HIGH-PERFORMANCE

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- Carbon fiber skeleton frames new airship
- Composites deliver *Curiosity* to Mars
- Machining update: Drilling dry stacks
- SAMPE Europe/JEC Europe 2014 reviews



by A&P Technology

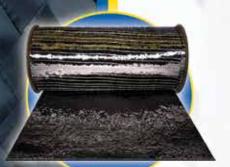


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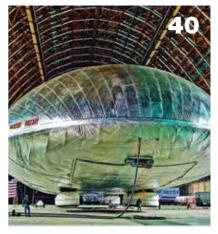
By Ginger Gardiner

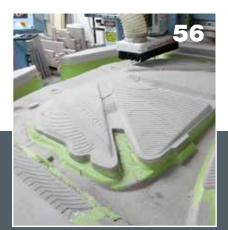
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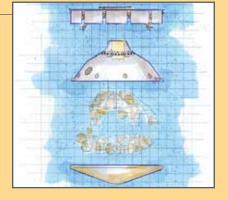
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FOCUS ON DESIGN

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From the mission's launch to its touchdown on the Martian surface 1.7 million miles later, composites did the job throughout and stuck the landing!

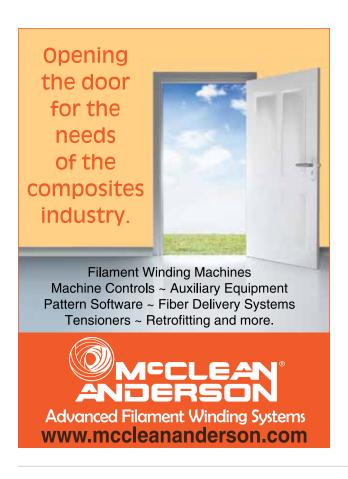
By Donna Dawson



ON THE COVER

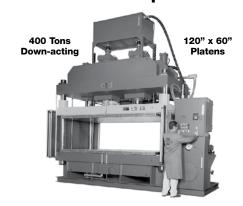
DARPA funding and an internal composite truss frame concept gave Igor Pasternak, founder, CEO and chief engineer at Worldwide Aeros Corp. (Aeros, Montbello, Calif.), the opportunity to launch the *Dragon Dream* prototype, a 266-ft/82m long variable-buoyancy airship with a wingspan of 110 ft/34m, and height of 50 ft/15.4m. Larger airships are coming for commercial shipping to sites without airstrips.

Source: Worldwide Aeros Corp.



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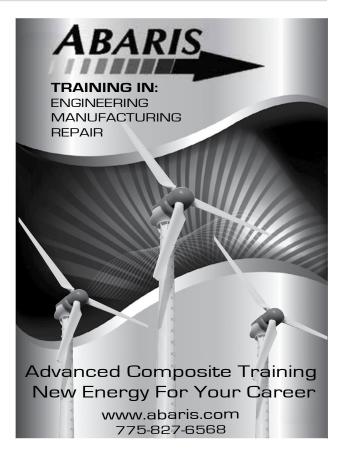


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FROM THE EDITOR

ombardier's Learjet 85 business jet flew for the first time on April 9 in Wichita, Kan. An aircraft's first flight is a significant milestone, and good cause for celebration. However, the Learjet 85's first foray into the air is, potentially, even more significant for the aerospace industry, and might be offering

us, at least symbolically, a glimpse into the future of resin, fiber and process use in composite aero-structure manufacturing.

The Learjet 85's significance does not lie in its composites-intensity. Almost every aircraft under development today — in commercial, business and general aviation — will fly composites in some

The more composites are used in aircraft, the more comfortable the FAA will become with what is a relatively novel material.

way, and many will make extensive use of carbon fiber composites in the fuselage, wings, tail and other structures. What sets the Learjet 85 apart is how and with what Bombardier is manufacturing the plane's composite structures.

Pierre Harter, engineering manager – M&P, technology readiness and structural certification Learjet, reported at SAMPE Tech in Wichita late last year that the wingskins and spars for the plane are manufactured in Belfast, Ireland, using an in-autoclave resin transfer infusion (RTI) process. Moreover, the fuselage and empennage are manufactured in Querétaro, Mexico, via an out-of-autoclave (OOA) vacuum-bagged process.

Infusion and OOA are not new, but their use in the manufacture of major aerostructures was, prior to the *Learjet* 85 program, largely unexplored territory. The production of the fuselage is particularly ambitious. It's done with Cytec Aerosapce Material's (Tempe, Ariz.) CYCOM 5320 prepreg, under vacuum bag in a conventional oven — at about 6,000 ft/1,829m above sea level in south-central Mexico. The altitude, of course, makes the vacuum calcula-



tions more challenging. On top of that, Harter says breathing methods, debulk cycles, dwell times and resin rheology needed special tweaking to achieve less than 1 percent void content in fuselage parts.

When asked why Bombardier is taking the time, and going to the expense and effort required to develop an OOA process for the Learjet 85, Harter said the company saw that

aerostructures manufacturing was headed in this direction and wanted to be in front of the technology, not chasing it ... or competitors.

Even more time, expense and effort, of course, was required to meet the most important challenge: the U.S. Federal Aviation Admin. (FAA). As Boeing and Airbus did with the 787 and A350 XWB

respectively, Bombardier was required to perform extra tests to meet the FAA's special conditions for certification. These focus on inflight flammability, post-crash flammability, crashworthiness, durability, toxicity in burn, damage tolerance and thermal expansion

at interactions with metals.

The more composites are used in aircraft, the more familiar and comfortable the FAA will become with what is still, in its view, a relatively novel material. Thus, theoretically, composite aircraft certification will become easier and faster. Until then, however, airframers like Bombardier will bear the brunt of the extra scrutiny on behalf of what should be a grateful industry and will surely earn a place among composites industry pioneers. Less certain, however, is the *Learjet* 85's place in the evolution of composite materials and process development. Does it mark the first large step out of the autoclave, or will it be an historical anomaly? I would wager the former, and I look forward to what the aerocomposites industry does next.





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MARKET TRENDS

AN INTERNET AID FOR ACCELERATION OF AEROSPACE COMPOSITES CERTIFICATION



Rani Richardson is a CATIA composites product specialist at Dassault Systèmes (Waltham, Mass.), responsible for leading all activities related to the CATIA brand for Composites in North America, concen-

trating on implementation, education and demonstrations for the CATIA V5 and V6 Composites Solutions. Previously, Richardson was the director of operations at Magestic Systems (Westood, N.J.).

n the March edition of this column, Purdue University's Dr. R. Byron Pipes suggested "Accelerating the Certification Process for Aerospace Composites" by certifying simulation software rather than manufactured parts (short.compositesworld.com/cdmHUB). This may seem radical, but it is, in fact, a logical concept that is not only possible but also has real potential to reduce and, perhaps, even *eliminate* the need for physical testing.

But there is a barrier to its implementation: Today's software-based simulation tools are readily available but they are at different maturity levels, don't communicate with each other seamlessly and have gaps in processes where no commercial or academic codes exist. Aerospace companies must write their own proprietary codes or develop best practices on the shop floor to compensate for this shortcoming, which ultimately causes delays in manufacturing.

The time and money an OEM invests in composite material testing and part development is extensive. The process is manual, and each OEM has its own processes to certify their parts. There is no "cookbook" for OEMs to use. The slightest design or material change increases cost, reduces productivity and, as a result,

lengthens part lifecycles, making it difficult for the OEM to keep its competitive advantage. It is unrealistic, then, to think an OEM or its supply chain could assess the functionality, accuracy and consistency of each simulation tool that is available today. There are simply too many to test and many composites manufacturing methods for which each would have to be validated. The cost alone would be prohibitive, and the effort would further increase time to market.

Theoretically, using the Internet to harvest data for both physical and virtual testing is ideal because all sorts of composite data is easily accessible. Whether data is collected from public sources or is purchased for a fee, it would be easier and faster than physical part testing. But right now, it's not very practical: Often, virtual and physical test data is gathered from multiple sources that offer different results for the same material, resin and/ or manufacturing process. This creates uncertainty about the data's accuracy. Also, suppliers publish material properties that become the basic information required to run virtual simulations. But this information is typically insufficient, requiring OEMs and suppliers to collect additional performance parameters.

Yes, independent companies also analyze material properties and then publish data on them for a fee. Although this sounds ideal, it is not. There are no uniform criteria for gathering the data. To compensate, OEMs have to purchase multiple material databases. Many times, this approach is still insufficient. Today, there aren't any better alternatives. The aerospace industry is forced to combine data from multiple sources, a time-consuming and error-prone process.

Although the industry has a long way to go to bring the composites software toolset to maturity and remove the uncertainties associated with composites manufacturing, there are things that can be done to narrow the gap between the

virtual and real worlds. One option that would facilitate the maturity process is to have *all* the toolsets, regardless of maturity level, accessible to all interested parties on an *Internet-based platform*.

One such platform is the Composites Design and Manufacturing HUB (cdm-HUB.org). This Web site's objective is to accelerate the development of, and knowledge about, a comprehensive toolset available to the entire composites community. It's intended as a platform for the birth, development, refinement, integration and commercialization of the simulation tools necessary to bring composites certification and manufacturing simulation to a level consistent with high-performance composites simulation tools for geometric and structural modeling, such as CATIA, NASTRAN, ABAQUS and ANSYS.

The cdmHUB has been built using the proven HUBZero architecture. The National Science Foundation (NSF) provided more than \$30 million in funding to develop the original nanoHUB technology and the HUBZero platform at Purdue University. Today there are 20 HUB organizations at Purdue using the same platform and RAPPTURE software, a toolkit that supports Rapid application infrastructure. (For more, visit https://nanohub.org/infrastructure/rappture/).

Supported by NSF, nanoHUB.org is the largest and most successful HUB. To date, it boasts 10,000 users worldwide. It has more than 350,000 simulations with more than 210 engineering tools to simulate important nano phenomena used in nanoelectronics, materials science, thermal science, physics and chemistry. More than 2,500 content items, such as tutorials, seminars and full classes, are available to the community. The user community consists of students at all levels, research professionals, faculty and industrial users. Tools range from molecular modeling and simulation to photonics.

The primary goal of the cdmHUB is to accelerate the rate of development of composites simulation tools by an order of magnitude. That will require development of a comprehensive set of simulation tools that connect composites from their birth in manufacturing to their lifetime prediction. With these tools, composites professionals can advance the certification of composite products by analysis validated by experiments, but to do so, current and future generations of engineers must be taught how to use the tools. To do that, software developers must work with industry, academia and government, and a platform like cdmHUB is the vehicle that will make that possible. This cloud-based platform, then, can be the "meeting place" for the composites community, where sustaining sponsors, simulation tool providers, and developers and tool users can work together toward this common goal.

The cdmHUB brings to that community a host of benefits:

- Education in the use of commercial and emerging simulation tool use
- Development of new simulation tools for composites manufacturing

- Evaluation of technology-readiness levels of emerging tools
- Establishment of protocols for simulation tool validation and verification
- Access to data sets required in composites manufacturing simulation
- Forecasts of the unmet needs in simulation tool functionality
- New tool development for composites design, manufacturing and processing simulation
- Development of research needs analysis for simulation tools

As noted by Dr. Waruna P. Seneviratin, technical director/scientist at the National Institute for Aviation Research (NIAR, Wichita, Kan.), building-block analysis validated by testing is a rational multilevel developmental model used by many aerospace companies to certify metallic and composite structures. The cost and time involved in performing experimental tests escalates as the OEM moves from lamina coupons level to details level and, eventually, to component level. So there is the potential for significant cost and time savings, if some of the higher level

testing could be reduced through the use of validated analytical models.

Dr. Seneviratin points out that if we are to fully realize the advantages of analysis supported by test, then we must investigate the accuracy and validity of the current state-of-the-art virtual analysis tools in terms of predicting the results of experimental physical tests. When these tools are validated, such analytical models can then be used to model more complex geometries and reduce the burden of certification testing requirements.

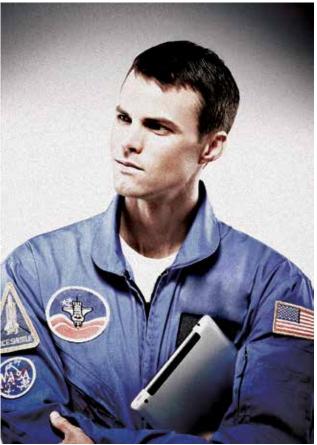
Realistically, a *lot* of work must be done just to get all the existing composites simulation tools gathered into *one* cybercommunity so they can be assessed and brought to the same maturity level. The cdmHUB is designed for that very purpose. In the near future, the aerospace community will be able to log on to the cdmHUB to begin that process.

But ... why stop at the aerospace industry? These same tools can be used in the automotive, marine, consumer goods and other industries. What we accomplish here will benefit everyone.

Editor's Note: HPC will update cdmHUB.org progress as details become available.







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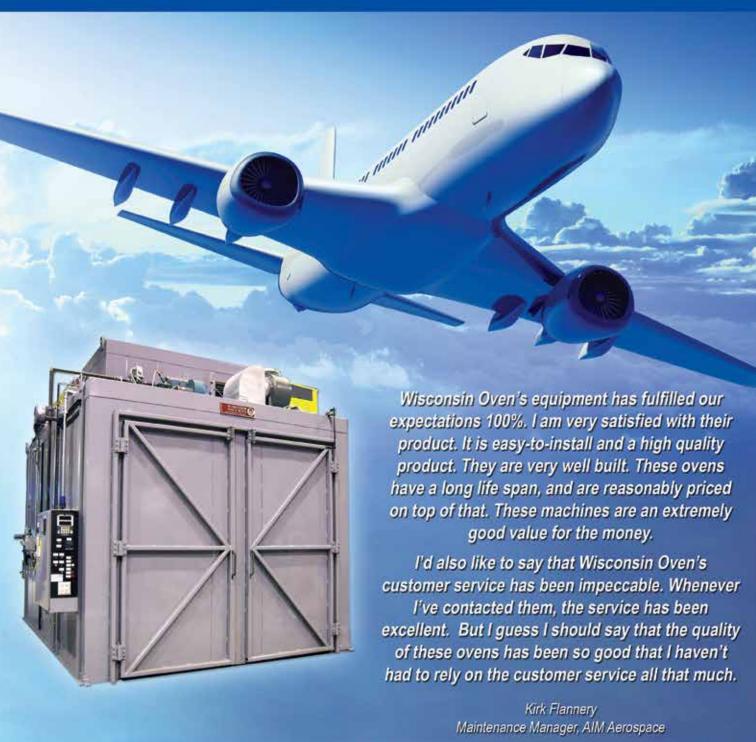
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COMPOSITES: PERSPECTIVES & PROVOCATIONS

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Dale Brosius is head of his own consulting company and the president of Dayton, Ohio-based Quickstep Composites, the U.S. subsidiary of Australia-based Quickstep Tech-

nologies (Bankstown Airport, New South Wales), which develops out-of-autoclave curing processes for advanced composites. His career includes a number of positions at Dow Chemical, Fiberite and Cytec, and for three years he served as the general chair of SPE's annual Automotive Composites Conference and Exhibition (ACCE). Brosius has a BS in chemical engineering from Texas A&M University and an MBA. Since 2000, he has been a contributing writer for Composites Technology and High-Performance Composites.

've attended the JEC show in Paris for many years, initially as a visitor, then as a part-time journalist and, for the past 10 years, as an exhibitor. I'm often asked what I saw on the show floor that indicates trends in technology, market focus or innovations. The time I have to walk the floor is pretty limited, because I am either tied up on the Quickstep stand with scheduled meetings or interfacing with prospective customers. My opportunity this year came on the afternoon of the third (and last) day, when floor traffic typically slows down and most of the discussions are "exhibitors talking to exhibitors." So, I zipped up and down the aisles, taking in the show in rapid fashion. Nonetheless, a couple of themes emerged, which are closely related.

The first is the race among thermoset resin suppliers, particularly epoxy and polyurethane, to develop fast-curing systems designed for the manufacture of structural automotive parts. Ten years ago, a 30-minute molding cycle time in resin transfer molding (RTM) was con-

sidered the state of the art for carbon fiber/epoxy parts. Several years ago, breakthroughs in high-pressure injection permitted cycle times as low as five minutes. This year at JEC, multiple resin suppliers touted resin systems with under three minute cycle times, with one major company advertising an epoxy system with a 90-second cycle time! These are times that rival engineering thermoplastics and are faster than most high-temperature thermoplastic molding times.

But will the industry really be able to take advantage of these fast systems in continuous fiber-reinforced parts? Or will production rates be constrained by other process steps? In the late 1980s, I was employed at Fiberite, then the world's largest prepreg supplier (acquired by Cytec Industries, Piedmont, S.C., in 1997). All of Fiberite's managers were required to read The Goal: A Process of Ongoing Improvement, by the late Eliyahu Goldratt. Written in the form of a "business novel," the book is the story of a manufacturing manager who faces problems delivering consistent volumes of products in a system of interdependent manufacturing operations, of which some are automated and others rely on manual labor. He faces issues with variability in cycle times, product yields, work-in-process inventory and capacity constraints because not all steps in the process can produce consistently at the same rate.

The protagonist struggles to find a solution, and it becomes clearer to him while leading a group of Boy Scouts on a long hike. Naturally, the faster boys go to the front, causing the line to stretch out (representing inventory accumulation), and the Scouts have to stop often to regroup. After many attempts to keep the group together, he decides to put the slowest boy in front, followed by the second slowest, etc. The group moves at a steady pace, but clearly not at the speed necessary to reach the endpoint on time. When he removes some items from the slowest boy's backpack (increasing his capacity to

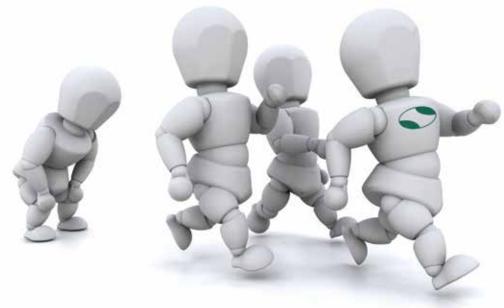
walk faster) and distributes them to the faster boys, the whole group speeds up and they reach their destination sooner. He goes back to the factory and applies similar principles to the production line, resulting in lower costs, faster production and reduced inventory. The Goal seems obvious to today's practitioners of lean manufacturing, but at the time, it was considered leading-edge thinking.

Back to the question above: What will be the rate-limiting operation in the manufacture of carbon fiber parts via RTM? I personally think it will be the preforming/fiber orientation step, but it could also be postmold trimming/machining or inspection, especially for more complex or integrated parts. In order for overall production rates to increase, all the steps must be addressed.

Which brings me to my second observation at IEC. At least five different companies at the show exhibited a carbon fiber roof panel from the R1 Roadster, built by Roding Automobile GmbH (Roding Germany). This included the panel's fiber manufacturer, Zoltek Inc. (St. Louis, Mo.): the fabric supplier, Chomarat (Le Cheylard, France); press systems supplier Dieffenbacher GmbH (Eppingen, Germany), which did the preforming; Henkel Corp. (Rocky Hill, Conn.), the resin supplier, and the machine supplier/project leader KraussMaffei (Munich, Germany), which supplied the injection unit and press. This group of suppliers, along with a few others not at JEC, collaborated to address all the major issues of manufacture and coordinate the process steps to deliver a successful finished part to the OEM.

I believe this sort of ad-hoc, or better, formal collaboration will be increasingly necessary to overcome inertia in markets such as automotive or offshore oil, which are unfamiliar with designing and manufacturing advanced composites. Collaborations also could accelerate growth within the aerospace industry as it seeks faster and less costly routes to composite manufacture.

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BY THE NUMBERS

COMPOSITES BUSINESS INDEX 56.3: BEST SINCE MARCH 2012



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

and an MBA from the University of Cincinnati.

n February, the U.S. Composites Business Index of 53.1 showed industry growth for the fourth time in five months — and at its second fastest rate since May 2012. Improving at a generally accelerating rate since July 2013, the CBI was 6.2 percent higher than it had been one year earlier. New orders grew, reaching their second highest level since February 2012. Production expanded at it second fastest since April 2012.

Backlogs increased for the first time since spring 2012, pointing to greater capacity utilization and capital investment in 2014. Employment continued to grow but at its slowest rate since September 2013. Exports were still mired in contraction at a rate similar to that in 2013. Supplier deliveries lengthened again. The rate was slightly slower than in the previous two months, but slightly faster than in the second half of 2013.

Material prices increased at a rapidly accelerating rate the first two months of 2014, and at its third fastest rate in CBI history. Prices received, rising in six of the previous seven months, grew at one of its fastest rates since January 2013, but increased much more slowly than material prices. Future business expectations soared, reaching their second highest level since the CBI began.

Facilities of all sizes grew again in February. The rate, however, was significantly greater for those with more than 20 employees. Fabricators with 19 or fewer employees recorded very slight growth.

Six of the seven U.S. regions registered expansion. The Pacific region grew fastest, followed by New England, the South Atlantic, West North Central, Mountain, and East North Central. After expanding in January, the Middle Atlantic was flat.

Future capital spending plans were 30.2 percent lower than a year ago.

In March the CBI of 56.3 showed industry growth for the fourth consecutive time and the fifth time in six months — at the fastest rate since March 2012. Industry improvement had accelerated since July 2013. The Index was 8.7 percent higher than in March 2013 and it was the seventh month in a row that it was higher than in the same month the year before. The annual rate of change had grown faster each of the previous two months.

New orders had grown for four months straight at a rate increased slightly from February but slower than in January. Production expanded for the third consecutive month, reaching its fastest growth rate in nearly two years. Backlogs had grown at an accelerating rate in the first three months of 2014, a trend indicating that composites fabricators' capacity utilization and capital spending should increase through the year. Employment had increased for 13 months, and the hir-

ing rate picked up sharply in March. Exports grew for the first time since April 2012. Supplier deliveries lengthened at the fastest rate since April 2012.

