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Aramid Fiber/ Thermoplastic Liners: SUBSEA PIPE REHABILITATION

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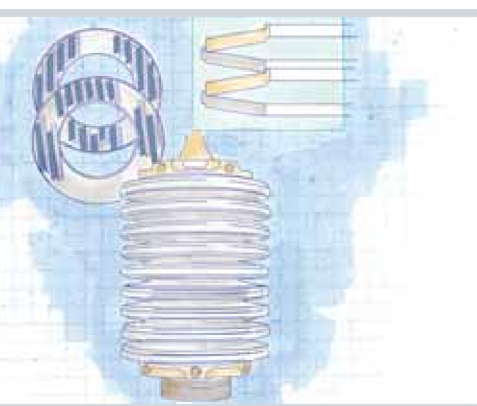
FEATURES

» ON THE COVER

Anticorrosion Protective Systems' (APS, Dubai, UAE) InField Liner, a cost-effective flexible aramid/thermoplastic liner that can be pulled through and inflated inside internally corroding undersea oil and gas pipelines to extend their service life, is shown here as its patented multi-stage vertical manufacturing process begins. Get the complete story on p. 50.

Source / APS

FOCUS ON DESIGN



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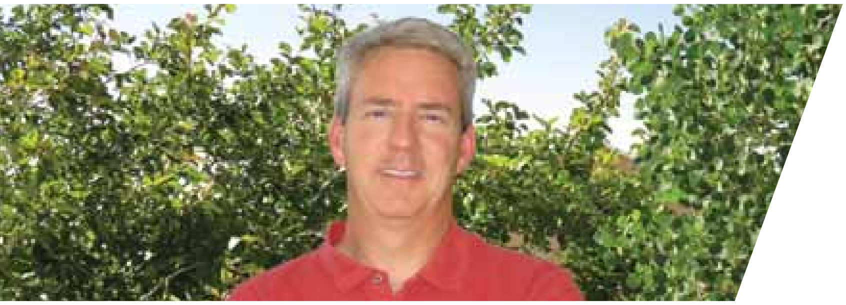


»It's mid-July as I write this, the time of year when a young *CW* editor's thoughts turn to intellectual property.

I'll explain this, but first some background. Each summer we begin editorial planning for the coming year. We do this for a couple of reasons. First, we must produce each fall a media guide to help real and prospective advertisers understand what their advertisement options are. Included in this guide is an editorial calendar, outlining in broad terms what stories we are featuring in each issue.

IP vigilance might seem like good business, but *is it?*

The second reason has to do with our editorial mission. *CW* is, at heart, a technical trade publication that emphasizes coverage of the use of established and emerging material and process technologies in real-world composites manufacturing. When they begin work on stories, then, our writers ask specific questions of their sources about how a part is designed, how tooling is developed, how the part is molded and finished. Almost all of the stories we publish require several months of research, fact-checking, review and final clearance before they can be sent to the printer.

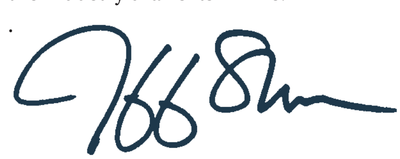
If we encounter resistance from a source as we develop a story, it's usually for one (or both) of two reasons: Concern about violating non-disclosure agreement (NDA) restrictions imposed by a customer/OEM (i.e., Boeing, Airbus, BMW, Vestas, etc.), or anxiety regarding protection of intellectual property (IP). We can get around the NDA by omitting information deemed, by the customer/OEM, to be "sensitive," or by allowing the customer/OEM to review the story to check for NDA violations. Nine times out of 10 we can get a story to print this way.

Coping with IP concerns (aka *trade secrets* and proprietary data) in a source, however, can be trickier. This is because many composites fabricators believe they are in possession of a material or process that is unique to their company. We usually learn of this "secret sauce" while conducting an interview for a story when a source reveals some detail of material or process about which we're writing. Then, during the review process, someone higher up the food chain will request that information be removed due to IP concerns — despite the fact the material and/or process in question is also in use by one or more other fabricators with whom we've also done stories.

Similarly challenging is our position in the industry as assemblers and purveyors of composites information. Much of our story research requires aggregation of information from multiple sources (papers, presentations, etc.) that are in the public domain. But sometimes, when this public information is collected into one story, our sources, again, become concerned about IP security. More than once we've had a source say, "I *know* it's public information, but I did not realize you were going to put it *all* in *one* article."

Such IP vigilance might seem like good business, but given the above, *is it?* Advancing innovation in the composites industry requires a tide that lifts *all* boats, and this demands a willingness on the part of suppliers, fabricators and OEMs alike to recognize the value of *shared knowledge*. The composites industry, given its relative youth and intense competition from legacy materials, needs to recognize that this is no time to cling jealously to perceived technological advantages, when greater advantage can be gained if we are more willing to talk openly about what we do and how we do it. In such a way, design and processing best practices can be more quickly optimized and fine-tuned.

This is, of course, easy for me to say. *CW* doesn't manufacture parts and we have no IP to worry about in the same way as many of you do. But we do have a unique vantage point and see, probably better than anyone, how limiting IP protection can be. Information sharing will be severely tested in the next few years as the Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US) begins its work, which involves hundreds of suppliers, fabricators and researchers. IACMI has promised to protect IP, but also demands openness. The consortium's success — and the composites industry's success — might depend on how and where the industry draws its IP line.



JEFF SLOAN — Editor-In-Chief

AFP/ATL evolution: Dual-process workcells

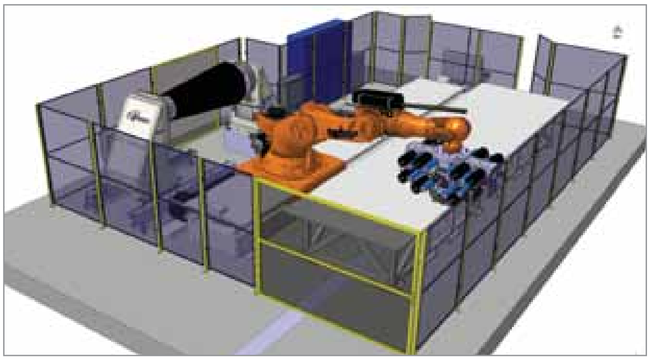
» My aerospace career spans 41 years, and manufacturing equipment has been its primary focus. I worked my way through college in an aircraft machine shop, where I operated a variety of metal processing equipment. When I got involved with aerospace composites in 1984, my experience with processing equipment continued, and my entire 31-year career in composites has been focused on automated lamination processes. When I started in composites, I was fortunate to work for the company that did a lot of the original development work on an automated lamination process known as automated fiber placement (AFP). I've watched AFP mature over the years and become the premier process for fabrication of composite aircraft primary structure, including fuselage structure on both the Boeing 787 and Airbus A350.

In the early days, AFP and automated tape layer (ATL) machines evolved to be quite large because they were developed typically for large aircraft structures (e.g., large skin panels). By contrast, the metals world in which I started my career had a wide variety of equipment sizes and configurations, and I often wondered when automated lamination technology for composites would mature to the point that a greater variety of machines would be offered to a wider range — and greater number — of potential customers.

The market for large ATL and AFP equipment has been driven, typically, by new aircraft programs (commercial and military) that have emerged every few years with expanded use of composite materials. But in the past few years, no new composites-intensive aircraft programs have appeared on the horizon. When Airbus and Boeing elected to re-engine their current A320 and 737 commercial aircraft instead of developing all-new, composites-intensive models (with composite content similar to the A350 and 787), the market for large ATL and AFP equipment was no longer as strong as it had been in previous years. This market reality has been a factor in machine suppliers' development of more variety in composites lamination equipment.

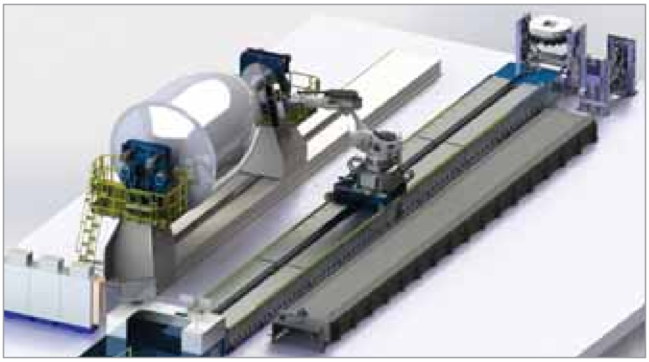
During the past few years, we have begun to see an expanding variety of composites lamination equipment, and I have noticed something that I feel will be the "next big thing" in automated lamination. Several machine suppliers are offering equipment that is based on commercially available robots. Although this is not exactly new technology and has been offered for a few years by some of the smaller companies that offer composites equipment, such as Automated Dynamics (Schenectady, NY, US) and Coriolis Composites (Queven, France), the technology also has begun to catch on with some of the major composites machine suppliers. The most interesting examples I've seen are the small "dual-process workcells." As the name implies, they have the capability to perform *both* AFP *and* ATL — one machine, *two* lamination processes. These have been developed by at least two of the major players, MTorres (Pamplona, Spain) and Electroimpact (Mukilteo, WA, US). Small, here, is a relative term. As the image captions at left indicate, the workcells are sizable, but they are much more compact than the AFP/ATL systems used to make aircraft primary structures, and they can be installed in most existing factories without major facility modifications prior to installation.

Dual-process workcells consist of a robot-based lamination machine that moves on x-axis rails/drives parallel to and between a layup table and a headstock/tailstock tool station. The layup table is primarily used for laying flat laminates, which are »



Mtorres dual-process workcell

MTorres offers its small dual-process workcell with two delivery head options, an 8-tow head and a 16-tow head. Heads can be configured to run slit tape widths of 6.35 mm or 12.70 mm. MTorres uses a KUKA Robotics (Shelby Township, MI, US) KR1000 Titan Robot for its dual-process workcell. Typical x-axis travel is approximately 9.14m. The workcell's installation footprint is about 13.7m by 7.6m.



Electroimpact's dual-process workcell

Electroimpact's system has a typical x-axis travel of ~12.2m, depending on the customer's size requirements. Installation footprint for this machine is about 18.3m by 12.2m. The workcell has AFP delivery head options of 8 or 16 tows and tow widths of 3.18 mm, 6.35 mm or 12.70 mm, and it also has a small ATL head option that will lay 76.2-mm, 152.4-mm, or 304.8-mm wide tape. All power and pneumatics are passed through a commercially available robotic toolchanger assembly. It also has integrated systems for laser projection, automated ply boundary inspection and automated lap/gap inspection.

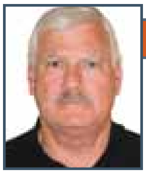
subsequently cut into individual pieces that are hot formed to achieve final part shape. When AFP is required to layup a more complex shaped part, the robot rotates to the side of the workcell that has a layup tool loaded into the headstock/tailstock. Electroimpact machine engineer Guy Faubion says, "One of the most attractive features of a dual-process workcell is it allows for complete cell utilization. The robot can be working in one workcell zone while personnel safely perform manual tasks, such as, part load/unload, part inspection, etc., in the other work zone."

In both the MTorres and Electroimpact workcells, the slit tape material spools are mounted on the delivery heads. When the head runs out of (or runs low on) material, it can be changed out quickly for a delivery head with full spools of material and, therefore, minimize process down time. On Electroimpact's dual-process workcell, for example, a spent delivery head can be dropped off and a fresh one picked up within 90 seconds.

With head quick-change capability, these workcells can use a conventional, individual tow-control AFP head to lay up complex-shaped parts and, if so desired, change to a compact-sized, low-complexity ATL head to lay up flat laminates. MTorres machine design engineer Manu Motilva says, "Changing delivery heads from AFP processing to conventional ATL processing especially makes sense when several material formats are used. For example, ATL works great with fiberglass and expanded copper mesh, while the AFP head, with a 16-tow capacity, provides a material band up to 8 inches (203 mm) wide, and this should be sufficient for laying carbon fiber flat laminates on the layup-table side of the workcell."

The processing flexibility, smaller size, ease of installation and lower cost of these robot-based workcells should make them very attractive to Tier II shops that supply smaller composite aircraft parts. Tier IIs have little need for (nor can they usually afford) large ATL and AFP equipment, but for many of them, at least some of the parts they build would benefit from AFP and/or ATL. Small dual-process workcells could provide the automated processing capabilities the smaller shops would like to have.

Dual-process workcell technology has been a need in aerospace composites for a long time. I suspect they will become quite popular in the coming years and that more suppliers will offer them. Automated lamination technology is, indeed, evolving … and that's a good thing. Stay tuned. The best may be yet to come. CW



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Carroll Grant is an independent contractor and occasional *CW* columnist. He provides marketing and automated process consulting services to the aerospace composites industry. For more information about his services, he can be contacted at (801) 495-1819 or **cggrant@xmission.com**

Additive manufacturing: The past, present — and future — of composites

» Nary a week goes by without the appearance in publications ranging from major magazines, such as *Businessweek* and *Forbes*, to Internet newsletters of articles about the latest advances in 3D printing — and how these advances are transforming the industrial world. If one extrapolates the enthusiasm expressed by the writers of these articles, we should then expect that, within the next two decades, *everything* will be printed on demand.

Without a doubt, 3D printing technology is advancing quickly, and it is capable of building parts with features not possible by traditional manufacturing methods, including internal channels with multiple curvatures. It obviates the need for traditional tooling and the time and cost associated with such tools, especially for low volumes. Most of the work to date has been with smaller, metallic parts, using powder-based processes. GE Aviation (Cincinnati, Ohio), for example, has touted work it has done on specialized components for jet engines. On the polymer side, Airbus (Toulouse, France) used 3D printing for more than 1,000 parts on the A350 XWB from SABIC's (Pittsfield, MA, US) ULTEM 9085, a polyetherimide plastic with excellent FST (fire, smoke and toxicity) properties. For large parts, Oak Ridge National Laboratory (Oak Ridge, TN, US) has used 3D printing of chopped carbon fiber-filled thermoplastics to fabricate the entire bodies of several automobiles, including a replica of the famous *Shelby Cobra*.

> All 3D printing is, indeed, additive manufacturing but not all additive manufacturing is 3D printing.

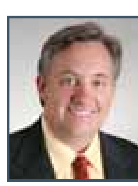
Recently, I have heard the terms "3D printing" and "additive manufacturing" used interchangeably, as if they are one and the same thing, and as if the whole idea of additive manufacturing hasn't existed before. I'm reminded of Venn diagrams from my university logic class — all 3D printing is, indeed, additive manufacturing, but *not* all additive manufacturing is 3D printing. For composites, this is a pretty significant distinction.

Additive manufacturing has been around for millennia — the ancient pyramid builders used an additive approach, placing blocks, layer by layer, incorporating tombs and passageways as they erected those giant monoliths. Advantages of additive approaches include minimal generation of offal, or scrap, that has to be disposed, recycled or otherwise handled. That's in stark contrast to *subtractive* manufacturing like the carving of the statue of David or Mount Rushmore — removing rock until the desired features and dimensions are obtained. Milling of molds from steel billets, or wingskins from thick slabs of aluminum, are common examples of subtractive manufacturing. Material removed in subtractive processes must either be recycled or becomes landfill.

Although I can't be sure what qualifies as the first additive manufacturing process in composites, the use of chopper guns that incorporate in-line mixing and deposition of polyester resin and glass fibers has existed for at least four decades. Applied layer by layer, and with the capability to vary thickness, this process, initially done by hand, has been highly automated since. Prepreg hand layup, it could be argued, is an additive process, but the fact that one starts with rectangular roll goods and cuts patterns, resulting in a fair amount of scrap, means that it starts out subtractive. The same is true of most preforming processes based on textile roll goods. To address these concerns, automated tape laying (ATL) and automated fiber placement (AFP) emerged and are true additive processes, because each results in minimal trim scrap.

As an industry, we still have a lot of work to do in this area, especially if we are to extend AFP/ATL beyond aerospace to industrial applications. As I have written before, the wind industry is able to manually place fabrics in molds at a very high rate, so machine costs have to decline substantially to make economic sense. To penetrate automotive markets, such machines must also be able to lay down materials on smaller components rapidly and at low capital costs. Several companies globally are working on this, not just on thermoset prepregs, but also thermoplastic tapes and dry fiber tows for RTM preform manufacture.

Lest one think I am negative about the potential of 3D printing, let me be clear: I see numerous opportunities for this technology in the composites industry, and it should become part of our *collection* of additive manufacturing processes. I would like to see the technology applied to long discontinuous materials or even continuous fibers via an inline pultrusion technique. Both should be suitable for many composite structures. Building tooling, either in composites or metal, seems an obvious approach to shorten lead times and reduce costs. But if we are to make composites the ubiquitous materials we hope them to be, additive manufacturing in *all* its forms must continue to evolve. CW



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Designing with composites: Optimizing for performance and manufacturing

» The choice to design with composites is often driven by market demand and cost. The promise of mass reductions, performance improvements and material and assembly cost reductions is enticing, but realizing a design with fiber-reinforced plastic (FRP) remains challenging. As FRP become the material of choice, based on design potential, traditional methods of analysis, design and manufacturing will not suffice. Based purely on the nature of the material itself, a composite design must be optimized not only for finished part performance but for manufacturability as well. Specifically, analysis and design must be performed *in the context* of the manufacturing process. Therefore, composite design requires a serious commitment to what I'll call *concurrent* engineering processes.

FRP parts are "inseparable assemblies" made up of tens to hundreds of plies that vary in number, and therefore thickness, across the desired part geometry. A combination of the part geometry, the material form *and* the manufacturing process affects the fiber orientations within the part; therefore, understanding all three characteristics is critical during the design phase. Fibers that deviate from the analyst's defined orientations will affect structural performance due to a significant impact on modulus and strength. In addition, in-plane or out-of-plane deformations that occur during production will result in increased manufacturing cost and effort to resolve issues downstream.

Preliminary analysis of composite parts is often performed based on idealized geometry and fiber orientations that meet loading conditions. However, without the understanding of fiber deviation, material knockdown factors are used to reduce the material's mechanical properties. The result is an overbuilt composite part, which neither achieves the structural performance nor the desired mass reductions. Virtual visibility into the deviation and deformation of the material during the manufacturing process can minimize the risk of overdesigning parts. Often referred to as "simulation of manufacturing producibility," »

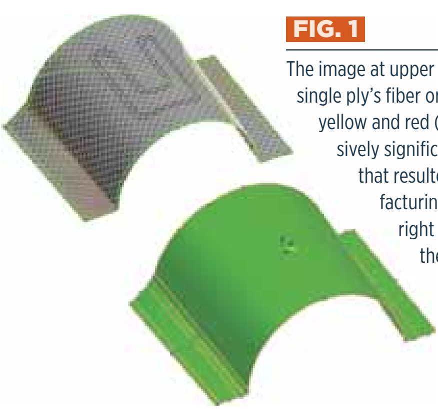

FIG. 1

The image at upper left is the part in CAD with a single ply's fiber orientations displayed in white, yellow and red (the colors indicate progressively significant "deviation from desired") that resulted from the simulated manufacturing lay-up process. The lower right is the part in CAE displaying the same ply's fiber orientations passed from the CAD model after the manufacturing simulations.

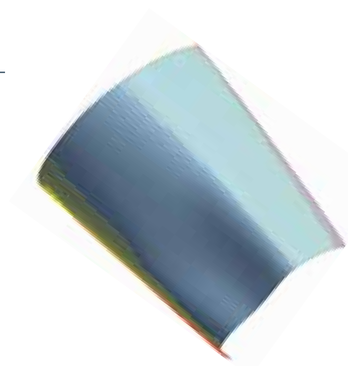

FIG. 3

A vector fiber field is displayed on the CAD part that represents the variance between the analyst's desired fiber orientations and the orientations mapped/defined during the detailed design phase. The vectors are shown in blue, yellow and red, depending on the degrees of variance, where blue is little-to-no variance and red is greater variance. The visualization depends on the desired amount of tolerance.

