as well as polyolefins, fluorinated polymers and metals, the one-step MolecularGRIP process combines plasma treatment with MPG's adhesion promoter chemistry. The plasma activates both the part surface and the coating molecules, which covalently bond onto the surface.

The technology is customizable with a range of plasma gases and organic chemicals to work with a variety of sensitive and inert materials to achieve superior bonding. MolecularGRIP can be used with either MPG's PlasmaSpot or PlasmaLine systems.

According to MPG, the process is both environmentally friendly — requiring relatively little energy, few chemicals and near zero emissions — and is easily scalable in a robust, industrial process. Additionally, to meet a range of customer needs, the company offers proven application development services, off-the-shelf R&D equipment, leasing and rental options and customized industrial solutions.

molecularplasmagroup.com

» COMPUTER-AIDED ENGINEERING

CAE software improves simulation efficiency

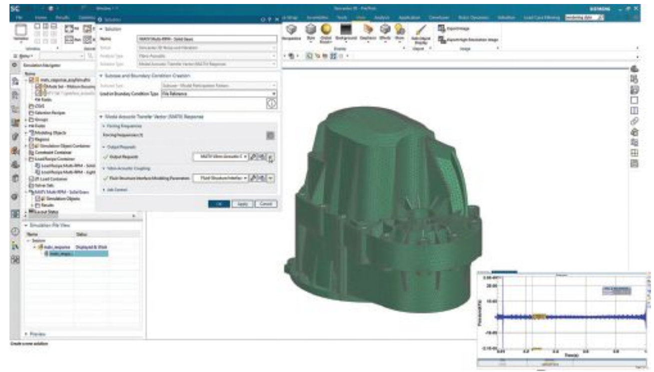
Siemens Digital Industries Software (Plano, Texas, U.S.) announces the latest release of Simcenter 3D software, a comprehensive, fully-integrated CAE solution for complex, multidisciplinary product performance engineering. Part of the Xcelerator portfolio, Siemens' integrated software, services and application development platform, the 2021 release is said to deliver improvements to Simcenter 3D's simulation efficiency. Enhancements include new simulation types, refinements in accuracy and enhanced performance speed.

The addition of the Simcenter Multimech tool enables automatic generation of geometry and full mesh separation of macro and microstructural models in order to predict how, when and why failures will occur in the overall part. This includes full representative volume element (RVE) separation and 2D and 3D automatic insertion of cracks or cohesive zones in advanced materials.

New to Simcenter 3D is an auralization post-processing tool that allows users to listen to simulated pressure results to evaluate sound quality. With this tool, Siemens says acoustics engineers can hear the noise produced from various vibrating components or products as opposed to having to visually evaluate through charts or graphs.

Because simulation-driven design can significantly reduce the time it takes to bring a product to market, Simcenter 3D's thermal analysis capabilities have also been scaled into a vertical solution for mold designers and design engineers. The new NX Mold Cooling product uses Simcenter 3D technology to allow designers to rapidly set up and simulate the thermal performance of an injection mold insert directly in NX as they are designing the mold, ensuring easy and rapid thermal analysis of injection mold designs without having to wait for expert analyst feedback.

plm.automation.siemens.com

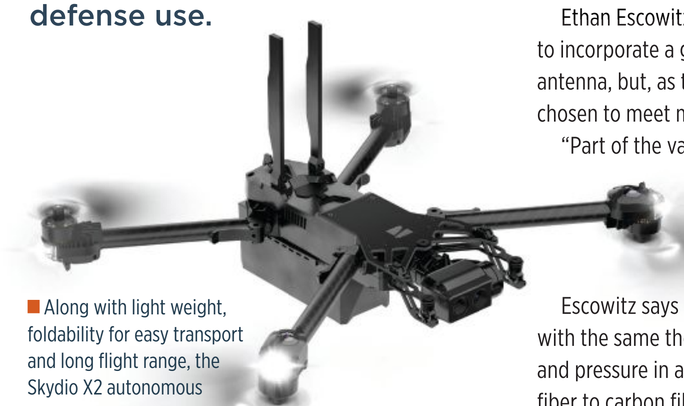


Evaluate sound performance with auralization: New in Simcenter 3D, pressure results as function of time (bottom right) can be played as an audio file.