Material prices increased again in March, but at a noticeably slower rate than in February. Material prices continued to increase, but prices received contracted for the second time in five months. Falling slightly compared to January and February, future business expectations in March was near its highest levels since the CBI began.

The CBI was up sharply for facilities with 20+ employees, and at a rate as high as at any time CBI history. But those with 19 or fewer employees contracted after two "up" months. The Index differential between plants with more and less than 20 employees was roughly 10 points.

For the first time, all seven U.S. regions grew in the same month. The East North Central and Pacific regions grew fastest. The East North Central had grown five of the previous six months and the Pacific grew for the sixth consecutive month.

After contracting in February, future capital spending plans increased 16.3 percent compared to March 2013. The annual rate of change in March was higher than in February.

THE COMPOSITES BUSINESS INDEX						
Subindices	March	February	Change	Direction	Rate	Trend
New Orders	57.5	57.0	0.5	Growing	Faster	4
Production	62.5	58.5	4.0	Growing	Faster	3
Backlog	53.1	51.5	1.6	Growing	Faster	3
Employment	56.8	51.5	5.3	Growing	Faster	13
Exports	51.1	47.3	3.8	Growing	From Contracting	1
Supplier Deliveries	56.7	52.6	4.1	Lengthening	More	28
Material Prices	64.3	68.4	-4.1	Increasing	Less	28
Prices Received	49.3	52.2	-2.9	Decreasing	From Increasing	1
Future Business Expectations	76.0	79.0	-3.0	Improving	Less	28
Composites Business Index	56.3	53.1	3.2	Growing	Faster	4



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TESTING TECH

REVERSED LOADING FLEXURAL FATIGUE



Dr. Donald F. Adams is the president of Wyoming Test Fixtures Inc. (Salt Lake City, Utah). He holds a BS and an MS in mechanical engineering and a Ph.D in theoretical and applied

mechanics. Following a total of 12 years with Northrop Aircraft Corp., the Aeronutronic Div. of Ford Motor Co. and the RAND Corp., he joined the University of Wyoming, directing its Composite Materials Research Group for 27 years before retiring from that post in 1999. Dr. Adams continues to write, teach and serve with numerous industry groups, including the test methods committees of ASTM and the Composite Materials Handbook 17.

tatic flexural testing has long been conducted because it is a simple method for evaluating all types of materials. Static flexural testing of composite materials, in particular, was discussed in my March and May 2013 columns (see "Learn More"). In all static flexural testing, the load is applied monotonically. That is, the goal is to bend the specimen in just one direction. The specimen, therefore, remains in contact with the support and loading points at all times.

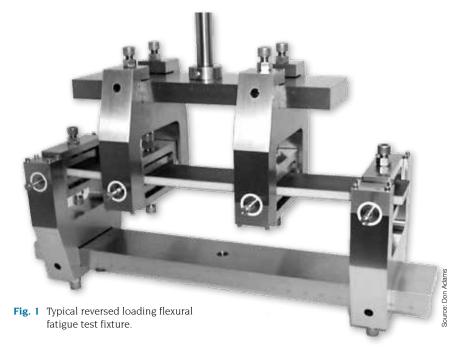
Monotonic flexural static loading can be readily extended to monotonic flexural fatigue loading by taking into account what are only minor additional considerations. For one, it is typically necessary to constrain the specimen axially, to prevent it from "walking away" from under the supports with repeated cycling. Likewise, any lateral movement must be constrained. This must be done because the specimen is being subjected to loads that cycle between a selected maximum load and a load as low as zero. As a result, the outer surfaces of the specimen lengthen or shorten (depending upon whether that surface is the tension or compression surface). This, in turn, causes the specimen to slide on the supports during each cycle unless some provision is made to prevent it.

This sliding may or may not affect the specimen integrity and/or the test results, depending upon the type of material being tested, the specified load levels and the magnitude of the specimen deflections achieved, but in any case, it will cause wear of the loading and support surfaces of the test fixture. (My March 2013 column discusses types of supports available for use.) However, the problems encountered here are not too difficult to overcome, and for that reason, monotonic flexural fatigue testing is occasionally conducted.

In contrast, reversed loading flexural fatigue introduces a significant additional problem. Here, the specimen must be both pushed and pulled at each loading point, so it must be in contact with loading points on both of its surfaces. Additionally, the specimen also must be constrained on both surfaces at the support points to prevent the specimen from lifting off of the support points during half of each cycle.

The specimen can be constrained at both the loading and the support points by clamping the specimen, with clamp faces positioned on directly opposing surfaces of the specimen at each point. Only a light clamping force is required to keep the fixture surfaces in contact with the specimen. However, the increased frictional resistance developed by using a greater clamping force will help prevent the "walking" action discussed above.

An additional consideration is that, by definition, the loading for reversed-cycle fatigue testing passes through zero during each cycle. And because the specimen is under no load at that instant, it is free to move if not constrained. Although friction forces developed by the clamps at the loading and support points might be sufficient to restrain this movement. any movement per load cycle, even if very small, will accumulate because a fatigue specimen might be subjected to a million or more load cycles. Thus, additional, more positive, constraint might be an option. For example, a pointed screw can be lightly pressed into each side of the specimen at each of the loading and support points, at the speci-



men mid-thickness (the neutral axis of bending stress). These screws prevent axial and lateral movement.

Finally, because the specimen is continually deflecting (bending) during each cycle, each of the loading/support clamps must be free to *rotate* so that they do not constrain the bending of the specimen.

An example of a test fixture that meets all of the above requirements is shown in Fig. 1. The base and loading beams are directly attached to the base and crosshead of a testing machine capable of applying an axial load in both tension and compression. The specimen loading and support span lengths can be varied by loosening the two bolts at the outer end of each loading/support assembly and sliding the assemblies along the beam to the desired position. These bolts can be seen at the top of the image in Fig. 1. As shown, the fixture is set up to perform four-point loading. For three-point loading, one of the loading head assemblies is removed and the remaining head assembly is moved to the center of the beam. (The comparative merits of three- and four-point loading were discussed in my previous columns.)

A pivoting cradle is mounted in each loading/support assembly (the bushings in which the cradle axes pivot appear as white circles in Fig. 1). These particular bushings were fabricated of a Teflon polymer. Oil-impregnated bronze bushings are stronger, are fabricated to closer tolerances and, thus, are more suitable for high fixture loadings, but the Teflon bushings generate little friction and, therefore, wear very well.

The fixture shown has flat loading and support pads since it is designed to be used in sandwich panel testing. Alternatively, cylindrically shaped pads can be used — these are sometimes *specified* for solid composite laminates. The pads are clamped against the specimen by tightening the bolt in each clamp half. Using two bolts permits the user to accommodate specimens of different thicknesses while keeping the specimen centered in the cradle.

Although there has been some interest in reversed flexural fatigue testing of composites for many years, there is at the present time no ASTM standard for such testing. However, there is a rela-

tively new standard for plastics, ASTM D 7772-12, "Standard Test Method for Flexural Fatigue Properties of Plastics," which does include reversed loading. Further, reversed flexural fatigue testing of composites appears to be increasing significantly. This is, perhaps, an indication of this industry's progress toward maturity — and the need for more realistic service data as applications become more demanding.

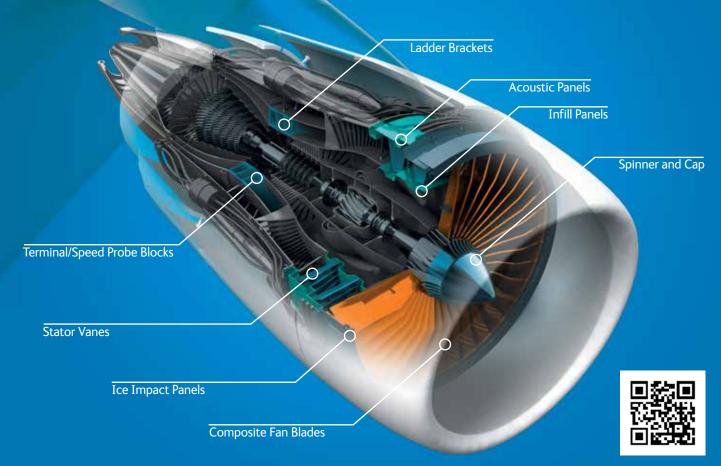


Read this article online at short. compositesworld.com/RLFlex.

Dr. Adams' commentary on "Flexural testing of composite materials" can be read in *HPC* March 2013 (p. 11) or by visiting short.compositesworld.com/H85ksD8P.

Dr. Adams' discussion of "Flexural test method standards for composite materials" can be read in *HPC* May 2013 (p. 11) or by visiting short.compositesworld.com/7hguppDi.





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NEWS

DARPA VTOL X-Plane program accepts Boeing's *Phantom Swift* prototype Boeing joins three other Phase I primes in hunt for optimum hover/high-speed cruise capability

uilt in less than a month by The Boeing Co. (St. Louis, Mo.), a prototype of the Phantom Swift has been accepted by the Defense Advanced Research Project Agency (DARPA) Vertical Takeoff and Landing (VTOL) X-plane program. Boeing is one of four program participants to produce a workable prototype in the program's first phase. The other Phase I prime contractors are Aurora Flight Sciences Corp. (Manassas, Va.), Karem Aircraft Inc. (Lake Forest, Calif.), and Sikorsky Aircraft Corp. (Stratford, Conn.).

DARPA hopes to mature a new aircraft configuration capable of efficient hover and high-speed cruise. "We were looking for different approaches to solve this extremely challenging problem, and we got them," says Ashish Bagai, DARPA program manager. "The proposals we've chosen aim to create new technologies and incorporate existing ones that VTOL designs so far have not succeeded in developing. We're eager to see if the companies can integrate their ideas into designs that could potentially achieve the performance goals we've set." DARPA plans to select one of the four models for fabrication and flight demonstration in 2015.

Under its agreement with DARPA, Boeing will receive \$17 million (USD), with which it intends to continue developing



the aircraft's previously incompatible target capabilities: It must not only take off and land vertically and hover, but it also must be able to achieve forward travel at speeds up to 400 knots.

Boeing's Phantom Swift design currently features two large lift fans — inside the fuselage — that provide efficient vertical lift. When the aircraft transitions to cruise mode, the fans are covered. Smaller, ducted fans on its wingtips produce forward thrust, and also provide additional lift and control when the aircraft hovers.

"Proving these capabilities in a single aircraft has been the Holy Grail for tactical military aviation," notes Dan Newman, Boeing Phantom Works Advanced Vertical Lift capture team lead. "We're confident that Phantom Swift could be the solution. Designing an aircraft to perform a vertical takeoff, while maintaining adequate low-speed control, is challenging. Sustaining efficient hover is also difficult, and adding a high cruising speed is even more challenging," Newman adds. Last year, Phantom Works used rapid prototyping and additive manufacturing techniques, such as 3-D printing, to quickly design, build and fly a scaled-down Phantom Swift.

SEE *HPC's* Special Report about additive manufacturing technology in this issue, on p. 44.

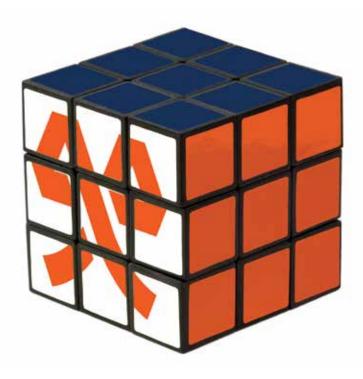
BIZ BRIEFS

Luxfer Group (Salford, U.K.) announced on March 24 that it had acquired **Vexxel Composites LLC** (Brigham City, Utah), a manufacturer of high-pressure composite cylinders for compressed natural gas (CNG). The company will operate as part of the Group's global Luxfer Gas Cylinders Division. Founded in 2012, Vexxel specializes in Type

IV (polymer-lined) carbon fiber composite cylinders for use as fuel tanks in CNG-powered alternative-fuel vehicles. Luxfer Group CEO Brian Purves says, "This acquisition provides our gas cylinder business with a facility purposebuilt for the manufacture of new Type IV composite cylinder products, which will be targeted primarily at the Class 8

heavy-duty truck market, where a high rate of conversion from diesel to CNG is widely anticipated. Luxfer is in the final stages of developing a new range of larger-diameter Type IV cylinders for growing CNG markets to complement its existing lightweight range of Type III aluminum-lined cylinder products and systems."

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Carbon fiber-reinforced thermoplastic cores new power transmission cable

elanese Corp. (Dallas, Texas) and Southwire Co. LLC (Carrollton, Ga.), North America's largest wire and cable producer, have introduced a new option for utility transmission lines: the C⁷ Overhead Conductor. The C⁷ features a lightweight, high strength-to-weight, multi-element composite core of Celstran continuous fiber-reinforced thermoplastic rods (CFR-TPR), made by Celanese.





Codeveloped by Celanese and Southwire, the conductor cable reportedly nearly doubles the transmission capacity of, yet exhibits less sag than, an aluminum conductor steel-reinforced (ACSR) of the same diameter. Mark Lancaster, Southwire's director of overhead transmission engineering, says the technology behind C7 was six years in the making and represents a step-change in overhead wire and cable design and engineering. The goal, he says, was to develop a product for utilities that need to increase right-of-way capacity without the expense of erecting new infrastructure. Line sag, he says, is the largest limiting factor in how much current can be passed through a utility line. "We wanted to increase capacity of the right of way over the same equipment." Reportedly, C7 not only increases capacity, but also provides costavoidance benefits by obviating the need for new towers and poles, which would be a necessary if capacity increases were attempted with conventional steel-cored conductor cables. C7 offers performance benefits and a strong value proposition for reconductoring applications as well, allowing for higher performance and emergency service rating of lines.

Michael Ruby, global composites business manager at Celanese, says, "This combination of ma- (continued on p. 23)



























































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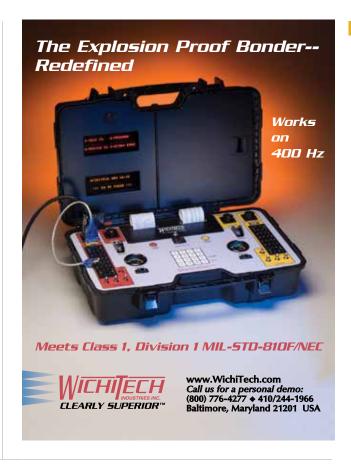
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COME TOGETHER. LEAVE YOUR MARK. (continued from p. 21)

terials provides distinct advantages compared to alternative High Temperature Low Sag (HTLS) technology and conventional conductors." The C7 Overhead Conductor comes in a variety of constructions, using Al-Zr and O-Temper aluminum. One standard configuration comprises a core of seven (or more, depending on cable diameter) 3.2-mm/0.13-inch diameter strands of aerospace-grade carbon fiber, each pultruded with a matrix of Fortron PPS (polyphenylene sulfide) from Celanese. The core is isolated from direct contact with the cable's aluminum conductor strands by an overwrap of polyetheretherketone (PEEK) to protect the aluminum from galvanic corrosion and to prevent abrasion of the core. The bundled strands, overwrapped by Southwire with an aluminum conductor, provide a redundancy of structural support in high-load conditions. In addition, Lancaster notes that the carbon fiber core operates at generally lower temperatures, which maximizes energy throughput and minimizes capacity loss. Nonetheless, the carbon fiber/thermoplastic strands reportedly can operate at high temperatures (180°C to 225°C), without line damage.

That said, Lancaster points out that the success of C^7 as a replacement cable product rides on whether or not cable installers can use the same tools and equipment they employ with metal-cored cables. "Install and repair strategies had to be the same," he says, "so that our customers can seamlessly integrate it into their work environment."





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Rolls-Royce will use composites in future commercial aircraft engines

n late February, Rolls-Royce (London, U.K.) shared details of its next-generation of jet engine designs, which will incorporate composites and could be ready within 10 years. The engine designs will take advantage of architecture and technology improvements that Rolls-Royce says are all currently at an advanced stage of development. A key component will be a CTi fan system that will feature carbon fiber/titanium fan blades and a composite casing that reduces weight by up to 1,500 lb/680 kg per aircraft, the equivalent of carrying seven more passengers at no cost. Advanced ceramic-matrix composites, which will operate more effectively than metals in high turbine temperatures, are also on the drawing board. Further, a geared design will deliver efficient power for high-thrust, high-bypass ratio engines of the future.

The company says two of the new-generation engine designs will build on the success of its Trent family of engines. The first, Advance, will offer at least 20 percent less fuel burn and CO_2 emissions than the first generation of Trent engines and could be ready by the end of this decade. The second, known as UltraFan, also will benefit from the geared fan design. Its variable-pitch fan system will be based on technology that could be ready for service by 2025 and will offer at least a 25 percent reduction in fuel burn and emissions against the same baseline.





"These new designs are the result of implementing our ongoing technology programs," notes Colin Smith, Rolls-Royce's director of engineering and technology. "They are designed to deliver what our airframe and airline customers tell us they need: even better fuel efficiency, reliability and environmental performance." Rolls-Royce says it also is positioned to mature technologies for its Open Rotor engine, should there be a clear market demand for such a product.

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Health concerns spur ergonomic sanding innovation for aircraft

orking with a European launch customer, Temple Allen Industries (Rockville, Md.) has developed new sanding tools designed to reduce worker stress and vibration injuries during sanding operations on composite aircraft wingtops and helicopter rotor blades.

Temple Allen's new CE-certified Wing-Top Sander system (pat. pend.) operates much like a powered floor buffer, permitting workers to stand erect rather than work on hands and knees. The lightweight equipment is reportedly easily carried up scaffolding to wing surfaces. The system operates pneumatically (a requirement in most aircraft production settings) and incorporates robust, dual-inline orbital sanding heads, a vibration-absorbing boom and an optional fluid delivery system. Like Temple Allen's recently introduced EMMA robotic sanding systems (see end note), the wingtop sanders accommodate a range of sanding pad sizes and orbital speeds as well as an integrated dust-collection system.

A second solution, for surface preparation of rotorcraft blades, is a modified version of its EMMA system for fixed-wing aircraft and wind blade operations. A sanding challenge, the blades present varying paint thicknesses (based on previous repairs/maintenance) and incorporate copper mesh immediately below the surface for lightning strike protection (LSP). Inadvertent gouging of the blade surface dur-





ing manual sanding, therefore, can damage the LSP, forcing replacement. The EMMA system employs a robotic arm, which in this case is designed to maintain uniform unit pressure and keep the sanding pads parallel with the blade surface. The worker operates the arm remotely, via control pad.

For more on EMMA, visit short.compositesworld.com/EMMA. For the full story on the Temple Allen's sanders for wingtops and helicopter blades, visit short.compositesworld.com/EMMA1.

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TenCate commits to composite air-cargo container market

enCate Advanced Armor USA (Newark, Ohio) has signed a teaming agreement with Air Cargo Containers LLC (Phoenix, Ariz.) to manufacture lightweight air cargo containers. TenCate



will supply the composite materials and perform container manufacturing and assembly at its Ohio facilities.

The already fully certified, lightweight, composite air cargo carriers have a tare weight of 480 lb/218 kg, about 350 lb less than that of competing aluminum containers — a 42 percent weight savings.

Air Cargo Containers was granted the U.S. Federal Aviation Admin.'s (FAA) Technical Standard Order (TSO C90d) certification for its lightweight composite AMJ model Unit Load Device (ULD) in December 2013. It is the first all-composite container to receive FAA certification.

Constructed of proprietary composite side panels and floor panel, built around an aerospace-grade aluminum frame, the ULD features a patented roll-up door with "destruction-proof" side glides and lock-down features for safety in operation. The lightweight, durable, flameretardant design reportedly reduces container maintenance and, therefore, lifecycle costs.

"The key composite materials used in Air Cargo Containers' proprietary container have been selected and optimized, utilizing the knowledge TenCate has in engineering advanced armor systems," said Mark Edwards, president of TenCate Advanced Armor. "Our advanced materials create a structurally strong yet lightweight container that enables users to

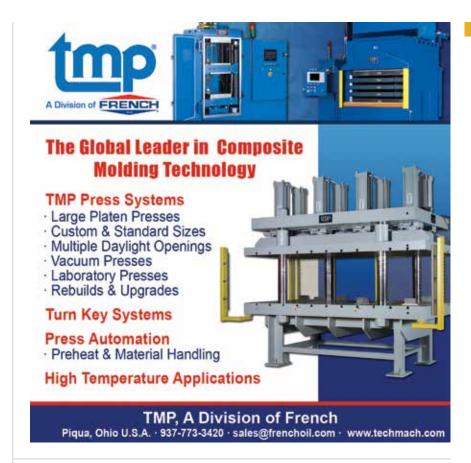
maximize fuel economy and reduce the industry's carbon footprint. The world-wide manufacturing and supply chain management capabilities of TenCate will allow containers of Air Cargo Containers to be produced and sold worldwide."

Air Cargo Containers cofounder and CEO Scott Oracheff commented, "We're excited to have TenCate manufacture our containers."

The first of the company's new ULD containers were recently presented at the World Cargo Symposium held in Los Angeles, Calif. "In addition," says Oracheff, "we look forward to introducing this breakthrough technology together at IATA [the International Air Transport Assn. Annual General Meeting 2014, June 1-3, in Doha, Qatar]."

PEOPLE BRIEFS

Nonwoven materials supplier Technical Fibre Products (TFP, Burneside, U.K. and Schenectady, N.Y.) announced on March 27 that it has appointed John M. Haaland to the position of president. Haaland ioined TFP in 2001. In his previous role, VP of sales and marketing, he had responsibility for the strategic growth and development of sales and business operations in the U.S. He has a BS in chemistry from SUNY Oneonta and combines a scientific background with 30 years of sales/marketing experience and 13 years of developing customer relationships. Haaland also will serve as president of TFP's U.S. holding company Tech Fibers Inc. TFP also announced that Robert E. Duvall has been appointed president of Schenectady-based Electro Fiber Technologies LLC (EFT), TFP's fibercoating facility. Duvall had served as EFT's VP of operations for the past 12 years, and had been responsible for developing and implementing fiber-plating methods. He brings to the new position more than 30 years of experience in metal-coated fibers. Both men will continue to report to TFP/EFT chairman Martin Thompson.







