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Composites 4.0: DIGITAL TRANSFORMATION OF COMPOSITES

JULY 2020

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COLUMNS

DEPARTMENTS

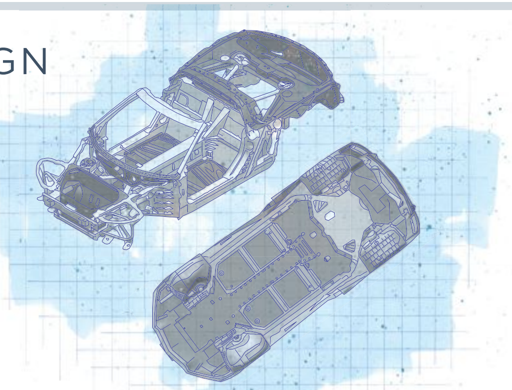
FEATURES

ON THE COVER

The German Aerospace Center (DLR) developed a flexible, AI-driven automation platform for its work cell to build families of CFRP aerostructures like rear pressure bulkheads and fuselage panels using collaborative robots. The robots are not taught, but instead define their own collision-free pathways. Pictured are DLR Augsburg cooperation robots. See p. 30.

Source / DLR Institute of Structures and Designs

FOCUS ON DESIGN



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In 1984, when the first *Terminator* movie came out — featuring Arnold Schwarzenegger as the time-traveling, man/machine assassin — I was a 17-year-old junior in high school and clearly in the movie's target demographic. Sure enough, I eagerly stood in a long line with several friends at the movie theater the night the movie premiered. And loved it.

If you have not seen *Terminator*, a quick synopsis: In 2029, computer and machine technology has evolved to outpace and outsmart humans. The machines build weapons to defeat humans and a human-vs.-machines civil war breaks out. The humans are, predictably, losing, but their leader, John Connor, is deemed so threatening that the machines decide it would be best if John did not exist at all. So, the machines fabricate a human-looking android, a "terminator" (Schwarzenegger), to time-travel back to 1984 to assassinate John's mother, Sarah, before she can give birth to John. After that, things get complicated in ways you can easily imagine, spawning a variety of sequels along the way.

> What, then, do we make of the threat of machine learning?

I remember thinking a couple of things after I saw *Terminator*. First — setting aside the civil war/time travel premise of the movie — although 2029 seems like a long way away, is it even possible that technology might, over the next 45 years, evolve such that machines could learn and become self-aware and intentional? Second, it seemed to me that learning machines might just as likely be put to use for positive purposes.

Fast-forward to 2020 and, suddenly, 2029 is close enough on the time horizon that we can start to imagine with greater fidelity how technology might evolve. Further, today artificial intelligence (AI), machine learning and evolving algorithms are employed in myriad ways — good and bad, seen and unseen — in manufacturing, healthcare, entertainment, policing, social networking, defense systems and hundreds of other applications. In short, machine learning is here.

What, then, do we make of the *threat* of machine learning? In 2018, the Pew Research Center published results for a survey ("Artificial Intelligence and the Future of Humans") of 979 technology thought leaders, asking for their assessment of the benefits and threats of algorithm-driven AI. Conveniently and ironically, the survey asked respondents to consider a timeline extending to 2030, just past the *Terminator* moment. AI concerns identified by the survey do not mention a man vs. machine war, but they do include loss of human agency, data abuse, job loss, cognition erosion and mayhem (cybercrime, weaponized drones).

In composites manufacturing, it's mostly upsides. The growth of algorithm-driven AI systems has birthed Industry 4.0 hardware and software, designed to help fabricators manage orders, materials, processes and delivery. It also provides fabricators unprecedented amounts of data about machine operations, process efficiency, product quality, design compliance and much more.

This thread — applied machine learning — runs through three stories in this issue of *CW*. The first, by senior editor Ginger Gardiner, on p. 30, focuses exclusively on the technologies being developed for what we call Composites 4.0. As Ginger says, "An evolving landscape of automation, sensors and AI software is not an end, but a means to achieve the cost, quality, efficiency and agility required for future manufacturing."

On p. 16, you will find my report on Spirit AeroSystems' new RTM production line in Prestwick, Scotland, that will manufacture wing spoilers for the Airbus A320. The focus here is process, but the line is very much enabled by automation and software that governs not just the machines, but the actions of the operators, creating an audit-compliant digital thread for each spoiler Spirit manufactures.

On p. 26, you will find my story on narrow-tapes ATL technology developed by Fives Lund LLC. While there is much discussion of tape width, a major enabler here is the use of process control technology linked to design allowables for the part, which allows the ATL to strategically and automatically deploy laps and gaps.

All of this is to say that an algorithm-driven, data-driven, machine-smart composites world is not a future notion. It's a here-and-now and necessary notion. And, properly and thoughtfully employed, it can do a lot of good.

JEFF SLOAN — Editor-In-Chief

Boron fiber: The original high-performance fiber

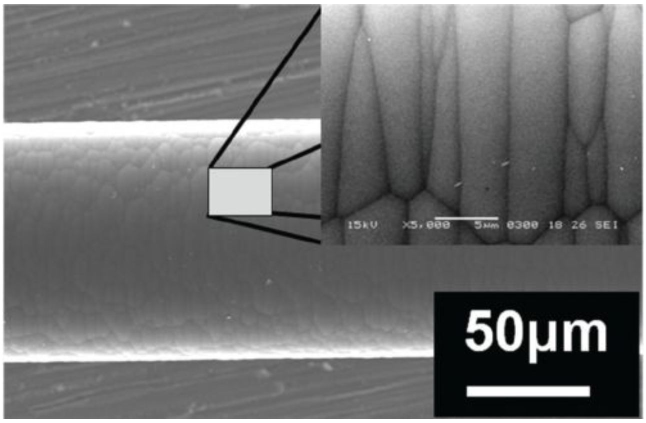

FIG. 1 CVD boron fiber

Surface morphology of CVD boron fiber showing surface roughness. Source | Profactor

» In January 1969, Grumman Aerospace Corp. (now Northrop Grumman, Falls Church, Va., U.S.) was awarded the Navy contract for the F-14 *Tomcat* fighter aircraft. In December of that year, the Air Force awarded McDonnell Douglas (now Boeing) the contract for the F-15 *Eagle*. Both aircraft were fixed-wing designs that required a high-strength, high-modulus fiber to reduce flutter and minimize the mass of each aircraft. At that time, carbon fiber was not available in continuous lengths and glass fibers did not have sufficient modulus. Ultimately, Grumman chose boron fiber for the horizontal tail skins on the F-14, and McDonnell Douglas chose boron fiber for the horizontal and vertical skins and rudder on the F-15. History was made when boron fiber (*not* carbon fiber) became the first high-performance fiber to be used in a production application. Even with the maturation of carbon fiber, it does not change the reality that boron fiber got the industry started. Thus, it seems fair to look at the fiber that started it all, and to understand why boron is still relevant today.

How boron fiber is made

Vapor deposition of boron fiber was first reported by E.J. Weintraub in 1911, and in 1959, workers at Texaco first demonstrated the ability to make a continuous high-strength, high-modulus fiber via chemical vapor deposition. This led to funding by the U.S. Air Force Materials Laboratory to develop and scale up the process. In 1964, General Bernard Schriever called the development of continuous boron fiber "the greatest breakthrough in materials in the last 3,000 years."

The production of boron fiber by chemical vapor deposition takes place in a borosilicate glass reactor. A 0.0005-inch (12.7 μm) diameter tungsten substrate is introduced through a mercury-sealed gas inlet and drawn through the reactor. The substrate is resistively heated to 1,300°C by a DC power supply while boron trichloride and hydrogen are introduced at the top of the reactor. As the tungsten passes through the reactor, boron is formed on the substrate by the hydrogen reduction of the boron trichloride. Gases of unused boron trichloride, hydrogen chloride byproduct and unreacted hydrogen are exhausted through an outlet port at the bottom of the reactor. These gases are then either scrubbed or recycled for future production use. The boron filament, typically 0.004 inches (101.6 μm) in diameter, passes through another mercury seal as it exits the reactor and is wound onto a take-up spool. In-line optical scanners monitor the fiber diameter prior to take-up, and adjustments are made to speed up or slow down the rate as needed by a feedback loop to ensure the diameter is within the desired specification. A unique feature of boron fiber is its rough, corncob structure (Fig. 1), which enhances mechanical gripping between fiber and resin.

Aerospace-grade boron fiber must undergo a rigorous series of tests that assess tensile strength and elastic modulus. To produce composite tape, the fiber is fed into a 1250-spool creel in which the fiber is collimated and precisely spaced, then combined with epoxy resin film. The typical products shipped to aircraft companies are 500-foot long, 6-inch wide prepregged tapes. Boron fiber prepreg looks and handles like graphite fiber-based prepregs and is amenable to many of the same manufacturing processes.

Early boron manufacturers

Initial manufacturers of boron fiber, along with Texaco, included United Aircraft Research Laboratory, Avco Systems Division, General Electric Research Laboratory, Monsanto, Battelle Memorial Institute and others. Only two companies remained in the boron fiber business by the late 1960s: Avco Systems and Hamilton-Standard, a division of United Aircraft Corp.

Avco constructed a 10,000 pounds-per-year production facility in 1970 to make boron-reinforced epoxy (B/Ep) composite tape. By the late 1970s, fiber production capacity was as high as 30,000 pounds per year. Both Avco and Hamilton-Standard were supplying B/Ep tape to Grumman for the horizontal stabilizer of the F-14, and to McDonnell Douglas for the horizontal and vertical stabilizers and rudders for the F-15. Other applications developed later included tubes for the mid-fuselage structure of the Space Shuttle Orbiter made by General Dynamics (Reston, Va., U.S.), the dorsal longeron of the B-1B bomber made by Rockwell (Oshkosh, Wis., U.S.), horizontal stabilizers for the Sikorsky (Stratford, Conn., U.S.) H-60 Black Hawk helicopter, the Dassault (Paris, France) Mirage 2000 rudder, and various sporting goods parts, including golf club shafts, tennis rackets and fishing rods.

By the early 1980s, Avco Specialty Materials had become the lone supplier of boron fiber. Textron purchased Avco in the late 1980s and the division became Textron Specialty Materials. In December 2001, Textron sold the boron business, and Specialty Materials Inc. (SMI) was formed as a privately owned small business.

In the late 1990s, Textron Specialty Materials began working on the development of a new class of hybridized composite materials consisting of boron and carbon fibers, taking advantage of the properties of both fibers. The addition of 4.0-mil boron fiber to carbon fiber composites can increase the compressive strength of the composite by 100-200% compared with carbon-only composites.

One of the first production applications for Hy-Bor was the spar caps below the wings of General Atomics' (San Diego, Calif., U.S.) *Reaper* unmanned aerial vehicle (UAV). The high compressive strength of boron fiber enabled an increased payload to be carried on the *Reaper*. More recently, a new generation of these products (Gen 2 Hy-Bor) has been developed jointly by SMI and Toray (Tokyo, Japan) that includes high-temperature resin matrices such as toughened epoxies, cyanate esters and bismaleimides (BMI).

Another new application for boron fiber is use in space structure components for optical imaging. Boron is the only fiber with a positive coefficient of thermal expansion (CTE) that can be hybridized with a high-modulus graphite fiber and provide composite components that have zero CTE with a stiffness as high as 56 Msi. Working with L3Harris Technologies (Melbourne, Fla., U.S.), SMI developed a 0.5-inch wide towpreg in a two-step process using 4-mil boron monofilament with a cyanate ester polymer. With this towpreg, L3Harris and Aurora Flight Sciences (Manassas, Virg., U.S.), using a 7-axis Electroimpact (Mukilteo, Wash., U.S.) automated fiber placement (AFP) machine, were able to fabricate high-value satellite components resulting in manufacturing cost reductions in the 30-50% range. Wider use of AFP will increase the design flexibility and performance of these materials.

As boron fiber moves forward into the next decade, its future looks promising. In addition to the *Reaper* and satellite components business, the new F-15EX suggests a steady opportunity.

Another high-growth application is hypersonics. According to Michael Griffin, the Undersecretary of Defense for Research and Engineering, developing hypersonic capabilities is the Defense Department's "highest technical priority." The government-funded budget for hypersonics development has grown from \$85.5 million in 2017 to \$256.7 million in 2019, with even higher growth rates projected in the next 5-10 years in funding and jobs. SMI's boron fiber is also being considered for some of these applications. CW

ABOUT THE AUTHOR

As Director of Business Development at Specialty Materials, Tom Foltz is responsible for sales and marketing of boron and SiC fibers. He received a B.S. in ceramic engineering from Rutgers, and an MBA from Northeastern. His previous experience includes R&D and sales at Harbison-Walker, Bay State Abrasives and Textron.

Seven year itch: Retrospective


Source | Getty Images

» As of the end of May, it is approaching three months without a face-to-face meeting with a co-worker or other industry colleague, and likely to be another month before that happens. But rather than bemoan fate, the days have become longer and warmer — always a positive trend — and there appears to be some increasing potential for those personal interactions to resume in the months ahead. On the plus side, working from home has resulted in a lot of home improvements being completed well ahead of schedule, including painting, home hardware upgrades and general decluttering. And my lawn has never looked better!

It has been a mixed bag for my sports hobbies. I bought a new carbon fiber tennis racquet just before my club closed, and it's only now, at the end of May, that tennis has resumed, and I can get it strung. My ski season was cut short in March; I had planned to demo skis during my last trip to the Rocky Mountains in April, as I am due for a new pair. That will now wait until next season. On the other hand, I am playing more golf (with social distancing) than I have in decades, highlighting the need to replace my driver that I have used for almost 30 years (it does have a carbon fiber shaft, though).

> The path back to normal will be filled with opportunities.

One thing about spending such an inordinate amount of time not "out and about" is that it offers some time for retrospection. I started writing this column for *CompositesWorld* in 2013. I did a look back after two years in June 2015, and a true five-year recap in May 2018. So here, after seven years, I will look at some more recent columns and see, in light of the current pandemic, how well they've held up.

In March 2019, I wrote about the North American International Auto Show (NAIAS) in Detroit, held the previous January, noting the lack of excitement and absence of key OEMs, following only a week behind the Consumer Electronics Show (CES) where many of these same OEMs had a big presence. In a big shakeup of a 30-year tradition, the 2020 NAIAS was rescheduled for June 2020, with a new format to include outdoor demonstrations. I was really looking forward to this, until the coronavirus pandemic squelched the event; now it's rescheduled for June 2021. While it's unclear what new models and features we might have seen at this year's show, it's almost a sure bet we will see a slew of battery electric vehicles and hybrids in 2021. General Motors, for one, announced a major initiative in March to become the leading North American supplier of electric vehicles in the next several years, and have maintained their investment in this initiative through the pandemic. I expect other OEMs to follow suit. While this may not mean a lot for composites in the short-term, I do believe it will long term.

In April 2019, I wrote about the impending end of manufacture of the double-decker Airbus A380 and the breakthrough composites technologies advanced by this aircraft, including thermoplastics, resin transfer molding, automated fiber placement and pultrusion. This paved the way for next-generation aircraft like the Boeing 787 and the Airbus A350 and all other aircraft to come. The pandemic has accelerated the retirement of the A380 by several carriers, including Air France and Lufthansa, and speculation that Qatar Airways and Etihad Airways may soon follow. In late May, the press reported that Emirates Airlines, the leading user of the A380, may retire a large portion of the fleet early. This was later refuted. I have yet to fly on one of these aircraft, which many have described to me as a great experience. Unfortunately, it may become a bucket list item never fulfilled.

Finally, in July 2019, I sang the praises of the young professionals and students I saw responding to initiatives by our professional societies to put them front and center at conferences and other events, showing them the value of making in-person connections. While this cohort is no doubt more adept at navigating the current virtual environment than us "old-timers," I worry that the pandemic has impacted the progress this new generation of industry leaders was making. It's imperative that all of us make sure we reinvigorate that progress as soon as we are able.

Clearly, the pandemic has impacted most facets of the composites industry, from product demand and workforce development, to accelerating or decelerating trends that were underway before the pandemic arrived. The path back to "normal" will be filled with opportunities. If we take advantage of those opportunities, we can create an ever stronger composites economy. 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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Flexure testing of sandwich composites

» Sandwich composites consist of thin composite facesheets bonded to a relatively thick, low-density core. The use of the core to separate the two stiff and strong composite facesheets produces composite sandwich structures that are especially well-suited for flexural loading. Under such loading, the facesheets are subjected to tensile and compressive stresses associated with bending, whereas the central core is subjected primarily to shear stresses. Therefore sandwich composites can experience facesheet or core failures under flexural loading, and test methods have been developed to assess these two types of failures. The primary differences between these two types of flexure tests is the sandwich beam specimen's support span length, long beam versus short beam, and the loading configuration, four-point versus three-point loading.

To produce facesheet failure in composite sandwich beam specimens and thereby determine the facesheet ultimate strength, relatively long span lengths and four-point loading configurations are used (Fig. 1). ASTM D7249, the long beam flexure test method for sandwich composites, specifies a 76-millimeter-wide and 600-millimeter-long standard specimen. A 560-millimeter support span length, coupled with a relatively short 100-millimeter loading span length, is specified as the standard loading configuration. This is intended to maximize the bending stresses in the facesheets while minimizing the shear stresses in the core. However, this standard configuration is intended for use only when the specimen design equations, provided in the ASTM standard, indicate that facesheet failure will be produced. Otherwise, changes in the support and loading span lengths are required to achieve the desired facesheet failure. Note that failure of the upper compression-loaded facesheet is expected, as the compression strength is lower than the tension strength for most composite materials. Additionally, ASTM D7249 provides a useful rule of thumb for specimen design: the support span length should be at least 20 times greater than the sandwich thickness. An additional concern is localized facesheet damage or core crushing at load introduction points. To address this concern, the ASTM test method specifies use of 25-millimeter-wide pivoting loading flats to help distribute the force over a larger area (Fig. 2). Additionally, the use of 3-millimeter-thick rubber pressure pads placed onto the steel flats is recommended to further reduce stress concentrations.