Source | Siemens Digital Industries Software

Additive Molding technology revolutionizes autonomous drone design

Arris' Additive Molding process uses consolidated glass/carbon fiber airframe to optimize performance and reduce costs to produce Skydio X2 drone for industrial, consumer and defense use.



■ Along with light weight, foldability for easy transport and long flight range, the Skydio X2 autonomous drone features situational awareness, infrared imaging and other advanced skills and software capabilities.

›Arris' (Berkeley, Calif., U.S.) Additive Molding technology combines 3D-aligned continuous fiber additive manufacturing with high-speed compression molding for fabrication of high-performance thermoplastic composite parts for a variety of potential end-use applications. Recently, Arris has partnered with drone manufacturer and autonomous flight technology leader Skydio (Redwood City, Calif., U.S.) to redefine drone airframe design using Additive Molding.

The autonomous Skydio X2 drone, said to be lighter and more robust with longer range than the company's previously launched consumer drones, has been developed for use in industrial, consumer and defense settings. Notably, Skydio X2's foldable airframe features a single glass and carbon fiber/thermoplastic structural component manufactured using Arris' Additive Molding process, consolidating the previous model's 17-part assembly with one multi-functional, multi-material structure. The new design also adds strength and stiffness at a fraction of the weight, enabling the Skydio X2 to reach higher speeds and distances up to 6 kilometers.

Ethan Escowitz, founder and CEO of Arris, explains that the airframe component needed to incorporate a glass fiber composite window for radio signal transparency over the drone's antenna, but, as the component is also a core structural part of the airframe, carbon fiber was chosen to meet mechanical requirements in a different region of the part.

"Part of the value of Additive Molding is that we can not only align the fibers in any region of a part, but we can also change the material composition within different regions of the same part," he says. "It is one continuous part from one end to the other, but the material composition transitions to meet functional requirements."

Escowitz says that in the Additive Molding process, glass and carbon fibers are prepregged with the same thermoplastic resin matrix and then laid up and bonded together under heat and pressure in a final compression molding step. "Even though you transition from glass fiber to carbon fiber, the part has excellent consolidation and a homogeneous matrix, so the parts perform exceptionally and consistently," he says.

