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Fast, flexible, efficient: CFRP PREFORM TECHNOLOGY

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COLUMNS

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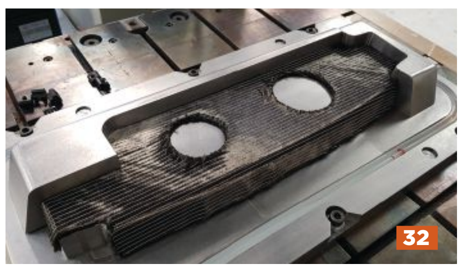

FEATURES

ON THE COVER

Teijin Carbon Europe GmbH has developed a method for rapidly creating near-net-shape preforms using binder-modified carbon fiber rovings that are subsequently infused and formed using HP-RTM. The first commercial use of the process was a large mounting bracket used to secure the spoiler/wing on Porsche *911 GT3 Cup II* cars See p. 28.

Source / Ing. h.c. F. Porsche AG

FOCUS ON DESIGN

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I was just nine years old in 1977 when the first movie from the *Star Wars* franchise was released. I was 52 in 2019 when the 11th and final movie was released. By virtue of its longevity and sheer quantity of films, *Star Wars* has become the de facto source of our understanding of traveling through and living in space, augmented by other notable space-based films and television series, including *2001: A Space Odyssey*, *Star Trek*, the *Alien* series, *Interstellar*, *The Martian*, *Gravity*, *Battlestar Galactica* (classic and reboot) and, more recently, *First Man* and *The Expanse*.

> Travel to the moon and Mars will require smart use of composites.

One of the things that has enabled all of these depictions, and has helped draw audiences to them, is the special effects made possible by rapidly advancing computer technology. I remember, in 1977, watching *Star Wars* for the first time, and feeling like a whole new reality was unfolding before me, replete with hovercraft, speed-of-light space travel, laser weapons and tractor beams.

I also remember, in 1977, not worrying *one bit* about how the world depicted in *Star Wars* violated innumerable laws of physics — particularly those governing space travel. *Star Wars*, and many of the films and shows that followed, took great liberties depicting momentum, gravity, radiation, pressure and temperature in ways designed primarily to drive plot and action. I also think many of us are willing to suspend our disbelief regarding the physics of space travel in exchange for an entertaining story.

Perhaps the most realistic — and harrowing — movie about space travel was 1995's *Apollo 13*, which was the true story of the third NASA mission, in 1970, intended to land American astronauts on the moon. Two days into the mission, the oxygen tank in *Apollo 13*'s service module failed, and the mission was aborted. The astronauts were forced to find a way to get back to Earth with limited oxygen supply. What made the *Apollo 13* film so compelling was its realism — because it was based on actual events, the movie's makers were forced to depict realistically the daunting physical challenge of the mission such as dwindling air supply, limited power, cold and wet cabin conditions and more. As faithful as this treatment was, however, it is the exception to the rule.

A result of all of this, I fear, is that many of us underestimate just how difficult it is to get people aboard a spacecraft into space and safely to their destination. First, you have to overcome Earth's gravity and the air resistance of its atmosphere. After that, you face the task of directing the craft toward its target — the International Space Station (ISS), the moon, Mars, etc. Today it costs about $1,000 to deliver 1 kilogram into low-Earth orbit (99 to 1,200 miles altitude), and a whole lot more to travel further.

Consider, for instance, that since the Space Shuttle program ended in 2011, the United States has not had a vehicle with which to take astronauts to the ISS. We hope to change this soon. Boeing and SpaceX are each working on spacecraft that will ferry astronauts to and from ISS. Boeing's is called *Starliner;* SpaceX calls its craft *Crew Dragon*. These vehicles have been years in the making, and both have had successes and failures emblematic of the trial and error associated with space development programs. Both also hope to deliver humans to ISS within the year.

Of course, the ultimate goal is to travel to the moon and eventually Mars, and doing so will require smart use of composites. One company in the thick of this effort is RUAG Space, which is working on out-of-autoclave fabrication of massive carbon fiber composite structures for the *Atlas* and *Vulcan* launch vehicles and is a supplier to Boeing's *Starliner* program. RUAG Space was kind enough to open the doors of its Decatur, Ala., U.S., plant to *CW* senior editor Scott Francis, and you will find his very interesting report on p. 42 of this issue.

If we do eventually put humans on Mars, the effort most assuredly will be governed by the laws of physics, which means it will be expensive, challenging and rewarding. And it will, no doubt, also be a movie.

JEFF SLOAN — Editor-In-Chief

Enabling a circular economy approach to advanced composites innovation, manufacturing and use, Part 1

»In its five years since launch, the Institute for Advanced Composites Manufacturing Innovation (IACMI – The Composites Institute; Knoxville, Tenn., U.S.) has continued to drive the large-scale adoption of advanced composites in diverse markets by investigating topics not only of interest to industry but also in the interest of national security and economic prosperity. Through these developments, IACMI has incorporated aspects of circular economy emphasis into many of its technical research projects.

Through a circular economy emphasis, technical research projects adopt a holistic approach: design and lifecycle perspectives are considered when developing new materials, equipment and manufacturing processes. Recycling is a key element for circular economy, but the most important mindset is to design materials and processes with the ultimate goal of reuse, and to support methodologies where multiple materials can be used through one process. Through these innovations and variations, industries are better equipped to adopt a more sustainable manufacturing practice.

IACMI projects are working to reduce the embodied energy of fiber-reinforced polymer composites.

This month's column focuses on one of two key aspects that increase lifecycle advantages in composite applications: reducing the embodied energy of fiber-reinforced polymer composites (FRPCs). Through technical projects and guiding priorities, the Institute is helping to address key challenges in circular economy adoption through technology development.

The polymer composites industry is a major economic contributor to a range of U.S. market segments. IACMI has a unique opportunity to make significant progress toward reducing the impact of landfill contributors in various markets deploying its nationwide network of composites expertise. The projections of key markets include:

- **Glass fiber**. The U.S. glass fiber market reached a value of $2.1 billion in 2018 and is expected to increase in volume by 20% from 2.5 billion to 3 billion pounds by 2023.[1]
- **Carbon fiber**. In 2018, the global demand for carbon fiber (CF) reached 187 million pounds (85,000 mt) and continues to grow by an average of 10-15% per year.[1]
- **Automotive**. Each year, 4.4 billion pounds of composite materials are sold for use in automotive applications.[1]
- **Wind turbines**. End-of-life (EOL) wind turbine composite waste. Globally, roughly 130 million pounds of this EOL waste is generated annually and is expected to increase by a rate of more than five times by 2030.[2]

Reducing embodied energy

In its first five years, IACMI has focused on the adoption of advanced composites to enable energy savings and greenhouse gas emission reductions through targeted applications in vehicles, wind turbines and compressed gas storage. The focus has been with the understanding that lighter-weight vehicles reduce fuel consumption, wind turbines operate more efficiently at a lower installed cost while displacing non-renewable energy sources, and compressed gas tanks permit the economic use of lower environmental impact fuels including natural gas and ultimately hydrogen.

Yet, the energy-intensive nature of advanced glass and carbon fiber composites production offsets some of the lifecycle energy advantages. These offsets include composites fabrication — for example, in wind turbine blade production — which uses glass fibers extensively and can be highly labor-intensive; as well as the reality that composites manufacturing technologies can deliver significant weight savings or higher volume for vehicles, but not both.

For potential carbon fiber-intensive applications, the cost and embodied energy of carbon fiber-reinforced polymer composites resides primarily in the production of the carbon fibers[3,4]. Therefore, the best way to reduce the embodied energy is to create materials and manufacturing processes that reduce the cost of production. The energy intensity of carbon fiber can be reduced through alternative precursors and advanced conversion processing technologies, while automated layup methods, fast-curing resin systems and robust inspection techniques can help improve manufacturing costs by reducing production cycle times.

IACMI and its partners are pursuing various technical activities, aligned with priorities identified in the technology roadmap, to overcome these challenges in advanced composites markets. Some of these priorities are discussed below.

Demonstrate lightweight automotive composite components. Volkswagen, Oak Ridge National Laboratory (ORNL), Michigan State University (MSU), Purdue University, and the University of Tennessee, Knoxville (UTK), along with industry partners, have developed a glass fiber sheet molding compound (SMC) composite manufacturing process for exterior automotive body panels. With targets including a condensed cycle time of 5 minutes and a 25% reduction in cost, energy and weight, this process is suitable for high production volumes and offers a promising lightweighting solution to substitute incumbent metals such as steel.

Develop novel oxidation, carbonization and heat-treating CF production technologies. Oxidation is the most expensive, energy-intensive and time-consuming step of carbon fiber production. 4X Technologies, 4M Carbon Fiber, ORNL and UTK are developing the world's first plasma oxidation oven for the oxidation phase of textile-grade carbon fibers. The project is anticipating less than half the processing time compared to conventional thermal oxidation methods, with significantly higher throughput and increased energy efficiency.

By initiating projects that develop new materials and processes that adopt a circular economy perspective, IACMI is enabling its members to develop manufacturing standards and best practices that support industry's bottom line and also benefit the U.S. national security and economic prosperity.

Next month's column will address improving composites' recyclability through both material and process developments.

Join us

IACMI has created an ecosystem of innovation that meets commercial needs, serves national security and drives national economic growth through its network of more than 150 members including academic institutions, and federal, state and local governments — supported by the U.S. Department of Energy's Advanced Manufacturing Office. Its efforts are driven by the major industry participation of its membership and made possible by the network of world-renowned talent that participates in the community. Dr. Soydan Ozcan, scientist at the U.S. Department of Energy's Manufacturing Demonstration Facility (MDF) at Oak Ridge National Laboratory and Recycling Lead for IACMI, has led several of the recycling initiatives for the institute and industry collaboration. IACMI's industry-led projects improve the flexibility of composites manufacturing processes, which in turn increases material diversity and allows optimization with improved energy efficiency, recyclability, material resource efficiency and lifecycle characteristics, including EOL disassembly and reuse.

Organizations of any size can join IACMI and, once a part of the consortium. Learn more at iacmi.org. CW

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[2] Psomopoulos, Constantinos S.; Kalkanis, Konstantinos; Kaminaris, Stavros; Ioannidis, George C.; Pachos, Pavlos. 2019. "A Review of the Potential for the Recovery of Wind Turbine Blade Waste Materials." Recycling 4, no. 1:7.
[3] Das, S. (2011). "Life Cycle Assessment of Carbon-Fiber Reinforced Polymer Composites," The International Journal of Life Cycle Assessment, Vol. 16, No. 3, pp. 268-282.
[4] Based on an IACMI analysis of energy intensity metrics for wind, vehicle, and compressed gas storage applications, carbon fiber represents 88-95% of CFRP embodied energy compared with other constituents including intermediates, resins, and molding & curing processes. Source: Brosius, Dale; Das, Sujit, "IACMI Baseline Cost and Energy Metrics," March 2017, Institute for Advanced Composites Manufacturing Innovation (IACMI).

ABOUT THE AUTHOR

Uday Vaidya serves as Director of the University of Tennessee's Fibers and Composites Manufacturing Facility (FCMF), IACMI's Chief Technology Officer, and is the University of Tennessee-Oak Ridge National Laboratory Governor's Chair in Advanced Composites Manufacturing. Vaidya is an expert on the manufacturing and product development with fiber reinforced polymer composites. Vaidya serves as the Editor-in-Chief for Elsevier's Composites B: Engineering journal. He engages a broad range of undergraduate and graduate students in experiential learning with composites technologies.

The coming decade: Clarity with a strong dose of uncertainty

» As we enter the decade of the 2020s, it's worth reflecting what the 2010s brought to the composites community and how these innovations may or may not shape the future. In the traditional composites market of aerospace, the Boeing 787 entered service in 2011, with the similarly composites-intensive Airbus A350 XWB following in 2015. Bombardier's *CSeries* single-aisle plane, with resin-infused wings, entered service in 2016. Airbus then acquired the *CSeries* product line in 2018, rebranding it the A220. Finally, and sadly, 2019 marked the cancellation of the Airbus A380, a larger-than-life airplane that pioneered many composite innovations.

What will the next 10 years yield for composites?

On the automotive front, BMW shook up the industry by introducing the *i3* and *i8* in 2013, establishing a global vertical supply chain and causing many to speculate that the age of carbon fiber-intensive vehicles would soon arrive *en masse*. Two years later, BMW brought forth the redesigned *7-Series*, a multi-material vehicle with approximately 15 structural parts in carbon fiber, suggesting perhaps an alternate path to mass adoption. Late in the decade, General Motors unveiled the *Sierra Denali* pickup truck with a compression molded carbon fiber-reinforced thermoplastic box, and in 2019 a rear-engine version of the Corvette with a curved, pultruded rear bumper beam.

In the area of composites recycling, especially for carbon fiber composites (beyond scrap fiber), the decade started with virtually no supply base and ended with more than a dozen suppliers, many providing commercial quantities into downstream applications. The wind energy industry had a banner decade, more than tripling capacity worldwide and proving to be a strong market for composites. I will cover wind in more detail next month, so will focus here on aerospace and automotive.

In December, I had the opportunity to visit multiple Fraunhofer Institutes and DLR facilities in northern and southern Germany, as well as several production facilities serving aerospace and automotive markets. These visits and discussions augment my observations in the U.S. as to where material and process developments are headed. Though differences exist at some level between countries, the main thrusts are truly global — increasing production speed and reducing costs dominate, with recycling and sustainability integral to these R&D efforts. Everything reconfirms that international collaboration to tackle these issues is not only beneficial, but imperative if composites are to truly displace traditional materials.

While questions remain, the future of composites in aerospace is becoming somewhat clearer. Despite no formal announcements regarding replacements for Boeing and Airbus single-aisle stalwarts, it is obvious that a lot of aerospace research is focused on delivering technologies to manufacture, machine, inspect and assemble large advanced composite structures at higher rates. It's one thing to deliver 100 to 140 widebody jets per year, but another thing entirely to build 700 to 900 single-aisle aircraft annually with composite primary structures. When one considers adjacent markets in unmanned aerial vehicles (UAV) and urban air mobility (UAM) such as air taxis, the volumes are likely to be in the thousands annually. While there is considerable interest in thermoplastics, the large structures for passenger aircraft are most likely to remain in thermosets (vacuum infused or out-of-autoclave cured prepregs), with thermoplastics in clips, brackets, ribs and other smaller components. For the UAV and UAM markets, expect the industry to consider thermoplastics and also incorporate technologies developed for automotive, such as high-pressure resin transfer molding (HP-RTM), pultrusion and compression molding.

The automotive world, on the other hand, shows considerable uncertainty. There is still strong interest in carbon fiber, but its value now must be considered in light of other driving forces — electrification, mobility and autonomy — not just lightweighting for lightweighting's sake. Over the last 10 years, cycle times and the cost of carbon fiber composites have been reduced by 50% or more, yet have further to go. Discontinuous carbon fiber, either recycled or from lower cost precursors/processes, will find a home as reinforcement for compression or injection molding compounds, where automation is high and scrap rates are low. Although BMW has recently announced that it will continue to build the *i3* until 2024, the German auto industry as a whole is stepping back from new applications for continuous carbon fiber. The future for carbon fiber in high-volume primary structures will depend on getting finished part costs down to less than €18 per kilogram (approximately $10 per pound). Possible intermediate-term solutions include continuous fiberglass or hybrid glass/carbon structures, as well as increased development of hybrid overmolded components.

What will the next 10 years yield for composites? For things that fly, the future looks bright. But for ground vehicles, we still need a few breakthroughs. 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 US-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.


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Composites Index ends year on production boost

December 2019 — 49.2

» The Composites Index closed 2019 with a December reading of 49.2. Readings during the second half of 2019 averaged 48.5, representing a mild contraction in the industry's activity level. Index readings above 50 indicate expanding activity, while values below 50 indicate contracting activity. The further away a reading is from 50, the greater the change in activity. Gardner Intelligence's review of the December data found that the Index was supported by an expansionary, six-month high reading for production. This boost to the Index was offset by a sharp contraction in backlog activity. Employment, supplier deliveries, new orders and exports all reported mild contracting activity, thus having little impact on the Index, which is calculated as an unweighted average of these six components.