To produce core failure in composite sandwich beam specimens under flexure loading, relatively short span lengths and a three-point loading configuration are used (Fig. 1). ASTM C393, the short beam flexure test method for sandwich composites, specifies a 76-millimeter-wide and 200-millimeter-long standard specimen. The relatively short 150-millimeter support span, coupled with the single central loading point, minimizes bending stresses in the facesheets and produces core shear failure. The same pivoting loading flats and rubber pressure pads specified in the long beam flexure test are used to prevent failure at the loading points. In fact, the same adjustable test fixture used to perform long beam flexure tests (Fig. 2) may be used to perform short beam flexure tests by placing one loading head at the midpoint and removing the other. Similar to the long beam flexure test, ASTM C393 provides specimen design equations for use in producing core shear failure prior to facesheet failure and localized core compression failure at the central loading point. Note that core shear and core-to-facesheet bond failures are considered acceptable failure modes.

Those reading ASTM C393 may also note that four-point loading configurations are included in the test method, even though they are not recommended for short beam flexure testing to determine the core shear ultimate strength. The reason? Prior to 2006, ASTM C393 was the only sandwich flexural test method for sandwich composites. As a result, this earlier version of the standard included short beam and long beam sandwich specimens and three- and four-point loading. In 2006, when ASTM D7249 was standardized for long beam flexure testing, ASTM C393 was rewritten to focus only on short beam flexure testing. However, the four-point loading configuration was retained in the standard for

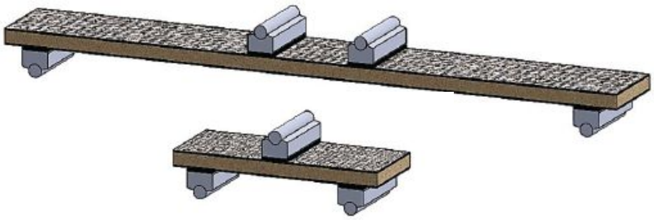

FIG. 1 Specimen configurations used in sandwich composite flexure testing. The top image shows a long beam flexure configuration (ASTM D7249). Below is a short beam flexure configuration (ASTM C393). Source | Dan Adams

FIG. 2 Long beam flexure test fixture and sandwich composite specimen. Source | Wyoming Test Fixtures Inc.

"historical continuity" with previous versions.

Additionally, in 2006, ASTM D7250 was standardized for use in determining the stiffness properties of sandwich composites using test results from the long and short beam flexure tests. This standard practice describes the procedure and presents equations for calculating sandwich flexural and shear stiffness as well as core shear modulus. Force versus deflection and/or strain data is required from at least one long beam (ASTM D7249) and one short beam (ASTM C393) flexure test configuration. These stiffness properties are determined by simultaneous solution of the deflection equations for each test configuration.

Having summarized the two standardized flexural loading configurations used for sandwich composites, I'll conclude by pointing out their similarities with those currently used for flexure testing of composite *laminates*, or solid composites. As in the case of sandwich composites, the two standardized flexure test methods also fall into the categories of long and short beam flexure tests. The solid composite long beam flexure test, ASTM 7264, permits the use of three- or four-point loading, with the choice left to the user. A span-to-thickness ratio of 32:1 is recommended for both loading configurations, which produce maximum bending stresses along the outer specimen surfaces. Specimen failure typically is produced at the top of the specimen due to the maximum compression stress, referred to as the flexural strength of the composite laminate. In contrast, the short beam flexure test for solid composites, ASTM 2344, uses a span-to-thickness ratio of 4:1 and three-point loading. This test method is used to determine the short beam strength, defined as the maximum shear stress produced at the mid-thickness of the specimen at failure. As discussed in my October 2017 column, neither the measured flexural strength nor the short beam strength measured using these tests are considered material properties of the composite material due to the nonuniformity of the stress state and the volume in which the maximum stress is produced. Under some conditions, however, these measured quantities may be used as material property *estimates*. CW

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Fabricators report slowing decline in business conditions for first time since COVID-19

May 2020 — 42.3

» The Composites Index improved by more than seven points in May to register 42.3 after setting an all-time low in April. For the first time since the government curtailed normal business operations to prevent the spread of the novel coronavirus, all components of the Index moved towards more "normal" levels. This turnaround was led by new orders and production, both of which reported gains from the prior month of more than 12 points. Excluding supplier deliveries, all components moved higher from their prior month readings although each remained below a reading of 50. The change in the direction of the readings is indicative of a slowing contraction, meaning that while conditions deteriorated further in the latest month, they did so at a much slower rate compared to the prior month.

The supplier delivery reading fell slightly in May, which may indicate a turning point in the unprecedented disruption that affected upstream production and slowed deliveries earlier in the year. By the nature of how this question is asked, quickening supplier deliveries lower the Index's reading. Despite the recent and significant contraction in new orders, prices for upstream materials continue to increase while May saw weakening prices for finished composites products. The last time that prices received for finished composite goods contracted was in the fourth quarter of 2016. This combination of results imply growing pressure on profit margins for the industry. CW

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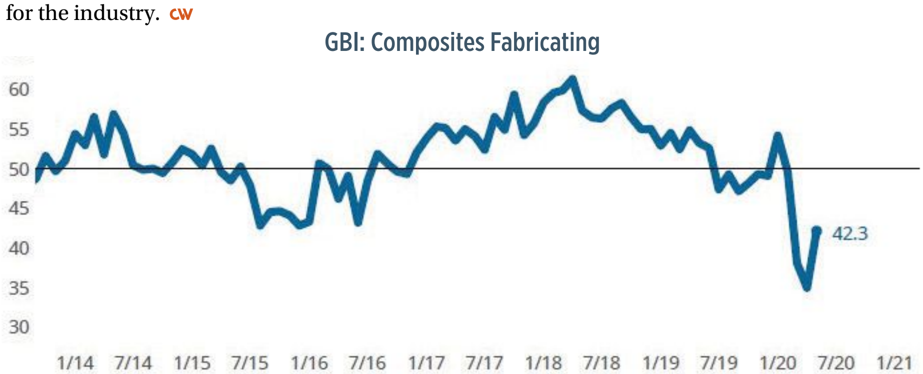
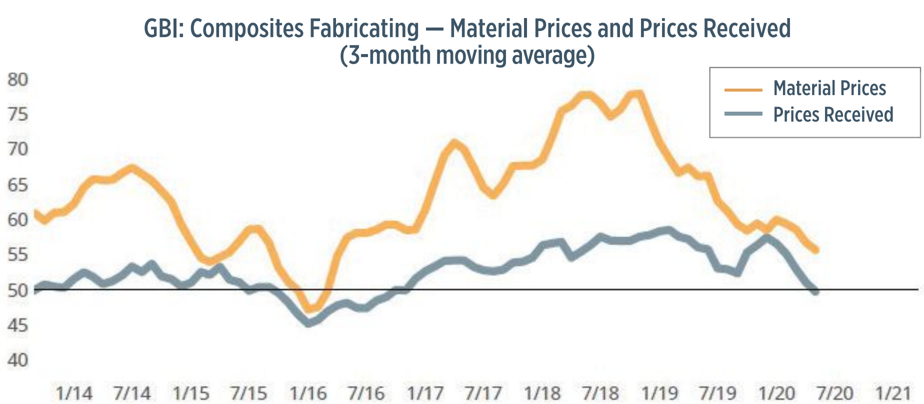


Composites Index

The Composites Index indicated that the industry experienced a slowing contraction in May. All components of the Index registered improved readings with supplier deliveries signaling a return to more frequent deliveries and reduced upstream disruption from COVID-19.



Survey indicates profit compression as material prices increase and finished goods prices contract

Despite the recent and sharp contraction in new orders for composites goods, surveyed fabricators continue to report rising material prices while also a slight contraction in their own pricing power. This combination of forces implies that profit margins are being compressed.

Resilience and Perspectives During COVID-19

– A message from IACMI CEO John Hopkins

Resilient. That is the word that comes to mind the most as I look back over the past three months. COVID-19 has impacted our lives in so many unprecedented ways. My heart aches for the people that have lost family members and friends to this deadly virus.

In just a short period of time, the coronavirus has fundamentally altered the way we live our lives and how nearly everyone conducts business. My work calendar over the past three months has been filled with conference calls, Zoom, Teams and WebEx meetings. Daily, I have spoken with people in a variety of organizations about COVID-related topics such as masks, face shields, ventilators, and test supplies, as well as the advanced composite materials used to make these items, the scalable innovation and immediate manufacturing needed, and supply chain independence required to respond to this emergency.

Many of you – our 150+ IACMI members – know this feeling all too well. You have transitioned and adapted your essential operations to meet the health and safety needs of your local communities as well as the nation. At the same time, many of you have pivoted to ensure that your organization's vision and strategic plan remain on course while adjusting to a changing business ecosystem. You have been forced to rethink priorities and potentially accelerate new initiatives centered on how they will serve your customers in the post-COVID era.

Our IACMI members are resilient. They make up and support the composites supply chain and include material suppliers; tiers 1, 2 & 3 suppliers; automotive and wind OEMs and fabricators; academia; and national laboratories. The current coronavirus pandemic underscores the importance of having our consortium aligned and connected with each other as a community, and the broader connectivity provided by the Manufacturing USA Institutes as a network of these communities, so we can accelerate technical innovations and rapidly manufacture solutions to meet U.S. demand.

Our IACMI innovation partners and members have demonstrated their creativity and resilience in support of multiple response initiatives.

COVID-19 is forcing all U.S. industries to become more resilient, responsive and more agile. As IACMI delivers on its current goals, we will continue working with our partners to improve the domestic manufacturing base and related supply chain resiliency and adaptability.

Experts vary in their assessment of the extent of the damage related to the virus; however, most agree that the impact will be severe, both in terms of the economy as well as the populous' wellbeing. Despite our resiliency, the crisis response has shown more clearly the challenges that our U.S. manufacturing supply chain faces providing emergency and surge response. Further, the impact of offshoring of specific parts of the supply chain has created vulnerabilities for the country. Greater adaptability and resilience of the domestic manufacturing base is necessary for national security and global competitiveness.

There have been several novel contributions by additive manufacturing to help better the crisis. Items that support the fabrication of masks, face shields, and other components for medical services, for example, have been developed by researchers across the country. COVID puts additive manufacturing in a different context where you really see in a concentrated way the importance of this manufacturing practice on the economy and nation's safety as well as the national security interest that IACMI and everyone in the composites field have all been working toward.

Throughout it all, IACMI and our consortium will remain steadfast in using every tool we have at our disposal to make a positive difference and to plan, design and provide new solutions that will enable our consortium environment to be more resilient.

Stay connected and learn more at iacmi.org.

JEC Group announces 13 winners of its annual Innovation Awards 2020, and a UAE-based aerostructures manufacturer provides opportunities for its multinational, female-dominant workforce.

JEC Group announces 2020 Innovation Awards winners

JEC Group (Paris, France) revealed the winners of the JEC Composites Innovation Awards 2020 during a virtual ceremony on Wednesday, May 13. Thirteen winners were designated in 11 categories.

"Beyond being a simple award ceremony, the JEC Composites Innovation Awards are intended to be a source of inspiration for the industry and a vector of excellence for all the winners. This is an unavoidable and long-awaited moment in the year for the composites industry that we could not miss," says Franck Glowacz, innovation content leader at JEC Group.

The winners for each category are listed below:

- **Additive Manufacturing: Eurecat (Spain)**
Eurecat won for its CFIP technology, a new post-processing technology that uses continuous fibers to reinforce parts of various materials and manufacturing technologies.

- **Aeronautics: Institut de Soudure Groupe, Arkema (France)**
Awarded for a newly developed and patented solution for high-performance welding of thermoplastic (TP) composites.

- **Automotive: Volkswagen (Germany)**
German manufacturer Volkswagen was rewarded for its lightweight FRP center tunnel (LehoMit-Hybrid), an innovative and profitable thermoplastic structural hybrid car body component, suitable for production in large quantities, which can be introduced before cathodic immersion treatment with the corresponding assembly technology.

- **Construction, Infrastructures Civil Engineering: Carbo-Link (Sweden)**
Carbo-Link won for its CL RESTRAP, thin strips of pre-impregnated and hardened carbon fiber-reinforced polymer (CFRP), wound continuously in a loop to form a flexible carbon strip. This process reinforces concrete beams of any size in infrastructure applications.

- **Design/Furniture: Mecelec Composites (Finland)**
The company won for its mass-produced flax fiber roofs, the first application of bulk molding compound (BMC) flax fiber for mass production.

- **Maritime Transportation/Shipbuilding: Norsepower Oy Ltd. (Finland)**
The company won for its Norsepower Rotor Sail Lightweight Solution, an aid for freight and passenger ships to reduce fuel costs by 5-30% by improving the propulsion system of a ship through the use of wind as auxiliary propulsion measurement.

- **Process: Engel Austria (Austria)**
The company won for its line for tailored thermoplastic composite blanks, an element composed of a pick-and-place stacking cell, a consolidation unit and heating and cooling, reportedly capable of producing a custom thermoplastic blank in a cycle of one to three minutes.

- **Railway Vehicles Infrastructures: Far-UK Ltd. (U.K.)**
The company won for Project BRAINSTORM, a lightweight tram frame composed of very light composite tubes. The frame is said to reduce investment and manufacturing costs as well as carbon emissions.

- **Recycling: Cobra International (Thailand)**
The company won for its closed-loop recycling process for epoxy-infused resin transfer molding (RTM) tools and watersport fins for Starboard and MFC.

- **Space: Hankuk Carbon (South Korea)**
The company won for its lightweight and linerless carbon fiber subscale cryotank, which reportedly makes it possible to reduce the weight of a space launcher by 30% by replacing the current fuel tank with a carbon fiber composite cryotank without a coating.

- **Sports Healthcare: Asics Corp. (Japan)**
The company won for its Future of Springs: Spike-Less CFRTP Sprinting Shoe, a new shaping methodology using preformed and randomly oriented ultra-thin carbon fiber-reinforced thermoplastic polymer (CFRTP) tapes.

- **JEC Composites Magazine Special Prize: Cookson Precious Metals**
The company received the award for its 3D-printed bushings for glass fiber production, which are reported to ease manufacture of glass fibers with innovative geometries.

- **Public Vote Award: Stratiforme Industries (France)**
The company won the public vote award for its project DESTINY thermoplastic resin train front end, which had the objective of launching a new range of components for the interior layout of commercial aircraft and rail applications based on thermoplastic composites.

Q&A with Strata workforce leaders

Strata Manufacturing (Al Ain, United Arab Emirates), a subsidiary of Mubadala Investment Co., manufactures composite aerospace parts and components for the Boeing 787, Airbus A350 and other commercial aircraft. The company employs more than 500 workers and prides itself on its 52% female, multinational workforce. According to Ismail Ali Abdulla, CEO of Strata Manufacturing, the UAE government actively encourages the role of women in the workplace and has introduced measures to achieve equality in all industries. Several of Strata's female leaders shared their experiences with CW:

CW: The aviation and manufacturing industries have traditionally been male-dominated fields. What has your experience been like as a female employee in manufacturing?

Maryam Al Kuwaiti, manufacturing engineer: It is no longer a surprise that a female Emirati like me can be part of the STEM field and can even excel in it. In the UAE, we have been blessed with leaders who are constantly encouraging the role of women in various sectors. Over the past two years I have actively participated and engaged with the youth in a number of STEM-related initiatives across the UAE.

Noura Al Braiki, senior production lead: My journey as a woman in this industry has been challenging and very rewarding at the same time. From the beginning, my ambitions in the aerospace industry included being a leader, reaching great heights and taking upon a huge responsibility that will prove [wrong] the misconception of women in STEM fields.

CW: What has been your proudest accomplishment so far in this field?

Noura Al Braiki, senior production lead: Ten years ago, I started my career manufacturing aircraft parts, and today it gives me tremendous honor to be the first female Emirati to be responsible for 14 production lines and oversee a huge number of employees.