JEC EUROPE 2014 REVIEW

The composites world met again in Paris — vibrant, stronger, and more forward-looking than ever before.

EC Europe 2014 (March 11-13, Paris, France) was, for the first time, spread across two floors at the Paris Expo's Porte de Versailles exhibition center, reflecting again this year the dynamism, creativity and ingenuity of the composites industry. (JEC is considering a third floor in 2015.) HPC was there and offers this glimpse of the materials and technology highlights. (HPC samples new products from the show on pp. 71-75)

The shape of things to come

Clear from the first day were several trends that show all the earmarks of transforming the way composites industry suppliers and parts fabricators approach their common goals in the future. Significant among them were the following:

Snap-cure resins: A molding system is only as fast as its resin, and it was clear at IEC that materials suppliers are getting that message. Dow Automotive (Schwalbach, Germany and Auburn Hills, Mich.) introduced VORAFORCE 5300, a lowviscosity epoxy for resin transfer molding (RTM) that offers a sub-90-second cycle time, and claimed that 60-second cycles are within reach. Henkel (Toulouse, France and Bay Point, Calif.), Momentive Specialty Chemicals (Columbus, N.Y.), Cytec Industries (Woodland Park, N.J.), Huntsman Advanced Materials (The Woodlands, Texas), Gurit (Isle of Wight, U.K.) and Bayer MaterialScience (Levekusen, Germany) were all on hand with thermosets in the same cycle-time range. Although most were developed with the auto industry's part-per-minute production standard in mind, aerocomposites manufacturers who are seeking to reduce cost and rely less on capital-intensive autoclave processes are taking note.

Carbon fiber-reinforced thermoplastics: Fokker Aerostructures (Hoogeveen, the Netherlands) pioneered the use of fiber-reinforced thermoplastics

> more than a decade ago with Airbus (Toulouse, France) on the wing leading edges of its A330-340 and, later, A380 commercial jets. Now carbon fiberreinforced thermoplastics (CFRTPs)are finding increased use in aerospace and automotive applica-

Fokker Aerostructures exhibited the latest iteration of this fuselage panel demonstrator made with carbon fiber/PEEK prepreg. It is layed up in a female tool, with the vertical stringers placed first and the skin placed on top via automated tape laying (ATL). The skin and stringers are cocured, after which the horizontal frames are induction welded (see inset image of stringer and frame intersection).

Biggest and busiest yet

JEC claimed 32,000 attendees toured two halls that housed a record 1,200 exhibitors.

tions. Fokker explored this new territory in the JEC Innovation Awards display, with a CFRTP fuselage panel demonstrator. Not an award winner, the panel is nonetheless unique, says Fokker's R&D director Arnt Offringa, in its use of a carbon fiber/PEEK prepreg provided by Cytec Aerospace Materials (Tempe, Ariz.). The panel is laid up in a female tool, with the vertical stringers placed first and the skin placed on top via automated tape laying (ATL). The skin and stringers are cocured, after which the horizontal frames are induction welded (see close-up of stringer and frame inter-

The SGL Group (Wiesbaden, Germany) and Toho Tenax (Wuppertal, Germany and Rockwood, Tenn.) each introduced a new carbon fiber sizing optimized for thermoplastic resins. Toho Tenax VP of sales Greg Olson said the sizing is formulated for use with polyetheretherketone (PEEK) in aerocomposites, but he added that the company also is looking at oil and gas and medical applications.

Victrex plc (Cleveleys, Lancashire, U.K.) reported success in the commercial aircraft market since Airbus qualified VIC-TREX PEEK 90HMF40. Reinforced with high-modulus carbon fiber, the polyaryletherketone polymer is reportedly an easily processed, high-flow material that results in parts with 100x longer fatigue life and up to 20 percent greater specific strength and stiffness than to aluminum 7075-T6 under the same conditions.

Bristol, R.I.-based Tri-Mack Plastics Mfg. Co. used the material to produce brackets for structural aircraft components that — using thermoset composites — take several hours to produce. Tri-

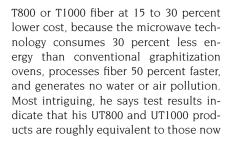




Hybrid seating for aircraft interiors

Source: Tenca

A JEC Innovation Award winner, Expliseat's (Raispal, France) Titanium Seat is the first composite aircraft passenger seat to pass dynamic 16G crash tests, yet it tips the scales at half the weight of its nearest competitor.



on the market. He also emphasized that he's not planning to engage in spinning or carbonization of raw PAN fiber and is willing to partner with other carbon fiber manufacturers interested in adapting his microwave process.

System integration: This third trend defined the proverbial handwriting on the wall: Touch labor is out, automa-



Carbo Tech (Salzburg, Austria) celebrated the opening of its second

production facility in Žebrák, Czech Republic, a highly automated

HP-RTM plant that can deliver 50,000 carbon fiber/epoxy parts per year, like the passenger "tub" (above) for the Volkswagen LX1.

Serial production automotive CFRP

Source: Volkswagen

Mack reportedly achieved manufacturing cycle times measured in minutes.

The snap-cure and carbon fiber/thermoplastics trends made it all the more noteworthy that Paul Mackenzie, VP research and technology at U.S. based aerospace carbon fiber and prepreg supplier Hexcel (Stamford, Conn.), introduced a new high-modulus carbon fiber (HexTow HM63), a new epoxy (Hex-Ply M92) and, notably, a new snap-cure prepreg epoxy targeted toward automotive applications. Characterized as a response to thermoplastics' incursions into automotive molding, its new HexPly M77 offers a two-minute cure. (Detailed data are available on p. 72. HPC readers interested in carbon fiber-reinforced thermoplastic automotive apps should see HPC's sister publication Composites Technology's JEC Europe 2014 coverage in June.)

With interest in carbon fiber/thermoplastic applications so high, pre-show rumors of vet another new PAN-based carbon fiber manufacturer piqued HPC's interest. The rumors proved untrue, but HPC found that the subject of the rumors, UHT Unitech Co. Ltd. (Zhongli, Taiwan), offers not a new fiber but a graphitization service for composites fabricators who purchase T700-grade PAN-carbon fiber from existing fiber manufacturers. Unitech president Ben Wang says the company's business model is to unspool PAN carbon fiber (3K to 48K) purchased from other sources, burn off the factoryapplied sizing, then graphitize it in Unitech's patented 2000°C/3632°F microwave ovens. Afterward, Unitech reapplies fiber sizing (Wang says he specializes in sizings compatible with thermoplastic resins for sporting goods and industrial applications) and re-spools the product. The result? Wang quips that "no one believes it" but he can deliver the equivalent of

ONE-SHOT NOSE LANDING GEAR DEMONSTRATOR

Coexpair SA (Namur, Belgium) displayed a re-engineered composite nose landing gear door representative of that currently used on the Airbus A350 XWB. The part was molded out of the autoclave, using Salt Lake City-based Radius Engineering's same-qualified resin transfer molding (SQRTM) process. The part, featuring an integrally stiffened double-curvature, was produced in one-shot, and the process is said to be viable for serial production. The sandwich construction of the original was eliminated to reduce cost — I-, J- and T-section stiffeners reportedly provide greater mechanical performance. The door required no postmold assembly, secondary bonding or mechanical fasteners, and no stitching of preforms or secondary bonding. One-shot processing was enabled by a complex tool that features 50 inserts.







Made from A350 program-qualified Hexcel Hexply M21 prepreg, the door's process parameters and mechanical performance reportedly match those of the autoclaved part. The door also features molded-in reinforced slots that accept its unique composite hinge brackets (see close-up photo, on left).

Coexpair contends that the part demonstrates that complex integrated structures can be developed with acceptable lead time, using the same tough prepreg used in the rest of the fuselage structure (rather than relatively brittle RTM resins) — two outcomes not previously demonstrated.

tion is in, and merely selling equipment is a strategy long out of date. Suppliers are uniting to offer OEMs complete manufacturing systems. Several consortiums introduced or emphasized turnkey manufacturing cells. FIDAMC (Madrid, Spain) and MTorres (Navarra, Spain) scored an aerospace "first," unveiling jointly developed technology that enables the automated layup and in situ consolidation of carbon fiber-reinforced polyetheretherketone (PEEK). The target? Aircraft primary structures, including fuselage panels

with integrated stiffeners. The equipment and process has already resulted in up to 40 percent crystallinity in the matrix and a degree of consolidation (DOC) sufficient to require no further heat, vacuum bag or autoclave processing.

Pinette Emidecau (Chalon-sur-Saône, France) announced a new multinational company, Global RTM, that will market complete high-pressure resin transfer molding (HP-RTM) production lines into the aerocomposites sector. Pinette's president Jérôme Hubert, who will also

head Global RTM, predicted eventual entry into the automotive market as well.

Headquartered in Bellignat, France, Global RTM will operate out of two assembly plants, one in Chalon-sur-Saône, the other in Zernien, Germany, and will benefit from the expertise of three France-based shareholders: toolmaker Compose (Bellignat), injection systems specialist Isojet Equipments (Lyon) and process control/monitoring specialist S.I.S.E (Oyonnax).

According to Hubert, the turnkey HP-RTM line integrates ply preparation, preforming, tool preparation, injection and forming, postcuring and finishing. The goal is supply systems capable of up to 150,000 parts per year.

Similarly, turnkey systems were touted by Dieffenbacher (Eppingen, Germany), Krauss-Maffei AG (Munich, Germany), Fives Cincinnati (Hebron, Ky.), Engel (Schwertberg, Austria) and RocTool (Paris, France) each working in collaboration with other suppliers primarily to meet automotive industry demands for the speed, consistency, repeatability and quality required to compete with legacy metals and metal-forming processes.

Passenger protection cells: A fourth trend could be the tip of the proverbial auto industry iceberg — without the negative connotation. Taking a page from builders of Formula 1 race cars, whose carbon fiber composite safety cells for drivers are well established on the world's racing circuits, automotive composites fabricators seemed to have determined collectively that the best way to alert automakers to their molding proficiencies was to mint a monocoque carbon fiber composite passenger protection cell ("tub" for short), either for a real car (high-end sports) or as a capability demonstrator. The HPC staff counted no fewer than 10 tubs on display. Among them was Carbo Tech (Salzburg, Austria), with an impressive display of a carbon fiber monocoque cell and wheels, the latter in both hybrid carbon fiber/aluminum and all-carbonfiber versions. The company mints tubs for the McLaren MP4-12C supercar, the Porsche 918 Spyder and Volkswagen's XL1 (see photo, p. 35) and recently opened its second production facility in Žebrák, Czech Republic, which it says is highly automated and can deliver 50,000 parts per year using epoxy HP-RTM. The global market for carbon wheels is estimated at roughly 1 million units per year.



In the air and on the ground

At its annual JEC Europe press conference, Hexcel's VP/GM Thierry Merlot reported on use of Hexcel fiber and resin in CFM International's LEAP 1A (Airbus A320neo), 1B (Boeing 737 MAX) and 1C (COMAC C919) engines, which feature carbon fiber blades and containment cases using HexTow IM7. Hexcel, he noted, "is preparing and ramping up for the

challenge" of the LEAP engine program, which by 2020 is expected to consume 1,800 shipsets per year. Hexcel president Nick Stanage anticipates revenues of \$2.5 billion by 2017, pointing to Boeing/Airbus backlogs totaling 10,000 units as evidence of good long-term demand for its fiber and prepreg. Hexcel officials said that given "guaranteed" long-term demand in aerospace and automotive,

Hexcel will spend "several hundred million dollars" on expansion in the next several years.

On display at the Hexcel stand was an aircraft fuselage demonstrator fabricated with the company's HiTape dry fiber reinforcements. Hexcel worked with Aerolia SAS (Saint-Nazaire, France) and Coriolis Composites (Quéven, France) to produce the self-stiffened skin, designed by

SIDE STORY

SAMPE Europe 2014 Review

SAMPE Europe's 35th International Conference (SEICO 14) was also its last. Beginning in 2015, SAMPE Europe will henceforth organize one large annual conference, combining its SEICO and SETEC events into a multitrack multidisciplinary conference and exhibition. The SAMPE France chapter will host the first one, in Amiens, France, under an as yet undetermined new name, and it will travel to major European industrial centers. In the spring of 2015, SAMPE Europe will put in place, alongside the JEC Europe show, a one or one-and-a-half day Executive Summit. It will feature presenters by invitation only, who will address key issues that affect the composites and advanced materials community in Europe, on the day prior to the JEC Europe show.



Gary G. Bond

Aerospace: Coming out of the autoclave

SEICO 14's aerospace keynoter, Gary G. Bond, from The Boeing Co.'s operations in St. Louis, Mo., spoke engagingly about "Taking the Pressure Off: Out-of-Autoclave Composite Prepreg, Past and Future." He began by telling attendees that when Boeing appointed him its new manager of disruptive technology seven years ago, the goal without doubt

was to get out of the autoclave (OOA), but the question was which method of OOA? Beyond the obvious savings in capital equipment and energy consumption, OOA would remove limits on part size. Boeing preferred familiar thermoset prepreg for its consistency and its potential for automation, also a goal. "This was not Boeing's first time at the rodeo," Bond quipped, noting that Boeing, preferring not to hurry into new development, began with a tooling prepreg, using it to save time and money getting prototypes in the air, despite porosity and other problems. Although engineers hoped a second-generation OOA prepreg, LTM 45, could be used for finished parts, its 10-day out-life was too tight. A third-generation toughened product, CYCOM 5320-1, however, can produce less than one percent void content, has a 30-day out-time and is performance-and weight-competitive with autoclaved prepreg.

Bond credited the Defense Advanced Research Projects Agency (DARPA) for creating a disruptive-technology funding program and partnering with Boeing "in a very real way," adding that DARPA, the Air Force Research Lab (AFRL, Wright-Patterson AFB, Ohio) and Boeing "worked very closely" and determined that the results should be, as much as possible, in the public domain. He told attendees, "We tried to make it as much yours as ours."

Bond said the goal was to "go ugly early" and try difficult configurations to discover the material/process "Achilles' heels and address them." Successes culminated in a recent demonstration of the material in oven-cured 68-ft wingskins for the *Phantom Eye* UAV. What's ahead? Bond says the goals include

larger and thicker structures, more robust processing and tougher resins that will allow ATL/AFP machines to operate at speed (but available at lower cost). Finally, 30-day out-time is good, he agreed, but it won't be enough for the large structures to come.

During a Q&A period, Bond commented in answer to a final question about goals that Boeing wants a "robust resin system that is much more forgiving." So much so that, "the worst tech, on his worst day, could make an acceptable part."

Automotive: A thermoplastic composite future?

During SEICO 14's second keynote, titled "Next Challenge in CFRTP for Mass Production Automobile Application," the University of Tokyo's Dr. Jun Takahashi observed that Japan makes 30 percent of the world's automobiles and 50 percent of its carbon fiber. For that reason, a Japanese National Project is addressing carbon fiber availability and price



Dr. Jun Takahashi

and the speed of automotive carbon fiber part production. Takahashi says the project has 34 partners, and will benefit from government funding — roughly €15 million (\$20.7 million) per year. The hope is to reduce car weight by 30 percent. The program timeline assumes that 2020 is the starting point for mass production of carbon fiber auto parts, and that, by 2030, fiber demand for auto production alone will reach 1 million metric tonnes (2.2 billion lb).

Notably, the program's matrix of choice is not a thermoset, but a thermoplastic — specifically, a maleic acid-modified polypropylene (PP). Takahashi argued that carbon fiber/PP doesn't shatter and break on the tensile side like carbon/epoxy, that the resulting parts can be welded rather than adhesively joined (welding is more familiar to auto OEMs), and that thermoplastics better accommodate nut inserts for component assembly.

That said, Takahashi noted, "CFRTP is not yet a mature technology." Program outcomes will depend on reductions in the cost of fiber production, sufficient supply to meet increased demand, design for manufacturing, and a major reduction in the cycle time for CFRP auto parts. Although part cost is directly related to mold cycle time, Takahashi emphasized that *recycled* carbon fiber holds the most promise for controlling part cost and that the use of recycled fiber will reduce the material cost of CFRP parts to a level competitive, in 2020, with aluminum. He noted that research indicates no depreciation of fiber properties during recycling and there is also no appreciable drop in finished part performance between those reinforced with continuous virgin fiber and those made with long but discontinuous recycled fiber. He added that recycled fibers of any length will find a place in auto production.

Aerolia to meet mechanical performance requirements for primary structure. Coriolis developed the dry AFP process and the dry preforms were made by Compositadour's (Bayonne, France).

Scoring a first, The Aquitaine region of France stand displayed a model (photo below) of the ARCOCE (ARrière-corps COmposite CEramique, or afterbody ceramic composite) jet engine exhaust cone made using ceramic-matrix composites (CMCs). Designed and built by Herakles (Le Haillan, France), it compris-

es a cone-shaped plug or centerbody and a complex, corrugated mixer. Fastened to the engine's aft flange, the mixer's "lobed" shape ensures optimal mixing of the hot gases from the engine with the cold bypass air. An ARCOCE measuring 1,625 mm/5 ft in length and 655 mm/2 ft in diameter, and weighing 24.5 kg/54 lb is currently undergoing an 5,000-hour testing campaign on a CFM56 engine.

Nearby, FACC AG (Ried im Innkreis, Austria) touted its reception of the 2014 JEC European Innovation Award

(Aeronautics) for a lightweight, carbon composite annulus filler for jet engines, developed with partners Rolls-Royce (London, U.K.) and the University of Applied Sciences (Rapperswil, Switzerland). This complex-shaped part sits between the engine fan blades, guides airflow for optimum aerodynamics during operation, and weighs 40 percent less than the machined forged metal it replaces. At 18 to 22 fillers per engine, their use reduces the load on the fan disk to which they are anchored, increasing cost and energy savings. The prototype is currently undergoing extensive ground testing before trials on a flying engine later this year.

Betting on infusion of aerocomposites

At a Cytec Industries (Woodland Park, N.J.) press conference, Ammar Alsalih, program manager, aerospace materials, noted that backlogs at aerospace primes are motivating calls for materials that can process faster and reduce part cost. In response, Cytec introduced its PRISM TX1100 Dry Tape system for automated fiber placement (AFP), it was developed specifically for Moscow, Russia-based Aerocomposit's MS-21 single-aisle jet, on which resin infusion will be used for the aircraft's wing and wingbox structures. (Cytec says it's also under evaluation by other OEMs.) A unidirectional split tape, it requires no off-axis fibers to hold it together. According to Alsalih, it's the only split tape now available for AFP. Heated as it is applied, its binder secures the tape. Compaction steps are eliminat-



CMC jet engine exhaust cone

Herakles (Le Haillan, France) showed off this prototype ceramic-matrix composite engine exhaust cone for the next-generation LEAP jet engines. The cone is 30 to 50 percent lighter than metal versions.



ed and the tape's low fuzz reduces machine stoppage for head cleaning.

The resulting preform is infused with the PRISM system's EP2400 Infusion Resin. Fully compatible with the TX1100 binder, the one-part epoxy infusion system has low injection viscosity and reactivity, extended pot life, a low cure temperature and proprietary technology that improves resin penetration. In tests, parts yielded fiber volume fractions of nearly 60 percent. Further, Alsalih reported that machine operators, in validation tests, confirm that the dry tape enables machines to run at their fastest rates. (See other new Cytec products on p. 72.)

ATL and AFP machinery supplier Ingersoll Machine Tools (Rockford, Ill.) reported on work with the National Center for Defense Manufacturing and Machining (NCDMM, Blairsville, Pa.) to develop a vision-based AFP inspection system designed to check the layup, while still on the tool, for gaps, foreign object debris, twists, bridging, edge accuracy, start/stops and folds. The goal, says Clarissa Hennings, composites business development at Ingersoll, is to bring to market by late 2015 an inspection system that can run on anyone's AFP machine.

Cutting tool supplier Sandvik Coromant (Sandviken, Sweden and Fair Lawn, N.J.) emphasized its ability to meet the needs of trimming, routing and drilling composite structures, especially stacks of composites and metals. Mohamed Hammadi, Sandvik's global application manager for composites, said there is increased interest in dry drilling, which eliminates the cost and mess associated with traditional cooling fluids, but poses new heat-management challenges (see related story this issue, p. 48).

Inductive tool heating takes flight

TenCate Advanced Composites BV (Nijverdal, The Netherlands) shared a JEC 2014 Innovation Award (Aircraft Interiors) for the Titanium Seat (photo. p. 35), built for Expliseat (Raispal, France), with partners Hexcel, RocTool, and A&P Technology (Cincinnati, Ohio). At 4 kg/8.8 lb per passenger, it is half the weight of competitors. Fuel consumption reductions could save €200,000 to €400,000 (\$274,370 to \$548,775) per year per aircraft.

For the Expliseat project, RocTool supplied its 3iTech induction heating technology, which integrates inductor coils directly into steel tools for compression

molding. At a JEC press conference, Roc-Tool CEO Alexandre Guichard show-cased a smartphone back cover, mass-produced with 3iTech for Motorola. Produced at a rate of 15,000 parts per day, it earned a JEC Innovation award in the Mobile Devices category. Guichard said RocTool aspires to place 3iTech systems with 30 major brands of Motorola stature. Toward that end, RocTool has opened a Taiwan subsidiary and announced two others in Japan and Germany. RocTool recently received a capi-

tal infusion of €3.6 million and now markets directly to OEMs rather than approaching molders — a strategy change adopted by other exhibitors as well.



Read a much expanded version of this JEC Europe 2014 Review article at the CompositesWorld Web site. Key in short.compositesworld.com/HPCJEC2014



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The Society for the Advancement of Material and Process Engineering's annual fall Tech conference is now a spring event.