Source (all figures) / Siemens PLM Software

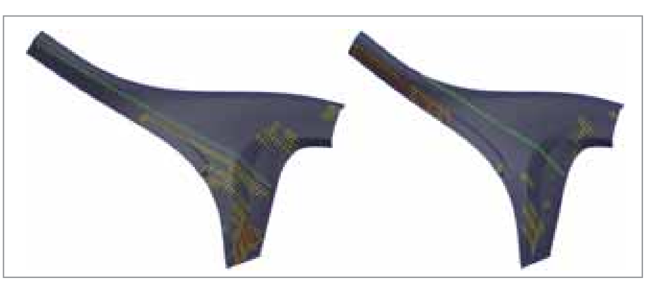

FIG. 2

The part in CAD can have the manufacturing process defined, refined and simulated to determine the best method with which to produce the part and how best to meet the analyst's desired fiber orientations. These two images demonstrate two different methods used for hand lay-up and the affect each had on the fiber orientations in blue, yellow and red. Yellow and red show deformations, where red indicates actual wrinkling of material.

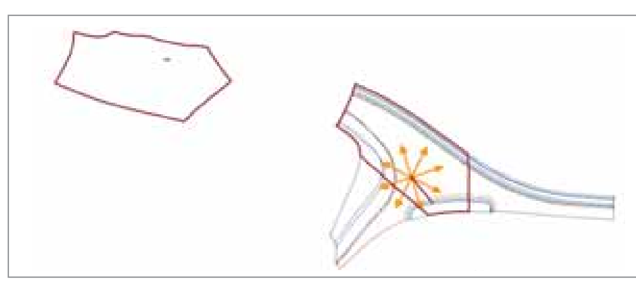

FIG. 4

Consistency in manual lay-up can be assisted by both standard laser projection and with plybooks that display the simulated manufacturing process that was used in CAD to obtain a flat pattern. The plybook features drawings (example shown here) that shows one or more boundary views and a flat pattern view. The boundary views can display the simulated manufacturing process, in orange, that was used to derive the flat pattern generated for lay-up.

this software-based capability is where the true fiber orientations can be known and then can be exchanged with those who do the analysis, as illustrated in Fig. 1, p. 12.

Taking a closer look, the detailed design process is started by importing the material lay-up from the analyzed finite element model and applying it to the CAD part. Next, the designer and manufacturing engineer, together, elect the best lay-up process and simulate it in the CAD environment, making the detailed part the basis for understanding the resulting material fiber orientations (Fig .2). The resulting material properties and true fiber orientations are then passed back to the analyst's pre-/post-solution, ensuring that local fiber orientations are known; thus, the analyst no longer is relying on theoretical orientations. The result is a part identified by correlating non-linear analysis with real part behavior, and can be designed within tight safety margins.

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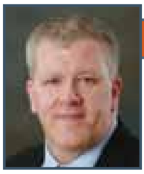
Delivering an optimized composite part requires that the fiber orientations of the production part fall within tolerance of an analyst's *desired* part, which requires *consistent* manufacturing. Today, the majority of composite parts are still produced with manual lay-up processes, which innately introduce the risk of inconsistency. Although consistency increases when automated manufacturing processes are employed, additional constraints are introduced, which can affect fiber orientations, thus impacting designed performance. In the case of automated tape laying and fiber placement methods, for example, intended fiber orientation can be constrained by material radius-of-curvature limits. To ensure consistency, then, it is always necessary to compare the as-manufactured fiber orientations with the as-designed orientations (Fig. 3), and to communicate the simulated lay-up process used in part and flat pattern development (Fig. 4). Consistency can be achieved by simulating the manufacturing process in the context of the desired fiber orientations, ensuring delivery of an optimized composite part for performance *and* manufacturing. CW



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AEROSPACE

Paris Air Show 2015: Can Airbus, Boeing maintain the pace?

At the 2015 edition of the Paris Air Show (June 15-21, Le Bourget, France), the numbers were as impressive as always: more than 2,300 exhibitors and in excess of 300,000 visitors — despite a bus strike — with hundreds of aircraft on display, on the ground and in the air show. Of most interest among the biennial Air Show's numbers, however, were those announced by the chief rivals in commercial aircraft manufacturing for their new aircraft orders. Toulouse, France-based Airbus ultimately emerged on top with US$57 billion for 421 aircraft, while Boeing (Chicago, IL, US) said it had racked up orders for 331 aircraft, worth US$50.2 billion. (But the combined value of the orders for both giants, US$107 billion, fell short of the US$134 billion set at the previous edition of the show, in 2013). Boeing's customers included Qatar Airways (10 777-8Xs and four 777 freighters) and Garuda Indonesia (30 Boeing 787-9 *Dreamliners* and up to 30 737 MAX 8s). Airbus also received a letter of intent from Garuda to purchase 30 A350 XWBs with which it plans to develop its medium- and long-haul networks. GE Capital Aviation Services (GECAS) announced a firm order for 60 Airbus A320*neo* family aircraft, to be powered by CFM International's (Melun, France) LEAP-1A engines, and Saudi Arabian Airlines presented a firm order for 20 Airbus A330-300 regional aircraft plus a firm order for 20 A320*neos*.

Source | Paris Air Show

Source | Airbus

The orders highlighted the unprecedented build rates that aircraft OEMs are trying to manage. Although that's good news for those who supply the composite materials and tier suppliers who mold parts for these OEMs, industry observers are asking, how will it be possible to build and deliver all of these planes? Jens Flottau and Guy Norris reported in *Aviation Week & Space Technology* magazine, on June 19, that Airbus is entering discussions with key suppliers to convince them that a production ramp-up is do-able.

According to the article, the OEM's 421 aircraft orders far exceeds the roughly 200 that Airbus CEO Fabrice Bregier had initially forecast. Given that 4,120 orders have been received since December 2010, Bregier now is pushing for an additional increase in narrowbody production rates before the end of this year and, Flottau and Norris say, Airbus is on track to raise the production rate from the current 44 aircraft per month to 50 in early 2017, and would like to hit 60 — potentially, even 63 — soon. Skeptics doubt that either OEM could achieve such a ramp rate, and if they could, that the market could absorb 120-plus narrowbodies a month from both Boeing and Airbus over an indefinite period. The *AW&ST* article poses the question: Should aerospace suppliers make big investments in equipment, facilities and workers to support higher production rates that might only be temporary?

For an Airbus-centric view of the Air Show's first day try this video: **www.youtube.com/watch?v=ADQZ1Fbyf9w**

For the same day from the Boeing perspective: **www.boeing.com/features/2015/06/showtime-a-packed-day-one-in-paris.page**

The Paris Air Show provides a fitting backdrop for a collection of notable aircraft announcements while the automotive, marine and energy markets each mark technology "firsts."

AEROSPACE

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BIZ BRIEFS

Source | Oxford Plastics

Oxford Plastics (Chipping Norton, UK) has won a French health and safety innovation award for its composite road plates, designed to replace the heavy steel plates currently used in road construction and utility maintenance applications. The interlocking plates, each of which weighs 44 kg, can be lifted and moved by two people, but can withstand the weight of a truck that weighs as much as 44 metric tonnes.

Source | car-revs-daily.com / Photo | Tom Burkart

Keep your eyes peeled for a new carbon fiber-intensive offering from automaker Volkswagen (VW, Wolfsburg, Germany), the *Golf GTE Sport* (above). This two-seat, hybrid-electric features three motors — two electric and one 1.6-liter turbocharged, direct-injection engine. Carbon fiber composites are used most extensively in the body panels, including in structural sections of its gullwing doors. Visible carbon fiber weave can be found in the exterior mirrors, splitters and diffuser. VW also says the material can be found in the car's interior.

AEROSPACE

Paris Air Show 2015: *Scorpion*, *Flaris*, *X6* turn heads

Source | Textron Airland

Not to be overshadowed by news in the commercial aircraft market at the Paris Air Show (June 15-21, Le Bourget, France, see p. 18), Textron AirLand's (Wichita, KS, US) light strike/ISR jet *Scorpion* generated quite a buzz in its first appearance at the Paris Air Show (it made its debut at Farnborough 2014). Designed by a group of longtime aircraft engineers *outside* the defense industry infrastructure, the *Scorpion* has a smaller silhouette than most of the fighter jets on the tarmac in Le Bourget, but reportedly made a big impression on US Pentagon and other government military officials, according to a *Defense News* report by Andrew Clevenger, dated June 18. The article went on to say that the *Scorpion*, which went from drawing board to prototype in a mere 24 months, could be providing ground support and reconnaissance to several militaries in short order. Recently in South America, the jet was tested by pilots in a country interested in buying multiple jets, but Textron AirLand officials declined to say which country. But the company's president Bill Anderson did tell *Defense News*, "The interest in the airplane remains very high," adding that there is also "significant interest" in the Middle East and on the Pacific Rim. In fact, Textron AirLand expects to submit its first formal proposal to a Pacific Rim nation at the end of the month, Anderson claimed.

Another notable newcomer, this time, a business jet, was the *Flaris*. Making its second appearance at a Paris Air Show, the single-engine, composites-intensive light jet, built by Metal-Master (Podgorzyn, Poland), is close to first flight, and certification activities have begun. "We are starting production next year [2016]. After the flight tests, the next stage will involve obtaining the required certification," says Metal-Master's Rafał Ładziński, the creator of *Flaris* and its project director. Another relative outsider, Metal-Master's primary business, in fact, is not aircraft but manufacturing technological lines and equipment for the automotive industry. The production of *Flaris* planes will be based on the company's previous experience in process automation and will implement the latest manufacturing technologies. "I believe that in the next two or three decades, the aviation industry will be taken over by international leaders in the automotive industry, whose current solutions," Ładziński

Source | Metal-Master

asserts, "are often way ahead of those used in aviation. We are already witnessing the birth of a new industry in Western Europe, which implements automotive technologies in the aviation industry."

A third standout, making its debut in the civil market, was Airbus Helicopters' (Marignane, France) new *X6*, a next-generation heavy-lift rotorcraft tailored for the civil market, especially for oil and gas missions. The newest in the company's "H" generation, the X6, says Guillaume Faury, president/CEO of Airbus Helicopters, "will be for the heavy segment in the next decade what the *H160* is today for the mediums. It will set new standards in the industry not only for design, but for its production strategy as well, as we will rely on the industrial capacities of our core countries, including the upcoming pillar in Poland," a new engineering design office there, in Łódź. The company noted a post-2020 entry into service.

Read *CW's* Focus on Design story about the *Scorpion* online | **short.compositesworld.com/LEAjettool**

AUTOMOTIVE

"Non-pneumatic" tires: Glass fiber/PET springs replace air

Source | SciTech Industries

It's every motorist's fondest wish: The automobile tire that won't go flat. In the past few years, several technologies aimed at realizing this dream have made news in the trade press: Tire manufacturer Bridgestone has introduced a developmental concept, Resilient Technologies has a prototype for military vehicles, and Michelin introduced its TWEEL polyurethane and steel-belted airless tire. Among the most recent, however, is SciTech Industries LLC's (Boca Raton, FL, US) airless tire. It reportedly fits a standard rim, runs cool and quiet at normal road speeds, and cannot go flat or blow out. Unlike Michelin's TWEEL, with its shaped plastic spokes from the wheel's center, SciTech's New Tech Tire features glass fiber-reinforced polyethylene terephthalate (PET) springs that support conventional rubber tread from the inside.

"It looks and even smells just like the tires on your car now, but our manufacturing process requires only three operations vs. the 36 different steps required for today's standard tires," says Morris Corn, president of SciTech Industries. Corn adds that the SciTech airless tire costs no more to make than current tires, yet should boost fuel efficiency by at least 2% because tire inflation and shape will no longer vary and weight is saved by eliminating the need for a spare tire.

SciTech worked with Sarasota, FL-area company Rapid Composites to help develop the process and equipment for manufacturing the tires on a commercial scale. Rapid Composites president Alan Taylor explains the process starts with preconsolidated glass fiber/PET tape, which is cut into blanks and loaded into an automated cell that includes high-speed transfer shuttles and heater systems and a custom hydraulic press. "The current short-run setup can produce eight springs in a 2.5-minute molding cycle," says Taylor, "but Phase 2 tooling will bring that cycle time down further and enable 50 springs in one press."

Standard automotive tires use 116 omega-shaped springs. But springs also can be tailored to thin wheels for bicycles, wide wheels for lawn equipment or 4.5m-diameter tires for heavy equipment. The composites can use continuous E-glass or S-glass in a variety of deniers and may exploit nanofibers or nanoclay for a reported 40% boost in flexural strength. Given the potential variety of application, Corn also presides over New Tech Tire LLC and Turf Tech Tire LLC (Boca Raton, FL, US), two additional companies formed to market the concept to other than automotive markets.

Read more about airless tire alternatives | short.compositesworld.com/NoFlatTire

CW / MONTH IN REVIEW

Notes on newsworthy events recently covered on the *CW* website. For more information about an item, key its link into your browser. Up-to-the-minute news | **www.compositesworld.com/news/list.**

UT of Arlington to help develop composites for aircraft
The university is collaborating with Sikorsky Aircraft through a $1.35 million grant to design more durable materials.
07/14/15 | short.compositesworld.com/arlington

Virgin Galactic's *LauncherOne* picked for satellite launches
It's aircraft-launched rocket will perform 39 satellite launches for OneWeb, which provides broadband access in underserved regions.
07/14/15 | short.compositesworld.com/Launcher1

Quickstep wins automotive OEM autocomposites contract
The Australian firm's niche volume order is for a series of up to 1,000 carbon fiber composite engine compartment parts, starting in early 2016.
07/13/15 | short.compositesworld.com/QScarparts

Airbus A350 to use CFRP window frames
Initially, the window frames were made of aluminum, but Airbus shifted to composite to reduce weight.
07/13/15 | short.compositesworld.com/A350frames

Bell Helicopter completes first flight of Bell 525 *Relentless*
The the world's first fly-by-wire commercial helicopter features metal and composite structures built by GKN Aerospace.
07/10/15 | short.compositesworld.com/Bell525

NASA's Mars airplane will be made with composites
A prototype of the Preliminary Research Aerodynamic Design to Land on Mars, is being prepared for a launch from a high altitude balloon.
07/09/15 | short.compositesworld.com/NASAMars

***Solar Impulse 2* completes five-day flight from Japan to Hawaii**
André Borschberg pilots the composites-intensive *Solar Impulse 2* non-stop on the longest leg of the plane's around-the-world tour.
07/06/15 | short.compositesworld.com/Si2Hawaii

Airbus expands commitments in China
Currently, 20% of the company's deliveries are provided to China, which is a number that is expected to grow.
07/6/15 | short.compositesworld.com/AirbusAsia

AutoDISC proposes new NDI method for composite aircraft
Aircraft are currently inspected part by part; AutoDISC aims to enable the scanning of an entire airplane.
07/06/15 | short.compositesworld.com/AutoDISC

Fives joins Jules Verne Research Institute
The Paris-based machinery manufacturer will join French-based research center on two strategic projects in additive manufacturing and composites.
07/06/15 | short.compositesworld.com/FivesJV

HK Research expands plant
The company operates the largest facility in North America designed exclusively for premium polymer coating manufacturing.
07/06/15 | short.compositesworld.com/HKexpands

Composites industry is forecast to grow by 4.5% in 2015
Market research firm Lucintel (Irving, TX, US) anticipates Asia will have a market share of approximately 50.7% by volume in 2020.
07/01/15 | short.compositesworld.com/LMR2015

MARINE

Magma Structures delivers world's tallest freestanding yacht masts

Source | Magma Structures

Composites specialists Magma Structures (Portsmouth, Hampshire, UK) reported on June 14 that it had delivered three of what it says are the world's tallest freestanding carbon fiber composite masts. The rigs are designed to withstand bending loads of more than 40 Mn — more than twice the load imposed on a Boeing 787 *Dreamliner* wing during flight. The masts were ordered by a German shipyard and are destined for a sailing superyacht.

Built at Magma Structures' waterside manufacturing facility near Portsmouth, the mast structures, or "rigs," were designed, developed, tested and built over three years by a team of more than 70, including an in-house team of specialist composite design engineers. The rig was conceived by Dykstra Naval Architects (Amsterdam, The Netherlands). Load analyses and engineering drawings were compiled by Magma Structure's in-house design team.

Despite their height, each cantilevered freestanding mast weighs only about 50 metric tonnes. The masts support a sail area greater than a standard sized football/soccer pitch, with full automation in terms of sail deployment, setting and reefing. Each mast is able to rotate using systems mounted on "wings" at the side of each mast, which added to both the design complexity and build challenge.

Magma says the freestanding, rotating rigs are intrinsically safer and more reliable than conventional rigs where failure through fatigue or overload of the many rigging elements can occur. The absence of standing rigging lines results in a much cleaner and uncluttered deck as well as significantly reduced maintenance issues.

Magma says a high-performance carbon fiber was used, and during the manufacturing process, the rigs were embedded with fiber-optic sensors that will yield real-time, comprehensive in-service load data on all aspects of the rig as well as safety warnings, historical data, condition monitoring and information to optimize the sailing performance.

Clive Johnson, managing director of Magma Structures, says, "These rigs are amongst the most technically challenging freestanding carbon composite structures to have been manufactured, due to their size, design load requirements and the marine environment in which they will be used. The skills developed and experience gained from building these rigs are already having a direct impact on projects we are developing in other sectors, including bridges, stadia and buildings where the benefits of manufacturing in composites can be significant."

Damon Roberts, technical advisor to the project, says, "The high-strength, fatigue-resistant nature of carbon has been the key in enabling us to develop and manufacture a freestanding structure much larger than anything currently built, including the current generation of wind turbine blades, and with much higher bending loads. The embedded fiber-optic monitoring data is invaluable in giving us real-time data to optimize the sailing performance as well as verify the design concepts and give us load case data to minimize the maintenance."

BIZ BRIEF

Huber Engineered Materials (Atlanta, GA, US) reports that it has acquired the Safire nitrogen and phosphorus halogen-free fire retardant technology from Floridienne Group and Catena Additives. Huber's goal is to take the patented Safire technology, integrate it within its existing halogen-free portfolio of flame retardants and smoke suppressants, and rapidly develop a line of commercial products. The Safire technology addition marks the third acquisition over the past 5 years for Huber's growing Fire Retardant Additives business, following the 2012 purchase of the specialty hydrate flame retardant business from Almatis and the 2010 acquisition of the Kemgard flame retardant and smoke suppressant business from Sherwin-Williams.

ENERGY

Composites for offshore drilling riser buoyancy: An inside job

Trelleborg Offshore US Inc. (Houston, TX, US) and partner Landing String Solutions LLC (Madisonville, LA, US) have unveiled the world's first composite buoyancy system deployed on a drill pipe landing string, that is, with buoyancy elements *around* the drill pipe *inside* the riser pipe. Manufactured by Trelleborg, the patented Landing String Buoyancy system has been tested and trialed and is slated for deployment by a major oil company sometime in 2016.

Source | Trelleborg Offshore US

This first integration of buoyancy elements within the riser enables the drilling contractor to deploy larger quantities of casing, thus reducing rig time, maximizing efficiency and reducing cost. The buoyancy system is designed to offset the landing string weight by up to 80% in some cases and enable safer and more cost-effective deepwater oil and gas operations, says Trelleborg.