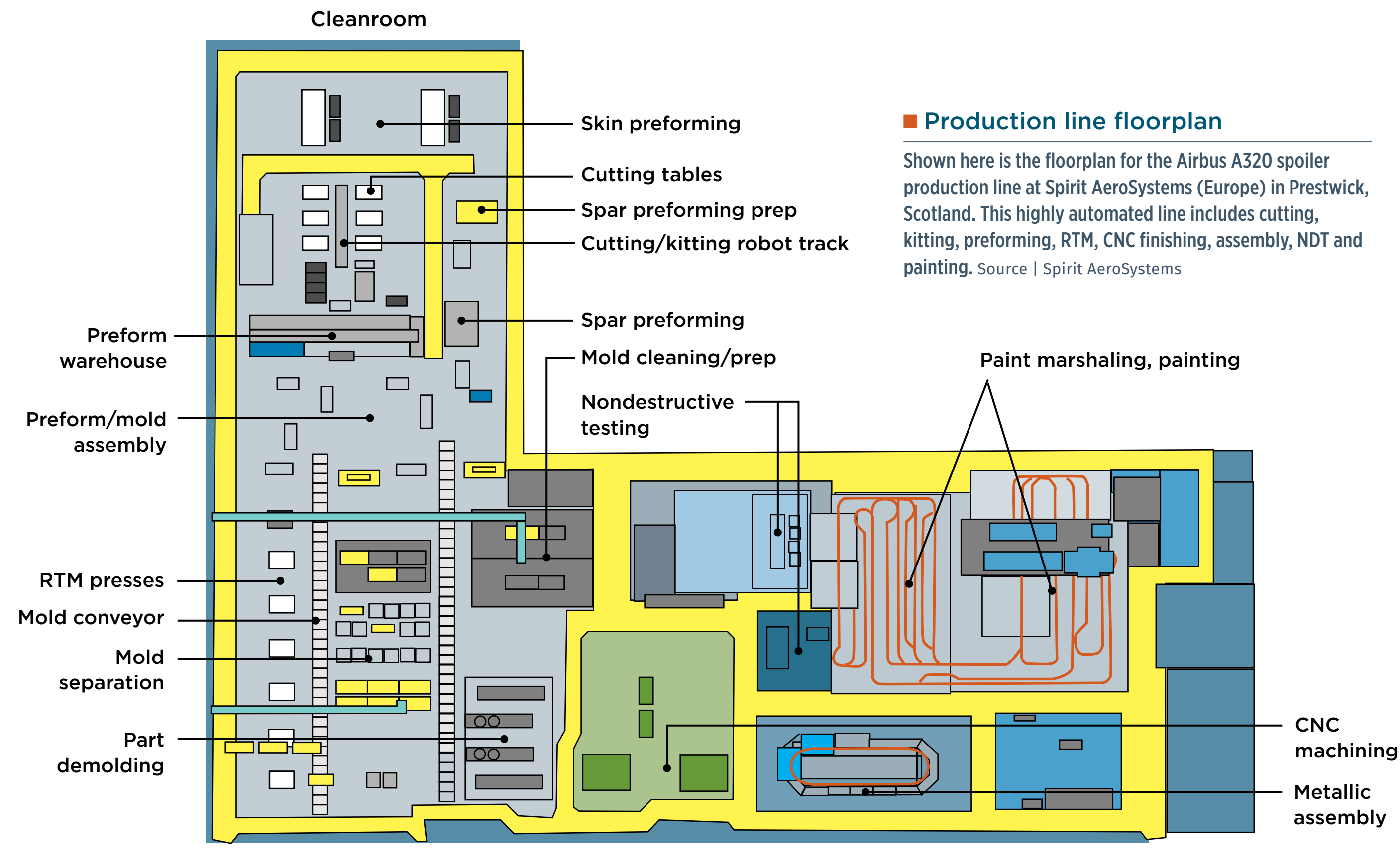
Maryam Al Kuwaiti, manufacturing engineer: The Boeing Vertical Fin (VF) program is considered a game-changer in the region's aviation industry, and for Strata to be the key supplier of such aerostructure composite parts is an important milestone in the company's growth. I am proud to be one of the first two Emirati female engineers to have completed the manufacturing engineering training program at The Boeing Co.'s headquarters in the U.S. in May 2018. ... Upon completion of the course, I truly felt empowered within my role at Strata with the additional knowledge and skills that I was able to implement in my own further learnings and to upskill the talent of my colleagues to ensure the smooth transfer of the Boeing 787 VF project from the U.S. to our facility in the UAE.

CW: What is your goal right now in aerospace manufacturing?

Noura Al Braiki, senior production lead: As a woman in a traditionally male-dominated industry, we now find ourselves in positions of leadership, and I believe we should continue to make the most of these opportunities and hold the door wide open to enable other women to walk through it. More importantly, as a female Emirati, I want to continue serving as an inspiration for the younger generation in achieving their goals.

Maryam Al Kuwaiti, manufacturing engineer: Moving forward, my goal is to continue to further enhance my skills, expand my knowledge and constantly grow my career in aerospace manufacturing. This will enable me to contribute towards nation-building and to the success of the company.

See full interview at **short.compositesworld.com/StrataQ_A**.



Production line floorplan

Shown here is the floorplan for the Airbus A320 spoiler production line at Spirit AeroSystems (Europe) in Prestwick, Scotland. This highly automated line includes cutting, kitting, preforming, RTM, CNC finishing, assembly, NDT and painting. Source | Spirit AeroSystems

High-rate, automated aerospace RTM line delivers next-gen spoilers

At Spirit AeroSystem's Prestwick facility in Scotland, a glimpse of the future of aerocomposites manufacturing in a resin transfer molding line for A320 spoilers.

By Jeff Sloan / Editor-in-Chief

»Every commercial aircraft has, as part of each wing, a set of spoilers. These are typically hinged panels or flaps on the rear surface of the wing that are deployed to reduce aircraft lift. They are used during flight for roll control to increase the rate of descent without increasing airspeed, and during landing to reduce lift and increase drag to slow the aircraft. Spoilers are mechanically actuated and, when deployed, are subjected to considerable mechanical stress from airflow. They are, in short, a critical component of aircraft flight function.

There are, on the Airbus A320 series of aircraft — including the A318, A319, A320 and A321 — a total of 10 spoilers, five on each wing. Each A320 spoiler has different dimensions depending on its location on the wing but, generally speaking, measures 1.8 meters long and 0.7 meters wide. Each spoiler is about 50 millimeters thick at the leading end and tapers to about 5 millimeters at the trailing edge. Each spoiler also features, in the middle of its leading edge, a 200-by-100-millimeter metallic bracket to which the mechanical actuator attaches — in the case of the A320, a rod end actuator. At the corner of each leading edge are also smaller metallic attachment points.

When the Airbus A320 was developed in the early 1980s, composites were not new to commercial aircraft, but their use was confined mostly to secondary structures. The first A320, which entered service in 1987, featured 10 composite spoilers, hand laid with carbon fiber prepreg laminates surrounding a honeycomb core. These spoilers, manufactured by Spirit AeroSystems subsidiary Spirit Malaysia in Subang, have ably served the entire A320 family for decades.

About three years ago, however, Airbus began contemplating increasing A320 production to 60 planes per month. The company also had been contemplating development of a new single-aisle to replace the A320, which might have production rates as high as 100 planes per month.

Ian Latto, project leader spoilers for Airbus at the company's Bristol, U.K., location, says the spoilers on the A320 are one of the few wing components that had not needed to be redesigned since the plane's 1987 debut. However, as Airbus considered higher build rates for the A320 family, a redesign of the spoilers was necessary to realize the cost and rate capabilities of new technologies. Further, as Airbus looked to the future, it knew it had to migrate spoiler manufacture away from hand layup and toward "a highly automated, low-variation, high-quality manufacturing process," Latto says.

Peter Smith, head of A320 family wing engineering at Airbus, and his team were challenged to re-engineer the spoilers for rate and cost. Moreover, he says, these new high-rate, lower-cost spoilers had to be fully interchangeable fit, weight and aerodynamic drop-in replacements for the existing spoilers. Smith says, "We studied numerous technologies and traded the benefit before settling on RTM." The new Airbus spoiler structure is a coreless, monolithic, skin-and-spar design — a significant departure from the legacy design it will replace.

Enter Spirit AeroSystems

Once Airbus made the decision to update the spoilers, conducted the trade studies and subsequent materials and process (M&P) development, it then needed a partner to develop the manufacturing processes to fabricate them. For this, Airbus, in mid-2017, turned to one of its longtime suppliers, Spirit AeroSystems (Wichita, Kan., U.S.). More specifically, it turned to Spirit AeroSystems (Europe), the company's R&D and manufacturing campus in Prestwick, U.K., located on the western coast of Scotland about 75 miles southwest of Edinburgh. The sprawling Prestwick campus, adjacent to the Glasgow Prestwick Airport, was founded in 1935 as Scottish Aviation Ltd., and later became BAE Systems Aerostructures. Spirit then acquired the facilities in 2006.

Spirit's Prestwick facility is home to aerospace manufacturing of composites and metallic components for a variety of Airbus programs. Much of the legacy work at Prestwick is build-to-print, but since being acquired by Spirit, the facility has positioned itself as a design-and-build aerospace supplier. As part of this transition, composites R&D has emerged as a core function. The company has established in Prestwick the Spirit Centre of Excellence and is in the process of completing construction of its 85,000-square-foot Aerospace Innovation Centre (AIC) at Prestwick, focused on aerostructures, composites fabrication and assembly technologies. The A320 spoilers project, thus, was a perfect fit.

Leading overall R&T at Spirit is Dr. Sean Black, VP chief engineer – Research & Technology, a Scot by birth but currently working out of Spirit's Wichita headquarters. Leading the engineering effort in Prestwick is Geoffrey Pinner, head of Wing Engineering & Aerospace Innovation Centre. Pinner, a Brit, is ex-Airbus and led the A350 design team. Black was an engineer on Pinner's A350 team and convinced Pinner to come out of retirement in 2019 to work with him at Spirit.

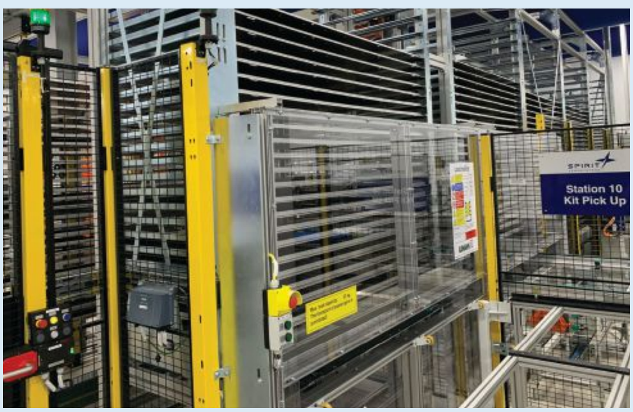
Once Spirit was selected as the manufacturing partner, Black says, "Spirit embarked on the journey of full process optimization of the RTM spoiler design." This included another trade study and, ultimately, design optimization. The design and manufacturing factors to be considered for the spoiler are considerable: Large mechanical loads, cantilevered structure, drop-in replacement, dimensional conformance, cost-effectiveness, high-rate manufacture, sustainability. Spirit took six months and conducted its own trade study, evaluating metal and composite options, including »

Spoiler alert

Spirit AeroSystems' resin transfer molded Airbus A320 spoiler, finished, assembled and painted.

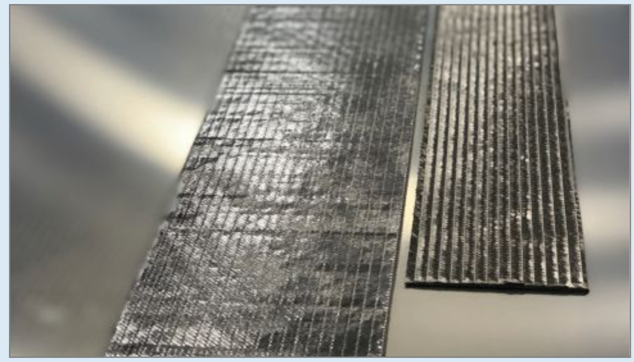
Source | *CW*

1 Spirit's A320 spoiler production line starts with fabric cutting and kitting. Six Schmidt & Heinzmann cutting tables are arranged in two rows of three, with an ABB multiaxis robot in between to sort spoiler skin and spar plies.

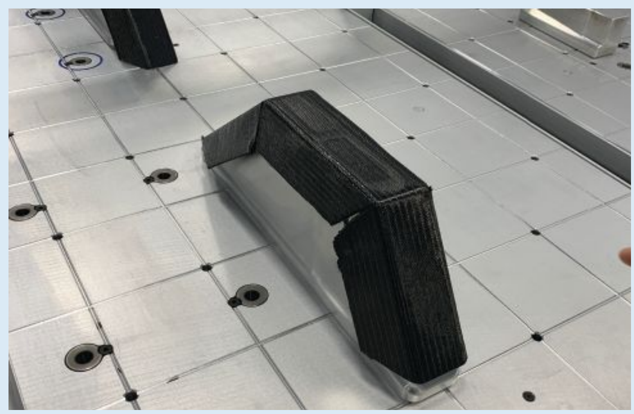


2 Spirit's warehouse system, developed with the help of ThyssenKrupp, uses metallic trays to automatically sort and store kitted plies prior to and after preforming.

3 A320 spoiler skin kits, following cutting, are delivered to one of two Pinette Emidecau preformers. The 43-minute cycle time of preforming sets the takt time for the entire production line.



4 The kitted fabrics for the spoiler spars, called "motherboards" by Spirit, are prepared for preforming.



5 A320 spoiler spar fabrics are fitted atop C-shaped tools for preforming.

6 All spoiler spar preforming is performed on this Pinette Emidecau press.

7 Preformed spar kits are next assembled around mandrels that are loaded into a cassette (red frame on left) prior to placement in the mold.

8 An operator stands at a workbench before the lower half of an A320 spoiler RTM mold, prior to lower skin, spars and upper skin preform loading. Each spoiler variation has three aluminum molds.

9 After the top half of the spoiler mold is secured to the bottom half, the entire tool is transferred to one of seven Coexpair RTM presses that Spirit has installed. The resin injected is Hexcel's RTM6 single-component epoxy.

10 Following molding, finished spoilers are demolded. Tools and mandrels — loaded vertically on a carousel — are then cleaned and conditioned before returning to the production line.

11 Molded spoilers are loaded into one of two CMS CNC machines for trimming and drilling.

12 Following machining and prior to final assembly of metallic fasteners, each spoiler is inspected using multiaxis robots and phased array UT systems.

All steps, Source | *CW*

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a variety of composites manufacturing processes — in and out of autoclave. "This project had high visibility and focus within the Airbus system," Pinner notes. "We took a focused, end-to-end, design-to-cost approach."

Spirit's assessment, which included composite and metallic options, agreed with the benchmarks established by Airbus. RTM of epoxy in carbon fiber meets all of the spoiler's requirements, including — critically — cost. However, it is not production cost, says Pinner, but system cost, which Spirit was able to reduce by 30%. "The RTM solution was most cost-effective from raw material to assembly onto the wing," he says. The winning solution also was weight-neutral.

Spirit worked quickly to turn the Airbus spoiler design into a manufacturing demonstrator that, ultimately, would successfully prove the concept. With a demonstrator in hand, what followed then was not only development of a high-rate, high-efficiency RTM process, but of a composites manufacturing concept that is emblematic of Spirit's solutions-focused approach in particular, and commercial aerospace's path forward in general.

Taylor Boyd, R&D manager in Prestwick, led the team that spent the last three years on Spirit's effort to turn the company's RTM manufacturing concept into reality. It became his team's job to acquire, develop and assemble all of the hardware, software and operators who would work in concert to convert raw material on the front end to fully assembled, tested and painted spoilers on the back end. Boyd says the effort was demanding but rewarding, and a departure from the norm for the Prestwick facility — particularly the integration of automation.

CW's visit to the A320 spoiler production line, in late February 2020, occurred as Spirit was putting finishing touches on material and equipment, prior to the official start-up of the line itself. Still, the complexity and efficiency of what Boyd developed was apparent.

Hands-free cutting, kitting, preforming

Fabrication of an A320 spoiler starts in a 1000-square-meter, Class 9 cleanroom that, at full rate, will be staffed each shift with six operators managing four processes: cutting, kitting, preforming and preform assembly. Operators are primarily responsible for moving material from one station to the next, and for assembly of preforms into the mold.

The first station in this production line is fabric cutting and kitting, which is performed in an enclosed, fully automated work cell that comprises six Schmidt & Heinzmann (Bruchsal, Germany) cutting tables. Each table measures about 2 meters long and 1 meter wide. They are organized in two rows of three, with a 7-axis, rail-mounted ABB Group (Zürich, Switzerland) robot between the rows, sorting, picking and placing — with an array of suction cups — cut material for the spoiler skins and spars. Four of the tables are devoted to cutting a carbon fiber non-crimp fabric (NCF) supplied by Teijin Carbon Europe GmbH (Wuppertal, Germany). The fifth table is devoted to cutting a glass fiber plain weave fabric from Hexcel (Stamford, Conn., U.S.). The sixth table is devoted to cutting preforms to final shape. Scrap material falls off the end of each table and onto one of two narrow

■ Bird's eye view

Aerial view of Spirit AeroSystems Prestwick campus, adjacent to the Glasgow Prestwick Airport.

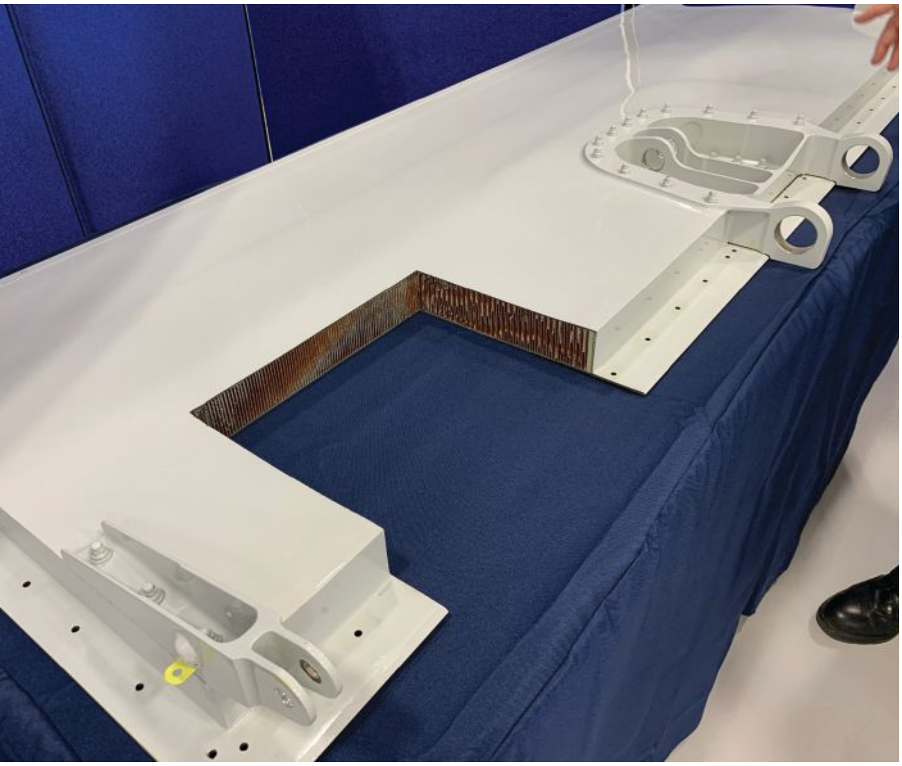
Source | Spirit AeroSystems

conveyors on the floor that run along either side of the robot's rails. These conveyors move scrap material to a bin at an opening in the enclosure fence, where an operator can retrieve it for recycling.