Ithough it has been for many years the fall conference follow-up to SAMPE's (Covina, Calif.) annual Convention and Exhibition in the spring. SAMPE Tech has been moved to early June this year to make way for the debut of the Composites and Advanced Materials Expo (CAMX), the new North American exhibition cosponsored by SAMPE and the American Composites Manufacturers Assn. (Arlington, Va.). CAMX combines SAMPE's former spring expo and ACMA's previous turn-of-the-year COM-POSITES trade show into one big supershow that will make its inaugural appearance in Orlando, Fla., Oct. 13-16, 2014.

New season, same reason

Despite the change in timeframe, SAMPE Tech Seattle 2014 will continue a long tradition of delivering high-quality education and networking opportunities. In recent years, it has incorporated a progressively larger exhibit space devoted to showcasing advanced materials and processes for aerospace and other hightech end-markets. SAMPE Seattle is billed as the right destination for those who use advanced composites in a variety of markets. Chief among them are aerospace (95.2 percent of visitors serve this market), wind energy (50.6 percent), ground transportation and marine (each of interest to 47 percent), sports & recreation (39.8 percent), medical (33.7) and infrastructure (19.3 percent).

SAMPE Seattle is expected to build on that pedigree. SAMPE organizers say its most recent Seattle event attracted 5,000 attendees, hailing from all 50 U.S. states and 32 other countries, world-

SAMPE Tech returns to the U.S. Pacific Northwest

SAMPE organizers say its previous Seattle event attracted 5,000 attendees, hailing from all 50 U.S. states and 32 other countries, worldwide.

wide. A similar crowd is expected to be on hand this year to take in hundreds of presentations by industry insiders, leaders and educators, and view the displays of some 200 exhibiting companies.

Given these statistics on attendance, the first Spring SAMPE. Tech event has, appropriately, been scheduled again in one of the hotbeds of the U.S. aerospace industry. Seattle is the site, of course, for the Commercial Airplanes unit of aerospace giant, The Boeing Co., and the U.S. West Coast — from Seattle to San Diego, Calif. — is home to, or the site of significant outposts of, hundreds of advanced materials suppliers, processing equipment manufacturers and composite parts fabricators.

Tech talk: Automotive

Despite the aerospace-intensive setting, SAMPE Seattle proceedings will be capped by a Keynote Address that highlights growing advanced materials use in automobiles. Keynoter Jörg Pohlman, managing director of SGL Automotive Carbon Fibers GmbH & Co. KG (Wiesbaden, Germany), will update the continuing story of SGL Automotive Carbon Fibers (ACF), the joint venture between BMW Group and SGL Group that is the exclusive suppler of carbon fiber materials to the BMW Group, the first carmaker in the world to use carbon fiber in series production of this scale for its new i3 commuter car and i8 sports car. Pohlman

will provide an overview of the entire value chain, ranging from precursor supply to the production of CFRP parts for the vehicles. The spotlight will be on carbon fiber production in Moses Lake, Wash., which operates on 100 percent renewable energy based on hydropower, as well as SGL ACF's Wackersdorf, Germany-based fabric-weaving and newly developed carbon fiber waste recycling operations that provide materials used in i3 and i8 roof and rear seat components.

WHERE: 800 Convention Pl.

Seattle, WA 98101

The first of four Featured Lecturers, Prof. Jan-Anders E. Månson, Ecole Polytechnique Fédérale de Lausanne (EPFL) Laboratory of Polymer and Composite Technology (LTC), will discuss the European Union's CO_2 auto emissions legislation and resulting focus on lightweight material alternatives that can be used in high-volume automotive manufacturing at a realistic cost, with realistic potential for recyclability.

Dodd Grande, VP of outdoor product development at Seattle-based snow ski and snowboard specialist K2 Sports will review the history and current uses of composites applications in sporting goods, explain why composites are ideal for them and then provide a look into the future of composites in the sports and recreation industry.

Prof. Douglas Scott Cairns of Montana State University's Department of Mechanical and Industrial Engineering will speak about manufacturing defects and their effect on design constraints and resulting "worst-case" design assumptions. He'll review a four-part framework for composite structure reliability, with an emphasis on progressive damage modeling that has been developed to address the issue.

Lastly, Dr. R. Byron Pipes, the John L. Bray distinguished professor of engineering at Purdue University, will propose a different approach to aircraft certification. Rather than certify parts and assemblies via physical testing, he'll suggest a radical departure: certification of the simulation software used for virtual testing. Certified simulation tools, he contends, would be used by engineers with the expectation that, within the bounds of the certification, no further verification or validation would be necessary. Pipes will review the significant challenges and the enormous potential savings of such an approach. (Dr. Pipes wrote Part I of a two-part series on this subject in the HPC March 2014 issue, p. 7. A colleague in this effort, Rani Richardson of Dassault Systèmes Americas (Waltham, Mass.) follows up in this issue with Part II, on p. 7.)

In addition to the above, the annual SAMPE Award Luncheon will also serve up a speaker presentation, this one from Bill Pearson, the technical director at North Sails (Milford, Conn.). He'll review his company's development of very thin and lightweight large-area composite membranes and structures (up to 500m²/5,382 ft²) — notably for yachtracing sails — using articulating and reconfigurable three-dimensional molds, robotic fiber placement, and North Sails' proprietary UD prepreg tape. He also will trace the migration of the company's sailmaking materials into other areas of boatbuilding as well as Formula One motorsports and solar-powered aircraft applications. (HPC's coverage of North Sails' sailmaking methods can be viewed online at short.compositesworld. com/8kX6ogwR.)

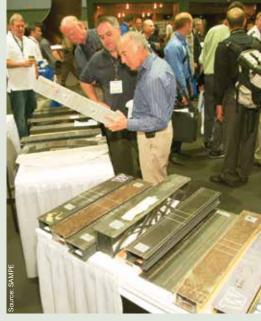
Preconference & conference

On Monday, June 2, SAMPE will present a daylong roster of preconference tutorials. Attendees who opt for Premium Conference Registration get tutorials at no additional charge. Otherwise, rates for the half dozen half-day tutorials are collected separately: \$175 in addition to Full registration (only \$75 for full-time students), and \$225 for tutorial only/ one-day registration/exhibits only pass.

Premium and Full Conference registrations include free exhibit hall passes (discounted conference rates are available to those who opt for early registration).

Then, June 3-5, hundreds of technical papers will be presented in 11 sessions over the three-day conference. For dates and times on SAMPE Tech Session topics and other events, see "SAMPE Seattle 2014 at a Glance," below).

SAMPE Tech 2014 adds a new feature. dubbed a conference-within-a-conference (CWAC). Produced in response to what SAMPE officials call "high demand for reliable, up-to-date education on textiles advancements," the CWAC will of-



Bridge building and breaking

SAMPE Seattle 2014 will serve as the platform for the perennial student Bridge Building Contest, a longtime feature of the spring convention.

fer an extensive set of presentations on the growing variety of technical textiles available for fiber-reinforced composite structures.

The Women in SAMPE Forum is expected to offer women who work in the advanced materials field a great opportunity to network and create valuable relationships with like-minded colleagues and participate in facilitated speedmentoring sessions.

For more information, contact Priscilla Heredia, Tel.: +1 (626) 331-0616, x610; E-mail: priscilla@sampe.org; Web site: www.sampetechseattle.org.

SAMPE Seattle at a Glance

Monday, June 2

¹Tutorials......9:00 a.m. to 12:00 p.m.

- · Composite Process Modeling
- Textile Technology for Composites Applications
- Overview of Composite Sandwich Design and Construction

Lunch......12:00 noon to 2:00 p.m.

Tutorials2:00 p.m. to 5:00 p.m.

- Thermoplastic Composites
- · Tooling for Composites Manufacturing
- · Introduction to Composite Materials

Tuesday, June 3

²Session 1.....8:00 a.m. to 9:45 a.m.

- Textiles 1
- Space Structures
- DARPA 1
- Design 1
- Manufacturing
- Bonding 1
- Textiles 2
- · Spaceflight • DARPA 2
- Sustainable
- Design 2 • Bonding 2

Keynote Address 10:00 a.m. to 11:00 a.m.

 "SGL Automotive Carbon Fibers: Lightweight Structure Expertise for the BMW Group" - Jörg Pohlman

Exhibit Hall Open 11:00 a.m. to 5:00 p.m. Student Bridge Contest.. 11:00 a.m. to 4:00 p.m. Lunch......12:00 noon to 2:00 p.m. Panel.....2:00 p.m. to 4:30 p.m.

· Additive Manufacturing

Session 2......2:00 p.m. to 3:00 p.m.

- Textiles 2
- Spaceflight 1
- DARPA 3
- Design 3 Nondestructive

Evaluation Coffee Break 3:00 p.m. to 3:30 p.m.

Session 3......3:45 p.m. to 4:45 p.m.

- Textiles 4
- Spaceflight 2
- Bonding 4
- Design 4 Nondestructive

Evaluation

SAMPE Tech Welcome

Reception5:00 p.m. to 6:00 p.m.



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Wednesday, June 4 Textiles 3 Additive Repair 1 Materials • Repair 2 Panel...... 2:00 p.m. to 3:00 p.m.

Featured Lecture 1 8:00 a.m. to 8:30 a.m.

"The Dual Tracks in High-Volume Composites" - Jan-Anders Månson

Session 4 8:00 a.m. to 9:45 a.m.

 Bonding 5 • Design 5

• Bonding 6

• Design 6

• Thermoplastics 1

- Manufacturing 1
- Coffee Break 9:45 a.m. to 10:00 a.m. Exhibit Hall Open 10:00 a.m. to 5:00 p.m.

Session 510:00 a.m. to 12:00 noon

- Thermoplastics 2
- Additive Manufacturing 2

Lunch......12:00 noon to 2:00 p.m. Women in SAMPE Forum . 12:30 p.m. to 2:00 p.m. Student Poster Contest.. 12:30 p.m. to 1:30 p.m.

Thermoplastics

Panel...... 2:00 p.m. to 4:30 p.m.

Textiles

Featured Lecture 2 2:00 p.m. to 2:30 p.m.

- · "Composites Applications in Sporting Goods"
- Dodd Grande

Session 6 2:00 p.m. to 3:00 p.m.

- Additive Manufacturing 3
- Repair 3
- · Nanocomposites 1
- Design 7

Coffee Break 3:00 p.m. to 3:30 p.m.

Session 7 3:45 p.m. to 4:45 p.m.

- Textiles Panel
- Additive Manufacturing
- Repair 4 · Nanocomposites 2

• Design 8

Student Social Reception.. 5:00 p.m. to 6:00 p.m.

Thursday, June 5

Featured Lecture 3 8:00 a.m. to 8:30 a.m.

· "Reliability and Progressive Damage Modeling of Composite Structures with Manufacturing Defects" - Douglas Scott Cairns

Session 8...... 8:00 a.m. to 9:45 a.m.

- Textiles 4
- Manufacturing Processing
- Resin Infusion 1 Nanocomposites 3
- · Thermoplastics 6
- · Smart Materials 1

Coffee Break 9:45 a.m. to 10:00 a.m. Session 9......10:00 a.m. to 12:00 noon

- Thermoplastics 7
- Textiles 4
- Smart Materials 2
- Resin Infusion 2

SAMPE Award Lunch12:00 noon to 2:00 p.m.

• "Textiles to Composites" - Bill Pearson

Featured Lecture 4 2:00 p.m. to 2:30 p.m

· "Accelerating the Certification Process for Aerospace Products" - R. Byron Pipes

Session 10 2:00 p.m. to 3:00 p.m.

 Textiles – Ballistics 1

Placement 1

- Nanocomposites 4
- Sandwich Structures 1 Automated Fiber Infrastructure 1

Coffee Break 3:00 p.m. to 3:30 p.m.

Session 11 3:45 p.m. to 4:45 p.m.

- Textiles Ballistics 2
- Automated Fiber
- Placement 2
- Structures 2 · Resin Infusion 2

Sandwich

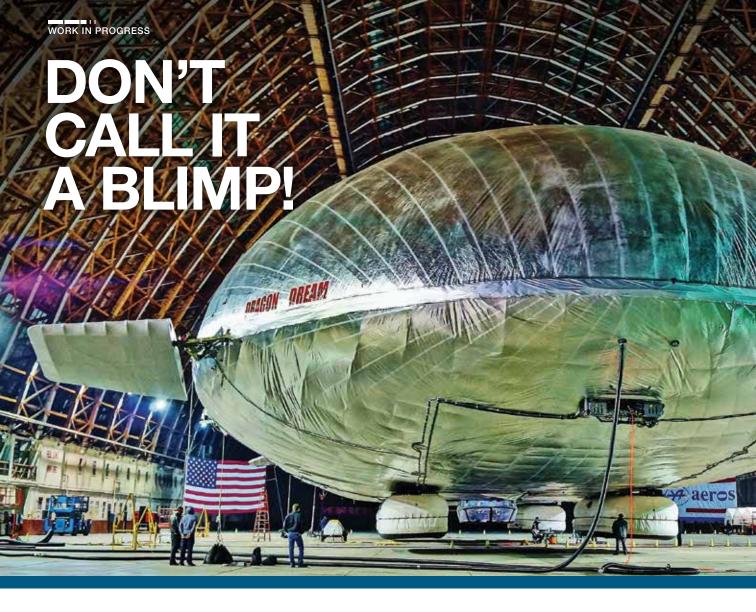
- Infrastructure 2
- Nanocomposites 3

¹A Separate tutorial registration is required for admittance to tutorials.

²Conference registration is required for admittance to sessions and panels. Listed presentations are subject to change and cancellation due to circumstances beyond SAMPE's control.

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The builders of this variable-buoyancy craft count on carbon fiber/epoxy trusswork to enable a new era of air transport.

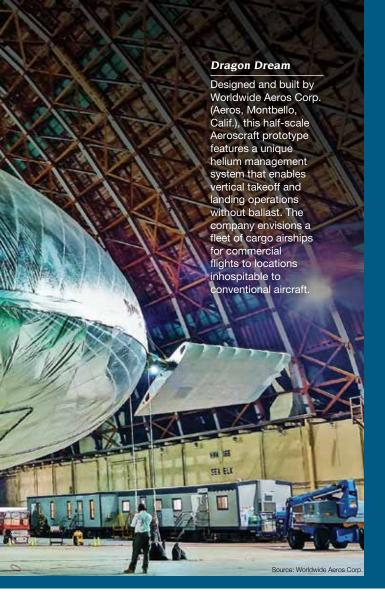
BY SARA BLACK

irships have been an important part of modern aviation since Count Ferdinand von Zeppelin envisioned the first such craft in 1874. Zeppelin's design, which involved a rigid framework that supported the outer envelope or skin, meant that an airship could be made much larger and support more load than a simple gas-filled blimp.

Unfortunately, Zeppelin could not obtain helium (only available from sources outside Germany, it was embargoed because of Hitler's armed buildup) and risked the use of flammable hydrogen. The Hindenburg tragedy in May 1937 and the onset of World War II ended Zeppelin's successful and fashionable transatlantic flights, and heavier-than-air craft came to dominate the airways. Yet, the allure of airships lived on in the imagination.

Igor Pasternak, for one, imagines a new generation of airships with greatly expanded capabilities. He's the founder, CEO and chief engineer at Worldwide Aeros Corp. (Aeros, Montbello, Calif.). Fascinated by lighter-than-air craft since childhood, Pasternak formed his first airship company in Ukraine, during the mid-1980s. After moving the company to the U.S. in 1994, he was able to secure funding through the development and sale of tethered military aerostats (lighter-thanair aerodynamic balloons) as well as conventional U.S. Federal Aviation Admin. (FAA)-certified airships. In 2005, he won a U.S. Defense Advanced Research Projects Agency (DARPA) contract to develop a strategic airlifter for possible military use.

The DARPA funds offered a chance to develop something radically new. Traditional blimps use helium-filled flexible





Trust in a trussed frame

The airship's lightweight internal trusswork, shown here fully assembled, must support the airship's helium-management equipment, its cockpit, cargo, and cargo containment structures. Carbon fiber/epoxy tubes in a range of sizes are combined with aluminum tubing (future airships will incorporate all-carbon tubing). Tubes are connected with aluminum joints, and adhesive bondlines prevent galvanic corrosion.



Aeros thinks BIG

This artist's rendering shows a future, full-scale Aeroscraft offloading its cargo. The largest airship that the company has designed, thus far, could reportedly airlift a payload of up to 500,000 lb (226.8 metric tonnes).

envelope to provide lift, but need ground crews and tethers to stabilize the craft. Newer "hybrid" helium airships feature aerodynamic lifting surfaces and require a runway for takeoffs and landings. But when either type is used to carry cargo, the load has to be compensated for during offloading by ballast, typically sandbags or sometimes water, to combat the static lift of the gas. Ballast exchange management is difficult and is the reason that large airships have never been successful cargo carriers. Pasternak and his design team envisioned, instead, a rigid, variable-buoyancy airship, equipped with short side fins, vertical stabilizers and vertical takeoff and landing ability that requires no ballast. Although the DARPA military program ultimately ended, Aeros is endeavoring to build a fleet of what are now called

Aeroscraft for commercial cargo roles. Its half-scale prototype, *Dragon Dream*, has successfully passed several tests and lift-off demonstrations.

Control of static heaviness

Aeros thinks big: Even the Dragon Dream prototype is 266 ft/82m long with a wingspan of 110 ft/34m, and more than 50 ft/15.4m tall. But two mammoth cargo craft have been designed: One 550 ft/169m long with a wingspan of 177 ft/54.5m and height of 120 ft/37m, will carry 132,000 lb (59.9 metric tonnes) of cargo, and a second, larger craft that will haul 500,000 lb (226.8 metric tonnes).

So what makes this concept, recognized by the U.S. Department of Defense and the U.S. Congress as worthy of further study, viable? That would be the central design element, Aeros' patent-pend-

ing "control of static heaviness (COSH)" system. Similar to a submarine's buoyancy system, says Tim Kenny, Aeros' engineering department director, it features a pumping system that can capture the helium within the vessel's envelope and compress it inside numerous holding tanks. When compressed, the gas becomes much heavier, and its containment creates a partial vacuum inside the airship envelope. Air is permitted to enter that void and inflate four large "expansion bladders" positioned along the vessel sides. The air inside the bladders plus the weight of the compressed helium causes a decrease in buoyancy, and the craft descends. When the helium is released back into the envelope, forcing the air bladders to empty, the airship ascends. Airship elevation is maintained and rate of ascent/descent is con-



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trolled via the helium's tank vs. envelope balance. The system renders ground tethering crews and ballasting unnecessary, and opens the way for cargo transport to remote and unimproved locations.

Key to the concept's success is the craft's rigid internal structure, which must support not only the weight of the cargo, but the heavy COSH helium pump, compressors and storage tanks. Early trade studies showed that carbon/epoxy tubes in various diameters, assembled to form an airy truss skeleton (see photo, p. 41), could provide sufficient support at minimal weight. To shave cost during the demonstrator phase, some anodized aluminum tubing is used with the carbon, but Aeros intends to field future airships with all-carbon trusses.

"We ultimately determined that a truss design was the best way to handle bending loads, after multiple design iterations," says Kenny. "We have divided the truss into sections, similar to a bridge design." Carbon fiber/epoxy tubes in a range of diameters from 0.5 inch/12.5 mm up to 4 inches/100 mm, as well as some heftier square tube profiles, are assembled, together with the aluminum tubing, to form truss sections. The larger tubing is used, he explains, where loads are heavier, under the compressor equipment and engines, and where lifting or bending loads are anticipated to be the greatest. Sections are connected by complex tubular aluminum joints — the adhesive layer isolates the carbon and aluminum, preventing galvanic corrosion.

Aeros used Solidworks software from Dassault Systèmes (Waltham, Mass.) for the truss design, and conducted finite element analysis (FEA) of the entire structure under cargo-loading and bending conditions, using Nastran FEA software from NEi Software (Westminster, Calif.).

A new way to carry cargo

The majority of the composites comprise the truss structure, but other composite

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

See a video of the *Dragon Dream's* first flight and other video documentation at http://aeroscraft.com/videos/4575674029.

elements include the instrument panel, honeycomb-cored glass and carbon fiber cockpit floor panels and abrasion-resistant aramid fiber-reinforced composite fabrics on the craft's ground-contact pads. Kenny reveals that in the full-scale airships, the outer skin might be made with more durable, rigid, lightweight composite panels, rather than the mylar film employed in the demonstrator.

The Dragon Dream successfully lifted off in 2013, says Aeros' director of communi-

cations John Kiehle. Since then, Aeros has inked four memoranda of understanding with cargo transporters Pacific Airlift, Cargolux Airlines, Air Charter Service and Bertling Logistics, to explore shipping possibilities — Aeros intends to lease, not sell, the craft and will act as fleet operator. Target markets include oil and gas and wind energy (transport of blades and towers). The goal, says Kiehle, is FAA certification by 2016, and an active fleet soon thereafter.





3-D Printing of continuous carbon fiber composites?

Additive manufacturing startup MarkForged aims to make it happen — and is already marketing systems.

BY SARA BLACK

dditive manufacturing (AM) is one of the hottest areas in parts fabrication. Interest is high, research dollars are being spent and company stocks are attracting investor attention. Why? First, because AM has moved beyond its initial role as a prototyping tool to a process that can build finished parts. AM technologies - stereolithography, fused deposition modeling (FDM), laser sintering (LS), material extrusion, direct metal deposition and more (see "Learn More," p. 47) — were able from their beginnings to accurately form complex, three-dimensional parts directly, without tooling or touch labor. They build them up in stacked, horizontal layers from digital design files (hence, the moniker "3-D printing"). But those early technologies came with some technical challenges that — particularly in the composites industry — limited their utility. Although they could produce a part, or multiple small parts, faster than many molding processes, early AM devices used lowend, unreinforced commodity thermoplastics or metals. In addition, machine

Additive manufacturing with continuous reinforcement

MarkForged (Cambridge, Mass.) will soon offer for sale the Mark One 3-D printer, reportedly capable of making printed parts with continuous carbon, glass and, soon, aramid fibers.

build enclosures were small, limiting part size. Most importantly, they could easily duplicate part dimensions within specified tolerances but rarely delivered the mechanical properties necessary in a finished part. In recent years, however, refined 3-D printers have built parts from a wider range of tougher, stronger materials. Beyond the "cool" factor, these processes now have enormous appeal to industry. Indeed, many OEMs, including The Boeing Co. (Chicago, Ill.) and GE (Fairfield, Conn.), have already adopted the technology for complex parts that are flying on aircraft.