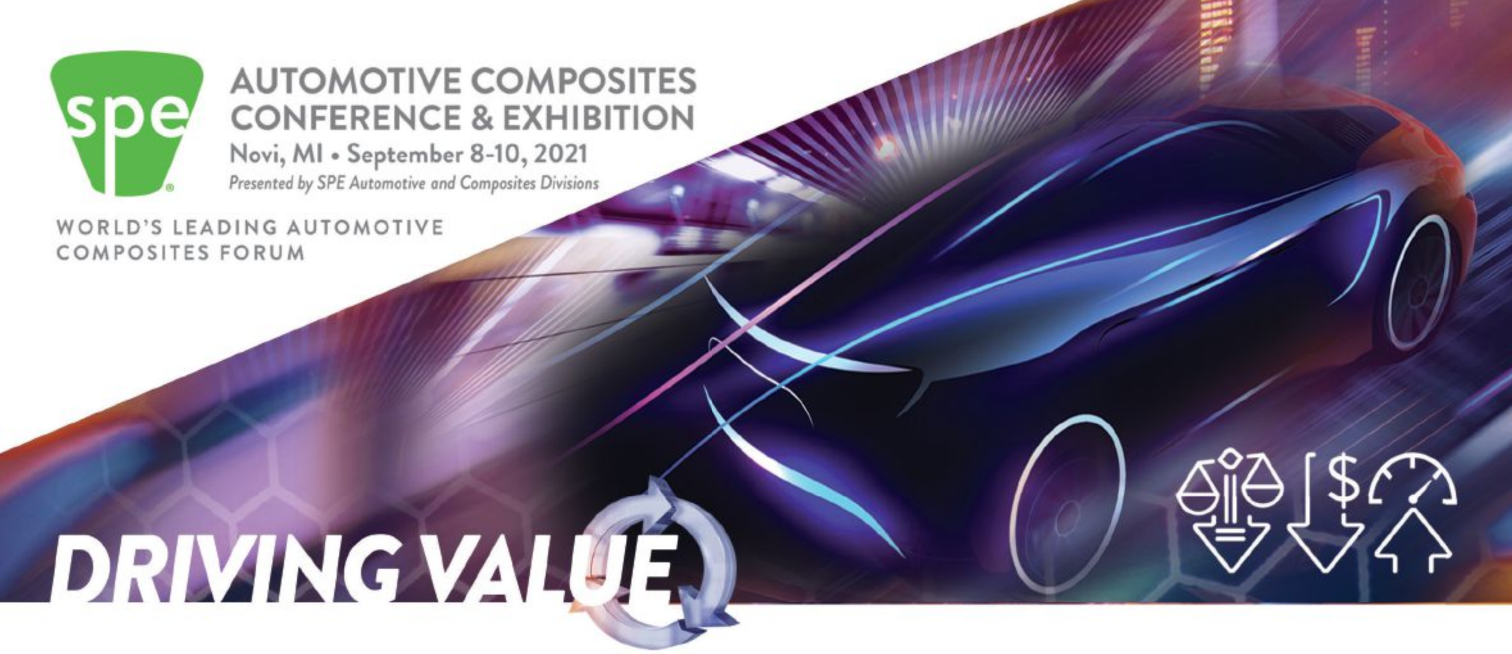
In addition, Arris' manufacturing method is said to enable aerospace performance in a scalable, automated manufacturing solution. "We're using aerospace methods, but producing parts with high-speed automated molding equipment typical in the consumer product world, where the norm is cost-efficient production with dead-on accuracy and repeatability," Escowitz says. The use of additive manufacturing also eliminates scrap and associated costs.

Skydio says the drone is ideal for a range of use cases, including situational awareness, asset inspection, security and patrol. Designed, assembled and supported in the U.S., Skydio X2 is NDAA compliant and has been selected as a trusted unmanned aerial vehicle (UAV) solution for the U.S. Department of Defense (DoD) as part of the Defense Innovation Unit's (DIU) Blue sUAS program. According to Skydio, the partnership with Arris further validates Skydio's commitment to innovation, supply chain security and U.S.-based manufacturing.

Adam Bry, CEO of Skydio, says, "We are excited about the value that our partnership with Arris will bring to our customers. At Skydio, we pursue cutting-edge innovation across all facets of drone technology. The unique properties of Arris' Additive Molding carbon fiber allows us to optimize the strength, weight and radio signal transparency of the Skydio X2 airframe to deliver a highly reliable solution that meets the needs of demanding enterprise, public safety and defense use cases."

"The evolution of aerospace design has been punctuated by breakthroughs in manufacturing and materials. Such a moment has come where manufacturing of optimized structures has converged with composite materials ideals to unlock previously impossible, high-performance aerospace designs," Escowitz concludes. "While we're working with leading aerospace manufacturers to improve aircraft performance, sustainability and costs, Skydio's culture and market have enabled an unsurpassed pace of innovation that has fast-tracked this transformation to deliver the next-generation of aerostructures. It's simply amazing to see such a revolutionary product broadly available and flying today." CW

■ Previous Skydio drones have been consumer-focused. The Skydio X2 is the first industrial model, designed for military missions, asset inspection and more with an expected range of up to 6 kilometers. Source, all images | Skydio



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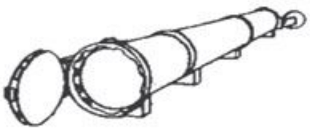

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SHOWCASE

ADVERTISING INDEX

■ **A first look at next-generation renewable energy**

Kinetic NRG set out to design a modular hydroelectric turbine able to capture more energy from water sources such as rivers and irrigation canals. The result is this spiral-shaped, glass fiber/epoxy turbine blade prototype.