Back on the tables, as plies are cut, the ABB robot places them on a stacking station at the end of the row of tables. Here, a video camera performs a quick inspection of each ply. The plies are then sorted and kitted according to their end use — skins, spars, ribs — and then spot welded together, activating a binder in the NCF. Complete kits are next moved by the ABB robot to a stacking plate, which is, basically, a steel tray. On this tray is a QR code that specifies the type of kit it holds, whether upper skin, lower skin, spar or rib. The QR code is scanned by the robot, which logs the kit with a manufacturing execution system (MES), the software that drives the entire spoiler production line.

The MES is a product of ThyssenKrupp (Essen, Germany), the overall systems integrator that provided some of the manufacturing hardware and material handling equipment Spirit uses. Boyd says the software is off-the-shelf from ThyssenKrupp, but it's been customized for the spoiler production line to provide Industry 4.0 capability. The MES was written not just to track material status and manufacturing progress throughout the plant, but to guide and prompt operator activity through each step — when to move material from point to point, when to load machines, when to unload machines, etc. "We don't want an operator to make a move here unless the MES says to make a move," Boyd notes. Moreover, he says, the MES provides full data traceability, which allows Spirit to capture and see full M&P information, from the raw material as it comes in the door to the finished spoiler as it goes out the door.

After a kit is scanned and logged, the ABB robot loads the tray into the "warehouse," which is comprised of a series of mechanized metal shelves located in the middle of the clean-room, adjacent to the cutting tables. The warehouse acts as an intermediate material storage facility for every spoiler component as it moves through production. When the next step in the production process — preforming — is ready for new material, the MES requests a tray of kitted fabrics. The warehouse locates »



Legacy A320 design

Legacy A320 spoiler design with honeycomb core surrounded by hand-laid prepreg. Source | *CW*

the requested tray and then delivers it to one of several operator retrieval stations around the warehouse. Simultaneously, the operator is notified by the MES that a kit of material is ready for transfer to preforming.

There are two preforming stations on the Spirit spoiler line; one is used to preform skins, while the other is used to preform spar components. Skin kits are sent to one of two large Pinette Emidecau Industries (Chalon Sur Saone, France) preformers, each of which measures 4 meters long and 2 meters wide; each contains two molds. The largest skin preformed here is 1.7 meters by 0.7 meter. At full rate, Boyd says, the preforming process is expected to take 43 minutes, which represents the longest cycle time in the spoiler production line. That 43 minutes, then, represents the takt time for the entire line at full rate production. After preforming, the MES sends the skins back to the warehouse.

Spar and rib kits, on the other hand, are directed to the second preforming station, which consists of a single (smaller) Pinette Emidecau Industries performer. There are, in all of the spoiler configurations, 10 different spar designs. A single kitted stack for a spar is called a "motherboard" at Spirit. Nine of the 10 motherboards are preformed on one of several C-shaped forming tools arrayed on the production floor next to the smaller Pinette performer. The MES will call for a specific tool, which is pushed by an operator over rollers and onto the press platen. Motherboards are placed on each tool by an operator, who actuates the press.

Each of the kits also contains an untrimmed motherboard that could not be trimmed on the sixth cutting table. The untrimmed motherboard is taken to a "clicker" press where it punched to final shape. This extra punching process is also used for one unique spar on Spoiler 1. The punched motherboards are then loaded onto a preform tool along with the other trimmed motherboards ready for the preforming process. There are 10 preform tools, one per spoiler configuration. Again, all preformed components are then sent back to the warehouse by the MES. It's then on to the final step prior to RTM: Preform assembly and mold loading.

Boyd says preform assembly and mold loading represents the most labor-intensive step in a spoiler manufacturing line that uses remarkably little labor at all. Here, operators collect upper skin, lower skin and spar preforms sent from the warehouse by the MES and deliver them to one of two assembly stations. Each station consists of a metallic table, arrayed with fixtures and clamps. On this table and into the fixtures, operators place a series of black aluminum mandrels that, when assembled together, will hold and position spar preforms inside the spoiler. Once the mandrels are assembled, they are then transferred to a mandrel cassette, a red metallic frame that holds the mandrels in their assembled configuration, but presents them on edge. This allows the operator to easily and quickly install preforms and adjust their position on each mandrel.

Meanwhile, on another table nearby, laser projectors guide another operator who is aligning a lower spoiler skin preform. He is working under a small set of crane-mounted suction cups that will, ultimately, pick up the skin preform and transfer it into the lower half of the spoiler mold, located inside a metallic frame beside his table. With the lower spoiler skin in place, the entire mandrel assembly (with spars) is lowered into the black aluminum mold, followed by the upper skin, which had been prepared like the lower skin. The lower half of the spoiler mold, with all preforms in place, is then transferred along rollers through a portal and to the next station, where the top half of the mold is loaded onto the lower half and locked in to place. Each of the 10 A320 spoilers has three molds and three sets of mandrels in rotation at Spirit, and represent a significant part of the investment in this production line.

Into the press, demolding

A fully assembled mold is now ready for the RTM process. Through the MES the mold is transferred along a metallic conveyor out of the cleanroom, through a red retractable door, and toward the RTM presses. The conveyor system is designed such that the MES can decide which mold will go to which press, and then automatically route it there. Inside a large, fenced enclosure, Spirit has installed seven RTM presses, supplied by Coexpair (Namur, Belgium). Next to each press is a resin pump system, also supplied by Coexpair. The mold travels along the conveyor and directly into the open press.

Meanwhile, back in the cleanroom, operators degas the epoxy resin system that will be injected into the mold. Airbus specified for the spoilers Hexcel's RTM6, a single-component epoxy that has become a standard for RTM in aerospace manufacturing. After the resin is degassed, it is delivered to the press, the mold is closed and injection begins. Boyd says a single spoiler takes five hours to inject and cure; cure temperature is 180°C.

The mold leaves the RTM press on the same conveyor on which it was delivered, but now is routed by the MES to the next enclosure, where mold lid separation is performed and the spoiler continues to cool to room temperature. Next stop is the demolding area, where the now cooled spoiler is removed from the mold and mandrels are separated. Molds are prepared for cleaning; mandrels are loaded onto one of several turntables that stores each mandrel vertically. Boyd says these were designed to allow operators to easily access each mandrel in a configuration that maximizes storage efficiency.

The next stop for the spoiler is one of two CNC machines, supplied by CMS (Zogno, Italy), where the outside profile of the spoiler is trimmed and holes are drilled for assembly. Boyd notes that the trim operation and hole-drilling performed here varies by spoiler type, and like everywhere else along this production line, machine operation is guided by the MES.

From the CNC machine, the MES routs the spoiler to nondestructive testing, which is performed inside a fenced enclosure by two Stäubli (Pfäffikon, Switzerland) robots using phased array ultrasonic testing (UT) in a system provided by Ultrasonic Sciences Ltd. (Aldershot, U.K.). One robot is used to inspect the skins; the other robot inspects the spars. After the spoiler passes inspection, it's on to final assembly and then metrology and painting.

For final assembly, the spoiler is mounted vertically on a red fixture that rides on floor-mounted rails through a series of

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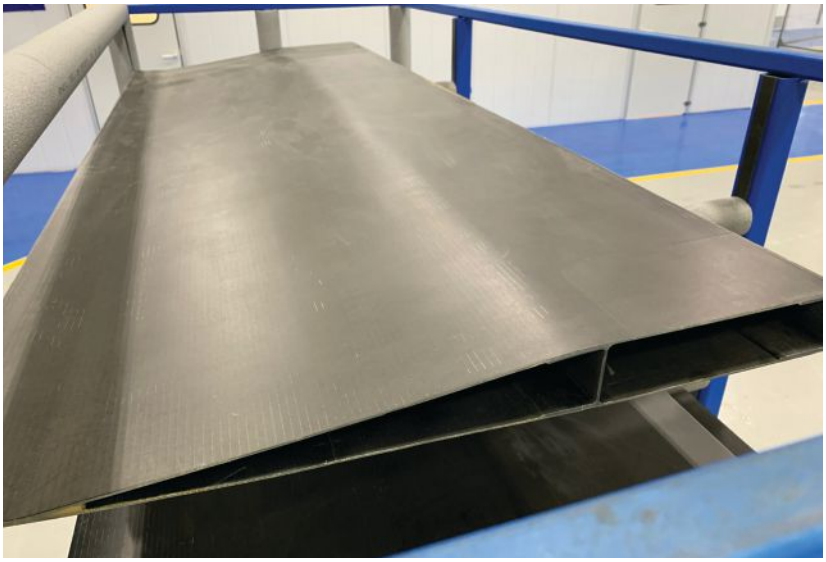

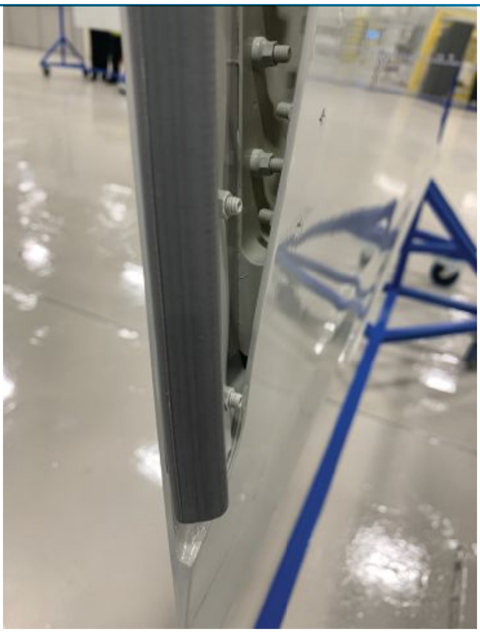

stations where metallic components are fitted and attached. These include the center fitting that attaches to the spoiler rod end actuator on the wing, outboard fittings, edge seals and main cavity block-offs. Included here also is a 95°C oven cycle to cure adhesives and seals.

The spoilers then go to metrology once they leave the oven and have cooled. After they pass metrology, the external surfaces are prepared for paint (light abrade) and tested for cleanliness. Then it's off to a large booth that is the paint marshalling area. This booth holds up to four spoiler shipsets (40 spoilers). Boyd says that it's here that a spoiler joins, for the first time, the other spoilers in its shipset of 10. Each shipset is painted as a group and then routed by the MES out of the production line and into preparation for shipping and delivery. The spoiler is complete.

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The first shipset to come off this line was expected in Q1 2020, followed by installation on an A320 in 2Q 2020. Airbus and Spirit originally expected the line would be at full rate production of 63 shipsets per month by mid-2021. However, the coronavirus pandemic forced Airbus, in April, to reduce A320 production to 40 planes per month, with further reductions possible. Regardless, Spirit designed the spoiler line for 65 shipsets per month, with flexibility to increase as needed.

Spirit and next-gen aerostructures

Spirit AeroSystems' A320 spoiler production system in Prestwick was formally opened on Feb. 28 at an all-hands ceremony that featured the Right Honourable Nicola Sturgeon, the First Minister of Scotland. She described the spoiler line as symbolic of Scotland's efforts to be a vital part of aerospace manufacturing. "This is a shining example of everything we want Scottish manufacturing to be," she said. "Spirit has been able to industrialize a new technology for the manufacture of a composite spoiler."

Indeed, at full rate production, this line will produce primary aerospace structures at a pace — with quality and consistency — heretofore unseen in aerocomposites manufacturing. At a rate of 65 shipsets per month, which would include Airbus' new A321XLR, the Spirit line will produce almost 6,500 spoilers a year. At a theoretical rate of 100 shipsets per month, that number jumps to 10,000.

Moreover, this is a product and manufacturing line that is destined to live on beyond the A320 and beyond the spoiler structure itself. Airbus' Latto, at that Feb. 28 ceremony, said that Airbus' and Spirit's work re-imagining and industrializing the A320 spoiler has given the product new life: "We have future-proofed this spoiler to give us flexibility for its use in other future programs." Airbus's Smith notes that the work to industrialize and automate the RTM spoiler is the first of many key steps to come. "The spoiler offers a relatively simple structure to prove the concepts and benefits for more complex and demanding structures, such as re-thinking of wing tips devices, wing skins and high-curvature fairings. In a high-rate, low-cost environment —in aerospace terms — the more integration and modular assemblies we can do, the better."

From a Spirit AeroSystems perspective, the spoiler production line demonstrates not just the cost-effectiveness of new technology, but how composites can be matured and leveraged for application

Up close and personal

Top left depicts an as-molded A320 spoiler, prior to machining, NDT, assembly and painting. Top right is a close-up of the trailing edge of the A320 spoiler Spirit manufactures for Airbus. Source | *CW* in next-generation aircraft. And the Prestwick campus in particular is banking on out-of-autoclave (OOA) M&P as a significant competitive advantage in the aerocomposites supply chain. “This program is clearly a significant milestone in our out-of-autoclave journey,” Spirit’s Sean Black says. “But it was enabled by several things that are critical to the company going forward: automation, software, support from academia and government support.”

Black and Pinner also note that Spirit’s partnership with Airbus, and an aligned approach, drove development of the next-generation spoiler. Working collaboratively with Airbus also eased matters considerably. Pinner says, “We have all of the business benefit of this project without having to do the convincing.”

The future (the elephant in the room)

What the Right Honourable Sturgeon and the people in attendance at that ribbon-cutting could not anticipate was the tumult and chaos about to be visited upon the global economy by the coronavirus pandemic. Indeed, on that Feb. 28, the commercial aerospace industry was still a few weeks away from a nearly total collapse in passenger air travel, and the attendant plunge in demand for new aircraft that would follow — not to mention aircraft already in service.

However difficult the short-term outlook is and might be for the aerospace industry, the almost 8 billion people who call Earth home will not remain grounded forever, which means commercial air travel *will* return. Which means that the dynamics and forces governing the aerospace supply chain will return in some form or another. Estimates, as of this writing in mid-May, suggest a 3-5-year recovery for passenger air travel, with demand for single-aisle aircraft leading twin-aisle aircraft design.

Thus the dynamics and forces governing composites in commercial aircraft also live on. This means that Airbus, Boeing or both likely will announce a new single-aisle aircraft in the next few years, thus opening the door to the application of composite materials and processes in new and creative ways. And it’s a good bet that material, process and software technologies similar to that developed by Spirit AeroSystems for the A320 spoiler will become not just common, but mandatory.

“Everything we’ve done here is an enabler for the high-rate environment,” Black contends. “We think this is the future of Spirit.” CW

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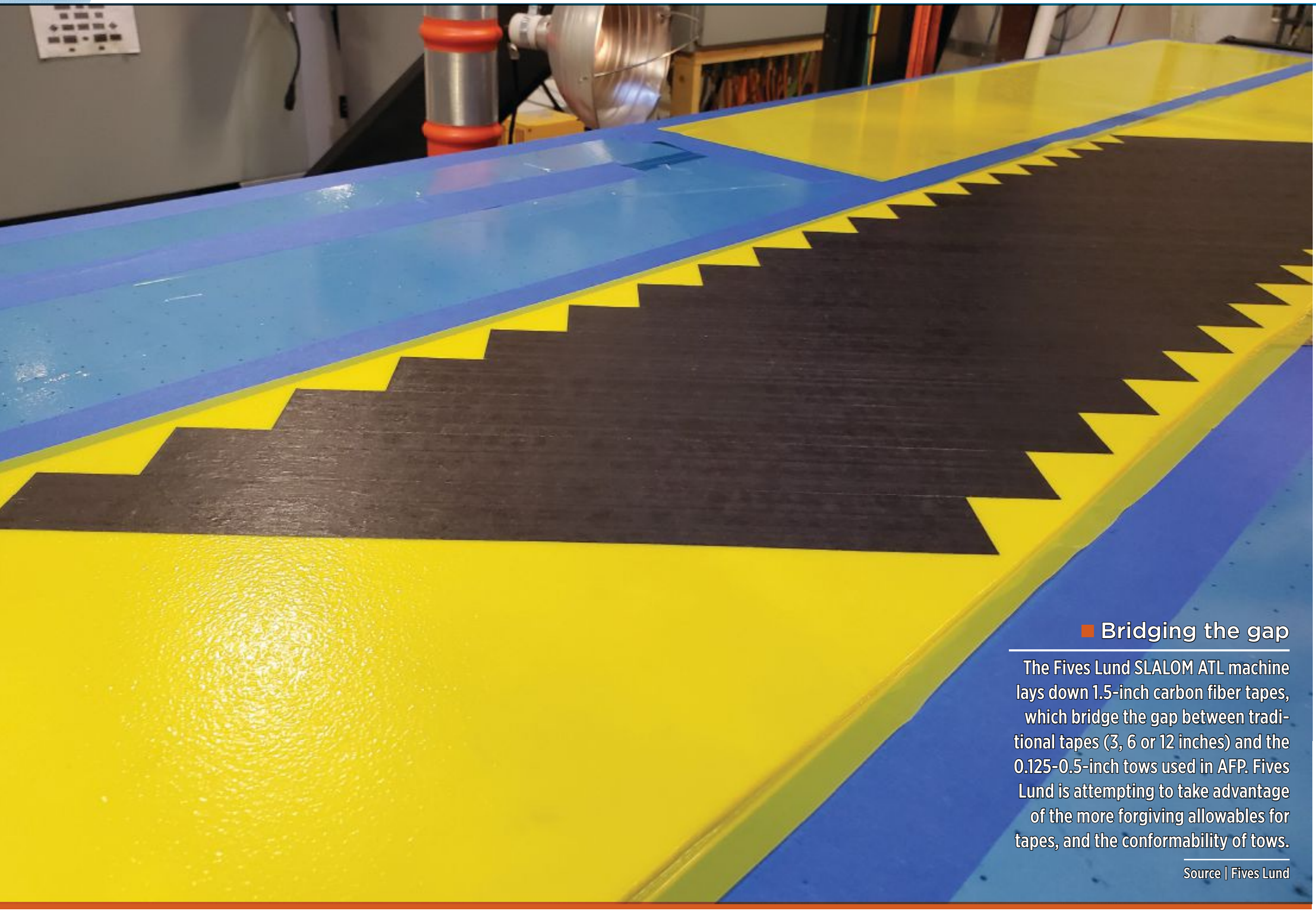


Bridging the gap

The Fives Lund SLALOM ATL machine lays down 1.5-inch carbon fiber tapes, which bridge the gap between traditional tapes (3, 6 or 12 inches) and the 0.125-0.5-inch tows used in AFP. Fives Lund is attempting to take advantage of the more forgiving allowables for tapes, and the conformability of tows.