Early in the second half of 2019, the composites industry experienced contracting business activity in both production and new orders. That contraction gave way to a new steady-state in the fourth quarter as readings oscillated around a reading of 50, which represents no change in month-to-month business activity levels. At the end of the year, certain business index components reported eroding activity levels — in particular, backlogs and exports. Supplier deliveries, which had played an important role in supporting the Index through the first three quarters of 2019, began reporting contracting conditions in the fourth quarter. CW

ABOUT THE AUTHOR

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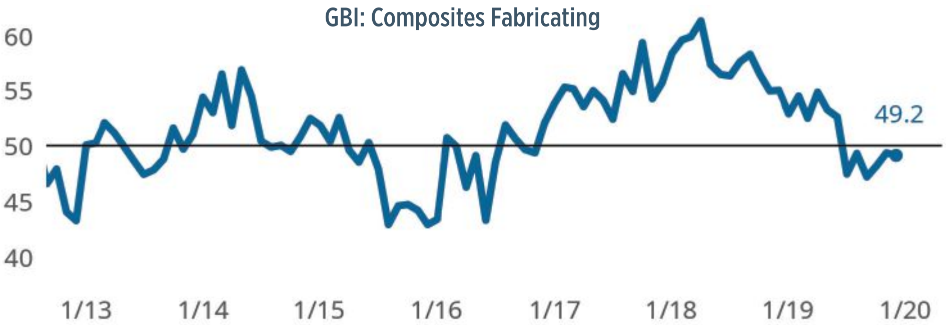
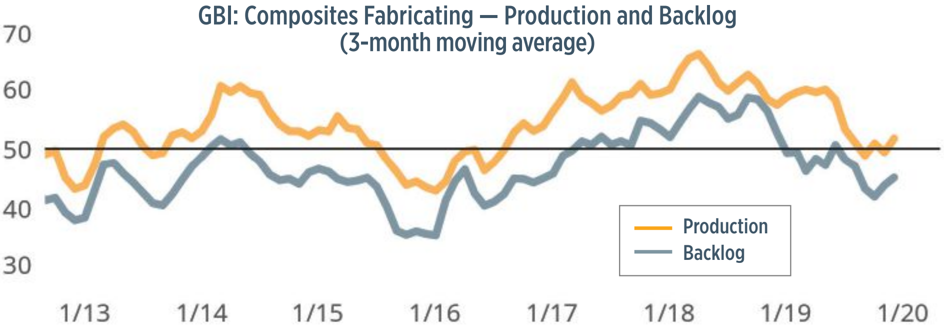


Expanding production, contracting backlogs

December's reading was supported by an expansion in production, which was counterbalanced by a significant contraction in backlogs. The Index averaged 48.5 in the second half of the year, representing a mild contraction in business activity.



Production and backlogs diverged during second half of 2019

Production activity expanded in three of the last six months; however, relatively weaker readings for new orders pressured backlog levels downward.

This month's composites industry trends include one company's advancements in continuous fiber 3D printing, a move toward sustainable autocomposites from waste, a project to develop composite panels for Jupiter spacecraft, research into new deep-ocean wind turbine designs and more.

3D-printed composites with 60% fiber, less than 1% voids

This CFRP rocker arm for a non-aerospace application actually meets aerospace laminate requirements and features more than 40 plies — each ply with a different fiber orientation to exploit anisotropy and optimize structural parts not previously possible. Source | 9T Labs

Continuous fiber 3D printing continues to be an area of research and development for many companies. For 9T Labs (Zurich, Switzerland), this goal extends to the production of industrial series structural components via carbon fiber 3D printing.

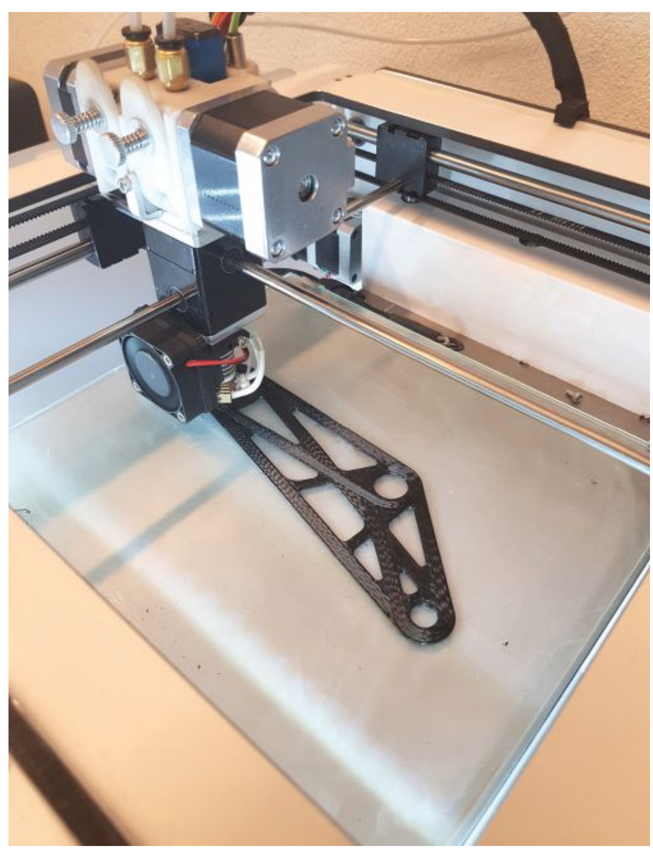
"If you talk to people who manufacture CFRP [carbon fiber-reinforced polymer] parts, most don't believe that it's possible to achieve super-low void content or good interlaminar shear strength (ILSS) between layers with continuous fiber 3D printing," says Giovanni Cavolina, 9T Labs co-founder. 9T Labs, however, has developed a patented post-process that eliminates voids. "We can now 3D print continuous fiber composites with great adhesion between layers and void content below 1%, which competes with conventionally manufactured composites."

9T Labs started with a research project in the Laboratory of Composite Materials and Adaptive Structures (CMAS) at the Swiss Federal Institute of Technology Zurich (ETH Zurich). Cavolina and 9T Labs co-founders Martin Eichenhofer and Chester Houwink had developed a composites printhead, "which we mounted onto a robotic arm and made lattice cores for ultra-lightweight sandwich structures, targeted for aerospace applications," Cavolina explains.

After receiving interest from industry, 9T Labs was established at the beginning of 2018 to prove the concept of 3D printing monolithic CFRP laminates that could meet potential customer requirements. This led to the creation of the CarbonKit, which transforms Ultimaker or Prusa 3D printers into a system capable of printing with continuous carbon fiber. "It allows you to use your existing printers in combination with our printhead, filaments and software to place continuous fibers, according to the load case, with 50% carbon fiber volume content — not 30%, which has been the norm in CFRP 3D printing," Cavolina adds.

The CarbonKit's limited release to 25 customers allowed 9T to establish valuable relationships with customers and learn what they expected and needed — and guided their next step.

That brings us to where 9T Labs is today. "We are commercializing the Red Series, which comprises two units: a classical FDM [fused deposition modeling] printing unit with a patented print head and an adjacent Fusion Unit for post-processing," Cavolina explains. "We don't achieve full in-situ consolidation during printing, but instead print



With the Red Series, 9T Labs has achieved 3D-printed CFRP structures, like this bracket, with more than 50% fiber volume and less than 1% voids at an affordable cost vs. current composites production methods. Source | 9T Labs and then consolidate in a second process. In essence, we are printing a preform which is placed in the Fusion Unit for post-consolidation using high temperature and pressure to achieve more than 50% fiber volume content with less than 1% voids. This two-step process achieves aerospace quality at an affordable cost."

The Red Series uses thermoplastic materials, for now. "We print carbon fiber with PEI, PEKK, PA (nylon) and have experience with PP as well," says Cavolina. 9T Labs can also use customers' existing material supply in their system. It tests the materials to make sure they fulfill certain feedstock requirements and determines the best parameters for printing.

9T Labs' print software is combined with a structural simulation software, Cavolina says. "Our software gives the freedom to design and then cross-check with a structural simulation. The other direction is to define a fiber-oriented layup in a structural simulation and then convert it into a print path in our software. We use an existing, well-tried and well-known partner for the FEA that runs in the background. You can also directly design a part in CAD and then upload that file into our program. There, you decide where you want the carbon fiber and where neat polymer is sufficient."

Current applications that 9T Labs is pursuing include aerospace (interiors, for now), biomedical and industrial automation (e.g., packaging machines), as well as leisure/luxury (e.g., motorsports, sport shoes, eyeglasses). The last market includes products which, Cavolina says, require structural composites, "but the requirements are not as strict as in aerospace."

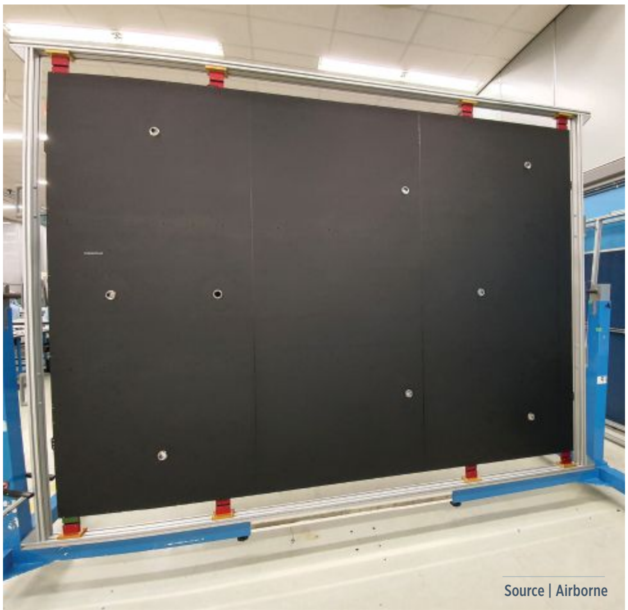
Cavolina cites the rocker arm (pictured) as a non-aerospace structural application "that you can produce in an optimized way using our technology," he explains. "It comes from an aluminum part that has been topology-optimized to save weight by orienting carbon fibers according to the load case." The rocker arm comprises more than 40 layers of fiber and polymer. "We tried four different layups, not restricted to quasi-isotropic. This freedom allows us to exploit the anisotropy of composites to further optimize the end-use structure. It would not be possible to do this with other current manufacturing methods," he says.

The Red Series, planned for launch this year, is aimed at smaller, monolithic parts for series manufacturing within a print area of 350 millimeters by 300 millimeters. What about print speed? "We're talking in a very concrete way about producing in the next 1-2 years 4,000 to 8,000 parts per year for different customers, achieved with the Red Series twin units," says Cavolina. "Because we have decoupled production of complex, detailed preforms from consolidation, it is now possible to ramp up production volume quickly."

For the full story, go to **short.compositesworld.com/9TLabs.**

AEROSPACE

Airborne substrate panels enable JUICE spacecraft solar array



Source | Airborne

Airborne (The Hague, Netherlands) is developing XL substrate panels for Airbus Defence and Space Netherlands (Leiden, Netherlands) for use in the solar array of the European Space Agency's (ESA) JUICE mission to Jupiter.

The JUICE (JUpiter ICy moons Explorer) is an interplanetary spacecraft in development by the ESA with Airbus Defence and Space Netherlands as the main contractor. The mission will study Jupiter's moons Ganymede, Callisto and Europa.

Given the mission's extreme distance from the sun, the JUICE spacecraft requires an exceptionally large solar array in order to generate sufficient power. Airborne was selected by Airbus Defence and Space Netherlands to develop and manufacture the XL substrate panels for JUICE's solar array. With a total surface area of 85 square meters, the satellite will be equipped with the largest solar array ever flown on an interplanetary mission. Each panel has a surface area of 9 square meters. To enable production, Airborne modified the manufacturing equipment, including extending the autoclave's inside diameter from 2.6 to 2.9 meters.

JUICE's solar array is built with ARA Mk4 technology, which has been developed and qualified by Airbus Defence and Space Netherlands in close cooperation with Airborne. The technology allows for 20% cost reduction and increases the robustness of the solar array by expanding the temperature range and adding stiffness. As the satellite will be exposed to extreme conditions during the full length of the mission, the panels need to withstand temperatures as low as -240°C, as well as space radiation.

The substrate panel features prepregs developed by Toray Advanced Composites (previously TenCate Advanced Composites, Morgan Hill, Calif., U.S.), which, according to Toray, are used on areas including the facesheets, edge members and patches. Toray RS-36, an epoxy-based thermoset prepreg for structural composite applications, was selected as the material solution for ARA Mk4.

The extreme temperatures to which the satellite will be exposed near Jupiter made additional qualification necessary on the panel design and its interfaces. Airborne manufactured 160 qualification test samples and two full-size panels that were delivered in January 2017. After an intensive testing campaign by Airbus Defence and Space Netherlands, Airborne manufactured a total of 10 substrate panels. The last four panels were completed in October 2019. Launch of the JUICE mission is planned for 2022.

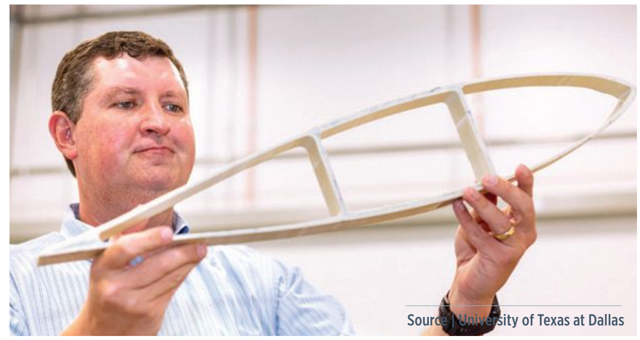
Arno van Mourik, CEO of Airborne says, "JUICE is a great example of what we can do in terms of state-of-the-art substrate panel technology for solar arrays of extremely demanding space missions. Building on this position, we are determined to move forward in the domain of affordable space panels for new space. Combining our knowledge on high-end substrates with our capabilities in the domain of industrialization of composites will allow us to provide the new space market with high-performance yet radically affordable solutions in high volumes."

BIZ BRIEF

Industrial furnaces specialist **Eisenmann Thermal Solutions GmbH & Co. KG** (Bovenden, Germany) has been acquired by **ONEJOON Co. Ltd.,** a Korean manufacturer of furnaces for processing cathode and anode materials in the lithium-ion battery industry. Eisenmann Thermal Solutions was part of the Eisenmann Group, which had filed for bankruptcy in August 2019. However, Eisenmann Thermal Solutions was not considered part of the Eisenmann Group's core business, so insolvency administrator Joachim Exner, managing partner of the German law firm Dr. Beck & Partner, was forced to develop a separate investor solution for this company. The actual purchaser of Eisenmann Thermal Solutions is ONEJOON Thermal Solutions GmbH (Boven den).

ENERGY

Researchers develop deep-ocean wind turbine blades


Source | University of Texas at Dallas

University of Texas at Dallas (UT Dallas) associate professor of mechanical engineering Dr. Todd Griffith and his team have developed a design for a vertical-axis, floating offshore wind turbine to convert deep-ocean winds into electricity. In December 2019, the team received a $3.3 million grant from the U.S. Department of Energy (DOE) to turn this design into a working prototype.

The Department of Energy estimates that state and federal waters along the U.S. coasts and the Great Lakes could generate twice the amount of energy generated by all of the nation's electric power plants combined. According to Griffith and his team, one of the biggest barriers to harvesting that energy has been the high cost of deploying wind turbines in deeper water, where floating platforms are required. Griffith's project aims to reduce the cost and overcome challenges with installation and connecting to existing energy grids with underwater cables.

Griffith's vertical axis wind turbine design, unlike traditional three-blade horizontal axis wind turbines, calls for vertical blades standing upright on a platform that sits partly above the ocean's surface and partly below. The platform is attached to the sea floor with cables, rather than anchored directly to the sea floor, under ocean depths of at least 200 feet.

According to the design, the turbine blades would rise between 600 feet and 700 feet above the ocean's surface, but could reach as high as 900 feet.

Griffith began investigating vertical axis wind turbine designs in 2009 when he was a principal member of the technical staff and offshore technical lead at Sandia National Laboratories' (Albuquerque, N.M., U.S.) Wind Energy Technologies Department. He joined UT Dallas in 2017.

Under the new grant, the UT Dallas team will include doctoral students, postdoctoral researchers and Dr. Mario Rotea, the Erik Jonsson Chair and head of mechanical engineering, who will lead the control systems thrust of the project. Through a process called control co-design, Rotea said he will work on developing the subsystems required to extract the most power with the least exertion of the turbine, which includes managing the forces on the blades and the turbine's speed in changing weather conditions.

According to Rotea, the research is critical to expanding the use of wind energy in the United States, especially in coastal areas. The nation's only commercial offshore wind project, which came online in 2016, is the Block Island Wind Farm about 4 miles off the coast of Block Island, Rhode Island.

UT Dallas researchers are working with the University of Illinois at Urbana-Champaign and corporate partners Aquanis Inc., VL Offshore and XFlow Energy.

"For me, this is an opportunity to do great research with a great multidisciplinary engineering team," Griffith says. "We're bringing together structural design, aerodynamics, control systems, floating systems, economics and installation procedures. It's a true systems-level engineering problem. I'm just excited to be able to lead this incredible group to bring all this technology together to realize the vision of the ATLANTIS program."

The grant is part of a $26 million Advanced Research Projects Agency-Energy (APRA-E) award funding 13 projects to accelerate floating offshore wind turbine technologies through the Aerodynamic Turbines, Lighter and Afloat, with Nautical Technologies and Integrated Servo-Control (ATLANTIS) program.

AEROSPACE

Rolls-Royce targets world speed records with all-electric plane


Source | Rolls-Royce

Rolls-Royce (Derby, U.K.) is developing an all-electric plane with the goal of breaking the record for world's fastest all-electric aircraft. After an unveiling of the aircraft in December 2019, work began on integrating the electrical propulsion system to enable the zero-emissions plane to reach its target speed of 300+ miles per hour (480+ kilometers per hour) in late spring of this year.