"A large number of ultra-deepwater well designs require 16-inch [406.4-mm] diameter and other long casing strings to be run at unprecedented lengths," says Chris von Eberstein, general manager at Landing String Solutions. "A deep well's longer casing requirements can result in extreme loads, both dynamic and static, approaching, equaling and/or exceeding the design safe working load of a rig's hoisting system. Working at, or near, design working load presents safety and environmental concerns. Our new system" he maintains, "reduces its weight and the hook load to a manageable level."

According to Trelleborg sales manager Jason Barfield, the Landing String Buoyancy system is designed to fit inside the riser and around the drill pipe, leaving a few inches of clearance for the drilling mud. Buoyancy is achieved with Trelleborg's low-density syntactic foam system, consisting of a combination of Trelleborg-manufactured hollow glass Eccospheres (microspheres and macrospheres) to provide uplift. The rugged exterior protective polyurethane skin reportedly provides excellent abrasion and impact resistance to avoid damage during handling and installation. All buoyancy installation hardware is fully composite (there are no metal fasteners/components), with composite stop collars on each joint of the drill pipe, which hold the buoyant units in place. The buoyancy system is qualified for a maximum pressure rating of 413.69 bar.

Mark Angus, executive VP within Trelleborg's offshore operation, sums up, "The buoyancy design will enable the use of heavier landing strings and allow rigs to run longer. In addition … [t]his design could allow older drilling rigs to step into field depths where previously only ultra-deepwater rigs could operate." The system has been successfully field-tested in the Gulf of Mexico.

BIZ BRIEF

Hexcel (Stamford CT, US) announced at the Paris Air Show (June 15-21, Le Bourget, France) that it has teamed with its distributor **Groupe Gazechim Composites** (Béziers, France), and its affiliate **Composites Distribution** (Orvault, France), to support MRO (maintenance, repair and overhaul) activities for composites-intensive aircraft. **Composites Distribution** is launching a product called CAB (for Composite AeroBox) made by **Sunaero** (Genay, France), which can store frozen prepregs, ancillary room-temperature materials, and a hotbonder control panel, all within an easy-to-transport box. The concept enables quick repair of damaged composite parts in the field, says Hexcel. The CAB unit, which supports a hot bonder and heater blanket, is reportedly approved by the Commercial Aircraft Composite Repair Committee (CACRC).

BIZ BRIEF

The US Environmental Protection Agency (EPA) and the US Department of Transportation's National Highway Traffic Safety Admin. (NHSTA) are proposing new fuel efficiency and emissions standards for 2021-2027 model year medium- and heavy-duty vehicles that could reduce CO_2 emissions by about 1 billion metric tonnes and cut fuel costs by about US$170 billion. These vehicles account for 20% of greenhouse gas emissions, but comprise only 5% of on-road vehicles.

SPE'S ACCE 2015 Preview

Automotive composites remain a hot topic in the Motor City.

By Peggy Malnati / Contributing Writer

» Composites remain a hot topic in the automotive industry as OEMs scramble to meet tough new fuel efficiency and/or tailpipe emissions standards that will come into full force in many parts of the globe in 2025. Any technology that can reduce mass and systems costs, improve durability and crash performance, eliminate secondary operations and enhance styling flexibility stands a good chance of beating out benchmark steel and more costly aluminum. Therefore, it's not surprising that attendance continues to grow at the Automotive Composites Conference & Exhibition (ACCE) organized by the Automotive and Composites Divisions of the Society of Plastics Engineers (SPE, Bethel, CT, US). Now in its 15th year, the event returns Sept. 9-11 at the Diamond Center at the Suburban Collection Showplace (Novi, MI, US) in the Detroit suburbs.

Last year's exhibition spilled out of the main Diamond Ballroom into Hall C, where lunch was served and the student poster and parts competitions were held, so this year, event organizers have moved all exhibits, meals and coffee breaks to that much larger space. So far, that seems to be a good decision: SPE reports that previous records for sponsorship dollars and the number and size of exhibits already have been broken — many exhibits will be larger this year owing to the additional room. To keep walking time between exhibits/food and session rooms short, all sessions will run either in the Diamond Ballroom (where keynotes and panel discussions also will be held) or the adjacent Emerald/Amethyst room.

Tech program: Slightly more compact but equally strong

One of the perennial strengths of the SPE ACCE is that it covers a broad array of materials and process technologies — from injection molded short-glass thermoplastics to autoclave-cured thermosetting carbon fiber-reinforced plastics (CFRP) and nearly everything in between. Although the 2015 technical papers list, at *CW* press time, was a little shorter than those of the past few years (77 regular papers, compared to 81 in 2014 and 90 in 2013), this year's lineup continues SPE's tradition of breadth as well as depth of topic.

Although sessions on polymers *per se* are smaller than in recent years, there is a large Enabling Technologies session on processing and equipment developments, with a strong showing in resin transfer molding (RTM) technologies, including high-pressure RTM, thermoplastic and surface RTM, and even cast-polyamide RTM. A standalone Bonding, Joining & Finishing session (last held in 2008) returns this year with talks on selecting surface films to improve adhesion between fabric and substrates, using »

Room for growth

Organizers of SPE's Automotive Composites Conference & Exhibition (ACCE) expect growth in attendance again this year as the annual event returns to the spacious Diamond Center at the Suburban Collection Showplace in the Detroit suburbs.

Source (Diamond Ctr. Photo) SPE / Photo | Pam & Mike Brady

Source (sign photo) | Teri Chouinard


CAMX
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Plant tour

Pre-conference social events will include a tour of the new world headquarters — shown here is the company's main atrium — for composites compounder/molder Continental Structural Plastics (CSP) in nearby Auburn Hills.

Source | Continental Structural Plastics

flame and plasma surface treatments to improve bonding, and new work on reversible bonded joints, using nano-ferromagnetic particles.

An entirely new session this year, featuring the hot topics of additive manufacturing & 3D printing, is expected to be well-attended. The ever-popular Opportunities and Challenges with Carbon Composites session will feature a paper on preforming, 3D woven composites, lightweighting structural components, as well as a talk on composite powertrain components on the US Department of Energy project, the Multi Material Lightweight Vehicle (MMLV), developed by Ford Motor Co. (Dearborn, MI, US) and Magna International (Aurora, ON, Canada).

Also of special interest are two new papers on systems for inline production of CFRP prepreg — one developed by Mitsubishi Rayon Co. Ltd. (Tokyo, Japan) and another by the Fraunhofer Institute for Chemical Technology (Pfinztal, Germany) — which hold the promise of doing for carbon fiber prepreg what inline compounded (ILC) direct long fiber thermoplastics (D-LFTs) did for compression-molded PP and polyamide (PA, also called nylon) in the late 1990s through mid-2000s.

The Nanocomposites session also is larger than usual this year, with a strong focus on newer nanocellulose and nanosilica particles. Always prominent at the SPE ACCE is the Virtual Prototyping & Testing session, which encompasses computer-aided simulation as well as physical part testing. This year's session doesn't disappoint, with several new offerings on draping simulation for fabric-reinforced composites, as well as simulations for impact, fatigue, durability, progressive failure, post-failure behavior, fiber orientation and anisotropic damping.

Parts competition

There's still time to submit nominations for the ACCE's popular Most Innovative Composite Part competition. Nominations are due August 30. Last year, the Body Exterior award went to Mitsubishi Rayon Carbon Fiber & Composites (Tokyo, Japan), for the CFRP prepreg compression molded decklid (pictured at left), featured on the Nissan *GT-R* supercar.

Source | SPE / Photo | Pam & Mike Brady

Another session with a good paper turnout for 2015 is Sustainable Composites, which includes biopolymers, recycled polymers and natural fiber composites. There are three smaller sessions on Advances in Thermoplastic Composites, Advances in Thermoset Composites and Advances in Reinforcements. These sessions will cover a wide variety of topics: development of a medium-duty truck bulkhead; hybrid long-fiber thermoplastics; new grades of lightweight reinforced thermoplastic (LWRT) composites for stone impacts; the effects of processing techniques on thermoplastic composites; the latest generation of fast-cycling polyurethane resins; lifecycle analysis of engineering thermosets vs. aluminum in an underhood application; lightweighting composites through selective fiber placement; and tools for chemical characterization of the process to convert lignin to carbon fiber.

ACCE's popular Tutorials tracks are back with a two-hour presentation on "Adhesive Bonding of CFRP Composites: Practices and Principles" by Louis Dorworth of Abaris Training »

Networking

Despite substantial growth over the past 14 years, the SPE ACCE still retains that small, friendly feel that makes networking easy. The conference venue features plenty of places for attendees to gather for impromptu meetings, or host meals, breaks and networking receptions that help others meet and exchange information when they aren't in technical sessions or walking the show floor.

Source | SPE / Photo | Pam & Mike Brady

Resources Inc. (Reno, NV, US) and a 90-minute talk on "Bioplastics & Biocomposites for Automotive" by Karen Stoeffler of National Research Council Canada (NRCC, Ottawa, ON, Canada).

Lively panel discussions and diverse keynotes

Well known for its lively panel discussions, SPE ACCE this year has scheduled a 90-minute panel organized by Prof. Jan-Anders Månson, the head of the Laboratory of Polymer and Composite Materials (LTC) at the Institute of Materials, Ecole Polytechnique Fédérale de Lausanne (EPFL, Lausanne, Switzerland). Panelists, unconfirmed at *CW* press time, will focus on the topic, "Carbon Steel to Carbon Composites – Can the Existing Automotive Infrastructure be Leveraged to meet Lightweighting Targets?"

Another perennial ACCE distinction is its diverse keynote addresses, and this year won't disappoint. Speakers confirmed by early July include Day 1 keynotes from Anthony Schiavo, research associate, Lux Research Inc. (Boston, MA, US) on the topic of "Carbon Fiber 2.0: Roadmap for Growth to 2020 and Beyond," as well as a multi-speaker group that will address the timely topic of the "Institute for Advanced Composites Manufacturing Innovation (IACMI): A Disruptive Moment in Automotive History." Presenters here will include Dr. Craig Blue, CEO, IACMI; IACMI directors Dr. Larry Drzal (Vehicles Technology) from Michigan State University; Dr. Byron Pipes (Modeling and Simulation Technology) from Purdue University; Dr. Brian Rice (Compressed Gas Storage Technology) from the University of Dayton Research Institute; and Cliff Eberle (Materials and Process Technology) from Oak Ridge National Laboratory. On Day 2 Deborah Mielewski, senior technical leader for Ford's Sustainable Materials and Plastics Research, will give a talk titled "Owning the Future: Sustainable Materials Research, Development & Implementation at Ford." After lunch on the same day, Stefan Stanglmaier, technology development CFK material and process safeguarding, BMW Group (Landshut, Germany), will address the topic of "Mass Production of CFRP in Automotive Applications – Potential and Challenges in Implementing Local Reinforcements."

And on Day 3 Antony Dodworth, managing director, Brite Lite Structures (San Francisco, CA, US), will discuss "A Platform for Novel Lightweight Automotive Composite Structural Design."

Social outings, awards & trophies

Popular aspects of the SPE ACCE include pre-event social outings in and around the

Detroit region. One such event is the SPE Automotive Division's annual day-long golf outing at beautiful Fieldstone Golf Club (Auburn Hills, MI, US). Another is a free tour of the new international headquarters of Continental Structural Plastics (CSP) in Auburn Hills, MI, US. SPE will provide transportation to and from the conference center for those who sign up ahead of time for the tour. Both the golf outing and the tour take place the day before the conference (on Tuesday, Sept. 8), and participants are invited to attend a reception that evening at the conference facility's Fireside Room.

The ACCE also presents Best Paper and student scholarship awards at the event, and conducts a student poster competition and a Best Part competition (both judged at the event site). Last year's Best Part – Body Exterior trophy went to Mitsubishi Rayon Carbon Fiber & Composites (Tokyo, Japan), which nominated the CFRP (carbon fiber-reinforced plastic) decklid made by its prepreg compression molding process, which was featured on the *Nissan GT-R* supercar by Nissan Motor Co. Ltd. (see "Learn More"). The ACCE's People's Choice award (chosen by conference attendees) went to Momentive Specialty Chemicals Inc. (now Hexion Inc., Columbus, OH, US) for its nomination of lightweight carbon fiber door structure with Class A appearance on the *Porsche 911 GT Cup* supercar, produced by Porsche AG (Stuttgart, Germany).

More conference details can be found at speautomotive.com/comp.htm.

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SPE ACCE proceedings and program guides from the previous 14 events are accessible free of charge in the ACCE Archives at speautomotive.com/aca. CW

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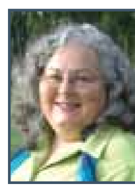
Read more online about the Nissan *GT-R's* decklid in "Prepreg compression molding makes commercial debut" | short.compositesworld.com/PCMdebut



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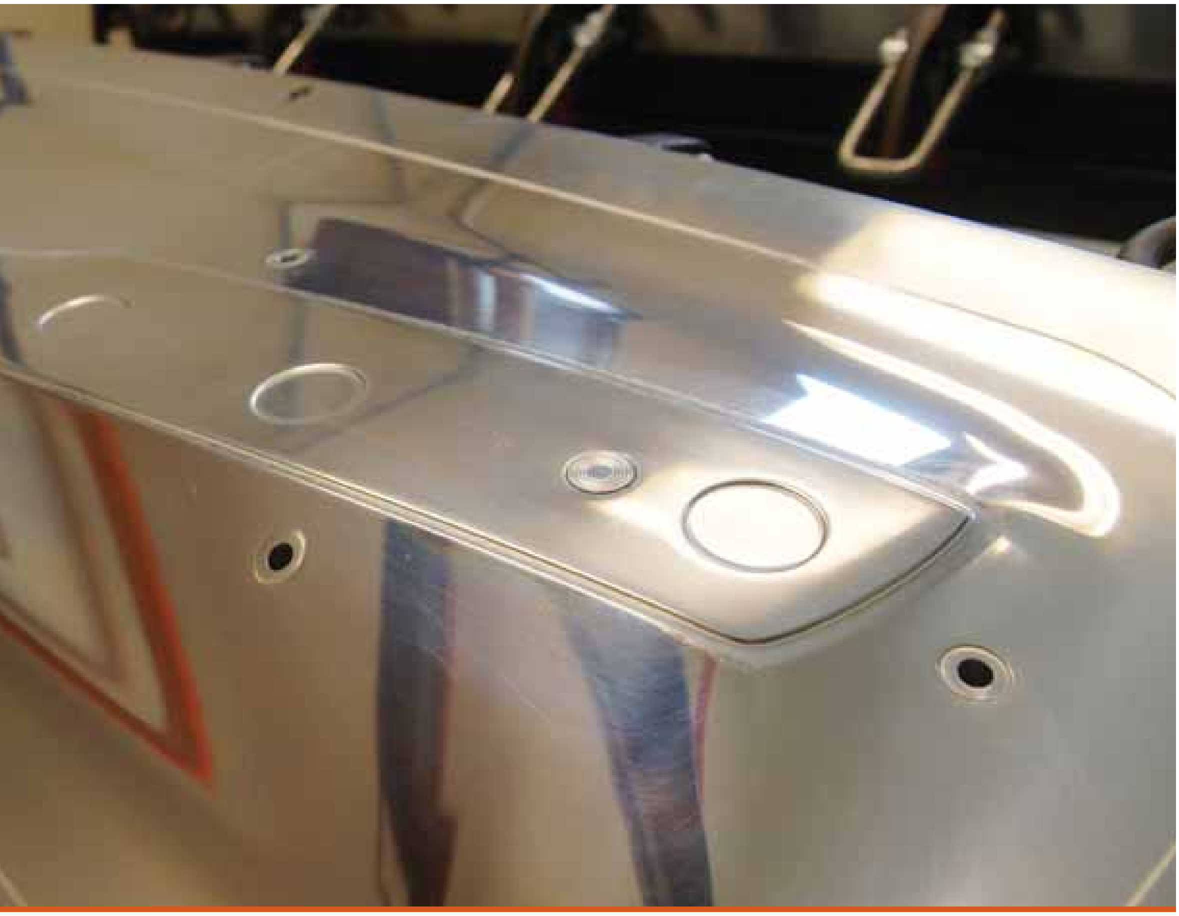


■ In-mold, in-situ sensing

Calloway Carbon (Santa Ana, CA, US) embeds "off the shelf" piezoresistive pressure sensors in its polished aluminum molds. Coupled with its own proprietary software, the sensors monitor and control manufacture of structural carbon fiber composite parts via RTM. Notably, part infusion will not initiate until sensors are within predefined pressure limits.

Source | Calloway Carbon

In-mold sensors: In-situ process monitoring for RTM

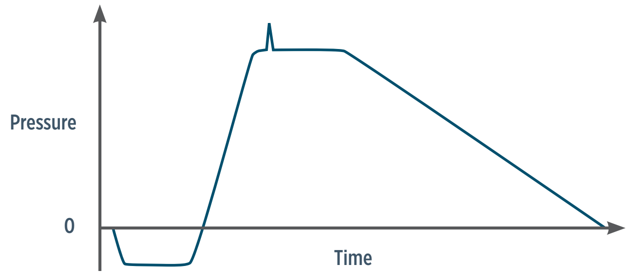
Technology for monitoring the molding process from within the mold cavity, a practice familiar to injection molders, is making an appearance in resin transfer molding.

By Michael LeGault / Contributing Writer

» In the injection molding of plastics, in-mold sensors, as part of a variety of process control packages, have been around for decades. But comparatively recently, similar technology has begun to make an incursion into composites manufacturing in resin transfer molding (RTM), one of a number of closed-molding processes that have eclipsed open molding of composites. One reason is that of all the closed molding models, RTM is most similar in format to injection molding.

The need for sensing technology is driven by customer emphasis on greater part quality and better part-to-part consistency. In response, several suppliers and at least one fabricator are developing and bringing to market new sensor technology specifically targeted at RTM, resin infusion and other types of composites manufacturing processes.

Paul Lagonegro, application manager, Kistler Instrument Corp. (Novi, MI, US), says the processing features particular to RTM are an ideal match for the capabilities of process-control sensors. Fabricators — and their customers — are fond of RTM's ability to produce lightweight parts with short cycle times and to tight tolerances. Yet RTM usually requires the ancillary manufacture of a preform, which adds steps and requires a greater degree of automation to carry out cost-effectively.



Sensor-controlled mold cycle

Much like injection molding, a pressure curve generated during RTM drives each part cycle. Pressure sensors inside the mold detect when a vacuum is created and held. If the vacuum holds, the process begins with infusion of the resin and catalyst. As infusion of the preform continues, the sensor-recorded pressure, represented by the curve, travels from a negative value, through zero, to pressure threshold lower limit, at which time the pump is turned off, preventing overfill and potential uncoupling of the mold halves. Source | Kistler Instrument Corp.

Given Kistler's experience in manufacturing control sensors for injection molding, Lagonegro says the company's decision to branch into composites was a natural stepping stone. In view of the growing sophistication of composites manufacturing, the company displayed a prototype sensor for composites processing at the 2012 K Show, and is introducing its first commercial mold-cavity pressure sensor, the 6161 AA, designed for both high- and low-pressure composite processing, this year. The sensor is designed for mold cavity pressures as high as 200 bar, as well as vacuum infusion, and comprises a 4-mm diaphragm welded into a 9-mm cartridge.

The 6161 AA is a direct-contact sensor. The resin acts directly on the front of the diaphragm, which generates a pressure curve via the use of a "charge amp" (transducer/amplifier that gauges the pressure, then converts it to a scalable output value).