Source, all images | ACS-A

Hydroelectric turbine blade design propelled by composites

Glass fiber composites power the development of a modular, spiral-shaped hydroelectric micro turbine blade for low-cost, high-efficiency renewable energy generation.

By Hannah Mason / Associate Editor

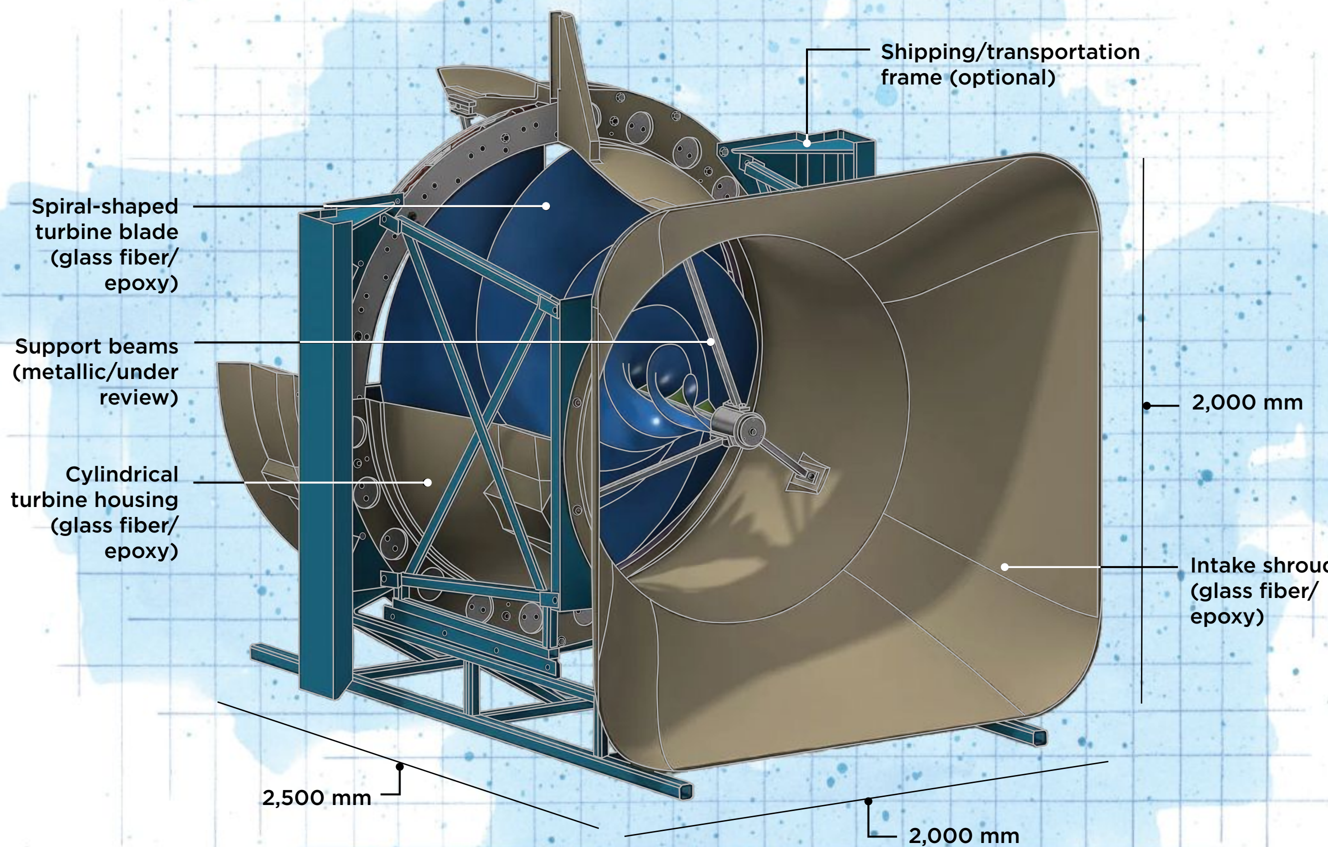
» The term "hydroelectric power" often brings to mind immense operations driven by purpose-built infrastructure such as dam systems and large turbines with traditionally metallic, propeller-based turbine blades. However, many areas are running out of new capacity for large, high-power hydroelectric power plants. At the same time, demand for more and lower-cost renewable energy generation continues to grow.

