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HIGH-PERFORMANCE Composites

SEPTEMBER 2014 / Vol. 22 / No. 5

- Maverick Manufacturing: The *Scorpion* Jet
- Automating Layup of the *CH-53K* Flexbeam
- Market Outlook: Thermoplastic Aerocomposites
- CAMX, Farnborough, SAMPE Seattle, CFK-Valley

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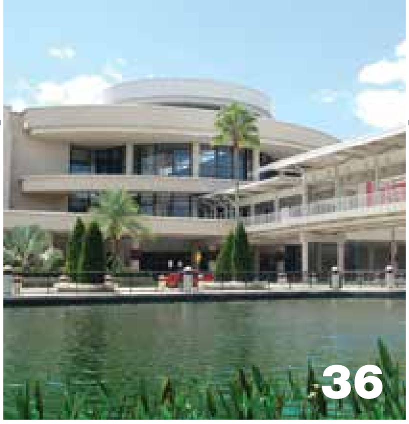
FEATURES



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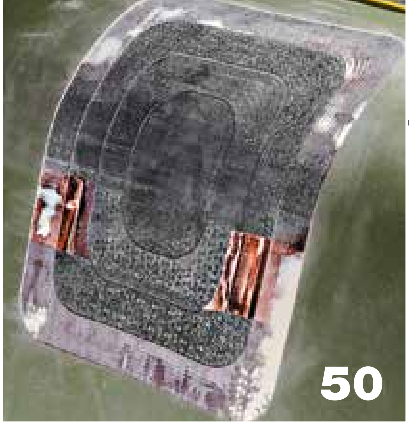
DEPARTMENTS

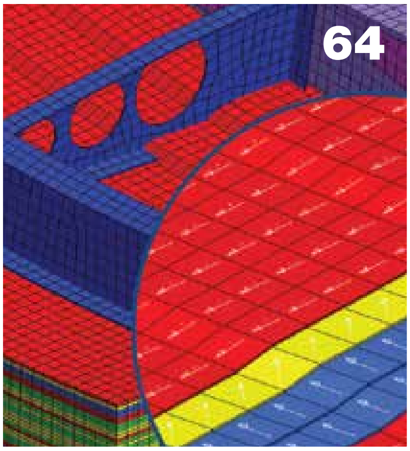
ON THE COVER

Unveiled this year and self-funded by Textron Airland LLC (Wichita, Kan.), the *Scorpion*, an all-composite, tandem-seat, twin-engine tactical jet fighter, was taken from concept to first flight in an unheard-of two-year time frame. That feat was made possible, in part, by tooling partner Leading Edge Aerospace's (LEA, Wichita, Kan.) cost-conscious resin-infused, oven-cured, CNC-machined composite tooling, which enabled molding of prototype autoclaved parts (see p. 86).

Source: Textron Airland

COLUMNS





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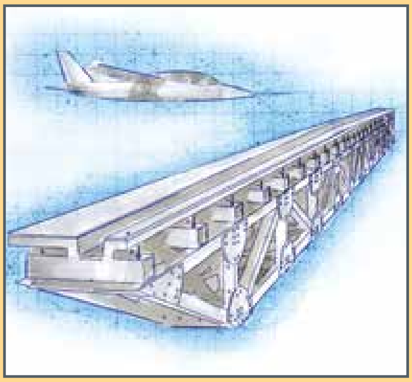

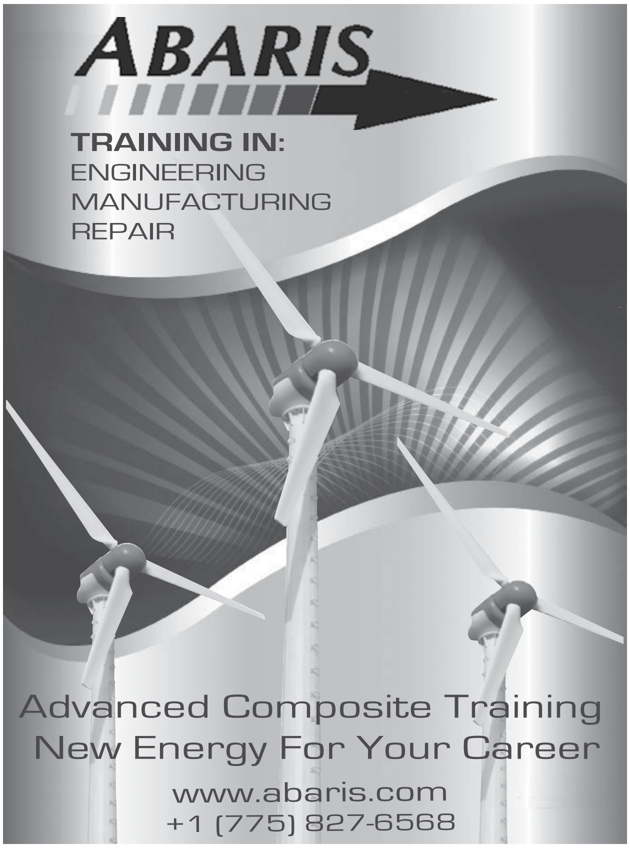

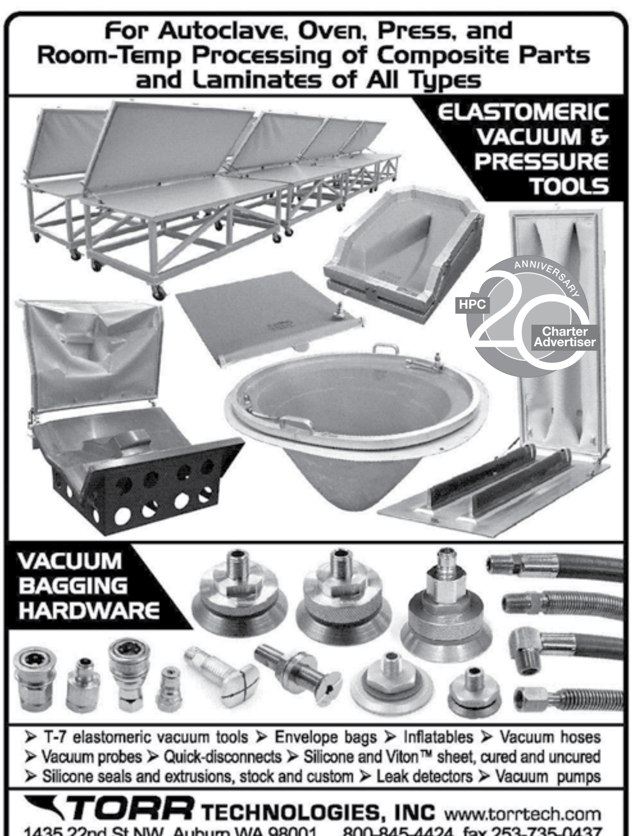

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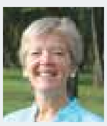

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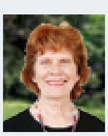

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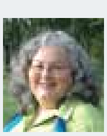

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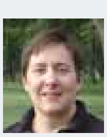

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FROM THE EDITOR

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My kids' high school opened in 1997 and, from the start, was an incomplete structure. For lack of funds, the school district was forced to leave out some amenities that are found in most schools — auditorium, swimming pool, running track, etc. Over the years, money was raised to add more classrooms, but that was the extent of the expansion. In the fall of 2012, however, the community approved funds that would enable the district to construct not only an auditorium and track, but also 10 new classrooms, a new (high-security) entrance and a ... wood shop. This last one got my attention.

"Wood?!" I exclaimed, when my wife, who teaches at the school, broke the news. "What about composites?"

> How does the composites industry "sell" to students the huge range of opportunities it has to offer?

I sat down and wrote a lengthy e-mail to the school's principal, explaining, first, what composites are, second, how composite parts are made and, third, how the teaching of composites fabrication methods would provide students with real, useful and unique skills that are desperately needed throughout the world. At a sit-down meeting with the principal, the activities director and the would-be wood-shop teacher, I again made my case for composites, drawing on the Boeing 787, the Airbus A350 XWB, wind blades, the BMW *i3* and other real-world examples to support my argument.

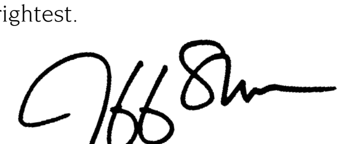
All of this was new to them, but then came the surprise: The school agreed to partition 600 ft^2/55.7m^2 of space in the wood shop and devote it to the creation of a composites lab. Not only that, but the wood shop teacher said he'd be willing to learn about composites and then teach the class.

Under construction right now, the addition should open by January 2015, in time for second-semester classes. Outfitting the composites lab will fall to me and a few other parents who have some composites knowledge and are eager to see the lab work (anyone with spare resin, fiber, mold-release or little-used equipment that needs a good home are encouraged to contact me at jeff@compositesworld.com).

All of this got me to thinking about how well parents, educators and employers do in making sure our students are attuned to the needs of a working world. There is, it seems, a significant disconnect between what employers seek in employees and what sort of potential employee our education systems deliver. Every spring, as high school and college graduates collect their diplomas, graduation speakers the world over exhort them to "follow your passion" or "be your dream" or "make a difference." But not all passions pay a living wage, and not all dreams line up with the demands of the job market.

Our educators try, sporadically, to get students interested in the science, technology, engineering and math (STEM) subjects that are in obvious and general demand, but American students, today, notoriously lag behind the rest of the world here — despite the fact that engineers are in great demand and command high starting salaries.

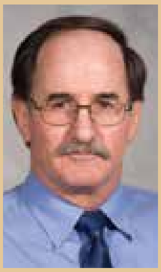
How does the working world communicate to students about the skills it needs? More specifically, how does the composites industry "sell" to students the huge range of opportunities it has to offer? Maybe high-schoolers who have an interest in and propensity for math and engineering should be offered a chance to tour a composites fabrication plant or a moldmaking shop. They could meet the engineers and designers who have the skills that are needed by the industry, and learn how those skills can be applied. Maybe composites professionals — of all stripes — should stop hoping that this industry will catch the eye of the best and brightest, and start actively looking for and recruiting the best and brightest.



Jeff Sloan

MARKET TRENDS

DISRUPTIVE TECHNOLOGIES POWER SMALL COMPOSITE AEROSTRUCTURE FIRMS TO MARKET PARITY



Bob Skillen, a former *F-14* carrier aviator, holds a BS in aerospace engineering from the U.S. Naval Academy and has 25 years of experience in aircraft design and composite aircraft manufacturing. Skillen has designed, prototyped and manufactured many aerospace parts and is well-versed in a wide range of composite manufacturing processes, including prepreg laminating, vacuum infusion and resin transfer molding.

Today, you can whip out your smart phone to check-in at home, read and respond to e-mail, download data and surf the Internet. You can do this in a park, riding a train and, in some cases, on a commercial aircraft flight. Our kids photograph objects with their phones, then reproduce them at home with 3-D printers, using free apps compatible with commercially available CAD/CAM software. The accelerometers and other technology in our personal devices are far superior to what NASA used to get to the moon. A generation ago, none of this was possible. We all know this … in the general sense. But for advanced composites professionals, how does this change the game?

Narrowing the focus

Whether you make a rocket, a race car or a high-tech tennis racket, the common thread is high performance and the common environment is competition. That's our business. And small businesses in our marketplace have never been in a stronger position.

Small businesses are like small cars. They are much more maneuverable and go farther on less fuel. But, there is much more to the analogy when you factor in the performance gains made possible by the computer revolution. Compared to the first microprocessor, introduced in 1971, modern CPUs are 4,000 times faster and use 1/5,000th of the energy. Today, $1 gets you computing capability that cost $50,000 in 1971!

As this explosion of computer processing capability intersects the maturing composites industry, the practical impact is enormous. The primary driver is capability. Tools that once were available only to primes and OEMs are now affordable and ubiquitous. The capability gap between large and small companies has narrowed dramatically.

The advantages of small business

Business is about satisfying the customer's need for the best "value." Although there are several variables in the value equation, cost is never, *never* an optional ingredient. Small businesses in our industry, equipped with modern tools, are typically in the best position to compete in terms of price. The lean structure, ease of communication and common lack of compartmentalization are all advantages. Operating costs are lower and efficiency is higher. In turn, much of the advanced composites industry centers on high-tech, relatively low-volume production.

Although much has been done to reduce touch labor and cycle times in high-volume industries (e.g., automotive), low-volume production of advanced aerocomposites is still the mainstay. The capitalization of tooling and automated equipment against small parts counts won't fit the business model in a competitive environment. Technology advances and availability, along with the inherent efficiency of the small business, is a win-win in the advanced composites marketplace.

What *is* an advanced composite?

The term *composite* is not very definitive. The adjective, *advanced*, doesn't make it much better. To keep it simple, an *advanced composite* describes the typical composite materials used in the aerospace industry: carbon fiber/epoxy structure with glass transition temperatures above 100°C/212°F. It can be defined by three basic criteria. The first criterion is *fiber volume fraction* (Fv). Strength-to-weight and stiffness-to-weight ratios are dependent on optimum resin content. Advanced composites, for this discussion, will have Fv values equal to or greater than 55 percent. The next criterion is *void content*, which is directly related to quality; void content will be limited to less than 1 percent. The last criterion is *quality management*. The small advanced composites business must have an acceptable quality management system — the aerospace sector requires AS9100 certification. Documentation of processes, procedures and testing are essential to customer satisfaction in terms of part quality. Also, the quality system must be subject to regular audit by an accredited outside agency. Given these criteria, the *advanced composite* category is much more confining.

Shape, methods and materials

2.1: Creating shapes. Complex shape generation has never been more convenient. Modern CAD software is exponentially more capable and affordable. Capability gains include generation and manipulation of complex surfaces with extreme accuracy. Virtual complex-curvature parts can be compared quickly with design parameters and virtually installed with mating structure in three dimensions. This design capability was once inconceivable and, not long ago, totally out of reach for small businesses.

Similarly, reverse engineering has benefitted from the computer-processing boom. Recreating the surface geometry of legacy aircraft, when spare parts are unavailable and original tooling is long since lost or destroyed, is a good example. Modern scanning equipment and software can convert existing surfaces into CAD models quickly, moving from the real world to the virtual world with staggering accuracy. And this information can be easily transmitted around the globe. The ability to generate and share this data is now common, available and affordable to small firms.

Although it is still compulsory to realize CAD designs in hard master models and tooling, what was once accomplished by skilled patternmakers is now done by CNC machinery, at speeds and with precision that are as accessible and affordable as they are remarkable. Very accurate 3-axis CNC routers with large worktables can be had for less than $100,000 (USD). Further, tool path software for these machines is available as add-on modules to CAD software. More complex, and certainly more expensive, is 5-*axis* CNC routing. But in many dedicated patternmaking shops, 3- and 5-axis routers have replaced traditional processes. If production volume does not justify an in-house 5-axis router, outsourcing work to a dedicated master modelmaker is a routine and effective alternative. Today, a 3-D model can be attached to an e-mail — never before have such mammoth quantities of technical data been so easily shared.

2.2: Methods and materials (Look, mom, no autoclave). Having designed complex surface geometry, the small advanced composites business must then produce it. Here, modern composite materials and processing methods have eliminated costly capital equipment — most notably, the autoclave.

For many years, high-quality advanced composite parts required elevated-temperature curing under high isostatic pressure. This environment was only available in a heated pressure vessel. But as parts were consolidated to reduce weight and assembly, autoclaves got larger. Because stress in the wall of a pressure vessel is a function of the radius of the cylinder times the operating pressure, large-diameter autoclaves are massive and can cost *30 to 40* times what is required for an equivalent-size ambient-pressure oven. When amortized into the per-part production cost, high-pressure curing of composite parts is enormously expensive. The question is "Is the expense justified?" More and more, the answer is "no."

There have always been out-of-autoclave (OOA) composites, but *high-performance* part quality was directly dependent on the autoclave environment, and its value justified the cost. But in recent years, the performance *difference* between autoclaved and OOA parts has narrowed. Major prepreg suppliers offer OOA materials and many data have been generated to validate their performance. OOA material performance is approaching parity with autoclaved materials. The value justification for autoclaved parts is difficult to make, especially for new programs. The large "aerospace-grade" composite structure is no longer an autoclave-only proposition. OOA methods and materials have drastically reduced the capital investment and, therefore, have increased the role of the smaller company in our marketplace.

There is little doubt about the increased capability of small businesses in this sector and little argument about their response time and cost advantages. Whether the industry is adapting to this change as rapidly as change is occurring is the question. Change is hard, but the view is definitely worth the climb. ■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COMPOSITES: PERSPECTIVES & PROVOCATIONS

WHAT WILL BE THE NEXT MAJOR ITERATION IN CARBON FIBER?

Dale Brosius is head of his own consulting company and the president of Dayton, Ohio-based Quickstep Composites, the U.S. subsidiary of Australia-based Quickstep Technologies (Bankstown Airport, New South Wales), which develops out-of-autoclave curing processes for advanced composites. His career includes a number of positions at Dow Chemical, Fiberite and Cytec, and for three years he served as the general chair of SPE's annual Automotive Composites Conference and Exhibition (ACCE). Brosius has a BS in chemical engineering from Texas A&M University and an MBA. Since 2000, he has been a contributing writer for *Composites Technology* and *High-Performance Composites.*

In 1984, I moved from a job as a production engineer responsible for day-to-day operations of a very large chemical manufacturing unit in Texas to doing market development of automotive composites in Detroit, both with The Dow Chemical Co. (Midland, Mich.). In Texas, I became familiar with composites, typically glass/epoxy or glass/vinyl ester for corrosion-resistant applications, such as tanks and piping. Upon arrival in Detroit, I was introduced to carbon fiber, because Dow supplied the resin used to manufacture carbon fiber composite driveshafts for the Ford E*conoline* van. Then (and still, for the most part), carbon was entirely too expensive for widespread use in automobiles, but it nevertheless offered fantastic strength and stiffness at very low weight. Unfortunately, the driveshaft went out of production a few years later.

After four years, I moved to Fiberite, at the time the world's largest intermediate processor of carbon fiber, and now part of Cytec Industries (Woodland Park, N.J.). At that point, my narrow interpretation of carbon fiber as standard-modulus PAN expanded immensely! My sales territory included fabricators of sporting goods, satellite structures and solid rocket motor manufacturers like Morton Thiokol (now part of ATK, Ogden, Utah), which built the boosters for the Space Shuttle. Sporting goods companies used cheaper standard-modulus PAN prepreg (*cheap* being a relative term, of course).

The first order I took for satellite structure prepreg used Amoco's Thornel UHM P-120 fiber (Amoco's fiber also became Cytec's). This pitch-based material was priced at more than $2,000/lb ($4,400/kg)! This was my first introduction to pitch fiber, and clearly I had hit the other end of the carbon fiber spectrum. Although P-120 orders were few and far between, I became familiar, shortly thereafter, with carbon fiber/phenolic prepregs using fibers based on viscose rayon. Developed in the late 1950s, rayon fibers predated PAN (1961) and pitch fibers (1970). They are still widely used as the ablative insulation for exit cones of solid-propellant rockets, having replaced fiberglass/phenolic in that application. In the 1980s, a big effort to replace rayon with PAN fibers in exit cones met with limited success, given the low thermal conductivity and superior ablation performance of rayon-based carbon prepregs.

That's where we stand today: Three commercial precursors, with dominant PAN holding a 90 percent market share. A lot has changed since 1988, with new market entrants, globally, and rapid growth of the carbon fiber market, driven by increased aerospace use and growing industrial acceptance. The future of large-tow (>24K) fiber is assured, following Toray's purchase of Zoltek in 2013, and Cytec's July announcement of its intent to enter the large-tow market. And increasing use in the automotive (finally!) and wind energy sectors is driving capacity expansion everywhere.

So what's next? A prominent option is to drive the cost out of industrial-grade carbon fiber, which is being approached from multiple angles. The logical starting place is PAN fiber. Today's production lines typically range from 1,500 to 3,000 tons/yr, so going to lines in the 5,000- to 6,000-ton range might cut costs a little. Alternate conversion techniques that use less thermal energy (e.g., microwave or plasma) are under exploration. So are true "textile-grade" precursor fibers and melt spinning of the PAN polymer vs. the energy-intensive solution-spinning process used today.

But what if the answer lies in a different precursor? More than a decade of research has gone into developing carbon fiber using lignin, a low-cost paper-industry byproduct. Although it is an attractive sustainable/renewable resource, raw lignin is quite variable and requires purification to make a polymer that can be spun into a fiber, adding considerably to cost. The product forms and properties of the resulting fiber continue to improve but, to date, are still well short of PAN-based carbon fiber. Polyolefins, such as polyethylene (PE), offer the potential for up to 86 percent conversion to carbon fiber (vs. PAN at 50 percent), according to Dow Chemical, but the conventional route to PE fibers that can be properly carbonized involves treatment with chlorosulfonic or sulfuric acid prior to conversion. Although a *non-acidic* route is being explored, it's still in the early stages. Successfully developed, lignin or polyolefin precursors might offer the opportunity to finally reach the magic $5/lb ($11/kg) target.

Meanwhile, researchers at Carbon Nexus (Geelong, Australia) are looking past precursor changes, exploring ways to improve carbon composite properties, especially shear and compressive strength. One approach is to adhere carbon nanotubes to individual filaments of conventional PAN fibers. I'm guessing this won't be "cheap" and, likely, will be of greatest interest to the aerospace community.

Chances are, the carbon fiber market will be 10 times larger a decade from now, so there is ample room for new precursors and product forms. And I'm pretty certain there will still be a rayon niche in whatever mix occurs. ■

TESTING TECH

THE EVOLUTION OF THE MODIFIED D 695 COMPRESSION TEST METHOD

Dr. Donald F. Adams is the president of Wyoming Test Fixtures Inc. (Salt Lake City, Utah). He holds a BS and an MS in mechanical engineering and a Ph.D in theoretical and applied mechanics. Following a total of 12 years with Northrop Aircraft Corp., the Aeronutronic Div. of Ford Motor Co. and the RAND Corp., he joined the University of Wyoming, directing its Composite Materials Research Group for 27 years before retiring from that post in 1999. Dr. Adams continues to write, teach and serve with numerous industry groups, including the test methods committees of ASTM and the *Composite Materials Handbook 17*.

ASTM D 695[1], "Compressive Properties of Rigid Plastics," defines the end-loading compression test method familiar to the composites community. It was introduced by ASTM Committee D20-Plastics more than 70 years ago but was not the first method developed in this area.

In the 1930s, the aircraft industry was beginning to use aluminum, particularly in sheet form, for wing, fuselage and empennage skins. Airframers needed a method for directly determining the compressive properties, particularly the compressive strength, of these thin materials. Extensive research during the 1930s and through World War II resulted in a number of published studies. The earliest approach (U.S. National Bureau of Standards, 1933) was to clamp 20 or more thin specimens together for testing, avoiding the need for lateral restraint against gross buckling. Known as the "pack" method, it was shown to produce compressive strengths comparable to tests of thick materials[2]. However, it was tedious and expensive because of the number of specimens required.

W.P. Montgomery (Vought-Sikorsky Aircraft Corp., Stamford, Conn.) is credited with the first scheme for testing a single thin sheet[3]. R.L. Templin's[4] work followed, resulting in the Montgomery-Templin method.[5] Its fixture supported each side of the 67-mm/2.64-inch long specimen with 25 steel rollers (each 2.93 mm/0.093 inch in diameter) spaced 2.54 mm/0.10 inch on center. Each roller was supported by an individual brass leaf spring on each end, so each roller could move independently. This roller spacing was calculated to prevent local buckling between rollers for aluminum specimens as thin as 0.5 mm/0.020 inch.

Although the Montgomery-Templin fixture produced strength and stiffness values comparable to those obtained by the "pack" method or by testing thick specimens, its 50 rollers and 100 springs made it expensive to fabricate and difficult to adjust. Therefore, other methods were investigated. Some used multiple steel balls to support the specimen faces, or lubricated and unlubricated solid support surfaces of steel, brass and even wood. Others employed grooved steel or brass plates — the grooves that contacted the opposite faces of the specimen were either aligned or staggered relative to each other. These methods were satisfactory as long as the coefficient of friction between the specimen and the supports was low and the clamping force was limited to that necessary to prevent buckling. The more promising and popular of these methods were incorporated into an existing standard, ASTM E 9[5], "Compression Testing of Metallic Materials at Room Temperature."

As plastics came into use, a similar need to compression test them in thin sheet form prompted adoption of the metals testing technology — specifically, grooved, aligned lateral supports were incorporated into ASTM D 695. A dogboned test specimen 3⅛ inches long was selected (7.94 cm/3.13 inch in the current standard). The increased cross-sectional area of the dog-boned ends reduces the likelihood of local buckling and/or end crushing. The lateral supports are 73 mm/2.875 inches long, allowing about 6.4 mm/0.255 inch maximum ➲

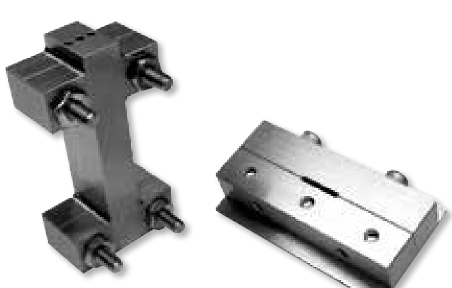

Fig. 1 I-shaped lateral support plates (left), per ASTM D 695, with an end cap (right) added to protect the specimen end that projects at the upper end of the lateral supports from locally crushing or buckling when loaded.

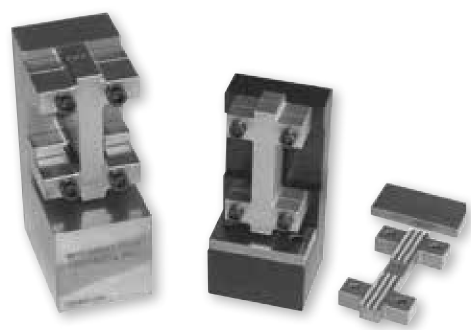

Fig. 2 The SACMA SRM 1R-94 fixture (left) and Wyoming fixture (right). The base and lateral supports of the former are thicker, making it look larger, but both fixtures accommodate the same-sized specimen.

Fig. 3 An example of a special-use fixture. The one at right, made from nickel superalloy, was designed to fit into a small-diameter tube furnace, but test a standard-sized specimen. The lateral supports are rectangular rather than I-shaped. The front support has a slot for specimen surface access by a laser extensometer.

Source (all photos): Don Adams

specimen deformation when loaded in compression. These supports are 11.1 mm/0.438 inch wide over the central 38.1-mm/1.50-inch length, with projections that have holes on each end so they can be bolted together to provide the desired clamping force (see Fig. 1). With the projections added, the lateral supports assume an I-shape. That shape (rather than the rectangular plate used in metals testing) and its central portion, narrower than the 12.7-mm/0.50-inch wide specimen, permit attachment of an extensometer to the specimen edge for strain measurement. ASTM D 695 hasn't changed in 70 years.