Cavity pressure measurement in RTM provides a number of distinct benefits, some similar to the injection molding of thermoplastic, and others unique to both composites processing and composite materials. Like injection molding, the sensors in an RTM mold can be used to monitor and control sequencing of multiple gates, to monitor the flow front and to shut off injection. More distinctively, with respect to RTM, cavity pressure sensors can monitor, as suggested above, mold cavity vacuum pressure as well. This provides, in turn, better control over injection pressure and quality-related issues, such as air inclusions and voids, which could arise from an insufficient or inconsistent vacuum.

> Sensors, as it turns out, are merely part, albeit it a key part, of a holistic control system developed by the company.

Also, much like injection molding, the pressure curve generated during RTM drives each part cycle and is a key tool that helps the fabricator establish process optimization (see the "Sensor-controlled mold cycle" graph, at top right). During the RTM cycle, pressure sensors inside the mold will detect if a vacuum is created and held. Assuming the vacuum is held, the process begins with infusion of the resin and catalyst. As infusion of the preform continues, the curve travels from a negative value, through zero, to the pressure threshold lower limit, at which time the pump is turned off, preventing overfill and potential uncoupling of the mold halves.

The use of a vacuum to infuse the part is, of course, one of the chief differences between injection molding and a process such as RTM, and this poses a challenge to sensor design. "Traditionally, our sensors have not been exposed to a vacuum," says Lagonegro, noting that the negative — as opposed to positive — pressure affects operating conditions and, therefore, posed a different set of sensor design considerations. The 6161 AA, therefore, is designed with an O-ring, which prevents low-viscosity resin from entering the gap in the mounting flange while the cavity is under vacuum. The sensors are calibrated by Kistler before they are shipped to the customer. The calibration data, and a NIST-traceable Calibration Certificate, which is delivered with the sensor, confirms that the sensor performs with a linear output throughout the manufacturing pressure profile and, as a result, those output values will be absolutely reliable as a measure of pressure during the manufacturing process.

Filling the void

As a manufacturer of highly technical, structural composite parts for the automotive racing and aerospace industries, Calloway Carbon (Santa Ana, CA, US) decided to take the matter of process control in composites manufacturing, or lack thereof, into its own hands. Reeves Calloway, founder and owner, says the combination of downward cost pressure and higher quality standards throughout the industry had been pushing the company in the direction of RTM and increasing amounts of automation for a number of years. Having reached the limit of what the company could do without process control technology, it opted to develop its own solution, in house.

Sensors, it turns out, are merely part, albeit a key part, of a holistic process control system developed by the company, one that encompasses hardware and software to close the loop on RTM manufacturing.

"In order to really automate RTM, or any closed molding process, we had to take it one step further than merely installing sensors in molds," Calloway says. Sensors, he reports, have to work hand-in-hand with software that will replicate all the sequences of part infusion, and monitor and control those sequences throughout each part cycle. "We created software, resulting in a recipe for a part that can control an automated injection system." In-mold sensors deliver continuous pressure readings to the process control software, which, in turn, monitors and controls resin metering, delivery, infusion and heating/cooling of the mold in a closed-loop configuration for each part cycle, a process the company refers to »

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as the "recipe." Once the recipe is understood, Calloway notes, it's simply a matter of replication.

The company has been using sensor-based, automated RTM manufacturing for about five years. Calloway says the sophistication of sensor technology was crucial to successful development of its in-house automation technology: "Fortunately, sensor technology is really good right now at the commercial level." Just as significant, RTM could be the composites manufacturing method that best lends itself to automation, because it is largely a sequential process. Calloway says the development of process control for it can be broken down into a series of programming problems — for example, how to ensure that step B does not happen until step A has been completed.

Growth of process control systems in composites will require, of course, the participation of those who manufacture molds, and Kistler's Lagonegro says the company's early marketing efforts will include toolmakers and fabricators.

Calloway Carbon cuts its own tools so, in addition to owning the process control system, it also controls process setup. Calloway says the number, type and location of the sensors in the mold is part dependent. Almost all the company's tools are CNC-machined from aluminum. Many, Calloway reports, use two or more piezoresistive pressure sensors, located at the "top" of the tool. He calls the process of determining where to locate the sensors "part science, part art and part luck," based on years of experience. Prior to production, each tool is run through an auto-calibrate sequence. Process control monitoring will not initiate until sensors are set within predefined limits (the recipe) to permit cycle start. Calloway's software also allows production to be run in manual mode until the recipe is refined and mature.

One of the more exciting developments in composites is the prospect of system use in the mainstream automotive market, a scenario that is already beginning to play out. Molders with process control technology are likely to have a step up on others in their efforts to meet the auto industry's stringent, Six Sigma-based quality standards. Lagonegro says that while the composites industry hasn't been clamoring for process control, "from our perspective, it's the next big thing." CW

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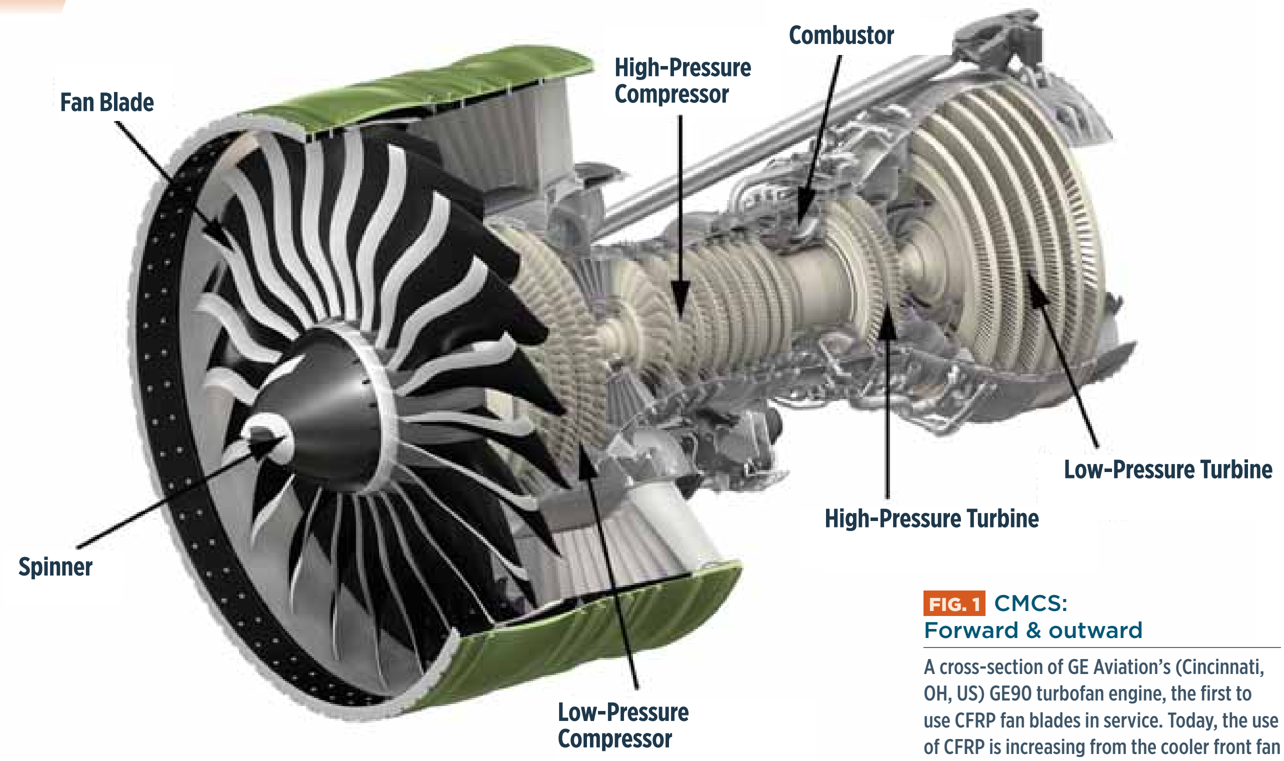

FIG. 1 CMCS: Forward & outward

A cross-section of GE Aviation's (Cincinnati, OH, US) GE90 turbofan engine, the first to use CFRP fan blades in service. Today, the use of CFRP is increasing from the cooler front fan and outer applications toward the hotter rear and inner sections. For CMCs, however, the evolutionary growth path is in the opposite directions, forward, from hotter to cooler zones, and from inner to outer structures.

Source | GE Aviation (text added by *CW*)

Aeroengine Composites, Part 1: The CMC invasion

As pressure for commercial aircraft fuel efficiency continues to mount, ceramic matrix composites evolve as they battle metals for application in the engine hot-zone and elsewhere.

By Ginger Gardiner / Senior Editor

»The airlines' push for jet engine fuel efficiency shows no signs of abating. *CW* reported earlier this year that the average fuel burn per aircraft seat-km today compared to 1980 has been reduced by 27% for widebody aircraft and 35% for narrowbody models (see "Learn More," p. 34). But more ambitious reductions have been called for by the Advisory Council for Aviation Research in Europe (ACARE) in *Flightpath 2050* — a 75% reduction in CO_2 per passenger-km, a 90% reduction in nitrous oxide (NOx) emissions and a 65% reduction in noise by the year 2050 vs. performance levels recorded in 2000. The dire need for, and rather drastic depth of, such reductions are precisely the sort of situation where the subject of this report, composite matrix composites (CMCs), promise a solution.

Although they're considerably more expensive — reportedly hundreds to thousands of dollars per kilogram — they are roughly one-third the weight and twice the strength of the nickel alloys currently used in jet engines, *and* they offer a 100-200°C improvement in high-temperature capability. No surprise, then … they're now in demand.

Engine application landscape

Notably, carbon fiber reinforced polymer (CFRP) composites (the subject of Part 2, which will appear in *CW* September) continue on an upward growth curve, but CFRP and CMC growth trajectories are on something of a collision course. According to Henrik Runnemalm, director of advanced engineering for Tier 1

Table 1 Ceramic matrix composite properties

Material properties of typical CMCs at ambient temperature, where the range spans minimum and maximum values of each property in different directions or for different CMC qualities (Ox/Ox covers CMC with alumina fibers and alumina or alumino-silicate matrix).

Source | Friedrich Raether, Fraunhofer Center for High Temperature Materials and Design HTL (Bayreuth, Germany), www.htl.fraunhofer.de

Property	Unit	SiC/SiC	C/SiC	C/C	Ox/Ox
Fiber content	vol.-%	40–60	10–70	40–60	30–50
Porosity	vol.-%	10–15	1–20	8–23	10–40
Density	g/cm^3	2.3–2.9	1.8–2.8	1.4–1.7	2.1–2.8
Tensile strength	MPa	150–360	80–540	14–1100	70–280
Bending strength	MPa	280–550	80–700	120–1200	80–630
Strain-to-failure	%	0.1–0.7	0.5–1.1	0.1–0.8	0.12–0.4
Young's modulus	GPa	70–270	30–150	10–480	50–210
Fracture toughness	MPa·m1/2	25–32	25–30	5,7–,3	58–69
Thermal conductivity	W/m·K	6–20	10–130	10–70	1–4
Coefficient of thermal expansion	ppm/K	2.8–5.2	0–7	0.6–8.4	2–7.5
Maximum service temperature	°C	1100–1600	1350–2100	2000–2100	1000–1100

supplier GKN Aerospace (Redditch, UK), "CFRP products are moving mainly from the front of the engine towards the back and also from the outside, moving inward." With much higher temperature resistance, CMCs are moving in the opposite direction, i.e., from the rear — the engine "hot zone" — towards the front and from the inside towards the outside (see Fig. 1, p. 38). "There will always be a mix of materials," says Runnemalm, observing that integration of CFRP, CMCs and metals will be a challenge, including joining techniques, how to deal with the stress distribution, assembly and disassembly requirements and managing the transition between heat zones in the engine.

The main types of CMCs include silicon carbide (SiC) fibers reinforcing a SiC matrix (SiC/SiC), carbon/carbon (C/C), C/SiC and Ox/Ox where the oxide is typically alumina (see Table 1, this page). SiC/SiC components used in oxidation-causing environments must be protected, using environmental barrier coatings (EBCs), and even the SiC fibers must be coated to prevent attack from oxygen molecules diffusing through the porous matrix. Because they do not require a carbon coating on the fibers or EBCs, Ox/Ox composites offer lower cost. However, they lag in thermomechanical properties vs. SiC/SiC.

CMCs take flight

GE Aviation (Cincinnati, OH, US) expects a tenfold increase in the use of CMCs in its engines over the next decade (see "Learn More"). One reason is that, unlike metals in the hot zone, CMCs don't need to be air-cooled, freeing up flow to boost the engine's propulsion and efficiency.

GE's first CMC parts to enter service will be the static first stage HP compressor shroud in the LEAP engine. Also called HP turbine shrouds, and reportedly some of the hottest parts in a turbofan, 18 of these direct airflow to ensure turbine blade efficiency. They are manufactured using SiC/SiC at GE's CMC-dedicated Asheville, NC, US, factory, which also will make the inner and outer combustion liners and stage 1 and 2 nozzles for the GE9X engine.

These parts not only reduce cooling air requirements but also improve durability. Finished parts from Asheville will proceed to Advanced Ceramic Coatings (ACC, Hickory, NC), which operates from the US facility of surface treatment specialist Turbocoating (Rubbiano di Solignano, Italy). ACC will apply GE's proprietary EBCs to protect SiC/SiC components from surface recession (erosion) and expects to deliver its first coated parts later this year.

Although CMCs were first targeted to static applications, the real revolution, say proponents, will come with dropping weight and cooling in *rotating* parts. In February 2015, GE successfully tested CMC rotating parts in an F-14 military jet engine. Similar to the fan disk reduction enabled by CFRP fan blades, these CMC LP turbine blades allow smaller, lighter metal turbine disks (see Fig. 2, below) and bearings and other parts can be downsized, multiplying weight savings by as much as a factor of three.

According to GE Aviation's CMC design section leader Jonathan Blank, replacing nickel alloys with CMCs inside the engine is a huge step and sets the stage for revolutionary jet engine design changes. GE is also exploring use of CMCs in helicopter engines and in gas turbines and compressors for electrical power plants. »

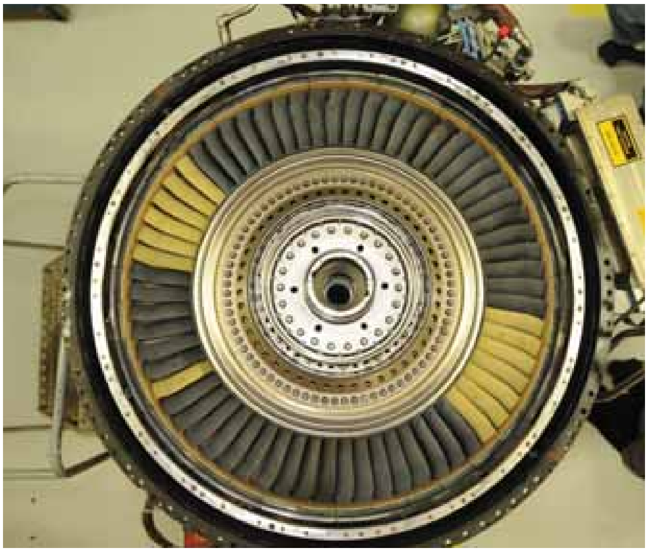

FIG. 2 CMC fan blades

A turbine rotor undergoing testing with lightweight CMC blades that enable smaller and lighter metal disks (shiny steel part in the center), reducing overall engine weight and boosting fuel efficiency. Yellow blades are covered with an environmental barrier coating. Source | GE Aviation

FIG. 3 CMC exhaust cone

The ARCOCE (ARrière-Corps Composite CEramique, or afterbody ceramic composite) engine exhaust cone is the first to fly in commercial sevice. Source | CW

FIG. 4 CMC mixer

Composites Horizons will produce the Ox/Ox CMC mixer, which cuts 20 kg from the GE Passport 20 engine. Source | CW

At Rolls-Royce (Manchester, UK), researchers tested SiC-SiC HP turbine blade tracks in 2013 and then SiC-SiC shroud segments, using a Trent 1000 test engine via the Environmentally Friendly Engine (EFE) program. The blade tracks — which could reduce component weight and engine cooling by 50% — also were key demonstrators in the US Federal Aviation Admin.'s (FAA, Washington, DC, US) Continuous Lower Energy, Emissions, and Noise (CLEEN) program. Testing is scheduled to run through 2015.

The higher pressure ratios planned in Rolls-Royce's Advance and UltraFan engines mean higher operating temperatures and increased NOx emissions — increases that could be mitigated through the use of CMCs. The company says it will definitely use CMCs in static parts, such as nozzles, and in its *Vision10* (technology-ready in 10 years) strategy outline, its HP turbine goes shroudless, using, instead, a CMC liner.

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Read this article online | short.compositesworld.com/Jet1-CMCs

Read *CW's* earlier coverage of this market online in "Composites in commercial aircraft engines: 2014-2023" online | short.compositesworld.com/MO-AeroEng

Read more about CMCs in "Ceramic matrix composites heat up" online | short.compositesworld.com/WrsprzMm

Read more online about Herakles' CMC exhaust cone in the *CW Blog* titled "Highlights: JEC Europe 2014" under the heading "CMC exhaust cone for LEAPX engines" | short.compositesworld.com/JEC14Blog

Pratt & Whitney (Hartford, CT, US) has said it sees low value for CMCs in static applications and, therefore, will focus CMC application efforts on rotating turbine blades and the combustor. In 2010, Pratt & Whitney Canada (P&WC, Longueuil, QC, Canada) tested a CMC reverse-flow combustor in a PW200-series rotorcraft engine, achieving a 30% NOx reduction at high power and a 20% cut in CO at low power vs. the standard metal unit. Patent application US 2014/0311152 A1 describes the annular combustor as having an inner liner comprising a dome portion, a small exit duct portion and a large exit duct portion, each an independently formed hemi-toroidal CMC shell. Although the combustor sees the highest temperatures in this engine, holes for cooling air delivery are not necessary, so no machining is required after liner sections are formed.

In 2015, P&WC presented results from computer analysis of thermal stresses on a combustor molded with Ox/Ox materials from COI Ceramics (San Diego, CA, US). It analyzed flat and curved segmented panels as well as 360° annular parts and identified potential for delamination at temperature transitions and panel edges, tensile rupture on the cool side, and compressive damage accompanied with fiber buckling on the hot side and panel edges. However, adding an insulation layer reduced stresses by a factor of three.

Upping performance at the exit

Herakles (Le Haillan, France), a subsidiary of Paris, France-based Safran, has been working on a series of CMC parts for the next generation of LEAP engines as well as new Safran-designed engines targeting the 2020-2030 timeframe. On June 16, it announced that its SiC-based exhaust cone (see "Learn More") is the first CMC part to fly on a jetliner in commercial service. Fastened directly to the aft flange of the CFM56 test engine's turbine frame, and interfaced with the nacelle, the exhaust cone comprises a centerbody and a complex "lobed" shape mixer. The latter achieves optimal mixing of the hot engine gases with the cold bypass air, improving the engine exhaust system's output and efficiency (see Fig. 3). Measuring 1,625 mm in length and 655 mm in diameter, the exit cone weighs a mere 24.5 kg. European Aviation Safety Agency (EASA, Cologne, Germany) certification for use on commercial flights slated for 2013 was finally received April 22, 2015. The company has completed demonstrations of other new commercial aeroengine applications:

- Prototype CMC mixers ground-tested on a CFM56-5C engine and flight-tested on an Airbus Helicopter (Marignane, France) Tiger rotorcraft.
- In-flight test of a CMC trailing-edge fairing on an A380 engine pylon.
- CFM56 engine ground-test of CMC LP turbine blades.