Source | Fives Lund

Narrow UD tapes to bridge the ATL-AFP gap

Automated tape laying and automated fiber placement are similar, but not the same. Can narrow tapes provide a middle ground with advantages of both processes for next-gen aircraft?

By Jeff Sloan / Editor-in-Chief

» It is well understood that automated tape laying (ATL) and automated fiber placement (AFP) were *the* enabling technologies in the application of carbon fiber composites in major aerostructures for the Boeing 787 and the Airbus A350 aircraft. Prior to the development of these planes, composites had been applied in gradually increasing amounts in commercial aircraft for more than 30 years, but mainly in secondary structures using hand layup and some automated manufacturing processes.

With the 787 and the A350, however, Boeing (Seattle, Wash., U.S.) and Airbus (Toulouse, France) responded to demand for lighter weight aircraft, which accelerated adoption of composite materials and processes for use in fuselage skins, stringers, frames, wing skins, wing spars, wing boxes and tail structures. ATL and AFP led the charge, allowing each OEM, and its suppliers, to efficiently lay down large amounts of prepregged unidirectional (UD) tapes and tows.

ATL found a place fabricating wing structures, which, being modestly contoured, took advantage of the wide format (3, 6 or 12 inches) of the tape products, which could be laid down quickly. However, what ATL offered in speed and volume it sacrificed in conformability.

AFP, on the other hand, which lays down multiple tows 0.125 to 0.5 inch wide, found a place fabricating fuselage and other more contoured structures that demand maximum flexibility and conformability. However, what AFP offered in conformability it sacrificed in speed and volume.

Further, as enabling as these technologies were, they clearly reflected the state of ATL/AFP art at the time of the planes' initial development, almost 20 years ago now. Indeed, the production pace of the 787 and the A350 (each now less than 10/month in light of the coronavirus pandemic) is well-aligned with previous-generation ATL/AFP technologies, which are relatively slow. These technologies also depend on human operators to provide in-process visual inspection and quality control, checking for the laps, gaps, wrinkles, foreign object debris (FOD) and other flaws endemic to the automated laydown process. This quality control step represents a significant bottleneck in the manufacture of composite structures.

But as commercial aircraft manufacturers look to the future (well beyond the coronavirus pandemic) and the aircraft they will develop — particularly new single-aisle (NSA) programs to replace the Boeing 737 and Airbus A320 — shipset volumes are likely to be on the order of 60-100 per month. This demands composite materials and process capability orders of a magnitude more efficient than those used to fabricate structures for the 787 and the A350.

The best of both worlds

Thinking about all of this for the last few years has been Erik Lund, CEO of Fives Lund LLC and CTO of Fives Composites (Seattle, Wash., U.S.), a subsidiary of Fives Group (Paris, France), which also owns Fives Cincinnati, Fives Forest-Liné and Fives Liné Machines, which supply ATL and/or AFP machinery into the composites industry. Lund, in particular, has been contemplating ways to increase tape/tow laydown efficiency, studying and assessing the advantages and disadvantages of ATL and AFP in cooperation with the entire Fives Composites team.

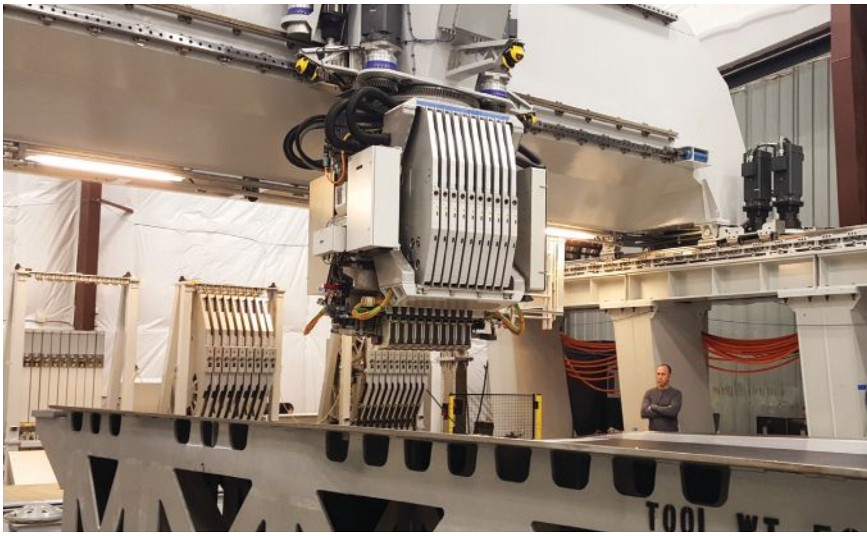
Understanding ATL and AFP strengths (and weaknesses) first requires an understanding of the design allowables environment in which these processes operate. Lund points out, whether a fabricator is laying down tapes or tows, there are process-induced errors that must be tracked and measured. For example, when two tapes or tows are laid down next to each other, ideally their edges should abut, so as to provide an uninterrupted, even ply surface. However, machinery and material imperfections can create laps and gaps. Laps — short for overlaps — occur when two adjacent tapes or tows overlap each other during the laydown process. Conversely, when two adjacent tapes or tows "drift" away from each other, a gap can be created. A lap or a gap by itself is not *necessarily* problematic, so the width of each must be measured, and any that exceed the allowables specified for the part must be brought back into conformity, usually via manual rework.

As noted, ATL's strengths lie in the fact that the process can quickly place large amounts of material over a large area. And as long as that area is flat or moderately contoured, tapes will not wrinkle or buckle. Further, because tapes are relatively wide, the total number of abutting tapes is relatively small, thus the opportunity for laps and gaps to develop is small compared to AFP. In this way, the ATL allowables environment is more forgiving.

Conversely, AFP, because it lays down multiple and smaller tows, can more easily steer those tows and conform material to complex and contoured surfaces. However, the opportunity for laps and gaps is greater — consider that a 24-tow AFP head alone theoretically presents 23 opportunities for laps and gaps — and thus they must be more closely monitored, often manually. Lund notes that many AFP allowables limit lap or gap violations over a given linear distance of material laid (usually 12 inches). Moreover, he says, laps and gaps that accumulate in a given area from layer to layer can also run afoul of allowables limits.

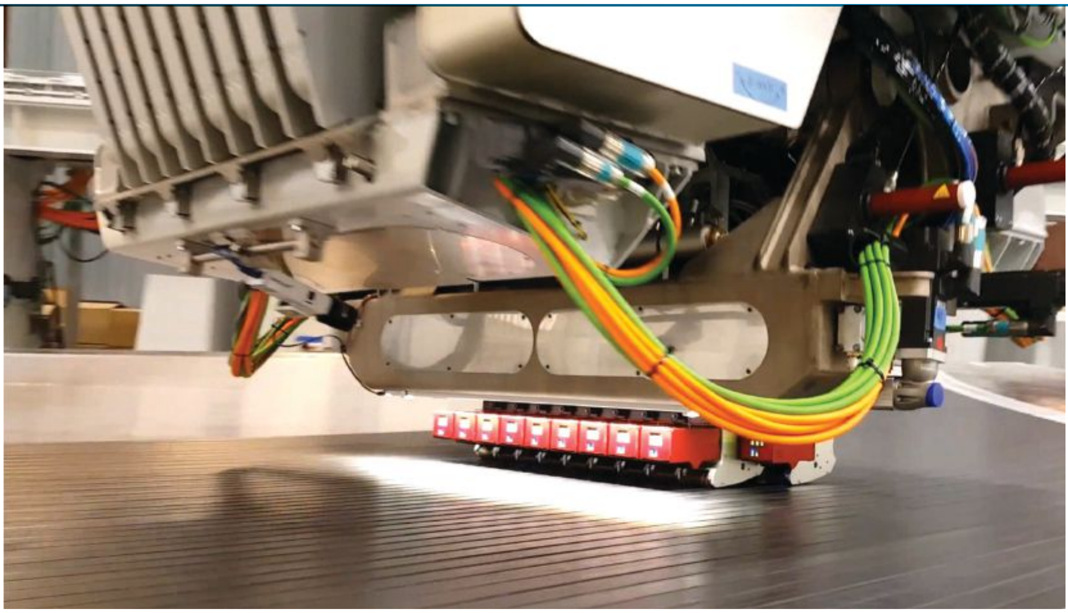
Another shortcoming of AFP is that the complex mechanical packaging in the laydown head leaves room for only so much hardware. As a result, all of the tows are compacted onto the tool surface by a single compaction roller. For wide AFP heads (24-32 tows), it can be difficult for the roller to provide uniform and consistent compaction pressure to each tow, which can affect ultimate laminate quality. For similar reasons, compaction consistency in ATL can also be a challenge, Lund contends, noting that "rework by operators, especially with 6-inch tape, can affect overall laminate quality."

The multiple tows in AFP, on the other hand, also provide a sometimes-overlooked benefit of the process: When placing material at a non-0 or non-90 degree ply boundary angle, an AFP head has the ability to independently cut each tow at the boundary and thus create a crenulated ply boundary. Such boundary crenulations help optimize material use in a way that is not possible with »



Changing the process

The Fives Lund SLALOM solution relies, in part, on individually actuated and compacted tape lanes. This enables substantially improved process control, including the ability to program laps and gaps according to allowables for the part. Source | Fives Lund



New technologies

Close-up of the Fives Lund Slalom ATL head. Each lane is individually controlled and actuated and allows for programmed laps and gaps.

Source | Fives Lund

ATL, which by necessity relies, says Lund, on "complicated cuts" to build an engineered ply boundary.

The solution: Narrow tapes

Lund says he and others at Fives Lund considered this complex world of fiber and tape placement and wondered if there was a middle ground to be exploited. They sought opportunities to leverage and integrate the advantages of ATL and AFP and focused on a material and process combination that is working today and shows substantial promise for next-generation, high-rate aircraft production.

"We were trying to achieve the conformability of AFP. We were also trying to get the benefit of crenulations at the boundaries," Lund says. "At the same time, we wanted the gap tolerances and allowables of ATL. The question was, 'What is the narrowest tape we can use that still employs tape allowables?'" The options were many, considering the narrowest tapes were 3 inches and the widest tows were 0.5 inch. However, Lund says, from an allowables and lap/gap tolerance perspective, there is a point at which a tape becomes a tow, and he wanted not to go past that point. "It took us about 30 minutes to settle on 1.5 inches as the tape width we would use," Lund remembers. "And we have thanked ourselves for that decision. What we developed would not have been mechanically possible with anything narrower."

> As a hybrid of AFP and ATL, narrow tapes offer features of both.

Of course, the system Lund developed is not just a head that lays down 1.5-inch tapes. As a hybrid of AFP and ATL, it has features common to both. First, each 1.5-inch tape lane is individually controlled for tape supply and has its own compaction roller, actuated independently from the other lanes. This allows compaction pressure to be individually programmed and controlled by tape lane. Second, as with AFP, each tape is individually added and cut at the ply boundary, which allows for the crenulations that Lund coveted.

Third, and perhaps most significantly, the system features inline sensing technology. This system works in conjunction with each independently positioned and servo-adjustable tape lane, which Lund says can easily control spacing between tapes. In short, the system allows programmable laps and gaps. Lund calls it "dial-a-gap" and says it gives the operator the option of programming overlaps or to open up gaps to meet different gap averages and to change each lane to a specific gap width. Further, the system can see patterns, measure standard deviations and then adjust to the overall mean or even for specific regions of the laminate.

"It statistically looks at lanes per pass and draws conclusions based on accumulation of data," Lund says. "You can then thin the laminate in certain areas if the gaps can be properly managed and controlled." Ultimately, says Lund, such tight process control, combined with machine learning, "represents the evolution of inspection to develop data you can trust. This elevates capability and expectations and minimizes variation."

Lund says this 1.5-inch tape machine — now commercialized as Fives Lund SLALOM — was developed in cooperation with Boeing, which owns some of the key intellectual property, including the independent compaction roller system. Fives Lund also worked closely with Boeing to qualify the 1.5-inch tape system. Three 19-lane Slalom machines have been in use for the last six years by Mitsubishi Heavy Industries (MHI, Tokyo, Japan) to fabricate wing skins for the Boeing 787. The three first-generation MHI machines, Lund says, add, lay and cut tapes at 0.6 meters per second. However, current technology being tested by Fives Lund has achieved aerospace tape laying tolerances and reliability with add speeds of 2.5 meters per second and lay/cut speeds of 4.5 meters per second using no heat to achieve consistent compaction. "There's not a lot of automation this size that goes that fast regardless of application," Lund says. "We underestimated the ultimate speed the composites would allow and had to redesign other manufacturing systems for the higher speeds and accelerations we wanted."

What the future may hold

Looking ahead at a potential single-aisle replacement program building 60-100 planes per month, Lund says 1.5-inch tapes are a good fit for the fabrication of stringers, spars, wing skins and horizontal and vertical stabilizers. They can also be used to build flat laminates that are subsequently shaped and pressed, allowing for tailored compaction and shear considerations.

LEARN MORE

Read this article online:
short.compositesworld.com/UDtape

Lund also acknowledges the biggest hurdle 1.5-inch tapes face is their "lack of institutionalization. There is very little history, very few channels in which to operate where 1.5-inch tape is being used."

That said, he believes narrows tapes answer the technical and rate questions the commercial aerospace industry is posing. Lund is thinking particularly about his 1.5-inch prepregged tapes compared to competing processes, like liquid resin infusion, which uses dry fiber. Airbus, through its Wing of Tomorrow program, is evaluating dry fiber infusion to fabricate wing structures for its single-aisle replacement. Lund argues that in a single-aisle production environment where carbon fiber composite wings are being fabricated, the critical process parameter will be tool start-to-start time: "The question is, 'How many tools do you need to meet rate?' Tools must be measured by throughput and utilization, and dry fiber processes doesn't free up that tool any sooner." With a well-managed 1.5-inch tape system, Lund contends, "you should be going from freezer to cure in two to three days max. If you can do that, then prepreg out-time is just part of the manufacturing 'noise.'"

Although the coronavirus pandemic has thrown a wrench into planning and development of new commercial aircraft, Lund believes the long-term outlook for commercial air travel is generally positive, and that development of next-generation materials and processes for this critical end market should and will continue at a brisk pace. "The commercial aerospace needs have driven the market for ATL and AFP, but as they recover we're looking to other industries that have less history to overcome with this new technology." CW

ABOUT THE AUTHOR

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Composites 4.0: Digital transformation, adaptive production, new paradigms

An evolving landscape of automation, sensors and AI software is not an end, but a means to achieve the cost, quality, efficiency and agility required for future manufacturing.

By Ginger Gardiner / Senior Editor

»Composites 4.0 is one small galaxy in the universe of Industry 4.0, which is the digital transformation in how goods and services are designed, produced, delivered, operated, maintained and decommissioned. For composites manufacturing, the goal is to use automation, sensors and data, 5G communications, software and other continuously evolving digital technologies to make products and processes more efficient, intelligent and adaptive.

Composites manufacturers are proceeding through this digital transformation along a spectrum. Initial steps include inline inspection and optimized processes that reduce waste and cost while increasing part quality and yield. More advanced solutions work toward intelligent, autonomous production that is not just agile, but responds to and even *anticipates* changing markets and customer demands.

"Composites 4.0 is not an end, but a tool," explains Dr. Michael Emonts, managing director of the AZL Aachen Center for Integrative Lightweight Production at RWTH Aachen University (Aachen, Germany), whose iComposite 4.0 project demonstrated an adaptive process chain with potential to reduce an automotive floor pan cost by 50-64%.

"There is a difference between just making things digital and digital transformation

No business case for teaching robots

The German Aerospace Center (DLR) developed a flexible automation platform for this work cell to build families of CFRP aerostructures that use the same process — dry noncrimp fabric, pick-and-place layup and resin infusion — to fabricate products like rear pressure bulkheads and fuselage panels. Collaborative robots are not taught, but instead define their own collision-free paths for picking and placing cut plies into a tool based on CAD and process definition inputs and AI algorithms. Such AI-driven automation is one basis for future smart Composites 4.0 factories.

Source | (top) DLR Institute for Structures and Design (bottom) KUKA AG

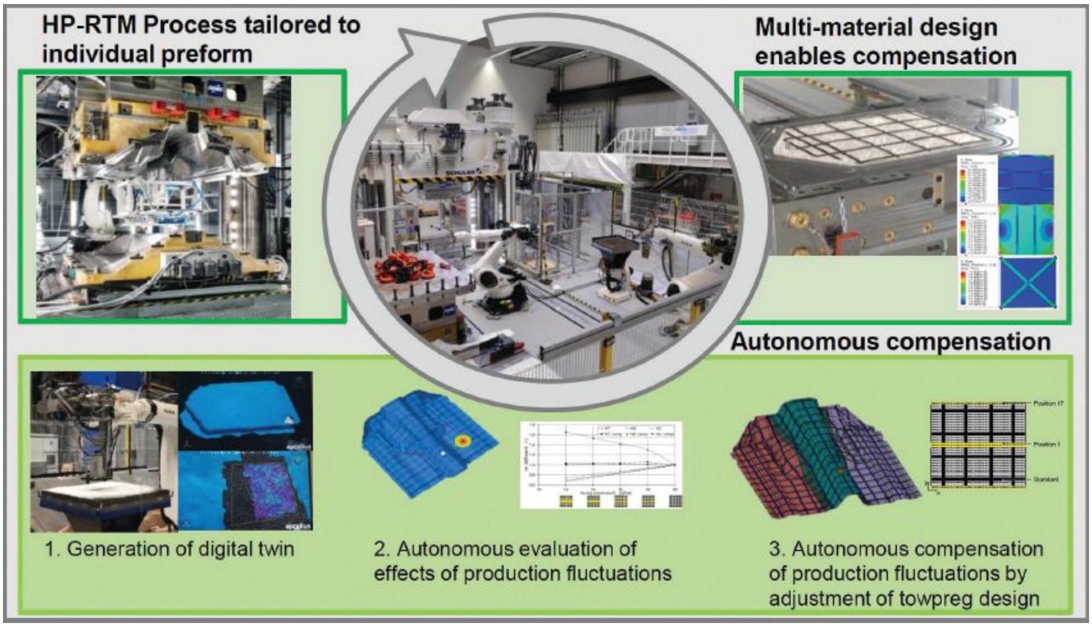


FIG. 1 iComposite 4.0 adaptive process

This AZL Aachen-led project combined 3D fiber spraying, automated UD tape laying and RTM into an adaptive process chain. Automation allowed the processes to react to each other based on preform quality, which is assessed by an optical laser between steps.