When a method was required for compression testing thin composites, ASTM D 695 was used in the late 1970s by The Boeing Co. (Seattle, Wash.) and others. A base was added to hold the lateral supports vertically in the testing machine and a tabbed, straight-sided specimen was used. Boeing specified a specimen length of 3.13 to 3.18 inches (79.5 mm to 80.7 mm). (It's unclear why a length *range* was specified.) SACMA (Suppliers of Advanced Composite Materials Assn.) later adopted this method as SACMA Recommended Method SRM 1-88 in 1988, with a specimen length of 3.18 inches, arbitrarily 0.05 inch/1.27 mm longer than the ASTM D 695 specimen. Although the lateral support length was reduced to 2.75 inches/69.9 mm (0.125-inch/3.175-mm shorter than ASTM D 695), SACMA's 1994 revision, SRM 1R-94, adopted ASTM D 695's 2.875 inches/73 mm.

Source: Don Adams

Fig. 4 A subscale fixture (right), designed to test a 25-mm/1-inch long specimen, compared to a Wyoming fixture.

In early 1992, ASTM Committee D30-Composites drafted a new standard, based on SACMA's SRM 1-88 document, but it was not released. Sicne SACMA disbanded in 2000, the "Modified D 695" compression test method has been homeless and somewhat unguided. As a result, a number of modified methods are in use, each with slightly different specifications. However, they all end-load a tabbed, straight-sided specimen. (See examples in Figs. 1-4.) ■

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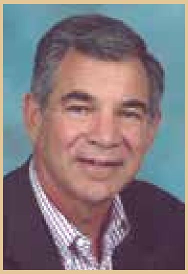
SPEAKING OUT

RAMPING UP TO THE CARBON FIBER SUPPLY CHALLENGE



Tom Lemire, president of T.F. Lemire Consulting Inc. (Irvine, Calif.), brings to his current consulting role 45 years of active duty in sales, market development and management at three major, technology-driven global operations that supply materials to the composites industry: Toho Tenax (Rockwood, Tenn.), BASF Structural Materials (Charlotte, N.C.) and Owens-Corning (Toledo, Ohio). Lemire served as cochair of the CompositesWorld Carbon Fiber Conferences held in 2009 and 2010 and was a panel moderator or speaker at SAMPE conferences in 2010, 2011 and 2012. He received his BA from Brown University and holds an MBA from Northwestern University's Kellogg School of Management.

The announcement on June 30, this year, that Mitsubishi Rayon Co. (MRC) would double its U.S. (in Sacramento, Calif.) carbon fiber manufacturing plant's nameplate capacity by mid-2016 came as no surprise to many in the advanced composites industry. Approximately 2,000 tons of capacity will be added to the current 2,000 tons, according to president & CEO Hitoshi Ochi, who made the announcement at Mitsubishi Rayon's headquarters in Tokyo, Japan. In a statement, the company mentions a "regular-tow carbon fiber," which I assume to be a 12K and 24K fiber, but it does not call out a specific fiber type (e.g., Process 330) that will be produced.

MRC's justification for the move is the growth of the overall carbon fiber market and the resulting need for a sufficient supply of carbon fibers to support demand in worldwide industrial applications, which the company believes will grow at an annual rate of more than 20 percent. Among the applications MRC credits with the growth and resulting increase in demand are renewable energy technologies, including wind-generated electricity and pressure vessels for CNG fuel tanks in both city truck and bus vehicles, as well as vessels for storage refueling stations and the large number of transport vehicles that will be used to bring CNG to these sites.

MRC's announcement surprised no one because it followed an earlier announcement on MMA (methyl methacrylate), made in conjunction with Mitsui and Dow, and news of its arrangement with SGL regarding its acrylonitrile precursor capacity in Otake, Japan. So this expansion is both consistent in content with the earlier partnership announcements (one needs a source for the raw acrylonitrile material before proceeding) and it demonstrates MRC's long-term commitment to support the advanced composites industry.

In my grad-school marketing courses, a basic tenet we were taught was "to be different than your competitors." You must answer your customer's question: *Why should I buy from you*? Those who best address that question become market leaders. Those with less compelling answers follow. In fact, the approach of "following the leader" is exactly what the leader wants because that company is already in the forefront and has an edge in the race. Following the leader, however, leads to overcrowding, and prevents one from promoting any unique benefits or advantages of using the new candidate material. Most industries don't want (nor do they need) additional "me, too" products.

> In my grad-school marketing courses, a tenet we were taught was "to be different than your competitors." You must answer your customer's question: *Why should I buy from you?* However, this is not Consumer Marketing 101, and we are not competing for shelf space or trying to become the lowest-priced, attractive item.

However, this is not Consumer Marketing 101, and we are *not* competing for shelf space or trying to become the lower priced, attractive item. For advanced composite applications in the industrial market, slight improvements are *preferable* to radical changes. In fact, claims of being "slightly different" or even "better" require more (and expensive) validation testing, especially with a fiber candidate that has a limited database of test values.

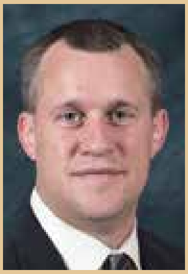
It's no secret that in advanced composites applications that require carbon fiber reinforcement, the benchmark is clearly Toray Industries' (Tokyo, Japan) T700 fiber. It has a deep, 20-plus year history. It is well established in major aerospace, industrial and recreational applications, and it has earned the right to be the standard against which all other carbon fibers are compared, not only for its delivered strength (i.e., how its performs in a laminate), but also for the consistency of its mechanical performance properties and its overall processability.

It's an exciting time to see our U.S. economy grow. The import gates are open, and there are many new carbon fiber manufacturers entering the market from South Korea, Turkey, India, China and other countries that also will try to gain some market share in the U.S. industrial market. If they are to succeed, their primary emphasis needs to be on fiber *technical support*, and for that they need people who can patiently work closely with a customer to demonstrate laminate property equivalency.

MRC has posted a good track record with its carbon fibers, its prepregs and the resulting composite parts, so this announcement should provide our industry some assurance that there will be a stable, sustainable supply of materials to support a growing economy. ■

BY THE NUMBERS

COMPOSITES BUSINESS INDEX 50.5: GROWTH IN 9 OF 10 MONTHS



Steve Kline is the director of market intelligence for Gardner Business Media Inc. (Cincinnati, Ohio), the parent company and publisher of *High-Performance Composites*. Kline holds a BS in civil engineering from Vanderbilt University and an MBA from the University of Cincinnati.

In June, the Composites Business Index (CBI) of 54.5 showed the industry had grown for a seventh straight month. Although the rate decelerated from May, June's growth was the third fastest since May 2012 — up 12.1 percent compared to one year earlier, and growth had accelerated in the previous five months.

Every June subindex but exports contributed to the slower rate. New orders expanded, continuing a trend begun in August 2013. Production increased for the sixth straight month. Backlogs contracted for the second time in three months but was still 7.7 percent higher than one year earlier. The annual rate of change in backlogs continued to accelerate, indicating higher capacity utilization and capital spending for the remainder of 2014. Employment continued to accelerate rapidly, while exports increased for the second time and supplier deliveries lengthened.

Material prices increased at a slower rate. Prices received increased for a third straight month. Future business expectations dipped from a February peak.

Growth remained above 60.0 for the third month in four at facilities with more than 250 employees. Plants with 50 to 249 employees improved but growth slowed dramatically for those with fewer than 50.

Regionally, the West grew fastest (>65.0) and the North Central – East followed, >56.0 for four straight months. The Northeast also posted growth but the Southeast and North Central – West contracted after expanding in May.

Capital spending plans reached their second highest level since July 2013. Compared to a year earlier, June's subindex was up 30 percent and the annual rate of change returned to double-digits for the first time since January.

For July, a reading of 50.5, indicated growth in nine of the past 10 months. The Index was 5.9 percent higher than in July 2013 — the 11th consecutive month that growth was greater than one year earlier. The annual rate of change had accelerated for six straight months.

New orders increased for the eighth month in a row. However, the rate declined from June's and was the slowest increase since November 2013. At a high level in 2014, the production subindex continued a downtrend begun in April. Having contracted in three of the previous four months, backlogs increased at its slowest rate since August 2013, yet were still higher than one year earlier in each of the previous 11 months — a positive sign for capacity utilization and capital equipment investment. Employment continued to grow, but at its lowest level since June 2013. After expanding in June, exports contracted again in July. Supplier deliveries continued to lengthen, but the rate had slowed since March.

In June and July, material prices increased at the fastest rate since early 2013. Fortunately, prices received had accelerated upward since March and was at its highest level since June 2012. Future business expectations were above the historical average in July, but they had fallen significantly since February and were at their lowest level since September 2013

Facilities with more than 250 employees had grown since November 2013, but the rate in July was the lowest since December 2013. Facilities with 20 to 49 employees experienced a similar decline. Fabricators with 50 to 249 employees grew at a rate similar to June. Those with fewer than 20 employees contracted significantly after growing for two months.

Only two regions expanded in July. The North Central – West was fastest, despite contracting in two of the previous three months. The only growth was in the West (its second slowest rate of 2014), which had grown every month but three since January 2013. The Northeast and North Central – East contracted slightly after seven and nine months of growth, respectively. The Southeast's contraction accelerated for a second month.

Future capital spending plans fell to their lowest level since November 2012. They were 35.7 percent less than they were one year ago. This was the first month-over-month contraction since February. ■

THE COMPOSITES BUSINESS INDEX

Subindices	July	June	Change	Direction	Rate	Trend
New Orders	52.3	58.8	-6.5	Growing	Slower	8
Production	56.1	59.6	-3.5	Growing	Slower	7
Backlog	43.3	47.5	-4.2	Contracting	Faster	2
Employment	50.6	57.7	-7.1	Growing	Slower	17
Exports	47.5	51.1	-3.6	Contracting	From Growing	1
Supplier Deliveries	53.2	52.5	0.7	Lengthening	More	32
Material Prices	66.5	67.4	-0.9	Increasing	Less	32
Prices Received	55.0	51.8	3.2	Increasing	More	4
Future Business Expectations	69.7	75.2	-5.5	Improving	Less	32
Composites Business Index	50.5	54.5	-4.0	Growing	Slower	8

NEWS

EU SMARTFIBER project brings “smart” composites closer to reality

Structural health monitoring gets big boost from 7th Framework Programme

Source: Ghent University/ Rendering: Nicolas Lammens

An emerging, widespread discipline with application in a variety of structures, including steel and concrete bridges and buildings, structural health monitoring (SHM) also has been pursued for decades in the composites industry. This effort has pursued several goals: 1) to prevent failures from overload, manufacturing defects or damage; 2) to reduce the frequency and cost of inspection during service; 3) to provide real-time understanding of the fracture mechanics in composites and generate validation data for existing finite element models, with a view also toward increasingly complex designs.

SMARTFIBER, a three-year project (September 2010 through August 2013) funded by the European Union’s 7th Framework Programme, played a significant role in that effort, with the goal of embedding a complete miniaturized fiber-optical sensor system — including both a sensor array and an interrogator (autonomous readout unit) — into a composite structure — in this case, a tidal turbine. SMARTFIBER’s seven partners are now claiming success. They have demonstrated that such a sensor system can be fully embedded in a composite material — a first — and they assert that this achievement paves the way toward “smart” composites that could enable continued and automatic monitoring of the structural health of composite material in components that include not only tidal turbine blades but wind turbine blades, airplane fuselages and wings, and marine structures (e.g., masts, antennas, hulls and propellers).

Partners in the project include nanoelectronics research center IMEC (Leuven, Belgium), Ghent University (Ghent, Belgium), Optocap Ltd. (Livingston, West Lothian, U.K.), Xenics (Leuven, Belgium), the Fraunhofer Institute for Integrated Circuits IIS (Erlangen, Germany), FBGS International (Geel, Belgium) and Airborne International (The Hague, The Netherlands).

The SMARTFIBER approach uses Fiber Bragg Grating (FBG) sensors and a low-cost, miniaturized interrogator, enabling wireless power and two-way communication with an external read-out unit. Notably, researchers demonstrated automated (rather than manual) placement of the sensors and interrogator unit during structure manufacture. FBG sensors were used because they can provide continuous monitoring yet are compact, lightweight, immune to electromagnetic interference (EMI), highly resistant to corrosion and possess high-temperature capacity as well as multiplexing capabilities. The team believes FBGs are superior to conventional strain-monitoring techniques (e.g., classical electrical strain gauges) especially in pursuit of automated embedding during manufacture.

Silicon photonics technology enabled the high miniaturization and low cost sought for the FBG interrogator. A photonics integrated circuit (PIC) transmits a signal, which, after it is processed, is then received by the external read-out unit. The latter also supplies wireless power to the interrogator. Another key interrogator component is a tailored Array Waveguide Grating (AWG) filter. A SMARTFIBER white paper asserts that all of these devices can be manufactured using well-established industrial silicon-based microfabrication techniques and infrastructure, as demonstrated by the partner companies.

For the demonstration, the sensor system was cast into an epoxy shape specifically designed by Ghent University to minimize impact on the composite material. The system, with attached fiber sensor chain, was then embedded into the blade of a tidal turbine fabricated by Airborne International. The blade, a sandwich construction with a foam core and noncrimp fabric faceskins, was molded using light resin transfer molding (LRTM). Extra layers of glass fabric were placed to minimize resin buildup around the embedded system and to reduce the abrupt change in stiffness from laminate to embedded elements. The optical fiber was placed along the longitudinal length of the blade in loops from tip to root and held in position by small dots of glue. A strategy for automated placement also was developed.

When tested, the embedded system’s performance was consistent with the project goals. “We are investigating steps to be taken towards commercialization of the device,” says project leader Dries Van Thourhout. “Input from potential partners is welcome.”

CORRECTION

In the July 2014 issue, *HPC* published a story about composites use in fabrication of a radio telescope for the Square Kilometre Array (SKA). (See “Composites steady radio telescope reflector,” *HPC* July 2014 (p. 36) or visit short.compositesworld.com/CFDish.) In the story we reported that the National Research Council Canada (NRC-Canada, Ottawa, Ontario, Canada) said the resin system used to mold the radio telescopes main reflector dish, HETRON 922 vinyl ester from Ashland Performance Materials (Dublin, Ohio), was being discontinued and that NRC-Canada was seeking a replacement resin matrix. Ashland has informed *HPC* that, in fact, it is not discontinuing manufacture of HETRON 922 vinyl ester. *HPC* regrets the error.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AGC Aerocomposites makes two announcements

AGC AeroComposites (Seattle, Wash.), part of AGC Aerospace and Defense, and ATK (Arlington, Va.) announced on July 14 an agreement intended to create an aerospace and defense industry resource that will span what the partners say is "the full scope and scale of aerospace composites structures." Under terms of the agreement, the companies will jointly pursue content on commercial and military aircraft platforms, with an emphasis on automated tape laying and hand layup solutions.

The deal is expected to combine the companies' core capabilities, providing mutually beneficial turnkey composite design and manufacturing capabilities and resulting optimized solutions. These will include structural and nonstructural advanced composite products, specialized equipment, and tooling and manufacturing processes that span fiber placement, automated tape laying, large-part resin transfer molding and finishing, and hand layup.

"This teaming agreement allows AGC AeroComposites to meet a wider range of customer needs and to grow our business efficiently," says Rick Armstrong, president and CEO of AGC AeroComposites. "It's a perfect fit with our overall strategic growth plan, and will allow us to continue to add to our presence on new-generation aircraft with high composites content."

Ten days previously, AGC together with Technical Fibre Products Ltd. (TFP, Kendal, U.K.) unveiled a new lightweight composite solution for aircraft fuel systems. This joint development, on which a patent is pending, enables precise control of the electrical resistance in composite components and reportedly has the potential to provide a weight saving of up to 200 kg/440 lb per aircraft. The two companies are collaborating in the joint development of electrostatic and lightning-compatible composite pipes suitable for use in aircraft fuel systems. The shared technology enables control of the glass fiber-reinforced composite pipe's surface resistivity, allowing engineers to electrically isolate the structure, making it resistant to lightning strike propagation yet sufficiently conductive to dissipate the static electricity resulting from fluid movement.

The development is reportedly the first of its kind and presents the opportunity to save weight in aircraft fuel systems by replacing heavier metallic equivalents, as well as enabling further weight and cost savings by reduced reliance on currently used palliative isolating/bonding techniques. Estimated weight savings could represent fuel savings of up to 26,000 kg/57,320 lb per aircraft, per annum.

UMaine composites technology gets Mars lander consideration

The University of Maine (UMaine, Orono, Maine) says that its patented Bridge-in-a-Backpack composite technology, originally developed to expedite bridge construction on *terra firma*, has attracted the attention of NASA. The U.S. space agency is reportedly considering a similar technology for use in its Hypersonic Inflatable Aerodynamic Decelerator (HIAD), which could one day help deliver astronauts to the surface of Mars.

Nose-mounted on a spacecraft, HIAD is a "giant cone of inner tubes" stacked like a ring toy and designed to slow the spacecraft as it enters a planet's atmosphere. Bill Davids, Joshua Clapp, Andrew Goupee and Andrew Young — engineers within UMaine's Advanced Structures and Composites Center — are now 18 months into a three-year, $750,000 project funded by NASA and are working on a 6m/19.7-ft diameter HIAD. Davids and Clapp say the HIAD technology is viewed as one of the most-feasible options for a successful human spaceflight to Mars. "Our role is to fill in holes in NASA's technical knowledge," says Davids. "They have developed the technology; we help them advance it through testing the structures in the lab and analyzing stresses and deformations in the HIADs."

Read more about the project online at the CompositesWorld Web site: short.compositesworld.com/UMaineMars.

Parallel efforts in U.K. and U.S. explore additive manufacturing of composites

GKN Aerospace (Redditch, Worcestershire, U.K.) reported on July 17 that it will lead a consortium of U.K. companies in a three-and-a-half-year, £13.4 million ($22.8 million USD) additive manufacturing R&D program called Horizon (AM). The research effort will build on what the company describes as its already extensive and fast-developing additive manufacturing (AM) capability. Backed by the U.K.'s Aerospace Technology Institute (ATI), the Horizon (AM) team includes GKN Aerospace, Renishaw Plc (Gloucestershire, U.K.), Delcam Plc (Birmingham, U.K.) and the Universities of Sheffield and Warwick.

The Horizon (AM) team intends to take a number of promising AM techniques from R&D status to viable production processes, with the aim to create components that could be as much as 50 percent lighter than their conventional counterparts, with complex geometries that, today, cannot be manufactured cost-effectively. These new processes reportedly will unlock innovations in low-drag, high-performance aircraft wing designs and lighter, even more efficient jet engine systems, leading to reductions in aircraft fuel consumption and emissions.


Source: GKN

Initially, the focus will be on using AM techniques to create near net-shape parts that require very little secondary machining. The goal is to improve the buy-to-fly ratio of the part by reducing the considerable cost in time and material waste associated with the conventional machining of metal forgings. With material waste as high as 90 percent for some parts, a significant reduction here also will yield major environmental benefits.

"AM incorporates a range of hugely promising manufacturing technologies that the U.K. aerospace sector must fully understand and exploit if it is to retain its position as the largest national aerospace industry outside the USA," explains Rich Oldfield, technical director, GKN Aerospace. "This strong consortium has the expertise and understanding to continue the process of industrializing these technologies for use in both current program updates and next-generation aircraft."

Meanwhile, in the U.S., materials scientists at the Harvard School of Engineering and Applied Sciences (SEAS) and the Wyss Institute for Biologically Inspired Engineering (both in Cambridge, Mass.) are claiming a breakthrough of their own, having developed cellular composite materials of unprecedented light weight and high stiffness, using fiber-reinforced epoxy resins and 3-D extrusion printing techniques. Because of their mechanical properties and the fine-scale control of fabrication, the researchers say these new materials mimic — and improve upon — balsa wood performance as a core material in composite sandwich constructions. A paper describing the results has been published online in the journal *Advanced Materials*.

Until now, contends principal investigator Jennifer A. Lewis, the Hansjörg Wyss Professor of Biologically Inspired Engineering at Harvard SEAS, 3-D printing has been used mostly with unreinforced thermoplastics and UV-curable resins, materials not typically considered for structural applications. "By moving into new classes of materials like epoxies, we open up new avenues for using 3-D printing to construct lightweight architectures," she explains. "Essentially, we are broadening the materials palette for 3-D printing." She adds that balsa wood has a cellular architecture featuring mostly empty space, and only the cell walls carry the load. It, therefore, has a high specific stiffness and strength: "We've borrowed this design concept and mimicked it in an engineered composite."

Lewis, with Brett G. Compton, a former postdoctoral fellow in her group, developed inks of epoxy resins modified with viscosity-enhancing nanoclay platelets and a compound called dimethyl methylphosphonate, and then added two types of fillers: tiny silicon carbide "whiskers" and discrete carbon fibers. A key to the versatility of the resulting fiber-filled inks is the ability to control fiber orientation. A video of the 3-D printing is available at http://www.youtube.com/watch?v=pnGPYwNM4rE&feature=youtu.be.

Sikorsky, Boeing to build demonstrator for future vertical-lift rotorcraft

Sikorsky Aircraft Corp. (Stratford, Conn.) and Boeing Defense, Space & Security, a unit of The Boeing Co. (Chicago, Ill.), have been selected to build a helicopter for the U.S. Army's Joint Multi-Role Technology Demonstrator Phase 1 program (JMR TD), paving the way for the next generation of vertical-lift aircraft. The U.S. Army Aviation Technology Directorate (AATD) selected the Sikorsky-Boeing team to continue the development of the SB>1 *Defiant*, a medium-lift rotorcraft configured to Sikorsky's X2 coaxial design, through flight testing. First flight is expected in 2017.

The *Defiant* aircraft will feature counter-rotating rigid main rotor blades for vertical and forward flight, a pusher propeller for high-speed acceleration and deceleration, and an advanced fly-by-wire flight control system.

The JMR TD program supports the U.S. Department of Defense's Future Vertical Lift (FVL) program, and the *Defiant* aircraft is expected to package evolutionary technologies in a new, innovative and affordable design that flies faster, farther and with more payload.

To date, Sikorsky and Boeing collectively have delivered more than 3,000 helicopters to the Army in support of its challenging missions. Sikorsky and Boeing teamed for the JMR TD Program in January 2013, and each company has invested significantly in the program.

MHI to ramp-up the production of Boeing 787 composite wingboxes

Mitsubishi Heavy Industries Ltd. (MHI, Tokyo, Japan) announced in mid-August that it is investing in expanded production facilities for the composite wingbox it manufactures for The Boeing Co.'s (Chicago, Ill.) 787 *Dreamliner*. The expansion, which will involve two Japan-based locations, Shimonoseki Shipyard & Machinery Works (Shimonoseki) and Nagoya Aerospace Systems Works (Nagoya), was prompted by Boeing's plan to increase production from the current rate of 10 shipsets per month to 14 shipsets by the end of the decade. Construction, according to MHI, is expected to begin in October, this year, at both locations.

Shimonoseki Shipyard is responsible for the composite reinforcing stringers used in the 787 wingbox. Nagoya's Oye Plant is the site for fabrication and assembly of wingboxes and composite skin panels. The increase in production rate is targeted to begin ramping up sometime in 2016.

Shimonoseki will expand its Aircraft Shop and add an autoclave for curing the layered prepreg parts it makes under high temperature and pressure. In the Nagoya Oye plant, an automated tape laying system will be added and the location's Painting and Assembly Factory will be expanded. This will include modification of its existing automated drilling machines and installation of a new painting robot.

Cytec to explore entry into the industrial-grade carbon fiber market

On July 8, Cytec Industries Inc. (Woodland Park, N.J.) made public its intention to enter into strategic discussions with acrylic fiber manufacturer Dralon GmbH (Dormagen, Germany), to support the exploration and development of large-tow (>24K) carbon fiber. Cytec cited predictions that demand for large-tow fiber will grow significantly in the coming years, driven by increasing use in industrial markets that include the currently awakening automotive sector, where OEMs are actively researching the technology to help them lightweight vehicles in pursuit of greater fuel efficiency.

"Cytec offers a strong channel to market, given our position today of supplying high-performance automotive applications, as well as our decades of experience supplying carbon fiber composite technology to the aerospace industry," says Shane Fleming, chairman, president, and CEO of Cytec Industries. "We are actively pursuing the development of carbon fiber-based composites for the next addressable serial automotive market." Large-scale adoption, he contends, will necessitate a robust supply chain for high-tow fibers — one that offers both low cost and a reliable supply that will preclude shortage-related price spikes.

Says Stefan Braun, Dralon's CEO, "We are investigating conversion of existing Dralon acrylic fiber production lines for the manufacture of high-quality, heavy-tow precursor as well as investment in new carbon fiber lines. With our local footprint, we will be able to offer superior security of supply ...."

Cytec and Dralon envision operating the carbon fiber production as a separate entity, and anticipate opportunities to seek additional external partners.

Cytec joins a growing list of carbon fiber manufacturers that are banking on the potential for carbon fiber in the automotive market. Among them are the most well-developed — the Wiesbaden, Germany-based SGL/BMW partnership behind the supply of large-tow carbon fiber used in BMW's all-electric *i3* — and the most recent — signaled by Toray Industries' (Tokyo, Japan) late 2013 buyout of large-tow producer Zoltek Corp. (St. Louis, Mo.), which for years was the world's largest supplier of industrial-grade carbon fiber. In fact, almost every major supplier of carbon fiber is seeking to develop a lower-cost precursor for the manufacture of large-tow carbon fiber for automotive and industrial applications. Notably, U.S.-based Oak Ridge National Labs (ORNL, Oak Ridge, Tenn.) has its own carbon fiber pilot line and is evaluating alternative precursors.

Despite this activity, it's far from clear that auto industry/carbon fiber market nuptials are near. Proposals from BMW and Volkswagen aside, some OEMs — Ford Motor Co. (Dearborn, Mich.) the most vocal — remain skeptical. If carbuyers demonstrate a preference for the benefits carbon fiber offers in cars now entering the market, the wedding bells might yet ring.

BIZ BRIEFS

GKN Aerospace (Cowes, Isle of Wight, U.K.) reported July 14 that it has been selected by aircraft manufacturer Bombardier Aerospace (Belfast, U.K.) to design, develop and supply the composite integrated rudder and elevator for the new Bombardier *Global 7000* and *Global 8000* ultra-long-range business jets. The multi-million pound

Source: Bombardier

contract adds to an already significant number of GKN Aerospace work packages on these aircraft.

These composite structures will be developed and manufactured at the company's Cowes facility. First deliveries to Bombardier's facility in Belfast will take place yet this year and are expected to continue through 2026. For the *Global 7000* and *Global 8000* aircraft, GKN Aerospace already has contracts to design, develop and produce the transparencies, including the high-performance cockpit windows and ultralarge passenger cabin windows (announced by Bombardier in July 2012), and to design, build and supply the advanced composite winglets and ailerons (a contract announced in August 2012).