NASA's (Washington, DC, US) efforts to mature CMC applications include a SiC/SiC combustor liner, SiC/SiC HP turbine vane, and an Ox/Ox exhaust nozzle through its Environmentally Responsible Aviation (ERA) project. This six-year project's Phase II culminates in 2015 with Integrated Technology Demonstrations (ITD) of downselected technologies to reach technology readiness level (TRL) 6. Advanced EBCs tailored for the combustor and vane are in development for surface temperatures to 1482°C, while the exhaust nozzle is targeted for service at 816°C.

In summer 2014, Boeing successfully ground- and flight-tested its Ox/Ox exhaust nozzle, developed through the CLEEN program. Results showed better thermal performance than Inconel at a weight 20% less than titanium, noise performance the same or better than metal and continuous operation at 816°C. Rated at TRL 7, a second design cycle is reportedly slated for 2015 with partners Rolls-Royce, Orbital ATK (Dulles, VA, US), American Airlines (Fort Worth, TX, US) and Albany Engineered Composites (AEC, Rochester, NH, US).

AEC, which worked with Boeing to develop the CLEEN nozzle's CMC substrate, is additionally exploring the ability to combine CMC and 3D woven composite technology. AEC's VP of research and technology Brian Coffenberry sees the potential for these combined technologies to improve toughness. Also, because of the automation already associated with 3D composites, the fabrication processes might also become highly scalable.

In 2014, Composites Horizons (Covina, CA, US) added a 3,252m^2 CMC-dedicated facility as well as a new autoclave, sintering ovens and CNC equipment after receiving the production contract for nozzle components in GE's Passport 20 engine, which will power Bombardier 7000 and 8000 ultra-long range business jets. According to GE director of Bombardier programs Judd Tressler, Ox/Ox CMC replaces what would have been graphite/epoxy in the four-piece panel that encloses the engine core and the nine-piece mixer (see Fig. 4, p. 40). Saving roughly 20 kg in the mixer alone, GE selected Ox/Ox for the Passport 20 in 2010 to help reduce engine weight.

As CMCs move outward and forward, they'll continue to be pushed toward higher operating pressure ratios in the hot zone. Slated objectives include next-generation turbine disk materials, an 820°C-capable compressor and 1,650°C turbine blades/vanes. But having pierced the veil, CMCs are already closing in on these targets. The challenge now will be to extend thermomechanical performance while at the same time enhancing manufacturing robustness *and* reducing per-unit cost. CW

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Structural health monitoring: NDT-integrated aerostructures enter service

SHM moves from structural testing to an FAA-qualified inspection alternative that reduces cost, streamlines operations and will mature toward lighter, more robust smart structures.

By Ginger Gardnier / Senior Editor

» Structural health monitoring (SHM), essentially, involves a nondestructive testing (NDT) system that integrates sensors into a structure to enable continuous or periodic inspection. The resulting data enable operators to identify the initiation and growth of damage *in situ* — without the expense or time required to take the structure out of service, then disassemble and manually inspect it. Ideally, it also determines the damage type, location and size as well as the structure's health prognosis.

When *CW* last explored the range of developing SHM technologies, in 2008 (see "Learn More," p. 49), it reported that some were nearing commercial readiness. Since then, the Aerospace Industry Steering Committee SHM-AISC was formed and first met in 2009. Its members — all the major aircraft OEMs as well as operators, regulators and technology suppliers — are striving to standardize SHM integration and certification requirements and to mature systems for widespread use. They achieved a critical milestone in 2013 with guidelines for SHM implementation on fixed-wing aircraft, published by SAE International (Warrendale, PA, US) as *Aerospace Recommended Practice ARP-6461*. Today, SHM systems are well proven

SHM: Alternative to manual inspection?

CVM sensors (see inset, for example) are flying on Delta Air Lines 737 aircraft like this one (left) as part of a program aimed to approve structural health monitoring as an alternative inspection technique to manual disassembly and visual inspection for commercial aircraft by 2016.

Source (main image) | Sandia / Photo | Randy Montoya.

Source (inset) | Structural Monitoring Systems

as tools to monitor structural and in-flight certification tests, and the first applications for monitoring structures in service are now flying on commercial and military aircraft (see Table 2, p. 47).

As a sign of this impetus and a possible tipping point, seven of The Boeing Co.'s (Chicago, IL, US) 737 narrowbody aircraft operated by Delta Air Lines (Atlanta, GA, US) have been outfitted with Comparative Vacuum Monitoring (CVM) sensors for crack detection (see "Structural health monitoring: The toolbox," p. 47) in a program that aims to obtain approval for SHM as an alternative inspection method by 2016. Part of a broader SHM initiative at the Airworthiness Assurance Nondestructive Inspection Validation Center (AANC) operated by Sandia National Labs (Albuquerque, NM, US) for the US Federal Aviation Admin. (FAA, Washington, DC, US), its goal is to schedule maintenance based on the actual condition of each aircraft's structures rather than on fixed time periods based on the average performance of an entire fleet. This could save millions of dollars in revenue currently lost due to lengthy but often unnecessary manual inspections and aircraft downtime.

At Airbus Operations Germany (Bremen), Dr. Clemens Bockenheimer, SHM leader and head of A350 composites, surface and standardization, reports that *local* SHM — limited-area monitoring close to sensors — has moved away from R&D and is now ready for qualification per specific aircraft application. Although reliability assessment for *global* SHM monitoring (systems that simultaneously monitor the health of an entire aircraft) is still in development, Airbus is proceeding with local SHM technology-readiness requirements. In fact, Airbus drafted the requirements section of *ARP-6461* and is preparing the Validation & Verification (V&V) Center within Airbus Materials, Process & Testing (MP&T) as its single entry point for SHM technology, with sister Airbus Group company, Testia GmbH (Bremen, Germany), named as the center's operator. Testia will help coordinate testing and other requirements with SHM technology companies, OEMs, parts manufacturers and aircraft operators, to minimize maturation time and cost. "This is a new and fresh approach that is just now being communicated to the industry," says Testia CEO Holger Speckmann.

Looking mainly at the two most mature systems — CVM and an acousto-ultrasonics (AU) technology called SMART Layers — *CW* here walks through SHM's entry into service and the potential it offers for future composite aerostructures.

SHM already in service

SHM has become a standard tool used in aircraft certification to monitor structures during ultimate load and fatigue tests. Sensors installed across components and complete aircraft structures eliminate the need to stop the test for manual inspection of selected areas. For example, acoustic emission (AE) sensors from Physical Acoustics Corp. (PAC, Princeton Junction, NJ, US) were used to monitor Boeing's full-scale fatigue testing of the carbon fiber reinforced plastic (CFRP) horizontal stabilizer on its 777 widebody aircraft. Also used during the structure's ultimate load and destruction tests, the AE systems supplied the data used in those cases to identify and evaluate subcritical damage propagation and to help define the part failure sequence.

Similarly, the Airbus (Toulouse, France) A380 full-scale fatigue test, performed by IABG (Dresden, Germany), simulated 47,500 flights over 26 months of cyclic loading and used a variety of SHM sensors, including CVM, eddy-current foil sensors (ETFS), acoustic emission (AE), and crack wires (each is defined in "The toolbox," p. 47). Installed throughout the fuselage and wings, these SHM systems provided detailed information about the initiation of cracks in the plane's aluminum structure, CFRP center wingbox and glass fiber aluminum (GLARE) fuselage sections.

The Airbus A350 and Bombardier's (Montréal, QC, Canada) *Learjet 85* also used SHM during structure certification and/or » flight testing, as do various SHM *protosystems* — early developments/smart structure forerunners that sense and communicate data about structures — flying on Airbus, Boeing and military aircraft today (Table 2, on p. 47).

One example, developed for the Airbus A340-500/600 family of long-haul aircraft, is the tail strike indication (TSI) system now also deployed on the Airbus A380. The TSI uses two sensors, each with two crack-wire lines for redundancy in sensing if the fuselage tail contacts the ground during take-off. If the conductive/resistive wires along the tail are disrupted, a cockpit indicator alerts the crew. A crewmember, then, can trigger procedures for inspection and proper maintenance actions before the plane resumes service. Integrating impact damage detection into the tail's structural design has enabled weight savings because ground contact is no longer a damage case for which the tail must be overbuilt to sustain continued service. Instead, it is detected and dealt with immediately.

Another example is the Life-Time Monitoring System (LTMS), an optional installation on Airbus A400M aircraft, which uses strain gages to measure and record aircraft structural loads, including overloads, hard landings and total cycles accumulated. These data enable operators to better track aircraft use and associated fatigue for more efficient maintenance planning.

Local first, then global

"Confidence in local SHM applications for selected technologies, for example CVM and eddy current, is no longer an issue," says Bockenheimer. Numerous demonstrator installations and durability tests for a wide array of SHM systems have been completed over the past two decades (see "Side Story," at left).

However, Bockenheimer cautions that local SHM applications are very different from global SHM systems. "Local is more restricted, monitoring under and close to the sensor, similar to conventional NDT, so how to prove it is more clear. For example, we proved Probability of Detection (POD) for CVM in 1995." How to prove detection capability for global monitoring and how the whole system communicates across the fuselage and with other systems is still in development. The industry is gaining confidence, however, as it continues to accrue successful flight history with local SHM systems.

"The need now is for standardization in the process for qualification and implementation in specific aircraft applications," Bockenheimer asserts. He notes that Airbus has been working with AISC-SHM and other industry groups for more than a decade to build a robust certification path.

"Aircraft engines have used condition monitoring systems for years," says Andrew Chilcott, director, Structural Monitoring Systems (SMS, Nedlands, Australia; Century City, CA, US and Ashford, UK). Bockenheimer agrees, citing Built-In Test Equipment (BITE) in avionics and Health and Usage Monitoring Systems (HUMS) in helicopters as additional examples of this trend to integrate condition monitoring into the overall aircraft systems architecture. He adds, "SHM will become one more core element in this architecture, enabling manufacturers to design and qualify systems that will reduce the time and cost of scheduled and unscheduled maintenance and increase aircraft availability."

Alternative aircraft inspection method

This is exactly the aim of the program at Delta Air Lines led by the AANC and its operator, Sandia Labs. "The program to achieve certification of SHM for routine use on commercial aircraft began several years ago," says Sandia senior technical fellow, Dennis Roach. The application is an aluminum fitting in the Boeing 737NG aluminum center wingbox, for which an airworthiness directive had been issued, mandating visual and eddy-current

SIDE STORY

Decades of SHM demonstrations build confidence in local SHM

Current momentum in local structural health monitoring (SHM) development can be credited, in part, to developmental effort on the part of the system developers that follow.

CVM system demonstrations in both metal and composites applications by Structural Monitoring Systems (SMS, Nedlands, Australia; Century City, CA, US and Ashford, UK) include installations flying on military fixed-wing aircraft and rotorcraft as well as commercial airliners in service, most notably for Delta Air Lines (see main article). The last readings from those systems — mounted to metal structures — were taken a couple of years ago, making that nearly a decade of in-flight service, and that data was subsequently shared with the US Federal Aviation Admin. (FAA, Washington, DC, US).

Brazilian aircraft manufacturer Embraer (Embraer-Empresa Brasileira de Aeronautica S.A., São José dos Campos) also has E-190 regional jet aircraft fitted with CVM and SMART Layer systems flying for several commercial airline customers, as it prepares to introduce a scheduled structural health monitoring (S-SHM) system that involves the installation of fatigue and corrosion sensors in hard-to-access areas of the aluminum airframe around the aft doors.

Meanwhile, Acellent Technologies (Sunnyvale, CA, US), the US Army Research Laboratory (ARL, Adelphi, MD) and the Aero-Flight Dynamics Directorate (AFDD, Moffett Field, CA, US) have been flight-testing Acellent's SMART Layers on H-60 *Blackhawk* helicopter metal structures for 5 years to validate their integration and long-term operation and survivability on rotorcraft. Acellent also has completed Small Business Innovation Research (SBIR) projects with the US Navy for SHM systems on composites, which are supported by H-60 manufacturer, Sikorsky (Stratford, CT, US), for future implementation on the more composites-intensive CH-53K.

Other large-scale tests include those completed by the Tokyo, Japan-based "heavies" — Fuji Heavy Industries, Kawasaki Heavy Industries and Mitsubishi Heavy Industries — as part of the Japanese SHM Technologies for Aircraft Composite (JASTAC) structures program. In 2013, Airbus (Toulouse, France) extended this program to a second phase — which also includes the Japanese Aerospace Exploration Agency (JAXA, Tokyo) — targeted to deploy Phase I optical fiber-based SHM technologies into aircraft, extending through what Airbus terms Generation 3 in its SHM Roadmap (see Fig. 1, p. 45).

inspection for crack detection at periodic intervals. "All aircraft are designed according to damage-tolerance principles," says Roach. "The FAA and OEM directives are thus based on how long and what loads it takes to make cracks form and grow." For the wingbox fittings, inspection is time-consuming, necessitating removal of seats and floor panels. Roach stresses that none of the normal maintenance is changed until the SHM method is certified: "Delta is doing both the traditional inspections as well as the SHM."

The ultimate goal is to have sensors mounted in place so that mechanics can plug in from a convenient location to acquire the required data without the time and cost of disassembly and manual inspection. This also reduces potential damage to structure during access and risk of human error during inspection. "We have seven aircraft flying with 10 sensors on each aircraft," says Roach. The program is using SMS' CVM sensors, shape-customized and adhered to wingbox fittings. These detect crack initiation and growth by monitoring the slightest pressure change between 0.64-mm channels or "galleries" laser etched into a Teflon pad.

Sensors are applied using a self-stick adhesive. Roach says some surface preparation is required to achieve a very tight seal, but on a fairly smooth surface that can be approached directly, "a single CVM sensor can be applied in 10-15 minutes." Vacuum tubes are then routed to a testing socket and attached using snap-clip connectors like those used in landline telephones. During the mandated inspections, a handheld scanning unit is plugged into these testing sockets to interrogate the sensors and give a clear pass or fail indication.

According to Roach, system interrogation for the 737 aircraft is performed every three months, typically while the aircraft is at a terminal gate overnight. The aim is to work with Boeing through the latter part of 2015 to compile collected data and present it to the FAA. "We hope that Delta is able to use SHM as an alternative inspection technique in 2016," says Roach.

This is just one part of a much larger SHM effort at Sandia, which includes testing of many other types of SHM systems as well as laboratory performance testing as a statistical basis for validation. Standardizing this validation process also is a key objective. "One of our tasks in this program at Delta is to see how well it fits vs. the *ARP-6461* guidelines," says Roach. "There must be some level of standardization in how SHM is integrated into the airline maintenance operations, including training of the maintenance personnel and cradle-to-grave issues, such as continued airworthiness of the SHM system."

Paving the path for composites

Many in the industry hope the Delta program will serve as a blueprint for SHM implementation on other commercial aircraft. "Once you have one system approved, it should be easier to get another approved," says Amrita Kumar, executive VP of business at Acellent Technologies (Sunnyvale, CA, US). "I am hoping we will get a composites SHM application approved within the next 2-3 years."

SMS CEO Toby Chandler sees the Delta program as key in developing recognition of SHM as a commercial technology.

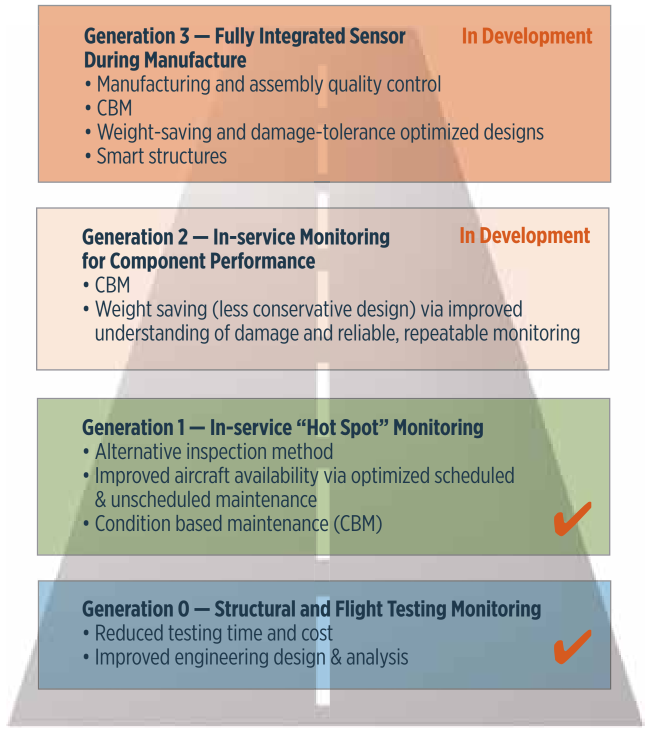

FIG. 1: Antidote to overdesign

In the Airbus Roadmap for SHM development, the Generation 1 CBM systems for "hot spot" monitoring (e.g., Delta Air Lines' wingbox fitting program) will be followed by Generation 2 applications, now in development, which enable less conservative, lighter weight designs. Source | Airbus

"We have clearly established that CVM is an effective tool, and regulatory bodies are close to allowing it as an inspection regime," adds Trevor Lynch-Staunton, project manager at SMS' manufacturing partner, Anodyne Electronics Manufacturing Corp. (AEM, Kelowna, BC, Canada).

"But this is just the tiniest tip of the iceberg," says Chilcott, "particularly with composites, where the understanding of damage is still young and developing. This type of capability with composites will allow reducing weight in the doors and vertical tails, for example, because you will develop an understanding of where and how the damage initiates and its progression. We don't have a good way to do that right now."

Condition-based maintenance

"With the growing number of older aircraft in service, the business case for SHM retrofit applications is gaining more and more momentum," explains Bockenheimer in the article "Structural health monitoring: A real-time on-board 'stethoscope' for condition based maintenance," published in the August 2014 issue of Airbus' *Flight Airworthiness Support Technology* (*FAST #54*) magazine. "Such an application is typically Generation 1 and aimed at known structure hotspots," he adds.

These hotspots are defined during an aircraft's certification testing and with continuous monitoring following entry into »

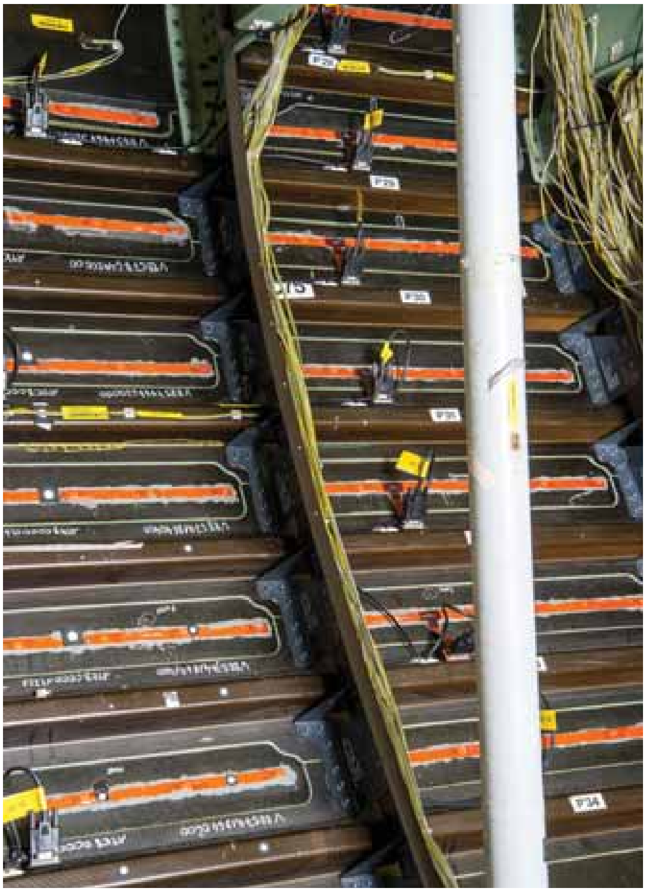

FIG. 2: In-service testing

This network of SMART Layer sensors (left) is currently undergoing flight testing as a local SHM system for impact detection on an A350 CFRP door surround panel. A handheld diagnostic unit plugged into the SMART layer sockets (right) will indicate damage location and size or display a red/green signal, indicating damage/no damage in the structure.