But until recently, AM offered no viable alternative to molders of high-performance composites. Some machines can form parts using reinforced plastics, but only very short fibers can pass through the deposition heads. Part strength and stiffness, therefore, could not match that achieved with continuous fibers.

A new era of instant awesomeness

A recent arrival on the AM scene. Mark-Forged (Cambridge, Mass.) is charting a course that could change that. A small startup, opened in early 2013 by MITeducated aerospace engineer Greg Mark, it is a spin-off from Mark's Aeromotions company, which produces computercontrolled carbon fiber wings for race cars. Although his experience with composites began with wet layup, he says, "we then moved to prepreg construction and autoclave cure and, finally, to outof-autoclave infusion." But, regardless of the method, the time required to make molds, obtain materials, and then lay up and cure the parts was not trivial — nor was the cost, he adds.

"That motivated us to develop our printing technology," Mark explains. "Our vision was always to make end-use parts, but a lot more efficiently. We wanted to use the mechanics of a 3-D printer to

automate carbon fiber composite layup." R&D was initially based on open-source 3-D printers, which the company refined iteratively to create a more robust and reliable process. The result is an AM printer that can produce parts made with continuous carbon fiber in a thermoplastic resin. Because MarkForged is, thus far, unique in its use of continuous reinforcements, Mark says, "we really had to think about controlling the print process with the machine's software." The Mark One machine was unveiled at the recent SolidWorks World 2014 conference (see "Learn More").

Unlike typical AM machinery, the Mark One has two print heads, both designed and built by the company. One dispenses polyamide (nylon) or polylactide (PLA) resin, and the second dispenses a continuous towpreg, either carbon or glass (dispensing of aramid fiber is in development). The towpreg is made in a proprietary process: A single carbon filament is coated with a specially developed thermoplastic resin, designed specifically for the printer. The Mark One uses FDM, an extrusion-like process, for placement of resin and towpreg in the flat x/y plane of the part. Mark says that the fiber can be oriented, or added selectively only where needed, in the x/y plane, but notes that, at present, vertical, or z-directional, orientations aren't possible. Each build layer is approximately 200 microns in thickness.

Says Mark, "The machine's software can choose the optimal fiber orientation based on some basic design rules, or in the manual mode, you can specify the orientation on a layer-by-layer basis, to allow for specific placement, for example, ±45°." MarkForged is currently designing plug-ins to work with the major computer-aided design (CAD) programmers, including Dassault Systèmes' SolidWorks (Waltham, Mass.), so that, eventually, any design software can be used to drive the machine for optimal fiber placement.

The "stage" on which deposition takes place is a plastic platform, to which the polyamide or PLA resin adheres, similar to other AM machines, explains Mark. "You scrape the finished part off when finished," he says. "The platform lasts for roughly 100 prints, then gets replaced." Unique to the Mark One is the use of a high-precision "kinematic coupling" to precisely level and fix the build platform. Used in silicon wafer processing, the coupling precisely constrains all six degrees of freedom so that the build stage can

simply be "clicked" into place. Set-toreset leveling is reportedly repeatable to within 10 microns.

Strong first steps

"For us, using carbon fiber and nylon together makes so much sense," asserts Mark. "If you're printing with the common materials such as nylon, being able to incorporate continuous fibers enables an entirely new class of parts." He adds that the Mark One can produce parts that are stronger than 6061 T6 aluminum, and, based on mechanical testing, provide good impact resistance.

He cites the part shown at the Solid-Works conference, a baseplate for attaching a race car wing to a car. Essentially a sandwich panel, the part has outer skin layers of neat polyamide for a good wear surface, while inside are three, 200-micron thick layers of carbon fiber laid around the outer edge, and a printed nylon honeycomb inside the carbon in the center of the part for increased strength to weight properties (see photo, p. 47). After the print is finished, the baseplate is ready to install (the print process creates the mounting holes), without the labor of layup or need for cure, and takes 6.5 hours of machine time to print, compared to perhaps a day for conventional infusion processing. "There's no labor, cutting, gluing, trimming, molds or fixtures," Mark points out. "The baseplate supports a wing that is capable of producing 860 lb/391 kg of downforce when the race car is traveling at 200 miles per hour," a sizeable load condition to entrust to a 3-D printed part.

Like any advocate of carbon fiber composites, Mark faces questions from potential customers about cost. "Yes, carbon fiber is an expensive material," Mark admits, but cautions interested parties to put that fact in perspective. "In the end," he points out, "the difference between an all-nylon wing baseplate and a carbon fiber/nylon baseplate is \$10." And his process is not subject to factors that contribute to part cost in conventional composites processes. "With this technology, there's no waste, no mold cost, no layup labor cost, and when you're finished, you have a net-shape part!"

MarkForged isn't just talking, it is producing desktop-sized Mark One machines, beginning at \$4,999, for customer shipment in the coming months.

"We are actually a '2.5D' system right now," he guips. You're putting down flat layers, and stacking them, but you're not able to follow a trajectory or a contoured surface." Aerospace companies, for example, will want more dimensions, and larger part sizes. Mark asserts that printing much larger structures is on the company's "road map" and envisions the ability to produce an entire auto chassis or unmanned aerial vehicle (UAV). "We will be able to address those demands. as well as more complex load cases," he predicts. Toward that end, MarkForged will offer more axes, via robotic handling, and larger build boxes, and its proprietary build heads will be able to handle the larger parts.



Tested material samples top aluminum

Continuous carbon/polyamide parts produced in the Mark One have undergone property testing (shown here), and are used by the company in race car wing applications. Properties are reportedly better than 6061T6 aluminum.







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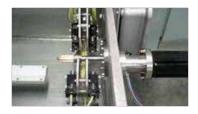
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Two baseplates, like this produced by the Mark One machine, attach an aerowing to a race car. Essentially a sandwich construction, it features polyamide outer skins, continuous carbon reinforcement around the part perimeter, and a printed polyamide honeycomb core (center).

Future directions

Ultimately, Mark is motivated to bring down not only the cost of composite part fabrication but of its development as well. If a car frame were developed using AM, he suggests, "it could be a functional prototype within a week." And the design could be tested, tweaked, then reprinted again, within a few days. "This significantly compresses the design process and cuts cost," he claims, noting that "if Boeing wanted to test a new UAV

design, they could conceivably come up with a working test vehicle in a week."

Mark reports interest from prosthetics and medical device manufacturers, who could quickly custom-print a medical implant or components for an artificial limb to fit an individual. To minimize cost during the fitting process, he explains, "You can first print in plastic until the shape is matched, then print with fiber reinforcement to produce the high-strength finished part."



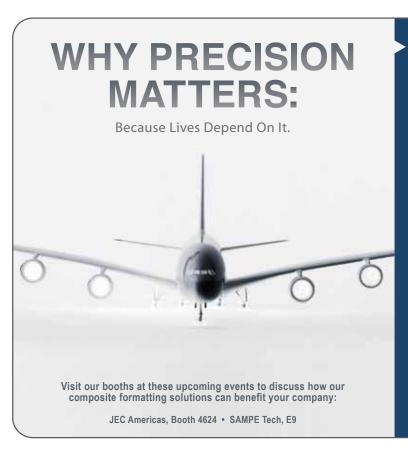
Read this article online at short.compositesworld.com/AM3Dcarbon.

For more on the MarkForged machine's unveiling, see CW's online coverage at short.compositesworld.com/3DPcfrp.

Read about additive manufacturing (AM) basics and the full range of available AM processes in "The rise of rapid manufacturing," in *HPC* July 2009 (p. 22) or read the article online at short. compositesworld.com/s1Zf43Fh.

Look back at AM authority Terry Wohlers' (Wohlers Associates Inc., Fort Collins, Colo.) 2010 predictions about the technology's future composites in *HPC's* sister publication, *Composites Technology*, in "Additive manufacturing a new frontier for composites" (*CT* April 2010, p. 5) or visit short.compositesworld.com/AMtrend.

Read about composites AM pioneer Royal Plastics Mfg. Inc.'s (Minden, Neb.) early use of a laser sintering process for "Direct manufacturing of military aircraft parts" in Focus on Design, *HPC* July 2009 (p. 58) or visit short.compositesworld.com/AMRoyal.



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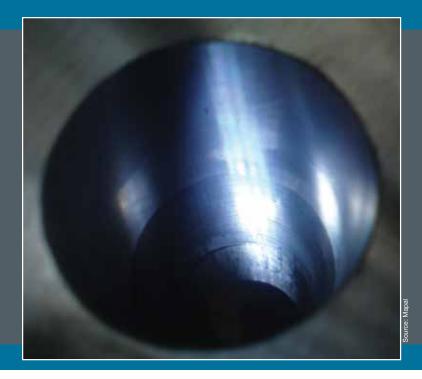


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One-shot dry drilling of stacked materials



BY GINGER GARDINER

Tool design innovations tighten tolerances and cut costs for those who drill composite-metal assemblies.

n the aircraft industry, where mechanical fastening of joined components is a necessity and the drilling of many thousands of holes per aircraft is, therefore, unavoidable, stacking the parts in joint position and drilling them in a single operation not only saves time, but also ensures proper hole alignment when fasteners are inserted. So-called one-shot drilling can produce a high-quality hole if all the joined parts are either all-metal or all-composite.

When carbon fiber-reinforced polymer (CFRP) and aluminum and/or titanium parts are stacked, however, the story is much different. Drilling composite/metal stacks, therefore, has usually involved multistep operations to permit the use of drill tools optimized for each material. This requires either tool changes or the use of multiple drill motors. Despite these precautions, poor-quality holes are still common. And in the best circumstances, all drilling, to date, has required minimum quantity lubricant (MQL) — minute amounts of high-quality lubricant applied, ideally, only at the cutting interface. This requires a method for controlled delivery of the lubricant,

Hole-ly focused on composite-metal stacks

In this example hole drilled in a trailing edge component for the Airbus A350 XWB wing produced by GKN (Filton, U.K.), the different layers in the stack are clearly visible.

typically through channels inside the cutting tool. And that, in turn, increases the cost of an already costly drill tool and complicates the drilling process.

This was the state of the composite/ metal stack drilling art until cutting tool manufacturer Mapal (Aalen, Germany) developed a promising alternative: A simpler, one-shot, dry (yes, lubricant-free) drilling process for stacked materials that reportedly cuts tool cost by up to 50 percent, increases tool life by up to 200 percent and produces high-quality holes (specifically, H8 with a CPK of 2.4, see "Hole quality defined," p. 51).

Why dry drilling?

"MQL was developed to lower the buildup of material on the cutting tool and augment chip removal, but these are functions a good tool design should achieve," contends Dr. Peter Mueller-Hummel, senior manager for Mapal's aerospace and composites business unit, adding that lubricants hide shortfalls in tool capabil-

ity. "We are using MQL to span gaps in tool performance."

Mueller-Hummel, who has sought a dry drilling option since his career began, says the use of MQL compensates for some problems, but actually causes others. First, the lubricant actually wets carbon dust, keeping it in the hole rather than allowing the tool flutes to drive it out. "Often, too much oil is introduced into the tool's airstream," he adds, "causing significant overspray from the hole exits, to the point where jigs and even floors are slippery. OEMs then become concerned about contamination in the part, and cleaning is added as a secondary operation to machining." Dry drilling eliminates all this, and eliminates the need to design lubricant channels into the tool.

"If you eliminate MQL," he maintains, "you cut tool cost in half, right off the bat." Further, MQL tools must be fashioned from special materials that, he argues, are not compatible with diamond-

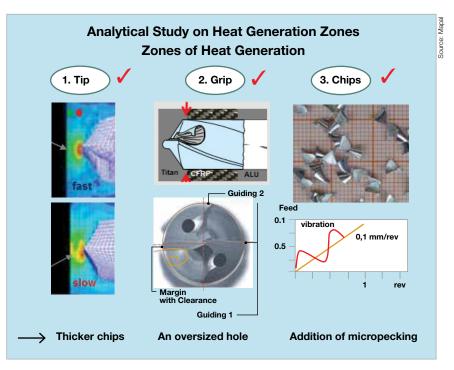
coating technologies. "Without MQL, we can use the best raw material, which enables complete chemical vapor deposition (CVD) coating of the tool with diamond, which extends tool life by a factor of two." Mueller-Hummel also points out that the MQL system must be calibrated to ensure proper air and oil flow. The calibration process, he explains, "requires special training and must be completed before machining can begin. If the test fails, the whole system must be recalibrated."

According to Mueller-Hummel, all of this time and expense can be eliminated by a shift to dry drilling. "One year ago, we started dry drilling with Bombardier on a wing application in Belfast [Northern Ireland]," he relates. With no necessity to deliver lubricant, drilling equipment could be simpler and less costly. "By eliminating MQL they could also use smaller, lighter drilling equipment, which is more reliable and requires less maintenance." The result? He claims, "The cost per hole has been reduced by at least a factor of four, and the process has a higher CPK, with no jamming and sticking of wet carbon dust."

Eliminating heat

In order to dry-drill H8 holes in composite-metal stacks in a single operation, the problems traditionally solved by using different tools, multiple drilling steps and lubricant had to be addressed in tool design and in control of drilling process parameters, specifically, rotational speed and feed rate. This required a fundamental understanding of the drilling processes for metals and composites.

"The drill tool action to cut through composites vs. metals is very different," says Mueller-Hummel. Developed before the advent of widespread use of composites, metal-drilling tools evolved from



Heat generation zones

By analyzing and mitigating heat generation zones, Mapal was able to develop a drill tool design that enables precision holes without MQL.

standard metals-cutting technology, where heat at the cutting interface actually melts the metal so that the tool can push through, similar to a hot knife through butter. "But that type of heat can damage composites," he notes. And in stacked drilling the heat "causes the metal to expand." The result is a larger hole diameter in the metal layer than in the composite layer. Thus, Mapal knew it must develop a tool geometry that works with metals at very low cutting temperatures.

A fundamental study of drilling metals revealed three main locations where a drill tool generates heat: the tip

(nose), the grip (edges/corners) and the chips (material removed from the hole). That stimulated the following developmental goals:

- The tip. Design a tip that could cut effectively at lower rotational speeds (100 m/min for CFRP, 120 m/min for aluminum) without melting the metal. "It was not easy to develop a tip which heats up only the relevant area and with the minimum heat required without transferring heat to the remaining tool body," attests Mueller-Hummel. (See chart above.)
- **The grip.** Because the tool body reaches its highest speeds at its

Actual situation with different diameters Composite Titanium Aluminium Ideal situation with same diameters Dealing with diameters One issue when drilling compositemetal stacks is the larger hole diameter (typically 0.001 inch greater) in the metal layer, due to the fact that it experiences greater thermal expansion than the CFRP layer.

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edges/corners, an increase in feed rate through the hole, to 0.1 mm/rev (.004 inch/rev), reduces the total length of time the tool is in contact with the material, and, thus, further limits heat transfer throughout the tool. Although changing the speed and feed rate might seem elementary, choosing a *slower* speed and a *higher* feed rate is the opposite of what is normally recommended for drilling of CFRP laminates.

• The chips. At a reduced RPM and higher feed rate, the tool cuts more deeply per revolution. "Now a problem arose in that this type of tool generates extra material, which has to go somewhere," says Mueller-Hummel. "In traditional metal drill tools, when that buildup tries to squeeze the tool, the tool pushes that material into the hole edges, which, in effect, workhardens the edge and improves its fatigue life." This

does not apply in composites drilling, so excess material must be evacuated as soon as possible. A progressive flute design now helps to evacuate the chips. In addition, the chip size is reduced by means of a technique called *micropecking*: The drill motor is designed to alternately apply force and retract, many times per second. This action literally hammers the chips into smaller pieces (see "Learn More").

SIDE STORY

Hole quality defined

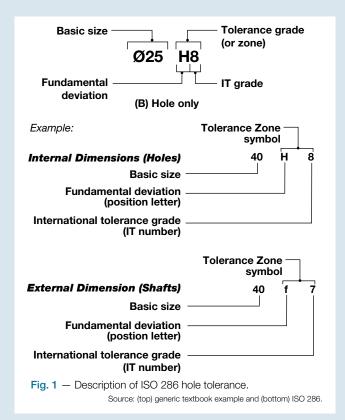
In manufacturing — and the prerequisite engineering — it is not possible to make components to an exact size every time. Thus, the amount the actual molded component's size may deviate from the target dimensions must be known and listed along with its nominal measurements. A component's maximum and minimum permissible size are known as its *limits* and their difference is termed the *tolerance*. These definitions also apply to the holes drilled to accommodate fasteners when joining multiple components to form an assembly.

ISO 286: System of Limits and Fits is a coordinated system of hole and shaft tolerances that is used in both engineering and production. It is defined and maintained by the International Organization for Standardization (ISO, Geneva, Switzerland), an independent, nongovernmental organization that comprises members from the national standards bodies of 161 countries. The ISO 286 standard states, "hole basis fits [as opposed to shaft basis fits] have four preferred hole tolerances (H11, H9, H8, and H7)." Hole basis fits are used when holes are made with standard machine tools (drills, reamers or end mills). The above hole tolerances are used to indicate the precision of drilled holes in aerostructures.

Fig. 1 shows a typical hole size and tolerance designation where size is most commonly given in milimeters (mm). The smaller the IT number, the more precise the hole diameter. Cutting-tool manufacturers often use H8, H7, etc. interchangeably with IT8, IT7, etc., to describe the precision of drilled holes.

According to Dr. Peter Mueller-Hummel, senior manager for the aerospace and composites business unit of Mapal (Aalen, Germany), "the standard for drilled hole tolerance in aerospace metals is H7, meaning that the diameter does not vary more than .010 mm [0.0004 inch or 0.4 mil]." He notes that the hole tolerance in The Boeing Co.'s (Chicago, III.) 787 *Dreamliner* program was initially relaxed to H8, or ± 0.018 mm (0.0007 inch or 0.7 mil), but because the holes being drilled still could not consistently meet that, the tolerance was dropped again to H9 at ± 0.04 mm (0.002 inch or 2.0 mil).

The other measure of hole drilling precision given is CPK, or $C_{\rm pk}$, which is defined as process capability index, a statistical tool that



measures the ability of a process to meet specifications. It compares the process data distribution — e.g., hole diameter — to the specification limits and predicts future performance. A CPK >1.3 is required for "reliable and safe" drilling operations in aerostructures, according to Mueller-Hummel, and 1.7 is necessary for OEM qualification (a higher number indicates better performance). Thus, the CPK of 2.4 that Mapal reports for its new tool in the dry drilling of a wingbox assembly's stacked materials is impressive.







Microreaming innovation

The concept of Mapal's Micro Reamer is illustrated here, although its actual 1 mil projection would not be visible without magnification.

To handle the excess material buildup in the metal hole's sidewall that results from the larger chips, Mapal employs an innovative single-blade reamer. "Normally, reamers have many blades, at least three to four," Mueller-Hummel explains. "Ours has two guide pads and only one cutting edge." By incorporating the single-blade reamer design into the drill tool, material that accumulates and puts a "squeeze" on the tool is removed — the guide pads move the material inward and then the reamer then cuts it off. "So we have refined the tool to perform a true cutting operation on its sides," Mueller-Hummel summarizes. There is no "jamming" at the cutting edge and heat is further reduced.

Dealing with different diameters

One problem, however, still remained. When Mapal first started working with Bombardier, the aircraft manufacturer wanted to maintain H8 hole tolerance in stacked materials, but the metal hole was consistently 25µm (0.001-inch) larger in diameter than the composite hole (see drawing, bottom of p. 49).

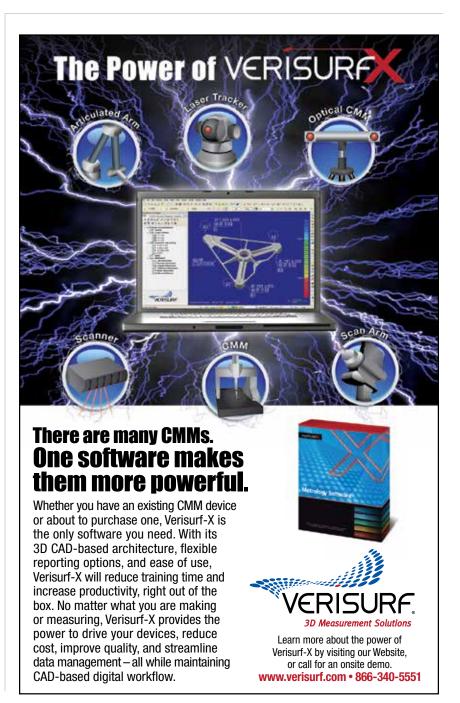
The solution was a second reamer. "Our idea was to put a *micro*reamer on the drill tool," Mueller-Hummel recalls. "By adding a small, very thin step of 10 μ m to 50 μ m [0.0004 inch to 0.002 inch], this additional cutting implement would only touch the composite and make its hole edge equal with that in the metal"

(see photo at left). Now trademarked as the Micro Reamer, this feature also solves the chronic problem of "burring," the term for the rough edge that remains on the composite after it has been drilled. In composites, the burrs or "hairs" remain because fibers aren't sheared cleanly. Notably, as the drill turns, the heated matrix will "smear" and trap ragged fiber ends against the hole side. "At first, it appears this has worked like in metals," he

notes, "but after a couple of days, the fibers flex back into the hole and you have a smaller diameter. Everyone thinks this is a problem with composite materials. It is actually a problem with the drill tool design."