Neil McManus, CEO, GKN Aerospace - Europe and Special Products, states, "This latest contract win illustrates both our growing relationship with Bombardier Aerospace, which includes the supply of critical structures for the C*Series* aircraft's advanced composite wings, and also our increasing participation in the business aviation market."

BIZ BRIEFS

Strata Manufacturing PJSC (Al Ain, U.A.E.), an advanced composite aerostructures manufacturing facility wholly owned by Mubadala Development Co., announced July 19 the signing of a 10-year, $16.5 million (USD) agreement with Dubai, U.A.E.-based **Premier Composite Technologies** (PCT). Strata will outsource to PCT the honeycomb core-cutting function for the production of the Airbus (Toulouse, France) A380 passenger jet's flap track fairings. Strata says it will benefit from time and effort saved by outsourcing the processing of these materials, in addition to the resulting reduction in inventory days on raw material, as well as working capital savings, and the reclamation of 400m²/4,306 ft² of its factory floor space, which can be repurposed for its internal production process.

Strata CEO Badr Al Olama says, "We constantly work towards building a local supply chain which will enable us to reduce risks and outsource some of the company's non-core operations, allowing us to focus more on value added operations."

In 2014, Strata's procurement from local suppliers amounted to 30 percent, a percentage it intends to increase annually. PCT has successfully passed both Strata and Airbus qualification audits and Airbus is currently in the process of adding PCT formally onto the Airbus Approved Suppliers List. In the second quarter of 2014, the A380 flap track fairing program honeycombs manufactured by PCT successfully passed qualification and first-article manufacturing phase. In addition to the A380 flap track program, PCT also will bid on the honeycomb packages for A330 flap track fairings, aileron and spoilers, followed by the Boeing programs that Strata's procurement team is in the process of tendering.

INAUGURAL TRADE SHOW: CAMX 2014 PREVIEW

Source: Orange County Convention Center

ACMA's and SAMPE's combined event promises a U.S. conference and exhibition of unprecedented scale and value to composite manufacturers from all segments of the diverse composites industry.

What:	**CAMX 2014**
When:	**Oct. 13-16, 2014**
Where:	**Orange County Convention Center, Orlando, Fla.**
Info:	**www.thecamx.org**

For many years, the North American composites trade event community has been ably served by two major conferences/exhibitions: one offered by the American Composites Manufacturers Assn. (ACMA, Washington, D.C.) and the other by the Society of the Advancement of Materials and Process Engineering (SAMPE, Covina, Calif.). Each show served a different segment of the market: ACMA covered what is often called "industrial" composites while SAMPE focused on "advanced" composites (well defined in this issue by guest columnist Bob Skillen, in "Market Trends," p. 9.)

However, the trend lines of the past few years — e.g., increased carbon fiber use in automotive and wind, increased out-of-autoclave processing in aerospace — have gradually pushed these segments closer together. This convergence will culminate next month with the debut of the Composites and Advanced Materials Expo (CAMX 2014). Premiering Oct. 13-16 at the Orange County Convention Center in Orlando, Fla., this joint ACMA/SAMPE undertaking is designed to offer composites fabricators of all stripes a "one-stop shop" for the latest materials, tooling, software, processes and other technologies that, today, are shaping *all* segments of the composites industry.

What you will find

CAMX 2014 will feature four days of conference sessions (Oct. 13-16) overlapping with a three-day exhibition (Oct. 14-16). The conference portion will combine the best of what ACMA and SAMPE once offered separately, in an extensive variety of educational options — technical papers, education sessions, panels and tutorials — plus a keynote address (Tuesday, Oct. 14 at 9:30 a.m.) by Kevin Mickey, president of Scaled Composites (Mojave, Calif.). Founded by composites legend Burt Rutan, Scaled Composites is at work with space tourism startup Virgin Galactic (Las Cruces, N.M.) to develop *MotherShipTwo* and *SpaceShipTwo*, designed to launch customers into low-Earth orbit. Mickey will discuss the future of composites and advanced materials, possibilities for transitioning aerospace-quality materials into an automotive-style production process and price point, and how the industry can approach traditional material users about *conversion* to composites. He also will describe the Scaled Composites approach to composites design and manufacturing, which centers on creating collaborative project teams. For all the details about the conference, pricing and registration, visit the CAMX Web site (www.thecamx.org).

On the show floor

The inaugural CAMX show, at *HPC* press time, already had more than 550 exhibitors committed to the show floor, The following is a mere suggestion of what's in store for attendees (for much more, see "Learn More," on p. 40):

Airtech International (Huntington Beach, Calif.) is featuring several infusion products, including Airflow 100R, a durable high-temperature and high-pressure autoclave hose, now available with 90° fixed end-fittings on one or both ends. The outer protective sleeve, of silicone rubber, encases a braided stainless steel tube with an a PTFE liner and a flexible steel spring conduit that prevents collapse from vacuum/autoclave pressures. The Airtech Vacuum Test Unit (pictured) is a compact, lightweight device for in-service equipment testing or to check equipment after maintenance (e.g., seal replacements on valves or end-fitting replacements on hoses). www.airtechonline.com

Altair Engineering Inc. (Troy, Mich.) will highlight its HyperWorks design/engineering tools for composites, based on finite element methods in conjunction with optimization algorithms that provide design guidance and insights. The software suite includes HyperMesh, which enables users to read composites data from the CAD model, with ply shapes and parameters comprehended and mapped onto elements. It can convert from ply- to zone-based modeling for solvers that have no native support for ply-based modeling. HyperView provides layer-based post-processing for composites, yielding results for individual layers and the aggregation of layers, identifying the maximum contributing layer. www.altair.com

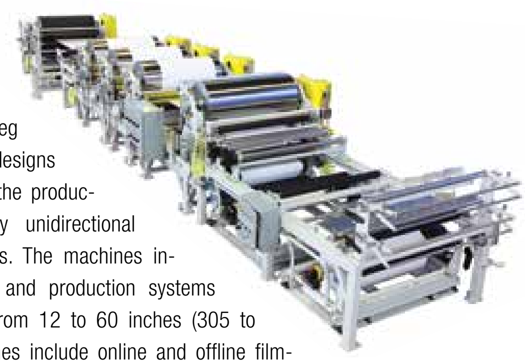
Anguil Environmental Systems Inc. (Milwaukee, Wis.) will emphasize its oxidation equipment, used in the manufacture of carbon fiber. Because the manufacture of carbon fiber is heavily regulated and oxidation and carbonization furnaces and industrial ovens have the potential to emit volatile organic

compounds (VOCs) that are health-threatening and/or contribute to global warming and the user's consumption of energy, Anguil will highlight its Thermal Recuperative Oxidizer, which features a stainless-steel heat exchanger within the oxidizer that reduces the supplemental fuel required to bring the process emissions up to combustion temperatures. A secondary heat recovery system, downstream of the oxidizer, captures most of the remaining heat. This is enough energy to preheat the air for the process equipment. www.anguil.com

Axson Technologies (Madison Heights, Mich.) is introducing to the North American market its highly durable, seamless modeling paste, SC 390. With improved temperature resistance and greater hardness, SC 390 is designed for large-scale tools in demanding applications. The enhanced properties are said to result in increased service life. The new paste already has been used to form the plug for a 50 ft long and 8 ft wide (15.2m by 2.4m) wind blade tool. Machined on a 5-axis CNC machine, it reportedly will withstand multiple pulls. www.axson-technologies.com

BYK USA (Wallingford, Conn.) will focus on wetting aids, dispersants and coupling agents formulated to improve glass, carbon and natural fiber composites. Products include air-release additives and defoamers, VOC- and odor-control solutions, scratch and mar control, pigment and filler dispersants and organo-modified clays for control of rheology, melt strength, dimensional stability and mechanical properties. The company's GARAMITE additives reportedly differ from other organically modified mineral thixotropes by exhibiting ease of dispersion, ease of use, high efficiency and high performance without unwanted viscosity. www.byk.com

C.A. Litzler Co. (Cleveland, Ohio) will spotlight its latest hot-melt prepreg machines. Litzler designs this equipment for the production of high-quality unidirectional and woven prepregs. The machines include development and production systems in widths ranging from 12 to 60 inches (305 to 1,524 mm). Machines include online and offline filmers as well as a patent-pending thermoplastic prepreg unit. Litzler's prepreggers are designed with the S-wrap prepreg process, which increases production up to 100 ft/min (30.5m/min) on a standard machine. www.calitzler.com



CGTech (Irvine, Calif.) will demonstrate the process of programming automated composite machinery. Visitors will view the steps taken to get from a CAD-designed composite part to CNC programs that drive an automated fiber placement (AFP) or automated tape laying (ATL) machine. CGTech also will demonstrate VERICUT composite applications: VERICUT Composite Paths for Engineering (VCPe); VERICUT Composite Programming (VCP); and VERICUT Composite Simulation (VCS). VCPe measures and evaluates the effects of AFP and ATL path trajectory, material steering, surface curvature, course convergence and other process constraints as they would be applied in manufacturing. It also provides producibility analysis of the fiber angle, based on part curvature and overlap and gaps needed for structural analysis. www.cgtech.com

CHEMIR's (Maryland Heights, Mo.) analytical experts and Canadian law firm Gowlings' (Ottawa, Ontario, Canada) patent law experts will team up to provide a technical presentation titled, "Intellectual Property Considerations and Strategy in New Product Development." Anita Nador, a Gowling partner and registered U.S. and Canadian patent agent specializing in chemical- and life sciences-related patents, will discuss the legal implications of conducting research on patented products, the first-sale doctrine, and reverse engineering (also known as *deformulation*) of a patented product, both from the perspective of a new market entrant and a patent owner. Dr. Albert Lee and Aaron Cassely, both scientists from CHEMIR, will present a case study of an adhesive deformulation to further illustrate these challenges. www.chemir.com

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Cytec Industries Inc. (Woodland Park, N.J.) will feature its full portfolio of structural and tooling prepregs, resin infusion systems and structural adhesives that are complemented by a range of process materials. Offerings for aerospace customers will include Cytec's out-of-autoclave (OOA) product portfolio, including its CYCOM 5320-1 resin system, its MTM44-1 resin system and its MTM45-1 resin system. During the CAMX conference, paper presentations by members of Cytec's technical organization are scheduled on the benefits and recent process developments surrounding these breakthrough technologies For the automotive market, products will include the XMTR50 resin system, Cytec's new two-component epoxy, developed specifically for the high-rate manufacture of auto components using a high-pressure resin transfer molding (HP-RTM) process, which reportedly enables the manufacture of components in three minutes at 120°C/250°F for a T_g .of 135°C/275°F. www.cytec.com

Dexmet's (Wallingford, Conn.) expanded Lightning Strike division will offer its MicroGrid precision expanded metal foils to makers of composite materials. MicroGrid's single-unit structure is said to be superior to woven material in that it won't unravel or produce loose strands that become problematic when processed into a prepreg material or during dry layup. The foil's homogenous design reportedly ensures uncompromised conductivity between strands when forming the material to a variety of shapes and contours, and provides a smooth surface on the end product. Dexmet says MicroGrid's biggest advantage is the company's ability to tightly control the manufacturing process to meet a specific weight, open area and conductivity requirement. www.dexmet.com

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CNC specialist **Diversified Machine Systems** (DMS, Colorado Springs, Colo.) will exhibit DMS D5E, an enclosed 5-axis overhead-gantry CNC router with twin moving tables, customized for composites machining. It features a Fagor 8055i CNC control, solid 2-ft by 3-ft (0.6m to 0.9m) twin tables and a 30-inch/762-mm Z stroke. It is said to be the first machine of its kind to offer a glass, clamshell-style roof on a smaller unit. Other features include airborne debris containment, a dual-table workspace and footprint efficiencies that are said to be in demand globally. www.dmscncrouters.com

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DMG MORI Ellison Technologies (Santa Fe Springs, Calif.) will demonstrate the ULTRASONIC Series from SAUER, the advanced technology division of DMG MORI. The series pairs kinematic overlapping of the tool rotation with an additional oscillation, which means that high-performance materials can be economically processed with what is said to be the highest achievable quality. For composite components, ULTRASONIC features include double feeds, and it results in clean edges, with no fiber pullout, no delamination and no heat-affected zones. The system also prevents buildup along edges and features an extraction concept with fine dust monitoring. www.dmghmoriseiki.com

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Hexcel's (Stamford, Conn.) many CAMX products will include HexTow HM63 carbon fiber, which offers what Hexcel says is the highest tensile strength of any high-modulus fiber, providing good translation of fiber properties in a composite, including what is said to be superior interlaminar shear and compression strength. HexTow HM63 is reportedly suitable for any high-stiffness and strength-critical applications, including space satellites, unmanned aerial vehicles (UAVs), commercial aircraft and helicopters. It's also said to meet the requirements for premium sports and recreation applications, including Formula 1 cars, marine craft, bikes and fishing rods. www.hexcel.com

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Huntsman Advanced Materials (The Woodlands, Texas) will launch three new benxoxazine resins for out-of-autoclave (OOA) composite manufacturing, and a new liquid shim adhesive for aerospace applications. In addition, Huntsman will showcase high-performance adhesives and composite resins used in automotive, aerospace and industrial applications. Huntsman also will present two papers at CAMX: "High-Performance, Rapid-Cure Liquid Shim for Aerospace Applications," by Tim Truong and K.P. Subrahmanian; and "Evaluation of Two-Component Structural PU Adhesive for Joining Dissimilar Materials in the Transportation Sector — A Case Study," by Hans Kaul and Saeil Jeon (Volvo Group Trucks Technology). www.huntsman.com/advanced_materials

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L&L Products (Romeo, Mich.) will launch a unique **reformable** epoxy adhesive film. Designated L-F610, it reportedly combines the adhesion and mechanical properties of an epoxy with the processing ease of a thermoplastic. L&L says L-F610 will facilitate new opportunities for the manufacture of composite parts, panels and laminates. With a tensile elongation of 40 percent, the film is said to offer high toughness, with better strength and better adhesion than conventional thermoplastic adhesives. L-F610 is formulated not only to adhere to many different substrates — metals, epoxy composites, plastics and wood — but also can be readily used to bond a wide range of

dissimilar substrates *and* can be debonded and reformed, allowing part modification in existing structures. Unlike epoxy film adhesives, L-F610 requires no refrigeration and has a long shelf life. www.llproducts.com

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Matrix Composites (Rockledge, Fla.) will emphasize its range of high-performance composites manufacturing services, including design, development, tooling, testing and integration. Markets served include aerospace, defense and commercial/general aviation. Visitors to the booth will find examples of the company's work, including spacers, radomes and vents. Says Jeffrey Sharbaugh, Matrix Composites' business development manager, "Over 20 years of lessons learned is a true differentiator for Matrix and our latest advancements in closed molding could really open up new doors for these companies." www.matrixcomp.com

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Resin manufacturer **Renegade Materials Corp.** (Springboro, Ohio) will spotlight its polyimides and bismaleimides (BMIs). The company's out-of-autoclave BMI (RM-3004) and BMI Infusion Resins (RM-3000 and RM-3010), currently in qualification at aerospace primes, will be the focal points. Renegade also says it plans to expand its BMI adhesive product line this fall. Renegade's polyimide prepreg system, MVK-14 Freeform, is now flying on commercial engine hardware and is in evaluation on primary structure for military engines. Also featured will be Renegade's low-dielectric prepreg systems, including cyanate ester (RM-5003) and its new modified epoxy (RM-2014). RM-2014 offers good dielectric performance and ease of processing at a reportedly lower cost than cyanate esters. www.renegadematerials.com

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Sicomin Epoxy Systems (Marseille, France) will show its accredited range of materials currently in use by several aerospace OEMs: Sicomin SR1526 is a fire-retardant prepreg epoxy system designed for in-house prepreg processes. It's accredited for several aerospace cabin interior applications. Sicomin SR 1126 is a self-extinguishing, low-viscosity epoxy that meets both Airbus' and Boeing's FST (fire, smoke and toxicity) standards. SR 1126's laminate classification approval has been identified as UL94/V0 and *FAR* 25-853 (a). Sicomin SR1720, an epoxy for resin transfer molding (RTM) in high-performance, structural applications, reportedly exhibits a low viscosity and can be used in combination with a slow-reactivity hardener for large-part manufacturing. www.sicomin.com

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Solvay Specialty Polymers (Alpharetta, Ga.) will introduce Radel PPSU foam, said to be the industry's first thermoformable polyphenylsul-

CW LEARN MORE @ www.compositesworld.com

For more product/service information, read a much-expanded version of this article online at short.compositesworld.com/CAMX14PR.

fone (PPSU) foam for insulative and structural components used in aircraft interiors. Positioned as an alternative to honeycomb core, Radel PPSU foam reportedly lends itself to high-rate manufacturing of sandwich structures with consistent quality at attractive prices. For cores and ducting, Solvay also will highlight Solef PVDF foam, which can be molded into complex 3-D shapes that offer excellent flame/smoke/toxicity (FST) performance, toughness, resilience, excellent resistance to aerospace fluids, and maintenance of mechanical properties at operating temperatures as high as 120°/248°F. Solef 3-D molded foam reportedly permits the production of parts with zero scrap and eliminates the need for interior insulation. www.solvayspecialtypolymers.com

The Composites Group (TCG, Highland Heights, Ohio) will feature five new thermoset compounding materials and two technical presentations at CAMX 2014. New items: The PremierUV line, which comprises PremierUV VSH-25S and PremierUV VLH-25S, for electrical and outdoor applications, including electrical enclosures, light housings and warning tiles. Both are glass-reinforced compounds with nonhalogenated flame-retardants that have color retention and resistance to chalking and glass bloom. The PremierLT family of lightweight, low-density materials is designed to meet market needs for structural and semistructural applications. PremierLT L701S boasts a specific gravity of 1.2 along with good moldability. It can be pigmented, exhibits low shrinkage, offers good strength and moldability with a specific gravity of 1.5. www.thecompositesgroup.com

Wisconsin Oven Corp. (East Troy, Wis.) will tout its line of electrically heated, gas-fired and indirect gas-fired, batch-type composite curing ovens. Each oven features a high-pressure recirculation blower, which includes fully enclosed and pressurized supply ducts designed for combination airflow arrangement, which is said to ensure uniform heat distribution throughout the work chamber, even with varying loads. The company's composite curing

ovens are typically guaranteed and certified for ±10° at 350°F/177°C temperature uniformity, but tighter tolerances and certification at other temperatures are available. Reportedly, equipment is completely tested prior to shipment and must pass a 154-point quality inspection prior to shipment. And ovens are available with the company's E-Pack Oven upgrade, an optional package that includes thicker wall panels, higher efficiency motors and other energy-saving features. www.wisoven.com

Source: SAMPE

SAMPE SEATTLE 2014 REPORT

Conference: Continued excellence

As always, SAMPE fielded a slate of well-attended presentations, panels and keynotes.

BY SARA BLACK & JEFF SLOAN

The Society's reconfigured spring advanced materials event in Seattle, Wash., attracts speakers, exhibitors and attendees in large numbers and international dimensions.

The Covina, Calif.-based Society for the Advancement of Material and Process Engineering's (SAMPE) Seattle meeting, held June 2-5, attracted nearly 3,500 attendees and drew 233 exhibiting companies, 40 of which were new to the show. Participants hailing from 28 countries gathered in the Washington State Convention Center in the heart of the city.

The vibrant event offered, as always, a slate of excellent presentations, panels and keynotes. Not least was the appearance on Tuesday morning of Jörg Pohlman, the managing director of SGL Automotive Carbon Fibers GmbH (ACF, Moses Lake, Wash.). He described that group's journey from helping to develop an initial car concept for the BMW Group (Munich, Germany) to its current role as a large-scale carbon fiber manufacturer. When Pohlman, an attorney, joined the hush-hush "Project *i*" in 2008, he recalled, the carmaker faced challenges that included changes in driver demographics and sentiments. "We were tasked with reinventing mobility," he said. "We wanted a new image and new customers." By now, most in the composites world know about the results of that secret brainstorming project: the *i3* electric and *i8* hybrid-electric cars that feature a carbon fiber composite Life Module (passenger cell) atop an aluminum chassis — the Drive Module — that supports a battery-energized electric powertrain (see "Learn More," p. 45). Pohlman reviewed not only the Life Module, but the *i3's* thermoplastic body panels and its seats and interior panels, which incorporate recycled polyethylene terephthalate (PET) reinforced with natural fibers. He also pointed out that the module/chassis concept, popular a century ago with the earliest automakers, enables fast and easy derivative model development. A different body design for a new model year, for example, can be mated with an existing chassis.

Of interest was BMW's goal of creating a "CO_2-neutral" car. "Rather than start with a 'cool' design, and then figure out how to manufacture it," Pohlman pointed out, "we turned it around, and talked

Source: SAMPE

Exhibition: Strong attendance

SAMPE's show floor boasted 233 exhibitors, attracting a reported 3,500 attendees.

first to production people, to figure out how to minimize energy and resource use during manufacturing before committing to a design." Production of the *i3*, as a result, consumes 50 percent less energy than any other "green" car, and 70 percent less water, because waterless body painting is involved, he contended. In addition, the energy used is largely renewable, thanks to wind turbines in use at the Leipzig plant and the hydropower afforded by the Moses Lake location. Pohlman revealed that the decision to build its fiber plant in the U.S. was not a popular decision in Germany: "We stimulated some political debate but, in fact, German energy costs five to seven times what we could obtain in Washington." For those who question the wisdom of shipping carbon fiber precursor from Japan to Washington, and fiber from Washington to Germany for converting, he stated that less than 1 percent of the *i3's* value chain energy is represented by shipping logistics. Further, materials are transported by ship rather than rail, again, out of consideration for the car's carbon footprint. Because carbon fiber supply is the limiting factor in the supply chain, and more than 50,000 *i3s* will be rolled out, SGL ACF has increased fiber production of its 50K fiber and has begun work on a third building that will ultimately increase annual nameplate capacity to 9,000 tons by the end of 2015 (see "Learn More"). Pohlman says the 50K fiber is "totally sufficient for our purposes."

Of high interest was a panel on additive manufacturing (AM), chaired by Brett Lyons of Boeing Research and Technology (BR&T, Seattle, Wash.), which looked at a spectrum of 3D printing approaches. Panelist Ian Ashcroft of the University of Nottingham (U.K.) described his group's work on topology optimization to develop the most efficient distribution of material in a part. He pointed out that AM is great at capturing and building very complex parts, but a complex part requires a more complex model mesh as well; his work on Quadtree and Octree data structure and nonlinear optimization is aimed at making 3-D printed parts better. In a wild contrast, Prof. Mark Ganter of the University of Washington (Seattle) described his students' experiments in using "free" 3D printing materials, such as ceramic clay or even foodstuffs. Justin Rivera of Bell Helicopter Textron (Ft. Worth, Texas) revealed that his company uses AM to produce prototypes and replacement parts, and that Bell makes nearly 400 helicopter parts in this way.

Thomas Cender, from the University of Delaware (Newark, Del.), talked to a standing-room-only crowd about void reduction in out-of-autoclave (OOA) processing during part consolidation. His work focuses on the effects of compaction, hold time under pressure, airflow process modeling and air-bubble migration patterns. Christian Hopmann, from RWTH Aachen University (Aachen, Germany), presented intriguing data regarding the use of microencapsulated dyes in laminate structures as a means of damage detection. Dye-filled microcapsules are placed on a carrier veil under the top surface layer in a laminate structure. When the structure suffers an impact, the capsules break and, thus, "bruise" the surface of the composite part, betraying damage (or potential damage).

Dr. Byron Pipes of Purdue University, a featured lecturer, discussed how the material certification process might be accelerated through simulation

Nondestructive inspection technologies

NDT Systems (Huntington Beach, Calif.) showed an automated C-scan imaging system (below) called TunnelScan, for composites manufacturing and repair applications, and its portable, battery-operated BondHub C-scan device (left) for adhesive bond evaluation, which captures images in resonance, pitch-catch or mechanical impedance modes.

Source (both photos): HPC/Photos: Jeff Sloan

Source: SAMPE

SAMPE Student Bridge Competition

A fixture at SAMPE events each spring for years, the contest continued in 2014 with a large number of entries.

tools that are developed and shared by both OEMs and the supplier community (see "Learn More"). Bill Pearson of North Sails (Milford, Conn.) spoke at the Awards Luncheon on Thursday about his company's articulating and reconfigurable three-dimensional molds designed to enable fabrication of composite membranes with large surface areas, using robotic fiber placement. The strategies have broad implications for future, customizable design and manufacture in composites.

Standout papers included a presentation by Dr. Angelos Miaris of Premium Aerotec (Bremen, Germany), a subsidiary of Airbus (Toulouse, France). He described the design and robotic manufacture of thousands of carbon fiber/PEEK thermoplastic laminate "clips" — parts that secure the Airbus A350 XWB's composite skin panels to the aircraft's network of fuselage frames and stringers. Wendy Lin, formerly principal engineer, composites, at GE Global Research (Niskayuna, N.Y.) and now a consulting engineer at GE Aviation (Cincinnati, Ohio), described the infusion of microcrack-resistant composites, using a nano-toughened, low-viscosity epoxy resin.

On the show floor, Laser Projection Technologies Inc. (Londonderry, N.H.) discussed its LPT 100 Projector, which integrates high-speed, laser radar with a 3D laser projection system. Launched in 2013, the system reportedly can be used for process control and verification as well as reverse engineering. According to company president Steve Kaufman, the system also can be set up for in-process inspection and feature recognition in automated processes: "Our system can measure the angle of a fabric and even individual tows to very high accuracy." The LPT 100 measures at 100MHz/second and creates a 3-D point cloud of the measured surface. When it is combined with the company's TOPO software, the LPT 100 visualizes production errors in the form of a topographical projection.

First-time exhibitor Nucap Industries Inc. (Toronto, Ontario, Canada), reportedly the world's largest producer of metallic brake system components, was on hand to gauge interest within the composites industry for its new product called NRX, a metallic sheet or strip treated mechanically to form thousands of tiny raised projections or hooks. The hooks can be created on nearly any type of metal, and sheets can be as thin as 0.3 mm/0.118 inch. The hooks and the formable metallic sheet could be used to create hybrid metal/composite solutions, says Nucap's chief operating officer Montu Khokhar.

Bondtech Corp. (Somerset, Ky.), a specialist in autoclave system design and manufacture, revealed that the Long Island Forum for Technology (LIFT) consortium, headquartered in Bethpage, N.Y., has selected Bondtech autoclaves for LIFT's Composites Prototyping Center (CPC), expected to become the center of a composites cluster on Long Island. CNC machining center manufacturer Quintax (Stow, Ohio), part of Stow-based Ferry Industries Inc., announced at the show that it has launched a redesigned Web site, for greater functionality and resource access for its customers.