Source (left) | Airbus

Source (right) | Acellent Technologies

service. They require periodic visual inspection supported by NDT (e.g., ultrasonics, eddy current). Inspection intervals are based on fixed in-service time or cycles and are prescribed for all aircraft of a given model. Very often, no damage is found, yet a huge amount of time must nevertheless be consumed dismantling and reassembling the aircraft to access and inspect these structures. Airbus has several programs in place to explore SHM implementation in composite structures with a view toward enabling condition-based maintenance (CBM) — triggering inspections based on actual health indications of each aircraft's structures instead of fleet-wide fixed time periods. This is also one of the goals of the FAA's programs via the AANC at Sandia.

One illustration is the acousto-ultrasonics (AU) system Airbus is developing to detect stringer disbond in composite structures surrounding the doors on its A350 XWB. Data show this region accounts for the majority of in-service fuselage damage on long-haul aircraft, with 15% of impacts sustained by doors, 22% amassed in cargo door surrounds and 31% accumulated in passenger door surrounds. Current CFRP fuselage areas have been designed and tested to *sustain* such impact damage, but any visible damage still must be inspected using NDT. Using SHM sensors would alleviate concern about impacts that don't produce visible damage, as well as do away with the need to inspect from inside the aircraft structure, which can involve time-consuming removal of interior sidewalls and other systems, resulting in lost flight revenue, especially when unscheduled. "Airlines estimate that $150,000 to $200,000 in revenue is lost for every day a narrowbody aircraft is not in service," says Chandler, "and $500,000 per day is lost for widebody aircraft."

The AU system now in testing uses a specially designed network of Acellent Technologies' SMART Layer sensors — polyimide films in which piezoelectric sensors are strategically distributed to communicate with each other by sending and receiving ultrasonic surface waves (Lamb waves). These provide damage assessment based on software analysis of the signal disruptions and changes in patterns vs. baseline data. Sensors are easily installed using aerospace-grade adhesives. When a handheld SCAN Genie diagnostic unit is plugged into SMART Layer sockets, it can indicate the damage location and size or simply display a red/green signal to indicate damage/no damage in the structure. The system also can be designed to connect to onboard diagnostic units for on-demand or automated interrogation.

Airbus has two flight validators: an A350 and the MSN001 A340 flight-test aircraft retrofitted with an A350 XWB CFRP skin panel in the surround structure of passenger door 1 (see Fig. 2, above). Instrumented with SMART Layer sensors, this area surrounding the door also is being tested in two ground validators: an A350 barrel section and a fuselage shell section that has been impacted »

SIDE STORY

The Structural health monitoring toolbox

Although *CW's* coverage of structural health monitoring (SHM) technologies in this issue focuses on those most actively employed in testing/demonstration environments and most ready for widespread deployment, there are a broad range of SHM types that take advantage of a variety of sensing mechanisms. The following is a short sketch of each, accompanied by two tables that indicate current uses and developmental progress.

Acoustic Emission (AE): Passive transducers listen for matrix cracking, delamination and fiber breakage.
Acousto-ultrasonics (AU): A grid of piezoelectric sensors sends and receives ultrasonic pulses and analyzes changes in wave patterns to identify and describe damage.
Comparative Vacuum Monitoring (CVM): The smallest air flow can be detected when galleries alternating between atmospheric pressure and vacuum (enabled by Teflon manifold patch) are breached by a crack or resin microcracks.
CVM Through the Thickness (CVM-TT): A <1 mm-diameter hole drilled through a composite into adhesive uses the CVM principle to detect disbond and delamination.
Crack Wire (CW): Conductive/resistance wires that trigger alarms when severed by cracks or damage.
Electro-Magnetic Interference (EMI): Uses embedded piezoelectric sensors and impedance analyzer. Increasing levels of internal release agent and moisture contamination, for example, produce increasing deviation from a reference index, indicating weak bonds.
Eddy Current Foil Testing Sensors (ETFS): Sensors generate an eddy-current field in conductive metals, which is disrupted by cracks and corrosion.
Fiber Bragg Grating (FBG): A mature type of Fiber Optic Sensing (FOS), it uses alterations in the refractive index of an optical fiber to measure temperature, strain and vibration as well as acoustic and ultrasonic signals for crack and damage monitoring.
Impact Damage Detection System (IDDS): Developed by Kawasaki Heavy Industries, this system uses two combined methods: (1) optical intensity measurement before and after impact, using optical fibers to assess damage and (2) shock wave measurement for impact localization via FBG sensors.
Imaging Ultrasonics (IU) — Miniaturized, integrated sensor networks generate a signal through the material. Changes in wave reflection indicate flaws or damage.
Strain Gauges (SG) — These output strain, stress and load, using traditional electrical foil sensors and an input voltage. Newer sensor types include fiber-optics, microelectromechanical systems (MEMS) and printed conductive-ink sensors.

TABLE 1	SHM TECHNOLOGIES										
Generic Use Case	CVM	ETFS	AE	IU	CW	IDDS	AU	FOS	EMI	CVM-TT	SG
Crack detection and assessment	**X**	X		X							
Rupture detection of structures	**X**			X	X						
Impact detection and assessment			**X**			X		**X**			
Delamination detection and assessment			X	X			**X**	**X**		X	
Bond quality assessment								**X**	X	**X**	X
Bonded repair monitoring								**X**		X	X
Debonding detection and assessment			X					**X**		**X**	
Stress/strain monitoring								**X**			**X**

Boldface "X" indicates proven high performance in that area.

TABLE 2	SHM TECHNOLOGY TESTING (not exhaustive)			
SHM	Suppliers	Demonstration Projects	In-service Monitoring of Certification Tests	Protosystems Flying on Aircraft
AE	**Physical Acoustics Corp** (PAC, Princeton Junction, NJ, US)		• B777 horizontal stabilizer full-scale fatigue and ultimate load tests • A380 full-scale fatigue test	Airborne Acoustic Integrity Monitoring System (AAIMS) on U.S Navy P-3 *Orion* fleet **
AU	**Acellent Technologies** (Sunnyvale, CA, US) SMART Layers	• Embraer in-flight tests at airlines • H-60 helicopter flight tests • A350 door surround impact detection - ground and flight validators	*Learjet 85* flight test monitor impact damage to composite vertical stabilizer (tail)	
CVM	**Structural Monitoring Systems** (Nedlands, Australia; Ashford, UK and Century City, CA, US)	• Embraer in-flight tests at airlines • Delta Air Lines/Sandia program testing seven Boeing 737 aircraft in service	A380 full-scale fatigue test	
CW			A380 full-scale fatigue test	Tail strike indication (TSI) system on A340-500/600 and A380
FBG		JASTAC I and II	A350 horizontal tail plane (HTP) structure & flight testing	
SG				A400M Life-Time Monitoring System (LTMS)

*** Supplier for AE sensors used in AAIMS is not known.*

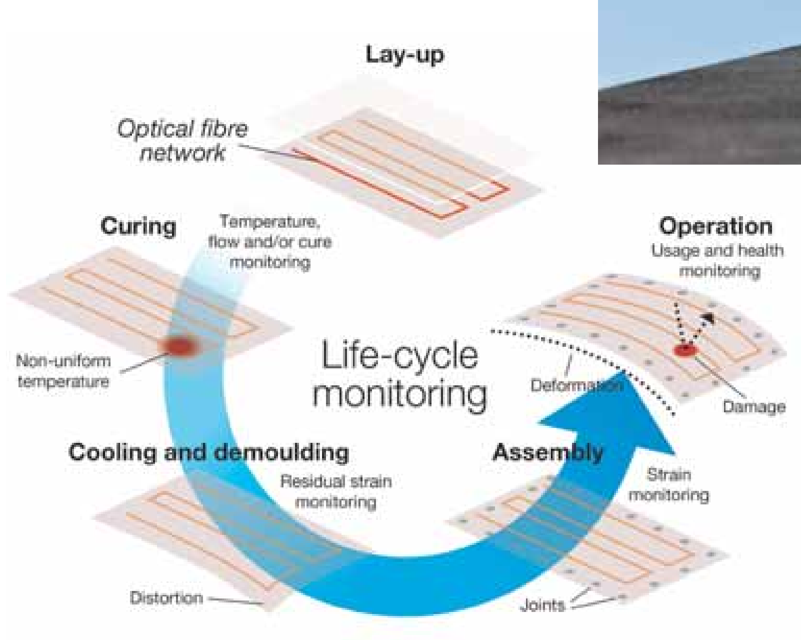

FIG. 3: Sensor integration

Both CVM and SMART Layer sensors (above) were developed to be built into composite structures rather than applied as a retrofit. This illustrates the final step in SHM development: Integration of sensors during part manufacture to provide quality control through assembly as well as CBM and lightweight design benefits for complete lifecycle monitoring (see diagram at left).

Source (above) | Acellent Technologies

Source (left) | Airbus

extensively and inspected with manual NDT (e.g., conventional ultrasound) inside vs. outside to verify the system's damage detection and assessment performance.

Advancing CBM to save weight

The next step beyond CBM (Generation 2 in Fig. 1, p. 45) is to use data collected from these applications to enable a less conservative, lighter weight design for structures in future aircraft.

Bockenheimer cites Airbus' Vertical Tail Plane Next Generation (VTP-NG) rib de-bonding detection system as an example. The VTP-NG program, which has been advanced by the Composite Technology Center (CTC, Stade, Germany), proposes a novel design and manufacturing approach for the vertical tail, based on composite ribs bonded onto cored sandwich skins. However, to determine if rib debonding has occurred in service via conventional NDT, the structure must be opened to access the interior.

"This makes the structure too difficult to inspect, so a bonded solution would be difficult to realize," explains Bockenheimer. "We proposed using CVM to detect rib debonding at any time we want, without having to access the inside. So now, we can work out the design for improved weight and decreased production costs."

Although it offers much promise, the VTP-NG program is still in development.

> The ultimate benefits of SHM are anticipated when sensors can be incorporated during manufacture ....

Straightening the path to qualification

But what is actually required for such promising SHM applications to reach commercial service, and how long will it take? "Until now, the path for qualification and certification has not been very well defined or straight," observes TESTIA's Speckmann, "and SHM technology companies have spent a lot of money and time." He adds that the framework being developed for Airbus' SHM V&V Center emerged out of its A350 SHM door-surround program, with the goal to provide SHM technology companies with a clear way to get onto commercial aircraft *without* going bankrupt.

"It's not in Airbus' interest for these companies to waste time and money," says Speckmann. It is planned that the V&V Center will become part of the Center for Eco-efficient Materials & Technologies (ECOMAT, Bremen, Germany), a locally funded science and industry research collaborative focused on new technologies in lightweight, multifunctional construction for not only aerospace but also automotive, wind energy, marine and building and construction applications.

Bockenheimer explains that Airbus MP&T is responsible for the development and qualification of SHM technologies. "We have formed multidisciplinary teams to integrate the structural sensing technology with the aircraft monitoring system architecture."

This approach also has led Airbus to establish a comprehensive set of key requirements based on the type of SHM detection.

Airbus has developed what it terms an "SHM Toolbox" of at least 14 pre-developed technologies for generic applications. "We then work with developers and operators to mature these tools for specific applications on an aircraft," says Bockenheimer.

"Not all of the technologies are ready to be implemented," Speckmann concedes, "but some should reach technology readiness within the next 5 years." He cautions that for a technology to be used in commercial service, the technology readiness level (TRL) "is for a specific SHM tool coupled with a specific aircraft application." When an SHM technology is applied to a different component or vice versa, the TRL must be reassessed. He also warns that companies will *say* their technology has reached TRL 7 — indicating it has flown on an aircraft — without having yet completed all of the testing required for TRL 4, TRL 5 and TRL 6.

Speckmann reports that there are five to seven different technologies in Airbus' SHM Toolbox that apply to composites, and it should be possible to move them from TRL 3 to TRL 6 within 2-5 years, depending on the type of application. "This will go faster if you have the money to do a lot of tests concurrently," he suggests, adding that time for testing also will decrease with computer modelling and simulation — like that now used to improve and automate NDT.

Through the envisaged SHM V&V Center, Airbus MP&T will define the maturation required for a given SHM technology and application. Then, TESTIA will work with the V&V Center, subcontracted in a way, to present SHM maturation and testing requirements to the technology companies, system integrators and OEM, organize the testing program and then help to perform these tests. Today, TESTIA is providing NDT services and training NDT personnel for a wide range of OEMs, airline operators and parts manufacturers.

"SHM will automate NDT on the aircraft," notes Speckmann, "so we will be installing the systems when the SHM solution has been accepted by the individual Airbus aircraft programs." Established in 2013 to support SHM implementation, TESTIA also will develop installation procedures and train installation personnel.

Finally, smart structures

The ultimate benefits of SHM are anticipated when sensors can be incorporated during manufacture to achieve the long-envisioned smart structures (see Fig. 3, p. 48). "Our SMART Layer materials were developed to be co-cured into a composite structure," says Acellent's Kumar. She notes that Acellent's SHM system is now capable of performing all *four* of the necessary functions required for oversight of composite structures:

1) Damage detection (is there damage?)
2) Localization (where is the damage?)
3) Quantification (how much damage?)
4) Characterization (what type of damage? — delamination, honeycomb damage, fiber breakage, etc.)

At SMS, much of its early SHM development work also was in composites. As an alternative to embedding sensor pads, SMS learned the composite itself can be molded or laser-machined to form the sensor galleries and then covered with a thin Teflon manifold. Chilcott recalls, "We did a lot of testing to make sure integration of the CVM sensors did not affect the composites' properties. The results were so positive, it generated a great deal of interest in our technology."

Also capable of reading strain, CVM sensors reportedly can detect a 0.00254 mm crack. "They are easily integrated into a CFRP stringer or door and detect when there is a disbond or delamination."

Airbus also is developing small-diameter (50-125 μm) fiber-optic sensors that can be embedded into CFRP structures during manufacture. They reportedly can measure temperature and stress fields during cure, residual stress build-up during assembly, and in the final structures, they can monitor impact damage and structural loads, helping to further weight-optimize designs.

Bockenheimer cites SHM as a key to achieving the best aircraft operability and revolutionary structural design, but acknowledges much work remains. "Many subsequent tests are required to prove durability," he says. "We want to define new tests which combine chemical, temperature and mechanical loadings, for example, to reduce cost and time."

Speckmann notes the formation of an OEM group within the SHM-AISC at its most recent meeting in April, which will initially include Boeing, Airbus, Sikorsky (Stratford, CT, US), Bombardier and Embraer (São José dos Campos, Brazil). It will begin identifying ways to work cooperatively on maturation of systems for commercial aircraft.

"We are already doing this independently," says Speckmann, "but there is too much work to be done yet for it to be duplicated." The ultimate goal, he says, "is to speed up maturation of SHM technology worldwide, so that all OEMs and operators can start to take advantage of its benefits." CW

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

Read *CW's* previous coverage of this subject online in "Structural Health Monitoring: Composites get smart" | short.compositesworld.com/SHMsmart

Read about design and fabrication of CVM and SMART Layer systems in CW's online sidebar, "Designing SHM systems" | short.compositesworld.com/SHMdesign

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Composites extend service of corrosion-prone oil and gas pipelines

Rehabilitation for subsea pipelines

Anticorrosion Protective Systems' (APS, Dubai, UAE) first InField Liner (IFL) was installed by APS during the summer of 2013 in a 203-mm (8-inch) diameter, 1.5-km-long crude oil pipeline between two offshore platforms in PETRONAS' Samarang oil field in the South China Sea, located offshore from Sabah, East Malaysia.

Source (all photos) | APS

Corrosion-resistant aramid fiber/thermoplastic liner gives new life to deteriorating steel subsea pipelines.

By Donna Dawson / Senior Writer Emeritus

The recent 101,000-gal oil spill off the California coast in the US offered grim testimony to the potential financial and environmental cost of corroded subsea pipelines. According to *The New York Times*, the cleanup of oil on beaches there had cost US$69 million, as of June 11, 2015, and costs were likely to climb. This and other articles about that incident pointed to pipe corrosion as the probable cause of the spill.

Global oil and gas interests operate more than 175,000 km of subsea carbon steel pipelines at varying depths around the world. These pipelines transport crude oil, gas and related products between offshore platforms and from offshore platforms to onshore facilities.

Counter-intuitively, one of the greatest threats to these undersea delivery systems is not saltwater, the external corrosive agent, but an unwelcome bacterial stowaway in crude oil that "breathes" the sulphates in crude and leaves behind highly corrosive hydrogen sulfide: "Due in large part to sulfate-reducing bacteria [SRB] accelerating *internal* corrosion, these pipelines can have a relatively short lifecycle," says Robert Walters, global project director for Anticorrosion Protective Systems (APS, Dubai, UAE). Together with PETRONAS Carigali Sdn Bhd (Kuala Lumpur, Malaysia), APS has developed in response an innovative composite liner system that places a corrosion-resistant barrier between an aggressive service medium, such as SRB, and the steel. Known as the InField Liner, or IFL, the liner also offers a secondary containment capability in the event of a rupture or damage to the outer steel pipeline and promises to dramatically extend the service life of the pipes, which Walters says have historically needed replacement in as few as four years.

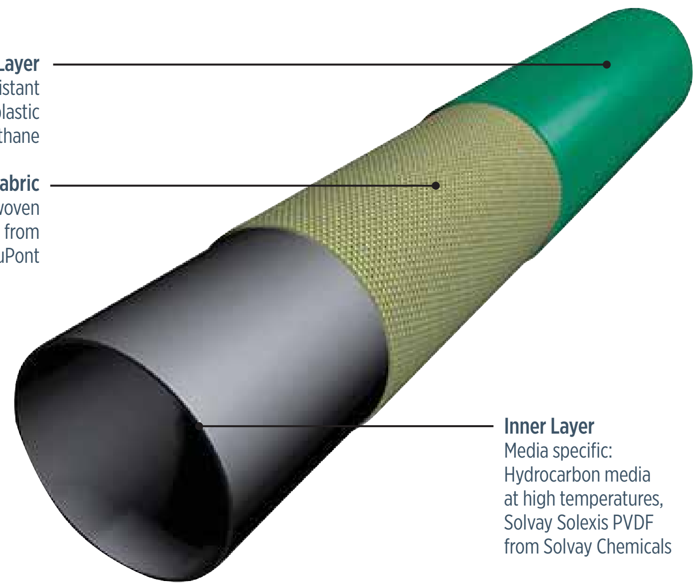
A team effort

Since 1978, APS has provided engineering, application and installation of specialized protective systems to the oil, gas, power and utility sectors in the Middle East and Asia through its Pipeline Rehabilitation and Specialized Coatings & Linings divisions. PETRONAS has expanded since its inception in 1974 as Malaysia's custodian of its national oil and gas resources, to become a fully integrated international conglomerate listed on *Fortune's* Global

500. Today, PETRONAS-related companies operate some 70% of the total 7,800 km of pipelines functioning in Malaysia.

For a number of years, protective composite liners for pipeline rehabilitation have been a growth technology onshore (see "Learn More," p. 54), but no comparable offshore technology existed in 2009, when Walters met with PETRONAS executives to discuss solutions to SRB-related and other internal corrosion of that company's subsea pipelines. Together, they determined the solution was a corrosion-resistant liner, and in April 2011, APS Pipeline Rehabilitation division went to work on a liner design concept.