The U.S. Department of Energy (DOE), in its 2018 "Hydropower Vision" report outlining the current state of hydroelectric power in the United States and its goals for the future, predicted that growth in the U.S. hydroelectric market — from 101 gigawatts (GW) of energy capacity in 2018 to a potential capacity of nearly 150 GW in 2050 — would require new advanced technologies that can provide more energy at lower costs.

One potential solution could be smaller hydroelectric generators capturing untapped energy from low-flow water systems like irrigation canals and streams, according to Darren Wren, general manager at Kinetic NRG (Gold Coast, Australia). Established in 2016 by the late founder, Paul Camilleri, Kinetic NRG is a privately funded, renewable energy company focused on the development of new hydro-powered generation technology to deliver low-cost, reliable electricity.

The company's first technology is called the Hydro-kinetic Energy Generator (HEG) system, which measures 1.5 meters in diameter with an output of up to 30 kilowatts (kW) from water flows of 2.0 meters per second. This output makes it a "micro" hydropower system according to classification bodies such as the U.S. DOE, which defines micro systems as those with up to 100 kW of capacity. Intended for direct use in rivers, irrigation canals or tail races channeling water from existing dams, the HEG is designed for low-head hydropower — meaning the "head," or distance between the water line and the turbine, is less than 20 meters.

The most significant thing about the HEG, though, isn't its size or output, but the spiral-shaped design of its turbine blade.



DESIGN RESULTS | **Hydro-kinetic Energy Generator (HEG)**

- Spiral-shaped composite blade design captures available energy from low-flow water systems.
- Blade's interlocking subcomponents enable lower-cost manufacture, reduced weights and shipping for on-site assembly.
- Magnet-based, integrated power module maximizes electricity output.

Susan Kraus / Illustration

Spiral blades have been developed and used by others before, "but not to this level," Wren says. Most hydroelectric turbines include propeller- or fan-shaped blades arranged radially around a center axis, and activate a rotor or other electricity-generating mechanism within the turbine when rotated by water that is channeled downward into the turbine. These turbines work best in "high-head" water systems, where the water drops over a longer distance, picking up speed and water pressure to enable higher energy output.

According to Wren, a spiral-shaped blade, also called a "full-capture" blade, combined with the nacelle "actually increases water pressure available for capture, extracting more energy than previously thought possible. Our founder, Paul, had these ideas about how we can accelerate water flow through the HEG and capture the increased energy from traditional river flows, and he developed this spiral blade shape based on previous research and a combination of many papers," he adds.

Development of the HEG and its spiral turbine blade has been in the works for about five years, Wren says. "It's been quite a journey. The design we have now came about literally through trial and error."

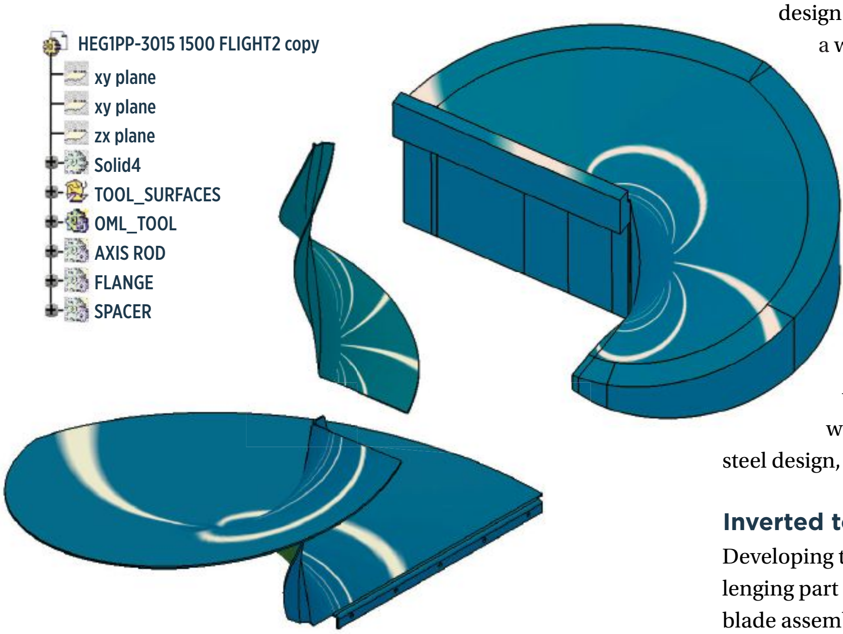
Designing a modular, manufacturable blade