NDT Systems (Huntington Beach, Calif.) introduced at the event an automated C-scan-type imaging system called TunnelScan, for use in composites manufacturing and repair applications. Designed to work with the company's Raptor imaging flaw detector, this dry, low-frequency scanner can be used to inspect foam cores, sandwich structures and traditional laminates, checking for disbond, delamination, crushed core and far-side defects. TunnelScan comprises an automatic X-Y scanner on a 12- by 18-inch (300 by 460 mm) bed that is attached to the part by magnetic or suction-type feet, prior to scanning. Also new from NDT Systems is BondHub, a bond testing C-scan device that captures images in resonance, pitch-catch or mechanical impedance modes. The portable, battery-operated unit is compatible with the company's Bondascope 3100 system.

In the SAMPE Student Bridge Competition, held each spring, the winners were:

- I-beam carbon and/or aramid fiber, 7,000 lbf: U. of Delaware, Tongji University, U. of Washington
- I-beam glass fiber, 7,000 lbf: Tongji University, Cal Poly San Luis Obispo, U. of Delaware
- I-beam natural fiber, 3,000 lbf: Tongji University, U. of Delaware, Cal Poly San Luis Obispo
- Square beam carbon and/or aramid fiber, 10,000 lbf: U. of Washington, Harbin Engineering University, Cerritos College
- Square beam glass fiber, 7,000 lbf: Tongji University, U. of Washington, Harbin Engineering University
- Square beam natural fiber, 3,000 lbf: Tongji University, Harbin Engineering University, U. of Delaware
- Open design, 15,000 lbf: U. of Washington, Cerritos College, Harbin Engineering University
- Poster: McGill University, U. of Delaware, U. of Delaware.

The spring SAMPE conference will move across the U.S. map to Baltimore, Md., in 2015, followed by return west, to Long Beach, Calif., in 2016, and a stop in Salt Lake City, Utah, in 2017. ■

CW LEARN MORE @ www.compositesworld.com

Read this article online at short.compositesworld.com/SAMPE2014.

CompositesWorld toured BMW's *i3* production facilities Leipzig, Germany, and reported on its manufacturing process in the June 2014 issue of *HPC's* sister publication *Composites Technology* (p. 40). Read it online at short.compositesworld.com/BMWLeipzig.

Read about the groundbreaking event for SGL ACF's third production building in Moses Lake at short.compositesworld.com/MosesLake3.

Read a two-part consideration of Dr. Pipes' ideas about certification via simulation:

"Accelerating the certification process for aerospace composites" *HPC* March 2014 (p. 7) or visit short.compositesworld.com/cdmHUB.

"An Internet aid for acceleration of aerospace composites certification," *HPC* May 2014 (p. 7) or visit short.compositesworld.com/cdmHUB2.

FARNBOROUGH 2014 AIRSHOW REPORT

Source: *HPC*/Photo: Bob Griffiths

BY BOB GRIFFITHS

No longer a novelty at aerospace trade events, composites nevertheless faced some competition from conventional materials at this year's event.

At the Farnborough International Airshow and others like it, the display of composite aerostructures has almost become normal in recent years, and they are a major feature in many new aircraft programs. However, this year, composites were less conspicuous than they have been at previous Farnborough shows.

Held every other year (alternating with the Paris Air Show in Le Bourget, France), Farnborough this year, July 14-20, was the stage for Airbus (Toulouse, France) and The Boeing Co. (Chicago, Ill.) announcements, respectively, of the new A330*neo* and 777X aircraft.

Metal strikes back

Actually significant revisions of popular existing models, both the A330*neo* and the 777X will proceed with *metal* fuselages. These outcomes underscored the need for composite structures to continue to earn their way onto aerospace programs, not only in terms of cost but also with an eye to the potential risk to program time scales.

That said, Boeing's 777X will have all-new and longer wings, made from composite materials, using 787 technology. Boeing judged that the dry fiber/infusion technology it developed for the movables of the 787 wing was not yet ready for such a large structure as the 777X wingbox.

The wing length was increased substantially to optimize the aircraft's aerodynamic performance. To enable the plane to operate from existing jet ways and aircraft berths at airports, many of which are too narrow to accommodate the greater wingspan, the outer portion of each wing will fold, rather like that of a carrier-based fighter jet.

The 777X fuselage will be made from metal and remain largely unchanged. It was a big surprise, however, that it will feature bigger windows (15 percent larger than those fielded by competitors) and sport enhanced cabin pressure and humidity. Previously, Boeing had claimed that these features, which are judged to be a big success on the 787, were made possible by the use of composite materials in that aircraft's fuselage.

The new announcement from the Airbus camp represents some strategic marketing decisions. In terms of size and, therefore, passenger capacity, the new A350 XWB sits somewhere between the Boeing 787 and the larger 777X. As a result, the smaller A330 has continued to sell well despite being very much a "previous generation" aircraft. Tom Leahy, COO of Airbus, announced that the company has finally decided to launch the A330*neo*, of which the company expects to sell 1,000 aircraft. This revised aircraft's most notable feature is a new Rolls-Royce (Derby, U.K.) Trent 7000 engine with a 112-inch/284-cm fan. The Trent 7000 builds on the record of the Trent 1000 used on the Boeing 787. Fully 95 percent of the A330*neo's* airframe will remain unaltered. The only new composite features reported were the wing extensions and Sharklet winglets. There will be some changes to the metal wingbox to save weight to balance the heavier engines and longer wings. The emphasis on this program is clearly to engage in a rapidly developed, low-risk project

Stiffened competition for aircraft supremacy

At airshows, of late, composite aerostructure introductions have become almost commonplace, thanks in part to the pioneering efforts of Airbus (Toulouse, France) on its A380 and The Boeing Co. (Chicago, Ill.) on its 787 *Dreamliner*. At the 2014 edition of the Farnborough International Airshow, however, metals held their ground on newly announced single-aisle updates.

Source: HPC/Photo: Bob Griffiths

Infused, oven-cured stabilizer skin

Irkut (Ulyanovsk, Russia) had an *MS-21* aircraft stabilizer skin on display at the show. Infused and then cured in an oven rather than an autoclave, it features materials supplied by Cytec Industries (Woodland Park, N.J.). The part's skin incorporates integral "T" stiffeners. The 7.5m/24 ft long strutcure weighs a mere 50 kg/110 lb.

Source: HPC/Photo: Bob Griffiths

New kid on the block

Airbus (Toulouse, France) had its new A350 XWB on hand, in launch-customer Qatar Airways livery, but the airframer made its biggest splash with the announcement of the A330*neo*, an updated version of its still popular but decidedly "previous generation" single-aisle passenger jet.

that will yield a passenger jet with performance that will rival that of the 787.

Discussions with Rolls-Royce's Tim Boddy revealed that the new Trent 7000 engine for the A330*neo* will incorporate conventional titanium fan blades. According to Boddy, composite blades and fan cases, which Rolls-Royce is codeveloping with GKN Aerospace (Redditch, Worcestershire, U.K.), demonstrate superiority over conventional materials only in larger engines with higher bypass ratios. Rolls-Royce is reportedly building a demonstrator to prove the concepts for the composite fan blades, spacers and fan cases under development by CTAL, a Roll-Royce/GKN joint venture based on the Isle of Wight, U.K.

The take-away from these Farnborough developments is clear: Composites have to work harder to justify their use because of higher nonrecurring costs (NRC) and perceived technical and manufacturing risks.

Infused single-aisle wing

Elsewhere, the Moscow, Russia-based airframer Irkut is at work on its MS-21 aircraft. Fitted with 180 seats, it will compete with the Airbus A320 and the Boeing 737, but will offer a wider cabin. Its advantage will be a composite wingbox and Pratt & Whitney's (East Hartford, Conn.) Geared Turbofan engines. Its composite wingbox will be fabricated by Ulyanovsk, Russia-based AeroComposit, which, like Irkut, is a subsidiary of the United Aircraft Corp (UAC).

MS-21 program deputy director Sergey Chernata explained that the stabilizer skin on display at the show had been infused and then cured in an oven rather than an autoclave, using materials supplied by Cytec Industries (Woodland Park, N.J.). The part's cosmetically beautiful skin incorporated integral "T" stiffeners, was 7.5m/24 ft long but weighed only 50 kg/110 lb (see "Learn More").

Outstanding stands

On the Cytec stand, that company's VP of technology, Carmelo Lo Faro, was asked about the merits of Cytec's dry-fiber unidirectional (UD) tape materials. He emphasized, first, that Cytec offered a wide range of products from which the customer could choose an optimum solution for their application. Dry UD tapes, he noted, meet the needs of some but not all customers. Benefits that help make the case for dry UD tape include the potential for weight optimization through the use of tailored ply drop-offs and that fact that precision automated layup systems are available.

Representing GKN, two young engineers — Ben Davies, a manufacturing engineer and Sophie Wendes, a research engineer — reviewed recently developed composites technologies, including

- the "STeM" project, undertaken jointly with Bombardier (Montreal, Quebec, Canada), Spirit AeroSystems (Wichita, Kan.) and GE Aviation (Evendale, Ohio), which demonstrated a winglet with one skin integrated with a "waffle" stiffening structure. The much-reduced parts count foreshortened assembly time; assembly time was further reduced, by 23 percent, through the use of a robot to drill the fastener holes.
- a composite wing leading-edge slat, on display at the show, featured electro-thermal ice protection and an erosion shield. Video footage of an impact test with a 4-lb/1.8-kg bird at 350 knots was shown. This technology is now supplied to Boeing for its 787.
- the likely *shiniest* composite part on display anywhere at the Farnborough airshow was GKN's laminar flow, wing leading edge demonstrator part. GKN made the part in conjunction with The National Composites Centre, near Bristol, U.K.

Mike Blair, VP and GM of the Aerostructures Div. of Exelis (McLean, Va.), reviewed the wide range of composite structures and other components made by the company. Although some parts were made using technology developed in-house, most reflected the company's current policy of being a "fast follower," that is, being the second to adopt a technology immediately after its successful development by another company. ➲

Source: HPC/Photo: Bob Griffiths

Open Rotor fan blade

Farnborough 2014's Clean Sky Joint Technology Initiative stand was the display forum for this composite fan blade, codeveloped by Safran (Paris, France) and the Fraunhofer Institute (Munich, Germany). Safran's prospective Open Rotor jet engines will power single-aisle jets that will enter service in the 2025-2030 time frame. This new type of engine comprises two distinct parts: a conventional gas generator, and a turbine that drives two counter-rotating *unducted* fans. Those fans are expected to enable the engines to operate at a 30 percent fuel savings. A demonstrator Open Rotor engine, on which Avio Aero (Torino, Italy, a GE Aviation subsidiary), GKN Aerospace and Aircelle (Normandy, France, part of the Safran Group) are codevelopers, is expected to begin flight tests on an Airbus A340 in 2019.

Source: HPC/Photo: Bob Griffiths

Composites enable inflight cellphone use

On the Cobham Antennae Systems (Stevenage, Hertfordshire, U.K.) stand, composite antennae covers for equipment that will enable the use of mobile phones by passengers in commercial aircraft took advantage of the radio-signal transparency of quartz fibers.

Traditional products based on their filament winding technology included JASSM wings and fuselages, still produced at a rate of 16 sets a month, and water and waste tanks for almost all the world's civil aircraft. But Blair reported on a number of new programs. These include

- more than 240 parts for the F-35, many in carbon fiber/BMI.
- fuselage frames on the Boeing 787-9 and -10, for sections 41 and 43.
- variable bleed valves and ducts for GE's engines for the Boeing 787 and 747.

To prepare for this work, the Exelis facility has been expanded from 130,000 ft^2 to 250,000 ft^2 (12,077m^2 to 23,226m^2) and will increase to 390,000 ft^2 (36,232m^2) by the end of the year (for a full list of new Exelis contracts, see the online version of this article, via "Learn More," p. 49).

At the Elbit Systems-Cyclone Ltd. (Karmiel, Israel) display, senior director Eitan Cohen proudly reported that the company had just won contracts for 16 composite parts on the F-35 *Lightning* II jet fighter. Other than saying that they were structural assemblies and fairings, Cyclone was unable to name parts they were going to make for Northrop Grumman, but did confirm that a dedicated factory was under construction and will be equipped with new machine tools, autoclaves and inspection equipment.

On display were two integrated, one-piece structures, an aileron and a winglet, made by resin transfer molding (RTM). The latter weighed 30 percent less than a conventionally assembled composite part.

Albany Engineered Composites (AEC, Rochester, N.H.) continues to produce parts in conjunction with its main European customer Safran. An AEC/Safran joint venture is building new production facilities on both sides of the Atlantic, one in Rochester and the other in Commercy, France. Both will make parts for CFM International's (Melun, France, and Cincinnati, Ohio) LEAP engine, including the main fan blades.

AEC also displayed its trademarked Ceramic Truss Core (CTC) sandwich panels. These much newer materials were intended to operate at 400°C to 1,200°C (752°F to 2,192°F). An outgrowth of the "X" Core carbon fiber product developed by Aztex, a company acquired by AEC nearly a decade ago, CTC panels have application in areas where hot exhaust gasses wash over structures, such as engine exhaust cones.

One rapidly expanding niche composite application was on display in both the TenCate Advanced Composites (Nijverdal, The Netherlands) and the Cobham Antennae Systems (Stevenage, Hertfordshire, U.K.) stands: Antennae covers for equipment that will enable the use of mobile phones by passengers in commercial aircraft (see photo, p. 48). Whatever air travelers might think of losing the one peaceful period in a business trip, all the major airlines are preparing to offer *inflight* use of cell phones. This requires the use of very high frequency signals (K_a and K_u band), and these signals must be transmitted at low loss through the covers that protect the antennae. For these covers, Cobham uses cyanate ester resin reinforced with quartz fibers supplied by TenCate.

U.S. export control

One of the most interesting meetings at Farnborough was hosted by the AIA (Aerospace Industries Assn.) and covered U.S. Export Control Reform. The panel was moderated by Marion C. Blakey, AIA president. The panel consisted of Kevin Wolf, assistant secretary of Commerce for Export Administration, U.S. Department of Commerce; Beth McCormick, director, Defense Technology Security Administration, Department of Defense; and Ken Handelman, Deputy Assistant Secretary for Defense Trade Controls, Bureau of Political and Military Affairs, Department of State.

The process of gaining permission to export controlled products and materials is in the process of being simplified and made more transparent. The ultimate goal of the reform effort is the creation of four "singles":

- A single Licensing Agency
- A single Export Control List
- A single Enforcement Coordination Agency
- A single information technology system

A primary task is an ongoing review of the U.S. Munitions List of the International Traffic in Arms Regulations (ITAR) administered by the Department of State (read more about this meeting online, via Learn More").

The conclusion that can be drawn from the airshow is that the aerospace industry's approach to composites has matured. Composite materials are no longer the "must have" feature that all new programs must adopt regardless of risk and cost. From now on, the composites industry will have to demonstrate that each application can be delivered on time with little or no risk. ■

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Read an extended version of this article online at short.compositesworld.com/FB2014.

Read more about Irkut's "Resin-infused *MS-21* wings and wingbox" in *HPC* January 2014 (p. 29) or visit short.compositesworld.com/MS-21wings.

Read more about LEAP engine fan case development in "Albany Engineered Composites: Weaving the Future in 3-D," *HPC* March 2014 (p. 58) or visit http://short.compositesworld.com/Albany3D.

CFK-Valley Stade 2014 CONVENTION REPORT

BY DAVID INSTON

Always a technical-paper gold mine, this local event, in 2014, was determined to expand its sphere of composites influence.

The CFK-Valley hosted, June 24-25, the 2014 edition of the CFK-Valley Stade Convention, focusing on some of the latest innovations in material and process development in composites fabrication. An advanced composites networking organization based in Stade, Germany, CFK-Valley comprises more than 100 member companies as well as the Composites Technology Centre (CTC GmbH), an Airbus (Toulouse, France) research organization.

This year's event attracted 350 participants from 15 countries. Most papers came from Germany, but two had their sources in France and one came from distant South Korea.

The conference was opened by Dr. Axel Herrmann, CFK-Valley's chief technology officer, who told the audience that the network has seen much change and growth in its first 10 years. He noted that "more power" is needed now. To that end, he announced that Dr. Gunnar Merz, previously with Dow Deutschland AG (Scwalbach, Germany), would be engaged full time as chief executive officer and chair of the board. Herrmann will continue in a part-time role.

Source: CFK-Valley

Preparing for expansion

Dr. Gunnar Merz, new CEO and board chair of CFK-Valley, presents his opening remarks at the 2014 CFK-Valley Stade Convention in Stade, Germany, June 24-25. Merz will preside over the CFK-Valley network's efforts to increase its influence in the realm of high-performance composites.

The presentations

Dr. Michael Jischa of the Institute of Applied Mechanics (Clausthal-Zellerfeld, Germany) gave the keynote address, "Limits to Growth." Jischa highlighted the accuracy of the world predictions made by the Club of Rome in the 1970s. A global think tank, the Club of Rome was founded in 1968 at Accademia dei Lincei in Rome, Italy. Describing itself as "a group of world citizens, sharing a common concern for the future of humanity," the group consists of current and former heads of state, United Nations bureaucrats, high-level politicians and government officials, diplomats, scientists, economists and business leaders from around the globe. Unfortunately, Jischa noted, not enough attention was paid to these predictions until recently. It's clear, he added, that scientists and engineers must now think beyond technical and economic reasoning and consider the environment and the impact of new technology on the future development of the world. In conclusion, Jischa pointed out that technology offers answers to many challenging questions, but society must be very clear about the questions.

Henri Girardy, business development manager at Hexcel Composites (Stamford, Conn., and Duxford, U.K.), presented "Hexcel's Development Status of Advanced Carbon Reinforcements for Primary Aircraft Structures Made by Using Cost Effective OOA Technologies." Girardy explained that although high-performance prepreg is the benchmark material for primary aircraft structure, the drive now is to reduce cost and weight and — as manufacturing rates increase to unprecedented levels — to make ever-larger, integrated parts. He noted that out-of-autoclave manufacturing via vacuum-assisted resin transfer molding (VARTM) is recognized as a cost-effective process, but he said improvements in material performance are required if the process is to enable fabrication of primary aircraft structure. This, he reported, has been the focus of Hexcel's effort. Two types of dry fiber material have been developed by Hexcel to match unidirectional (UD) prepreg performance. The first is a noncrimp fabric (NCF) that exhibits improved performance. The second, a dry UD tape called HiTape, is designed for use with standard automated tape laying (ATL) and automated fiber placement (AFP) machines.

Hexcel's approach with HiTape involves the application of a thin veil of thermoplastic material to the dry reinforcement. The veil forms a toughened interlayer in the final cured composite. Girardy says that Hexcel has demonstrated, in laminates built up with widely qualified HexFlow RTM6 and HiTape, at a fiber volume fraction of 60 percent after infusion, almost equivalent properties to prepreg.

Tassilo Witte, project manager at Airbus CTC, gave a paper titled, "Recycled Carbon Fibres and the Development of Semi-Finished Products for Aircraft Interiors." Witte reviewed CFK-Valley's work on an industrial process for recycling composites by a pyrolysis method, using the gases emitted by the heated resin matrix as the fuel to drive the process. The goal now of a CTC project that will run through 2016 is to develop a recycled carbon fiber veil prepreg to replace current glass fiber products now used in aircraft interior applications. Reportedly, this would be the first application of recycled composite material on a civil aircraft. Witte's work, thus far, has shown that the recycled fiber is comparable to the original virgin fiber in terms of strength. However, the fiber length is short, and when it is reprocessed into a veil of random orientation, the strength of the original textile cannot be expected. In aircraft interiors, however, this is of less importance than the flammability, heat release and smoke-generation properties of the material.

Michael Schumann, an R&D engineer from Fraunhofer Institute for Manufacturing Engineering and Automation (Rostock, Germany), gave a paper titled, "Development of Strand-Laying-CFRP Bridge Systems With Automated Manufacturing Processes." This project's goal was to manufacture a bridge support structure by an automated strand-layering technology that applies wet-impregnated carbon fiber roving of a defined, pre-stressed CFRP design to carry pedestrians and cyclists over a 50m/164-ft clear span. The possibility to carry motor vehicles already has been calculated but has yet to be approved. The work at Fraunhofer has developed a strand-laying machine that precoats rovings in a resin bath and then applies them, pretensioned, over pre-positioned GFRP ribs. See a model curved bridge structure online via "Learn More," p . 53).

Dr. Hyun Kyul Shin, director of the Korea Institute of Carbon Convergence (Seoul, South Korea), gave a compelling talk on his work to develop and manufacture a geometrically complex CFRP automotive engine cover, using microwave curing. Shin noted a 30 percent reduction in cure time and energy consumption, using this process. Although mechanical properties fall short of those achieved by oven or autoclave cure (by less than 10 percent), they are still consistent with acceptable part quality. He believes that properties will improve further as the process is refined.

Roland Lichtinger, research associate at the Technical University of Munich (Germany), presented an impressive selection of simulation videos showing AFP in process. They demonstrated clearly that, due to the nature of the process and because of an accumulation of overlapping areas within the infrared preheating lamp's footprint, the result is a nonlinear thermal map across a layup. Depending on the part thickness and considering that large, thick parts see a long outtime before the part is finally cured, it is possible that some areas of the part may be beyond their outlife or even partially precured before final cure.

A paper by Dr. Steffan Czichon, stress engineer at Elan-Ausy GmbH (Hamburg, Germany), described "Numerical Modeling of Fiber Undulation Induced by Voids and SHM Sensors." Fiber undulations, waviness and voids are known to negatively affect the properties of composites. Czichon showed that the effect of voids can be predicted by simulation. He went on to say that embedded structural health monitoring (SHM) sensors have similar effects. Czichon pointed out that with careful design of the sensors' shape, their effect on composite properties can be minimized.

Fabian-Timmo Seebo, an engineer at Hamburg-based Spitzner Engineers HAW, impressed the audience with his paper, "Transferring Knowledge From Aerospace to Wind Energy." He began by noting that it is common to see modern civil aircraft with winglets. These devices serve to reduce turbulence at the wingtips in flight, thus improving aircraft fuel economy. Seebo's work has adopted this principle by applying a winglet device onto the end of wind turbine blades. Spitzner Engineers also has redesigned the leading edge of the blade root, including holes that allow air to flow into the blade then exit through corresponding holes at the blade's far end. The result is an increase of almost 14 percent in output on a wind turbine fitted with such blades. (The concept can be seen online. See "Learn More).

Dr. Claus Bremer, president at BCT GmbH (Dortmund, Germany), gave an account of the sophisticated composites repair machining equipment that BCT has developed and manufactured with several partners, in cooperation with Airbus. The machines, both mobile and static, automatically adapt themselves to the surface to be machined in five axes via laser scanning. Using a high-speed ultrasonic milling spindle, they mill out damaged areas and scarf the laminations to standards that are reportedly impossible to meet by manual preparation. The machines also apply atmospheric plasma to the scarfed area to activate it for subsequent bonding of the repair patch (see images online).

Source: CFK-Valley

Automated aircraft skin-repair preparation

Dr. Claus Bremer, president, BCT GmbH (Dortmund, Germany) described BCT's automated composite repair system, developed in conjunction with Airbus. It uses laser scanning and high-speed ultrasonic milling to machine and scarf damaged areas to reportedly unprecedented quality standards.

Dr. York Roth, head of components methods and processes at Airbus Operations GmbH (Stade, Germany), presented "High Quality Components Require Intelligent and Robust Tooling." Roth explained that the tooling for the production of earlier Airbus aircraft families (e.g., the A320) was designed and manufactured years ago and was not robust enough to keep up with ever-increasing Airbus production rates (up to 50 aircraft per month). Tooling, therefore, has had to evolve to maintain the exacting quality standards. Roth gave an interesting explanation of the methods necessary to achieve this goal. For example, he explained that extensive use had been made of Ishikawa diagrams to highlight all of the causes that affect the overall issue of tool robustness, molded part tolerance and manufacturing repeatability. Each cause has been addressed systematically, and that has led to the development of improved tooling that can withstand the rigors of very demanding production rates. He noted, further, that much of the tooling originally developed in metal is now fabricated from composites, avoiding many of the issues created by CTE mismatches and part springback. ■

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Read this article online, accompanied by an expanded complement of illustrative images, at short.compositesworld.com/CFK-VS2014

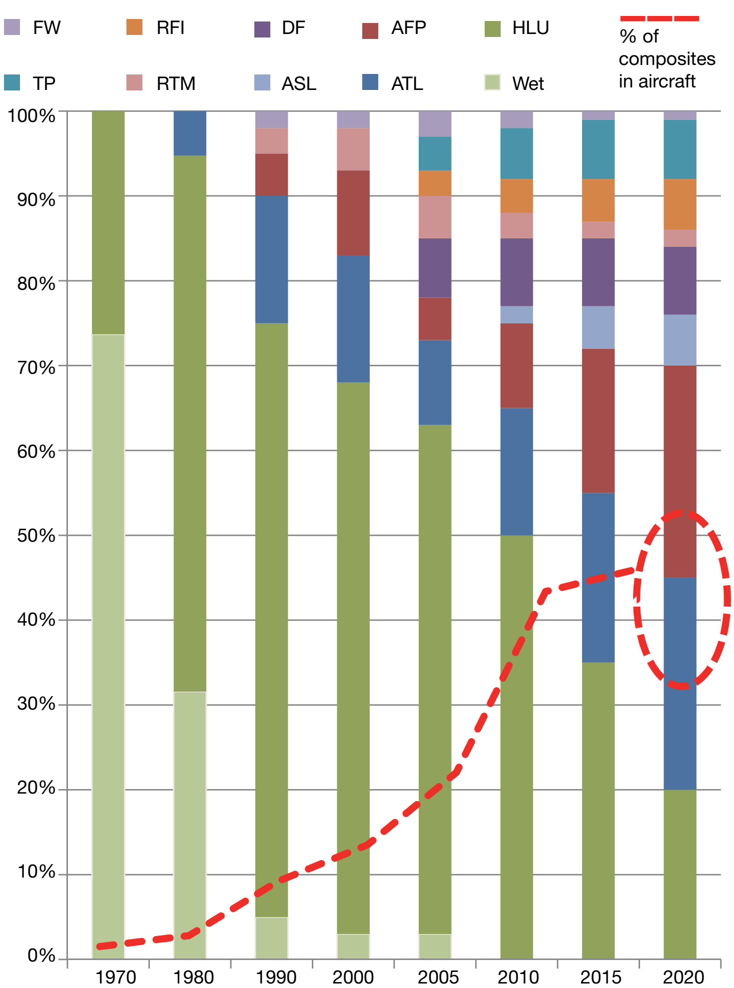
The Outlook for Thermoplastics in Aerospace Composites, 2014-2023

Capable of volume production, thermoplastic composites will gain new market share in the aerospace industry.