Although APS designed and developed the liner system and is named as the joint inventor of the IFL technology, PETRONAS owns the IFL patent and trademark because it underwrote the development costs. APS is now negotiating with PETRONAS to secure an exclusive 20-year license to apply the intellectual property globally.



Light & flexible but abrasion/corrosion tough

The Kevlar core of the InField Liner is a strong, flexible structure supporting an abrasion-resistant TPU exterior layer that contacts the damaged host pipe, and a corrosion-resistant polyvinylidene fluoride (PVDF) inner layer that is exposed to the corrosive service medium. Source | APS

Critical design factors

The liner was designed to be pulled through pipe lengths of up to 5 km with multiple 90° bends having radii as small as 5D (*D* = nominal pipe outside diameter; 5D is a radius bend length that is five times the nominal pipe diameter). Each liner is custom designed and manufactured to match the original host pipeline bore, in nominal diameters from 152.5 mm to 457 mm (6 to 18 inches). To install the liner, then, it must be flexible enough to be folded and temporarily bound so it can be pulled through the pipe and around corners without damage or stoppage, and then subsequently inflated.

APS used Abaqus Unified FEA software (Dassault Systèmes, Waltham, MA, US) to develop and simulate a liner composition and manufacturing process that would meet the necessary mechanical strength properties — primarily the theoretical towing loads, liner folding and inflation forces, and the bending forces that would be incurred during installation, when the liner would be pulled through an existing pipe, particularly around tight bends.

APS envisioned the liner with a tightly woven, 100% aramid fiber cylindrical core. Kevlar — a product of DuPont Protection Technologies (Richmond, VA, US) — was selected as the liner's structural aramid core largely due to its combination of high tensile strength and high degree of flexibility, which would allow it to be manufactured, folded and spooled in long lengths. Thermoplastic matrices were incorporated into the design as extruded layers, forming inner and outer barriers to chemical/corrosion resistance and giving the liner abrasion resistance during installation as it's pulled through the bends of the pipe pathway.

Beyond the general design, each individual liner can be enhanced to meet environmental prerequisites, especially if it must withstand aggressive, hot, sour hydrocarbon service conditions of up to 110°C, or it can be planned and prepared for less »

Ready to install on arrival

Here, an IFL, still wound on its transportation drum, is lifted aboard an offshore platform in the Samarang oil field, South China Sea.

1 A single-ply, 2-mm-thick cylindrical structure is woven from Kevlar. The aramid fiber is drawn from hundreds of spools and woven in a manner similar to sock knitting, in (as shown) vertical format. Source (all step photo) | APS

2 Via a proprietary method, a layer of Solef PVDF (gray) is then extruded over the inner surface of the Kevlar cylinder, and a layer of thermoplastic polyurethane (green) is extruded over its outer surface as the aramid core moves continuously downward, held under tension to assure a smooth and consistent operation.

3 After the liner cools and the thermoplastic layers solidify against the core, the liner is reeled onto a transportation drum in a flat configuration.

aggressive service conditions, such as water re-injection or gas transmission.

Notably, a critical factor in each *individual* liner design is determining which end of the pipe to pull from. "The critical factors when pulling a liner tend to relate to the number and locations of the bends involved," Walters explains. In a recent analysis undertaken by APS for a 3.5-km long pipeline that has six 5D bends, for example, different pulling force requirements were calculated for different directions of pull. That is, the pulling force requirement in one direction was calculated as 12 tons, but in the *opposite* direction it was calculated as requiring nearly 72 tons. This difference was primarily due to the *location* of the 5D bends on the pipeline. Walters interprets the findings: "This analysis shows that it is not just a static tensile value of a liner that is important, but makes it clear that all the host pipe specifications and parameters combine to add into and impact onto the final calculation process. In the case of this particular pipeline, if the liner were to be pulled in the 12-ton loading direction, the liner then still retained a safety factor of well over 100% in relation to its overall tensile strength."

Design and manufacture have followed testing and qualification procedures in accordance with the American Petroleum Institute (API, Washington, DC, US) *Recommended Practice API RP 15S* (First Edition, March 2006) *Qualification of Spoolable Reinforced Plastic Line Pipe*, as well as API series 17 *Subsea Production System*, and applicable ASTM (W. Conshohocken, PA, US) and NACE (Houston, TX, US) standards. All liner-testing qualifications have been subjected not only to full verification

4 The liner is folded and taped as it is reeled onto a dedicated installation drum, which is transported to the offshore site with other installation equipment and personnel.

6 The liner is then pulled through the host pipe by a winching cable at about 10m/min.

5 After the host pipeline and the riser pipe are prepared, the liner is guided into the riser.

7 When installation is complete, the liner is cut to length and air-inflated until it expands to form a tight fit against the host pipe. End-termination connectors are then installed, and the pipe is hydro-tested for 24 hours before the pipeline is recommissioned.

by independent laboratories but also to third-party inspection, Walters says.

Synchronized vertical production

APS InField Liners are produced in a multi-stage patented and proprietary process that is executed throughout vertically rather than in the horizontal orientation typical of pultrusion, continuous filament winding and other linear composites fabrication processes (see Steps 1 & 2, p. 52), with all process phases carefully synchronized. "The complete IFL is produced in a single process, with only the length being the defining factor as to when production should be started and stopped," Walters says. The entire APS production system is computer-controlled to produce the stipulated weaving pattern, tube diameter and length to meet specific liner design requirements. The control system is a proprietary software package specifically designed for this function.

"Every element of the fully automated manufacturing procedure is carefully and continuously monitored and controlled with real-time computer assessment and feedback so as to ensure absolute operational precision," Walters emphasizes. "Every facet of the liner production quality assurance is recorded, and the produced liner quality is, thereafter, further verified by extensive testing prior to factory acceptance and certification."

Production begins with the liner's aramid core cylinder (Step 1, p. 52). The Kevlar aramid is woven in the tubular shape *without a mandrel*, in a manner similar to knitting a sock, says Walters. Instead of the circular needles often used for knitting socks, the patented weaving system uses an automated circular wheel. »

To produce an IFL for a recent nominal 152.5 mm (6-inch) outside diameter pipe, the system pulled from a battery of more than 250 spools of dry Kevlar aramid cords to weave a high-strength, single-ply, 2.0-mm-thick cylindrical structure. DuPont defines a Kevlar *cord* as a single string of Kevlar, which is composed of a number of threads, which, in turn, comprise a number of filaments.

While the finished core cylinder moved downward as it was woven, the highly corrosion-resistant inner and outer thermoplastic layers were extruded onto it (Step 2, p. 52). The inner barrier layer — the initial line of internal corrosion defense — was first extruded onto the inside surface of the Kevlar core. For this layer, which is directly exposed to the corrosive service medium, APS chose Solef PVDF, a polyvinylidene fluoride resin from Solvay Specialty Polymers (Alpharetta, GA, US). This semi-crystalline fluoropolymer provides stability in harsh thermal and chemical environments and has an established record of high-performance service in offshore hydrocarbon applications.

PETRONAS Carigali says the IFL has saved as much as 50% of the capital cost of a replacement pipeline.

The IFL's outer layer, which contacts the inner surface of the host pipe, was then extruded onto the exterior of the core. The outer layer is an abrasion-resistant thermoplastic polyurethane (TPU) from BASF Polyurethanes (Waterloo, Germany).

After inner and outer extrusion layers were applied, the liner was allowed to cool under controlled conditions until the extruded thermoplastic layers crystallized and solidified against the core. When the crystallization phase was complete, no secondary manufacturing operations were necessary. During the entire process, the vertical cylinder of core and its interior/exterior thermoplastic layers continued to move downward, held under tension to assure a smooth and consistent operation as the liner was continuously produced and then cooled. In this way, the liner "actually removes itself from the weaving system and related internal and external extrusion processes," Walters explains. The cooled crystalized liner was then automatically reeled directly onto a transportation drum in a flat configuration and prepared for shipment to the customer's location (Step 3). Shipping reels are specifically designed to accommodate up to 5 km of liner and can be packed into standard 20-ft- or 40-ft-long shipping containers.

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Successful, cost-effective installations

The first installations, in 2013 and 2014, went into internally corroded pipelines that had been marked for imminent closure. The inaugural IFL, in the summer of 2013, was installed by APS in a 203-mm (8-inch) diameter, 1.5-km-long crude oil pipeline operating at 10 bar, between two offshore platforms in PETRONAS's Samarang oil field in the South China Sea, located offshore from Sabah, East Malaysia. The liner was shipped to the project yard in Labuan, where it was put through a folding-and-banding process: The flat liner was pulled from the shipping reel and passed through a series of machines that fold it lengthwise into a U-shape, then use flexible PVC film-based tape to hold the liner's folded shape in position. This process reduced the liner's diameter and, thus, reduced the pulling forces required to pull it through the host pipe.

The folded/taped liner was then reeled onto a dedicated installation drum (Step 4, p. 53). The drum and other installation equipment and personnel were transported to the offshore site and a guidance framework was set up to define the liner pulling path. The host pipeline was cleared of its flow media and thoroughly cleaned, measured and assessed for its exact condition. Next, the riser pipe — the vertical pipeline that connects the platform-based processing equipment above the water line to the horizontal pipeline network and related equipment on the seabed — was modified to accommodate installation of the liner end connector units after liner installation.

A winching cable was pulled into position in two steps: First, a specially designed pig was blown from the main winching platform to the liner installation drum platform. (A *pig* is a device commonly used for cleaning and maintenance of pipelines; it can be blown through a pipe by raising the air pressure behind it, which pushes the pig forward). The pig carried a small, lightweight cable through the pipeline. A secondary winch on the installation platform was then attached to the small cable, which, in turn, wss used to pull a larger, main winching cable through to the installation drum for connection to the liner towing head.

When the existing pipeline was thoroughly cleared and cleaned, the winching cable was in position and other liner installation preparations were complete, the liner was positioned (Step 5) and pulled through the host pipe (Step 6). Pulling force was closely monitored and controlled during the installation process. This pulling operation is normally performed at an approximate pulling speed of about 10 m/min, Walters notes. A liner can be pulled through a 1.5 km pipe in about 2.5 hours.

After it was in place, the liner was cut to length, and then inflated, using low air pressure (Step 7). As it inflated, the banding tapes broke and the liner expanded to fit tightly against the host pipe's inside surface. End-termination connectors were then installed and the pipe was hydro-tested for 24 hours at a pressure set at approximately 1.5 times the normal pipeline operating pressure, or ~15 bar (1.5 times the 10-bar pipeline pressure). When the hydro test was deemed successful, the pipeline system was recommissioned for service.

Another IFL installation, in a 152.5-mm (6-inch) diameter, high-pressure (60 bar) gas pipeline, took place at the same time and in the same location. And in 2014, following the success of the first IFL installations, APS installed its liners in four additional PETRONAS Cargali 152.5-mm gas pipelines, totaling some 4 km in length, in the West Lutong field, about 50 km offshore and north of the city of Miri, in Sarawak, Malaysia.

The result? Walter says, "PETRONAS now estimates the service life of these lines to have been extended by at least 30 years." Further, PETRONAS Carigali says IFL has saved the company as much as 50% of the capital costs of a replacement pipeline.

Commercial solution for offshore pipe

Walters says that IFL is market-ready and APS is able to service all the major oil companies that have expressed interest in the IFL subsea pipeline rehabilitation system. Since the successful Samarang installations, Walters has approached major offshore oil and gas operators in Southeast Asia, the Middle East, North America and West Africa.

"The response to the enormous potential of this subsea technology has been overwhelming," he says, emphasizing, "For the first time in the history of offshore pipeline operations, there is now a viable alternative to pipeline replacement. And not only a technology advance, but an alternative, whereby major anticipated cost savings — compared to new pipe laydown — is the main driving factor."

Rehabilitation and repair by *lining* rather than *replacing* deteriorating pipelines on land using cured-in-place pipe (CIPP) has proven to be a remarkable time- and cost-saving idea that has captured about half of the sewer line rehabilitation in the US — including sewer lines in onshore oil fields and petrochemical manufacturing plants — and also has been formulated for drinking water. Further, it is on a growth curve in Europe, for gas and pressurized water distribution, foul outflow and sewage line systems (see "Learn More," p. 54).

Since its inception, CIPP in a variety of forms has created a substantial market for composite materials in the rehabilitation and repair rather than replacement of underground pipelines. Although IFL by APS is a distant cousin to CIPP, technologically, it is the first commercial composite liner for pipeline operators in the *offshore* market. IFL looks like an idea with equally great potential to create a similar rehab/repair market for under*sea* pipelines. CW

ABOUT THE AUTHOR

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Composites Events

Sept. 8-10, 2015 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
www.speautomotive.com/comp.htm

Sept. 9-11, 2015 — Toulouse, France
2015 Int'l Conference on Lightning and Static Electricity (ICOLSE)
www.icolse2015.org

Sept. 9-11, 2015 — Cambridge, UK
ACIC 2015 – 7th Biennial Conference on Advanced Composites in Construction
www.acic-conference.com

Sept. 14-16, 2015 — Toulouse, France
SpeedNews 16th Annual Aviation Industry Suppliers Conference
www.speednews.com/all/conference

Sept. 15-17, 2015 — Louisville, KY, US
IBEX 2015
www.ibexshow.com

Sept. 15-17, 2015 — Amiens, France
SAMPE Europe Conference 2015
www.sampe-europe.org

Sept. 15-18, 2015 — Husum, Germany
HUSUM Wind 2015
www.husumwind.com/content/en/start/welcome-2015.php

Sept. 21-22, 2015 — Stuttgart, Germany
1st Int'l Composites Congress (ICC)
www.avk-tv.de/events.php?page=&year=2015&month=09

Sept. 22-23, 2015 — Boston, MA, US
JEC Forums 2015
www.jeccomposites.com/events/jec-forums-boston-2015

Sept. 22-24, 2015 — Stuttgart, Germany
Composites Europe
www.composites-europe.com/startseite_1.html?sprache=englisch

Sept. 22-24, 2015 — Seattle, WA, US
SAE 2015 AeroTech Congress and Exhibition
www.sae.org/events/atc

Sept. 23-24, 2015 — Edinburgh, UK
High Performance Polymers for Oil and Gas 2015
www.oilgasconference.com/register/events

Oct. 5-7, 2015 — Orlando, FL, US
2015 Polyurethanes Technical Conference
polyurethane.americanchemistry.com/Polyurethanes-Technical-Conference

Oct. 20-21, 2015 — Knoxville, TN, US
Additive Manufacturing 2015
www.additivemanufacturinginsight.com/conferences/am-workshop

Oct. 20-22, 2015 — Singapore
JEC Asia 2015
www.jeccomposites.com/events/jec-asia-2015

Oct. 26-29, 2015 — Dallas, TX, US
CAMX – The Composites and Advanced Materials Expo
www.thecamx.org

Nov. 4-5, 2015 — Birmingham, UK
Advanced Engineering UK 2015
www.advancedengineeringuk.com

Nov. 4-7, 2015 — Sao Paulo, Brazil
Compocity 2015
www.almaco.org.br/compocity/2015

Nov. 12-14, 2015 — Istanbul, Turkey
PUTECH Eurasia/Eurasian Composites Show
www.eurasiancomposites.com

Nov. 17-19, 2015 — Seville, Spain
2nd Aerospace Structural Impact Dynamics Int'l Conference
asidiconference.org

Dec. 8-10, 2015 — Knoxville, TN, US
Carbon Fiber 2015
www.compositesworld.com/conferences/compositesworlds-2015-carbon-fiber-conference

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COMPOSITES LIGHTEN DRIVING SIMULATOR DOME

A first for its developers, the low-mass enclosure spawns a new product venture

Designed by Pagnotta Engineering Inc. and built by JRL Ventures, this projection dome for CEAL's driving research simulator met all technical, weight and cost requirements, using fire-retardant, resin infused composites. Source | PEI & JRL Ventures

Pagnotta Engineering Inc. (PEI, Exton, PA, US) and JRL Ventures (Cape Coral, FL, US) each have a long history and reputation for excellence in construction of domed virtual-reality projection enclosures for the flight-simulation industry. Recently the two collaborated on a *driving* simulator dome, a first for both and a successful study in dome lightweighting.

The 5.8m diameter by 4m tall fiber-reinforced plastic (FRP) projection dome — designed by PEI and built by JRL Ventures — is part of the DriverLab driving research simulator, one of four interchangeable, self-contained laboratories that can be mounted on a 6m by 6m six-degrees-of-freedom hydraulic motion platform. Because each dome payload must not exceed the platform's maximum weight limits, DriverLab had to meet a strict weight target.

DriverLab is part of the Toronto Rehabilitation Institute, University Health Network's (TRI-UHN, Toronto, Canada) Challenging Environment Assessment Lab (CEAL). CEAL's motion simulator labs mimic everyday environmental challenges faced by older people and those with disabling injuries or illnesses. DriverLab will be used to assess driving skills and investigate the effects of weather, glare, traffic and devices (e.g., navigation aids, mobile phones) on driver performance, as well as to evaluate the impact of new treatments and remediation technologies developed at TRI.

"Images projected onto screens will surround the driver, who will actually be 'driving' a specially modified Audi A3, which will sit on the turntable inside the dome," explains PEI engineering manager, Alex DiEdwardo. "The simulator will put drivers into different situations and see how they react." He adds that because this simulator lab includes an actual car, the weight requirement was especially challenging. DriverLab, in fact, will be lowered through floor grates in front of the hospital into CEAL's underground research facility. Therefore, minimizing crane size, alone, is cost-advantageous. "JRL ... suggested cored construction and vacuum infusion processing to control resin content and keep weight minimized," he notes.

PEI worked with projection systems developer International Development of Technology (Breda, The Netherlands) to refine the dome's design and specifications and then generated digital drawings for its roof, floor and 2.7m tall by 2.3m wide sidewall segments. From these, JRL Ventures made the molds for each, using CNC-machined expanded polystyrene (EPS) foam. The shaped EPS was sheathed with fiberglass and resin, then overlaid with syntactic, which was machined to the final dimensions of the dome's inside surface. Given the small part count, foam molds were practical and saved time and cost but presented a potential lack of vacuum integrity for infusion, a problem for which Diamondback tooling gel coat from Polycryl (Oakland, TN, US) provided a solution.

"Because this simulator would operate in the basement of a hospital building, it had to meet building fire codes," DiEdwardo explains. For that reason, Hawkeye Industries' (Bloomington, CA, US) Duratech vinyl ester in-mold primer was applied over the prepped mold surfaces prior to dry layup, to enable cured parts to be painted with fire-resistant paint. Parts were then layed up as sandwich constructions of (variously) 13 mm to 19 mm thick Airex foam core (3A Composites Core Materials, Colfax, NC, US), chosen for its fire-retardant properties, between skins of Vectorply (Phenix City, AL, US) biaxial noncrimp glass fabrics infused with AOC's (Collierville, TN, US) Firepel polyester infusion resin, also selected, in part, for its fire-resistant properties.