The plane is part of a Rolls-Royce initiative called Accelerating the Electrification of Flight (ACCEL), and is a part of Rolls-Royce's strategy to promote electrification. The project involves partners such as electric motor and controller manufacturer YASA Ltd. (Oxford, U.K.) and the aviation start-up Electroflight (Staverton, U.K.). Half of the project's funding is provided by the Aerospace Technology Institute (ATI; London, U.K.), in partnership with the U.K. Department for Business, Energy & Industrial Strategy and Innovate UK.

The *ionBird* test airframe, named after the electrical technology propelling the aircraft, was also unveiled. The *ionBird* will be used to test the propulsion system before it is fully integrated into the plane. Planned tests include running the propulsion system up to full power as well as key airworthiness checks.

According to Rolls-Royce, the ACCEL plane will have the most power-dense battery pack yet assembled for an aircraft, providing enough energy to fuel 250 homes or fly 200 miles on a single charge. Its 6,000 cells are packaged to minimize weight and maximize thermal protection, and its advanced cooling system is said to provide optimum performance by directly cooling cells during high-power record runs.

The propeller is driven by three high-powerdensity axial electric motors and, compared to a conventional plane, the propeller blades are said to spin at a far lower RPM to deliver a more stable and far quieter ride. Combined, they'll continuously deliver more than 500 horsepower for the record run. Even during the record run, the all-electric powertrain is reported to power with 90% energy efficiency and zero emissions.

"This is not only an important step towards the world-record attempt but will also help to develop Rolls-Royce's capabilities and ensure that we are at the forefront of developing technology that can play a fundamental role in enabling the transition to a low carbon global economy," says Rob Watson, director of Rolls-Royce Electrical.

AEROSPACE

Hybrid CFRP-AM metal design to reduce weight on future aircraft structures

Today's aircraft structures consist of many different materials. For example, the fuselage and wing structure of the Airbus A350 XWB is constructed mainly of composites with some metal parts. Here, parts are joined, per classical hybrid design, with bolts and rivets. This design leads to long assembly time, effort and cost. Additionally, the large number of fasteners in this classical hybrid design introduces unnecessary weight, as well as stress concentrations at load introduction points.

In the project TOAST, Premium AEROTEC (Augsburg, Germany), a Tier 1 supplier of fuselage structures for the A350, has presented completely new methods of joining composites and metals. In this way, the disadvantages of the classical hybrid design with bolts and rivets can be eliminated. Premium AEROTEC developed and manufactured, in less than five months, a demonstrator for an aircraft airbrake-like structure, using a modern hybrid design. It comprised a titanium load-introduction fitting, made via additive manufacturing (AM), and a carbon fiber-reinforced polymer (CFRP) thermoplastic composite plate, joined using thermoplastic composite overmolding.

The innovation of this demonstrator is the connection of the different materials without bolts or fasteners. This was made possible by the use of additive manufacturing and thermoplastic overmolding. The titanium fitting was designed with pins on its lower side and ribs designed with gyroid structures, both readily produced with AM. The AM titanium part and a thermoplastic composite plate were then placed into a thermoforming mold. The two components were pressed together in a thermoforming process with an injection molding step immediately after. During this step, the V-shaped thermoplastic composite ribs were overmolded and pressed into the sponge-like gyroid ribs of the titanium fitting.

The joints in this hybrid demonstrator were realized either by material connection (CFRP – CFRP) or form closure (titanium AM – CFRP). In parallel, structural tests for the determination of the mechanical properties of the joints were performed. These tests showed that the load transfer capabilities were similar to those with rivets and bolts.

Advantages of this hybrid design include fast manufacturing and assembly without fasteners, fewer parts necessary, and shorter and more automated process steps for the assembly. This technology can be applied anywhere where loads must be transferred between points and surfaces.

AEROSPACE

Camber morphing wing could increase aircraft range, performance

The U.S. Air Force Research Laboratory (AFRL, Wright-Patterson Air Force Base, Ohio, U.S.) has developed a potentially game-changing camber morphing wing technology that could increase aircraft range and performance.

The AFRL-developed Variable Camber Compliant Wing (VCCW) is capable of changing shape to improve aerodynamic performance and morph itself to various flight conditions and missions. Wing camber, or the shape of a wing surface, is a fundamental element of aerodynamic flight. Conventional wings with discrete hinged control surfaces have greater drag, whereas wings with a smooth camber are efficient and maneuverable. The ability to morph the wing according to aerodynamic conditions would give an aircraft increased lift, when needed, without weight penalty — typically at takeoff and landing — and greater fuel-efficiency and maneuverability in flight.

AFRL reported the successful flight demonstration of the aircraft in December 2019. This flight experiment demonstrated the second iteration of the VCCW, a smaller, more compact version than the first, which was used primarily in wind tunnel experiments. This 8-foot wing was designed to be flown on a commercial, off-the-shelf, remotely controlled aircraft, simulating an unmanned air vehicle. During the series of flights, held in September and October 2019, the wing was flown at low speeds, completing a number of maneuvers and demonstrating active shape control for optimized drag reduction and increased agility.

The VCCW features smooth and continuous skin construction, which not only reduces noise by eliminating sharp surfaces and gaps, but improves aerodynamic performance as well. According to Dr. James Joo, AFRL Advanced Structural Concepts team lead and VCCW program manager, the improved aerodynamics translates into potentially significant fuel savings.

"Early estimates show VCCW technology saving aircraft fuel consumption by 10%," Joo says. "This was one of our main goals, and it fits the Air Force's efforts to reduce overall energy costs."

Joo adds that although other research organizations have explored the morphing camber concept, AFRL's version is unique because it is a true flexible wing without discrete control surfaces to assist in takeoff and landing. This seamless surface can increase range, making it ideal for a variety of long-range platforms. He says the team will continue to refine the concept and look into additional ways it can benefit existing aircraft.

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CARBON FIBER

University researchers to transform coal pitch into carbon fiber

A research project at the University of Kentucky Center for Applied Energy Research (CAER; Lexington, Ky., U.S.) is attempting to transform coal tar pitch into carbon fiber for use in aircraft, automobiles, sporting goods and other high-performance materials. The $1.8 million project includes Department of Energy (DOE) funding and industry and university cost-share.

CAER researchers and partners will convert coal tar — a byproduct from coke production for the steel industry — into mesophase pitch, a liquid crystal, which can then be spun and thermally converted to carbon fiber. If successful, the University of Kentucky claims this new carbon fiber product could increase the value of coal tar pitch by five to 55 times its current value, and be used in high-stiffness, low-weight composite applications such as passenger cars and light duty trucks.

A new DOE grant announced in December 2019 will support development of simplified, multi-filament melt spinning of the produced mesophase pitch into "green" (not yet carbonized) fibers, followed by continuous thermal processing, or oxidization, of those green fibers. The CAER team will then create woven preforms from the fibers for composites manufacture, as well as chopped carbon fiber for filled thermoplastics suitable for injection molding.


Source | University of Kentucky

As part of the project, CAER researchers will be working with industry partners Koppers Inc. (Pittsburgh, Pa., U.S.) and Materials Sciences LLC (Horsham, Pa., U.S.).

"Being able to efficiently upgrade a coal byproduct into high-value carbon fiber for composites would be a terrific benefit to Kentucky's and the nation's manufacturers," says Matt Weisenberger, associate director for materials technologies at CAER and principal investigator on the award. "It would add significantly to the coal value chain."

"We are excited to be at the forefront of developing coal as a valued precursor for products," says Rodney Andrews, CAER director.


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AUTOMOTIVE

Ford to turn McDonald's coffee waste into sustainable autocomposites

Source | Ford Motor Co.

In efforts toward sustainability, some people compost the waste from their morning coffee grounds. McDonald's is turning its coffee waste into automotive composites. Announced in December 2019, Ford Motor Co. (Dearborn, Mich., U.S.) has teamed up with fast-food chain giant McDonald's USA (Chicago, Ill., U.S.) to turn coffee chaff — the dried skin of the coffee bean that peels off naturally during roasting — into commercial vehicle parts such as headlamp housings.

The companies found that chaff can be converted into a durable material reinforcement for vehicle parts. The process involves heating the chaff to high temperatures under low oxygen, combining it with plastic and other additives, and turning it into pellets that can then be molded into parts.

According to Ford, the chaff composite meets quality specifications for parts like headlamp housings and other interior and underhood components. The resulting components are also said to be about 20% lighter and require up to 25% less energy to produce during the molding process. Heat properties of the chaff component are also said to be significantly better than the currently used material.

McDonald's says it will begin directing a significant portion of the coffee chaff produced at its North American locations to Ford for incorporation into vehicle parts.

"McDonald's commitment to innovation was impressive to us and matched our own forward-thinking vision and action for sustainability," says Debbie Mielewski, Ford senior technical leader, sustainability and emerging materials research team. "This has been a priority for Ford for over 20 years, and this is an example of jump starting the closed-loop economy, where different industries work together and exchange materials that otherwise would be side or waste products."

Ian Olson, senior director, global sustainability for McDonald's, adds, "Like McDonald's, Ford is committed to minimizing waste, and we're always looking for innovative ways to further that goal. By finding a way to use coffee chaff as a resource, we are elevating how companies together can increase participation in the closed-loop economy."

Other project partners include Varroc Lighting Systems, which supplies the headlamps, and Competitive Green Technologies, the processor of the coffee chaff.

Source | CW

What:
JEC World 2020

Who:
JEC Group

When:
March 3-5, 2020

Where:
Paris Nord Villepinte Exhibition Centre in Paris, France

JEC World 2020 preview

JEC World 2020, the largest composites-focused trade event, will be held March 3-5 at the Paris Nord Villepinte Exhibition Centre.

By Jeff Sloan / Editor-in-Chief

» The 2020 iteration of JEC World, the largest composites-focused trade show, is coming next month and will be held March 3-5 at the Paris Nord Villepinte Exhibition Centre in Paris, France. Event organizer JEC Group (Paris) says it expects more than 1,400 exhibitors and 45,000 attendees from 112 countries at this year's exhibition.

In addition to the exhibition itself, JEC World also includes several ancillary events and presentations. The JEC Innovation Awards, a staple of the show, are back and feature composite products and technologies focused on specific end markets, including aerospace, automotive, sports and recreation and more.

Also returning, for the fourth year, is the Startup Booster, a startup competition that recognizes innovations that offer significant impact on the industry and promotes them to decision-makers. The finalists will have their innovations showcased at JEC World's Startup Hub.

The Innovation Planets will also be featured again, highlighting some of the latest composite innovations in four display areas, each focused on themes: Mobility, Aero & Space, Construction & Energy, and Sports & LifeStyle.

Among other events is the Composites Challenge, launched in 2018, which recognizes selected Ph.D. students for the quality of their composites research. Each researcher will present themselves and their ideas to an audience.

New this year are 3D printing and bio-based solutions hubs, designed to showcase the latest developments in these two domains from participating companies.

And, this year a dedicated zone will present 50 years of expansion in the composites industry across 15 application sectors. This retrospective is designed to put the potential of composite materials and technologies into a broader perspective.

In the technical conference at JEC World, presentations will focus on:

- eco-design, sustainability and recycling,
- concrete and composites,
- biomimicry,
- carbon fiber,
- artificial intelligence and
- fiber and nano-reinforced materials for additive manufacturing.

The Agora Stage at the exhibition hosts several well-known speakers who will share their vision of the composites market. Featured this year is French "Flying Man" and Flyboard inventor Franky Zapata, founder and CEO of the Zapata Co., who will talk about how innovative materials and engineering concepts can democratize personal air mobility.

Finally, for the second year, JEC Group will present the results of "JEC Observer, an Overview of the Composites Market, 2019-2023," its overview of the broader composites marketplace.

For more information about JEC World 2020, and to register to attend, visit www.jec-world.events. A three-day visitor pass is €55 ($62), although a free pass can often be obtained from exhibitors. There is a separate fee for admission to the technical conference. CW

Part-via-preform

Teijin Carbon Europe GmbH has developed an efficient method for rapidly creating near-net-shape preforms using binder-modified carbon fiber rovings that are subsequently infused and formed using HP-RTM. PvP's first commercial use was on a large mounting bracket used to secure the massive spoiler/wing on Porsche *911 GT3 Cup II* cars.

Source | Porsche AG

CFRP preform technology is fast, flexible, efficient

Porsche racecar is first to sport part-via-preform technology.

By Peggy Malnati / Contributing Writer

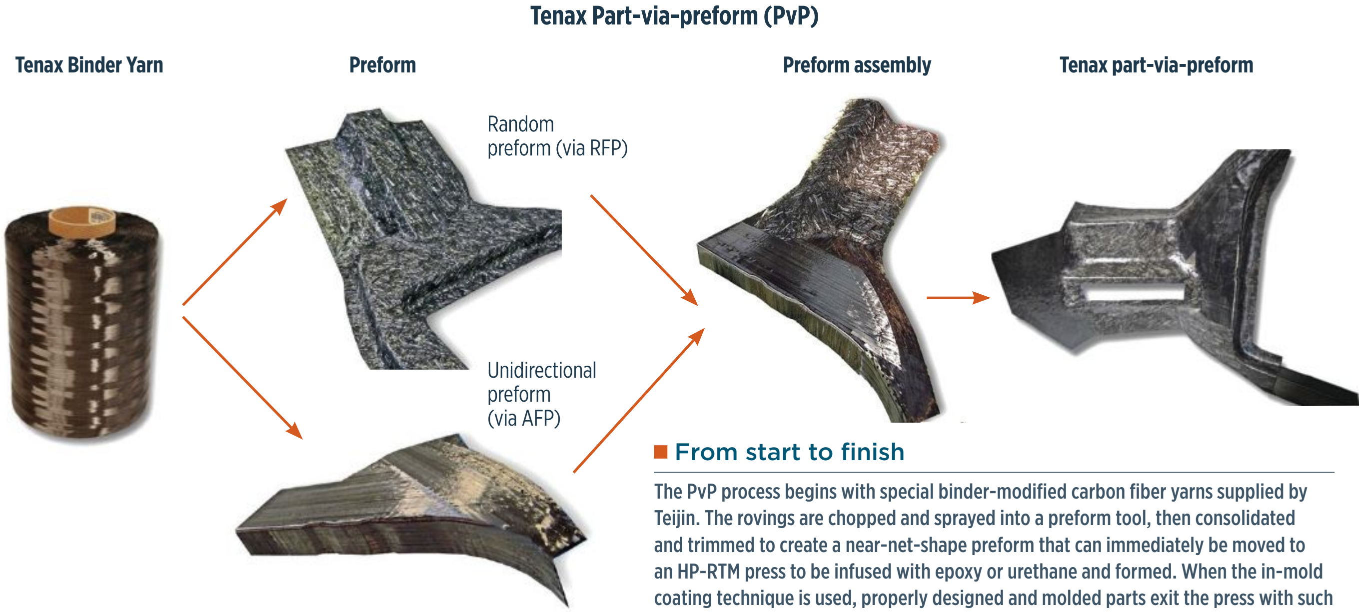
» In the ongoing quest to make carbon fiber composites more affordable and better suited for high-volume automotive production, Teijin Carbon Europe GmbH, a Teijin Group company (Wuppertal, Germany), has developed a process it calls part-via-preform (PvP). Specifically designed to meet the needs of the automotive industry, PvP is a method for rapidly creating near-net-shape preforms using binder-modified carbon fiber rovings. Preforms are subsequently infused with epoxy or polyurethane resins and formed via resin transfer molding (RTM) or high-pressure RTM (HP-RTM). When combined with RTM/HP-RTM, the process is said to optimize material use, reduce waste, offer high levels of design flexibility, use commonly available equipment, produce both structural and aesthetic (automotive Class A) parts and reduce production steps, labor, waste and costs compared to manufacturing with other fabrics or prepregs. Presently, Teijin is only selling finished parts made via the PvP process rather than licensing the technology itself.

Optimized design, material placement

The PvP process was developed to replace more costly and labor-intensive textile-based technologies with bindered carbon fiber rovings (Tenax binder yarns with binder already in place). These rovings are chopped and sprayed into a preforming tool, where they are consolidated and the binder is cured; then the preforms are trimmed to near net shape. Since the preform is dry, it can immediately move to an HP-RTM press for infusion and final forming. Using PvP eliminates steps such as purchasing dry textiles, adding binder, cutting fabrics and curing binders to make preforms prior to infusing and forming. It also eliminates the need to buy, cut, layup and mold prepreg.

The bindered rovings are most commonly chopped and sprayed into a tool using a random fiber placement (RFP) technique, which, compared to the stiffness of continuous fiber fabrics, can be ideal for forming complex 3-D geometries. Because fibers are short and resin flows in the HP-RTM tool, parts achieve fairly high levels of isotropy, particularly with respect to mechanical properties. The process also permits tows of different sizes and performance to be used to meet application requirements. So far, fiber volume fractions (FVF) of up to 50% have been achieved, though Teijin says even higher FVFs may be possible.