Fig. 1

Source: Composites Forecasts & Consulting

Change in Composite Manufacturing Process vs. Airframe Content



FW = Filament winding
TP = Thermoplastics forming processes
RFI = Resin film infusion
RTM = Resin transfer molding
D F = Drape forming
ASL = Automated stringer lamination
AFP = Automated fiber placement
ATL = Automated tape laying
HLU = Hand layup
Wet = Wet layup

BY CHRIS RED

Thermoset resins and autoclave curing have been the mainstays of aerospace composites since their introduction to aircraft. During the 1960s and 1970s, most aerocomposites manufacturers borrowed heavily from the wet layup techniques used in the boatbuilding industry. But the inconsistencies and variability of the wet layup process gave way in the 1980s to more consistent, repeatable hand layup of prepreg materials. In the 1990s, prepreg layup gave way to more productive automated tape laying and fiber placement technologies. In all cases, the autoclave was considered necessary to ensure that laminates met void content targets. The first decade of this century, however, saw out-of-autoclave (OOA) processing techniques attract interest, with promises of speedier production and lower fabrication costs.

As a consequence of this paradigm shift toward *process/cost efficiency*, reinforced thermoplastics now appear on the cusp of capturing a significant piece of the aerospace raw materials market (see Fig. 1, at left) on the strength of a significant distinction. Unlike thermosets, thermoplastics do not need to crosslink (cure). These polymers shape easily under sufficient heat and simply harden and maintain those shapes (at speeds much faster than thermosets can cure) when cooled. Further, they retain their plasticity — that is, they will remelt and can be reshaped by reheating them above their processing temperatures. This characteristic offers intriguing possibilities for both faster and more innovative composite processing techniques compared to their thermoset counterparts.

The introduction of OOA processes and thermoplastics to the aerospace industry has complicated the aeromanufacturer's palette of material/process options: OOA processing can involve either thermosets or thermoplastics. At the same time, manufacturing with thermoplastic composites (TPCs) can sometimes involve the use of an autoclave. For these reasons, this TPC-focused market outlook adapts some data that was included in a recent *HPC* OOA Market Outlook (see "Learn More"), but includes a number of significant differences and benefits from a number of critical updates and continued research.

Thermoplastic composites: What and why

There is a wide range of thermoplastic materials now used in advanced composites components for the aerospace industry. Six general classes of thermoplastics are seen most frequently (see Table 1, top right):

- Polycarbonates (PC)
- Polyamides (nylon, PA-6, PA-12)
- Polyphenylene Sulfide (PPS)
- Polyetherimide (PEI)
- Polyetheretherketone (PEEK)
- Polyetherketoneketone (PEKK)

Within this context, many of these thermoplastic polymers have raw material prices comparable to, and the high tensile strength of, common thermosetting resins, including:

- Phenolics (PH)
- Epoxies (E)
- Bismaleimides (BMI)
- Cyanate esters (CE)
- Polyimides (PI)

The potential value that thermoplastics bring to the aerospace market becomes more apparent when neat resin performance characteristics are compared with raw material costs (see Fig. 2). Thermoplastics generally exhibit superior impact toughness, fire/smoke/toxicity (FST) performance and, with the exception of PEIs, chemical resistance. (PEIs are susceptible to attack by anti-icing fluids and to moisture absorption, which limits their use in aircraft skins.) Thermoplastics also exhibit a near-infinite shelf life at room temperature. This compares quite favorably to a shelf life of fewer than six months in refrigerated storage for typical prepregged thermoset materials.

PEEK, PPS, PEI and PC show many favorable characteristics for application in both aerospace structures and interior components. Although the raw material costs of aerospace thermoplastics can — in some cases — be higher than competing thermosets, the cost of the finished component can

Table 1 Source: Composites Forecasts & Consulting LLC

Comparison of Selected Aerospace Thermoset and Thermoplastic Resin Matrices

Resin Family	Continuous Service Temp. (°C / °F)	Cure Time (min)	Tensile Strength (ksi)	Tensile Modulus (Msi)
Thermoset Resins				
Phenolic (PH)	170 / 340	60+	6.9	0.55
Epoxy (E)	180 / 350	60-240	9.7	0.34
Cyanate ester (CE)	180 / 350	60-180	7.4 - 13.2	0.38 - 0.45
Bismaleimide (BMI)	230 / 450	120 - 240+	10.5	3.9
Polyimide (PI)	370 / 700	120+	16.6	-
Thermoplastic Resins				
Polycarbonate (PC)	120 / 250	< 20	9.4	0.33
Polyphenylene sulfide (PPS)	240 / 464		13.5	0.5
Polyetherimide (PEI)	200 / 390		6	0.8
Polyetheretherketone (PEEK)	250 / 480		14 - 33	0.58 - 3.4

Fig. 2 Source: Composites Forecasts & Consulting LLC

Normalized Tensile Strength vs. Raw Material Price for Aerospace Thermoset and Thermoplastic Polymers

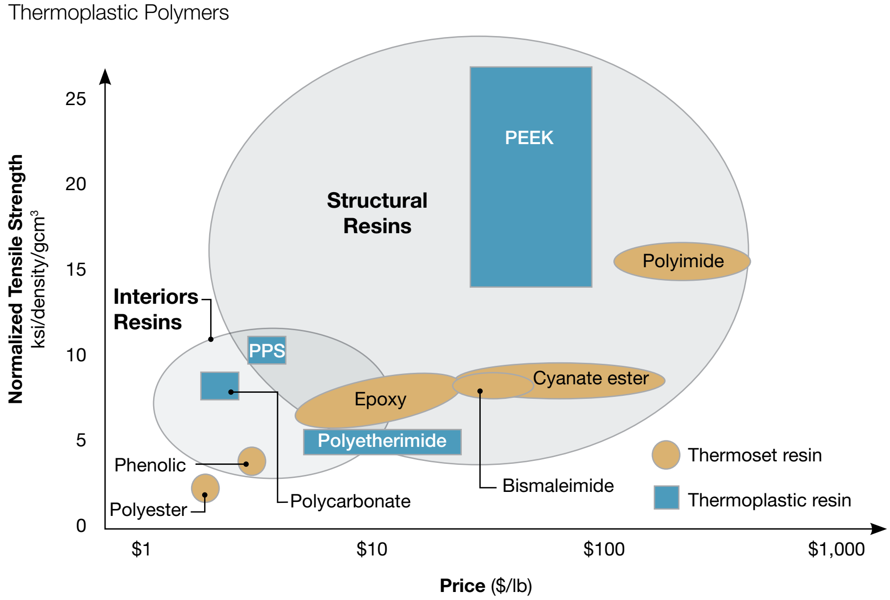


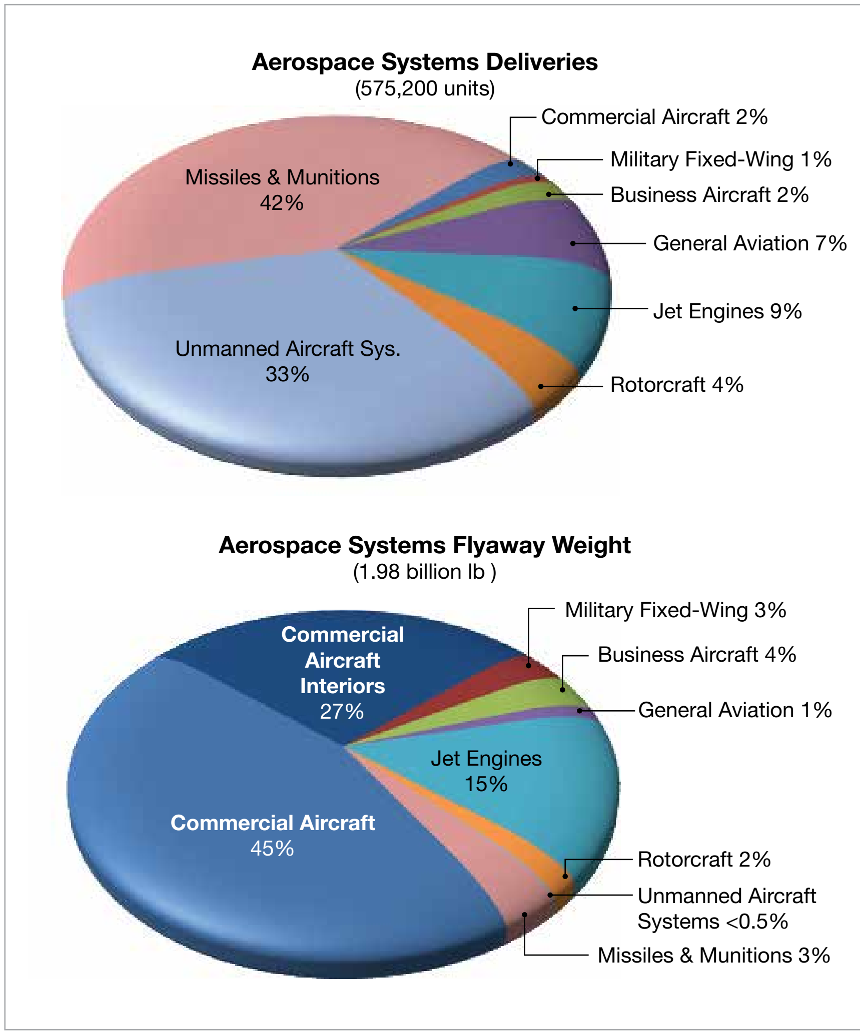
Table 2 Source: Composites Forecasts & Consulting LLC

Annual Fuel Burn Cost Reductions from Each Pound of Weight Savings.

Aircraft Type	Fuel Burn Savings
Regional Turboprops	$185 - 360/year
Regional Jets	$175 - 432/year
Single-Aisle Jets	$150 - 450/year
Twin-Aisle Jets	$175 - 660/year
Jumbo Jets	$440 - 715/year

Fig. 3 Source: Composites Forecasts & Consulting LLC

Forecasted Aerospace Deliveries and Flyaway Weight Requirements, 2014-2023.



be roughly 20 to 40 percent lower due to reduced handling, processing and assembly costs. Thermoplastics also offer the option to fuse or weld molded subcomponents, which can reduce assembly weight and stress concentrations by eliminating fasteners and adhesives.

For high-temperature applications, PPS, PEI and PEEK polymers also offer excellent thermal stability — a critical property in a number of military, aeroengine and prospective supersonic business jet programs where aerofrictional heating can generate continuous service temperatures beyond the capabilities of high-temperature epoxy thermosets (~180°C/~350°F). At these elevated temperatures, PEEK and PPS thermoplastics, priced between $4 and $72/lb ($9 and $160/kg) can offer potentially substantial savings compared to BMI and PI thermosets, priced between $42 and $400/lb ($92 and $880/kg).

Structural TPCs: on the rise

Despite the intrinsic appeal of TPCs, their adoption has been slow. European manufacturers are leading the way. One of the first successful structural applications was the undercarriage door for the now out-of-production *Fokker* 50. This door included ribs and spars made from carbon fiber/PPS prepregs. An ongoing example would be the pressure and nonpressure floor panels that Fokker Aerostructures BV (Hoogeveen, The Netherlands) has supplied to aircraft manufacturer Gulfstream Aerospace Corp. (Savannah, Ga.) for its intercontinental luxury jets since the mid-1990s.

> Despite the intrinsic appeal of TPCs, their adoption has been slow. Only in the past 10 years have TPC applications appeared that can legitimately be considered “large” and “high volume.”

Only in the past 10 years, however, have applications appeared for TPCs that can legitimately be considered “large” and “high-volume.” The Airbus (Toulouse, France) A340-600 and A380, which entered into service, respectively, in 2002 and 2007, feature some of the largest structural thermoplastic components currently in service. These include thermoplastic skins reinforced with welded ribs, which reportedly weigh about 20 percent less than comparable aluminum structures. Savings per shipset for the A380 run about 200 kg/441 lb.

The 18m/59-ft long keel beam for the A340-600 features a large number of carbon fiber/PPS ribs and angle brackets for the keel’s internal structure. These components exhibit a 20 to 50 percent weight savings compared to their aluminum and titanium alternatives. The A340-600 ailerons feature a number of TPC ribs in the main body of the component, as well as angle brackets and panels for the structures’ leading edges. Although the majority of these TPC components are relatively small,

they quickly add up to considerable volume. Within the A380 airframe, TPCs account for more than 1,000 individual part numbers, representing a mass of more than 5,000 lb/2.27 metric tonnes or about 7.5 percent of the aircraft's total composite airframe flyaway weight.

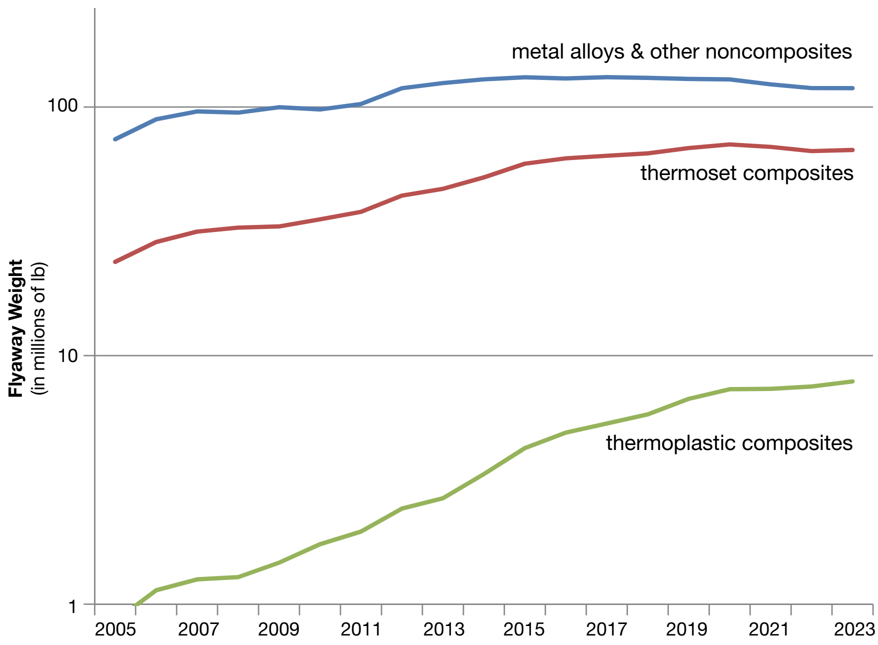
The all-composite fuselages on mid-size, twin-aisle transports present myriad opportunities for small TPC parts. An army of carbon fiber/PPS clips and cleats help secure exterior skins to their circular frame sections. Reports are that The Boeing Co.'s (Seattle, Wash.) 787 family requires between 10,000 and 15,000 such composite parts per aircraft, while the Airbus A350 XWB is believed to use fewer — around 8,000 per aircraft. Although these components are fairly uniform in size, there are more than 100 unique configurations in production. TPCs also are used to provide localized reinforcement between some of the fuselage frames, in the form of shear webs, on the 787 (about 150 per aircraft). Daher-Socata (Tarbes, France) and Dutch Thermoplastics Co. (Amsterdam, The Netherlands) are among the leading producers of these components (see "Learn More"). Both report that they are actively busy scaling up capacity to meet demand.

Previously mentioned, Gulfstream's *G450*, *G550* and now the *G650* business jets all include TPC floor panels. Beyond business jets, however, TPCs are now finding homes in other aircraft flooring systems. Airbus Military's A400M's cockpit flooring is composed of a variety of TPC profiles. The cargo floors of Sikorsky Aircraft's (Stratford, Conn.) *CH-53K* heavy-lift helicopter for the U.S. Marine Corps represent another effective application of low-cost TPC manufacturing and assembly — one that is expected to extend to other large rotorcraft (including the V-22 *Osprey*) during the remainder of the decade.

Notably, the *CH-53K* cargo floor, which is quite large, measuring 8.5 ft/2.6m by 44 ft/13.6m, could soon weigh less than 1,500 lb/680 kg, thanks to TPCs. [*Editor's note*: At *HPC* press time, Sikorsky was reportedly considering aluminum floors for test aircraft while it pursues final selection of a composite flooring system.]

Fig. 4 Source: Composites Forecasts & Consulting LLC

Trends in Aerospace Systems Flyaway Weight Requirements



Gulfstream's *G650* also features a first-of-its-kind welded thermoplastic composite rudder and elevator tail section, developed by Fokker. Designed and developed to take advantage of a new induction welding method that joins the components into an inseparable unit, the fabricating and joining process yields parts that are 10 percent lighter and 20 percent less costly than the preceding carbon/epoxy sandwich construction. Similar components are now in development for Dassault Aviation's (Paris, France) *Falcon 5X* and *8X* business jets.

Aircraft engine applications are also on the rise. Carbon fiber/PEI materials have been used in the acoustic liners for several major turbofan engines. Many of the engine brackets for both civil and military jet engines, and supporting hoses, cables and printed circuit boards, are now produced with carbon fiber/PEEK tapes and molding compounds — replacing conventional milled titanium hardware. Ishikawajima-Harima Heavy Industries (Tokyo, Japan) recently announced that it will pioneer the use of TPC guide vanes in a new engine program. TPC engine seals, shielding components, trusses and other structures also are being made and planned for future engine families. And TPC use extends to some of the smallest aircraft, including unmanned aerial vehicles (UAVs). In Lockheed Martin's (Bethesda, Md.) *Desert Hawk* III, for example, TPCs find use in lightweight propellers.

The all-composite fuselages on mid-size, twin-aisle transports present myriad opportunities for small TPC parts. Aircraft engine applications are also on the rise.

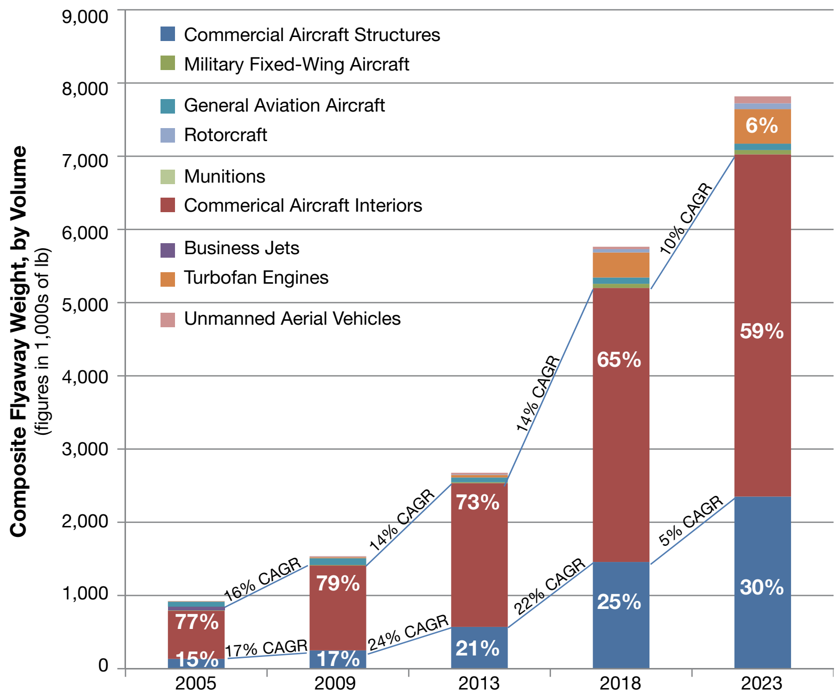
Thermoplastics creeping into the cabin

Although advancements in processing techniques are opening opportunities for TPCs in structural/airframe components, the largest opportunity in the foreseeable future is in the aircraft interiors market. For many of the current and emerging components within cabin interiors, dozens, hundreds and, in some cases, even thousands of identical components may be required for each new aircraft or cabin retrofit.

TPCs have been particularly effective at displacing metals in the aircraft cabin. Several studies have shown compo-

Fig. 5 Source: Composites Forecasts & Consulting LLC

Forecasted Thermoplastic Composites Flyaway Requirements by Market Segment



nent weight reductions of as much as 40 to 50 percent, compared to aluminum, with a 20 percent reduction in delivered part costs. Further, TPC's excellent FST performance and inherent toughness and short process cycle times make them promising candidates for aircraft interiors.

There is a downside, however. Despite demanding performance requirements, cabin components are cost-sensitive. Accordingly, PEI- and PPS-based TPCs tend to be the most commonly used.

As they have in emerging structural applications, TPC clips, brackets and support rails are becoming common interior features across a number of aircraft platforms. Standout applications include:

- Stowage bin brackets produced by Quatro Composites (Orange City, Iowa) for the Boeing 787.
- Sidewall and ceiling attachment rails produced by Xperion Aerospace GmbH (Herford, Germany) for the Airbus A330 and A340 families.
- Pans, backs and trays, and even seat frames, for premium and coach passenger seats.
- Panels for lavatories, galley equipment and service trolleys.

The examples noted, thus far, show how thermoplastic composites can be used to replace existing metal components. But some of the newest opportunities for TPCs involve replacements for glass fiber/phenolic and carbon fiber/phenolic components. In this case, the thermoplastic polymers offer solutions that are inherently more robust, process in a fraction of the time required for thermoset composites and offer an 18 percent reduction in density as well as enhanced FST performance. From a manufacturer's perspective, thermoplastics also eliminate the outgassing of formaldehyde and/or water vapor that occurs during the phenolic resin cure cycle.

For this reason, a small number of demonstration trials have explored the use of PEEK polymers with continuous and discontinuous carbon fibers to replace phenolic composites in cabin ceilings and sidewalls as well as cargo compartment panels. For smaller regional jets, these components could total around 1,400 lb/635 kg per aircraft. On larger planes, these components could account for 3,000 lb/1,630 kg or more of total weight. Assuming a modest 10 percent reduction in the overall weight of fiberglass and carbon phenolic composite components, carbon fiber/thermoplastics could reduce aircraft fuel burn by 10,000 to 72,000 gal annually (see Table 2, p. 57). Fleet operators could potentially save tens- or hundreds-of-millions of dollars each year based on this materials substitution. These annual savings are compounded by an expected service life of about eight years between refurbishment cycles. And for new aircraft, the savings could be accrued over more than two decades of passenger service.

Aerospace thermoplastics outlook

Scarce in civilian and military aerospace segments a decade ago, TPCs now can be found in virtually every major segment of the market. To quantify TPC use for this Market Outlook, more than 400 programs, including fixed-wing aircraft (transports, business jets, general aviation, fighters, etc.), rotorcraft, turbofan engines, UAVs, and missile systems were studied from around the world.

Considering only manned aircraft, nearly 7,700 units were delivered during 2013 — an increase of about 6.5 percent over 2012. Civil aircraft led growth, posting almost 25 percent more deliveries compared to the market bottom in 2010. Continuing strength in the commercial, business and general-aviation aircraft and rotorcraft sectors is expected to push up annual deliveries by nearly 30 percent in the coming two years.

As unmanned aircraft become common in civil airspace during the next four years, annual aerosystem deliveries (aircraft, engines and munitions) are expected to nearly triple in the next 10 years. During the 2014-2023 forecast period, we predict that approximately 575,200 UAVs will be produced (see Fig. 3, p. 57).

Increased activity on OEM assembly lines is expected to offer excellent growth for those who manufacture and supply raw materials to aerospace composites manufacturers. The 400-plus programs reviewed for this report required an estimated 175 million lb (79,128 metric tonnes) of finished parts and structures in 2013. By the end of 2014, that number is expected to reach 185 million lb (83,938 metric tonnes). It's not surprising, then, that over the 2014-2023 forecast, commercial aircraft will consume nearly 75 percent of the 2 billion lb (907,441 metric tonnes) global aerospace market's raw materials — in commercial aircraft structures (45 percent) plus interiors (27 percent). The turbofan jet engine manufacturers, many of which support the commercial aircraft industry, represent the next largest consumer, and could account for 15 percent of aerospace structure deliveries, by volume, through 2023.

The distribution of composite structures tracks fairly closely with the overall aerosystems flyaway weights detailed in Fig 3. When considered separately, the 10-year aerostructures and interiors total shows some interesting trends that pertain to thermoset and thermoplastic composites. In 2005, composites made up about 15.5 percent of finished aerospace components, by weight. By 2013, this share grew to 19 percent. By the time the market reaches its next expected peak, around 2018-2019, composites should represent about 25 percent of total aerospace component deliveries, yet would still represent only about 4 percent of total raw material purchases, due to the considerable amount of metals that are machined or trimmed away during fabrication. In some applications, more than 90 percent of a metal billet is turned into "revert" on the shop floor.

This analysis shows that thermoset composites continue to gain market share in the aerospace industry until around the end of this decade, at which point the trend lines (see Fig. 4, p. 59) become increasingly parallel. Over this same period, however, thermoplastic composites volumes will show considerable upward momentum. During 2005, the analysis found approximately 923,000 lb (419 metric tonnes) of TPC components were delivered to the aerospace industry. At this volume, thermoplastic composites made up about 0.6 percent of total aerostructures (all materials) and about 3.7 percent of total composite shipments. In less than a decade, the aerospace industry has increased its demand for TPCs by roughly 400 *percent*.

This rate of adoption has exceeded previous expectations. In *HPC's* coverage of this subject in 2009 (see "Learn More"), author Ginger Gardiner provided details about a number of emerging applications within commercial aircraft. Based on those limited applications, TPC aircraft interiors were projected to reach between 300,000 and 625,000 lb (134 and 283 metric tonnes) this year. This more recent analysis shows that current volumes are much closer to 2.3 million lb (1,044 metric tonnes). Based on the aircraft production forecast, the volume of TPCs in interiors could easily double or triple again over the 2014 to 2023 forecast (see Fig. 5, p. 60). By the end of our forecast period, TPCs should represent at least 11 percent of the total market for aerospace composites (structures and interiors), with plenty of additional potential for adoption in the OEM aircraft cabin, the interiors aftermarket, and secondary structural components.

Challenges and opportunities ahead

Given the wide range of TPC components employed in the aerospace industry today, it's obvious that a lot of progress already has been made. Based on existing applications alone, it is anticipated that the tonnage of these materials will increase 200 to 300 percent in the coming decade, encroaching on market share now owned by metals *and* thermoset composites. Advances in thermoforming, welding and bonding are opening up new opportunities for TPCs in secondary and primary structures, as well as high-volume interior components. In five years, that could vastly expand our TPC tonnage and market-share estimates.

That said, hurdles remain. Manufacturing complex forms with continuous fiber-reinforced thermoplastics still poses a considerable challenge. For the more structurally demanding composite components made from PEEK and PEKK, the raw material cost can be significantly higher than alternatives that feature toughened epoxy or BMI matrices. Additionally, most thermoplastic prepregs are delivered as preconsolidated sheets or boards. Therefore, they must be preheated to more than 400°F/205°C to become pliable for forming — often done *outside* of the mold tools (an added process step). Further, the requirements for optimal laminate properties often require complex temperature-controlled tooling as well. As a result, upfront investment can be *greater* than that required for thermoset composites, an undesirable scenario especially in low-volume production.

These tooling and heating requirements often limit an engineer's freedom to consider large, complex TPC parts. The diaphragm forming process, for example, uses an autoclave to ensure high-quality parts — lengthening processing time from minutes to about an hour — and employs a disposable diaphragm, typically made from expensive superplastic-formed aluminum or polyimides which vastly increase recurring process costs.