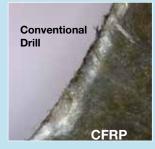
The Micro Reamer is evenly CVD-coated so it works like a grinding tool, removing the uncut fiber. (See photos, p. 54).

At first, Mapal thought the Micro Reamer would only work when the



Hole clean-up

The Micro Reamer on Mapal's new drill tool grinds away burrs and scratches (see photo left) leaving a high-quality hole that is within tolerance (right).









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email: wtf@wyomingtestfixtures.com www.wyomingtestfixtures.com composite was the first material in the stack, but after much study, found it doesn't matter where the composite is because the hole diameters of the composite are consistently smaller than in the metal. Therefore, the Micro Reamer only removes encroaching fibers and burrs from the composite, and does not remove metal.

That said, the metal is most often positioned at the bottom of the drill stack as reinforcement for the composite structure. Metal chips that aren't successfully evacuated can leave scratches (typically 1 mm deep) in the composite hole's sidewall. Mueller-Hummel says, "This is no longer an issue because the Micro Reamer removes all of these scratches."

Status and qualifications

Mapal has demonstrated that, at lower speeds and higher feed rates, the new drill tool can cut H8 holes in one shot, without MQL, for CFRP/CFRP and CFRP/ aluminum stacks. "We can also drill H8 holes in CFRP/titanium and aluminum/ CFRP/titanium stacks in a single operation, but," Mueller-Hummel concedes, "we have to use MQL." However, he adds that his team has developed a new tool that works with titanium and is now refining it to eliminate lubricant.

Nonetheless, Mapal's tool design and drilling regime has achieved qualification at six OEMs and Tier I suppliers and is in the beginning stages with multiple others. And the potential for savings is significant. Mueller-Hummel reports, "We have another customer working on a large airframe drilling CFRP/aluminum stacks in four to five steps, requiring 30 minutes per hole and ending up with very poor quality. Our trials so far have reduced drill time to two minutes with an H8 quality in one shot and no MQL." ■



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VX AEROSPACE: SMALL COMPANY, BIG PERFORMANCE

Innovative design, OOA manufacturing and C-PLY laminate construction produce "big fabricator" aerostructures in fewer steps at low cost.

BY GINGER GARDINER



X Aerospace is an advanced composites company near the Appalachian Mountains in Morganton, N.C., close to a growing composites hub in the Carolinas that is home to several of VX Aero's key suppliers, Chomarat North America (Anderson, S.C.), Materials Innovation Technologies (MIT, Fletcher, N.C.), Highland Industries (Kernersville, N.C.), Saertex USA (Huntersville, N.C.) and, soon, Toray Industries (Tokyo, Japan), which has a new carbon fiber plant near Spartanburg, S.C., on the drawing board to support the booming aerocomposites manufacturing base in Charleston, S.C.

Although VX Aero designs and manufactures a wide range of tooling and parts for automotive and heavy-truck applications, and even carbon fiber-reinforced composite ceiling fan blades, aerospace structures are its core competency. It is certified to AS-9100:2009, the "aerospace standard" for quality management and a prerequisite for participation in military and commercial aircraft production.

VX Aero's founder and chief engineer, Bob Skillen, is a degreed aerospace engineer and ex-U.S. Navy F-14 aviator. His more than 25 years of experience in manufacturing includes tenures in Navy depot operations and on the MIL-Hand-book-5 and NAS standards committees. On his watch, VX Aerospace was the first composites manufacturer to field an out-of-autoclave (OOA) part on an active-

duty Navy aircraft, the CH-46E SeaKnight helicopter. VX Aero has designed, prototyped and produced more than six-dozen unique composite components for that craft, many replacing aluminum parts.

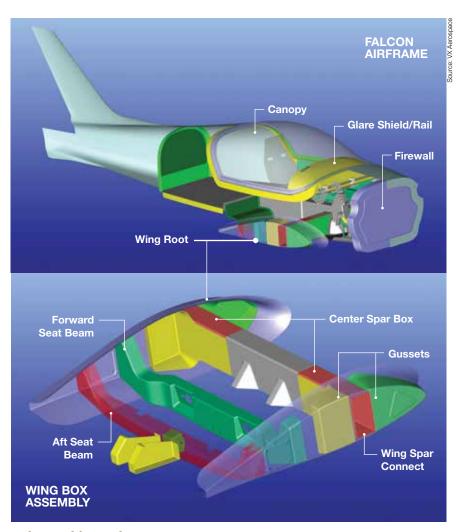
A comparatively small firm, VX Aerospace thrives on its ability to innovate quickly and cost-effectively. Skillen credits that, in large part, to today's computer-aided modeling (CAM) and computer numerical control (CNC) machining technologies, which speed product development, and the advent of high-quality OOA processing: Parts are layed up in the company's 4,000-ft² (372m²) cleanroom and then cured in its 40-ft by 12-ft by 10-ft high (12m by 4m by 3m) propanefired oven. Complete cure cycle logs are printed and saved for traceability, thanks to a Yokogawa (Tokyo, Japan) digital temperature controller and DASYLab data recording software from Measurement Computing Corp. (Norton, Mass.). Together, these tools have helped level the playing field in his case, says Skillen, between big and small manufacturers in terms of capability. But he also places special emphasis on his company's willingness to adopt new composite materials — most recently, thin, biaxial reinforcements called C-PLY.

Why C-PLY?

"My first exposure to the concept which later became C-PLY was as a student in Dr. Stephen Tsai's 'Composite Design Workshop' offered by Stanford [University]," says Skillen. "The approach made a lot of sense," he recalls. "Rather than try to make laminates that approximate isotropic materials, C-PLY is designed around the fiber properties and ply orientations (angles) that enhance laminate performance." (See "Learn More," p. 64.)

C-PLY combines several positive traits: It is a noncrimp fabric (NCF), it features anisotropic biaxial construction, and its fibers are oriented at a low angle — it is sometimes described as "bi-angle" due to its $0^{\circ}/\theta^{\circ}$ construction, where a low value of θ , e.g., 20° to 30° , reduces interlaminar stress, enhancing load transfer between plies without matrix cracking. Further, its spread-tow construction makes it remarkably thin.

Although quasi-isotropic symmetric lay-ups (traditional "black aluminum") are commonly used in composites because they mimic the properties of the metals they replace, computer-based an-



Redesigned for productivity

The heart of the VX Aerospace design for the U.S. version of the Falcon airframe is its wingbox assembly, anchored by a 3-D woven carbon fiber composite spar box. Self-rigging assemblies are used to cut production cost and time by using dimensionally accurate structures — in this case the spar box — to locate and align the next higher assembly — for the Falcon, that includes seat beams, wing roots and wing spars.

alytical tools enable detailed ply-by-ply analysis, allowing designers to exploit the benefits of low-angle anisotropic design. The end result is better properties for the same weight or as much as 40 percent less weight than an aluminum structure for similar performance.

The use of a larger number of very thin plies reduces interlaminar stress and enhances toughness. "Like in a beetle shell, an optimized composite theoretically would have layers just a few fibers thick," explains Skillen. C-PLY uses 12K, 24K, 48K or 50K tow, spread very thin but without gaps. The 12K spread tows VX Aerospace has used so far (0.003-inch/0.076-mm ply thickness) are much thinner than

most unidirectional (UD) prepregs and weigh in at only 75 g/m² (2.2 oz/yd²).

VX Aero expects to have a steady source for the new material. Chomarat is installing a production line (scheduled to be operational by mid-year 2014) capable of producing any stitched multiaxial configuration, but optimized to produce 100-inch/2.5m wide NCF with angles from 30° to 90°. Multiaxials with angles of less than 30° are available in a reduced width. Skillen emphasizes that the stitched two-ply fabric VX Aerospace has been using — totaling 0.006-inch (0.152-mm) thickness and 150-g/m² (4.4-oz/yd²) weight per layer — is tailored for structural loads but is far easier to

FEATURE / PLANT TOUR



CNC-machining masters

Plastic tooling board masters are cut from CAD file data by VX Aerospace's DMS 3-axis machining center.



Tooling quality with economy

Void-free, high-gloss tools, like these produced for the *Falcon* wing roots, have tooling surfaces formed with standard carbon fiber plainweave fabric (below, left) with low-cost recycled carbon fiber mat behind them as bulking plies (below, right), which are then infused with 350°F/180°C epoxy tooling resin, postcured and surface-coated.

place and much less equipment-intensive than automated tape placement.

Currently, two composite aircraft projects occupy the company's 17,000-ft² (1,579m²) production space. Both will make extensive use of C-PLY. The first is the Falcon, a sleek, low-wing, high-performance sport aircraft esteemed by some as "the Ferrari of light aircraft." Originally built in Hungary, a handful of the planes made it to the U.S. before the manufacturer, Corvus, went bankrupt. A groundswell of demand spurred an effort to put the plane into production in the U.S. Via a memorandum of understanding with Renegade Light Sport Aircraft (Deland, Fla.), VX has assumed responsibility for design, engineering, tooling and manufacture of the Falcon airframe, while Renegade controls sales, marketing and FAA certification.

The other aircraft is a 1:4 scale version of the VX Aerospace-designed VX-1 KittyHawk. Its unique blended wing/fuselage is designed to exploit aerodynamics and potential alternative fuels to cut flight cost per mile by a factor of three while offering more internal volume and payload. Like its Wright Brothers namesake, the KittyHawk is poised to score a first of its own: It will be the first aircraft to fly with C-PLY laminates.

Skillen believes that the new material combined with OOA processing can enable small composite airframers the opportunity to produce structures with the same precision and performance as those fabricated by big aerospace OEMs and primes, but at a fraction of the latter's delivery time and cost.

Designed for manufacturability

The single-engine Falcon is 21 ft/6.4m long, with a 31.5-ft/9.6m wingspan. It can cruise at 140 mph (225 kph), burning less than 5 gal/18.9 liters of fuel per hour. For the North American market, VX Aero is maintaining the plane's look and basic dimensions but also taking steps to improve its structural design.

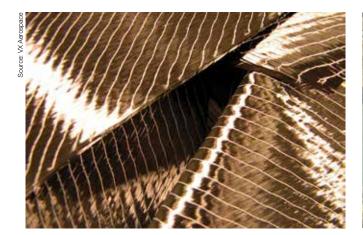
Because the plane's defunct creator's design data were unavailable, development began with white-light 3-D digital scanning of the entire aircraft (using a structured-light scanner rather than a laser scanner) from which it developed CAD surface models. Then came the critique: "Original production was most likely using hand-built masters and tooling," says Skillen. The fuselage had a significant amount of asymmetry. There were butt-jointed cored panels without any means for

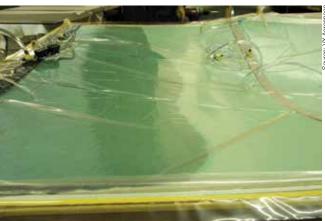




Masters prepped for tooling layup

VX Aerospace's quality tooling begins with the master patterns. Surfaces of male patterns are putty-filled, sanded and sealed then polished and recoated with sealer again in preparation for the tooling laminates. The master for the *Falcon* fuselage's right-side tooling is on the right side of the photo.





load transfer and a lack of hard points for structural connections. The construction scheme needed improvement, and it would be necessary to optimize the design for manufacturability. "Quality and efficiency had to be designed into every assembly and process," he says, "to control costs and cycle time in an actual production environment."

In pursuit of those goals, VX Aero is employing the concept of 'self-rigging subassemblies' in the Falcon's design. For example, the heart of the airframe is a carbon fiber-reinforced plastic (CFRP) spar box. As the anchor component of the wingbox assembly (see top of p. 57), its outer mold line (OML) surfaces align with and locate those of the next higher assembly. This helps to minimize the cost and complexity of assembly fixtures yet hold tight tolerances.

The new wingbox assembly also addresses an issue in the original aircraft. Namely, landing gear loads were directly imparted to the fuselage with no load path carry-through from one side to the other. And because the large fuselage cutout for the polycarbonate cockpit canopy is located directly above the region that absorbs gear loads, this structural configuration resulted in unacceptable deflection. To compensate, VX Aero redesigned the forward and aft seat beams as key elements of the wingbox assembly. They are now attached through the wing roots to the spar box, which now provides the primary load path for the wing moments.

Materials and assembly

The spar box is a continuous box beam with 0.1-inch/2.5-mm thick walls. Both its A and B (inner and outer) sides are critical dimensions. The outside locates

VX-1 KittyHawk C-PLY airframe laminates

Layup for the VX-1 $\it KittyHawk$ top and bottom skins used +45°/0° and -45°/0° C-PLY (left), alternating in a six-layer stack (12 plies per six layers), with a 150-g/m² weight and 0.006-inch thickness per two-ply layer. Parts were then infused (photo on right) with the same high-temperature epoxy used to infuse the tooling.

the fore and aft gussets — they add stiffness and supplementary paths for landing gear loads — while the wing spars must fit *inside* the spar box ends. A 3-D fabric, woven from T700 carbon fiber supplied by Toray Industries, was chosen to handle the structure's high interlaminar shear loads. Supplied in the form of a sock-like preform by Highland Industries, a subsidiary of technical textile source Takata (Tokyo, Japan), it enables quick lay up of 10 plies over an expandable mandrel.

Notably, VX Aero has replaced the sandwich construction of the original craft, which featured extensive use of foam and honeycomb core, with monolithic skins reinforced by post-bonded hat stiffeners to reduce weight and enhance manufacturability. The canopy cutout is now bolstered by a CFRP rail that Skillen integrated into the glare shield as a one-piece structure. Thus, a reliably consistent fuselage/canopy interface is achieved with minimal parts and assembly. "The canopies will fit easily into the fuselage opening every time and be interchangeable with each other in the field," Skillen explains.

Once the wingbox assembly is complete, fixed inner cockpit panels will be attached to the forward and aft seat beams and then the rail/glare shield will be affixed, followed by the cabin floor and firewall, which separates the engine from the cabin. Finally, the fuselage halves will be bonded using a fixture de-

signed to account even for the glue thickness tolerances.

After the firewall and fuselage are bonded, the aircraft's engine, still connected to its wheeled stand, is bolted to the firewall. Because the Falcon fuselage will only weigh 70 lb/154 kg, the assembly can be wheeled around the production floor easily, eliminating the need for a crane.

The wingbox assembly is all CFRP: 3-D woven material in the spar box and 3K plain weave in the other components. Like the original, the new Falcon will use glass fiber prepreg in the fuselage. Glass reinforcement is sufficient because the fuselage loads are smaller than those in the wing, and glass reinforcement will enable the radio transmissivity of internal antennae.

Prepreg layup, rather than what would be a complex infusion setup, was chosen for the fuselage, based on manufacturability and consistency/repeatability. Prepregged C-PLY will be used in the wing spars, wing skins and horizontal tail. Most of the other small parts will be infused, but some will be made using wet layup. Each material and process has been chosen with the balance between part performance and manufacturing efficiency in mind.

Fast Falcon retooled

After 18 months of computer modeling every component on the airplane, CAD files were fed to VX Aero's 3-axis CNC



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Composites Optimization and Analysis in Space Launch Vehicles: United Launch Alliance (ULA) Utilizes Free Size Optimization for a Doubler Repair of a Gouge Type Defect

EVENT DESCRIPTION:

Doublers are commonly used in launch vehicles to repair composite sandwich facesheet defects, such as gouges or depressions, because they locally increase the strength of the facesheet in the area of the repair. Although doublers can be of a different material than the facesheets, they often have comparable strength and stiffness. Therefore, the doubler's influence on the overall extensional and bending stiffness of the sandwich can be significant. ULA explored the use of OptiStruct, HyperWorks' structural optimization and analysis solver, to optimize the size and shape of a composite doubler to minimize the stresses.

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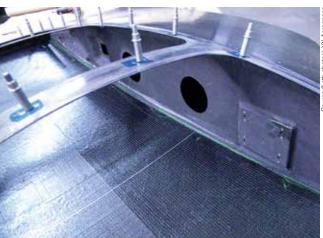
Tim Harrell is a structural analyst at United Launch Alliance. He received his degree from Tennessee Tech University in Civil Engineering with an emphasis on Structural Mechanics. At ULA, the majority of time has been spent working on analyzing non-conformances on both the Atlas and Delta launch vehicles to determine if they still are structurally sound.

Dr. Robert Yancey is Vice President—Aerospace Solutions for Altair where he focuses on developing and delivering innovative simulation and design based solutions. Throughout his academic and professional career he has been involved with the characterization, design optimization, and analysis of composites in a variety of industries. He holds degrees from MIT, Virginia Tech, and the University of Dayton and has been with Altair since 1999.

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machining unit by Diversified Machine Systems (DMS, Colorado Springs, Colo.), which cut precision masters (top photo, p. 58) from 38-lb/ft³ (0.6-g/cm³) RAKU-TOOL plastic board supplied by Rampf Tooling (Grafenberg, Germany). Pattern surfaces were prepped and sealed with Chemlease (Chem-Trend, Howell, Mich.) and then polished and coated with Chemlease again in preparation for laminate lay up (bottom photo, p. 58).

VX Aero uses recycled carbon fiber mat (photo, p. 58) from Materials Innovation Technology Recycled Carbon Fiber (MIT RCF, Fletcher, N.C.) as the tooling bulk layers to build thickness quickly and cheaply (less than \$2.00/ft2), interspersed with 3K carbon fiber plain weave fabric (about \$5.00/ft2). This dry laminate is then infused with 350°F/180°C-cure PT5712 epoxy tooling resin from PTM&W Industries (Santa Fe Springs, Calif.), postcured at 25°F over T_g for 18 hours and then surface coated. The Falcon's fuselage tools were made using LTM318-1B glass fiber/epoxy OOA tooling prepreg from Cytec Aerospace Materials (Tempe, Ariz.) to match the final part materials.

"Everybody loves vinyl ester surface coats because they are hard, not prone to air leaks and have less water ingression," notes Skillen, "But they are not compatible with epoxy matrix resins." VX Aerospace achieves a vinyl ester (VE) surface coat by using 1799-006 vinyl ester primer from Hawkeye Industries (Bloomington, Calif.). Skillen says the resulting tools are void-free with very high gloss surfaces (see middle photo. p. 58).

By the end of 2013, VX Aerospace had completed masters for the Falcon's horizontal tail and all of the fuselage components. Tooling from those masters is

Assembly of the VX-1 KittyHawk blended wing body

Ribs were bonded to the bottom skin (left), and then the top skin — with openings for payload access — was bonded onto this assembly; the silver cleco clamps show the drilled holes where fasteners will be installed. The photo at right shows the VX-1 KittyHawk airframe readied to receive its payload access cover.

close to completion. The wing tooling is next in line. Limited rate production of 20 aircraft per year is planned using a team of 20 employees.

First in flight

The VX-1KittyHawk strikes a marked contrast with the Falcon. Its blended wing body features wings that are smoothly blended into an airfoil-shaped fuselage, achieving a 50 percent greater lift-to-drag ratio than conventional designs.

Skillen points out that the most efficient airfoil is elliptical, like a Spitfire. "This is exactly the top profile of the KittyHawk," he adds.

At full scale, the plane will measure 26 ft/8m in length with a span of 22.5 ft/7m and a body height of 4 ft/1.25m, offering significantly more usable internal volume than other aircraft of similar gross weight. (Empty weight will be ~750 lb/340 kg, using 100- to 125-hp engines). "It will offer a 7-ft/2m cockpit width, which is

SIDE STORY

A UAV fueled by CNG?

Originally developed for manned flight in light aviation, the VX-1 KittyHawk has received more recent attention as a long-range, fuel-efficient unmanned aerial vehicle (UAV). "There is nothing like it flying today," claims Bob Skillen, the founder and chief engineer at VX Aerospace (Morgantown, N.C.).

The plan for both markets is to power the *VX-1 KittyHawk* with compressed natural gas (CNG). Skillen relates that Aviat Aircraft (Avton, Wyo.) generated a lot of press for its *Husky* CNG-fueled model at the EAA AirVenture 2013 show in Oshkosh, Wis.

"The tank hung below the belly, and the aircraft achieved 80 to 90 mph, burning only 8 to 9 gal/hr," Skillen recalls. "A full-scale *KittyHawk* can accommodate CNG tanks *without* any aero-dynamic compromise or cockpit modifications." CNG is currently one-third the cost of aviation fuel, which the U.S. government would like to see phased out anyway, he points out, because it contains lead. With CNG at \$2/gal, Skillen projects the *KittyHawk* can fly two occupants at 140 mph/225 kmh with a fuel cost of \$.08/mile. "Currently, most light aircraft have a fuel cost of \$.20 to \$.30/mile," he notes, "So the *KittyHawk* would reduce that by a factor of three, but also cut emissions by up to 40 percent."







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C-PLY source

Chomarat North America's C-PLY production line in Anderson, S.C., will produce any stitched multiaxial configuration, but is optimized for 100-inch/2.5m wide 0° noncrimp fabric, stitched to layers angled from 30° to 90°. Fiber angles less than 30° are no problem, but are produced at a reduced width.

unique in this size aircraft." As a UAV, its larger internal volume permits more payload and sensors. In the manned light aircraft market, it means more cockpit comfort, and greater cargo and fuel capacity. There are also no wings to break off upon landing, improving aircraft recovery for UAVs, and it offers the option to be powered by compressed natural gas (see "A UAV fueled by CNG?" sidebar, bottom of p. 61).