Source | AZL Aachen

that actually changes the processes behind your business and opens new opportunities and business models," contends Christian Koppenberg, managing director for composite parts producer Dynexa (Laudenbach, Germany).

"Composites 4.0 is not just using robots," asserts Dr. Michael Kupke, head of the German Aerospace Center's (DLR) Center for Lightweight Production Technology (ZLP, Augsburg), which has developed an artificial intelligence [AI]-equipped work cell where collaborative robots can switch from producing composite rear pressure bulkheads to fuselage panels without reprogramming or retraining. "It is the technology that ensures you don't have to teach the robots, because there is no business case for that. Composites 4.0 is more than just increasing efficiency and cutting cost. It is a change in how companies think about and approach production that will determine which companies survive and which do not."

> "Markets are becoming more fragmented across all industries and everyone is facing a paradigm shift."

Adaptive preforming, RTM

"The idea of the iComposite 4.0 project was to create preforms from cost-effective rovings and tows by combining dry, long glass fiber (25-30 millimeters) sprayed and subsequently reinforced with a grid of unidirectional (UD) carbon fibers via automated fiber placement (AFP)," Emonts explains. "The chosen demonstrator, a rear under-vehicle floor pan, was previously made with more costly textiles which also produced more than 60% waste."

The Composites 4.0 transformation required integration of the fiber spraying, fiber deposition and subsequent resin transfer molding (RTM) processes so that they reacted to each other and adapted based on the part quality measured between steps (Fig. 1). "We used a machine vision system from Apodius GmbH [Aachen, Germany] with an optical laser sensor and a camera module to characterize the surface topology of the sprayed preform," Emonts says. "Apodius adapted the software to analyze the percentage of fibers in each direction. The iComposite 4.0 line compared this to the digital design and decided if it met the mechanical requirements. If yes, it applied the standard UD grid for reinforcement. If no, it decided where to place additional UD fiber layers."

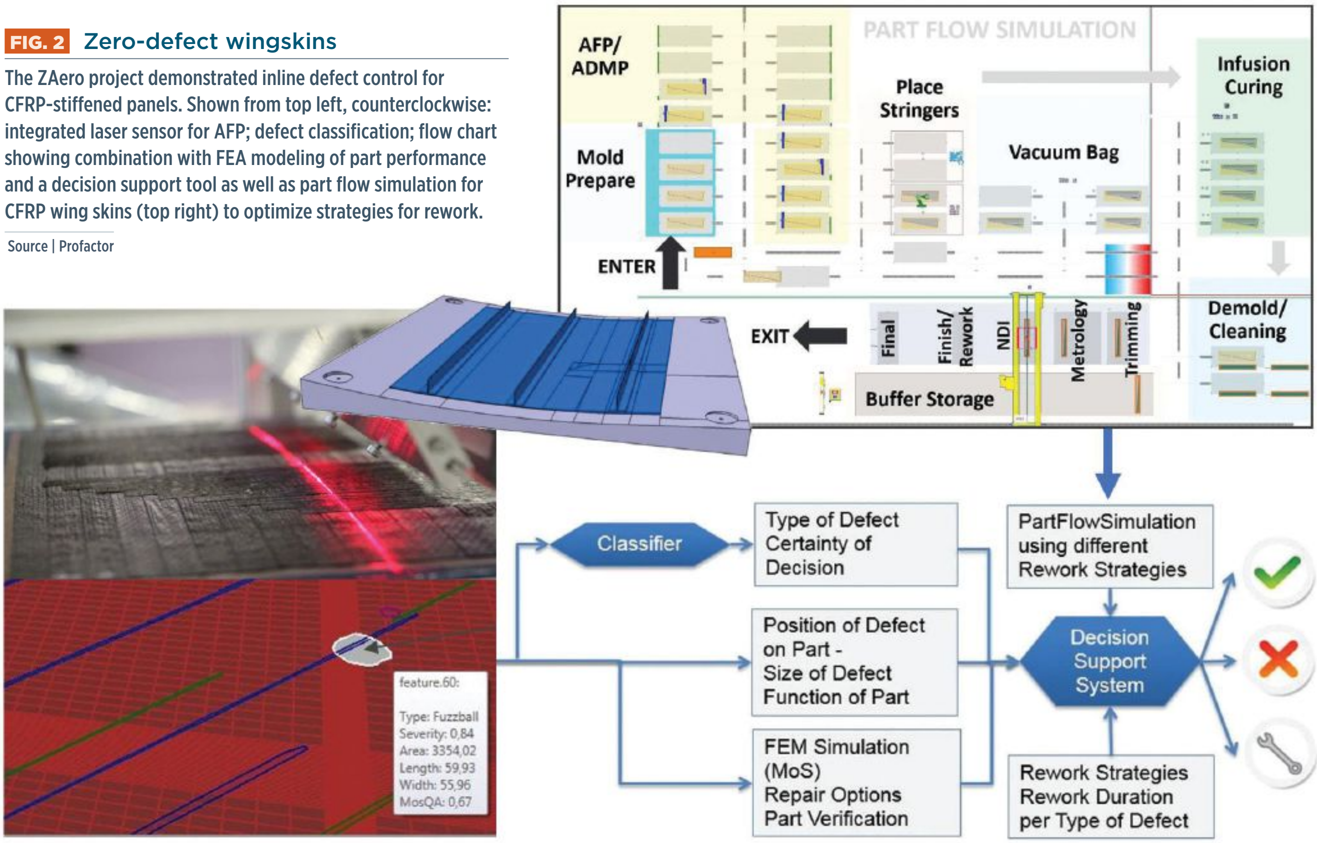
However, these additional UD layers could cause part thickness and geometry to exceed tolerances. "Therefore," he explains, "we combined the preforming line with an adaptive RTM process which, if necessary, adjusted the part thickness by increasing pressure on certain parts of the press." This too was automated, with the aim to replace intervention from the line operator, but it did require simulation of part performance using measurement data and standard FEA software.

"Currently, simulation of the part mechanical properties is performed offline," Emonts says. "We generated a database of process and part variations, created algorithms to react to each variation and validated these via FEA. Thus, based on the variations measured by the line, the algorithms directed it to perform an appropriate mitigation. To make the line adaptive in-situ, the next step would be to add machine learning." Meanwhile, AZL is pursuing numerous Composite 4.0 projects including self-optimized production of hybrid thermoplastic composites and »

FIG. 2 Zero-defect wingskins

The ZAero project demonstrated inline defect control for CFRP-stiffened panels. Shown from top left, counterclockwise: integrated laser sensor for AFP; defect classification; flow chart showing combination with FEA modeling of part performance and a decision support tool as well as part flow simulation for CFRP wing skins (top right) to optimize strategies for rework.

Source | Profactor



injection molded parts with integrated stiffening of tape-based tailored blanks.

Zero-defect CFRP wingskins

The ZAero project (see Learn More) is another key Composites 4.0 project, started in 2016. It aimed to increase productivity for large carbon fiber-reinforced plastic (CFRP) structures such as wingskins. Defects would be reduced by using automated inline inspection with either prepreg AFP or Danobat's (Elgoibar, Spain) automated dry material placement (ADMP, Learn More). Process monitoring during resin infusion or prepreg cure would predict state of cure and shorten cycle time. Collected process and defect data were used with FEA to predict part performance. This was then input into a decision support tool for how to address identified defects. A part flow simulation for CFRP wingskins was developed that, when fed into this tool, helped to optimize a rework strategy (Fig. 2). Today, many such parts are reworked during manufacturing, but only after NDI. Earlier rework and improved process control were indeed goals of the ZAero project, as well as enablers for its targeted 15% increase in production rate, 15-20% reduction in production cost and 50% less waste.

By the September 2019 final review, the prepreg AFP sensor developed by project leader Profactor (Steyr, Austria) not only achieved automated inline inspection, but could also be used to correct parts in-situ. "This sensor can detect the standard defects such as gaps, overlaps, FOD [foreign object debris], fuzzballs and twisted tows, as well as early and late cut of each tow," says Dr. Christian Eitzinger, head of machine vision for Profactor. A missing tow can be corrected automatically with the placement of an additional tow where it was omitted. The machine must be stopped, however, to remove fuzzballs or a twisted tow. "A database built using Dassault Systèmes' (Paris, France) 3D Experience for CATIA allows us to calculate the effects on the part's performance based on the size, shape and type of defect. Processing all defects in a ply takes only seconds. The machine operator then decides what defects can be left and what must be reworked."

For infusion process monitoring and control, Airbus (Toulouse, France) worked through subsidiary InFactory Solutions (Taufkirchen, Germany) to develop three sensors that measure temperature, state of cure and resin flow front (Learn More). "We have integrated these with CATIA 3D Experience and shown that the data can be reliably acquired and added to each part's digital thread," Eitzinger says. (Learn More.)

The final of three part demonstrators was an upper wing cover subsection with three stringers. For this part, Profactor's decision support tool was demonstrated live at partner FIDAMC (Madrid, Spain), connected to the part flow simulation — based on Siemens PLM (Plano, Texas, U.S.) Tecnomatix Plant Simulation software — running on Profactor's server in Austria. In addition to building a defect database, ZAero conducted experiments with machine learning. Manually designed, generative computer models combined with deep neural networks detected and classified defects, achieving

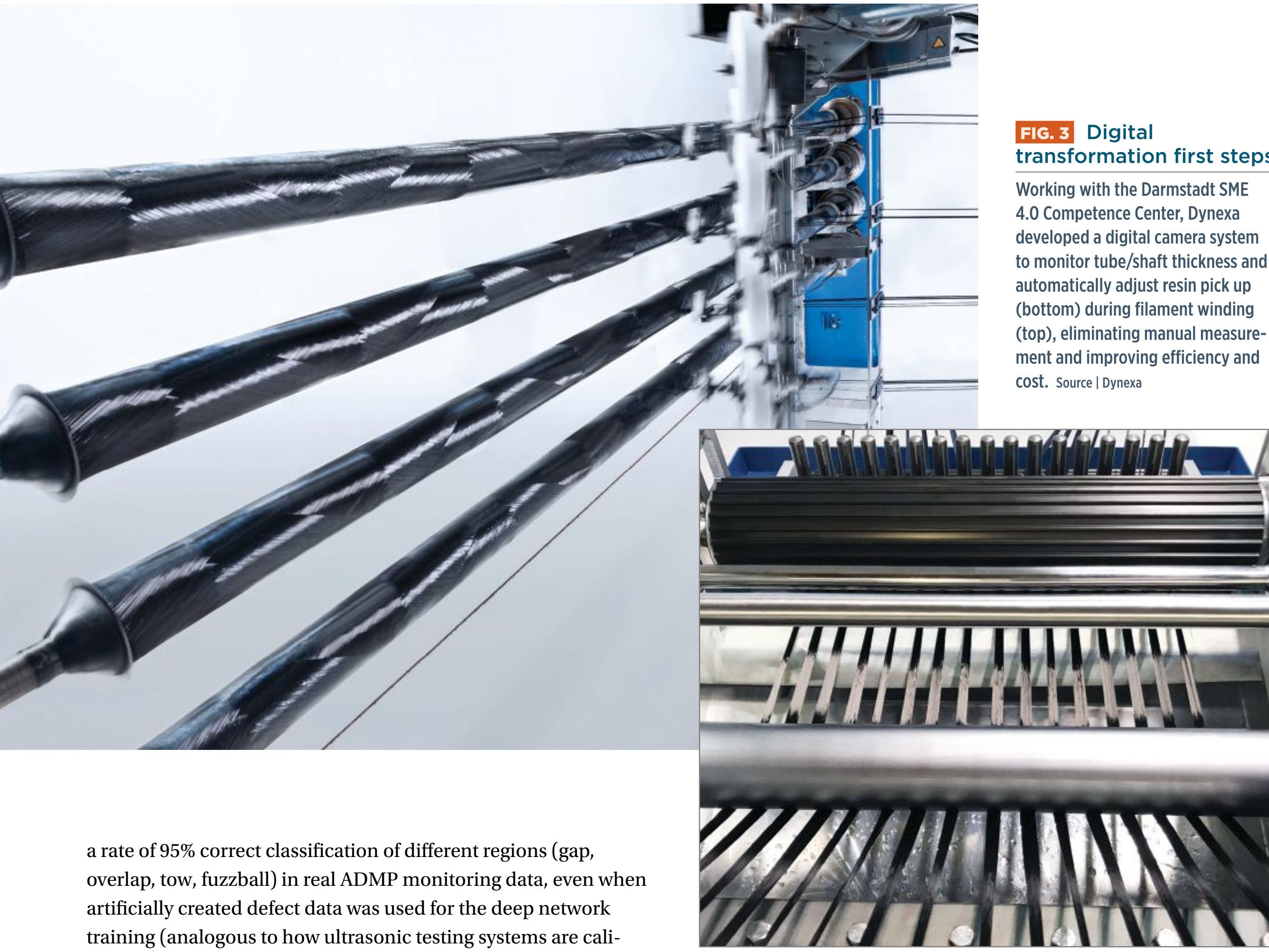


FIG. 3 Digital transformation first steps

Working with the Darmstadt SME 4.0 Competence Center, Dynexa developed a digital camera system to monitor tube/shaft thickness and automatically adjust resin pick up (bottom) during filament winding (top), eliminating manual measurement and improving efficiency and cost. Source | Dynexa

a rate of 95% correct classification of different regions (gap, overlap, tow, fuzzball) in real ADMP monitoring data, even when artificially created defect data was used for the deep network training (analogous to how ultrasonic testing systems are calibrated on a range of deliberate defects).

"We will definitely pursue some kind of next phase," Eitzinger says. Meanwhile, Profactor is commercializing modular sensors for fiber orientation and defects during automated layup. InFactory Solutions is also offering its AFP and resin infusion sensors, and fiber placement partners Danobat and MTorres (Torres de Elorz, Navarra, Spain) are now selling their equipment with integrated inline inspection.

Dynexa's digital transformation journey

Dynexa is a composite parts manufacturer specializing in CFRP tubes and shafts. "We had always tried to digitize everything," Koppenberg says. "We already got rid of manual and analog processes, integrating everything mostly into our ERP [enterprise resource planning] system. But how do we do this in manufacturing? We understood that everything we put into a worker protocol or procedure is a code, and this is a basis for digital transformation. But where is it stored? On a local server, in the cloud or within the machine? We would ask five people and get seven answers as to what we should do." (Learn More.)

Fortunately, the German government had set up a program for universities to provide free Industry 4.0 consulting for small and medium enterprises (SMEs). Dynexa began work with the Darmstadt "Mittelstand (SME) 4.0" Competence Center. "They said not to worry about the digital architecture but look more to what you need to measure and how to do that," recalls Koppenberg. "We picked one process that involved significant manual measuring, where we knew we had quality, time and cost issues."

Dynexa uses a wet filament winding process (Learn More). A key step is resin pick up, where the dry fiber is run onto a compaction roller that rolls up out of the resin bath. Sitting against the compaction roller is a doctor blade that determines the amount of resin to be combined with the dry filament before it's wound. "If we pick up too much resin, we may exceed the specified tube diameter," says Koppenberg, "but with too little resin, we risk falling below the minimum diameter allowed."

"Without measuring, you only know the final diameter after cure, when all of the value has been invested," he points out. "So, the operator must stop the machine, measure the part, write it down and then restart. From years of experience, we know what the laminate thickness should be at each stage of winding. Thus, the operator compares the measurement and adjusts the doctor »

FIG. 4 On-demand Manufacturing Portal

Airborne launched its online portal for composites in 2019 (top) where customers enter designs and receive cost and estimated delivery for laminates/parts made by Airborne's automated manufacturing cells, including, in a future extension, the Falcon high-volume thermoplastic composites line developed for SABIC (bottom). Source | Airborne

blade to correct resin pick up as necessary, but this is very manual and relies on operator skill and experience."

To digitize this, Dynexa talked to myriad laser and camera manufacturers. "They would say, 'we have the solution' but then no one could make it work," Koppenberg says. The University of Darmstadt team, however, enabled use of a camera by figuring out the corrections needed due to certain physical factors, such as light reflection from the wet surface. "Now, we have the winding machine connected to the measuring device, which operates in a very standardized way," he adds.

The team developed a database of correction tables and decision algorithms that enables the filament winding machine to know what the target needs to be for each stage of the specific tube being wound. "If the measuring device input shows that the resin pick up is not where it should be," explains Koppenberg, "the filament winding machine responds by adjusting the doctor blade to bring it back into spec without stopping winding to measure."

Every winding machine now has the digital measuring system, *and* an ethernet card. "The most expensive part was installing and running the cables to the server," quips Koppenberg, "but now we can talk to every machine and collect all the data." And there is another benefit. "Before, operators were programming at the machines, but once we connected them to the server, we can program at any desktop or laptop computer. This has further reduced downtime and removed another production bottleneck."