Despite the generally random placement of fibers, the process yields fairly homogeneous parts. To test this, Teijin researchers did



From start to finish

The PvP process begins with special binder-modified carbon fiber yarns supplied by Teijin. The rovings are chopped and sprayed into a preform tool, then consolidated and trimmed to create a near-net-shape preform that can immediately be moved to an HP-RTM press to be infused with epoxy or urethane and formed. When the in-mold coating technique is used, properly designed and molded parts exit the press with such good surfaces that they can immediately be painted or clear-coated. Source | Teijin Ltd.

a study of a complex RTM'd part produced from a PvP preform. A total of 55 specimens with 25-millimeter diameters were subsequently punched out across the structure and weighed. Average specimen weight was 537 milligrams with a standard deviation of ±53 milligrams and a 9.8% coefficient of variation.

If a part needs higher mechanical performance in specific locations, an aligned fiber placement technique (AFP) can be used during preform production to add unidirectional reinforcing patches (in the form of tapes, fabrics, or even longer binder yarns) to boost local anisotropy. The PvP process offers versatility in its ability to combine both random and aligned fiber placement, and to achieve complex shapes and local thickness variations while also holding tight tolerances.

Still more design flexibility comes with the RTM/HP-RTM process, which can create complex parts with significant geometry, including ribs, bosses, inserts and through-holes, and can vary thickness across the part while minimizing voids. Using RTM/HP-RTM can create true 3-D parts, compared to the 2-D or 2.5-D panels produced via compression molding.

"PvP is a technology that enables optimized design and material placement — without excess or deficiency," explains Yasunari Hotani, assistant business unit manager, automotive business global supply chain, composites business unit, Teijin Ltd. "That makes it an ideal process for balancing performance with cost. It represents optimized manufacturing of CFRP [carbon fiber-reinforced plastic] components."

Fast, efficient, cost-competitive

With standard epoxy or urethane resin systems, HP-RTM cycle times can run 4-6 minutes, depending on part thickness. If snap-cure resins are used, cycle times are even faster.

Another PvP benefit is that properly designed and molded parts should require no post-mold rework when the in-mold coating process is used. This occurs toward the end of the molding cycle. As the part cures/cools, the tool opens slightly and a liquid coating is injected between the A-side of the part and the tool. The press then recloses and the now-coated part finishes curing/cooling prior to ejection. Parts exit the press with a primed surface that is ready to be painted or clear-coated, significantly reducing post-mold finishing steps. With smaller parts, additional productivity can be gained using family tools with multiple cavities.

Both PvP and RTM/HP-RTM processes can be automated, allowing for scale-up between developmental and higher-volume production needs. The ability to integrate automated inspection equipment reduces the need for quality checks once the design is finalized, and assures the production process is stable.

Unlike alternative textile-based preforms or prepregs, where material waste tends to run high, both PvP and RTM/HP-RTM produce little scrap, contributing to an average 30% cost reduction. Another benefit is that no specialized equipment is required to use the technology, besides a tool mounted in an RTM or HP-RTM press and spray heads and choppers.

One of the disadvantages of PvP is that the resulting parts have a chopped/random fiber look, so they may not match the aesthetic needs of all potential users, although the fibers can be hidden with paint or a layer of real fabric, or a simulated-fabric film could be backfilled in the tool before clear-coating. Another downside is that, for the time being, molders cannot access PvP technology except in the form of finished parts.

"Basically, PvP's business model is as an integrated production process up to [production of] parts," Hotani notes. "However, we can supply the preform technology when it is reasonable both for »

First application

In 2017, Teijin Carbon Europe GmbH produced large mounting brackets that span most of the width of the massive spoiler/wing of Porsche *911 GT3 Cup II* cars. The bracket helps secure the wing to the car and replaced an earlier bracket produced with vacuum-infused carbon fabric that was higher cost and did not provide required stiffness. Source | Teijin Ltd. (left) and SPE Automotive Div. (right)

us and clients, depending on the circumstances." Whether that would involve licensing the process or offering it free as part of a larger materials/services purchase will be decided in the future based on customer interest and other parameters.

First commercial application: Porsche mounting bracket

Initial work on PvP began in 2012 as Teijin evaluated opportunities to expand its carbon fiber business downstream to intermediates (preforms) and part production. In 2014, the company introduced PvP as a highly efficient method to produce CFRP parts. And in 2016, the company announced it had developed an integrated production method by combining PvP with HP-RTM. As work on the technology proceeded, the team looked for customers and applications where the technology could be used.

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The first commercial application came in 2017 with a large mounting bracket (assembly carrier) spanning most of the width of the massive rear spoiler on Porsche *911 GT3 Cup II* cars from Ing. h.c. F. Porsche AG (Stuttgart, Germany). The bracket helps secure the wing to the vehicle. The spoiler provides downforce to improve stability and steering during high-speed driving. These limited-edition, high-performance cars are meant for day racing, but are also street legal, and, therefore, require maximum performance and safety while also minimizing weight.

Previously, the brackets had been produced via vacuum infusion using woven carbon fabrics. However, incumbent parts were both costly and lacked desired stiffness owing to the challenge of getting stiff fabrics to drape into complex 3D geometries. That led to lots of wasted fabric, which further contributed to high costs. Additionally, the infusion process was labor-intensive and slower than HP-RTM.

By applying PvP and HP-RTM technology to the design using a standard automotive-grade epoxy and 50-millimeter chopped carbon fiber (50% FVF), Teijin Carbon Europe produced high-quality parts with excellent load behavior that met all of Porsche's performance requirements, and shipped them from its Heinsberg, Germany, production facility to the automaker's plant. Reportedly, costs were significantly lower owing to automation of the fast PvP/HP-RTM processes with in-mold coating, which reduced both production steps and scrap. Unlike benchmark brackets, no post-mold finishing was needed to achieve a smooth, pin-hole-free surface, so parts could proceed directly to clear-coat painting.

Next steps

Although the Porsche assembly carrier was a short production run part, PvP technology is not restricted to low-volume applications. In fact, Teijin reports that the technology is Industry 4.0 ready and, depending on part size, thickness and preforming time, roughly 50,000 pieces can be produced annually from a single tool set with a 5-minute takt time. Faster-cure resin systems could increase production capacity, as could family tools.

While initial work has focused on epoxy and urethane matrices, other thermoset resin systems are also being explored. It might even be possible for thermoplastics — probably reactively polymerized systems — to eventually be used, although no work has yet been done with such polymers. Teijin also reports that several patents have been granted on the technology. CW

ABOUT THE AUTHOR

Contributing writer Peggy Malnati covers the automotive and infrastructure beats for *CW* and provides communications services for plastics- and composites-industry clients.
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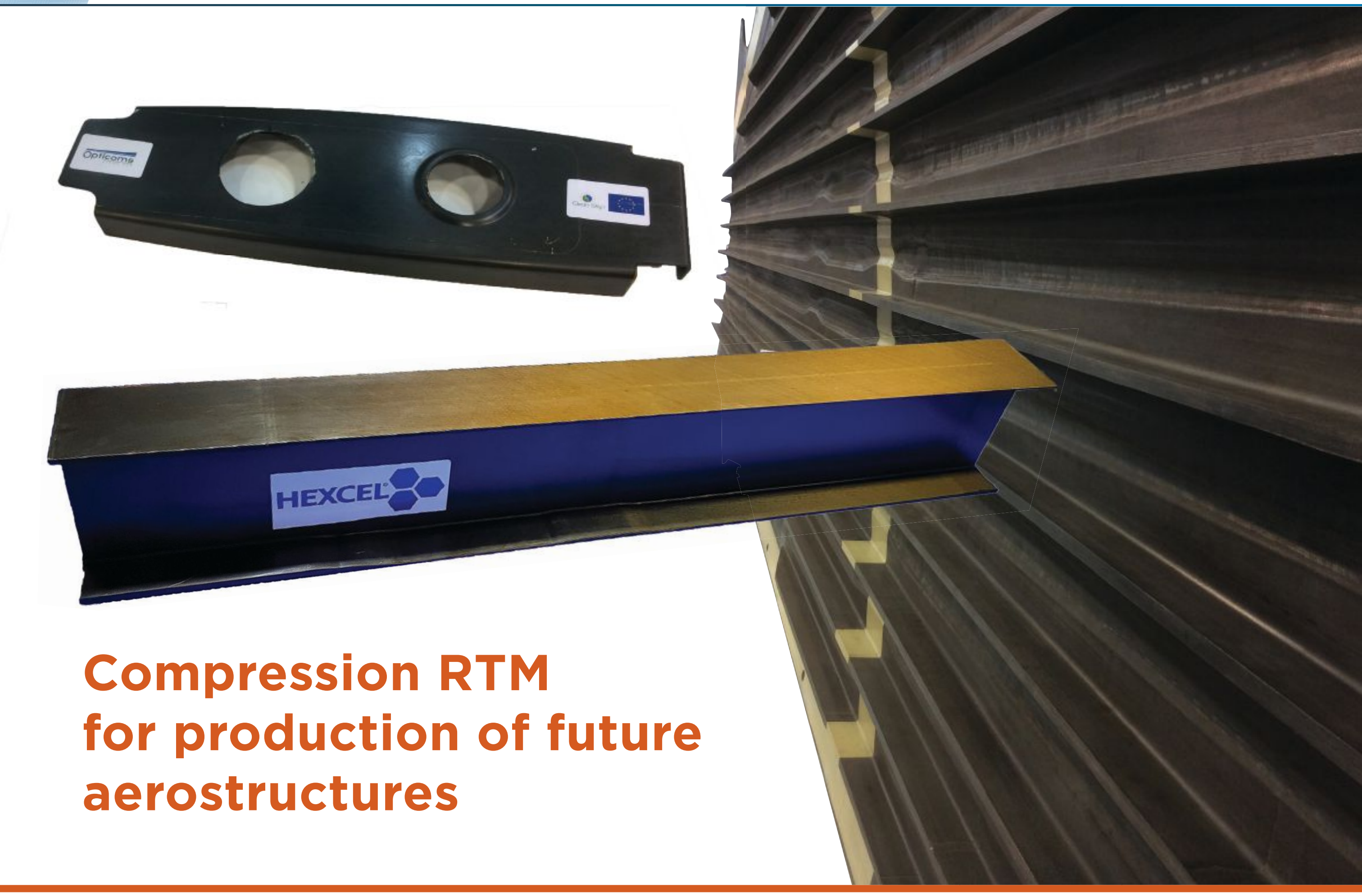


Compression RTM for production of future aerostructures

Automated preforming and 5-minute resin infiltration show a way forward for lower-cost CFRP primary structures.

By Ginger Gardiner / Senior Editor

» Composites have secured a permanent place in commercial airliner airframes because they enable high-strength, lightweight structures that provide lower maintenance costs compared to metal. Current projections for the next generation of both wide- and narrow-body aircraft show continued growth in composite airframes, but only if materials and processes can meet challenging targets for low cost and high production rates. Although autoclave-cured epoxy prepregs have reigned supreme in carbon fiber-reinforced polymer (CFRP) airframes to date, developers of next-generation aircraft are aggressively pursuing out-of-autoclave (OOA) technologies with integrated automation and inline inspection as key enablers for future Industry 4.0 production.

Equipment and automation supplier Techni-Modul Engineering (Coudes, France) and its U.S. subsidiary Composite Alliance Corp. (Dallas, Texas, U.S.) have partnered with the U.K. and French business units of materials supplier Hexcel (Stamford, Conn., U.S.) to demonstrate automated OOA production of CFRP ribs and stringers. The parts are made with automated preforming of Hexcel dry carbon fiber reinforcements and a compression resin transfer molding (C-RTM) process that offers fast infiltration of Hexcel HexFlow RTM6 liquid epoxy resin to produce parts with 60% fiber volume and less than 1% voids in a 4.0- to 4.5-hour cycle that can be scaled to produce multiple parts for high-rate production.

High fiber volume, low-void ribs and stringers

Techni-Modul and Hexcel partnered to demonstrate production of CFRP ribs and stringers using automated preforming and a fast-injection form of resin transfer molding (RTM). The goal is affordable, OOA primary structures like this infused wingskin made by Premium Aerotec using Solvay materials.

Source | Techni-Modul Engineering and *CW*, Ginger Gardiner.

Development of dry reinforcements

"We see liquid composite molding (LCM) as offering an answer to the three-way challenge to reduce cost, be rate ready and provide primary structure performance," explains Rémy Pagnac, Hexcel technical support engineer for liquid composite molding. Hexcel has developed its HiMax noncrimp fabric (NCF) and HiTape unidirectional (UD) carbon fiber materials to address primary structure performance needs when using LCM processes. HiMax enables large, flat structures such as wingskins to be laid up quickly, while HiTape enables tailored layups for large, complex structures with minimal waste. "We can achieve properties equal to latest generation UD prepregs," Pagnac adds.

Hexcel has worked to reduce bulk and improve drapability with HiMax NCF, including a fine, 20 dTex stitch yarn. HiMax materials are made at the previous Formax facility in Leicester, U.K., which Hexcel acquired in 2016. The lightweight, spread-tow multiaxials produced at this facility already had a long history of providing solutions for demanding applications such as racing yachts, supercars and Formula 1 racecars. Now NCF materials have been used in a wing demonstrator project completed by Airbus Defense and Space (Airbus DS, Cadiz, Spain) and Danobat (Elgoibar, Spain) using the latter's Automated Dry Material Placement (ADMP) technology — a type of automated fiber placement (AFP) for NCF (see Learn More) — and in the Airbus-sponsored ZAero project for zero-defect CFRP structures such as stringer-stiffened wingskins (see Learn More). Since 2016, Hexcel Leicester has also been working on HiMax solutions for aerospace applications with majors OEMs.

With both HiMax and HiTape, Hexcel integrates layers of thin, low-areal-weight thermoplastic filament veils that act as a binder, eliminating the need for powder binders historically used in dry materials for preforming and liquid molding. For HiMax, this veil is interleafed between NCF plies; for HiTape, the veil is applied to both sides of the carbon fiber unitape.

"With this, you don't need to use powder binder to hold the UD layers in place," explains Pagnac. "HiTape is calibrated, and is not a slit tape, so there is no fuzz and there is less variation in width for improved AFP processing. The thermoplastic veil also adds toughness to the final laminate, and we have demonstrated that we can achieve high material deposition rates with the next generation of AFP machines." In a May 2015 SAMPE paper (see Learn More), Hexcel describes a single-curvature preform manufactured using 0.25-inch-wide HiTape applied with a laser-equipped Coriolis Composites (Quéven, France) AFP machine at a layup speed of 1 meter per second. It has also worked with Electroimpact (Mukilteo, Wash., U.S.) AFP systems to demonstrate deposition rates of up to 150 kilograms per hour for a full-size spar.

Adapting C-RTM for aerospace

C-RTM was first introduced with high-pressure RTM (HP-RTM) for automotive composites. As with conventional RTM, C-RTM entails placing a dry fiber preform into a matched metal mold, injecting liquid resin into the preform and then applying heat and pressure using an actuated press. In C-RTM, however, the mold is only *partially* closed, leaving a gap between the dry preform and the upper mold surface (Fig. 1). Vacuum is then applied, a precise dose of mixed resin is injected and the press closes the gap in the mold, forcing liquid resin down into the preform in the z-direction across the whole part. "This is much faster than injecting resin through the part," explains Techni-Modul Engineering process engineer Thomas Chevallet.