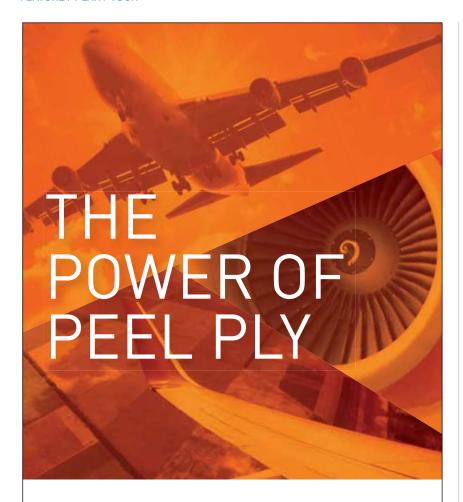
With support from North Carolina State University (NCSU, Raleigh, N.C.), computational fluid dynamics (CFD) analysis and wind tunnel testing were completed in October and November 2013, managed by Dr. Richard D. Gould, chair of the Mechanical Engineering and Aerospace Department. According to Skillen, results have exceeded expectations. The aircraft generates 20 lb/44 kg of lift at 0° angle of attack (i.e., no tilt relative to the airflow direction), which equates to 100 ft/ sec (31 m/sec) at 68 mph/109 kph. In other words, the aircraft generates lift quickly without requiring a lot of speed to take off. "That's almost twice as aerodynamically efficient as most other light aircraft," says Skillen. It also demonstrates good dynamic stability (ability to recover after disturbance from normal flight), and no further modifications will be needed prior to flight testing. NCSU will help here as well, says Skillen, by flying the 1:4 scale aircraft with a telemetry package to map out all of its flight characteristics and, thus, verify the CFD analysis.

Prototype to production

"We are applying modern CFRP technology to make the traditional performance of blended wing body aircraft even better," says Skillen. The aircraft's structurally efficient shape eliminates the need for high-strength spars. Thus, the airframe is essentially hollow. Beyond its top skin, bottom skin and four ribs that make up the body, the only other parts required are vertical fins and flight control surfaces. Skillen asserts that this makes the KittyHawk easy and cost-effective to manufacture.

Such a design, however, requires large, unsupported, high stiffness-to-weight structural panels. "This is the sweet spot for CFRP construction," Skillen claims, noting that, here, "C-PLY furthers the weight savings possible, with skins that are significantly lighter than if using 3K plain-weave fabric."





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He adds that C-PLY speeds the layup, with two plies applied at once, and results in laminates with a more homogeneous fiber distribution throughout, which increases fracture toughness compared to conventional unidirectional materials.

Tooling for the 1:4 scale aircraft was directly CNC-machined from plastic tooling board because it is temporary and, therefore, can be designed for short life and low cost. Layup of the 1:4 scale aircraft structures used six lavers (12 plies total) of C-PLY, again with a 150-g/m² weight and 0.006-inch thickness per twoply layer (left photo, p. 59). Parts were then infused (right photo, p. 59) using PTM&W's 2712 epoxy resin. Demolded parts were then assembled. First, ribs were bonded to the bottom skin; then the top skin — which includes openings for payload access — was bonded to this assembly (see photos, p. 61). The payload access cover was then attached with mechanical fasteners.

The first finished airframe (see p. 56) was displayed by Chomarat at JEC 2014 (March 11-13, Paris, France). A second 1:4 scale aircraft, assembled in March, was delivered to NCSU for flight testing.

Skillen anticipates full-scale aircraft production will likely use C-PLY prepregged with Cytec's Cycom MTM45-1 OOA prepreg resin. However, the final decision, prepreg vs. infusion, will be made based on the customer's production volume. (Several potential customers, are awaiting flight test results before making commitments.) Parts can be layed up quickly using C-PLY.

Skillen estimates the VX-1 KittyHawk will use 6,000 ft²/557m² of C-PLY per plane. "We could design and make this aircraft with traditional carbon fiber roll goods," Skillen admits, "but the efficiency and performance C-PLY delivers gives a small company like us a real competitive advantage."



For a primer on how C-PLY works, see "Bi-angle fabrics find first commercial application," *HPC* January 2013 (p. 46) or visit short.compositesworld.com/8937KYrm.

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May 24-25, 2014	Rotortech 2014 Conference Sunshine Coast, Queensland, Austr www.austhia.com		Sept. 30-Oct. 2, 2014	Exhibition (ACCE) Novi, Mich. speautomotive.com/comp.htm IBEX 2014
June 2-5, 2014	SAMPE Tech 2014 Seattle, Wash. www.sampe.org/e	Oct		Tampa, Fla. www.ibexshow.com/tampa2014.php Composites Europe 2014
June 2-6, 2014	MCM-2014, the XVIII International Mechanics of Composite Materials Riga, Latvia www.pmi.lv/New/EnConferenceAbout.html		ct. 13-16, 2014	Düsseldorf, Germany www.composites-europe.com CAMX - The Composites and Advanced Materials Expo Orlando, Fla. www.thecamx.org
June 8-11, 2014	1st International Conference on Mer Composites (MECHCOMP2014) Atlanta, Ga. I https://sites. google.com/site/	chanics of Oc	ct. 27-29, 2014 See more events	SAMPE China 2014 Beijing, China I www.sampe.org.cn s at www.compositesworld.com/events



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APPLICATIONS

Carbon landing gear leg cushions UAV landing

Using its Lost Core Resin Transfer Molding (LCRTM) system, Wichita, Kan.-based Fiber Dynamics Inc. produces complex, hollow structures in a single molding operation. For the past 10 years, the company has used the process, developed inhouse, to manufacture the main landing gear strut for the *Predator* B MQ-9 *Reaper* unmanned aerial vehicle (UAV), produced by General Atomics Aeronautical Systems (San Diego, Calif.).

"Conventional prepreg processes were unable to economically provide the structural performance required, and metallic options would typically weigh and cost more," explains Fiber Dynamics' CEO Darrin Teeter. "In comparison, our LCRTM system reduces weight and cost, and improves structural integrity through a unitized structure."

More than 600 of these struts — functionally, hollow leaf springs — have been made using S-2 Glass fiber from **AGY** (Aiken, S.C.) with a carbon fiber center stiffener (see photo, top right). Now, Fiber Dynamics is developing a prototype strut for another as yet unidentified UAV (image below). "This one uses a shock absorber to cushion the landing instead of the spring action of the strut itself," Teeter says. To meet the higher stiffness and load requirements of this design, IM7 unidirectional carbon fiber from **Hexcel** (Stamford, Conn.), aligned in the

primary load-bearing direction (longitudinal), is woven together with a plain-weave carbon fiber fabric, to Fiber Dynamics' specifications, by **Fabric Development Inc.** (Quakertown, Pa.).

Fiber Dynamics begins the manufacturing process by casting the core from its proprietary Thermocore material. Tailored for lowmelt viscosity and minimal thermal expansion, the material "behaves like a ther-

moplastic," Teeter says. The cast core is then machined to the exact shape of the inside surface of the part's hollow cavity. It serves as a male mold for formation for the carbon preform and as a sacrificial mandrel during molding.

Dry fabric for the preform is cut into preprogrammed ply patterns on a CNC cutting system from **Eastman Machine Co.** (Buffalo, N.Y.), and the plies are layed up directly on the core mandrel — along with doublers and fittings — using customer-approved epoxy tackifiers. Titanium doublers are interleaved with the carbon fabric around the primary loadbearing bushing, which is molded-in and hinged to enable landing gear deployment and retraction.

"The titanium plates fit very tightly

against the bushing to help mitigate and transfer the high loads into the laminate — especially the high impact loads created on landing the more than 4,000 lb [1,814 kg| UAV," Teeter says. The dry preform is then consolidated, either by vacuum or mechanical compression. "We are able to compress it to the net shape of the mold cavity," Teeter explains, noting that the preform volume, then, is "60 percent fiber, and 40 percent air,"



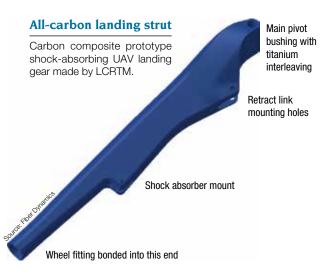
A fiberglass leaf spring made by LCRTM for the *Predator B MQ-9 Reaper* UAV. Its carbon fiber stiffener strengthens the attach point to the airframe (lower right).

a match for the part's expected 60/40 fiber/resin ratio.

The net-shape preform and core are enclosed in the female closed mold that defines the part's outer geometry, and then it is infused with an unnamed epoxy resin system supplied by Momentive Specialty Chemicals (Columbus, Ohio), using standard RTM techniques. The part is cured at a temperature below the melting temperature of the Thermocore mandrel. After demolding, the part is CNCtrimmed and holes are drilled for fittings and fasteners, which, synergistically, provide drainage paths for the mandrel when the part is postcured at a proprietary temperature that melts out the Thermocore. After postcure, the part is cleaned to remove residual mandrel material.

Still in the test phase, Fiber Dynamic's carbon composite LCRTM landing gear is proving its ability to absorb the landing loads imposed by the UAV. "Based on test results, we expect the landing gear leg to be fully implemented when the UAV begins production," Teeter says. When that will be has not yet been determined.

Teeter points out that the UAV market provides opportunities to try new processes and produce prototypes that would be much more difficult to attempt on a manned aircraft. However, he adds, "that will probably change as UAVs start entering public air space." A test program is underway to safely implement integration of unmanned aircraft systems into U.S. airspace in 2015.



Demonstration software modeling exercise aids Taiwan's yachtbuilding community

Well known for its electronics expertise, Taiwan also maintains a respected luxury motoryacht industry. In 1987, the country exported 1,755 vessels, worth more than \$190 million (USD), and today, postrecession, it reportedly has the sixth-largest yachtbuilding community in the world.

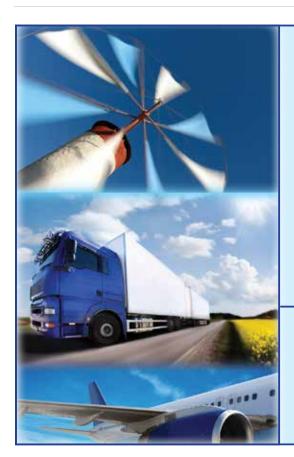
To advance its boatbuilding expertise, the country is constructing a dedicated yachtbuilding precinct as part of the Kaohsiung Port City Reconstruction project. Ray Tsai, technical director of **Simutech Solution Corp.** (Taipei, Taiwan), a **Dassault Systèmes** (Waltham, Mass.) partner and an expert in the latter's SIMULIA application, says that despite the island's standing in the motoryacht market, its yachtbuilders lacked expertise in CAD/CAE and composite layup optimization, particularly for carbon fiber composites.

"Many yacht companies weren't familiar with computer tools and traditionally outsourced the upfront design to foreign partners," says Tsai. Together with colleagues Rey-Yie Fong of Tiny Machine and Mechanics Laboratory (TiMMeL, National Taiwan University), and Chia-Chuan O and Yu-Chieh Lin, both deputy engineers with the Ship and Ocean Industries R&D Center, also in Taipei, Tsai developed a demonstration modeling exercise to show builders that SIMULIA enables design iterations far earlier in the development cycle and traces problems during every stage of the pre-production process. "We wanted to help

them move iterating cycles from the manufacturing stage to the design stage so that the performance criteria could be evaluated earlier, when it costs much less to modify," he explains.

Fong chose three elements of yacht design that challenge Taiwanese manufacturers: composite layup architecture; ventilation and thermal analysis; and wave-impact transient analysis. "Designers, manufacturers and customers were struggling with how to achieve the optimal intrinsic strength and stiffness in their designs along with cabin ventilation efficiency, and navigating the tradeoffs around static structure performance and dynamic wave-slamming impact," says Tsai.

The SIMULIA application portfolio, based on Abaqus finite element analysis (FEA), and Dassault Systèmes' Simulayt simulation software were tapped for layup analysis and manufacturing process management. Abaqus CFD (computation fluid dynamics) came into play for ventilation and thermal analysis. Abaqus/Explicit was used for Coupled Eulerian-Lagrangian (CEL) analysis, which is central to slamming impact simulation. The CAD tool was Dassault Systèmes' CATIA, which Fong says seamlessly integrated with all three CAE functions for the demonstration. He chose a 70-ft Monte Carlo-type yacht (photo, top left, p. 69) as a simulation benchmark because it is the median size for Taiwan's yacht industry, and it conforms fairly closely to the proprietary specifications of most manufacturers.



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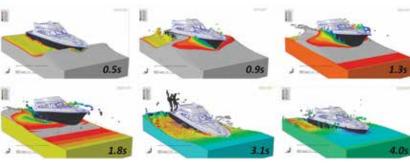


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Tsai says the team was able to import geometry from CATIA and use Simulayt with the composite modeler for Abaqus (CMA) to analyze composite layups. The same models were reused for the CFD simulation, and material properties and conditions could be shared between models without duplication. CATIA Composites came into play at the detailed design stage, helping to optimize design for manufacturability, and it also generated the composite layup geometry, which could then be assigned to Abaqus with specified material properties and fiber orientation. An interface connects CATIA Composite and Abaqus CMA with automatic data transfer, eliminating the possibility of typos and tedious layer-by-layer property assignments. The Simulayt tool then simulated the forces on a composite structure during manufacturing, rounding out the analy-

sis by predicting plant floor fabrication issues, such as hogging loads during hull lifting and demoldings, that can be mitigated earlier in the development cycle. This makes it easier to meet production timeframes within budget.

In terms of slam loads and wave impacts (see images, top right), the team used Abaqus CEL to simulate the yacht's transient and nonlinear varying response to these conditions in straight runs and turning maneuvers. Slamming contact pressure on the hull also was output to determine structure loading under transient impact.

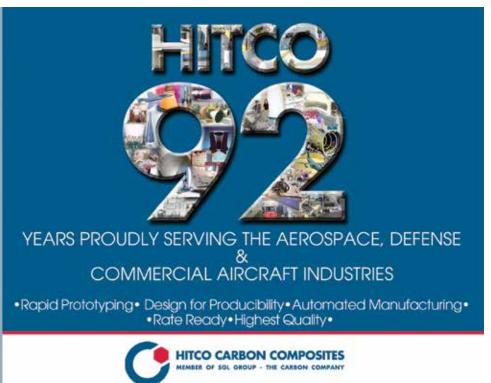
Concludes Tsai, "More widespread use of these advanced simulation methodologies will help Taiwanese yachtmakers. Simulation can help them innovate designs faster while keeping costs in check."

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Introduced at JEC Europe 2014

Carbon fiber, prepreg, epoxy resin

Hexcel (Stamford, Conn.) introduced several new products in Paris. Topping the list is high-modulus HexTow HM63 carbon fiber. With what Hexcel says is the "highest tensile strength of any HM fiber," HM63 reportedly provides good translation of fiber properties in a composite, including very good interlaminar shear and compression shear strength. Targeted to high-stiffness and strength-critical applications (satellites, unmanned aerial vehicles, commercial airplanes and helicopters) it also meets the special requirements for premium sports and recreation applications, including Formula 1, marine craft, bikes and fishing rods.

New HexPly M92, a "multipurpose" 125° C/ 257° F-cure epoxy prepreg, offers hot/wet T_g performance of 115° C/ 239° F, enabling it to operate at higher service temperatures from a lower-cost 125° C/ 257° F cure. The system is self-adhesive to honeycomb and fire resistant, exhibits low exotherm, has a long out/tack life and is compatible with vacuum-bag cure.

HexPly M77 is a rapid-curing epoxy prepreg that allows automotive components and sporting goods to be press-cured in a two-minute cycle at 150°C/302°F (80 bar pressure). It features low tack, which allows the prepreg to be cut by laser cutter. Once in the mold, HexPly M77's "optimized" gel time allows the resin to flow into contours to produce the geometries required. T_g of 125°C/257°F enables cured parts to be demolded while hot to speed cycles. www.hexcel.com

Carbon fiber sandwich construction cure via microwave

Vötsch Industrietechnik GmbH (Reiskirchen-Lindenstruth, Germany) announced that its HEPHAISTOS VHM microwave-based curing systems are now being used in a serial-production environment to cure carbon fiber composite sandwich parts for aerospace applications. Microwaves selectively penetrate the material and heat the product, but the oven chamber remains cool during this



process. This facilitates shorter temperature ramp up and cooling in the part, thus reducing production costs and cure cycle time. A fairing hinge on display in the Vötsch stand was manufactured with microwave technology. It reportedly is the first nonmonolithic aerocomposite cured by microwaves. Vötsch says material characterization showed equivalent or better values compared to conventional heating processes. Vötsch adds that its ovens maintain $\pm 2^{\circ}$ K accuracy at rated temperature and can be listed in class 1, according to AMS 2750 E. Ovens are rated as high as 450° C/842°F — sufficient for processing thermoplastics such as polyehteretherketone (PEEK). www.voetsch-ovens.com

LSP surfacing film

Henkel (Toulouse, France and Bay Point, Calif.) displayed its LOCTITE EA 9845 EC lightweight surfacing film with incorporated expanded copper foil lightning strike protection (LSP), which reportedly offers a 30 percent weight reduction compared to other LSP products. The epoxy-based system cures at 120°C to 176°C (248°F to 349°F) and



reportedly reduces surface imperfections and prepaint surface preparation while boosting UV and chemical resistance. On-stand at JEC, Henkel displayed a *Learjet 85* tailcone section manufactured by Bombardier in Querétaro, Mexico, which has qualified the new lightweight LSP for use across the aircraft's fuselage. www.henkel.com

Integrated, real-time health monitoring

Fraunhofer IPT (Aachen, Germany) reported that it has developed a quasicontinuous fiber-based measurement system that assesses the temperature and rate of expansion in composite structures. The system comprises fiber probes up to 70m/230 ft long. In up to 7 million checkpoints, the probes record temperature variations of 0.1°C/0.18°F and expansions of 1 micrometer per meter. Fraunhofer says the small caliber of the fiber, combined with its flexibility, means it can be built relatively easily into components and semifinished products. www.ipt.fraunhofer.de

Composites cost-estimating software

Galorath (El Segundo, Calif.) announced that its SEER for Manufacturing costestimating software is now available as an integrated module of Dassault Systèmes' (Waltham, Mass.) CATIA V5 design software. The integration will allow manufacturers to use SEER's Ply Cost Estimator in CATIA and let fabricators model and test composites manufacturing processes and evaluate tradeoffs during the earliest stages of product design. SEER features composite part cost estimates for labor (setup, direct, inspection, rework), material and tooling. Estimates are updated and refreshed as the design evolves, and the user can save multiple scenarios for each part to compare and trade options - a feature that enables the designer to understand the cost of design decisions. Part cost estimates include ply placement, debulking, core prep and machining, panel layup, hot press forming, curing (autoclave, RTM or VARTM), postcure trim, nondestructive inspection, tool prep, cleaning and tool design and fabrication. Galorath officials said the built-in material and labor cost data are generic, but can be customized to the facility by the user. Other variables (e.g., the experience of the labor force and overall plant efficiency) also can be changed. Galorath is working on integrating the same software into CATIA V6, as well as Dassault's DELMIA software. www.galorath.com; www.3ds.com

Design data module

Granta Design (Cambridge, U.K.) demonstrated at JEC Europe 2014 the latest release of its Composites Design Data Module, which provides traceable design data from the Advanced General Aviation Transport Experiments (AGATE) and National Center for Advanced Materials Performance (NCAMP) global aerospace database projects. This material property data compilation covers the constituents, intermediates and processing steps used to generate more than 600 laminates, including design data tested in up to four standard conditions. It has applications across research, design, testing and simulation. www.grantadesign.com

Noncontact optical linear encoder

Renishaw (Hoffman Estates, III.) debuted ATOM, a noncontact optical linear and rotary incremental encoder system that combines miniaturization with dirt immunity, signal stability and reliability. With a readhead as small as 6.7 by 12.7 by 20.5 mm (0.26 by 0.5 by 0.8 inch), ATOM is said by Renishaw to be the world's first miniature encoder to use filtering optics with auto gain control (AGC) and auto offset control (AOC) for enhanced signal stability and dirt immunity. Applications include laser scanning, precision microstages and space-critical motion control (cutting tables, machining fixtures), inspection and metrology. ATOM features a low Sub-Divisional Error (SDE), low jitter, analog speeds to 20 m/sec and digital resolutions to 1 nm when used with Renishaw interpolation electronics. The readhead includes a set-up LED to allow quick and easy installation, and an auto-calibration routine to enable faster optimization. Scale options include linear and rotary (angle) scales in stainless steel and glass. www.renishaw.com

Surfacing veils

Technical Fibre Products Ltd. (TFP, Burneside Mills, U.K.) and Technical Fibre Products Inc. (Schenectady, N.Y.) showcased its newest Optiveil carbon fiber veil, which it claims is one of the lightest nonwovens available, at a weight of only 2 g/m² or 0.1 oz/yd². The Optiveil product line ranges up to 400 g/m² and is used for electrical conductivity, EMI shielding and stabilization for frag-

ile reinforcements and as an adhesive substrate. Other developments include recycled carbon nonwovens and an extended range of lightweight PEEK, nylon, PEI and PPS thermoplastic veils, which can be incorporated as interlaminar layers in a composite structure to reduce microcracking and, thus, improve fracture toughness. www.tfpglobal.com

Versatile ply-placement guide

Visitors at the Anaglyph Ltd. (London, U.K.) stand had the opportunity to see the company's latest versions of its software products Laminate Tools, LAP and CoDA and see the new software/hardware capabilities of its trademarked



PlyMatch ply-placement technology in action. Unlike conventional fixed, overhead-mounted laser ply placement systems, the PlyMatch system is designed to be uniquely flexible: Notably, its laser projection head and support arm and/ or the mold tool can be moved by the technician without system recalibration — the system self-calibrates — and its compact design enables it to guide manual placement on vertical surfaces and inside enclosed spaces. Further, the ply data can be generated by any CAD application, although Anaglyph's Laminate Tools application is recommended for full and integrated functionality without the need to generate additional data. Quality control is assured by the digital video recording provided by the system, enhanced by optional measurements of boundary deviation or fiber orientation misalignment. Anaglyph noted that one of the first users of PlyMatch in the aerospace industry, aerospace manufacturer Applied Composites Engineering (ACE, Indianapolis, Ind.), is using PlyMatch to produce complex-shaped heated inlets for AgustaWestland's (Cascina Costa, Italy) AW 189, a new 8-metric-tonne class, multirole helicopter. www.anaglyph.co.uk/Placement.htm