Kinetic NRG's first, small-scale spiral blade models were formed from metal, but when the time came to manufacture the full-scale, 1.5-meter-diameter prototype, "we actually found that we couldn't make it," Wren says. The concept was to start with a flat piece of metal and then to form or forge a set of spirals radiating out from the center. "We just couldn't find a way to access certain points of the part to create the strength that we needed," he explains.

The company eventually abandoned its metallic efforts, but not the design itself. Wren says Kinetic NRG partnered with a local university to explore alternative manufacturing techniques and materials such as nylon or ceramics, and began talking with 3D »

Modular installation

The HEG system can be installed via floating, fixed or portable modular units, the goal being scalable, low-cost installation.



Designing the tooling

ACS-A says designing the tooling for the blade's four interlocking subcomponents was the most challenging aspect of the design. CAD files show the upper and middle sections of the tool, which was manufactured by Sykes Australia.

printing companies to see if additive manufacturing could be a viable option. Still, no solution presented itself that provided the right combination of manufacturability and mechanical properties. Finally, after a three-year journey, Kinetic NRG was introduced through a supply network connection to the team at engineering company Advanced Composite Structures Australia (ACS-A, Melbourne), which specializes in design and manufacture of low-volume, high-value-added composite components for a variety of end markets.

Wren calls what happened next "a meeting of minds," explaining that Kinetic NRG worked with Paul Falzon, general manager at ACS-A, and his team on various methods to manufacture and design the part using composite materials — materials that ACS-A knew from experience would be able to deliver the shape, weight and stiffness requirements Kinetic NRG needed.

The innovative blade shape was the key design challenge for the project, with mechanical requirements for the blade based, according to Wren, on standards set by the U.S. DOE and the International Electrotechnical Commission. The rest of the system's components — transmission, power management, communication, etc. — are standard off-the-shelf products that are known to meet all necessary regulations.

According to Falzon, ACS-A first evaluated the metallic attempts at the blade design, and then determined how to achieve the required shape, dimensional tolerances and weight of the blade. The blade also needed to be able to withstand aquatic environments, and to be stiff enough to support the turbine's steel shaft onto which it is attached. The ACS-A team started with the original metal design and "reverse engineered" a glass fiber composite blade to match the original stiffness, Falzon says. However, some design changes needed to be made when switching from a welded, metal-formed structure to a composite laminate. As Falzon explains, "We took a step back and asked, 'Okay, if we're going to take full advantage of composite materials, what does this thing look like?'"

After several iterations and discussions, the current design that took shape comprises four, identical composite blades that interlock to form the final spiral shape. "The composite blade is actually thicker than the steel design, but lighter because of the lower density of the materials we're working with," Falzon says. "Being thicker also means we get a lot more bending stiffness compared to the steel design, so you actually get a much stiffer product overall."