Although developments in continuous compression molding are making TPC parts longer than 10ft/3m practical, component geometries are still somewhat limited. Automated fiber placement is a workable alternative for more complicated TPC shapes with varying part thickness (e.g., fuselage shells, wing and stabilizer torsion boxes and stringers), but one of the challenges is void removal — more difficult with thermoplastics than with thermosets. Another promising solution for making larger parts affordable is the 3-axis pick-and-place robot, which can build ply stacks rapidly but requires less capital investment — an approach already in use on the *G650* business jet.

TPCs will certainly challenge thermoset composites for pride of place. TPC heat and pressure processing methods bear a greater resemblance to those used with metals than they do to thermoset processes. That fact has encouraged rapidly expanding use of TPCs in place of aluminum and titanium in clips, brackets, trays and other simple parts. In the next several years, continuing research could broaden the practical range of part sizes and shapes — soon enough to potentially sway the material selection processes for the Airbus A320*neo* and Boeing 737 MAX. ■

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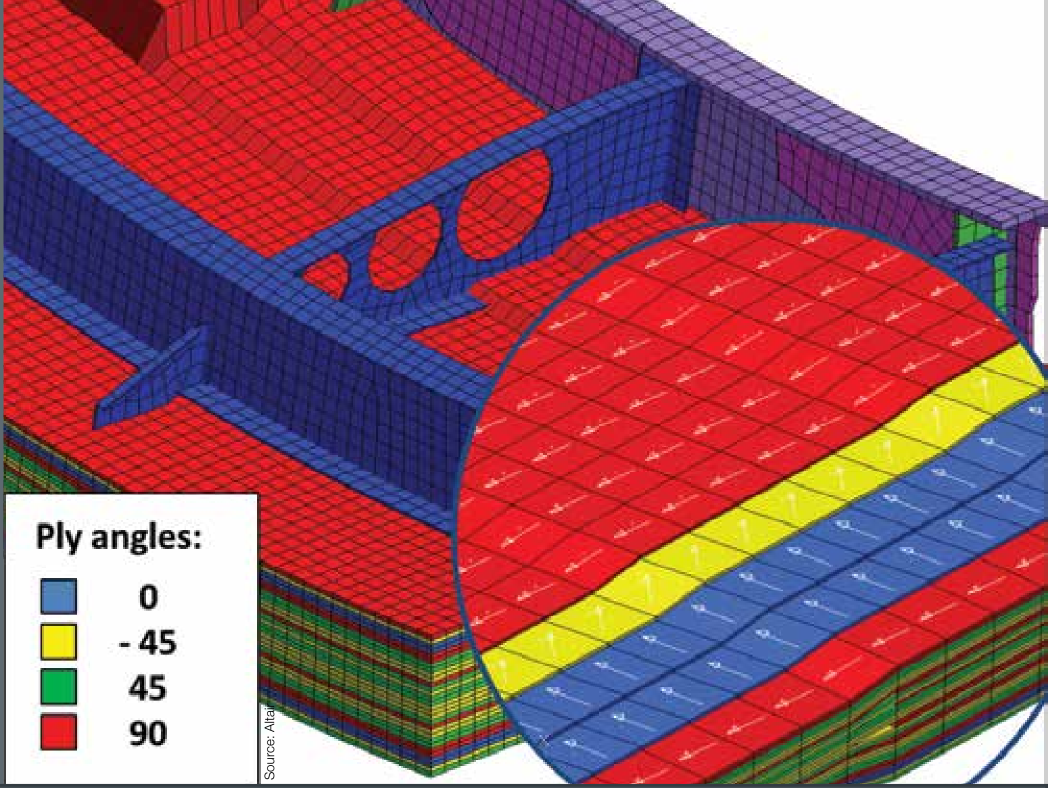
Read this article online at short.compositesworld.com/TPCOutlook.

Read more about Daher-Socata's role in development of TPC fuselage frames in "Inside a thermoplastics hotbed," HPC January 2014 (p. 42) or visit short.compositesworld.com/TCHotbed.

Read more about the inroads made by out-of-autoclave processes into aerocomposites manufacturing in "The Market for OOA Aerocomposites, 2013-2022," *HPC* March 2014 (p. 42) or visit short.compositesworld.com/ooaoutlook.

Read *HPC's* previous feature-article examination of this subject in "Thermoplastic composites: Inside story," *HPC* March 2009 (p. 38) or visit short.compositesworld.com/TPCInside.



The goal: Optimization

Altair's HyperWorks suite, which includes OptiStruct, a simulation-driven design and optimization solver, allows visualization of the model in multiple dimensions. Shown here is a composite laminate visualization with overlay of ply-layer angles.

SOFTWARE UPDATE: SIMULATION *SAVES*

A look inside the increasingly well-equipped virtual toolbox for composite design, analysis and manufacturing.

BY KAREN WOOD

In the world of software, buzzwords are endemic. But if one buzzword trumps all, today, in the composite industry, it's *simulation*. If there is an aspect of composites design, development or production that it would be advantageous to simulate digitally before facing the expensive proposition of producing the physical product, there's a software product for it. Over the past few years, there's been a big push to add or expand composite-focused simulation tools to existing software suites (signaled by Dassault Systèmes' acquisition of Simulayt, Siemens PLM's acquisition of Vistagy, and Autodesk's numerous acquisitions of simulation software, including that created by Firehole Technologies). There is a strong drive to bring such software to maturity, providing more reliable validation of composite material systems, part design, structural analysis and manufacturing processes.

It's a virtual world

It's axiomatic: Money spent in the virtual world is much *more* money saved in the real world of product development. But there's a catch: By nature, composites are far more complex and variable than the metals that preceded them. Yet, many software developers are rising to the challenge, and now, more than ever, the composites industry has a plethora of simulation software choices to add to its toolbox.

And none too soon. "When companies began working with composites, it was a very manual approach from design to analysis to manufacturing. Speed wasn't necessarily as important as ensuring the part wasn't over-designed or under-designed and met structural integrity," says Rani Richardson, CATIA sales, North American market, Dassault Systèmes (Waltham, Mass.). "Today, there is a big push on the manufacturing side to streamline automation and produce high-quality parts *faster*. Machine *throughput* is critical. However, the design and simulation software used to feed the automated machine tools needs to be integrated and capable of producing numeric code to run the machine."

The key from the developers' side, says Richardson, is *integration* of software tools. "With integration from virtual design to virtual testing to virtual manufacturing, design engineers, stress analysts and manufacturing engineers have the ability to provide feedback to the other disciplines prior to sending the part to the shop floor. In the end, there is reduced lifecycle, improved part quality and an increase in the probability the part will be produced correctly the first time."

Dassault Systèmes provides a variety of product development applications, including CATIA, SIMULIA finite element analysis (FEA) and DELMIA for manufacturability. Along with the company's simulation software, these tools enable 3-D design, engineering, 3-D CAD, modeling, simulation, data management and process management. Earlier this year, the company announced Release 2014X of its 3DExperience platform's on-site and on-the-cloud portfolio. Also of note is cdmHUB.org (Composites Design and Manufacturing Hub), which is hosted by Dr. Byron Pipes at Purdue University, and provides access to simulation tools, including Dassault's. "The intent of this site is to recognize simulation software maturity level and assess gaps in the process while educating the composites community of what tools are available," explains Richardson.

Better optimization

What drives the majority of composites simulation, for the user, is optimization. Leigh Hudson, Fibersim product manager, Siemens PLM Software (Waltham, Mass.), says, "People are finally getting to the point, especially in the aerospace and defense markets, where it's not a question of 'Can we build it?' but 'How can we optimize it?'" Today's customers want it all: decreased weight, increased part quality *and* faster production rates.

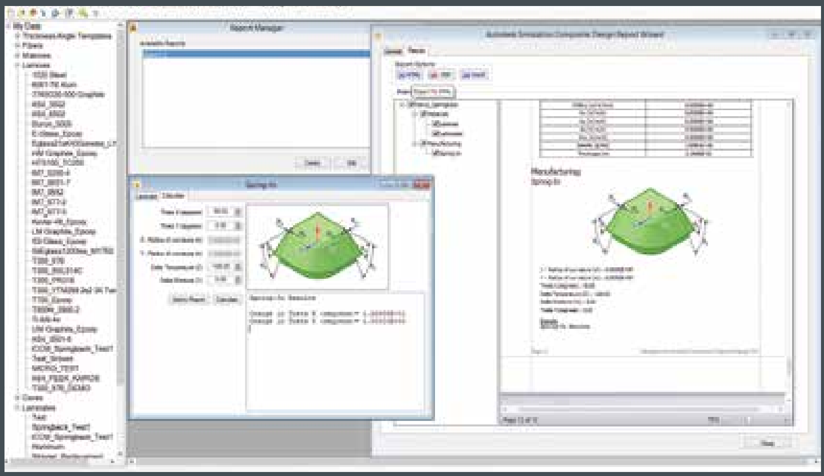
Siemens PLM has a significant focus on automotive, according to Hudson, believing that the materials and processes developed for automakers will be adopted by other industries. "In high-volume automotive, lightweighting is creating demand for decision support as they attempt to find the right mix of materials and processes that meet demanding production cycle times. Therefore, automotive has the challenge of optimizing the use of composite materials while at the same time looking at different production techniques to meet one- to two-minute production cycles," he adds.

Like Richardson, Hudson affirms that "there has to be a much closer integration, or at least interoperability, between the design tools that are performing material, part shape and manufacturing simulations and the tools that are being used for FEA." With a more complex part, the optimization time between design and FEA can go on too long. "One way we've worked to speed the process is by working with the CAE community to develop common language that can be used by NX CAE, as well as other CAE solutions, and Fibersim, our composite design solution," explains Hudson.

A second area of focus is on closing the loop between manufacturing, design, and analysis. "Optimized use of composite materials requires a tighter upstream exchange of information between manufacturing and development," says Hudson. "In the past, analysts defined desired orientation based on load paths and used significant material property knockdowns. The method was employed because the effects of manufacturing processes were unknown to the analyst and fiber misalignment has a large impact on product strength and stiffness," he explains. "Today, when we go through a manufacturing producibilty simulation process in Fibersim, in the CAD tool, and develop a flat pattern based on that simulation to pass to the layup technician, we also provide a ply book showing the flat pattern, its location on the 3-D part, and the layup process." Hudson believes the next step is to supply similar information to laser projection systems to assist in hand layup. "Today, there's still too much variability from one layup to the next, which can affect fiber orientation," he says.

For automated manufacturing, says Hudson, the design engineer doesn't have the same path planning tools as the manufacturing engineer. "As a result, the simulation that the design engineer uses and the layup strategy that a path-planning tool generates could result in very different fiber orientations," he points out. "It's a little bit like designing with blinders on. The solution is to ensure that the designer can validate that the path planning results in acceptable fiber orientation for part performance." Fibersim is capable of bringing the path planning information into the world of the designer to ensure that functional requirements are met, he contends.

The current release of Fibersim (v13.0) has several *must have* features, Hudson adds. "Fibersim's Multi-Ply design capability is making traditional ply-based design a thing of the past," says Hudson. Multi-Ply is an additive ply design method that brings design change automation to traditional ply-based design. "This approach is yielding efficiencies in the development cycle of up to 80 percent over the traditional approach," he reports. Also available is Fibersim's



Source: Autodesk

Designing for manufacturability

Autodesk's Simulation Composite Design 2015 release is geared toward preliminary design and includes additional solutions that address manufacturing considerations, such as spring-in of laminates due to temperature or moisture changes.

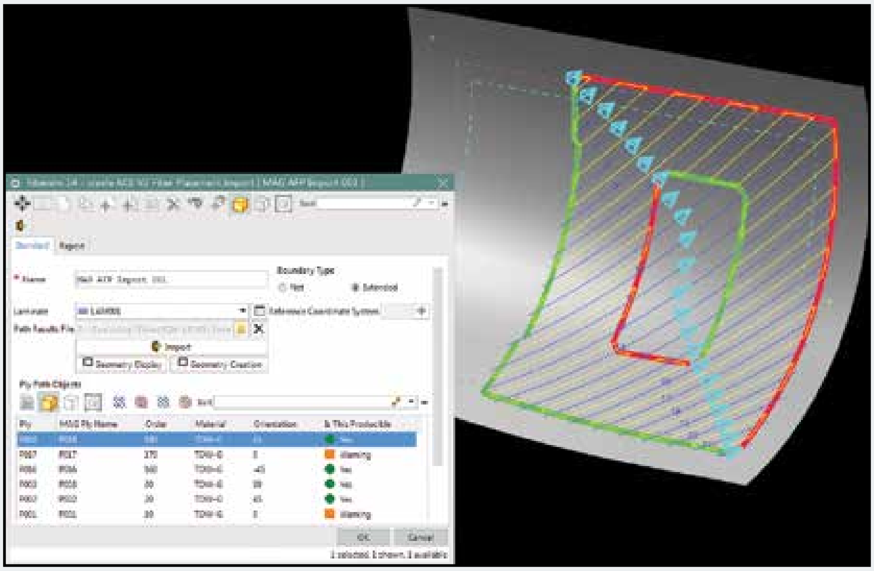
Parametric Surface Offset technology, which derives an accurate inner mold line or intermediate surface at any point in the design that is modifiable and updatable. "Parametric Surface Offset is making final part definitions and tooling based off part designs easily achievable," asserts Hudson.

Complete visualization

"The aerospace and auto-racing industries' need for better composites design and analysis tools have been the primary drivers for the significant enhancements to software tools over the past five years," contends Dr. Robert Yancey, VP, Aerospace Solutions, Altair (Troy, Mich.). But he agrees that, going forward, change will be driven by the unique requirements not only of the auto industry but also the wind energy industry, which, he says, "uses more mixed-material architectures that are creating the need to better model transition zones between different material types and configurations."

In addition to its CAE software suite, HyperWorks, Altair offers a host of composites-centric tools. Yancey says the OptiStruct application, which is part of Altair's HyperWorks, features a simulation-driven design-and-optimization solver and "has the ability to optimize laminated composite structures to produce the lightest weight laminate that meets design requirements." He adds that the new application has made a positive impact in the aerospace, auto-racing and biking industries. In the past year, Altair added a ply drop-off rate constraint to OptiStruct and many enhancements for visualization of model setups and results in HyperWorks.

Currently, says Yancey, the must-have feature is the ability to visualize the model in multiple dimensions. With metals, visualizing overall part geometry was sufficient, he explains. For composites, however, the user must also see the ply geometry, the ply angles and laminate configurations for laminated composites, as well as the fiber orientations and distributions for short-fiber composites, the weave patterns for woven composites, and core configuration, such as honeycomb structures. These visualizations need to be available, he adds, "in both the model setup pre-processor and the results-reporting post-processor."



Source: Siemens PLM Software

Spotting problems prior to production

Import of AFP path planning data into Fibersim, which include the courses, centerlines and tow starts/stops. This information allows the designer to review and make changes to troubled areas of the design *before* the expensive process of creating a demonstrator.

Without robust visualization capabilities for composites, the process of design and analysis can be overly tedious, very inefficient and prone to errors," he sums up, adding that "much progress has been made in just the last few years, which is making composites design and analysis more intuitive and efficient" (see "Learn More," p. 73).

With metals, visualizing overall part geometry was sufficient. For composites, the user must also see ply geometry and much more.

Affordable manufacturing

Given the variety of resin, fiber, tooling and process options available for composites, the challenge is deciding which combination of material and process is both the best *and* the most cost-effective manufacturing option, says Craig Collier, president, Collier Research Corp. (Hampton, Va.). The company's software tool, HyperSizer, which recently launched Version 7, is used with CAD, FE modelers and FEA programs to achieve a composite design that is fully optimized *and* manufacturable.

HyperSizer is used throughout the design process to quantify critical failure modes, reduce structural weight and sequence composite laminates for fabrication to avoid unexpected design problems and weight growth as the design matures. The first step is to import an FE model that is a single plane of shell elements or that discretely models the component. Four fundamental meshing techniques are supported. However, the more discretely meshed a model is, he says, the less opportunity for sizing optimization because variables become locked down by the mesh.

New in HyperSizer 7.0 are several tools designed to bring optimization to maturity, explains Collier. For example, composite designs — especially those that use automated fiber placement (AFP) or automated tape laying (ATL) — include many *ply drops*, that is, patches of carbon fiber fabric placed strategically to meet specific and often localized mechanical requirements. Ply drops, however, are time-consuming and expensive to apply. Version 7 attempts to move away from ply drops toward an overall design that has more consistent thickness, avoids the use of ply drops, minimizes material use, yet meets all required mechanical loads. This could be particularly applicable to wing or fuselage skins, which are famous for their patchy ply drops, he suggests.

HyperSizer 7.0 also allows for simultaneous optimization of stringers and

skins. Historically, says Collier, these two structures are optimized separately, despite the fact that they function together in the application.

HyperSizer also has tools to optimize sandwich structures on space launch vehicles. He believes this will be particularly attractive in the commercial space market, which has become very competitive, forcing OEMs to find ways to save more weight in composite structures. "The ability to *find* minimum weight is not good enough anymore," he says. "It's got to be something we can *make*."

Micro-level modeling

Digimat, from e-Xstream engineering (Mount-Saint-Guibert, Belgium), focuses solely on modeling composite materials from the micro-level up, and might provide an answer for improved design- and analysis-driven manufacturing process control. The software predicts lamina properties, using a homogenization technique that also maintains matrix and fiber results individually when coupled with FEA software. (Digimat interfaces with most FEA structural analysis codes, including MSC, Nastran, Marc, Abaqus and ANSYS.)

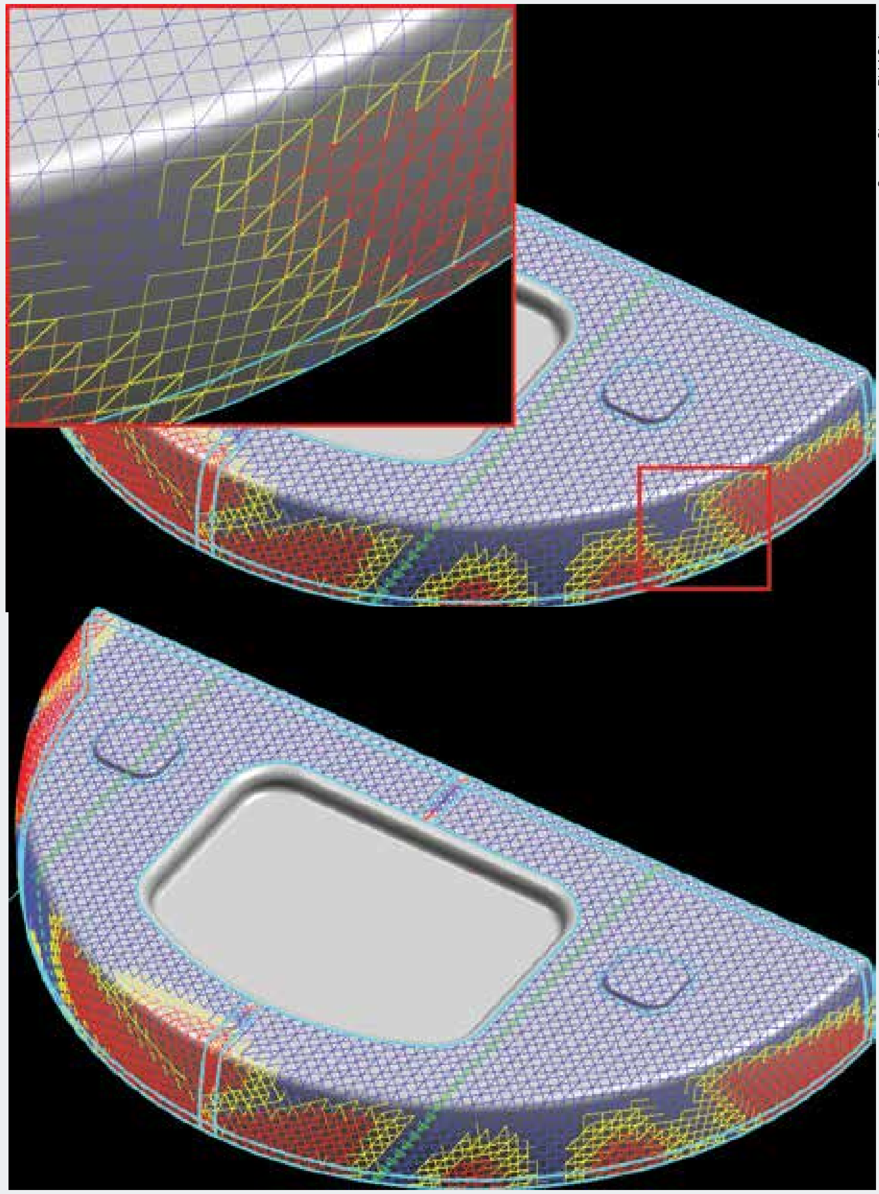
"Accurate predictions of new materials is a big driver for us," explains Bob Schmitz, e-Xstream's business development manager. That includes "not only accurate simulations for the structural analysis of parts but accurate predictions of how a new material will perform, so that our customers can down-select to the best material for the application *before* testing physical samples."

This is critical in a time when companies are evaluating many types of composites, not only traditional aerospace continuous fiber/epoxy systems or short fiber structural plastics, but also many alternatives and hybrids, such as overmolded components, reports Schmitz, noting that Digimat is not restricted to a specific type of composite.

"According to feedback from customers in the automotive industry using short fiber-reinforced polymers in composites, prototype testing has been reduced by 50 percent or more, using Digimat," Schmitz reports. "Our software enables the inclusion of fiber orientation directly into the structural analysis," he adds. "By doing this, users are able to more accurately simulate the true material performance and thus the true part performance before going to test." In addition, users are able to identify high-risk areas, and capture stiffness and strength more accurately, he notes. "Generally, in the analysis process, geometric effects causing stress concentrations or localized strain increases can be identified," he says. "With Digimat, we're also able to evaluate how the processing of that part is affecting the stress contours and strain distribution throughout the part."

Scheduled for release in August, Digimat-FE imbeds an FE solver directly into Digimat, enabling engineers to create and solve a detailed finite element model of a material microstructure, all in one tool. "The benefit is the ability to study detailed stresses and strains throughout a composite microstructure, such as how they are distributed between the fibers and matrix, and how adding additional fillers or voids impacts the materials behavior," explains Schmitz.

"One of the trends we're seeing is simulation being done by material suppliers," he adds. "Material suppliers can

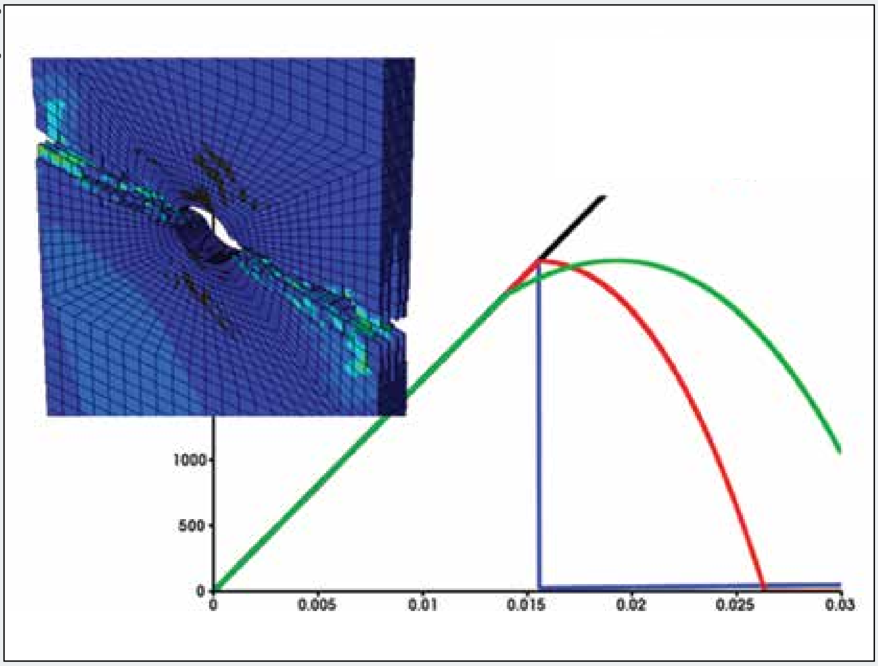


Source: Siemens PLM Software

Anticipating fiber deformation

Noncrimp fabric simulation in Fibersim includes detection of buckling. Blue indicates no deformation; yellow shows some deformation; and red shows severe deformation that requires attention. In the buckled fiber closeup (top left), crinkled fibers are the ones buckling.

Source: e-Xstream engineering



Micro-level modeling

Digimat focuses on modeling composite materials from the micro-level up, predicting lamina properties via a homogenization technique that also maintains matrix and fiber results individually when coupled with FEA software.

use Digimat to develop their material models, and then deliver those validated material models to their customers for use in their simulations."

Looking ahead, more advanced progressive failure models are planned for structural FEA applications, says Schmitz. The company is developing Digimat-VA, which will automate the process of creating virtual coupon testing — creating the coupon, running the simulation, testing it and delivering certain test results very rapidly.

Refining failure models

Autodesk's (San Rafael, Calif.) portfolio of simulation software includes Autodesk Simulation Composite Design (ASCD) and Autodesk Simulation Composite Analysis (ASCA). Earlier this year, in a webinar hosted by CompositesWorld, Doug Kenik, product line manager, Autodesk Simulation Composite Products, discussed the need for simulating past first-ply failure in conventional implicit FEA tools, and how to achieve convergence using ASCA (see "Learn More").

Simulating ultimate failure in composite structures using traditional implicit FEA codes can be challenging. "The behaviors of composite materials are inherently nonlinear during failure cascades, and the FEA solvers can have difficulty converging on solutions during such events," says Kenik.

Typical FEA programs integrate a variation of a Newton Raphson scheme, an iterative or nonlinear solver that updates stiffness, stress and strain at every increment, explains Kenik. This approach assumes that the response of the structure can be approximated as smooth. "However, composites have discrete failure modes in which the stiffness is lost instantaneously," explains Kenik. FEA programmers have developed approaches to overcome convergence problems for highly nonlinear events, such as contact and unstable damage growth for composites. One method implemented to mitigate the effects of discontinuity in nonlinear analysis is the use of material viscosity, which allows the solution to dampen out the effects of damage evolution by providing a stiffness variable that is dependent on viscosity and time.

> FEA programmers have developed approaches to overcome convergence problems for highly nonlinear events ....

"Viscosity is great for converging on a solution, however," warns Kenik, "you have to study how the viscosity affects the problem. Viscosity is just another variable that you have to tune to make sure that your finite element model is behaving correctly."