Techni-Modul Engineering saw an opportunity to adapt C-RTM for aerospace during its role as a partner in the Clean Sky 2 "Optimized Composite Structures" (OPTICOMS) project. Organized within Work Package B-1.2 ("More affordable composite structures"), OPTICOMS aims to reduce small aircraft (e.g., regional jetliner) production costs via integrated structures and automated manufacturing, exploring both prepreg and liquid resin methods. OPTICOMS has designed a composite wing demonstrator comprising an upper wingskin with three spars, produced as an integrated structure in a one-shot process. The full-scale wing (Fig. 2, p. 36) is part of an AIRFRAME Innovative Technology Demonstrator (ITD) for evaluating and maturing technologies toward technology readiness level (TRL) 6 for next-generation aircraft in production from 2025 onward. Israel Aerospace Industries (Lod, Israel) was selected as the coordinator for OPTICOMS »

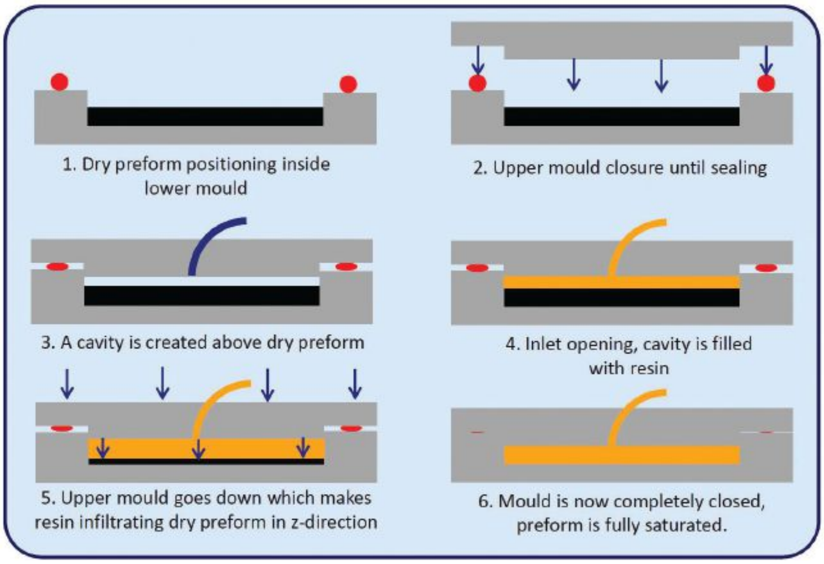
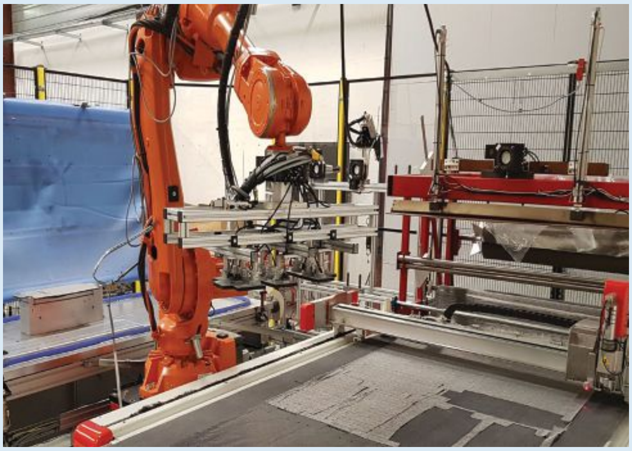
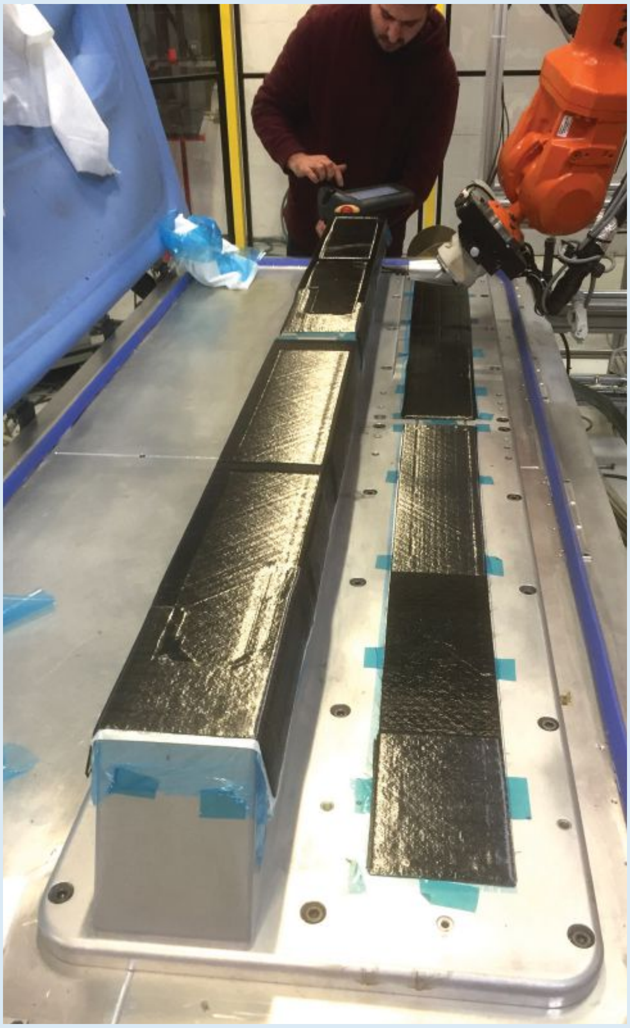


FIG. 1 Compression RTM

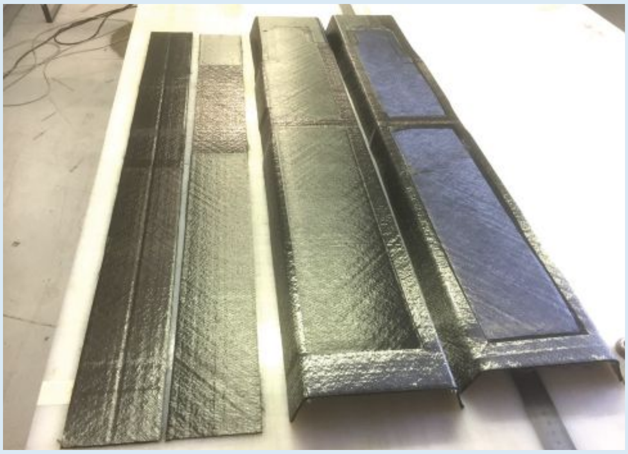
In C-RTM, the dry preform is placed into an RTM mold, but the mold is only partially closed, leaving a gap between the dry preform and the upper mold surface. Vacuum is then applied, resin is injected and the press closes the gap in the mold, pushing the liquid resin down into the preform in the z-direction across the whole part. Source | Hexcel



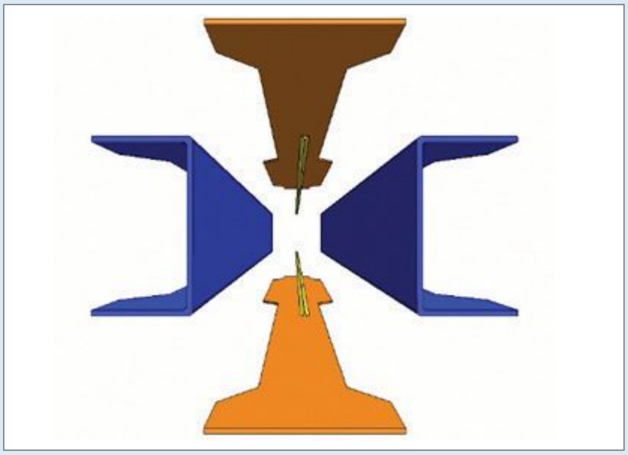
1 Within the Techni-Modul Engineering automated cell, a pick-and-place robot removes plies from an automated cutter and applies them to a heated preforming tool. Source for all step images | Techni-Modul Engineering



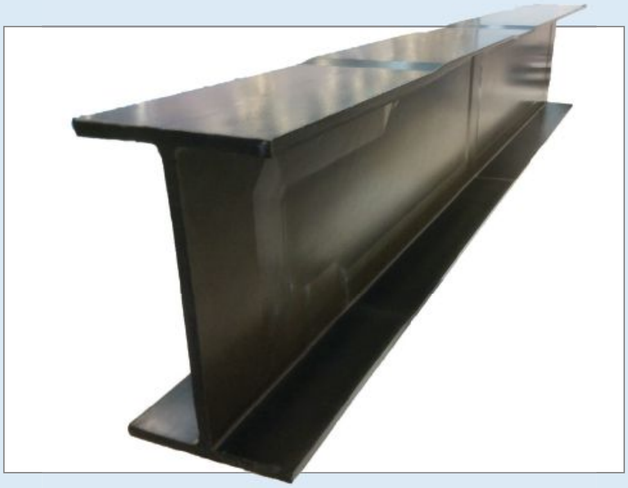
2 The preforming tools sit on a compaction table with a hinged reusable vacuum membrane (blue, at left) used to complete a heated debulk/hot drape forming (HDF) every 5-8 plies during layup.



3 Each stringer preforming cycle produces one C-beam preform (two comprise the I-beam web) and one flat flange preform. Two sets required for each I-beam stringer are shown here.



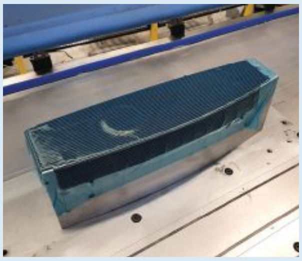
4 The four I-beam stringer preforms are placed into the RTM mold, vacuum is applied and resin injection is completed in 5 minutes



5 After a 90-minute cure, the stringer is demolded and resin flash is trimmed for a complete part cycle of 4.5 hours. Source | *CW*, Ginger Gardiner.

6 Rib preforming

6a A robot places cut plies on the heated preform tool. Every 5-8 plies, a heated debulk is completed to compact the preform.

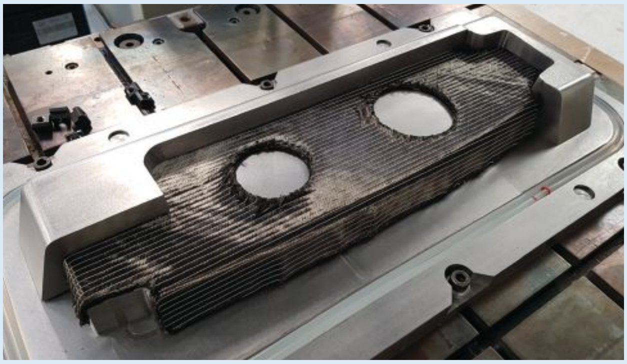


6b Before debulking, blue release film is applied.

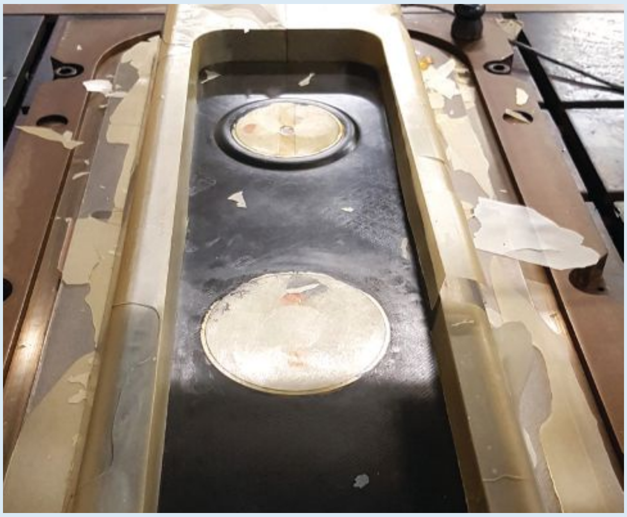
6c Breather is used to extract air across the preform.

6d After final debulk, the preform is cooled on the tool and cutouts are trimmed (bottom image).

7 The RTM tool for the OPTICOMS rib comprises multiple parts



8 The rib preform is placed into the RTM tool.



9 Vacuum is applied, resin is injected and infiltrates the preform, followed by a 90-minute cure. Here, the press has been opened to reveal the cured part.

10 After demolding is completed, resin flash will be removed for a complete part cycle of 4 hours.

»

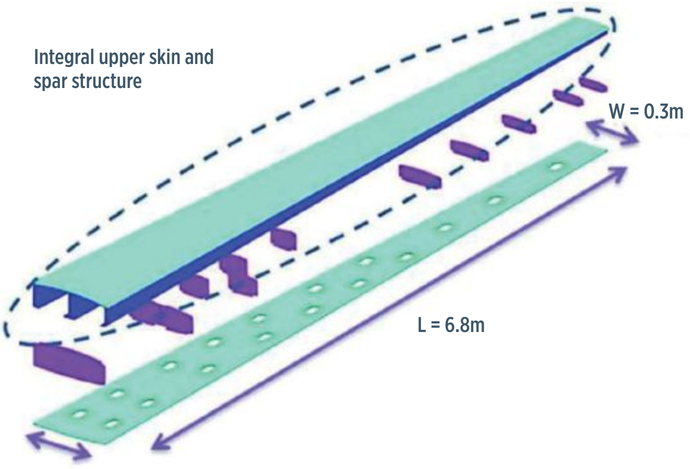


FIG. 2 Clean Sky 2 OPTICOMS rib

Techni-Modul is a partner in the Clean Sky 2 "Optimized Composite Structures" (OPTICOMS) project, which has designed a composite wing demonstrator comprising a lower wingskin, multiple ribs and an upper wingskin with three spars. The latter is produced as an integrated structure in a one-shot process. The demonstrator will be evaluated for next-generation aircraft in production from 2025 onward. Source | Clean Sky 2

in July 2016. The consortium also includes small aircraft OEM Piaggio Aerospace (Savona, Italy), Techni-Modul Engineering and AFP equipment suppliers Coriolis Composites and Danobat.

"C-RTM was well known in the industry," explains Chevallet, "but with HP-RTM, a big press is still needed. Our development was to adapt C-RTM for fast injection using lower pressures, enabling less costly production of aerospace parts with very strict requirements for high fiber volume, fiber alignment and low voids. Injection time for the 0.7-meter long by 0.2-meter wide wing rib in the OPTICOMS project was cut from 40 to five minutes. In a separate test program for an I-beam stringer measuring 900 millimeters long and 150 millimeters high, injection time was shortened from one hour to less than five minutes."

"This reduction in injection time offered by C-RTM would be even greater for large parts such as full wingskins or helicopter rotor blades," Chevallet adds. He notes that C-RTM also allows injection of high-viscosity resins as well as lower-pressure injection systems and lower-tonnage presses, which reduce costs. "The mold pressure during C-RTM is only 6 bar, much lower than what is used in HP-RTM," Chevallet explains. "The process achieves aerospace-quality composites yet works well for large, thin parts and smaller, complex-shaped parts."

> "We are just at the beginning of what we can achieve with C-RTM processing."

Automated preforming

Although faster, lower-cost resin injection and OOA molding are key parts of this approach for more affordable aerocomposites production, the process chain still requires multiple steps for cutting and layup of materials and preforming. "For us, OPTICOMS was also about automation," says Chevallet. Techni-Modul Engineering supplied not only a C-RTM injection system for the OPTICOMS project, but also a pick-and-place robot and a hot drape forming (HDF) machine, all integrated into a fully automated production cell.

Shortly after OPTICOMS commenced in 2016, Techni-Modul Engineering subsidiary CAC won the ACE Equipment and Tooling Innovation Award in the manufacturing category for its automated 3D preforming cell at CAMX 2016 (Anaheim, Calif., U.S.). Able to produce 3D preforms from dry fiber or prepreg, the cell used vacuum suction grippers to pick up, place and fold cut plies onto a heated preform mold. Techni-Modul Engineering and CAC developed software to prepare the cut plies of 2D materials for shaping into complex and developable surfaces. This cell was further developed in OPTICOMS and the I-beam test project.

"We have automated the classic manual stacking of plies using robotic pick and place," says Chevallet. "The robot picks up plies from an automated cutter and transfers these to the heated preform tool which sits on a compaction table [Steps 1 and 6]." A peel ply (blue film in Step 6), breather (white material in Step 6) and hinged reusable vacuum membrane (light blue at left in Steps 2 and 6) are applied, followed by vacuum and heat to preshape and remove air from the textile stack (hot drape forming, HDF) while melting the thin thermoplastic veils to create a compacted preform.

"How many plies you can compact at one time depends on the materials and shape of the part," Chevallet explains. "For parts with low curvature, like a wingskin, then you could possibly compact every 50 plies. The OPTICOMS rib, however, has 90-degree angles, and the test I-beam stringer has T-shapes, so you must be careful not to form wrinkles in the plies during preforming." He adds that such complex shapes may require compaction every 5-8 plies, but can still be part of a high-volume, industrialized process: Stack plies, 2-minute HDF compaction, reopen and stack again, followed by repeated compaction cycles with a final cooling of the preform on the tool before transfer to the RTM mold.

"Our automated cell can place at a rate of 15 seconds per ply," Chevallet notes. "Layup for the OPTICOMS rib, with less than 20 plies total, was completed in 20 minutes." Layup for the I-beam stringer was longer — 45 minutes due to its complex shape and laminate stack, including thickness variations from 1.2 to 6 millimeters. "This is still much faster than manual processes and reduces error risk, increases repeatability and quality while lowering cost," he adds.

Smart control

Another key feature of Techni-Modul Engineering's automated preforming cell is its integrated control system. Referred to as SMART CONTROL, its backbone is a camera system and multi-use software that compares pictures taken during processing to the part's CAD database, enabling preform shape recognition, fiber orientation control, ply positioning and detection of »


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TABLE 1	PART CYCLE TIME	
	Rib	I-Beam Stringer
Layup	20 min	45 min
Preforming	30 min	30 min
Preheat/Injection	40 min	40 min
Ramp/Cure	105 min	105 min
Cooling/Demold	45 min	45 min
Trimming	2-5 min	2-5 min
Total	245 min	270 min

Source | Techni-Modul Engineering

defects and foreign object debris (FOD). The SMART CONTROL feedback instructs the robot how to pick up and place the plies in the correct sequence and timing, but also alerts the cell operator when it detects errors. "The system can be configured so that the operator then manually removes the ply and restarts the system to replace it," Chevallet explains, "or we can work with the customer to create an automated solution for removing defect plies and correcting errors."

The same optical images used to detect ply edges and contours are also used for controlling fiber orientation. Chevallet concedes that if the part is very large (e.g., 2 meters long compared to 200 by 200 millimeters), "you may need a camera taking pictures [from a] higher vertical position to detect the edges of plies, and then move closer to the part for checking fiber orientation. You calibrate this sequence for each type of part. For detecting wrinkles and FOD, there is a database of different defects and you can add to this, so the deep learning algorithm improves over time. The idea is to have a system that is adaptive."