Inverted tooling

Developing the shape for tooling, Falzon says, was the most challenging part of the process. The ACS-A team evaluated the original blade assembly's shape using CATIA software from Dassault Systèmes (Waltham, Mass., U.S.). This led to development of the blade surfaces and design of tooling concepts. "When you look at the parts as they are today, they're actually made in an upside-down orientation. The blade model had to be inverted to create the tooling, and it's bizarre until you see the actual tooling when it arrives. It's quite complex," Falzon says. He explains that the tooling had to be inverted "to ensure we could achieve the required surface finish on the side of the blade exposed to the water flow," and to ensure each of the manufactured blade components could be demolded in one piece. The tooling also had to be precise: the interlocking blade components had to be able to align exactly when assembled, with each other and with the turbine's central shaft. For the prototype, the tooling, supplied by Sykes Australia (Sydney), was manufactured from low-cost tooling paste deposited onto a foam backing and then CNC machined to the final shape.

Once the tooling was developed, the current, full-scale prototype blade was constructed from glass fiber noncrimp fabric (NCF) and epoxy resin, manufactured via hand layup and cured at room temperature, followed by post cure in an oven at elevated temperature and application of a marine-grade paint. The materials were selected, Falzon notes, to meet both the structural and cost requirements for the part. The interlocking subcomponents are adhesively bonded — chosen over mechanical fastening for better control and dimensional accuracy in assembly. "The real trick," he says, "is to make sure that the blades can interlock, but once we laminate it all and bond it together it forms a very rigid assembly that achieves the needed structural and hydrodynamic shape performance."

Digital analysis of the structure's stiffness and other mechanical properties was performed using tools from MSC Software (Newport Beach, Calif., U.S.). "This system is much more efficient, lighter and able to do more work than the original design," Falzon adds.

Powering toward commercial production

According to Wren, Kinetic NRG's initial production target will be 950 units over a three-year period, and will scale up from there to several thousand per year. Potential customers, Wren says, may include private individuals and companies, power companies and municipalities — a wide range, underlining the versatility of the HEG concept. The systems can be installed as "mini hydropower plants" within irrigation canals, or placed downstream from existing hydroelectric generators to generate power from under-utilized off-flow, or as supplemental power for remote communities or businesses, he says.

+ LEARN MORE

Read this article online | short.compositesworld.com/KineticHEG

Currently, the full-scale HEG prototype is undergoing in-water mechanical testing; meanwhile, large-scale manufacturing processes are being evaluated for commercial production.

ACS-A expects to continue fine-tuning the blade design, as needed, depending on mechanical testing results and requirements for the most cost-effective manufacture possible. Specifically, Falzon says ACS-A is exploring automated preforming processes "so we can get the shape right with minimal hand labor," followed by light resin transfer molding (L-RTM) or another higher-speed process.

Finishing touches

The blade is finished with an anticorrosive, marine-grade paint before installation with the rest of the turbine.

Methods for turbine assembly are also under evaluation, the goal being, Wren says, for the blade subcomponents to be produced modularly and assembled locally, to avoid the costs and challenges in shipping entire full-scale units, while creating local employment opportunities and reducing installation costs. To make this possible, ACS-A may need to modify the way the blades interlock and the number of subcomponents in each assembly, as well. "We'll still have the full blades in their original shape, that'll still be a key part of it," Wren says, "but we may change where the transitions occur in order to make the same shape in fewer components for easier onsite assembly."

The two companies also are evaluating conversion of metallic components of the turbine into composites, to cut down on weight of the overall assembly. "We'll use glass where appropriate and carbon fiber where appropriate, but ultimately, we need to achieve a price point for the technology in order to make the cost of energy generation for the system cost-competitive," Falzon says.

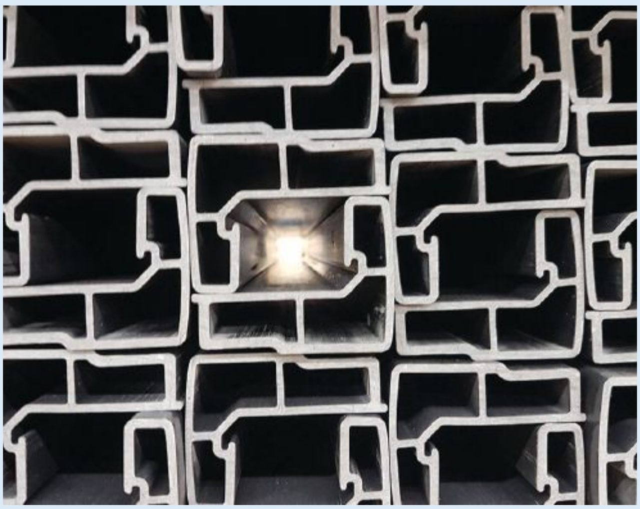
As the design and manufacturing process nears optimization, the next challenge will be, according to Wren, securing the right investment and manufacturing partnerships to scale up to commercial volumes. CW