To avoid uncertainty, Autodesk's ASCA uses composite-specific proprietary methods to converge on a solution in nonlinear FEA, says Kenik. "It converges *without* relying on viscosity, and it is very efficient." The robust convergence offered by ASCA dramatically reduces simulation times and helps to reduce testing of physical components. ASCA 2015 is embedded with traditional FEA packages — MSC Software, ANSYS, Abaqus, NEi Nastran — using multiple failure theories, including Tsai-Wu, Hashin, Puck and constituent-level MCT theory. ASCA also provides capabilities to simulate complex failure modes, such as coupled inter- and intra-laminar failure, as well as algorithms to reduce mesh sensitivity of progressive damage simulations. The software comes prepopulated with a database of multiple unidirectional and woven materials, which can be used in addition to standard material data.

ASCD 2015 is geared toward preliminary design. The tool is a standalone desktop application that combines a prepopulated materials database, a laminate module with capabilities for laminate stress, strain and failure simulation, and solutions for deformation, bending, vibration and compressive stability of laminate plates, sandwich panels, tubes and beams. The application allows composite engineers to quickly iterate early in the design process by using the closed-form solutions embedded within the product. The 2015 release has additional solutions for manufacturing considerations, such as spring-in of laminates from temperature or moisture changes as well as a new reporting utility.

During the past year, Autodesk also has sponsored two free technology previews — known as Project Cassidy and Project Sundance — to generate interest and gain feedback from the community for new and future directions of advanced materials simulation within Autodesk (see "Learn More"). "Both are helping to ease new users into composite simulation," says Kenik. "One of the most difficult tasks in composite simulation is defining material orientations for the FEA analysis. Both technology previews provide easy and intuitive interfaces to help users include material orientations in their simulations and understand their impact on performance, which leads to lighter designs and a more efficient design process." (For more on materials database integration, see "Granta" item in "Learn More.")

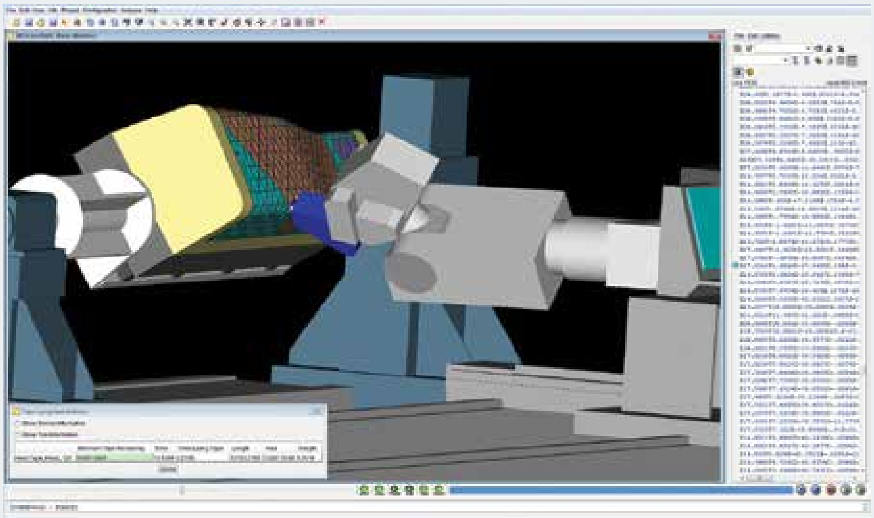
Closing the loop

CGTech (Irvine, Calif.) sees its suite of VERICUT composite applications as the first major steps for automated composite manufacturing processes toward closing the loop between design and manufacturing. For years, the company specialized in numerical control (NC/CNC) simulation, verification, optimization and analysis software technology for manufacturing. Recent additions to its products include VERICUT Composite Paths for Engineering (VCPe), VERICUT Composite Programming (VCP) and VERICUT Composite Simulation (VCS).

"Using software to do virtual layup experiments offers an effective tool for confirming that the part design is producible, and that the as-built part will match the design intent," says CGTech's product marketing manager Bill Hasenjaeger.

VCPe, he says, gives the user the ability to measure and evaluate the effects of automated fiber placement (AFP) and automated tape laying (ATL) path trajectory, material steer-

Source: CGTech



AFP simulation

This screen shot from CGTech's VCS software shows a frame from a simulation that depicts an automated fiber placement (AFP) machine creating an aerospace wing spar.

ing, surface curvature, course convergence and other process constraints as they would be applied in manufacturing. The software also provides producibility analysis of the fiber angle, based on the curvature of the part, and overlap and gaps needed for structural analysis. Tape course geometry can be written to various CAD formats for further evaluation by the user's analysis methods and tools.

"It allows engineers to understand fiber orientation, not just through simulation on the design tool, but through simulation based on what the manufacturing engineer is going to use to actually produce the path planning," explains Hasenjaeger.

VCS validates the layup process through simulation. The program reads CAD models and NC programs from VCP or any industry path-generation program and then simulates the sequence in a virtual CNC environment, applying simulated material, according to the NC layup instructions.

VERICUT is a standalone software package, but can be integrated with leading CAM systems, including Dassault's CATIA and Siemens PLM's NX. CGTech has a strategic partnership with Siemens PLM to provide rapid design and manufacturing iterations, thereby optimizing the development of composite structures produced via AFP and ATL.

Enabled to do "more iterations, with faster and better feedback earlier in the development process, firms are better able to evaluate the tradeoffs between manufacturing complexity and cost," says Hasenjaeger. "It also allows engineers to design specifically for the manufacturing process and take advantage of innovative uses of composite materials."

> Enabled to do "more iterations, with faster and better feedback earlier in the development process, firms are better able to evaluate the tradeoffs ...."

Looking ahead, Hasenjaeger points to the development of new AFP machine technologies, many using robots, to apply material over complex shapes at a lower cost than traditional gantry-style machines. "Today, many manufacturers are still struggling to apply current AFP technology to complex high-curvature part shapes," he says. "Innovative NC programming approaches are needed to successfully and reliably fiber-place complex parts while achieving the structural requirements of the laminate."

Optimizing RTM

ESI (Paris, France) offers a suite of applications designed to realistically simulate and fine-tune composites manufacturing processes. Focused on structures made of continuous fibers in a thermoset or thermoplastic matrix, ESI's tools enable analysis and optimization of each manufacturing operation, while transferring material history (change in fiber orientations, curing degree, temperature distribution, etc.) from one operation to the next.

ESI's composite simulation products include PAM-FORM for analysis of forming and preforming of dry textiles or prepreg materials; PAM-RTM for analysis of liquid composite molding and curing processes; and PAM-DISTORTION, which predicts manufacturing-induced residual stresses and shape distortion of composite parts. ESI also offers a CATIA V5 PLM-based composites portfolio that combines PAM-RTM and PAM-QUIKFORM. The pair simulate unidirectional composite deformation during the draping process and can detect, early in the design process, whether or not a selected material is viable for manufacturing.

"ESI's Composite Simulation Suite allows better understanding and control of the draping stage, the injection strategy and the distortion due to curing," says Federico Martin de la Escalera, head of Research and Technology Dept., Aernnova Engineering Solutions Iberica SA (Madrid, Spain). Aernnova implemented the PAM-RTM software in its engineering process while applying RTM to two Airbus A350 XWB parts — the bearing rib and the leading edge of the horizontal stabilizer — as a means to better understand and control the injection process and to manage final part quality, according to ESI. Tests based on Aernnova engineers' initial RTM mold design and injection strategy resulted in wrinkles and dry spots that affected the mechanical performance of the structural parts. According to ESI, PAM-RTM analysis led to the addition of new vent points that eliminated the dry spots.

Aernnova's engineers also simulated the preforming stage using ESI's composites forming application, PAM-FORM, to predict the fiber angle in the preform. These results were then used in PAM-RTM as a function of shear angle, which improved the prediction of resin flow pattern and filling time, says ESI.

Validation across industries

An assortment of maturing simulation tools is available to the composites industry. More importantly, software developers and composites engineers understand that by working together to validate simulation models and develop common languages, simulation methods can be strengthened across the board. Although there is still work to be done, the wheels are in motion and the gaps are getting smaller. ■

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Read this article online at short.compositesworld.com/Simulate.

Doug Kenik's webinar presentation, titled "Composites Optimization and Analysis in Space Launch Vehicles: United Launch Alliance (ULA) Utilizes Free Size Optimization for a Doubler Repair of a Gouge Type Defect," can be viewed at https://www1.gotomeeting.com/register/982718104.

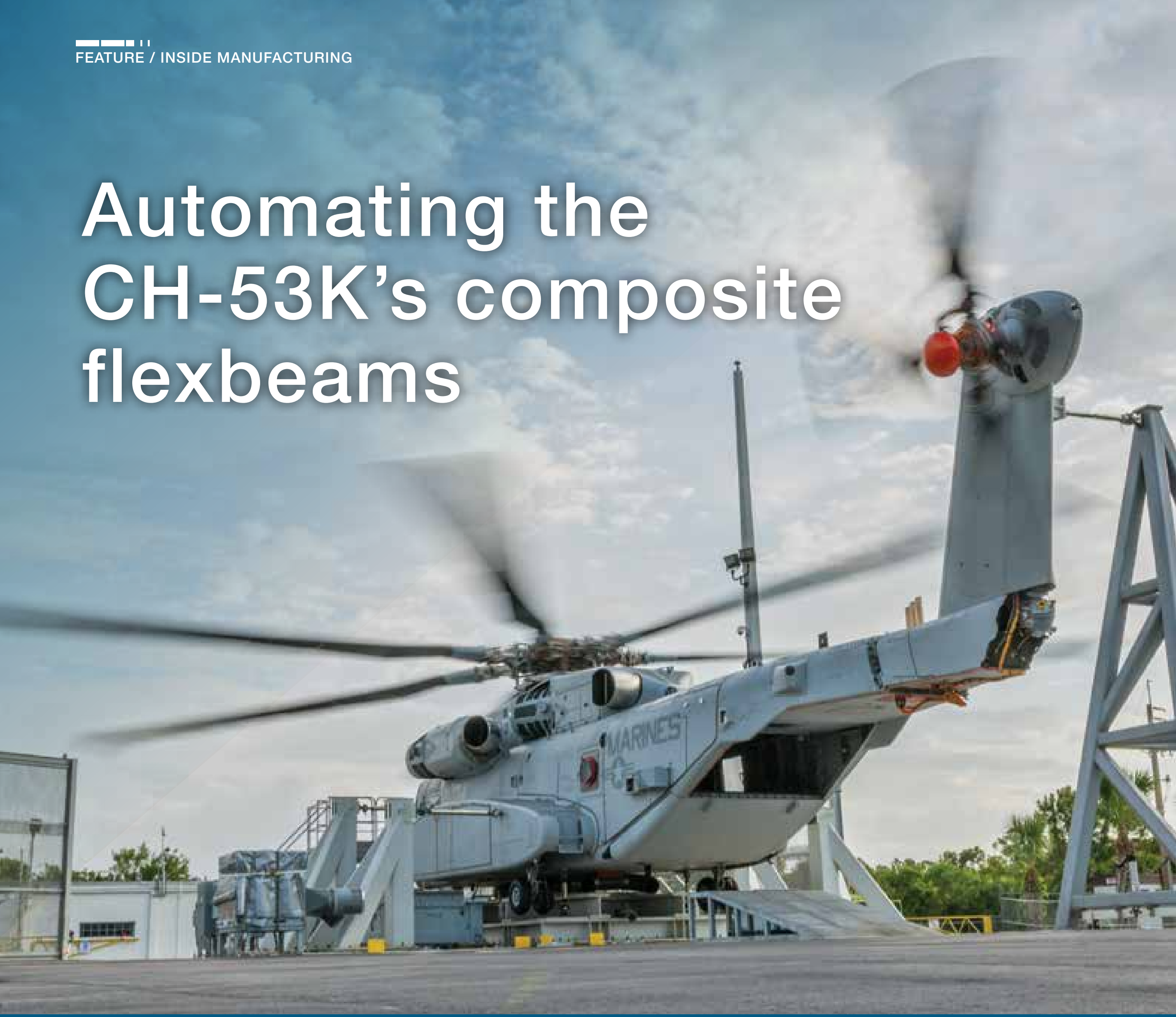
Robert Yancey's webinar on the subject of "Simulating ultimate failure: Converging on a solution with composite materials," can be viewed at https://www1.gotomeeting.com/register/418694968.

Read more abut Autodesk's free technology previews online in "Autodesk launches online design simulation, analysis labs," at http://short.compositesworld.com/ADlabs.

Software developer Granta Design (Cambridge, U.K.) provides "Materials database support for simulation/analysis" of aerospace composites. See this online-only sidebar at short.compositesworld.com/Simulat2.

Altair's Robert Yancey and Tim Harrell, of United Launch Alliance, discuss a software tool that enables the user to simulate a repair, in this online-only sidebar. See short.compositesworld.com/Simulat3.

Automating the CH-53K's composite flexbeams



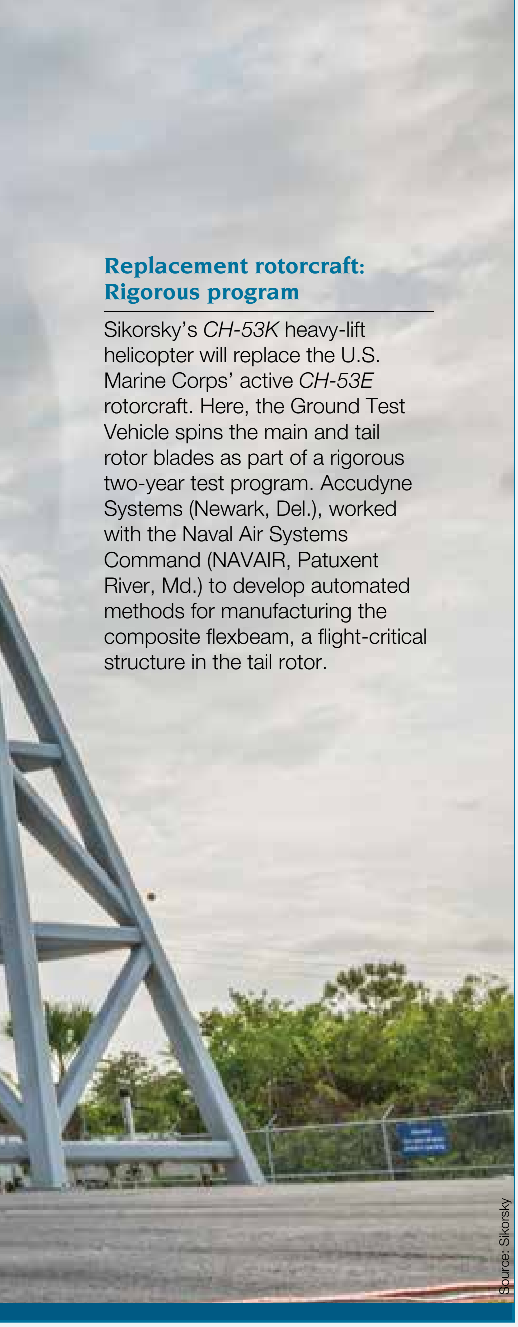
Accudyne doubles the part production rate and eliminates layup errors through stepwise automation of this primary structure's complex hand layup process.

BY GINGER GARDINER

Scheduled for first flight this year and entry into squadron service in 2019, the U.S. Marine Corps' (USMC) *CH-53K* heavy-lift helicopter is designed to raise the maximum gross weight ceiling of the currently used *CH-53E* to 88,000 lb (39,916 kg) without increasing its basic size. The operational goal is a three-fold increase in external load-carrying capacity, to more than 27,000 lb/12,247 kg over a mission range of 110 nautical miles/204 km. The extended payload capacity will be partially enabled by composites that include 35-ft/10.7m long fourth-generation rotor blades and a new, hybrid metal-composite airframe, which the OEM, Sikorsky (Stratford, Conn.), claims is more than 75 percent composite.

One of the enabling composite structures is the flexbeam, a flight-critical tail-rotor component that attaches the spar, upper skin and lower skin in each rotor blade to the rear horizontal shaft. The structure, 64 inches long by 13.5 inches wide by 3 inches thick (1,626 mm by 343 mm by 76 mm), has a dogbone shape reminiscent of a tensile test specimen, but with a 9° twist along its axis.

Each flexbeam incorporates 737 plies of prepreg. The USMC has ordered 200 aircraft. That's a lot of hand layup.



Replacement rotorcraft: Rigorous program

Sikorsky's *CH-53K* heavy-lift helicopter will replace the U.S. Marine Corps' active *CH-53E* rotorcraft. Here, the Ground Test Vehicle spins the main and tail rotor blades as part of a rigorous two-year test program. Accudyne Systems (Newark, Del.), worked with the Naval Air Systems Command (NAVAIR, Patuxent River, Md.) to develop automated methods for manufacturing the composite flexbeam, a flight-critical structure in the tail rotor.

Worse, the current layup process involves multiple ply cutting, placement and debulking steps, which not only require extensive man-hours and inflate production cost, but also present health and safety concerns, because some of the steps are ergonomically challenging. In 2011, therefore, the Naval Air Systems Command (NAVAIR, Patuxent River, Md.) awarded a Phase II Small Business Innovation Research (SBIR) contract to custom manufacturing solutions developer Accudyne Systems (Newark, Del.), to automate layup.

For the CH-53K's composite flexbeams, NAVAIR had made its goals clear:

- Accelerate production and cut labor cost by reducing cycle time from 40 to 10 hours per flexbeam.
- Eliminate operator ergonomic issues.
- Improve quality by laying 737 plies with no errors.

Theoretically, automation could minimize these risks, given the consistency of programmed machines in combination with continuous inline inspection via computer-based vision systems. Practically, Accudyne had the expertise and experience to provide the solution. The company had previously developed *part-specific* automated tape laying (ATL) and automated fiber placement (AFP) machines (that is, optimized for a single part or series of similar parts) and complete manufacturing cells. Further, it had developed a range of mechanized solutions for a wide variety of other operations, including preforming, robotic pick-and-place, ply consolidation and resin transfer molding (RTM), as well as noncomposites solutions to manufacturing and physics problems, such as a 75-ton "air crane" (lighter-than-air cargo transport), the world's fastest lithium foil windup system for battery manufacture, and a six-station rotary cell that fabricates door windows.

Given NAVAIR's brief and Accudyne's history, it's noteworthy that, rather than proceed directly to full automation, Accudyne adopted a *graduated* approach designed to validate, progressively, the ability of key automated system components to meet production rate and quality targets *before* its client had to commit to investing significant capital in a fully automated system.

Heavy man-hours for heavy-lift part

That decision was the result of a careful investigation. Development of equipment and process steps to meet NAVAIR's production requirements was preceded by an analysis of the flexbeam's manual layup process. Accudyne discovered that most of its plies are cut from 48-inch/1.2m wide unidirectional tapes supplied by Hexcel (Stamford, Conn.), roughly 60 percent IM7 and 40 percent S-2 Glass, both using 8552 epoxy resin. A smaller amount of IM7 fabric/8552 is used in 50 woven plies on the thick end of the flexbeam and 35 plies on the thin end. These pieces are cut and labeled automatically on a ply-cutting machine at Hexcel, assembled into 25 kits of approximately 25 plies each, and then stored in a freezer until lamination. To achieve the beam's dogbone shape, plies that span the full length of the flexbeam are interspersed with short plies on the ends. In the center "neck" section, the plies are cut to one-third of the starting width and layed side-by-side, comprising three separate but adjacent plies and one full-width layer. These so-called "zebra" plies present a significant challenge in the already complex layup.

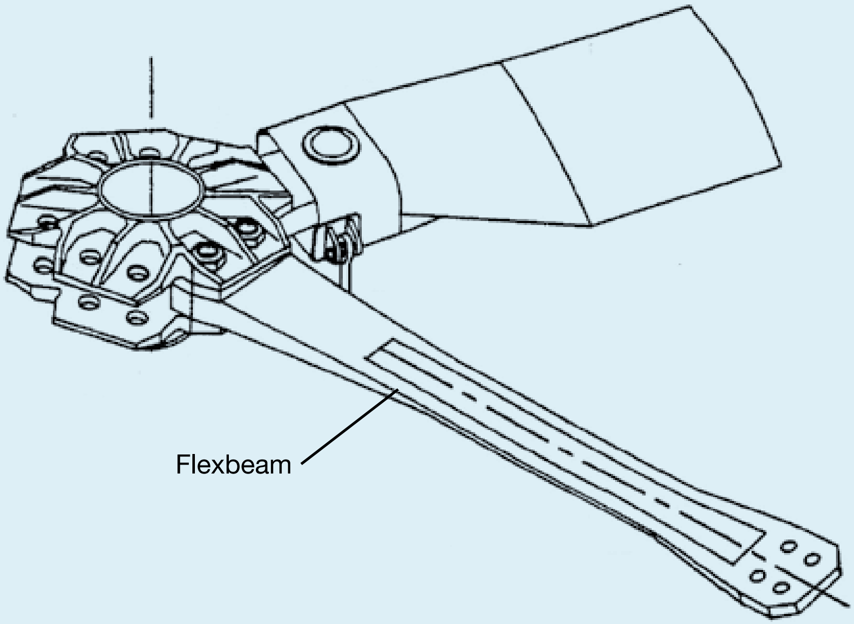
The manufacturing tolerances, the quality assurance tasks that ensure conformity to them, and debulking steps (required every 25 to 30 plies) add man-hours and extend cycle time (see Table 1, p. 76). Further, the monotony of manually laying similar plies offers significant potential for mistakes in sequencing. An incorrectly placed ply must be pulled up and a replacement cut. This is a time-consuming digression: The new material must be thawed, which can require an overnight wait. The new material itself might have defects and require replacement, further lengthening the delay.

One step at a time

"Many of our customers want to delve straight into fully automated production equipment," notes Accudyne project engineer Tracy Dolan. "But NAVAIR was very cautious about jumping to that level from no automation at all." Dolan also points outs, "without intermediate steps, it is hard to validate the increased production, improved quality and cost reductions needed to justify the investment in automation." NAVAIR and Accudyne agreed that a step-wise approach would be best.

Based on its analysis, Accudyne developed nine automation concepts. Of these, four were selected and presented to NAVAIR (see Table 2, p. 77). "These were the most promising," explains Dolan. "The ones in between [not shown] were hybrids." NAVAIR, however, decided the best combination of low risk and high reward was to focus on the first *two* of the four Accudyne selected, beginning with Concept 1 and *building* to Concept 4. Accudyne would take graduated steps toward automation, automating first the process steps that require the most labor and time and present the highest risk for error: 45° laminating, conforming plies to the curved mold, and debulking.

Source: 1994 patent awarded to United Technologies Corp.



Automating layup of a flight-critical structure

The flexbeam attaches the spar, upper skin and lower skin in each tail rotor blade to the rear horizontal shaft. Measuring 64 inches/1,626 mm long by 13.5 inches/343 mm wide by 3 inches/76 mm thick, this flight-critical structure in the *CH-53K* helicopter has a dogbone shape reminiscent of a tensile test specimen but with a 9° twist along the axis, and is made using 737 plies of prepreg.

Table 1

Flex beam manufacturing tolerances, QA and manual debulking steps

TOLERANCES		
Ply positioning	0.030 inch	
Angular orientation	unidirectional	± 2°
	woven	± 5°
LAMINATION QUALITY ASSURANCE		
• Count each of the backing papers.		
• Check each ply orientation.		
• Count plies as laminator applies them.		
• Continuously inspect backing films for foreign object debris (FOD).		
DEBULKING SEQUENCE		
1. Apply vacuum bag to layup after each full-length unidirectional ply.		
2. Add pleats with butyl tape for sealing at perimeter to enable conformability at center.		
3. Insert two vacuum ports.		
4. Apply vacuum; bag is sealed in ≈ 3 minutes		
5. Minimum debulk time is 15 minutes, average is 30 minutes, and a kit can stay under vacuum overnight.		

45° unis on a roll

"There is no commercially available unitape with only +45° or only -45° fibers on a roll without stitching," says Dolan. So Accudyne's first undertaking was to build a 45° tape-making machine. Eight clamps engage the incoming roll of 0° unitape prepreg, which has already had its backing paper removed automatically. The unitape is then pulled, using a pneumatic system, and cut at a 45° angle with a knife. A robotic head supplied by EPSON Robots (Carson, Calif.) then places the 45° ply onto white backing paper (see Fig. 1, p. 77). "To make the continuous roll," Dolan recounts, "we overlapped two half-thick 45° sections to enable a transition with a full thickness." Accudyne had to show that the equipment could produce that joint within the ply thickness tolerance for the part. "The result is similar to film splicing, and produces a continuous roll of 45° unitape on backing paper," she relates.

Automated ply placement and debulk

In Concept 1, the operator still manually cuts the lengths of 0° and 45° unitapes and stacks two plies at a time so a robot can pick them up and place them onto the curved flexbeam tool. "Our challenge," explains Dolan, "was to develop a head that would pick up a ply layup, which could actually be two plies of short length or one full-length 64-inch ply, from a flat belt and place it onto a double-curved tool in the right location and without wrinkles."

Accudyne had already developed an innovative pick-and-place robotic system for manufacturing T- and Z-stringers, which can integrate insertion of precut plies with shape forming for more than 160 different stiffener geometries. This system had reduced per-stringer cycle times that previously ranged from 30 to 60 minutes to a mere eight minutes. That system also alleviated the difficulty in aligning the ply packs by hand, which had previously resulted in excessive scrap and caused inconsistencies in dimensional integrity.

For the *CH-53K* flexbeam, the conformable head uses dozens of suction-cup fixtures to pick up the plies (see Fig. 2, p. 77). Dolan clarifies that the full production machine will have this conformable head attached to the end of a six-axis robot (see Fig. 4, p. 78). Accudyne's prototype did not yet incorporate a fully actuated robotic arm because it first had to demonstrate that the conformable head could pick up plies (see the gray-and-white tray in the foreground of Fig. 2) and place them onto the curved mold (see the black flexbeam layup directly beneath the suction cups in Fig. 2).

For debulking, an elastomeric bladder was laid flat over the part and tool, extending beyond the tool edge to permit operators to seal it against the table on which the tool sat (see Fig. 3). Vacuum is pulled through openings in the table surface. This conforms the prepreg plies to the tool and smoothes small wrinkles that might occur during placement. In the fully automated production equipment, the bladder will be positioned on the table and removed by a device mounted on a separate gantry frame located behind the tool table (see Fig. 4).

"In the beginning, we thought debulking would be our high-risk area of this work cell," Dolan relates, "but it became less so as we understood the requirements and nuances." In the manual process, debulk was necessary every 25 to 30 plies and consumed 15 to 30 minutes each time. Dolan recalls that Accudyne looked at many alternatives, including using two layup tools and debulking according to the manual process specs but nesting certain tasks within the automation. "In the end," says Dolan, "we realized we could debulk as part of the automation while the machine maneuvered to grab the next set of plies to place." In this scenario, debulking is performed every one to two plies, but each debulk lasts only one minute.

Table 2

Accudyne's selections for the most *promising* omposite flexbeam automation concepts.