Cycle time and future production

Preforms for the OPTICOMS rib were made using HiMax, and the I-beam stringer used HiTape. The resin system for both was Hexcel's HexFlow RTM6 one-component (1K) liquid epoxy, which has a cure cycle of 90-120 minutes at 180°C. This cure is the longest step in the part cycle times for both the OPTICOMS rib and test I-beam stringer, as can be seen in Table 1.

To date, this has been the only epoxy qualified for RTM of aerospace structures. However, interest is growing in qualifying two-component systems that are mixed at the injection head, offering increased cure cycle flexibility and obviating the need for refrigerated shipping and storage required to prevent premature reaction of the premixed RTM6.

Airbus Helicopters (Donauworth, Germany) worked with Alpex Technologies (Mils, Austria) in the SPARTA project to demonstrate an HP-RTM process using a two-component version of RTM6 to achieve 30-minute cures at 180°C for an A350 door frame, which is a complex-shaped primary structure measuring 2 meters tall, »


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200-250 millimeters wide and 8-10 millimeters thick (see Learn More). Airbus also has demonstrated a 1.5-meter by 0.5-meter CFRP rib made using HP-RTM by its Composite Technology Center (CTC, Stade, Germany) subsidiary, achieving 20-minute molding cycles for parts with 60% fiber volume and less than 2% voids. In the past year, CTC has worked with a number of tier suppliers to transition hand layup prepreg parts to HP-RTM for the A320. However, 2K resin systems must be qualified for aerostructures production, and CTC is concerned about the ability to continuously ensure the mix quality of 2K resin systems in situ. Alpex is using in-mold sensors from Netzsch (Selb, Germany) and Kistler (Winterthur, Switzerland) to help achieve this, and other solutions are being developed (see Learn More).

Even without 2K systems, higher production volumes may be possible. Door frames in the SPARTA project were removed after the initial 30-minute cure at 180°C and post-cured out of the press, under vacuum to remove thermal stress and ensure mechanical properties. According to Alpex's head of R&D Bernhard Rittenschober, this requires extra sets of tools, but only a single press and injection unit. He explains the extra tool cost is offset by lower process and press cost and can be recouped quickly, even with a low volume of 500-1,000 parts/year.

"The main achievement from these demonstrators is the ability to make primary aerostructures with a short resin injection versus conventional aerospace RTM processes, where it has been a difficult, lengthy process to infiltrate resin into such large parts with UD carbon fiber reinforcements," says Pagnac. "We are just at the beginning of what we can achieve with this type of intelligent automated preforming and C-RTM processing," adds Chevallet. "It has the potential to achieve the more cost-effective, sustainable production of stiffener-integrated skin structures being envisioned for future aircraft." CW

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Plant Tour: RUAG Space, Decatur, Alabama, U.S.

■ Launcher systems

Composite payload fairings in various stages of completion at RUAG Space's Decatur, Ala., U.S. facility. *CW* Photo | Scott Francis

OOA composites manufacturing facility comes of age with first U.S.-made parts for the *Atlas V* launcher, and qualification parts for the *Vulcan*.

By Scott Francis / Senior Editor

In 2015, United Launch Alliance (ULA, Centennial, Colo., U.S.) announced a strategic partnership with RUAG Space (Zurich, Switzerland) that would move production of composite structures for the *Atlas V* rocket to the U.S. The move was part of a transition by ULA from the *Delta* and *Atlas* rocket programs toward the next-generation *Vulcan* family of launchers, which will start with the *Vulcan Centaur* as early as 2021. The *Vulcan* program will adapt and evolve technologies of *Delta* and *Atlas,* consolidate the expenses of the two lines and allow for ULA to retire the currently used and Russian-developed RD-1 engine in favor of the BE-4 engine developed by Blue Origin (Kent, Wash., U.S.). The *Vulcan* program will serve satellite launches as well as crewed missions. The first planned *Vulcan* mission is to launch an Astrobotic (Pittsburgh, Pa., U.S.) lunar lander in 2021. A Sierra Nevada Corp. (Sparks, Nev., U.S.) *Dreamchaser* mission is slated for later that year.

As part of its partnership with ULA, RUAG Space set up shop in Decatur, Ala., U.S., in a 130,000-square-foot ULA building that was originally used for the *Delta* program, and began production in 2017. The company stripped nearly everything out of the facility, polished and leveled the floors and installed all new equipment. Parts of the flooring were taken out to put in reinforcements for the 54-ton payload fairing mold that enables RUAG Space's out-of-autoclave (OOA) process. Today, the only recognizable remnant of the old *Delta* building is the repurposed paint booth.

While development and qualification of the *Vulcan* hardware is underway and is a large part of the work happening at the Decatur facility, RUAG Space is also working to produce parts for currently scheduled *Atlas* flights. The Decatur operation delivers carbon fiber composite structures for ULA's *Atlas* launchers, including the payload fairing for the *Atlas V-500* launcher and the interstage adapter for the *Atlas V-400*, as well as carbon fiber structures for qualification of the new *Vulcan* launcher — namely, payload fairings, interstage adapters and heat shields (see Fig.1). While the Decatur plant has been up and running for a few years, the first parts produced at the facility that will appear on missions are just now reaching completion. Until now, RUAG Space parts that appeared on currently used spacecraft came from Switzerland. With *Atlas* parts scheduled for flights in the coming year and with *Vulcan* rocket production on the horizon, the Decatur plant is poised for some exciting days ahead. Plant manager Randy Darling gave *CW* a tour and explained the layout of the facility and function of its equipment.

On the plant floor at various stages of completion were an *Atlas V* payload fairing that will be used on a flight scheduled for October 2020, an *Atlas V* interstage adapter that will be on a solar orbiter mission scheduled for February 2020, and various parts for qualification for the *Vulcan* program, including a heat shield demonstrator and a payload fairing demonstrator that will be used for acoustic testing and vibration frequency identification.

RUAG Space's payload fairings use a sandwich architecture (see Fig. 2) composed of aluminum honeycomb material from Hexcel (Stamford, Conn., U.S.) laid up between an inner and outer face sheet of woven carbon fiber prepreg from Solvay (Alpharetta, Ga., U.S.). A layer of cork applied to the outer face provides thermal protection against the frictional heat generated during launch. Paint on the outside of the payload fairing keeps it from absorbing moisture and reflects the heat of the sun as the rocket sits on the launchpad. The payload fairings comprise two longitudinal halfshells that are mechanically fastened together during launch preparation. *Atlas* fairings measure 5.4 meters in diameter and are available in three lengths: 20.7 meters, 23.4 meters and 26.5 meters. The components for each fairing half shell are consolidated and oven-cured as one single sandwich structure. »

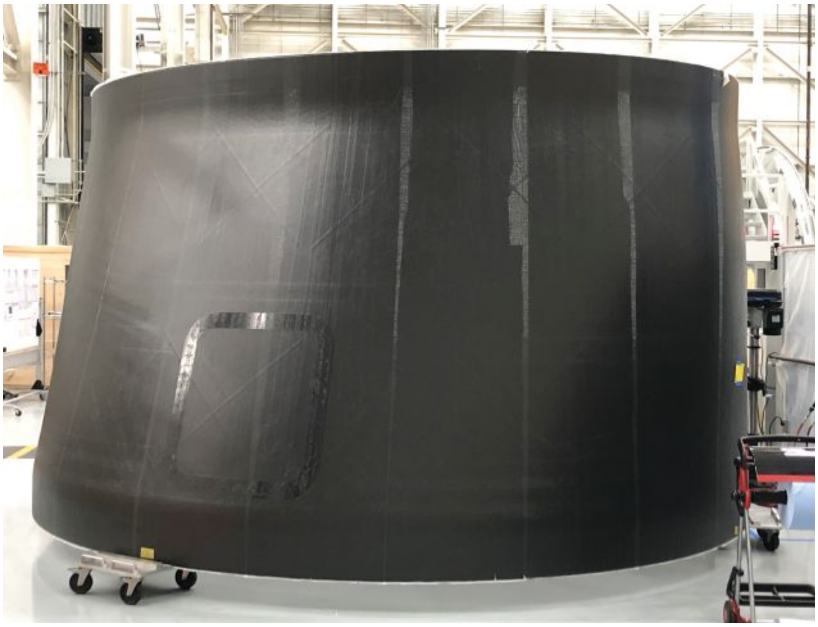


FIG. 1 Heat shield

This heat shield demonstrator for the Vulcan program is made using a similar sandwich construction to the payload fairings. *CW* Photo | Scott Francis

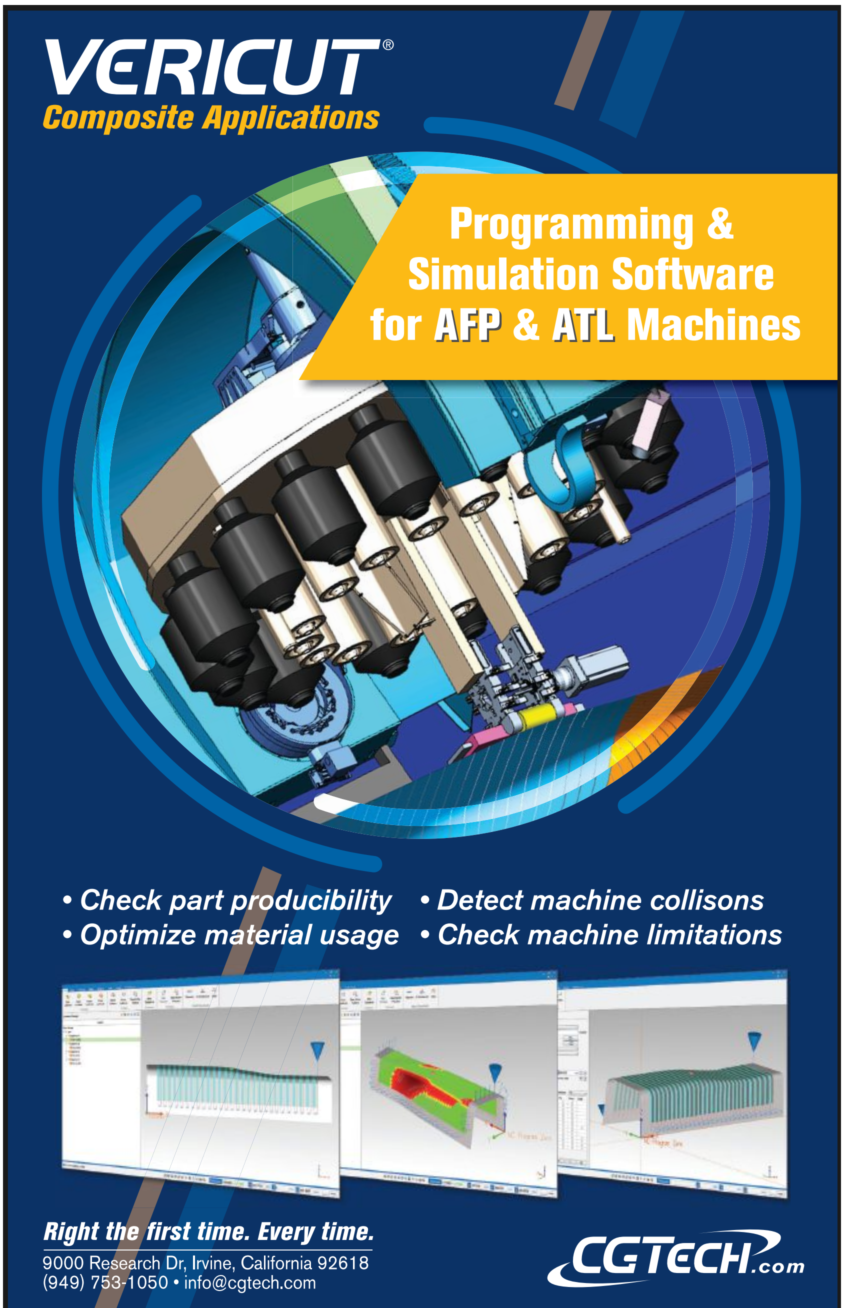
FIG. 2 Sandwich construction

Aluminum honeycomb core is sandwiched between an inner and outer skin of carbon fiber prepreg and then covered with a layer of cork to form the payload fairing. *CW* Photo | Scott Francis

FIG. 3 Material prep and layup

A CNC cutter table is used to cut custom-shaped pieces; a semi-automated layup table is used to layup the large skins for the cylinder section of the payload fairing.

CW Photo | Scott Francis



Material preparation and layup

The first stop on *CW*'s tour is the core expansion table and area for core bending. Here, the aluminum honeycomb core material is cut from compressed blocks, expanded and, using a dedicated tool, is bent into a radius corresponding to the part being fabricated.

Next to the core material preparation area is a CNC cutter (Fig. 3) supplied by Zünd (Altstätten, Switzerland) for cutting individual pieces of material. The cutter has an interchangeable head and can be used for cutting carbon fiber prepreg, aluminum honeycomb core and cork. The machine also marks each piece with a serial number to indicate location in the layup.

After it is cut, all material is then prepared for layup to build the composite structures. Because of the payload fairing's shape — cylindrical with an *ogive* or cone-shaped portion at the end — it is laid up in two portions simultaneously using two molds to improve efficiency (Fig. 4).

Large sections of ply that can exceed 15 meters in length are used for the cylindrical section of the payload fairing and are laid up using an approximately 6-meter by 21-meter CNC-controlled layup table custom-built by Eugen Ostertag Automation (Laichingen, Germany). A semi-automated fabric lay-down machine rides along rails on the edges of the table and rolls out woven prepreg for the inner and outer face sheets. Depending on the design, the table can lay up in straight plies or 45-degree diagonals. Layup on the table is guided by a laser projection system provided by Virtek Vision International (Waterloo, Ontario, Canada). A vacuum-bagged debulk is performed after each ply placement.

"This makes the material adhere to itself and takes the bulk out of it, making it possible to pick it up and drape it over the mold," says Darling.

As Darling explains, one layer is laid out and debulked, and then the process repeats for subsequent layers until the required number of plies is reached. Once layup is complete, a dedicated jig is then used to lift the inner face sheet and drape it over the cylinder section of the main bonding mold (Fig. 6, page 46).

At the same time, the layup of the inner face sheet of the ogive section is performed by hand on the main mold. "The ogive is a complex shape and requires a lot of custom pieces," says Darling. "Laser towers lock into points along the mold and during hand layup of those individual pieces the lasers project the shape and position where each piece needs to go."

Once the ogive portion of the inner face sheet is complete and the cylindrical section is in place on the main mold, the aluminum honeycomb core is laid up over the entire inner face sheet. With the honeycomb in place, another debulking step is performed.

"We do several steps of debulking on the mold to help it retain its shape," says Darling.

As the core material is placed, layup of the outer face sheet of the cylinder section of the payload fairing is performed on the layup table and then draped over the mold as with the inner face sheet. Meanwhile, to save processing time, the outer facing for the ogive is laid up on a secondary mold with another set of lasers projecting the position of the custom pieces. Here, layup of the ogive's entire outer face sheet and cork layer is done simultaneously. A debulking step is performed, and then a dedicated jig is used to transfer the ogive outer facing to the main mold. Finally, a layer of cork is applied to the outer face sheet of the cylindrical section.

Placing the cork is a very manual process, says Darling. To place the material, technicians climb up and down arched, "rainbow" ladders that extend into and over the mold (Fig. 5). Cork is laid by hand sheet by sheet, guided by lasers that project the shape and position for each numbered piece from nearby laser towers.

According to Darling, having the secondary mold as well as simultaneous processing of the different layups for the cylinder and ogive cuts the overall processing time by at least 60% compared to using a single mold, and ensures curing of the sandwich structure before prepreg expiration. With the layup complete, the entire part is ready for vacuum bagging and cure.

In addition to the molds for the payload fairing halves, molds for the *Vulcan* heat »

FIG. 4 Fairing molds

RUAG Space's payload main bonding mold (left) is positioned in the large curing oven. A secondary mold (right) is used for the layup of the outer skin of the ogive section of the payload fairing.

CW Photo | Scott Francis

FIG. 5 Ladders and lasers

Shown here are ladders used to place material on the bonding mold and the laser towers that project the shape and position for each piece. *CW* Photo | Scott Francis

FIG. 6 Main bonding mold

RUAG Space's main bonding mold is shown here inside the curing oven. Thermocouples monitor the temperature of the layup during processing.

CW Photo | Scott Francis

FIG. 7 More molds

Bonding molds for the heatshield (left) and payload attachment fitting (PAF).