ABOUT THE AUTHOR

Hannah Mason joined the *CompositesWorld* team in 2018 after working as an editorial intern for sister magazine *Modern Machine Shop* and earning a Masters of Arts in Professional Writing from the University of Cincinnati.

Post Cure

Highlighting the behind-the-scenes of composites manufacturing

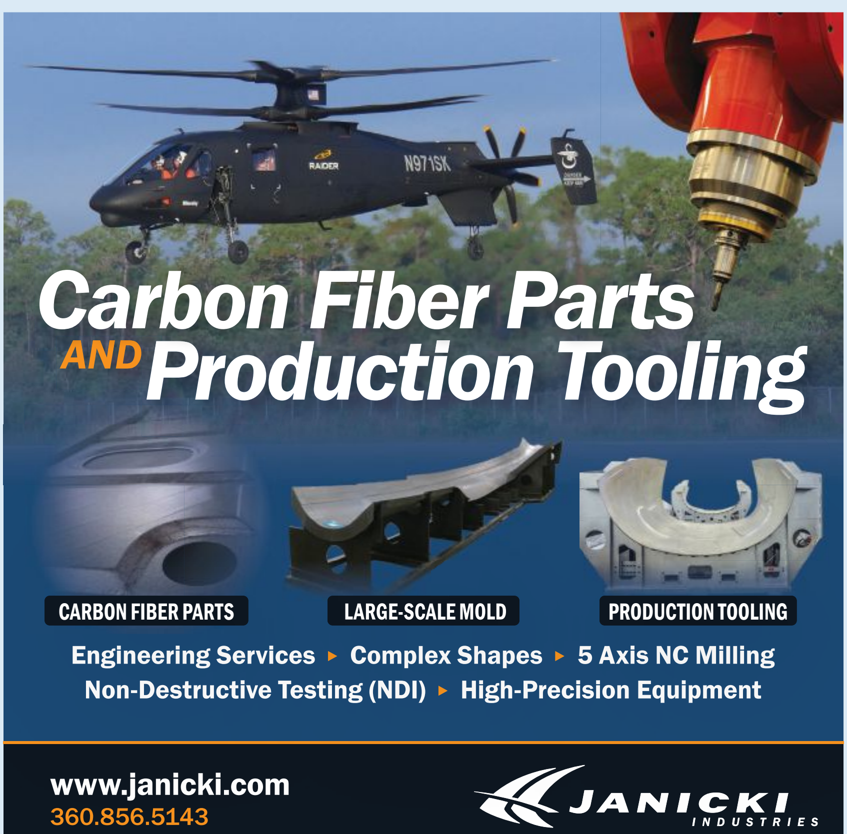


Source | Thomas Technik & Innovation

Making pultrusion more accessible and efficient

Thomas Technik & Innovation (TTI, Bremervörde, Germany) aims to make pultrusion more accessible and portable with pullCUBE, a 3.5-meter-long pultrusion machine that is 75% shorter than existing equipment. Launched in 2020, pullCUBE produces glass and carbon fiber-reinforced composite profiles with no length restriction, enabling large structures without joins for projects such as bridges.

TTI has also redesigned the start-up process to drastically reduce scrap and eliminated the need for mold cleaning purges, which reduces production waste and optimizes cost and efficiency. An estimated annual savings of almost €150,000 is possible. pullCUBE uses TTI's patented moving mold technology and Radius Pultrusion process to produce both straight and curved profiles.



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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* Associate Editor Hannah Mason at hmason@compositesworld.com, or connect with us on social media.

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