This first digital step has allowed Dynexa to improve its process control, quality and efficiency, allowing it to become more cost-effective. It has also spurred further transformation.

Changing paradigms for composites

"We are in a stepwise process of providing a new ecosystem for our customers," says Matthias Bruckhoff, Dynexa's head of sales and marketing. He gives an example: "In Amazon, you can see what you have bought and when, as well as suggested new products. We used to take customer requirements and then respond in a few days using our calculations and engineering tools. Now, this will be online. Our customers will look at products and calculate what they need, cost and delivery in a matter of minutes. This is not new, but it *is* for our industry. Just as we freed up our machine operators to focus on more machines and higher-level tasks, we will now free up our engineering team to focus on more specialized and sophisticated products."

Airborne (The Hague, Netherlands) launched its On-demand Manufacturing Portal for automated manufacturing of composites in September 2019 (Learn More). Using this tool, customers enter designs into the web-based platform. The system then creates the machine code on the fly and determines the production duration and cost. Products can then be customized and, once ordered, produced in an automated manufacturing cell. The portal was launched using Airborne's Automated Laminating Cell (ALC) to process thermoset prepreg. It will be extended to other processes, for example, the high-volume thermoplastic composites (TPC) production line developed for SABIC's (Riyadh, Saudi Arabia) Specialties business unit.

"This portal is a key building block of how we see the digital future of composite manufacturing," says Marcus Kremers, chief technology officer at Airborne. "Five years ago, we changed from a parts manufacturing business model to helping customers with automation and digitization. We are developing a portfolio of solutions that make it easy for customers to build with composites." This portfolio includes the ALC, automated honeycomb potting, automated ply kitting and the high-volume line using TPC tapes, dubbed the Digital Composites Manufacturing Line (DCML) by SABIC and Falcon by Airborne. The latter is an example of Airborne's bespoke solutions. "We are embedding our composites materials and parts manufacturing knowledge into these automated systems so that the customers don't have to be specialists," Kremers says.

Airborne has three business models: buy the automation, rent it or leave it with Airborne to operate via manufacturing as a service (MaaS). Airborne automated cells have sensors and inline inspection systems that generate alerts based on a database of defects and tolerances defined by the customer. "The Falcon line has very low tolerances for visual quality defects," Kremers notes, "but our automation for aerospace is more driven by structural tolerances. We are also continuously advancing our technologies to be self-learning and self-adaptive. For example, our next software version for ALC tape laying will have the ability to identify defects and amend the production program on the fly."

Longer term, the vision is to expand the on-demand portal to collect composite parts production capacity distributed across multiple companies and regions. Kremers cites Protolabs (Maple Plains, Minn., U.S.), which provides injection molded, sheet metal, CNC machined or 3D-printed protoypes on-demand in as little as a day. Similarly, Plyable's (Oxford, U.K.) (Learn More) online app provides molds to manufacture composites, offering materials ranging from polyurethane board to steel, including composite and 3D-printed tools. "That is a different way to organize the value chain," Kremers says. "We are making the machines and software that will make this possible for composite parts."

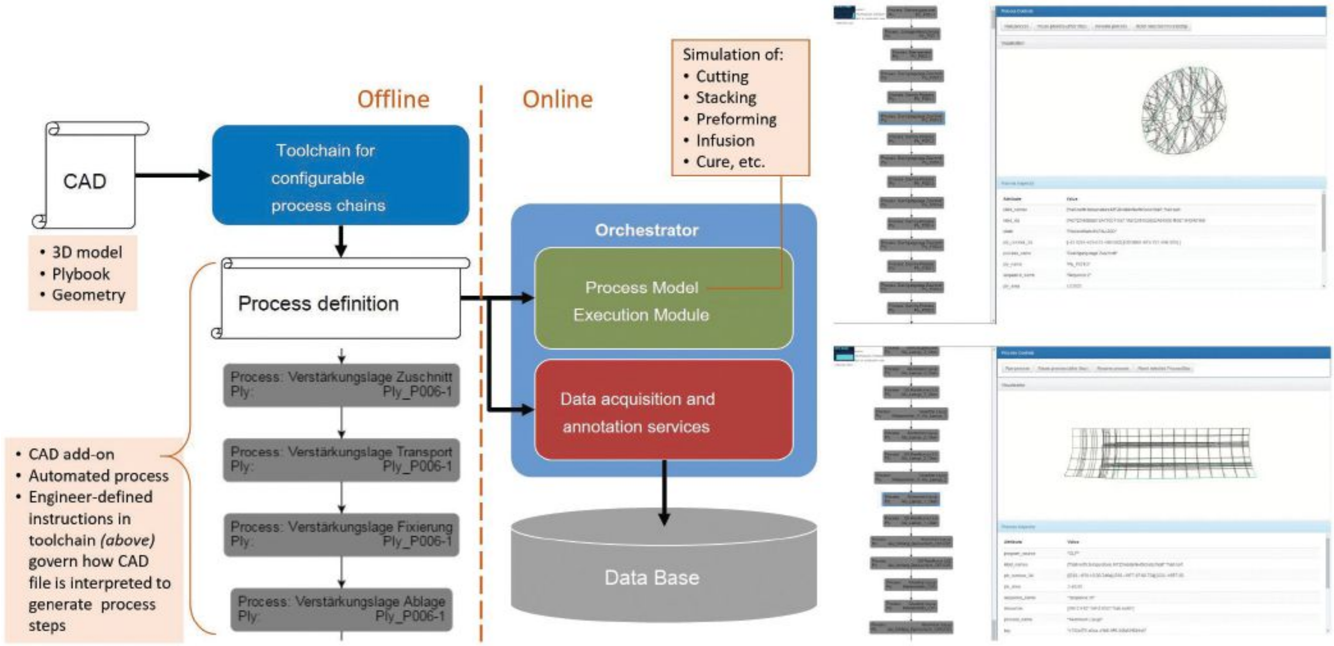
AZL Aachen is also pursuing this goal with its Ultra-Fast Consolidator Machine, developed to produce multi-layer TPC laminates in less than five seconds. Commercialized in 2019, it uses Conbility (Aachen, Germany) robotic, laser-assisted AFP applicators and 25-millimeter-wide UD tapes as well as a piece-flow principle — state-of-the-art in the high-speed printing industry — to produce TPC laminates, simply tacked or fully consolidated, in a variety of thicknesses, with local reinforcements. "Our vision is to provide scalable machines that will enable online platforms," Emonts says. "Lines can have multiple stations, each with multiple AFP applicators. The customer will enter the requirements and get options for plybook, cost and delivery. Once finalized, the applicators communicate to each other to organize production, not the operator. This is completely intelligent production of tailored composites."

Automating the automation

The ZLP's main focus is automated production of CFRP structures. "Automation for just one part or program is hard to justify," notes Florian Krebs, ZLP team leader for flexible automation. "However, if you move beyond task-specific machines to an automation platform that is reconfigurable with almost no additional setup, now you have a business solution. The more flexible the platform, the quicker the return on investment."

The work cell shown in the opening images (p. 30) was designed as part of the ZLP project PROTEC NSR to build a family of parts that follows the same process route: pick-and-place layup of dry noncrimp fabrics and resin infusion (Learn More). "This process was designed for the Airbus A350 rear pressure bulkhead, but you could also make a fuselage panel or a wing cover on this line because the steps are similar," says Krebs.

"To achieve flexible automation platforms requires certain technology bricks, including algorithms for the robots, as well as sensors and how to understand the data they produce," Kupke says. "For example, the PROTEC NSR production line is designed toward maximum modularity — all modules interconnected to each other to demonstrate a self-configuring, -correcting and -optimizing system, scalable in size and complexity." »



He explains the modules as shown in Fig. 5, which include CAD model, process definition, process model that allows simulation and execution of the process, manufacturing execution module, sensors to acquire data, software to annotate the data and database for storage.

"On the left side of this diagram, you make a plan. The execution module then implements that plan," says Kupke. "During the process steps, we acquire data from all involved machines and processes — for example, the cutter, the robots, the building (temperature, pressure, humidity), the cameras during pick-and-place, etc. We analyze the data in real time during the process and also annotate the collected data automatically with metadata to feed it into the database, which forms the basis for the digital twin of the process. The most important point of the digital twin is to have one central repository, one source of truth. Each part's CAD model and process definition are part of its single source of truth."

With these modules in place, the line operates autonomously with the push of a button. From the CAD model, production plan and cameras, the robots infer which cut piece comes next and look for it on the table (e.g., from 100 other cut pieces). "They decide how to configure the grippers to pick it up and lay it in the tooling, and know where to place it." Based on the production plan, the robots determine each start/end path for all of the process model and know when each is done. "Usually, these paths are taught by a human," Kupke notes. "But in our system, each path is defined automatically, collision-free and in real time. If you change the CAD model or the process definition, then the robots will adapt without any additional teaching effort. But what if you change the part completely? With this type of automation, you could make that change very quickly. This is the route to flexible production. Our role at ZLP is to pave this route by developing technology bricks and linking them together."

FIG. 5 Digital structure for flexible, intelligent automation

For the PROTEC NSR project, ZLP developed a flexible automation platform that can produce a CFRP rear pressure bulkhead (top right) or fuselage panel (bottom right), and switch between these quickly by simply changing the CAD file. Engineered-defined instructions in the toolchain (dark blue box) govern how to interpret the CAD data to automatically generate new process steps.

Source | DLR Institute for Structures and Design

Opportunity and ontology

The COVID-19 pandemic has highlighted the value of flexible production. It also has created an increasingly unpredictable business environment. "In the last two to three years, everything has gotten more volatile," notes Dynexa's Bruckhoff. "Our customers want answers very fast, in order to respond to their customer. By offering our new online ecosystem, we make the whole supply chain more competitive."

This is well-recognized by the aviation industry. "We need a digital basis for production lines and whole sites that enables both horizontal and vertical integration," says Marc Fette, chairman of the aerospace technologies division of the German Association for Engineers and COO for Composite Technology Center (CTC, Stade, Germany), an R&T subsidiary of Airbus. CTC projects in Composites 4.0 include material and asset tracking, collaborative robots, advanced process chains and more. But Fette stresses the need for ontology — a terminology and common protocol for digital communication and data exchange (Learn More).

"You need a holistic networking for all the machines and production systems in a given plant," he explains, "but this must also extend to the entire value-creation chain, including disciplines such as engineering, procurement, logistics and materials and process certification, on the one hand. On the other hand, all stakeholders, such as suppliers, have to be considered and involved in this change process. We see a lot of pilot projects, but when you look in detail, there is still a lack of strategy for a holistic approach per company or production chain."

He continues: "We have a very large, global network of suppliers and they have the same requirements in order to operate as a digitally connected supply chain. Most of our suppliers are SMEs working for both aircraft manufacturers, Airbus and Boeing. If there is no discussion about a common standard, then you pass these challenges on to the suppliers. They most likely cannot afford to comply with two sets of differing standards for all of their machines, including documentation, assessing data, cyber security, etc."

Fette concedes these are big ideas and says that aircraft OEMs are creating plans to address these challenges. "But there are many obstacles like this, and it's really complex, involving not just technology but social, economic, ergonomic and legal issues — it's a change process mentally. We are just at the beginning. But to succeed, we must understand that these new systems rely on people and these people must be on board, not just at OEMs, but in the whole global network."

"Markets are becoming more fragmented across all industries and everyone is facing a paradigm shift," notes ZLP's Kupke. "Many people don't see that as an opportunity." But those who do envision democratized access to composites enabled by Composites 4.0, and with that, a much broader market, including applications that we are only beginning to conceive. CW

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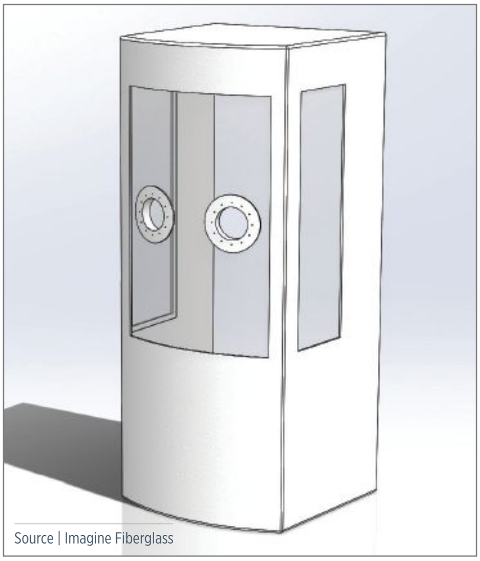
Fiberglass composites enable lighter, sturdier COVID-19 testing booth design

Canada-based Imagine Fiberglass' IsoBooth station is designed to eliminate the need for PPE by healthcare workers testing patients for COVID-19.


Source | Imagine Fiberglass


Source | Imagine Fiberglass

Inspired by a polycarbonate and aluminum COVID-19 testing booth designed and built by Brigham and Women's Hospital (Boston, Mass., U.S.) earlier this year, Imagine Fiberglass Products Inc. (Kitchener, Ontario, Canada) has developed its own lighter, sturdier version using fiberglass-reinforced composites.

"We felt that we could create a booth that could be deployed quickly in many different settings by making it extremely lightweight, sturdy and portable," says Jim Ashton, president of Imagine Fiberglass.

The company's IsoBooth, which is based on a design originally developed by Harvard Medical School researchers, allows a clinician to stand inside, apart from the patient, and administer a swab test from gloved external hand ports. A shelf or customized tray on the front of the booth holds test kits, supplies and a canister of sanitizing wipes used to clean the gloves and the shield between patients.

"The IsoBooth is intended to give healthcare providers a safe and comfortable place to administer tests while significantly reducing the amount of PPE [personal protective equipment] consumed by traditional testing methods," Ashton says. "The booth can eliminate as much as 143,000 pounds of biomedical waste per 1 million tests."

He adds that the United States alone intends to ramp up to as many as 5 million tests per week, which would produce up to three quarters of a million pounds of waste in the form of disposable gloves, face masks and other PPE per week using traditional methods. The IsoBooth could lead to significant cost savings and reduce biomedical waste, he says.

Imagine Fiberglass' design incorporates three clear polycarbonate viewing panels attached to three tinted fiberglass gun roving/polyester panels reinforced with polypropylene honeycomb core in places that require additional stiffness. The composite panels are open molded and coated with a white gel coat exterior. "Once demand picks up, the process will be converted to light RTM [resin transfer molding]," Ashton says. The polycarbonate panels and arm ports are machined on Imagine Fiberglass' CNC router; the only parts not made in-house, Ashton says, are the gloves.

The booth weighs about 90 pounds, can be easily carried by two people, and at 33 inches deep, is designed to fit through most standard commercial doors.

According to Ashton, there are several other competing booths that have been designed, but most of these rely on polycarbonate or acrylic panels that are fastened together at the corners with aluminum. "[These are] more fragile and awkward to move, and also considerably heavier," Ashton says.

Besides light weight and durability, the molded composite booths are also tapered from back to front, allowing multiple units to be nested on a skid for shipping or for storage. In contrast, Ashton says competing plexiglass booths would require a larger storage room or transport vehicle, or would have to be disassembled and reassembled for transport or storage.

After consulting with Dr. Kris Olson, director of the Consortium for Affordable Medical Technologies at Harvard University, Imagine Fiberglass designed its booth's arm ports to be oval-shaped, allowing maximum range of motion. The design also incorporates a clear polyvinyl chloride (PVC) curtain at the back of the station so that HEPA-filtered air can be pumped into the unit, eliminating the need for the healthcare provider to wear a mask, gown, face shield or goggles.

In addition, the booths are built to last for years. Ashton envisions the IsoBooth being used in COVID-19 testing facilities, emergency rooms, ICUs and pharmacy clinics. IsoBooths could also be used in workplaces as companies implement testing procedures as employees return to offices.

"Our intent has always been to reduce cost and environmental waste by eliminating disposable PPE for COVID-19 testing," Ashton adds. "The IsoBooth is also a big help when there is a huge shortage of PPE, as there is today. An IsoBooth can be paid for in as little as one day of testing, depending on the current cost of PPE and the number of tests per day." CW

New Products

»DISPENSING AUTOMATION

Automated sealing for aircraft components

Source | Broetje-Automation

Supplier and distributor of automated systems for aircraft construction, Broetje-Automation (Rastede, Germany), presents its automated solution for sealing aircraft components. Meant to replace the time-consuming process of manually sealing edges of aircraft parts, the company claims the product's modular system will enable faster production by carrying out sealing applications safely and cleanly, and with high precision and effectiveness, even on complex components. Broetje-Automation claims the concept saves up to 20% in overall efficiency, while improving the quality of the components.

Broetje-Automation gave the sealer a modular structure to meet the complexity of aircraft components, including processing components at precise locations to avoid contamination; cleanly sealing hard-to-access, curved surfaces and joints; and mixing difficult-to-process sealants for the aircraft components themselves. Depending on the application, the system can be operated autonomously within a robotic cell or with small, collaborative robots (cobots). The system also provides a "digital twin," which is integrated into the automated NC programming environment SOUL OLPS and can fully simulate the processes. The system, the company states, is thus optimally prepared for use in digital factories.

Further, to meet global customer requirements, the technology team at Broetje-Automation has developed various end-effectors for application of materials. The system can use polysulfide and epoxy sealants using pre-mixed cartridges or with a "mix-on-the-fly" module that can combine several components in-process during sealant application.

Four types of sealing — with individually developed special nozzles — are currently available: Fillet sealing (e.g., for clips, stringers, frames), cap sealing (for sealing of rivet heads), epoxy edge sealing (for composite components) and complex shapes (curves, connections). broetje-automation.de


Source | Capture 3D

»3D SCANNING TECHNOLOGY

Blue light 3D scanning technology

Capture 3D (Santa Ana, Calif., U.S.), a provider of 3D measurement solutions and the official U.S. partner of GOM GmbH/Zeiss (Braunschweig, Germany), has added the compact ATOS Q to its ATOS blue light 3D scanning product line.