Woven beam preforms

3-D weaving pioneer **Biteam** (Bromma, Sweden) displayed the first produced sample, an I-beam demonstrator, made using a new weaving technology capable of directly manufacturing beam-like 3-D profiles in which fiber orientations in the web and flange are, respectively, $+\theta^{\circ}/-\theta^{\circ}$ and $0^{\circ}/90^{\circ}$. Developed for the aerospace, aeronautical, motor sports, automobile, engineering and building/construction markets, the beam's web and flange fibers intersect in the z-direction (through the thickness), making the preform delamination-resistant and, thus, more capable of bearing shear and tensile loads as well as imparting structural stability during premold handling and impregnation steps. The technology's inventor, Dr. Nandan Khokar contended, "This development has been particularly directed at weaving fully integrated objects, for example the wing of an aircraft, complete with skin and stiffeners/ribs, in one step to quicken manufacture of reliable and consistent composite materials." www.biteam.com

New-generation, recyclable PET foam core

3A Composites (Sins, Switzerland) unveiled what it characterized as a "completely new technology platform" for polyethylene terephthalate (PET) foam core materials, under the tradename AIREX GEN2. The company's second-generation PET foam reportedly features a very homogeneous cell structure, yet has enhanced mechanical properties compared to its predecessor, AIREX T92. While it remains a recycled and recyclable material, its formability and

processability have been improved. Thanks to a lean and highly automated production process, GEN2 will offer customers a considerable total-cost savings in the end application. Philipp Angst, director of product management, says, "GEN2 marks an important milestone in the further industrialization of structural foam core materials and will leverage the use of PET foam cores in yet more applications." www.3acomposites.com

Automotive production products

Cytec Industries Inc. (Woodland Park, N.J.) launched new products and accompanying technologies for serial automotive production. XMTR50 a new, two-part epoxy resin system, was developed specifically for the high-rate manufacture of components using a high-pressure resin transfer molding (HP-RTM) process, claiming a cycle time of three minutes at 120°C/250°F for a $\rm T_g$ of 135°C/275°F. MTM 23, the industry's first application of a volatile-organic compound (VOC)-free thermoset vinyl hybrid resin, woven glass-reinforced prepreg, reportedly enables the manufacture of parts by press molding in five minutes or less. Cytec also introduced trademarked FM 3500 EZP peel ply, a resin-rich, fiber-free composite bonding product that reportedly eliminates the need for additional prebond surface preparation. Formulated specifically for one-piece removal, it exhibits handling properties that support manufacturing efficiency. The peel ply's long shop life, durability during extended cure cycles and compatibility with most 177°C/350°F-cure prepregs allow for manufacturing flexibility. www.cytec.com





MRO-friendly PMI foam core

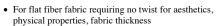
Evonik Industries AG (Essen, Germany) took the unusual step of developing a new polymethacrylimide (PMI) foam product that can mimic honeycomb core's tendency to permit visible laminate damage. Evonik's spokesperson Mary Erwin explained that during mandatory aircraft inspections, it is the damage that



does not show on aircraft surfaces that most concerns maintenance and repair organization (MRO) personnel. Historically (not to mention ironically), Evonik's ROHACELL foam products support the faceskins of aircraft structures so well that minor laminate damage may not be in evidence on the visible exterior surface. Aerospace fabricators report that the free-space between honeycomb walls more easily permits laminate indentation or perforation. For that reason, Evonik developed new ROHACELL HERO PMI foam core. As the photos show, the new PMI foam (left) responds like honeycomb (right), yet still prevents the incursion of moisture that occurs with damaged honeycomb, which — in the temperature extremes endured by aircraft — can freeze and thaw, causing faceskin/core delamination. www.rohacell.com

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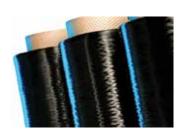
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3-D CNC-machining center

Thermwood (Dale, Ind.) featured its Model 77 5-axis CNC machining center for large aerospace composites applications. The M77 is specifically developed for three-dimensional machining. Its stationary table and high-wall enclosure was designed with advanced 3-D software, using finite element analysis. All major weldments are stress-relieved to provide long-term stability. Laser-calibrated to assure accurate absolute positioning and repeatability, it features full, 5-axis simultaneous motion, executes extremely large CAD-generated programs at high speed without pausing, and self-performs automatic axisalignment verification. Available in standard 5-ft by 10-ft (1.5m by 3m) and 10-ft by 10-ft formats, the center's table length can be increased on request in 5-ft increments to a 60-ft/18.3m maximum. www.thermwood.com

TP-sized CF

Toho Tenax Europe GmbH (Wuppertal, Germany) talked about the impending launch of a Tenax carbon fiber filament yarn with a new tailored sizing for thermoplastic and high-temperature applications.



The commercialization of Tenax-E HTS45 P12 (12K, 800tex) and Tenax-E IMS65 P12 (24K, 830tex) is planned for 2014. Both new fiber types will be produced at the company's production site in nearby Oberbruch and will be globally available. Both yarns are compatible with PEEK, PPS, PEI and other high-temperature thermoplastics as well as low-temperature polyamide based systems (PPA, PA12, PA6, etc.). The P12 sizing also allows low viscosity and in-situ reacting thermoplastics to be combined with Tenax fiber. Both fibers can be processed as commingled yarn, woven fabrics, multiaxial fabrics and 3-D fabrics, and are suitable for pultrusion and prepreg processes. www.tohotenax-eu.com

Nonhalogenated flame retardants

Clariant (Muttenz, Switzerland) highlighted the advantages of its nonhalongenated, phosphinate-based Exolit OP range and Exolit AP range of flame retardant (FR) additives. Designed initially for the electronics and electrical equipment markets, the Exolit OP range is said to offer high thermal stability and good property profiles at comparably low doses in epoxy and polyester resin systems used in commercial aircraft interior composites applications. The Exolit AP range, based on ammonium polyphosphate, is formulated for use in thermoset resins that form the matrices in fiberglass-reinforced composites. Intended as a replacement for brominated and chlorinated FR products, the AP range can be used alone or in combination with ATH. "Halogenated flame retardants guench the reaction in the flame zone," says Dr. Adrian Beard, the head of marketing and advocacy for flame retardants in Clariant's Additives business unit, "but they create a lot of smoke. So in addition to the environmental problem, there is the aspect of smoke toxicity in case of fire." Further, most FR additives must be mixed with other products to create an intumescent layer that foams and hardens to isolate flammable materials from oxygen. The AP products, however, interact with the internal chemistries of epoxy and polyester resins to create the intumescent effect without other additives. As a result, additive loadings, part weight and cost can be reduced. Clariant plans to work with aerospace primes to qualify the Exolit AP range for aircraft interiors. www.clariant.com

Closed molding consumables

Airtech International (Huntington Beach, Calif.) introduced two extruded fluoropolymer films: The first, Wrightlease 2R, is coated with a rubber-based (nonsilicone) pressure-sensitive adhesive. Its light green color is visible on most substrates. It offers multiple releases from all common resin systems and good adhesion to metals, composites, tooling blocks and rubber tooling. Its high



elongation and strength reportedly ensures coverage of complex contoured surfaces. The other, Toolwright 3, is coated with a silicone pressure-sensitive adhesive and is thinner and, therefore, more easily applied over complex contours (see photo) than Toolwright 5. Toolwright 3 offers not only high elongation and strength but high-temperature resistance and easy cleanup after re-

moval. Benefits include extended tool life, tear resistance, fast application and improved part surface quality. Also on offer were two reformulated products: Airseal 2 sealant tape features improved tack, feel and cleanup as well as extended shelf life. Designed for room- and medium-temperature applications, it also can be used for vacuum bag applications at higher temperatures (Airseal 2 Tacky, a softer version, has better tack in colder environments). Airpad HTX now reportedly performs better than competing rubber caul sheet materials. Benefits include low shrinkage; dimensional stability; good bonding to reinforcing layers and surfacing release films; aggressive self-bonding for easier repairs; high Shore hardness for better pressure intensification, and good solvent resistance. www.airtechonline.com

Thinner foils for LSP

Lightning strike protection (LSP) material specialist Dexmet (Wallingford, Conn.) touted new additions to its MicroGrid expanded metal foils line: Foils that feature reduced planar thickness with a smaller open area in the grid. The foils offer the same conductivity as thicker foils because they have identical mass. But the installed foils give the airframer an LSP solution that is less costly and, importantly, reduces aircraft weight, because a thinner adhesive layer is required during application. Dexmet's thinnest copper foil, for example, weighs 175 g/m² but is only 0.002 inch/0.045 mm thick. All Dexmet foils are available in widths of 36 inches and 52 inches (914 mm and 1,320 mm) — they are reportedly the only LSP foils available in the larger width.



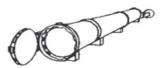


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COMPOSITES CARRY THE CURIOSITY

From launch to touchdown, composites performed in flight and

hen engineers at NASA's Jet Propulsion Laboratory (JPL) were given the job of sending another rover to Mars, they knew they faced a sizeable challenge. The NASA rover mission launched in 2003, for example, involved the twin golf-cart sized (5 ft/1.6m long) Mars Exploration Rovers, Spirit and Opportunity. Each weighed a mere 185 lb/84 kg. The proposed mission, however, would require a rover the size of a mini-compact car — about five times as

heavy and twice as long (1,984 lb/900 kg and 10 ft/3m long).

The reason for the substantial size increase is that the rover, nicknamed *Curiosity*, is more than an explorer — it is a robotic investigator. Officially designated as the Mars Science Laboratory (MSL), *Curiosity* is exactly that, and its overall mission is to determine the planet's habitability for humans, as part of NASA's long-term Mars robotic exploration program. It was equipped to gather samples of Martian rocks and soil,

take them on board and distribute them to test chambers inside its 10 analytical instruments.

But first it had to get there.

Protecting precious cargo

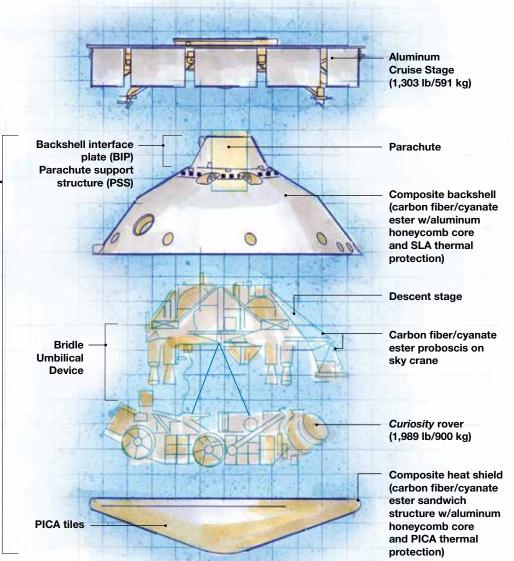
For the 127-million mile trip from Earth to Mars, *Curiosity* was enclosed inside a spacecraft aeroshell. Comprising a back shell and a heat shield to protect the rover during entry into Martian atmosphere, the aeroshell was jointly designed by JPL and Lockheed Martin Space Systems

NASA/JPL's MSL FLIGHT SYSTEM

Aeroshell Entry Vehicle (7,026 lb/3,459 kg)

DESIGN RESULTS

- An aeroshell capable of delivering the much heavier (5x) *Curiosity* rover safely to Mars and through the intense heat of atmospheric entry.
- A sandwich construction that unites the heat shield's biconic (two-cone) design in a single structure for one-off molding and cure.
- Material selection (including the use of ablatives) that permits ovencure rather than autoclave cure of the aeroshell's composite back shell and heat shield.



ROVER TO A SAFE MARS LANDING

stuck the landing!

BY DONNA DAWSON
ILLUSTRATION / KARL REQUE

(Denver, Colo.). Because Lockheed Martin had built all the aeroshells for JPL's six previous Mars rovers, the MSL engineers were able to call on a considerable design heritage.

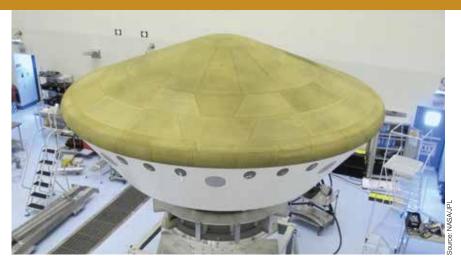
Richard Hund, Lockheed Martin's MSL aeroshell program manager, clarifies that Lockheed Martin considered all the loads that the aeroshell would see throughout its life, including test loads as well as launch and entry loads. Different load cases and different events influence the design of different parts of the structure, he explains. For example, the design of the aeroshell structure's parts that are closest to the launch vehicle is typically driven by the launch loads.

The primary design loads, however, are sustained during entry into Mars' atmosphere. "The aeroshell is traveling at a certain velocity," says Hund. "When it hits the Mars atmosphere, the rover wants to keep driving in at velocity, but friction in the atmosphere is slamming on the brakes." These pressure loads are transmitted along the primary load path from the heat shield up into the backshell, through the backshell and back down to the rover inside. Entry test loads, then, were more than 100,000 lbforce/45,359 kg-force, enough to safely withstand an entry velocity of ~13,200 mph (5,900 m/sec).

According to David Scholtz, Lockheed's heat shield principal engineer, the MSL team employed NX NASTRAN to perform finite element analysis of the structure, and MSC Adams dynamic simulation software for Mar's entry/landing component-separation analyses (MSC Software Corp., Newport Beach, Calif.),

Biconic backshell

Scholtz says the biggest challenge in designing the MLS aeroshell was to "provide the volume [space] in the aeroshell that JPL needed for the rover within the constraints of the Atlas V launch vehicle and the payload fairing [the expendable clamshell that protects the spacecraft during launch]." The solution was a 15-ft/4.5m



Packed and ready for launch

With Curiosity securely seated inside, the heat shield (shown here on top) and the backshell are joined. The phenolic impregnated carbon ablator (PICA) heat shield protected the MSL from extreme entry conditions. The phenolic resin ablates as it undergoes pyrolysis and forms a carbonaceous char

maximum diameter asymmetrical biconic backshell and heat shield.

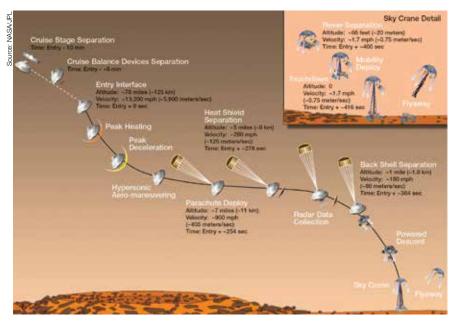
Biconic refers to two cones joined together at their perimeters, but in this case, composites processing enabled Lockheed Martin to build the backshell structure in one large piece by using sandwich construction. The backshell's structural sandwich is formed with prepreg made with a satin-weave fabric woven from Toray M55J, an intermediate modulus carbon fiber from Toray Carbon Fibers America (Flower Mound, Texas). in a BTCy-1A cyanate ester prepreg from TenCate Advanced Composites (Morgan Hill, Calif.), with a Flex-Core aluminum vented honeycomb core. BTCy-1A is a toughened resin that offers the advantages of low-pressure 350°F/177°C processing, low moisture absorption and negligible volatile emission in space. It has characteristics similar to epoxy, but was developed specifically for service in vacuum as an alternative to epoxy, which is more hygroscopic (water-absorbent) and tends to outgas in a vacuum.

Lockheed Martin hand layed the skins and core over a male mold. The prepreg's satin weave helped it conform to the part contours. The ply schedule was tailored for stiffness and strength to accommodate the expected loads. Six-inch/152-mm prepreg tape was added in areas that required local reinforcement (e.g., load points for interfaces to other hardware). A proprietary fastening system was designed specifically for the shell's access doors, to facilitate quick removal and replacement on the launch pad. Notably, the part was oven-cured at 350°F/177°C for about two hours.

Although the backshell is not the first line of defense against the extreme heat generated during entry into the Martian atmosphere, it is in the eddy of the heat wave. For thermal protection, therefore, Lockheed Martin covered the cured backshell with its Super Light Ablator SLA-561V system, a ground cork, silica and phenolic mixture in a silicone binder that is hand packed into a phenolic honeycomb, developed by Lockheed Martin (Bethesda, Md.). After ablator application, the backshell was painted white.

Heat shield

But the backshell was only half of the aeroshell solution. The other half, the heat shield, entailed more than its share of the design challenges, in part, be-



Cruise, entry and landing

As the MSL Flight System began its descent, the Cruise Stage separated from the aeroshell, which entered Mars' atmosphere 78 miles from its surface, at 13,200 mph (5,900 m/sec). The heat shield endured 3800°F/2100°C temperature. After deceleration aided by onboard engines, the parachute was deployed and the heat shield was jettisoned at the five-mile mark. One mile up, the backshell was jettisoned. At 66 ft/20m elevation, the rover separated from the descent stage but remained attached to the sky crane bridle. At touch down, connecting cords were severed and the descent stage flew clear to avoid collision.

cause the increased size and mass of the MSL mandated a different angle of entry than past Mars missions. This resulted in a higher velocity and a more extreme aero-thermal entry environment than previous heat shields had experienced. So the heat shield and its thermal protection system (TPS) were designed to withstand the G-forces and up to 250 watts/cm² (1,613 watts/in² or 1.53 BTU/s/in²) of heat, "about 2,500 times what we feel when we walk out into the bright sunshine," says JPL's principal engineer Eric Slimko.

SLA-561V was previously used on the heat shields of the two *Viking* Landers in 1976. Although early tests indicated this TPS solution would also work for the MSL heat shield, Slimko says parameters of shear stress, turbulence and *enthalpy* (a measure of the total energy of the thermodynamic system) had not been factored into the testing process.

"Unfortunately, matching the four parameters of heat flux, shear stress, enthalpy and turbulence is nearly impossible to obtain in ground test facilities," Slimko explains. To validate the tests, Slimko's team developed an approach of matching one or two parameters while straddling the remaining parameters.

When enthalpy was matched with shear stress and heat flux, the SLA-561V failed test requirements for MSL entry.

Suddenly, the heat shield material that had served so well during previous safe entries into Martian airspace was deemed inadequate for the landing environment this larger, heavier rover would face. A search for alternatives produced candidates that included a modified SLA 561V, a carbon-carbon with carbon fiber insulation, a fully dense carbon phenolic, and the finalist, phenolic-impregnated carbon ablator (PICA, pronounced *peak-a*).

Invented at NASA Ames in the early 1990s, PICA comprises a fibrous carbon substrate. Trademarked as FiberForm by Fiber Materials Inc. (Biddeford, Maine), PICA is impregnated with phenolic resin inside a custom-built vessel under proprietary temperature and pressure conditions. During high heat (in this case, entry into Mars atmosphere), the phenolic resin ablates as it undergoes pyrolysis and forms a carbonaceous char.

The PICA was cut into tiles, which were arranged in a structural architecture to meet design specifications for entry forces. Then, the tiles were bonded onto the outer face of the composite heat

shield, using HT424 adhesive film, an aluminum-filled, modified epoxy/phenolic resin from Cytec Aerospace Materials (Tempe, Ariz.) and grouted using RTV 560, a low-temperature, two-part silicone rubber compound from Momentive Specialty Chemicals (Columbus, Ohio). The result was the largest — and the first tiled — ablative heat shield ever built.

Before final assembly of the aeroshell, Curiosity was tucked into the heat shield. tethered to the JPL-patented sky crane, for final lowering of the rover safely to Mars' surface after separation from the heat shield, backshell and parachute. Attached to the descent stage by a bridle, or harness, the sky crane, was also connected to the backshell, along with a parachute and parachute support structure (see drawing, p. 78). The backshell and heat shield were joined by nine separation fittings. These and other attachment fittings featured pyrotechnically released separation bolts so the heat shield could be separated from the rover and back shell during the Mars descent and the backshell and other descent stage components could be jettisoned during the landing sequence (see graphic, at left).

Satisfying Curiosity

The aeroshell delivered Curiosity, the largest rover yet landed on any planet, unscathed to Mars' surface in August 2012. In its first year, the MSL established that ancient Mars offered a wet habitat with conditions favorable to microbial life. The rover is now traveling to Gale Crater, where geological layers might yield further evidence of ancient habitability.

When asked if the landing could have been done without composites, Slimko says *definitely not*. Designers cite their low weight, high stiffness, low coefficient of thermal expansion, exceptional producibility and their capacity to form large, complex shapes and biconic angles.



Read this article online at short.compositesworld.com/Curiosity1.

Several parts on the descent stage and rover itself were built from composites. See *HPC's* online report, "The *Curiosity* Mars rover: Decent stage composites," at short.compositesworld.com/Curiosity2.

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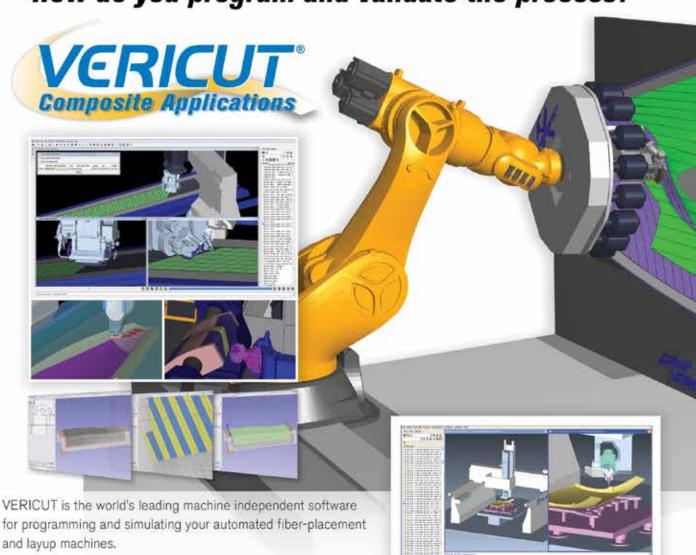
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