CW Photo | Scott Francis

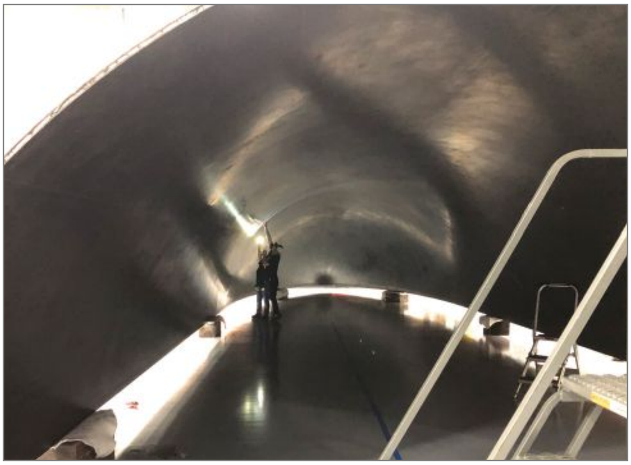


FIG. 8 Visual inspection

Manual inspection is conducted prior to ultrasonic NDI. *CW* Photo | Scott Francis

FIG. 9 NDI

Ultrasonic NDI is then conducted to search for voids and foreign object debris (FOD). *CW* Photo | Scott Francis

shield and payload attachment fitting (PAF) are located nearby (Fig. 7). Material layup for these parts is conducted in a similar manner to the payload fairings. Also nearby is a cork drying oven and an edge cutter for putting chamfers on the cork.

"Coming from the ogive of the rocket there is a chamfer down to the main body," explains Darling. "The top has thicker cork to protect from the heat of the launch, while the main body has a thinner layer of cork."

Out-of-autoclave curing

Once layup is complete, the bonding mold with the payload fairing half shell sandwich construction is moved into the large curing oven supplied by ASC Process Systems (Valencia, Calif., U.S.). The oven floor features a center channel with ductwork that redirects air up into the mold. Heat flows out across the top of the mold and comes down the sides. It returns in the ceiling and is recirculated. Thermal mapping and baffles allow technicians to control the thermodynamics of the mold.

During cure, the oven is monitored for vacuum pressure integrity. Thermocouples monitor the temperature of the face sheet, giving real-time feedback to the oven, which monitors channels against a recipe, allowing operators to make real-time adjustments as needed.

Each air return in the ceiling of the oven represents an independent zone on the mold that the team is able to individually moderate. In addition, multiple parts can be cured simultaneously as long as the recipe is similar, which yields efficiency gains. This also allows RUAG Space to cure test coupons along with the payload fairing. The coupons are subjected to destructive testing including strength, structural, twisting and bending tests, and are cut to verify

FIG. 10 Horizontal integration station

Separation systems are installed and the payload fairing is trimmed using a specialized machine.

CW Photo | Scott Francis

that porosity meets the specification.

After cure, the payload fairing half is moved to the inspection station for nondestructive inspection (NDI). First, however, manual inspection is used to check the inside surface finish, looking for voids, porosity and inclusions (Fig. 8). An ultrasonic NDI is then conducted to search for voids and foreign object debris (FOD) undetected by the visual inspection (Fig. 9). Genesis Systems (Davenport, Iowa, U.S.) supplied the NDI system, which is carried on KUKA (Augsburg, Germany) robots.

Postcure

Once the inspection is complete, the payload fairing half moves to a horizontal integration station (Fig. 10) where a machine executes precision cuts and drills holes, enabling the installation of the payload fairing's separation systems — a horizontal system that separates the fairing from the launch vehicle and the vertical system that jettisons the payload fairing halves enabling deployment of the payload. A saw runs along tracks down each side of the fairing half, trimming its perimeter to final dimensions. A second cutter goes over the radius of the fairing shell and trims the back.

"This has to be precise," says Darling. "We cut and install the separation system on one shell and then we only cut and drill the other shell, and we have to guarantee that two halves will come together. The only way we can do that is with this machine."

The machine is configurable for different lengths, which makes it possible to work on different models of the payload fairing. *Atlas* payload fairings are available in the three aforementioned lengths; *Vulcan* fairings will be available in two lengths, 15.5 meters and 21.3 meters. Interstage adapters can be trimmed using the machine as well.

From here, the payload fairings move to a machining station where cutouts are made manually using diamond-tipped »

FIG. 11 Machining station

A dedicated machine is used to lift and rotate structures, allowing full access to make cutouts. *CW* Photo | Scott Francis

FIG. 12 Vertical integration station

After parts, such as this interstage adapter, are machined and painted, wiring harnesses and mission-specific hardware is added. *CW* Photo | Scott Francis

routers (Fig. 11). The payload fairing is mounted on a movable jig that lowers, lifts and rotates the structure nearly 90 degrees in any direction. A surrounding operator platform allows technicians to stand comfortably with full access to perform cutouts. Mechanical templates and jigs are attached to the side of the fairing, and the cutter follows the path to make the necessary cuts by hand.

According to Darling, cutout configurations on the payload fairings change based on individual missions and payloads. Because of the complexity of payload fairing customization, Darling says it's easier and more efficient for RUAG Space to use hand machining to cut features, such as an access door, rather than develop and program an automated system. "You'd spend all of your time and money programming instead of actually getting work done," he says.

LEARN MORE

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Learn more about RUAG Space's OOA process | short.compositesworld.com/RUAG_OOA

In the final step, completed fairings are painted with a special electrically conductive paint that dissipates static electricity during launch. Once they are machined and painted, parts move to the vertical integration station (Fig. 12), where technicians integrate environmental controls, ducts, tubing, wiring harnesses and mission-specific hardware. After decals are applied, the structures are then deemed complete and ready to go (see Learn More).

As rocket programs continue to evolve, so does RUAG Space's approach to making its composite launcher parts. For example, in the interest of reducing weight and assembly time, the company is beginning to work with hot bonding for some joints on *Vulcan* structures, rather than using a metallic joint with fasteners. RUAG Space is also looking ahead to work on Dynetics' (Huntsville, Ala., U.S.) Universal Stage Adapter (USA) that will join the upper stage of NASA's super heavy-lift Space Launch System (SLS) to the *Orion* crew module, an architecture that will be used for Artemis program missions to the moon. RUAG Space will manufacture the adapter's 8.4-meter-diameter shells — much larger than the 5.4-meter-diameter *Atlas* payload fairing shells the company is currently producing, and made in four sections that will be hot bonded together.

With eight *Atlas V* flights coming this year, and the first launches of the *Vulcan Centaur* and the *SLS* planned for 2021, RUAG Space Decatur is in for some busy and exciting days ahead, indeed. CW

ABOUT THE AUTHOR

Scott Francis, senior editor for *CompositesWorld*, has worked in publishing and media since 2001. He's edited for numerous publications including *Writer's Digest*, *HOW* and *Popular Woodworking*.

Continuous fiber-reinforced thermoplastic composites enable wheel blade for all-electric SUV

Covestro's Maezio continuous fiber-reinforced thermoplastic (CFRTP) composites are being used in the production of a wheel blade for NIO's all-electric SUV.

Spoke-like blade inserts for automotive wheels, also known as wheelblades, have become a popular tool for design engineers looking to boost the aesthetics and aerodynamics of the wheel. While carbon fiber is a popular material choice for these non-structural parts, many designers are looking to showcase the material in different ways besides the traditional woven look that is typically used for exterior components and accent areas. Covestro (Leverkusen, Germany; Shanghai, China) recently announced that its Maezio continuous fiber-reinforced thermoplastic (CFRTP) composites are being used in the production of a composite wheeblade used on the aluminum wheels for the ES6 and ES8 all-electric SUVs manufactured by NIO (Shanghai, China). The material gives OEMs and designers a new alternative to the traditional woven look of carbon fiber, offering a unique appearance with unidirectional carbon fiber optics and a variety of finishing options.

"Designers are looking for new styles to differentiate their applications," says Covestro automotive composites specialist Florian Dorin.

"Maezio composites are a very unique material because they kind of redefine how beauty is associated with carbon fiber," adds Yanbing Wang, NIO's senior CMF designer. "They have set a new aesthetic direction with the unidirectional strands of fibers that feel dynamic and full of energy."

Introduced in October 2018, Maezio includes unidirectional (UD) reinforced tapes and sheets made from carbon fibers impregnated with Covestro's Makrolon polycarbonate (PC) matrix. Maezio UD tapes can be laminated at different angles to form sheets tuned to meet a variety of performance and mechanical criteria. Resulting sheets are strong, stiff, lightweight and have a natural, unidirectional surface finish.

For NIO's wheelblade, Maezio sheets are laid up from plies of UD tape to the required thickness. Screw bosses are overmolded and then welded onto the part. Maezio's thermoplastic matrix system allows it to be easily joined to other functional components during processing. In this particular case, the wheelblade inserts are joined to the spokes via overmolded polycarbonate screw bosses. The use

Matt finish

NIO selected Covestro's Maezio for its wheelblade based on the material's unidirectional aesthetics and aerodynamics. It can be produced with a smooth finish (left image) or matt (right).

Source | Covestro

of the same resin ensures adhesion between the screw boss and the wheelblade.

NIO selected Maezio for its wheelblade primarily based on the material's aesthetic properties and aerodynamics — the blades are a non-structural part designed to reduce wind resistance around the wheels to improve fuel efficiency. However, Dorin also stresses that there were several performance factors that had to be taken into consideration. Wheelblades are subjected to turning forces and high thermal loads created by braking. According to Dorin, Covestro's Makrolon polycarbonate provides good, straightforward adhesion properties and is compatible with a wide range of coatings and decoration processes for designing unique surfaces while still meeting performance requirements.

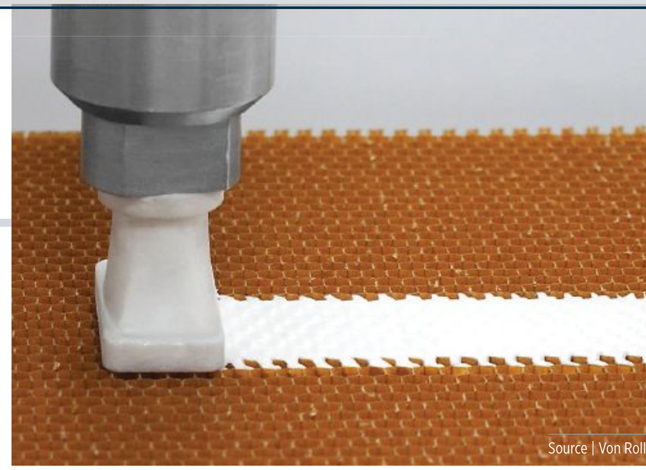
Covestro was unable to name its coating supplier, but a coating system was developed for the wheelblades that not only retains the beauty of the unidirectional fibers but also provides the required protection. The coating system fulfills rigorous safety and performance requirements including impact, chemical and weather resistance. In addition, the polycarbonate also displays high thermal stability qualities, so the wheelblade insert can survive braking-induced temperatures of up to 150°C. The part itself underwent mechanical testing and was subjected to rolling, bending, durability and braking tests. It was also subjected to high-pressure waterjetting, gravel impact, long-term heat-aging tests, temperature and exposure to such chemicals as gasoline, diesel and brake fluid. The material passed all requirements.

Based on the success of NIO's wheelblade, Covestro sees a possible opportunity for use in other aftermarket wheels, and the application gave the company the opportunity to validate the overall performance of the material for other exterior applications such as spoilers. Dorin also noted the material's potential for use in automotive interior applications.

"Particularly on the interior, everyone fights over every millimeter of constructive space," says Dorin. "Significant use of composites to make parts thinner while retaining the stiffness and structural properties and enabling aesthetic surfaces is what we see as a big benefit of our material."

In addition to its aesthetics and durability, Maezio is a potential material enabler for high-volume production. The material can be thermoformed at high yield rates and shorter cycle times to produce millions of parts per year. According to Dorin, cycle times for the material are perhaps slightly longer than typically seen in injection molding, but much faster than processing of epoxy-based materials. Despite numerous technical challenges Covestro and its partners had to overcome, the NIO wheelblade was developed from scratch in only 18 months, and mass production commenced in the third quarter of 2019. CW

New Products


Source | Von Roll

» CORE MATERIALS

Core filler for aircraft interiors promises less weight, lower costs

Von Roll's (Breitenbach, Switzerland) NEXT GEN core filler is designed to maximize local stiffness and increase strength of honeycomb core in composite sandwich panels while saving weight. According to Von Roll's internal testing, NEXT GEN core filler's most important advantages are its long pot and storage life at ambient conditions, and its precise dosability, which the company says makes this product particularly suitable for automated honeycomb potting in aircraft interior applications and other industries.

According to Von Roll, application of filler compounds can be one of the most time-consuming parts of manual sandwich structure construction. The automation of this process can cut production costs by more than 30%, not only by reducing the manual labor hours, but also by reducing material scrap rates while increasing quality and repeatability. The velocity of the robot tool during dispensing of the potting material is limited by the maximum extrusion rate, so a material providing a higher extrusion rate than state-of-art potting resins allows for higher production throughput.

The NEXT GEN core filler can either be dosed and inserted into the honeycomb core manually with a spatula or by using high-precision automation with a robot-based metering system. Von Roll says that pairing NEXT GEN core filler with automated potting can result in up to 20% material savings. The company also claims the filler can lead to cost reductions through higher accuracy and repeatability of the potting, which reduces material waste, manual labor in the manufacturing process and non-conformities.

The core filler promises extremely low viscosity, leading to precise, homogenous and reliable filling for honeycomb cells as small as

3 mm. Von Roll also says the low viscosity results in high extrusion rates when using robots in an automated application process, enabling users to process more material in less time in a faster production process compared to traditional materials. In addition, fillings in circles, angular shapes or honeycomb form are possible for local reinforcements.

Von Roll says its fillers exclude smell- and volatilization-causing anhydrides, halogens and solvents. Unlike other fillers that consist of two components that need to be mixed before use, NEXT GEN core filler comes in a single component ready for use.

The product's density of 0.7 g/cm³ or less is reported to offer significant weight reduction benefits. With standard curing temperatures of between 125 and 150°C (257 and 302°F), the NEXT GEN core filler is said to be compatible with all kinds of curing processes and cycle times of common prepregs for the aircraft interior industry. Furthermore, it is reportedly easy to handle and can be stored for up to 5 weeks at room temperature, even in contact with humidity. In addition, the core filler's expansion coefficient is near zero under the influence of heat or load.

In addition, NEXT GEN core filler is compatible with phenolics and epoxies. For example, it is compatible with a new class of Von Roll's FST-compliant prepregs belonging to the EP200 family, which are said to provide the highest mechanical properties and surfacing quality on standard honeycomb cores and can be processed together with the core filler on any kind of honeycomb support.

Two variants of the NEXT GEN core filler are currently available: EP401 and EP411, to offer to the market solutions which are compatible with or without the use of a dedicated press. vonroll.com

» TESTING, MEASUREMENT & INSPECTION SYSTEMS

Flaw detector includes new features to improve inspection workflow

Source | Olympus

Olympus's (Waltham, Mass., U.S.) OmniScan X3 flaw detector collects total focusing method (TFM) images through full matrix capture (FMC) for faster, more efficient job setup and increased decision-making confidence. When an inspection is complete, the detector's software tools simplify analysis and reporting.

The OmniScan X3 is designed for use with composites, pressure vessels, welds or pipes. It combines the tools needed for phased array ultrasonic testing (PAUT) inspections, such as time-of-flight diffraction ultrasonics (TOFD), two ultrasonic (UT) channels, eight groups and 16:64PR, 16:128PR and 32:128PR configurations (the 16:64PR configuration limits the number of groups to 1 TOFD, 2 PA and 2 TFM), with innovations that include:

- TFM/FMC with 64-element aperture support, improved phased array imaging, including a live TFM envelope feature,
- acoustic influence map (AIM) simulator for TFM mode,
- 25 GB file size,

- up to 1,024 by 1,024-pixel TFM reconstruction and four simultaneous, live TFM propagation modes,
- simplified user interface with onboard scan plan, and
- wireless connectivity to the Olympus Scientific Cloud (OSC) to keep the instrument's software up to date.

The comprehensive onboard scan plan tool is said to enable users to visualize the inspection, helping reduce the risk of errors. The entire scan plan, including the TFM zone, can be created in one simple workflow. Creating a setup is also faster with improved calibration tools and support for simultaneous probe and beam set configuration, onboard dual linear, matrix and dual matrix array creation and automatic wedge verification.

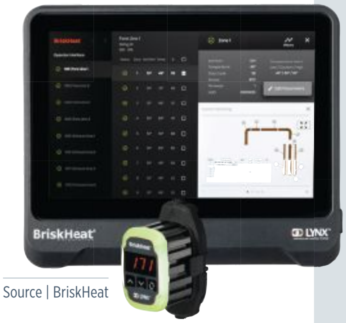
Certified IP65 dustproof and water-resistant, the instrument is said to be reliable, easy to use and produces high-quality images that help simplify interpreting flaws. With the total focusing method, users can produce geometrically correct images to confirm the characterization of flaws identified through conventional phased array techniques and obtain better images throughout the volume of a part. Additional features include a 16-bit A-scan, interpolation and smoothing and a vivid 10.6-inch WXGA display that provides clarity and visibility in any light.

The OmniScan X3 flaw detector makes analysis and reporting faster, both onboard the instrument and on a PC. The instrument also comes with a variety of data interpretation tools such as circumferential outside diameter (COD) TFM image reconstruction to facilitate interpretation and sizing of long seam weld indication, and a merged B-scan to facilitate the screening of phased array weld indications while simplifying workflow.

olympus-ims.com

» TEMPERATURE CONTROL

Temperature control system enables individual heater control



Source | BriskHeat

BriskHeat's (Columbus, Ohio, U.S.) LYNX Temperature Control System is a modular PID temperature control system that controls up to 1,024 zones and is designed for use with composites curing and other applications.