"Our total weight budget was 3,000 kg, but that included the dome and a steel stanchion," says DiEdwardo. "The FRP weight ended up being 1,000 kg, including ventilation ducting, so we met the weight requirements without issue and also used cost-effective materials to meet the cost budget." The dome successfully completed factory acceptance testing by IDT and TRI-UHN in February and, pending timely Audi A3 delivery, will be installed in August.
PEI and IDT are now codeveloping a standard line of driving simulators to serve the needs of research institutes and car manufacturers. CW

Product Showcase

» INTEGRATED MANUFACTURING SYSTEMS

Automated composites manufacturing with cure tracking

Combined Composite Technologies (CCT), a business unit of **Hexion Inc.** (Columbus, OH, US), has introduced a programmable logic-controlled (PLC), automated resin curing and molding system. The new, self-contained Optibox tool system uses closely tracked data on resin filling and curing to optimize resin-processing cycles for greater productivity and better-quality laminates in composites manufacturing. CCT notes that in a typical composite manufacturing process, once a resin infusion tool is closed, there is no way to monitor what is actually happening inside. Processing steps are arbitrarily timed, according to the resin manufacturer's suggestions despite that fact that, in actual practice, the optimal timing of these steps can vary. The Optibox tool enables composites manufacturers to track and adjust each step's timing and heating automatically and precisely, and then trigger the next step as soon as the material is ready. This technology reportedly improves efficiency through faster cure cycles and helps reduce product flaws in preforms, prepreg molding and resin infusion processes, including vacuum assisted resin transfer molding (VARTM). The Optibox tool device is a portable, self-heating, single- or double-sided mold tool with an LCD readout. Interchangeable upper tool configurations enable flexible, rigid, heated and multi-cavity functionality.

When loaded with fiber reinforcement, the Optibox tool enables cycle time optimization by tracking resin filling and curing through a variety of sensors, and logging the data for quality assurance. Variables monitored include resin flow, temperature profile over as many as 20 zones, extent of mold-filling, gelation, vacuum level, and degree of cure. Multi-zone heat controls respond to sensor feedback, promoting optimized curing to achieve desired part tolerances and finish. The fully programmable cure cycles combined with integrated pre-set or selectable vacuum settings afford the user complete process control. CCT says the Optibox tool is designed for small to mid-size composites enterprises because it allows for efficient use of time, space, energy, expense and manpower. Technical educators reportedly have expressed interest in using the device in demonstrations, so students will understand, in detail, how composite processing works.

www.hexion.com

» THERMOPLASTIC RESIN SYSTEMS

Foam, prepreg and semi-finished materials

Solvay (Brussels, Belgium) has launched Tegralite, a family of high-performance, semi-finished thermoplastic-based materials designed for use in aircraft interiors applications. Tegralite grew out of Solvay's work with its alliance partners **Aonix** (Ottowa, ON, CA), **JSP** (Madison Heights, MI, US) and **3A Composites** (Sins, Switzerland). The Tegralite line includes foams, composites and sandwich materials manufactured from Solvay's portfolio of polymers. One of the first products in the Tegralite line is Tegracore PPSU, a foam used in the cabin of the Airbus A350 XWB and the *Solar Impulse 2*. Also available are thermoplastic sandwich materials made of Tegracore and sulfone-based prepregs manufactured by Aonix. Solvay says Tegracore PPSU is a super-tough structural foam that meets all flame, smoke and toxicity (FST) requirements in the cabin and also resists aerospace liquids, such as Skydrol. Other benefits of Tegralite, says Solvay, include reduced labor costs for primary and secondary part-production operations, and the completely thermoplastic nature of the materials further opens the avenue to onboard repair (e.g., welding) in contrast to incumbent thermosets. The Tegralite product portfolio also will include prepregs.

www.corematerials.3acomposites.com | www.aonixcorp.com
www.solvayspecialtypolymers.com

» PUBLICATION: FIBER REINFORCEMNTS

Glass fiber sizings assessed in new book

GlassFibreSizing.com (Glasgow, UK) offers *Glass Fibre Sizing: A Review of Size Formulation Patents*, a new book by James L. Thomason that offers an analysis of glass fiber sizings, based on a review of patents on the technology. Thomason notes that the intense level of industrial secrecy around size formulations makes it difficult for processors to assess and understand sizings. This book contains analysis of more than 500 examples of patented size formulations, many of which are "probably still used in commercial glass fiber production," Thomason notes. The book features an introduction and eight chapters: "Sizes and Sizing in Glass Fibre Production," "Size Formulations in Patents," "Size Patents Of Owens Corning," "Size Patents of Vetrotex," "Size Patents of PPG Fiber Glass," "Size Patents from Other Companies," and "Glass Fibre Product Identification." Thomason reportedly has 25 years of experience at Shell Chemicals and Owens Corning, leading global product development programs involving extensive fundamental research and development of glass fiber sizings and composites. He is currently a professor of Advanced Materials and Composites at the University of Strathclyde, In Glasgow, where he leads the University's Advanced Composites Group. The book is available for purchase for £189 (~US$297) at the Web site:

www.glassfibresizing.com

» PREIMPREGNATED REINFORCEMENTS

Ultralight/ultrathin uni carbon fiber prepreg tapes

North Thin Ply Technology (NTPT, Penthalaz-Cossonay, Switzerland) has developed a unidirectional prepreg tape with an areal weight of only 15 g/m^2, producing what the company believes is possibly the thinnest prepreg tape on the market. NTPT achieved this outcome by spreading an intermediate-modulus carbon fiber and adding the high T_g epoxy resin ThinPreg 120EPHT$_g$ – 402. The resulting prepreg can be used to create lightweight sandwich panels for use in ultralight aircraft, UAVs and other aerospace applications as well as the rigid wingsails now used in racing yachts. **www.thinplytechnology.com**

» PREIMPREGNATED REINFORCEMENTS

Flax-fiber prepregs for aircraft interiors

At the Paris Air Show, in Le Bourget, France, **Lineo NV** (St.-Martin du Tilleul, France) recently displayed its flax-based epoxy prepregs for aircraft interiors, called FlaxTape, which reportedly are 35% lighter than carbon fiber/epoxy prepreg tapes. Flax fiber, according to Lineo, has the same mechanical properties as glass fiber and also demonstrates useful damping properties. Lineo also offered a sandwich product, called Simbaa, as an alternative to traditional sandwich constructions. The company is reportedly ramping up production of FlaxTape for the automotive industry as well. **www.lineo.eu**

» METER/MIX/DISPENSE EQUIPMENT

Gel coat proportioner

Graco (North Canton, OH, US) has introduced the Graco RS, a new flexible and precise gel coat system for molded composite components, designed specifically for use in automotive composites applications. Graco's gel coat system proportioner offers on-ratio dispensing, while the company's RS gel coat gun offers both superior spray performance and ease of maintenance. The Graco RS gel coat gun is up to 44% lighter than competing gun technologies, leading to better handling and spraying control for operators. The gun also delivers what Graco says is a superior spray pattern, due to its Air Assist Containment (AAC) technology. The AAC technology wraps the spray in a containing shield of air, preventing atomized droplets from escaping the intended spray pattern. The resulting decrease in overspray, says Graco, reduces material waste and creates a healthier environment for operators. Additionally, the gun's quick-disconnect front end reduces maintenance, while the system's needle clamp design is said to prevent operators from having to adjust needle settings after routine maintenance. **www.graco.com/us/en.html**

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ADVERTISING INDEX

ADVERTISING INDEX

SHOWCASE

Carbon composite spring: Big performance, small package

Disc spring stack is lighter, reduces friction and can be performance-tuned.

By Sara Black / Technical Editor

» Helical coil springs are a mainstay in today's automotive suspensions, with a basic design essentially unchanged since their advent. MW Industries (Rosemont, IL, US) is the largest US spring manufacturer/supplier and the largest supplier of high-performance springs to motorsports through its Hyperco division (Pontotoc, MS, US). The company stays abreast of new materials and, therefore, began investigating carbon fiber composites for high-performance springs several years ago, recalls Mark Campbell, corporate head of new product development: "We actually invited some composites specialists to come in and partner with us on designs." That collaboration resulted in a *helical* all-carbon composite spring design that seemed reasonable, says Campbell, but did not perform as expected, because "carbon does not perform well when placed in torsion."

Further experiments included carbon composite "bump stops," suspension components designed to prevent metal-on-metal contact under extreme compression for NASCAR racing teams. Although these were ultimately banned by the racing body, the bump stop's compressible components led Campbell and Hyperco to an "ah-ha" moment, the fruit of which are lightweight *disc springs*, sold under the Carbon Composite Bellows Spring (CCBS) trademark.

An alternative to the metal coil spring

CCBS disc springs — stacks of slightly conical compression molded carbon/epoxy discs manufactured by the Hyperco division (Pontotoc, MS, US) of MW Industries (see above) — form strong, reliable suspension components in race cars, like this one (right), driven by SCCA racer Chris Farrell.

Source (all photos) | Hyperco

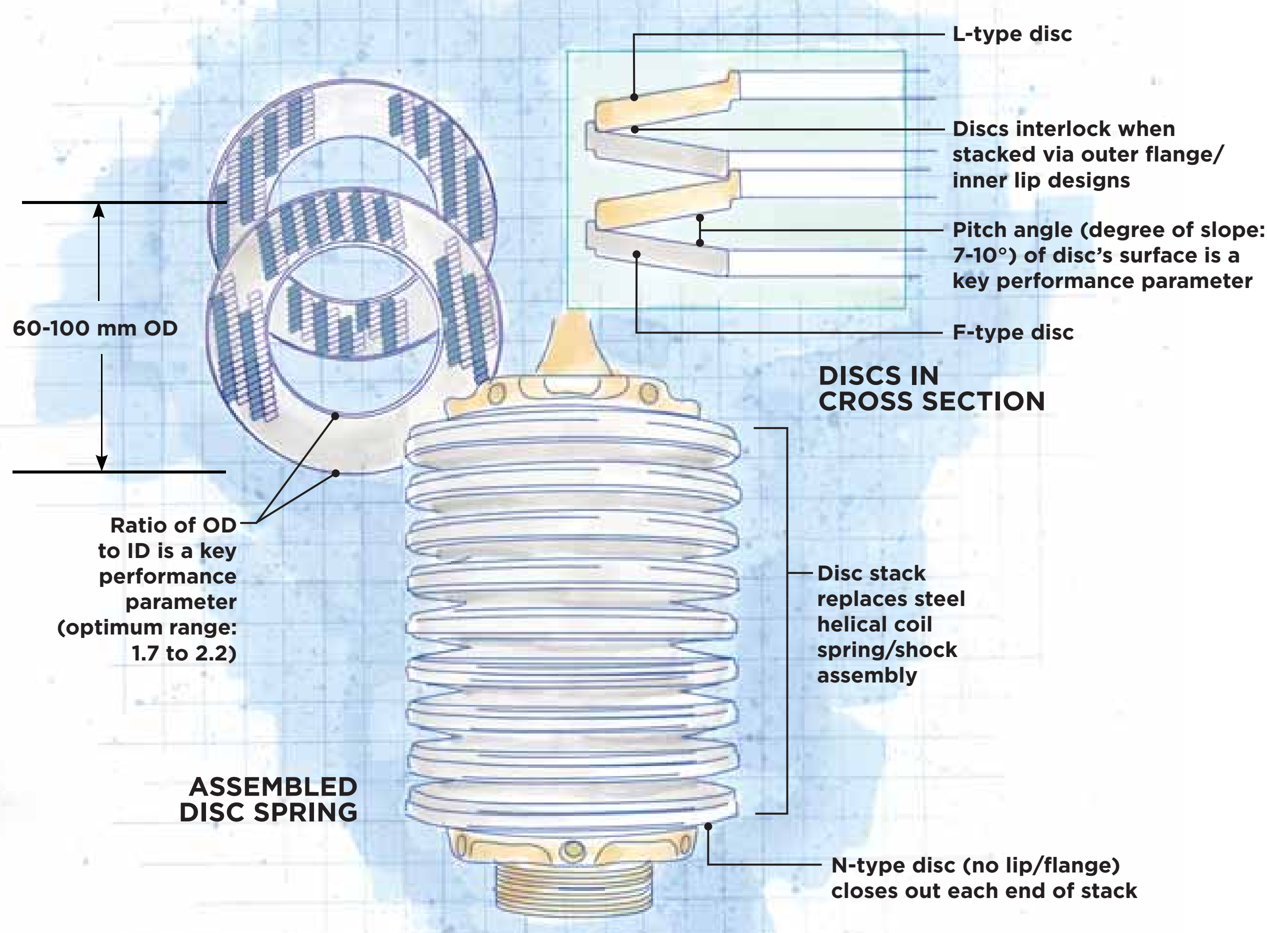
The Belleville washer

Hyperco's CCBS incorporates a type of "Belleville washer," an industrial widget with a long and storied history. Invented in the mid-1800s by industrialist Julian Belleville, the truncated-cone-shaped steel washers could resist high loads in a small space, providing high spring force over a very short distance as well as high-energy storage capacity. Commonly used in industrial valve assemblies, the washers ultimately proved invaluable in warfare, particularly as return springs in large-caliber artillery. In fact, Belleville washer designs used by the U.S. military were classified until the 1970s.

Campbell's team believed that, given the success of the bump stops and the history of Belleville washers, a composite disc spring was achievable. By stacking multiple carbon composite discs (see drawing, p. 63), it seemed possible to achieve spring performance equivalent to a helical spring, or to steel disc springs, but at a weight reduction of as much as 60%. Stacked discs would be especially appropriate for race cars, which typically weigh less than passenger cars and, therefore, require less spring stroke length but need stiff springs for high-speed control.

Despite the history and possibilities, *data* were scarce. "The mathematical equations of how Bellevilles work are hard to come by, with no design formulas," asserts Campbell. "We had to develop our own equations for the shape and size of the composite versions, for the spring characteristics we wanted. It has taken a huge amount of time and testing."

The team had to consider many variables in search of optimum values for the overall disc diameter, the ratio of disc outer diameter (OD) to inside diameter (ID), the disc's laminate thickness and the pitch angle (degree of slope) of the disc's upper surface.



DESIGN RESULTS **Hyperco Carbon Composite Bellows Spring (CCBS)**

- Small carbon composite discs, molded at pitched angles, are stacked alternately, in series.
- The disc design flattens under axial load, eliminating undesirable spring side loads.
- Stacks can be "tuned" to meet specific compression and extension conditions.

Illustration / **Karl Reque**

The team also needed a means of mechanically interlocking adjacent discs, when stacked. Further, a disc spring made with carbon composites would take advantage of carbon fiber's high tensile properties in bending but had not been tried for high-frequency cyclic loading typical of an automotive suspension (between 0.3 to 33 Hz).

What was obvious, says Campbell, is that the design would eliminate a major disadvantage of the coil spring, which "when axially loaded, always produces undesirable torsional side loads, and when installed in a coil-over spring/shock assembly, these side loads create significant friction on the shock shaft bearing and seal." This phenomenon, referred to as *stiction* (from *static* and *friction*), adversely affects the shock action, and puts stress on the car's suspension that can lead to handling problems. The composite discs, by comparison, would generate no side loads, since they simply flatten out under axial load.

Friction *is* a problem, however, in the key disc-spring variable of *spring rate*, the amount of load required to deflect a spring one inch. The disc design needed to deliver consistent spring rates, from part to part. Here, Hyperco had to investigate the spring phenomenon known as *hysteresis*. The term refers to the fact that when load is applied to the spring, causing it to compress a certain distance (e.g., 10 mm), that load (in kilograms) is *greater* than the load measured during *extension* (springback) or unloading of the spring, for the same measured deflection, says team member and carbon composite program manager Greg Hazard. As a result, the suspension unit does not move as freely as it should. Spring manufacturers work hard to reduce hysteresis — that is, to ensure that the deflection value is the *same* during compression and extension, and, thus, contribute to a more predictable, controllable suspension system that reacts faster and more precisely to imperfections in the road surface.

"In a *disc* spring," says Hazard, "hysteresis is caused by the friction at the mating surface of two adjacent discs." That friction adds load to the spring during compression, but reduces load during extension. Hyperco believed it could use the molding process to vary the shape of the disc contact region to manipulate the friction to damp suspension load energy for some application requirements. Hazard says, "Hysteresis exists, and we might as well be able to use it as a tuning tool to the driver's advantage." »

Greater control of a key spring variable

Hyperco's CCBS discs are molded in the style of Belleville washers, and are available in a variety of sizes capable of producing a variety of spring rates.

Greater design freedom and market potential

The CCBS disc springs are adaptable to, and "tunable" for desired performance in, a variety of aerospace, industrial and recreational applications, including motorcycles.

High-tech + trial & error

Hyperco had the advantage of proprietary and established in-house spring development programs and testing equipment. Says Hazard, "We knew the characteristics we wanted to achieve, so we built and tested our designs in a trial-and-error process, and used that data to adjust the mathematical formulas, then went back to producing more prototypes, in an iterative fashion."

Disc iterations were compression molded from woven carbon/epoxy prepreg supplied by TCR Composites Inc. (Ogden, UT, US), prepregged Qiso slit braid from A&P Technology Inc. (Cincinnati, OH, US) and materials from other suppliers. Three basic disc designs were molded: F-type discs have a small outer flange; L-types have a lip that centers the mating F-type flange (see drawing, p. 63); and N-types have no flange or lip, and are used as the last disc in a stack, to provide a solid carbon surface on the spring perch. "The layup varies," Campbell says, explaining, "We've created 'families' of disc sizes, and can create different spring rates by varying disc thickness and fiber orientations." Hyperco is working on establishing design standards for the discs, to make information available for CAD software programs and to raise awareness of the technology for engineers.

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Hyperco's Mark Campbell unveiled the CCBS "Bellows Spring" at *CW's* Carbon Fiber 2013. Read about it online | short.compositesworld.com/ALTDgT6F

Prototype discs underwent C-scan nondestructive inspection followed by spring rate testing on Hyperco's high-accuracy machine from Larson Systems Inc. (Minneapolis, MN, US), equipped with sensors and special software that provided data on spring rate and hysteresis based on deflection measurements. Special fixtures were required to test individual discs and disc stacks, says Hazard. Testing included long-term cyclic fatigue, with load cell setups at high frequency to detect creep or fatigue failure.

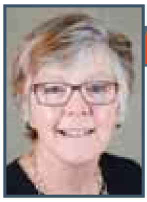
The data show that pitch angles between 7° and 10° are possible, depending on the application, and allow an appropriate degree of deflection and spring rate at desired loads. Further, the optimum window for OD/ID ratio ranges from 1.7 to 2.2, "to optimize the amount of storable energy vs. the design envelope," that is, the chassis space available for spring installation, says Hazard.

Hyperco's refined in-house molding processes now yield discs consistently within ±2% of the designated disc spring's spring rate, and Campbell points out that the carbon composite offers better repeatable rate change during spring compression than steel. Hazard adds that it is possible to design in some friction between discs to achieve damping for energy control, perhaps not for motorsports, but for other industry applications for which the company has begun testing.

Track-proven

The beauty of the CCBS for motorsports, explains Campbell, is that racers can "tune" disc stacks, with higher or lower spring rates, to match track conditions. "Although our standard size range is optimum, we can also produce custom sizes for specific needs," adds Hazard. A number of amateur racers, among them Sports Car Club of America (SCCA) national champion Chris Farrell (see photos, p. 62) have adopted the CCBS, with great success. Although it costs more than a metal coil spring, its "tunability" is appealing. When racers factor in several different sets of *steel* springs for different tracks/conditions, the price-per-rate cost is competitive. Unfortunately, US pro racing organizations, including NASCAR, IndyCar, IMSA and NHRA, have ruled out carbon disc springs, for now. But Campbell contends, "As with any new technology, acceptance takes time and we believe ... they will allow it in the future."

"Lightweighting in automotive is a huge issue now," concludes Hazard, "and no one else is approaching the issue of lighter springs like we are." CW



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