Reportedly serving a range of end markets including aerospace, automotive, consumer, medical and power generation, ATOS scanners are used throughout product development, quality control, near-line and in-line production to accurately obtain a digital blueprint of parts, components, assemblies, tooling and molds. According to Capture 3D, ATOS captures millions of accurate points through quick scans to create a high-definition file with intricate feature detail, whether the object material is cast, formed or injection molded. Capture 3D says ATOS Q has been designed to combine high-tech electronics and optics with robust design and versatile software, delivering high-precision measurement results across diverse applications.

Designed for industrial use, the ATOS Q is engineered with 8 million or 12 million points per scan (PPS), a bright blue LED Light Equalizer and Triple Scan technology, the combination of which is said to reduce the number of individual scans needed and to accelerate measurement time, even of complex parts. The scanner's compact design is suited for applications in dimensional inspection, reverse engineering, rapid prototyping, CFD/FEA analysis, digital assembly and other manufacturing processes. ATOS Q features a fiber-optic connection enabling rapid data transmission, an intelligent self-monitoring calibration system and active temperature management.

The system can be configured with a tripod, an industrial camera stand or a desktop stand, or it can be fully automated with the ScanBox 4105. The company says it is also can be integrated with rotation tables or a tilt-and-swivel system for semi-automated applications. Catering to various measurement requirements, it has five interchangeable measuring volumes from 100 by 70 mm^2 to 500 by 370 mm^2. Like other ATOS scanners, the system is supported by GOM Inspect Suite software. **capture3d.com, gom.com**

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Composites-intensive masterwork: 2020 *Corvette*, Part 1

Eighth-generation vehicle sports more composites and features parts produced using unique materials and processes.

By Peggy Malnati / Contributing Writer

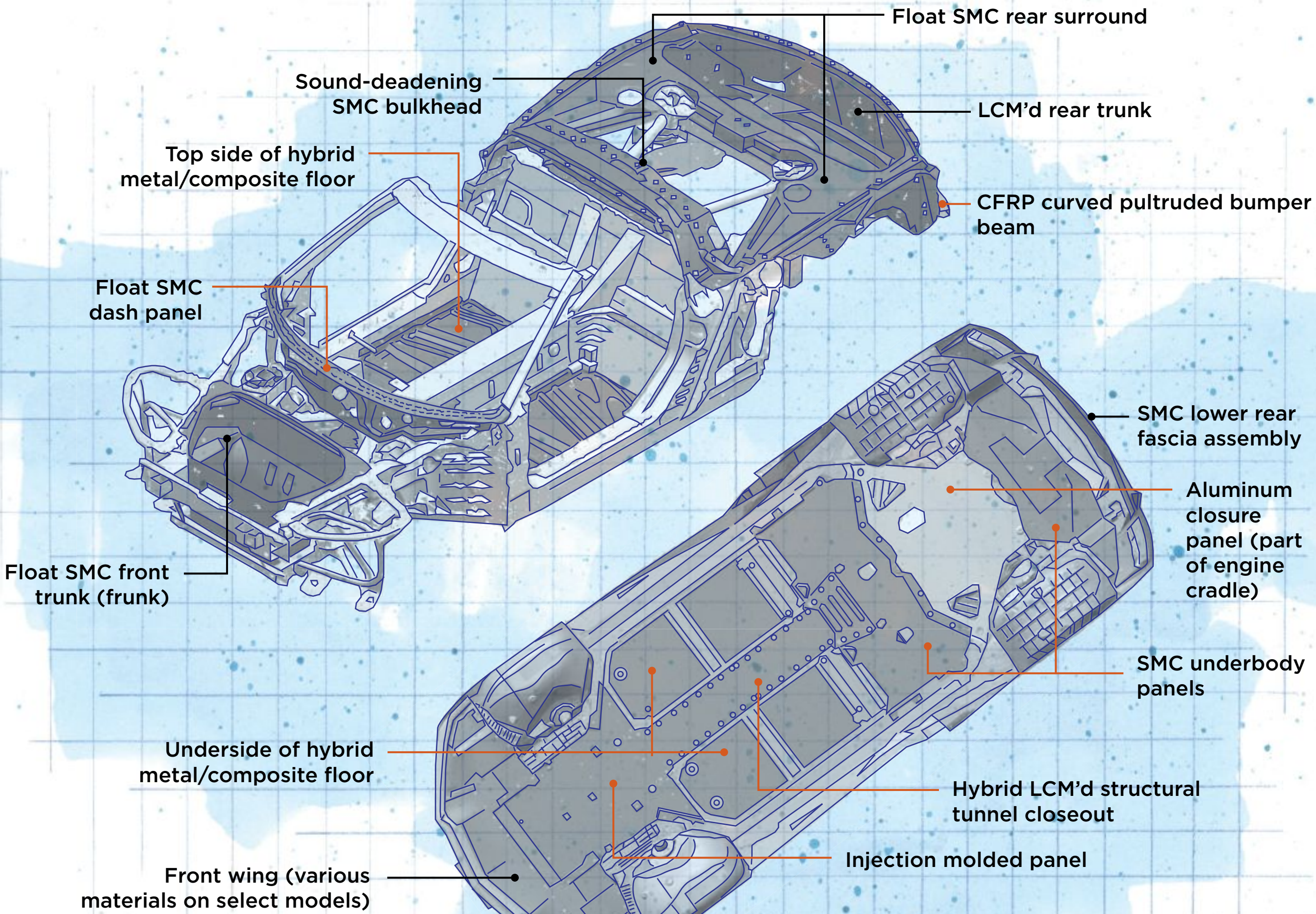
Eighth-generation lineup

The eighth-generation Chevrolet *Corvette* — all eight generations (C1-C8) shown above, left to right respectively — from General Motors Co. started production earlier this year. This mid-engine sports car is not only impressively fast, and the most composites-intensive *Corvette* yet, but it features an array of genuinely innovative composites applications. Source | General Motors Co.

» The much-anticipated eighth-generation Chevrolet *Corvette* (C8) from General Motors Co. (GM, Detroit, Mich., U.S.), which has been generating accolades since its official reveal on July 18, 2019, began commercial production earlier this year. The new *Corvette Stingray* convertibles and coupés are notable not only for their beauty and the fact that GM has produced a high-performance, street-legal, mid-engine rocket ship starting at less than $60,000 USD — one-third the price of comparable-performance mid-engine cars — but they also sport an impressive array of new and genuinely innovative composites content, which we'll describe here and in Part 2 next month.

GM engineering went into preliminary design knowing they'd be working on a mid-engine vehicle — the first production *Corvette* in eight generations to sport that configuration. "We evolved the front-engine architecture as far as we could for performance, so shifting to a mid-engine design was the next logical step to improve an already great car and be the segment leader," explains GM's Tadge Juechter, executive chief engineer-Global *Corvette*. Equipped with the Z51 performance package, the 2020 *Corvette Stingray* can accelerate 0-60 mph (0-97 kmh) in 2.9 seconds and reach top speeds of 194 mph (312 kmh). Pushing the engine toward the vehicle's rear affected many things, including the car's center of gravity, the relative position of occupants, transmission location and design of underbody panels and trunk storage. The mid-engine design also introduced higher operating temperatures and noise to new areas of the car.

"Because of the mid-engine, we had to do things differently," explains Ed Moss, *Corvette* body structure engineering group manager. "From the start, we had so many discussions about how to lay out the body structure. At one point, everything was on the table as we discussed the best way to design and build each system. For example, we debated metallic versus composite for wheelhouses. If we'd kept the C7's composite wheelhouses, we'd have to bond to the hinge pillar [A pillar], which is immediately adjacent to the front wheel in a mid-engine vehicle, leaving very



Parts marked with orange rules are referenced in Part 1 (July 2020 CW); parts marked with black rules are referenced in Part 2 (August 2020 CW).

DESIGN RESULTS | Mid-engine *Corvette*

- To meet rear styling, packaging and performance requirements at GM's demanding dollars per kilogram targets, a unique curved pultruded CFRP bumper was used, reducing mass 66% vs. aluminum.
- To reduce mass in structural parts while meeting performance requirements, float SMC (with SG < 1.0) was used extensively on non-Class A parts — many of them in low-VOC formulations.
- A hybrid structural lower tunnel closeout panel in LCM'd carbon/glass composite contributed 10+% of the vehicle's total torsional rigidity, reduced mass 3 kilograms, eliminated secondary attachments, and reduced capital expenditures vs. aluminum.

Susan Kraus / Illustration

little package space. We went with metal there. We even briefly discussed metal versus composite body panels. However, it would've been economically infeasible to create the C8's styling lines in metallics."

"A real challenge we faced was how to handle air induction," recalls Chris Basela, *Corvette* body structure lead engineer, explaining the need for a different method to funnel cooling air into and across the naturally aspirated, 495-horsepower, 6.2-liter V8 engine, which generates 470 foot-pounds (637 Newton-meters) of torque. "We tried all kinds of designs that forced air to take really torturous paths, creating eddies and flows we didn't want. It took lots of iterative work with the powertrain team to develop the best path for airflow because the car needs to breathe freely with no restriction. We also needed access to the air box and had to work around rear trunk space. Another issue was heat and engine noise in the passenger compartment, because occupants no longer sit behind the engine but are positioned directly in front of it. And we were especially conscious of cabin air quality as laws had changed in Europe and elsewhere since the C7, so we worked really hard to reduce VOCs [volatile organic compounds]."

"Even working out how to *assemble* the car was a challenge," Moss adds. "With a front-engine design, you have a long hood and large engine compartment, providing operators plenty of room to build the car from inside the compartment, even with the front bumper beam already welded on. On the mid-engine *Corvette*, with its very short front clip, we keep the front of the car open as »

Meet the team

GM and its suppliers have already won many awards for innovative composites use on the 2020 *Corvette Stingray.* Pictured above are key GM engineering team members at last November's 49th annual Automotive Innovation Awards Gala, where GM won SPE Automotive Div.'s Vehicle Engineering Team Award. A number of composite parts on the vehicle also were finalists or category winners at the event. Source | SPE Automotive Div.

Curved rear bumper beam

An auto industry first, the 2020 *Corvette* sports a curved rear bumper beam in pultruded carbon fiber composite produced with 87 individual carbon tows and eight carbon fiber non-crimp fabrics (NCFs) impregnated with polyurethane-acrylate resin. The hollow, two-chambered beam is 66% lighter than the outgoing aluminum beam and met GM's demanding dollar-per-kilogram targets.

Source | Shape Corp.

the vehicle is built out, then bolt on the front bumper."

"It was quite a balancing act to get the proper shapes, while ensuring our suppliers could produce the parts and our team in Bowling Green [GM's Kentucky-based *Corvette* assembly plant] could assemble them," continues Basela. "In the end, there was only one carryover composite from the C7's body to the C8." This was tough Class A, 1.2 specific gravity (SG) sheet molding compound (SMC) developed for the 2016 *Corvette* and used in a variety of exterior closures on the new vehicle.

Vehicle architecture

For four generations (C5-C8), *Corvettes* have featured a three-layer, multi-material body structure: the **frame**, usually a mix of aluminum or steel — this time with a carbon fiber-reinforced composite (CFRP) part; the **body structure**, which is largely bonded composite to capitalize on design and manufacturing flexibility; plus bolt-on **closeouts** (body panels), which have been composite since *Corvette's* June 1953 debut. This layered hybrid structure not only provides affordable lightweighting in high production volumes — particularly for cars of this performance class — but also permits multiple vehicle variants to be produced at low tooling investment. In fact, for the current C8, GM managed to produce all Class A composite body panels (bonded inners and outers) on both the base model coupé and convertible using just 20 tools.

In addition, *Corvettes* have always been engineered with an open-roof architecture, regardless of whether they were actually convertibles or coupés with fixed or removable roof panels. Because open-roof vehicles are generally less stiff than those with fixed roofs, an important focus for each *Corvette*'s engineering is always to create the stiffest foundation possible to improve suspension and steering. Historically, tunnels (housing transmissions and driveshafts on front-engine vehicles) have dominated *Corvette* body structures and have been key enablers for achieving high torsional rigidity. In the case of the new *Corvette*, GM achieved even higher rigidity. With the roof removed, the C8 body is 53.78% stiffer than a benchmark high-performance mid-engine competitor, 29.27% stiffer than a second high-performance mid-engine competitor, and 13.79% stiffer than the C7. Two composite parts made important contributions to vehicle stiffness — one directly attached to the frame structure (rear bumper beam) and another attached to the underbody (lower-tunnel closeout).

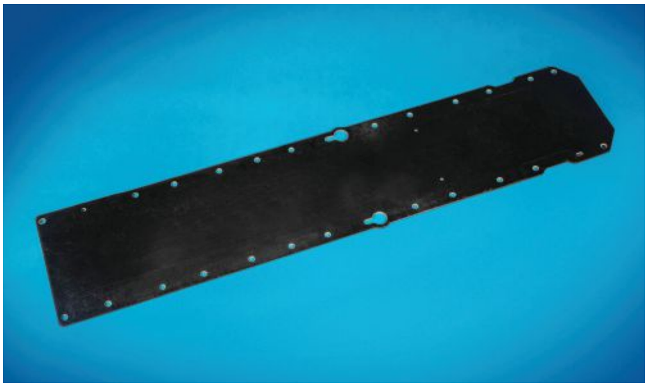
Frame structure

The C8's frame is largely aluminum alloy with one CFRP part developed to meet GM's stringent dollar-per-kilogram targets. In contrast, the C7 frame was all-aluminum and the C6 was mostly steel.

The only composite part directly mounted to the frame that travels with the body-in-white (BIW) through the electrophoretic rust-coat process (which GM calls ELPO), is a unique CFRP rear bumper beam. This part helps stiffen the frame and contributes to rear-impact performance. Its curved shape — possible thanks to a novel radius pultrusion process developed by Thomas GmbH + Co. Technik + Innovation KG (TTI, Bremervörde, Germany) — enables it to match rear styling cues and fit in limited package space while maintaining dimensional integrity close to engine-bay heat. As the auto industry's first curved pultruded part (see our full feature on this part in the *CW* May 2020 issue), the hollow, two-chambered beam was produced by Shape Corp. (Grand Haven, Mich., U.S.) on equipment developed and built by TTI. The beam weighs just 1.3 kilograms and features a bonded/bolted tow-hook eye capable of 25 kilonewtons of pull-out force.

Body Structure: part A

Virtually all of the C8's body structure components are composite and are bonded and/or bolted to the frame after the latter undergoes ELPO. Notable composite parts at this level include structural



Lower-tunnel closeout

This hybrid-composite, lower-tunnel closeout is produced using a variant of liquid compression molding. It eliminated secondary attachments, lowered mass by 3 kilograms and reduced labor, tooling and capital costs vs. aluminum.

Source | SPE Automotive Div.

SMC float

An important contributor to vehicle lightweighting on the C8 is the extensive use of "float" SMC. With specific gravity values less than 1.0, this low-density but structural SMC developed by MFG is used in a variety of non-Class A parts, including underbody panels, the dash panel, air-induction ductwork and the front trunk. Source | Molded Fiber Glass Co.

underbody closures and the floor — which we'll cover in this issue — and front and rear trunks, induction ducts and the rear surround and bulkhead — which we'll cover, along with body panels and trim, next month.

The removable lower-tunnel structural closeout on the C8, which acts as an access door, contributes more than 10% of the vehicle's torsional rigidity and acts as a primary load path during a crash. This hybrid-composite panel consists of three layers of glass fiber preform. These consist of continuous/woven and chopped/random fibers at 38% fiber volume fraction (FVF), with veils added to top and bottom face layers on each stack for improved surface finish. Glass preforms are interleaved with two layers of preforms made using Toray (Tokyo, Japan) T700 12K standard-modulus carbon fiber in the form of NCF biaxial fabric at 21% FVF and a vinyl ester (VE) matrix. The closeout is produced by Molded Fiber Glass Co. (MFG, Ashtabula, Ohio, U.S.) using its proprietary PRiME (Prepositioned Reinforcement ensuring Manufacturing Excellence) process, a type of liquid compression molding (LCM).

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Aside from a single aluminum closeout near the rear wheels that is part of the engine cradle, the remaining underbody panels consist of either compression molded SMC or injection molded thermoplastics. Among other benefits, these panels reduce underbody turbulence and drag, improve fuel efficiency and keep moisture, dust and stones out of the vehicle's engine and driveline. Further, they provide the dimensional foundation for multiple exterior and interior interfaces.

The low-density but *structural* SMC panels feature new formulations (in this case, 40% FVF chopped fiberglass/unsaturated polyester (UP) resin) developed by MFG. The material is called "float" SMC because each panel's density is less than 1.0 (average SG=0.97) and thus can float in water. MFG produced all structural SMC and LCM'd parts on the car.

The vehicle also sports a hybrid floor optimized for torsional bending and side-pole impact protection (engaging the rocker panels and tunnel, to which it is joined). Floor panels feature cabin-facing stamped aluminum bonded to sheets of road-facing 1.5-SG composite (60 wt-% continuous and woven glass fiber/VE) produced via the PRiME process. Before heat-bonding both layers with Pliogrip 9100 polyurethane structural adhesive from Ashland Global Holdings Inc. (Wilmington, Del., U.S.), MFG cleans and preps the materials.

All composite parts directly bonded to the C8 frame are first subjected to laser ablation, a process developed by GM, MFG and Adapt Laser Systems LLC (Kansas City, Mo., U.S.) for the 2016 *Corvette,* and adapted from a composites industry method for mold cleaning. Laser ablation replaces hand sanding and reduces labor, time and cost, eliminates dust and improves repeatability. Laser path, angle of attack and energy level are customizable for each part's material and geometry. To maximize manufacturing flexibility, the entire underbody, including the floor, is connected to the frame and itself via bonding and screws.

In the August issue of *CW*, we'll continue covering composites innovation on the new *Corvette*, resuming with additional components at the body structures level and finishing with exterior closures (body panels), plus additional trim and upgrades. CW

ABOUT THE AUTHOR

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