Each heater can be individually controlled and monitored using the LYNX system, ensuring that users know each unit's performance status, which is indicated through a large full-color touchscreen interface, indicator lights, remote monitoring and email alerts.

The LYNX Operator Interface controls up to eight lines of connected temperature control modules with up to 128 modules per line, up to 1,024 heaters, with user-configurable graphical mapping and naming to match the customer's application and facility. It features global and individual programming with the menu-driven interface.

The compact temperature control module can be used as a free-standing unit for use with any of BriskHeat's heaters up to 7 amps. It features three-button programming and a highly visible status indicator light, and can communicate to other systems using Modbus. briskheat.com

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Composites enable novel flying speedboat

Candela Boats' *Seven* speedboat combines all-electric propulsion with precision foiling in a design made possible by creative composites engineering.

By Jeff Sloan / Editor-in-Chief

The global electrification of transportation is an uneven evolution, simultaneously enabled and hindered by the myriad forces that govern technology development and affect everything from automobiles and unmanned aircraft to rail transport and marine craft. These enabling/hindering forces include fast-maturing but heavy batteries, government oversight that is sometimes slow to adapt, principles of gravity and friction, strict passenger safety requirements, anxious insurers and uneven development of lightweight materials.

Still, materials, processing, hardware and software innovations are making possible products that just a few years ago were inconceivable, and there may be no better example of this than the *Seven*, a new all-electric, high-range, all-composite foiling speedboat being manufactured by Candela Boats (Lidingö, Sweden) using resin matrix solutions provided by Sicomin Epoxy Systems (Châteauneuf les Martigues, France).

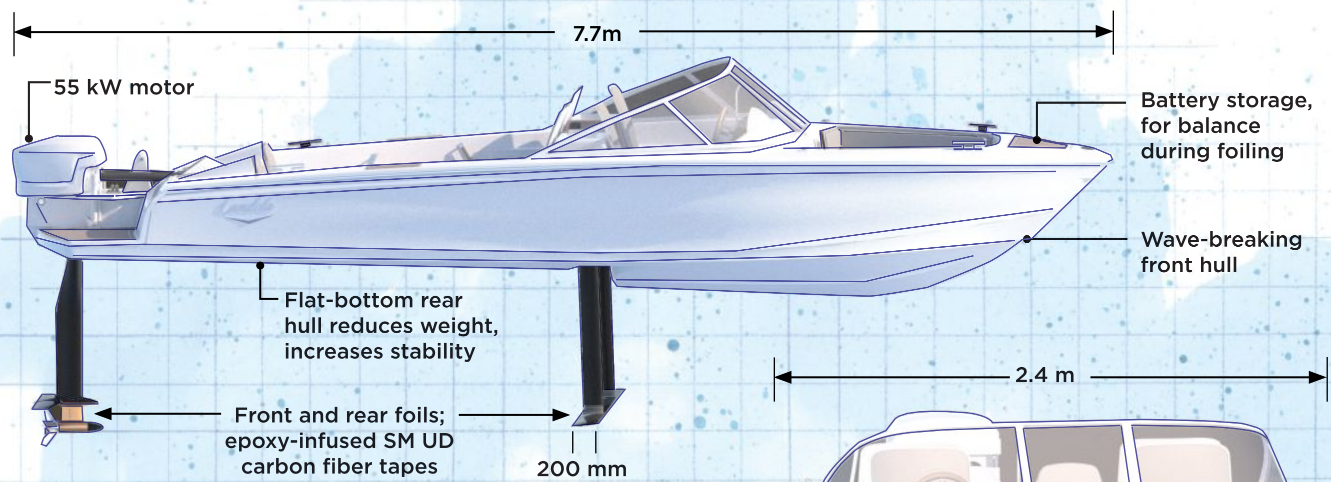
How we got here

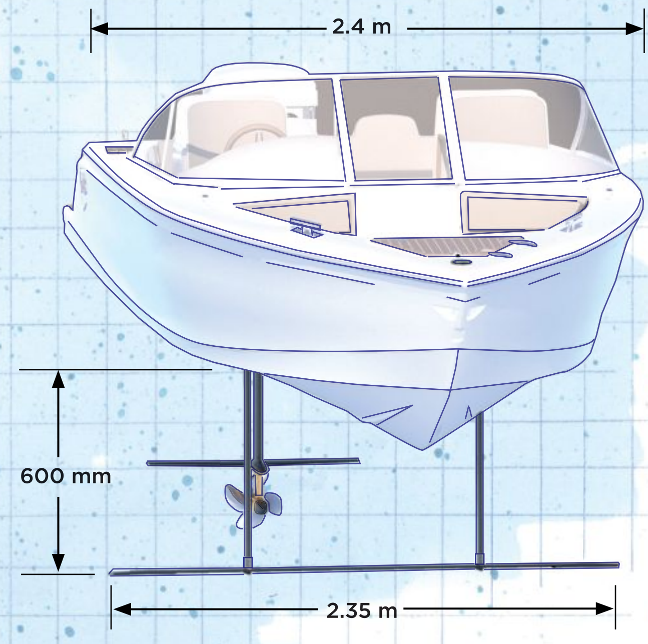
Candela Boats was founded in 2014 by CEO Gustav Hasselskog, who, although an engineer by education, had worked previously as a consultant in the consumer chemicals market. By his own admission, Hasselskog "had become bored" with the corporate environment and decided that he wanted to find more meaningful work. He quit his job in 2014 and during that summer retreated with his family to a home located on one of the archipelagos that surround Stockholm, Sweden.

"We had a 25-foot boat with a V-8 engine," Hasselskog recalls, adding that going anywhere and getting anything required a boat trip to Stockholm, which cost at least $50. "It felt a bit weird, to be spending so much money on a boat," he says. Reverting to his engineering heritage, Hasselskog did some math, wondering what it would take to make recreational boating more efficient. "What I discovered," he says, "is that the topic has not been addressed to make boats more efficient *and* make them electric."

A foiling boat to maximize efficiency

Candela Boats CEO Gustav Hasselskog drives the *Seven* in foiling mode. The all-electric boat cruises at 22 knots, has a top speed of 30 knots and a range of 50 nautical miles. Hasselskog was looking to develop a boat that offers the maneuverability of a planing boat while taking full advantage of an electric propulsion system. The *Seven* is 4-5 times more fuel-efficient than a comparable gas-powered planing boat. Source | Candela Boats





DESIGN RESULTS

All-electric foiling speedboat

- Unprecedented, highly efficient, highly stable deepwater foiling in a six-passenger speedboat.
- Cruising speed of 22 knots, maximum speed of 30 knots and a range of 50 miles per charge.
- Reduced carbon footprint via fuel-efficiency 4-5 times better than onventional gas-powered planing boats.

Susan Kraus / Illustration

Hasselskog began studying the recreational marine market further. He studied battery and electric propulsion technology, figuring out what would be required to give a planing boat a range of at least 50 nautical miles — a goal he thought reasonable. Until now, application of all-electric propulsion in planing watercraft has been plagued by lack of power and lack of range, primarily because of the water surface friction a boat must overcome. Further, to increase range or power in a planing boat requires the addition of batteries, which also adds weight and, by extension, drag. In short, Hasselskog discovered, it wasn't possible to make a planing boat more efficient. "A planing boat is a dead end. You can't make it more efficient," he says. "Foiling is the only way." So, Hasselskog sold the family's summer home on the archipelago, and in 2014 Candela Boats was born.

Foiling is not for the faint of heart

The primary challenge of foiling lies in the inherent instability of a boat moving through and over water, but not *on* the surface of the water. A foil — or, more accurately, a hydrofoil — is a wing-like structure attached to the bottom of a boat hull. The foil passes through the water perpendicular to the direction of travel and, using the same principles of aircraft flight, at a certain speed provides enough lift to elevate the boat completely clear of the water. Hull friction is eliminated, leaving foil drag and air as the only resistors.

Foils can take a variety of shapes, but in all cases they must provide a flat planar surface that passes through the water edge-first. And, like an aircraft wing, a foil's angle of attack in the water can be adjusted to increase or decrease lift. Foils also can be deployed at a variety of water depths, but depth does affect stability and efficiency. For example, shallow, surface-piercing-only foiling is more stable, but less efficient. Deeper foiling is more efficient but less stable.

In any case, "flying" over water presents a very different hydrodynamic environment compared to that faced by a planing boat on the water's surface. Out of the water and riding on foils, a boat behaves differently — weight distribution, turning, wind resistance and turbulent waters must be carefully managed.

Foiling technology, although more than 100 years old, until now has been used primarily in large racing yachts and some passenger ferries. Foiling racing yachts are typically manned by large crews well-trained to manage a dynamic, fast-moving, deep foiling structure. Foiling ferries rely on more stable surface-piercing foiling. »

■ **Making foiling safer**

Foiling is inherently unstable because of the complex hydrodynamics involved. Candela Boats developed a sophisticated system of sensors and controls to manipulate the foils and ensure a smooth, safe ride. Source | Candela Boats

■ **Struts and foils**

When the *Seven* is not in foiling mode, the two 1.6-meter orange struts that connect to and actuate the foil pull it flush to the hull. The white and orange foil is visible here just below the hull and just above water level. Source | Candela Boats

Hasselskog decided to make his speedboat as efficient as possible and so opted for deep foils. The challenge would be to make a deep-foiling boat operate easily, seamlessly and safely, regardless of who is at the wheel. Doing so would require development of an unprecedented foiling control system, and a boat structure that is not only lightweight, but designed specifically for foiling.

Building the perfect foil

The *Seven* is 7.7 meters long, 2.4 meters wide, weighs 1,300 kilograms and has a capacity of six people. It uses two foils, the largest of which is deployed about 2 meters from the front of the boat. The design of the primary foil is relatively simple: Two 1.6-meter struts pass through the hull into the water and attach at right angles to a foil that is 2.35 meters long, 200 millimeters wide and 25 millimeters thick. The foil — also called an inverted ∏-foil (pi) — is oriented perpendicular to the direction of travel. The foil struts are motor-actuated to move up and down to lower and raise the foil. When the boat is not foiling, the foil is fully retracted flush with the boat hull. At foiling speeds, the foil is deployed into the water to a typical depth of 600 millimeters.

At the rear of the boat is a second, smaller T foil that also acts as the rudder. It is attached to a 55-kilowatt electric motor that actuates a driveshaft in the rudder that turns a propeller at the end of the rudder. The motor is powered by rechargeable batteries, located in the very forward section of the hull, to provide balance when the boat is foiling. The *Seven* begins foiling at 14-15 knots, cruises at 22 knots, has a maximum speed of 30 knots and a range of 50 nautical miles.

Teodor Hällestrand, product manager at Candela Boats, says the foil struts and foils are carbon fiber/epoxy composites and posed a significant design engineering challenge. To provide the control required for a smooth ride, Candela needed to be able to adjust the foil to changing boat conditions. This requires a highly dynamic sensor/control system paired with a highly responsive foil. "The foil is straight, but we wanted to be able to twist it in the water, depending on speed, roll angle, pitch angle and yaw angle," Hällestrand says. "We can understand how the boat is positioned and then adjust for orientation to make the ride as smooth as possible." This is accomplished by the control system, which dynamically manipulates the struts to either change the angle of attack of the foil or to twist the foil, particularly for turning.

Hasselskog says, "We need to be able to twist the front foil or provide a different angle of attack." All of these actions happen under load, he says, "so we need a material with low torsional stiffness, but with high bending stiffness." The result is a "fairly elaborate layup plan" that uses unidirectional (UD) carbon fiber tapes (mainly ±45 degrees) to provide the stiffness and bending capabilities required. The foil uses standard modulus carbon fiber from a variety of suppliers and infused with SR1710 epoxy resin supplied by Sicomin Epoxy Systems. The foil is room-temperature cured, followed by a 40°C post-cure.

Not your average hull

Nowhere is *Seven*'s departure from planing boat design standards more apparent than in the hull — both in design and engineering. Most noticeable is the fact that although it features a standard

Built like an airplane

The interior of *Seven*'s hull shows the stringers and ribs that are cut from carbon fiber/epoxy composite laminates and then bonded into place with adhesive and mechanical fasteners. This architecture allows Candela Boats to quickly assemble hulls and provides flexibility to adapt to design changes. Source | Candela Boats

Balancing act

The battery pack of the *Seven* is located in the forward section of the hull, to provide much-needed balance when the boat is in foiling mode.

Source | Candela Boats

V-shaped, wave-breaking hull at the front of the boat, the hull is flat from the front foils to the aft. Hasselskog points to several reasons for this. First, he says, we "only need the V shape to pierce the waves." It also protects the foils when the boat is not foiling. Second, flattening half the hull simplifies manufacturing and saves much weight. Third, he says, the flat bottom makes the boat incredibly stable at the dock for embarking/disembarking. "It's like a barge," he notes.

Inside the hull, however, is where Candela has worked to make the *Seven* not only structurally sound, but adaptable to efficient, relatively high-rate manufacturing. Hällestrand says the hull is comparable in design to an aircraft fuselage — a skin surrounding a lattice of stringers and ribs. Like the foil, the hull is infused, using the same UD carbon fiber and SR1710 epoxy, fabricated on composite tooling also made with SR1710. Hull thickness below the waterline is 3 millimeters; hull thickness above the waterline is 2 millimeters.

Marc Denjean, export manager at Sicomin, says the SR1710 is a performance epoxy system that provides "way above average mechanical properties." Sicomin also provides an in-mold epoxy high-build primer, which facilitates demolding for painting.

To build the stringers and ribs, Candela starts with solid laminate carbon fiber/epoxy infused panels (3 meters long, 2 meters wide and 3 millimeters thick) that are waterjet cut to shape, depending on where in the hull the laminate is being placed. To build the hull structure — stringers and ribs — these cut shapes are then assembled by Candela and attached to each other and the hull with adhesives and mechanical fasteners.

This laminate cut-and-assemble design/manufacturing process, Hasselskog says, has proved highly efficient and allows Candela Boats to build the hull structure in just 40 hours. It also allows the company to easily adjust internal structures to design changes without the expense and time required to modify molds. "It's easy to scale up, make changes or build new structure just by changing machining code," he says.

The bottom line

In keeping with Hasselskog's original vision, the efficiency of the *Seven* is difficult to beat — it is 4-5 times more energy-efficient than a comparable gas-powered planing boat and converts 90% of its chemical energy to mechanical energy. Further, the cost of ownership of the *Seven*, according to Candela, is 95% less than a gas-powered planing boat.

The company has 190 orders for the *Seven*, and it expects to assemble 40 boats in 2020. Currently, Candela is a boat designer and assembler only. Although fabrication of composite structures is being done by third parties, Hasselskog says Candela may bring that work in-house as it seeks to optimize manufacturing processes and reduce the company's carbon footprint. "We have to get our costs down, and that means manufacturing more efficiently," Hasselskog says. "We're not there yet, but we are headed in the right direction." CW

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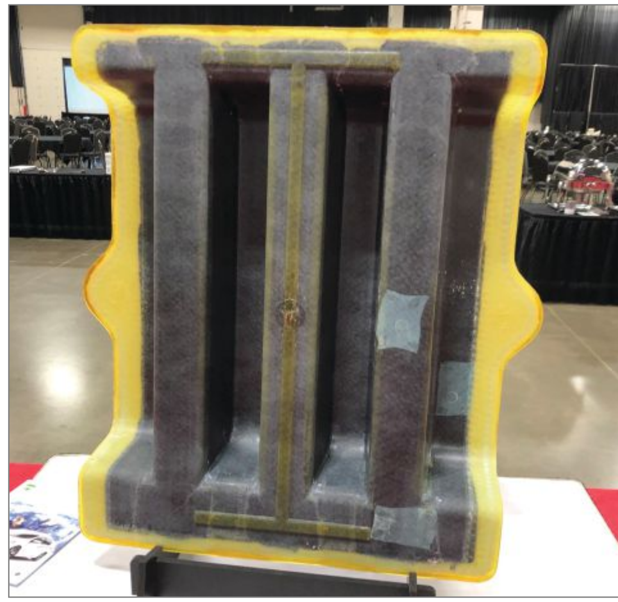

Automotive floor reinforcement

Taken at the 2019 Society of Plastics Engineers (SPE, Bethel, Conn., U.S.) Automotive Composites Conference & Expo (ACCE), this carbon fiber composite floor reinforcement structure – manufactured by General Motors (GM, Detroit, Mich., U.S.) and Continental Structural Plastics (CSP, Auburn Hills, Mich., U.S.) in a Department of Energy (DOE, Washington, D.C., U.S.) funded project led by GM – features a hybridization of carbon and glass in a single preform using Coats' (Stockley Park, Uxbridge, U.K.) Lattice technology. The part was produced via high-pressure resin transfer molding (HP-RTM) using rapid-cure resins from Hexion (Columbus, Ohio, U.S.). *CW* photo | Scott Francis


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