Concept 1	Concept 4
	
Semi-automated process. Pick and place robot ($). Operator still hand places plies but does not conform them onto mold. Operator places two plies onto flat table, hits button and robot conforms plies onto mold.	**More automated process features pick-and-place robot ($$).** Robot cuts rolls of incoming materials to size as needed and then conforms them to mold.
Concept 7	**Concept 9**
	
Pick-and-place robot + ATL-type head on gantry ($$$). Robot only picks up 45° materials while the ATL is used to place 0° materials.	**Most automated, entirely ATL ($$$$).** Six automated heads lay six different rolls of materials (0° and ±45 for both IM7 and S2) directly onto the curved mold.

Source: Accudyne

Fig. 1

Accudyne developed automated equipment to cut incoming 0° uni prepreg at a 45° angle and place it on backing paper to make a continuous roll of 45° unitape without stitching.

Source: Accudyne

Fig. 2

To automate layup, Accudyne developed this conformable head with suction cup fixtures to pick up and deposit pre-cut plies.

Source: Accudyne

Fig. 3

For debulking, an elastomeric bladder was laid flat over the flexbeam layup, extending beyond the tool to seal against the table on which the tool sat. Vacuum was then applied through openings in the table surface, and supplied the pressure to conform the prepreg plies to the tool and to smooth any wrinkles that may have occurred during placement.

Source: Accudyne

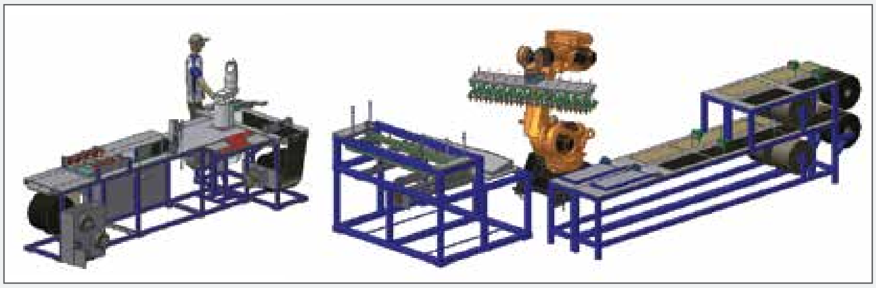


Fig. 4

Accudyne is in the process of completing and testing the modifications that will result in the finalized Concept 4 automated flexbeam production cell, including development of the cutting cell that will feed out materials from rolls and integration of a six-axis industrial robot. Bladder actuation will be conducted by a device on the gantry frame behind the table (see the dark grey mechanism behind the light grey wedge-shaped tool).

Prototype testing

After the two machine prototypes were built, Accudyne tested them to define the process parameters and verify process outputs and cycle times. "There were so many questions to answer," recalls Dolan. "How easy is it to run the machines? How accurate is the overlap joint in the 45° unitape maker? How accurate is the pick-and-place head? How much debulking is enough?"

It was during these tests that Accudyne developed its process for making a complete flexbeam. "We corrected our estimates of the timing for various steps and established how fast this automated process could make one full beam," says Dolan. "We had already reduced the cycle time to 10 hours, but then we were able to go further, to eight hours per beam."

Accudyne also identified modifications and improvements. "For example, we originally anticipated that operators would hand place the zebra plies. But we learned from running the prototype machines that the pick-and-place *should* be able to place those as well," says Dolan, pointing out that this will save an additional 30 to 60 minutes.

"The prototype machine couldn't do this, so I had to do it," Dolan recalls, admitting, "It was tortuous. *That* was when we figured out how to modify the machine," she quips.

When the pick-and-place head's suction cups lifted the one-third-width zebra plies, the material would droop, depending on where it was on the cups, so it couldn't be placed flat on the curved tool. The key, then, was cup arrangement. "If we place the cups differently," she asserts, "we can eliminate the sagging, enabling the head to place the plies correctly."

Progress to date

Dolan says Accudyne has demonstrated that Concept 1 meets NAVAIR's goals and has identified what further developments are needed to fully achieve Concept 4. These include not only modifying the suction cup spacing to accommodate the zebra plies but also enabling debulk after *every ply* without operator involvement, and fully automating the rebacking of the 45° material. Accudyne also will need to design, build and trial the cutter assembly that will feed material from rolls and present it to the 6-axis robot (see the station at right in Fig. 4). "We need to integrate the conformable head onto a robot and integrate that into the cutter assembly and debulk station," Dolan sums up. "All of the major components have been examined. It's simply a matter of integrating them."

Future directions

Accudyne is in discussions with NAVAIR about the path forward for the modifications, final integration and nondestructive and destructive validation. "Several beams will need to be loaded to failure and to simulate flight conditions," explains Dolan. After that, she says the goal will be to work with NAVAIR's contractors to put Concept 4 into production. "We've already proven Concept 4 can operate just as accurately as the more automated systems [Concepts 7 and 9], though perhaps not quite as quickly, but then the investment into the ATL heads is not required." In the end, the OEM and its Tier 1 suppliers will make the final trade-off analyses and decisions.

Accudyne is pleased with its automation concepts and stepwise approach, thus far, and Dolan believes the latter can be applied readily elsewhere. "While this particular part had some exceptionally challenging geometric features," she observes, "the … methods we employed could improve consistency, quality and cost for a wide range of structures. This step-wise approach … enables affordable investment and offers the ability to increase automation as part volume and program needs grow." ■

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CW **Dec. 9-11, 2014**	Carbon Fiber 2014 La Jolla, Calif. I www.compositesworld.com/conferences/compositesworld-2014-carbon-fiber-conference

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APPLICATIONS

Camera-based ply placement cuts time, cost on complex rotorcraft parts

Applied Composites Engineering (ACE, Indianapolis, Ind.) is manufacturing a heated inlet, part of a proprietary anti-icing system designed by Cox & Co. (Plainview, N.Y.) for AgustaWestland's (Cascina Costa di Samarate, Italy) new twin-engine, medium-lift *AW189* helicopter.

ACE uses PlyMatch ply placement technology from **Anaglyph Ltd.** (London, U.K.) to speed layup of the complex-shaped part and eliminate costly secondary assembly and bonding. PlyMatch uses a "smart" digital camera to acquire a live video image of the part, while its position and direction in space are specified by a coordinate measuring machine (CMM). Data from both devices are continuously fed into a computer, which then successively generates images of the fabric plies, in sequence, for layup. The computer-generated image of each ply is superimposed onto the live video image from the camera, giving a virtual-reality (Anaglyph calls it "augmented reality") compound picture. Alternatively, a complete video recording of the layup operation may be saved to hard disk, showing any deviations from nominal ply position or fiber orientation. The system also can be used to locate manufacturing or assembly-sequence features, such as inserts, bolt holes or labels.

The PlyMatch system is available in flexible configurations to meet the specific requirements of each manufacturer, but includes as a minimum: A PC with display, a digital camera with boom stand, a CMM with wireless and tool reference probes, placement software, Anaglyph's Laminate Tools software for video and CMM probe interfaces and image blending and onsite training.

Unlike laser-based ply projection systems, PlyMatch is self-calibrating: Operators can move the camera or the mold without loss of system accuracy. According to

Leigh Sargent, president of ACE, "We undertake many complex composite fabrications where laser projection is inadequate. The three PlyMatch systems we have in place are utilized daily, eliminating expensive templates and radically decreasing time to first article delivery." He adds, "The ability of the operator to move the mold when working with these intricate parts is another advantage, particularly in parts like complex ducting."

Destroyer deckhouse roof meets U.S. Navy fire code with phenolic composite

Although the U.S. Navy's new, nearly $4 billion (USD) *Zumwalt*-class destroyer has a steel hull, it is topped with an all-composite deckhouse superstructure that cuts topside weight and gives the ship stealth capability by reducing its radar signature. Built by Huntington Ingalls Industries (Gulfport, Miss.), the superstructure features flat sandwich panels of balsa core (**Alcan Baltek Corp.**, Northvale, N.J.) between faceskins of T700 carbon fiber (**Toray Carbon Fibers America Inc.**, Flower Mound, Texas) woven by **Sigmatex Inc.** (Benecia, Calif.) and infused with vinyl ester resin from **Ashland Performance Materials** (Dublin, Ohio).

The balsa-cored panels offered good fire performance, compared to foam- or honeycomb-cored alternatives, for the majority of the superstructure, but when the Navy expressed concern about the fire-readiness of its roof, more robust fire-resistant panels were developed by phenolic laminate specialist DuraSip LLC (Union, Miss.), a subcontractor to Navy contractor Temeku Technologies Inc. (Herndon, Va.), to meet the Navy's fire code. DuraSip's CEO and composites engineer Max Ware says the 2-ft by 2-ft by 1.5-inch thick (0.62m by 0.62m by 34-mm) panels were produced with multiply reinforced phenolic skins bonded to rigid phenolic foam under heat and pressure, using a phenolic adhesive. DuraSip used **Momentive Specialty Chemicals Inc.'s** (Columbus, Ohio) trademarked Cellobond J2027L phenolic resin, supplied through **Mektech Composites Inc.** (Hillsdale, N.J.). "Fiberglass or carbon fiber-reinforced phenolic laminates maintain structural properties at elevated temperatures better than laminates made with any other thermoset resin," he comments. "Also, they give off the least amount of toxic gasses compared to other thermosets, so the phenolic panels were the right choice." They also act as thermal insulators, to help keep the deckhouse interior at a comfortable temperature.

The roof panels, totaling 6,000 ft^2/557m^2, were bonded to the deckhouse with either adhesives or mechanical fasteners, and the phenolic laminate surfaces received a weatherproof coating after assembly.

NEW PRODUCTS

OOA epoxy vinyl esters for carbon fiber composites

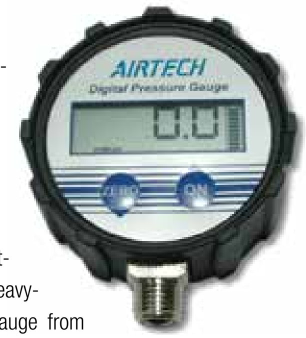
Global resin supplier **AOC** (Collierville, Tenn.) has developed its R058 series, a line of out-of-autoclave (OOA) epoxy vinyl ester resins formulated to meet demand for high-performance composites in aerospace, automotive, wind energy, military, marine and other markets. Specifically designed for use with carbon fiber reinforcements, R058 resins are said to create lightweight composite parts with exceptional strength-to-weight ratios. The series reportedly combines the performance of epoxy resins with the processing speed of unsaturated polyesters. Designed for vacuum infusion and resin transfer molding (RTM), R058 reportedly yields excellent mechanical properties and chemical resistance. Other benefits include room-temperature cure for laminates as thin as 2 mm/0.08 inch; low viscosity that shortens mold fill times and promotes thorough fiber wetout; and good strength, toughness and chemical resistance over a range of temperatures. Additionally, its low laminate exotherm improves surface aesthetics, and there is no post-cure requirement. **www.aoc-resins.com**

Automated dry material placement

DANOBAT Composites (Elgoibar, Spain) recently announced that the company is developing highly specialized solutions to automate manufacturing with dry composite materials. Automated Dry Material Placement (ADMP) is used to

automate the deposit of dry reinforcement fabrics for use with infusion-based composites manufacturing processes, including resin transfer molding (RTM). DANOBAT says manufacture of an aircraft wingskin or frame is feasible with ADMP. Developed because current manufacturing processes for prepreg are labor-intensive and costly, ADMP, says the company, replaces manual steps with automation and the use of dry material enables manufacture of highly integrated composite structures, reducing assembly costs. As a result, the company claims, ADMP has demonstrated the capability to deposit fabric 100 times faster than current wet processes, yet reduce material cost by 50 percent. **www.danobatgroup.com**

Digital vacuum gauge



Airtech Advanced Materials Group (Huntington Beach, Calif.) has introduced the Vac-Gauge 40D, a digital vacuum gauge used for leak detection and vacuum determinations under a vacuum bag during infusion manufacturing processes. The gauge offers vacuum readings in four selectable units: mBar, mmHg, inHg and KPa. A heavy-duty, ridged plastic jacket protects the gauge from damage during normal shop use. The Vac-Gauge 40D connection stem is a 0.25-inch/18-NPT thread fitting that is compatible with Airtech's Airlock 450TF, 550TF and AQD quick disconnects. The gauge has a time-selectable auto-off function and can be calibrated. **www.airtechonline.com**

Epoxy composite tooling materials

Sika Deutschland GmbH (Bad Urach, Germany) has introduced Biresin CR132 ST and Biresin CR136, epoxy tooling resin systems for composite molds. Biresin CR132 ST, a paste-like epoxy, is used to couple a gel coat to the first laminate layer with what is said to be minimal print-through of the first fabric layer. Biresin CR136 is a filled epoxy that reportedly helps conduct and distribute heat across the mold area, when the tool(s) is(are) heated by steam, oil or other fluids, ensuring that all areas of the tool cavity are equally heated. The resins offered by Sika in the Biresin range are fully compatible, offering what is said to be a high-performance, easy-to-use tooling system with a T_g of 130°C/266°F, allowing usage up to 120°C/248°F. **http://toolingandcomposites.sika.com**

Fiber-optic strain sensing

4DSP (Austin, Texas) has developed RTS125, an off-the-shelf, distributed fiber-optic sensing solution. Able to monitor tens of thousands of strain or temperature sensors simultaneously, and do so up to 100 times per second, the RTS125 offers the same sensing capabilities on as many as eight fiber-optic sensing channels, like its predecessor the RTS150, but is housed in a lighter and more rugged enclosure. 4DSP describes the distributed sensing capability as "comprehensive" because the unit can measure several parameters using a single system, simplifying the collection and monitoring of diverse measurements. Further, Fiber Bragg Gratings (FBGs) enable real-time extraction of environmental parameters, such as strain loads and temperature gradients, continuously, along each sensor's entire length. The system also can be used to sense and display the three-dimensional shape of a sensor, with a resolution of 450 micrometers. The eight-channel system features 2,048 equally spaced sensors per fiber, 0.1 cm to 10 cm spatial resolution, less than 50 ms latency, a 100Hz refresh rate, 3-D shape-sensing capability, resistance to electromagnetic/radio frequency interference/radiation, and networking capability via Ethernet. **www.4dsp.com**

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RESIN INFUSION PRODUCES AUTOCLAVE-

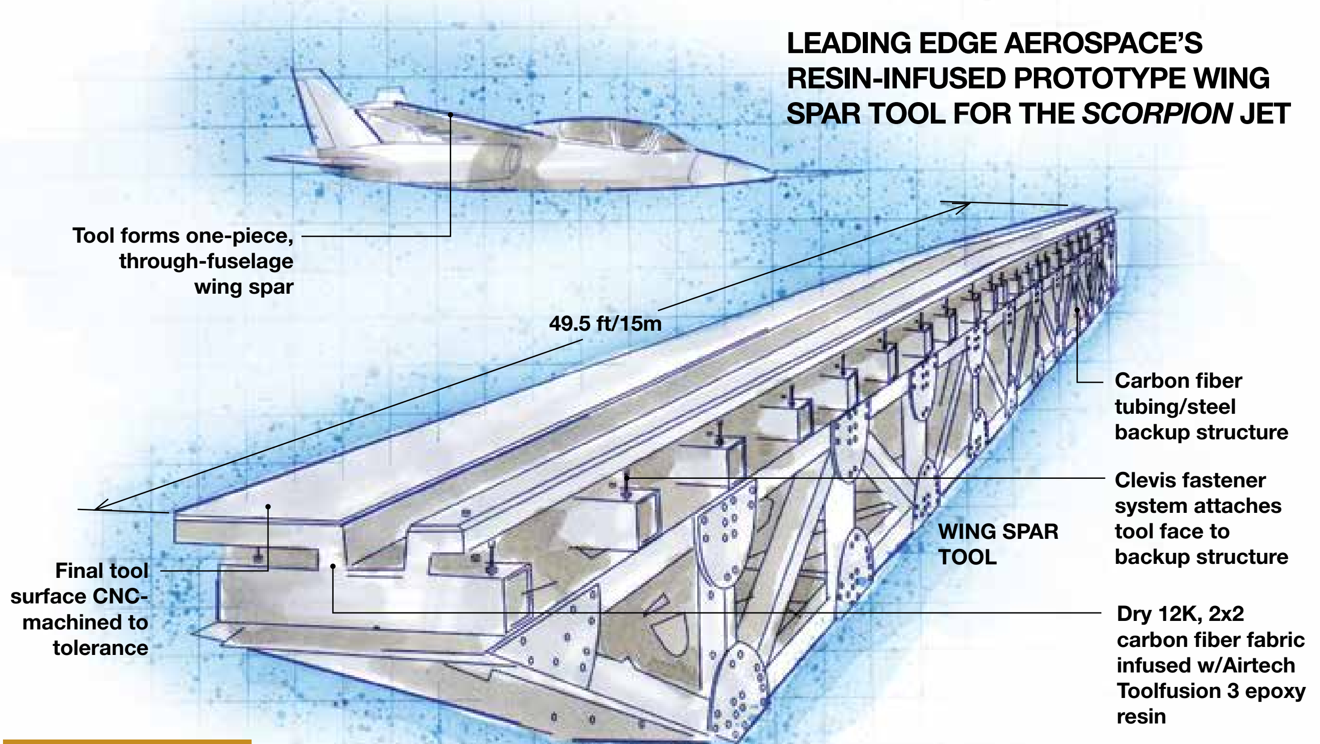
Leading Edge Aerospace designs and builds cost-effective prototype

As defense budgets shrink and world unrest expands, military agencies the world over are looking for ways to economize. High-end fighter aircraft, such as the Lockheed Martin F-35 *Lightning* II, cost in the neighborhood of $100 million (USD), a steep price tag for any air defense entity. Textron (Providence, R.I.) and Airland Enterprises LLC (Garland, Texas), a group of aerospace and defense veterans that includes former U.S. Air Force Secretary Whit Peters, decided in 2012 to team up and develop a more affordable complement to traditional high-dollar fighter aircraft. Working secretly at a Cessna Aircraft facility in East Wichita, Kan. (Cessna is a Textron company), the "skunk works"-like endeavor was a "clean-sheet" design of a small yet effective jet aircraft for multiple markets and — significantly — realized with *off-the-shelf* technology. The result is the *Scorpion*, a composites-intensive, tandem-seat, twin-engine tactical jet fighter, unveiled this year and self-funded by Textron Airland LLC (Wichita, Kan.), a joint venture of Textron and Airland Enterprises.

Textron Airland took the *Scorpion* from concept to first flight in an unheard-of two-year time frame, a feat made possible, in part, by tooling partner Leading Edge Aerospace (LEA, Wichita, Kan.). "This was an extreme development schedule," says Dale Tutt, Textron Airland's chief engineer. "We had to develop the tools in parallel with actual aircraft design. We were very fortunate that LEA provided innovative tooling concepts that kept us on schedule."

Meeting requirements with the right process

LEA's composites manager Rod Brown explains that Textron Airland's mandate presented a huge challenge. The customer wanted autoclave-capable prototype tooling that could hold tight tolerances on an accelerated schedule, but at relatively low cost. Two wingskin tools (upper and lower), each 49.5 ft/15.1m long and approximately 7 ft/2.1m wide, would be required, as well as four spar tools, to fabricate the supporting spars for the main wing and the horizontal stabilizers. Further, an assortment of smaller tools, for the multipiece fuse-



DESIGN RESULTS

- Infusion of dry carbon fiber fabrics in carefully designed vacuum process produces robust tools for the autoclave.
- Dry reinforcements cost far less than prepreg, reducing cost during initial prototyping phase.
- Machining of critical tool surfaces to tight tolerances makes it possible to deliver tools on a faster timetable.

CAPABLE TOOLS FOR *SCORPION* JET

tools for maverick military aircraft concept.

BY SARA BLACK
ILLUSTRATION / KARL REQUE

Composite-airframed jet concept from U.S. draws attention in U.K.

The *Scorpion* jet flies over Corfe Castle, in Dorset, U.K., near the end of its first transatlantic crossing. The tactical jet prototype has garnered interest at its appearances in Europe, including the recent Farnborough Air Show.

lage and other parts, had to be produced as well. All parts would be molded from carbon fiber prepreg and autoclave-cured.

"We had to juggle the tradeoffs between materials and process," Brown recalls. "If we had chosen prepreg for autoclave service and durability, the cost would have been too high for prototype tooling. We had to find a way to minimize costs and still get the tool quality we wanted." LEA opted to try infusion and oven cure, using more economical dry carbon fiber fabrics with epoxy resin, and then using postcure CNC-machining to bring tool faces to final tolerances.

The approach presented some risk, Brown admits. "Every step in the process had to be perfect," he explains. "Any shortcuts that led to vacuum leaks could cause voids in the laminate, which ultimately would cause tool leakage." In his view, however, many companies give up too soon on infusion for tools, without fully understanding and optimizing their methods. He believed that LEA had a plan that would work.

Textron Airland provided LEA with CAD files, produced using CATIA software from Dassault Systèmes (Waltham, Mass.), for each of the *Scorpion's* composite parts. Brown says LEA evaluated the files in detail and modified them to create tool files. Generous edge flanges, for example, were added for vacuum bagging. Likewise, excess material was added to the tool face, where needed, to account for postcure machining, and backup structures and transport carts were designed.

Mastercam software from CNC Software Inc. (Tolland, Conn.) was used to convert the modified CAD files to the machining files for the pre- and postmold machining operations that would control LEA's CNC machining center, manufactured by Anderson America Corp. (Pineville, N.C.).

High-density polyurethane foam supplied primarily by Coastal Enterprises Co. (Orange, Calif.), in densities ranging from 10 to 30 lb/ft^3, was machined to form the tooling masters. "If a tool surface was not planned to be CNC-machined, then the master was made as a male and the final tool surface was layed up against it," explains Brown. If, however, the final tool surface was to be machined, typically for "controlled" aerodynamic parts that would be exposed to the airstream, it could be made as a male or a female, provided sufficient allowances were made for the postcure machining operation. The machined masters were sealed with a primer supplied by Hawkeye Industries Inc. (Bloomington, Calif.) and then finished with Hawkeye's Duratec topcoat.

Airtech International Inc. (Huntington Beach, Calif.) supplied the tooling materials, which included a 2x2 12K woven carbon fiber fabric, and Toolfusion 3 infusion-optimized epoxy resin. Although he initially considered Airtech's Toolfusion 1 room-temperature cure resin, Brown ultimately selected Airtech's Toolfusion 3, designed for higher-temperature cure. "We believed that Toolfusion 3's 120°F/49°C oven cure profile, combined with a standing postcure, would give us a higher T_g and better autoclave performance," he asserts.

To ensure the highest quality in the infused laminates, LEA devised an infusion schedule that allowed up to three hours for the resin to fully saturate the layup, followed by a 12-hour oven cure cycle, under vacuum. After demolding, each tool would be post-cured at 400°F/204°C for 12 hours.

There was some concern, initially, that the part shapes might cause lockup in the tool, preventing part removal. Also, the work envelope on LEA's CNC machine was, at that time, smaller than the largest tools in the tool set. (LEA has since installed a larger Anderson CNC machine.) Both issues indicated that multipart tools might be required, says Brown, so a deep-draw, two-part infused demonstrator tool was fabricated to prove feasibility (see top photo, p. 80). A longitudinal seam runs down its middle where the two parts are bolted together on the back side; a bead of high-temperature silicone along the seam would prevent tool leakage. "In the end, we didn't have any lockup with any of the parts," he says, "but some of the tools required multiple sections due to their size."

Maximum tools, minimum price

Tool layup involved balancing the number of material plies with part pro-

Source (both photos): Leading Edge Aerospace

Fuselage tool demonstrator

This two-piece, infused carbon demonstrator fuselage tool (top) was developed with a two-piece strategy to ensure removal of a trapped part, given the *Scorpion* jet's narrow forward-fuselage shape. The back side of the demonstrator tool (second photo) shows the backup structure and integrated "ribs" on the tool surface to add rigidity.

Source: Leading Edge Aerospace

Upper wingskin tool

Leading Edge Aerospace's owner Stan Unruh stands beside the 49.5-ft long upper wingskin layup mold. Like the wing spar tool, it is fabricated with 12K carbon fabric and infused with Airtech International's (Huntington Beach, Calif.) Toolfusion 3 epoxy resin, and then CNC-machined to surface tolerance following cure.

duction demands. Says Brown: "If you use a single piece of cloth along the length of the layup, it can induce warpage of the tool face during heat cycles." Instead, the carbon fabric was cut into smaller panel shapes and several plies were layed over the sealed foam masters in a manner that reduced the risk of distortion. An Airtech tackifier held dry plies in place, maintaining fiber orientations during the layup process. The goal was a tool thickness of 0.25 inch/6.35 mm — anything thinner would be too flexible. Greater thickness would use more cloth, adding weight and cost, and also would take longer to heat during the cure process. "Production tools are typically closer to a thickness of 0.5 inch [12.7 mm], for better durability and longer life, but we didn't need that for the prototype *Scorpion* parts."

For those tools slated for postcure tool face machining, layups were built up from the backside on a female foam master. Grooves machined into the master face allowed layup of carbon cloth to form a pattern of integral ribs, adding backside stiffness to the cured tools (see middle photo on this page).

Demolded tools were machined with either natural diamond grit-coated tools or polycrystalline (synthetic) diamond (PCD) tools, explains Brown, who adds that a "very good" dust collection system captured the highly conductive carbon dust. LEA says it is able to achieve tolerances of ±0.005 inch/0.127 mm on machined tools.

Tool rigidity was ensured with steel or carbon-composite square-tube backup structures with wheels. An adjustable clevis system on the long wingskin and spar tools and some smaller tools enabled tool-face adjustments to maintain accuracy over tool length. Ultimately, the customer was happy with a variance of ±0.020 to ±0.030 inch (±0.51 mm to ±0.76 mm) over the length. Following postcure, tools were treated with sealer and Chemlease mold release from Chem-Trend LP (Howell, Mich.).

"Vacuum infusion can produce tools better than wet layup, and nearly as good as prepreg," concludes Brown. "It's a function of good shop practices." The prototype infused/machined tools should be more than sufficient for five production cycles, at considerably less cost than a prepreg solution, he claims. Flight and systems testing is ongoing for the first prototype aircraft, and a second prototype from LEA tools is in process.

A commercial product with military potential

After more than 70 flights, including a trip to the Farnborough International Air Show in July, *Scorpion* is attracting potential customers. "We are working with more than one credible country," says Textron Airland's president Bill Anderson. Said to be capable of security and reconnaissance missions, in a niche between strategic but aging military craft and elite strike fighters, *Scorpion* will have a price tag of about $20 million (USD) and much lower operating cost than the latter. Low-volume production could begin in 2015. Brown says LEA hopes to be selected for rate tooling and is considering both carbon/epoxy prepreg and Airtech's Beta benzoxazine prepreg, based on resin technology from Henkel Corp. (Dusseldorf, Germany). ■

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